Autonomous Vehicles to Evolve to a New Urban Experience

DELIVERABLE

D2.2 Second Gap analysis and recommendations on autonomous vehicles for public service

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Acronyms

ADS	Automated Driving Systems
AI	Artificial Intelligence
API	Application Protocol Interface
AV	Autonomous Vehicle
BMM	Business Modelling Manager
CB	Consortium Body
CERN	European Organization for Nuclear Research
D7.1	Deliverable 7.1
DC	Demonstration Coordinator
DI	The department of infrastructure
DMP	Data Management Plan
DSES	Department of Security and Economy Traffic Police
DTU test track	Technical University of Denmark test track
EAB	External Advisory Board
EC	European Commission
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	Federal Roads Office
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
OCT	General Transport Directorate of the Canton of Geneva
ODD	Operational Domain Design
OEDR	Object And Event Detection And Response
OFCOM	Federal Office of Communications
PC	Project Coordinator
PEB	Project Executive Board
PGA	Project General Assembly
PRM	Persons with Reduced Mobility
PSA	Group PSA (PSA Peugeot Citroën)
PTO	Public Transportation Operator
PTO	Public Transport Operator
PTS	Public Transportation Services
QRM	Quality and Risk Manager
QRMB	Quality and Risk Management Board
RN	Risk Number
SA	Scientific Advisor
SAE Level	Society of Automotive Engineers Level (Vehicle Autonomy Level)
SAN	Cantonal Vehicle Service
SDK	Software Development Kit
SMB	Site Management Board
SoA	State of the Art
SOTIF	Safety Of The Intended Functionality
SWOT	Strengths, Weaknesses, Opportunities, and Threats.
TM	Technical Manager
UITP	*Union Internationale des Transports Publics*
V2I	Vehicle to Infrastructure communication
WP	Work Package
WPL	Work Package Leader

Executive Summary

This second Gap analysis is conducted as a follow-up on the first gap analysis. The purpose of this Gap analysis is as the first deliverable to specify in detail the technological innovation potential for the AVENUE services and solutions, while at the same time proposing innovative and state-of-the-art features and recommendations for the AVENUE projects.

These recommendations are based on in-depth investigation and analysis of the barriers and obstacles that arise during the deployment of autonomous vehicles in public transport and urban areas. These obstacles are described in three categories: technical, legal and social and can be seen as the first experience gathered in the consortium. The recommendations should be understood as guidelines to support the further development of the AVENUE project.

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 autonomous 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 autonomous 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 autonomous 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 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 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.

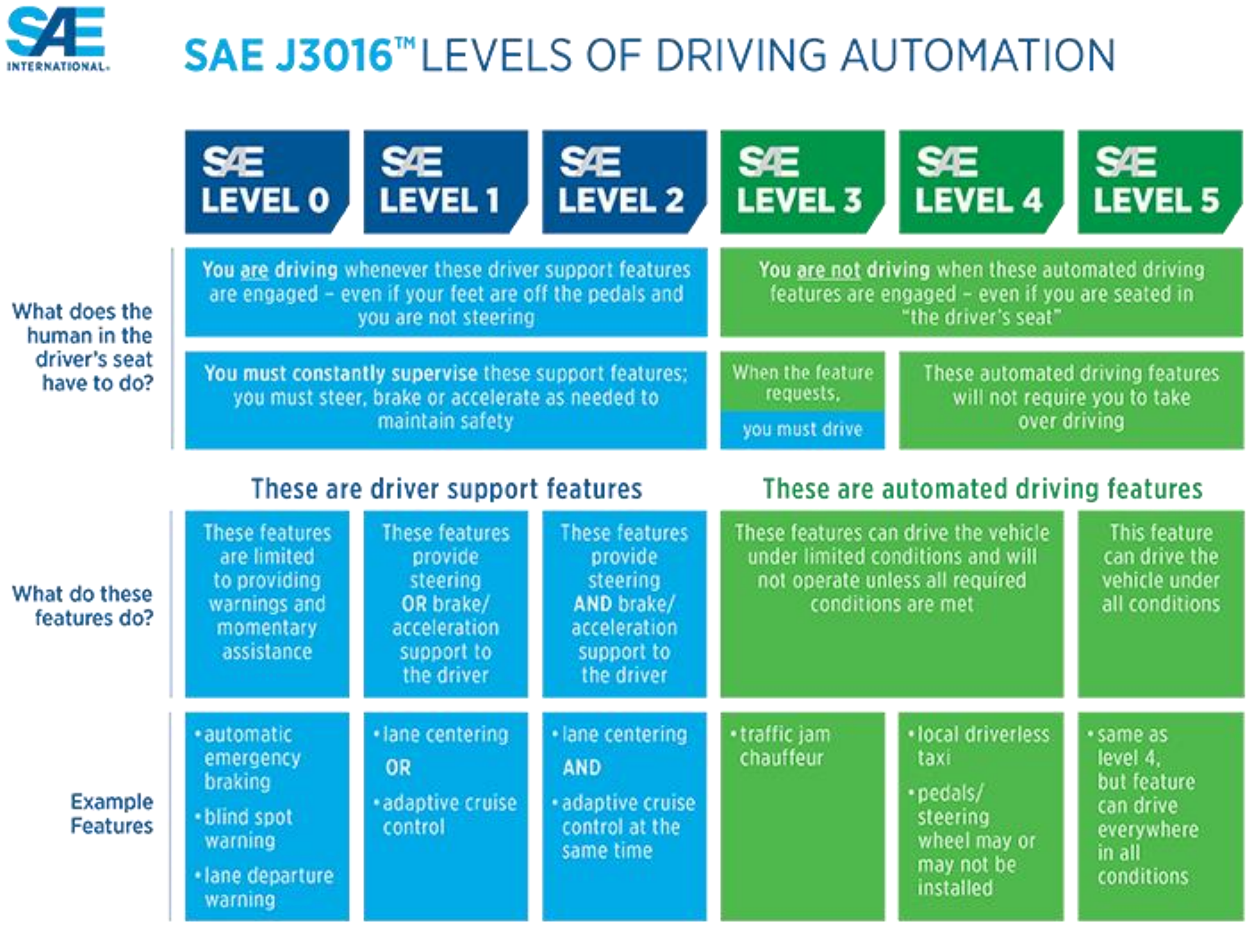
On-demand transport differs from other public transport services in that vehicles do not follow a fixed route and do not use a predefined timetable. Unlike taxis, on-demand public transport is usually also not individual. An operator or an automated system takes care of the booking, planning and organization.

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

1.2 Autonomous Vehicles

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

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



1.2.1 Autonomous vehicle operation overview

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

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

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

1.2.2 Autonomous vehicle capabilities in AVENUE

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

1.3 Preamble

The second Gap analysis is, as the first deliverable, structured in 4 sections; AVENUE goals, SoA analysis, the gap and recommendations. Each section is shortly described and introduced in the following sections.

2. AVENUE goals
This first chapter describes the basis of the AVENUE project and introduces the project goals and vision. These goals are perceived as the proposed state, e.g. where we wish to end up in the AVENUE project.

3. SoA analysis
The second chapter introduces the SoA analysis, which is conducted with the purpose of defining and describing the current technological development of autonomous vehicles. The point of understanding the current technology, hereby both the limits and potentials, and the current experience and expertise, is to better understand how to move forward with the deployment of autonomous vehicles, without making the same mistakes.

4. The gap

The third chapter describes the gap between the current state and the proposed state, e.g. what stands between the current situation and the AVENUE goals. In the process of understanding the current state, experience and deployment achievements from the AVENUE partners are used to define technical, legal and social barriers that the AVENUE project must overcome in order to reach the proposed state.

5. Recommendations

The fourth chapter presents the recommendation of this Gap analysis. These recommendations are categorised in technical, legal and social, and should be understood as guidelines on how to further steer the AVENUE project towards the proposed state. The recommendations are based on the barriers and obstacles presented in chapter three.

The overview

To ensure a common and holistic understanding of the relationship between the four chapters, the following figure 1 visualises how each chapter contributes to the overall purpose of the Gap analysis.

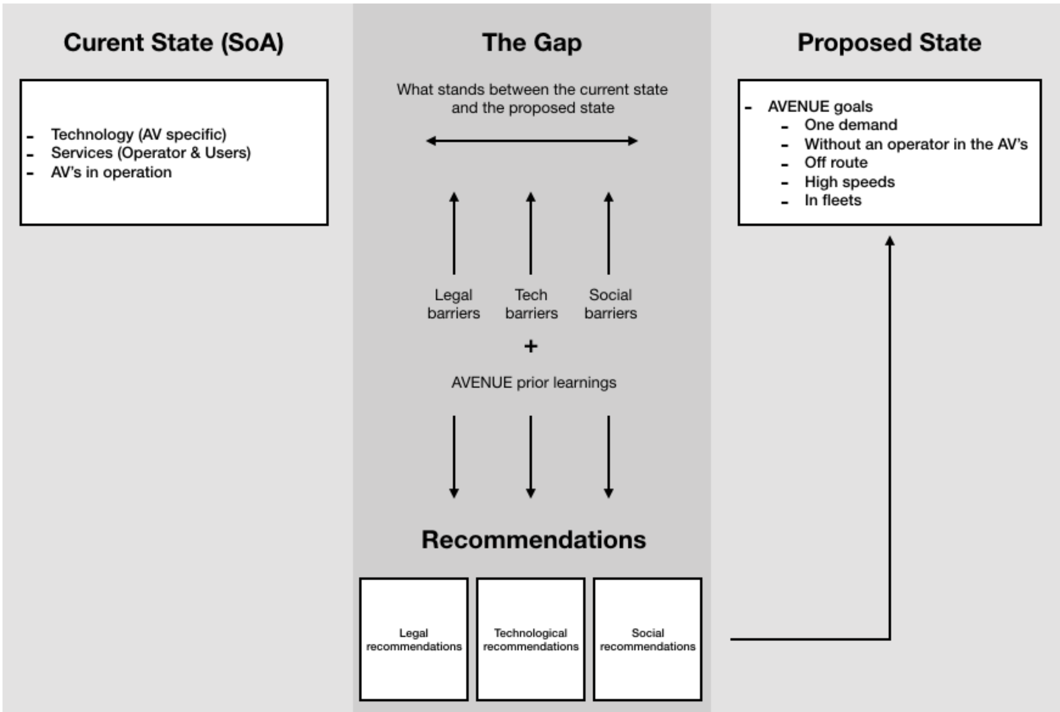


Figure 1 - The gap visualised

Figure 1 illustrates how the gap is defined as the "space" between the proposed state and the current state, e.g. the barriers and obstacles that stand between the current state and the AVENUE goals. The barriers and obstacles are defined in three categories: Legal, Social and Technical barriers. Combined, this gap and prior AVENUE learnings from deployment of autonomous vehicles, shapes the recommendations. These recommendations then represent the actions required to reach the proposed state.

The content and analysis presented in this gap analysis are based on the following data:

- Existing deployments and pilot projects conducted by the operating project partners - both in and out of the AVENUE project.

- Information about technologies, solutions and insights learned from pilot projects conducted by or under development by non-AVENUE-partners.

- Review relevant existing guidelines, good practices and standards, conducted and learned from European, North American and other international tests and operations of autonomous vehicles for public transport, e.g. demonstrations and pilot projects.

- Academic reports and articles based on existing pilot projects and demonstrations with autonomous vehicles in and out of public transport.

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. The AVENUE's 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's road behaviour safety.

As the AVENUE project targets future urban mobility and transport planning, it is essential to include the concept for Sustainable Urban Mobility Plans (SUMPs) as a terminology and focus of the European Commision. The SUMPs main vision is to ensure focus on the "functioning city" by using, implementing and benefitting from high-quality and sustainable mobility and transport. Within the SUMPs there are 10 goals[2] and the SUMP has to contribute to the development of an urban transport system which:

- Is accessible and meets the basic mobility needs of all users;
- Balances and responds to the diverse demands for mobility and transport services by citizens, businesses and industry;
- Guides a balanced development and better integration of the different transport modes;

[1] Within urban transportation sustainable most often refers to electric vehicles.
[2] https://ec.europa.eu/transport/sites/transport/files/legislation/com%282013%29913-annex_en.pdf

- Meets the requirements of sustainability, balancing the need for economic viability, social equity, health and environmental quality;
- Optimises efficiency and cost effectiveness;
- Makes better use of urban space and of existing transport infrastructure and services;
- Enhances the attractiveness of the urban environment, quality of life, and public health;
- Improves traffic safety and security;
- Reduces air and noise pollution, greenhouse gas emissions, and energy consumption;
- Contributes to a better overall performance of the trans-European transport network and the Europe's transport system as a whole;

As an overall goal the SUMPs have to focus on a balanced and integrated development of all modes including inter-modality. The above stated goals are to the extent possible to be included in the AVENUE project. As a part of WP9 many of the aspects will be included to ensure a sustainable approach to the implementation of the AVENUE services. SUMP will hence as a terminology be used as a tool to consider the business models of AVENUE, cost-attractiveness, smart-city planning and integration of automated vehicles into existing transport systems.

To summarise the AVENUE goals can be defined as follows in figure 2.

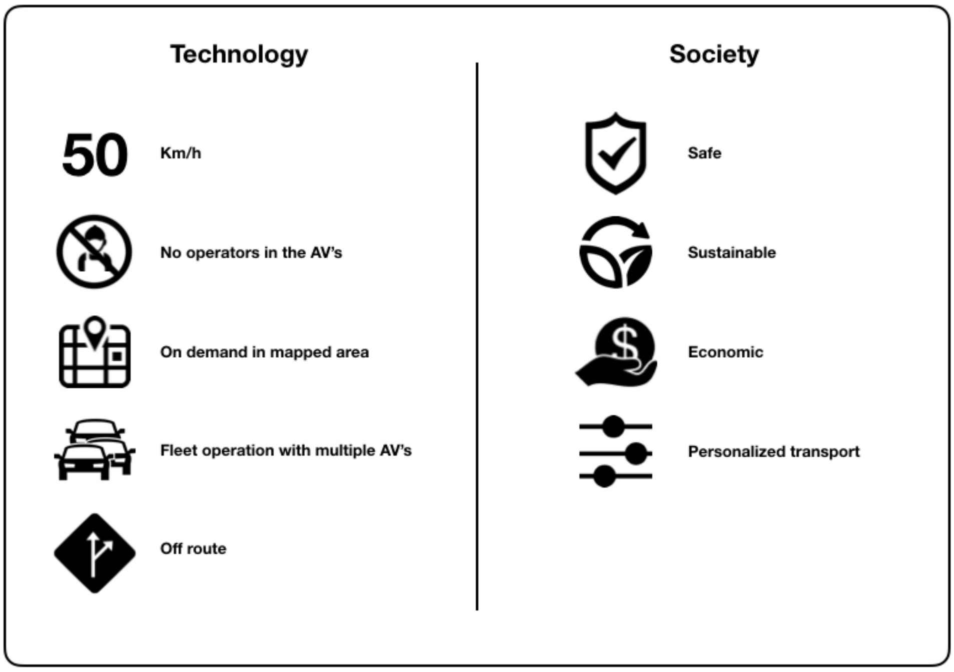


Figure 2 - AVENUE goals

3 SoA analysis

The SoA analysis analyses the current state of the AV development - AV's and services connected to autonomous driving. Furthermore, the SoA investigates 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 autonomous vehicle technology, Automated Driving Systems (ADS) are used to increase 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[3]

3.2 Autonomous technology (AV specific)

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 3 below. Besides the 5 main vehicle requirements, the vehicles must be electrically driven.

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

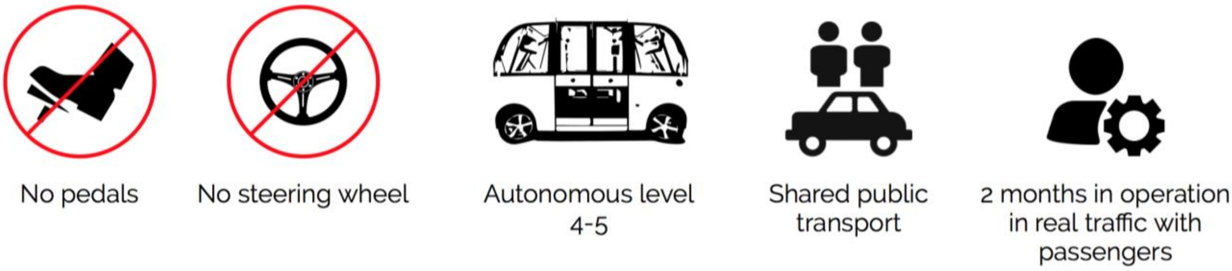


Figure 3 - AVENUE AV scope

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. Knowing what has been developed can help the AVENUE consortium to steer clear of potential pitfalls and prior mistakes.

The following tables define 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.

In system - not in scope In consortium and relevant	
Navya Autonom Cab	

Table 2 - In system - not in scope - in consortium

Navya Autonom Shuttle	

Table 3 - In system - in scope - in consortium

In system - in scope Not in consortium but relevant

2getthere GRT		2getthere PRT	
Baidu Apolong		EasyMile EZ10	
Ohmio Hop		Sensible 4 Gacha	
Yutong 5G			
Table 4 - In system - in scope - not in consortium			

In system - not in scope Not in consortium but relevant			
COAST Autonomous		HEAT	
Local Motors Olli		Ohmio Lift	

Transdev/Lohr i-Cristal		WinBus	
ZERO shuttle			

Table 5 - In system - not in scope - not in consortium

Not in system - not in scope Not in consortium but relevant			
Cruise		DeepBlue Pandabus	
May Mobility		Oxbotica	
Streetdrone		Tesla	

Uber		Voyage	
Waymo			

Table 6 - Not in system - not in scope - not in consortium

As seen in the tables, there are three levels in the system:

- In scope
  There are currently eight vehicles that fit the AVENUE AV scope shown in Table 3 and Table 4; Navya shuttle, 2getthere GRT, 2getthere PRT, Baidu Apolong, EasyMile EZ10, Ohmio Hop, Sensible 4 Gacha and Yutong 5G. As a part of the consortium is only the shuttle from Navya, the rest is outside the consortium.

- System
  There are multiple autonomous vehicles under development - both within and without the consortium (Table 2 and Table 5) - which potentially could fit within the timeframe of the AVENUE project. E.g. NAVYA's Autonom Cab might be piloted in real traffic with real passengers during the project, hence over time fitting within the AV scope. All the vehicles introduced in table 4 - meaning in system but not in scope are perceived as relevant because they face the same barriers and obstacles for their commercial deployment. Also these vehicles might be piloted and developed, hence move into scope.

- Outside system
  Vehicles that do not fit the vehicle scope of the project are placed outside the system (Table 6), 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 The Navya Shuttle

Autonomous, driverless and electric: The shuttle developed by NAVYA serves cities and private sites by bringing ever more mobility.

In the city or on a private site, the shuttle conceived by NAVYA is an innovative, effective, clean and intelligent mobility solution. AUTONOM SHUTTLE guarantees autonomous transport performance as well as a comfortable trip for the first and last mile, thanks to its gentle navigation.

Capable of transporting up to 15 people, AUTONOM SHUTTLE combines a number of advantages. AUTONOM SHUTTLE fleets make it possible for operators to improve productivity on private sites, and ease road congestion in urban centers. Passengers also enjoy a pleasant trip while making the most of their travel time.

3.4 Technical description of Navya Shuttle

A technical description of the main sensory system that enables the Navya Shuttle to operate autonomously.

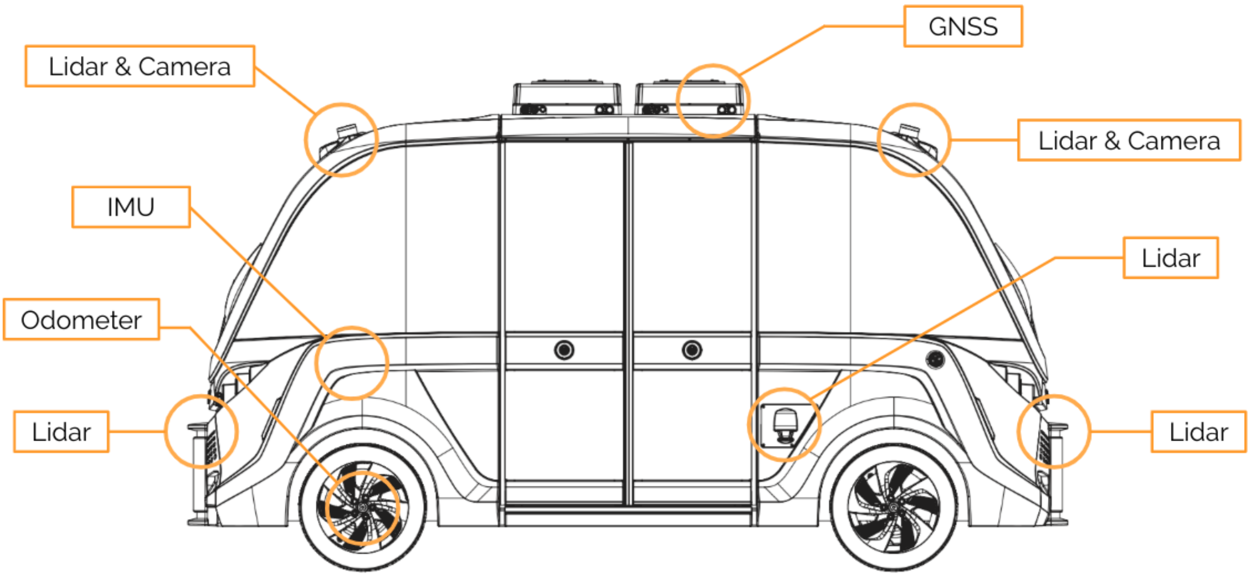
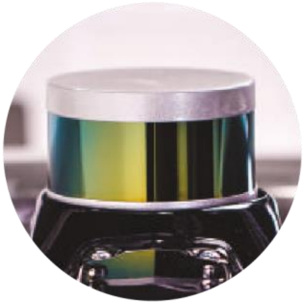


Figure 4 - Technical drawing Navya Shuttle

LiDAR sensors

Using laser technology to measure distance, LiDAR sensors perceive the vehicle's surroundings in three dimensions. They ensure detection of obstacles and calculate the vehicle’s precise positioning thanks to 3D-mapping. The vehicle has three types of LiDARs



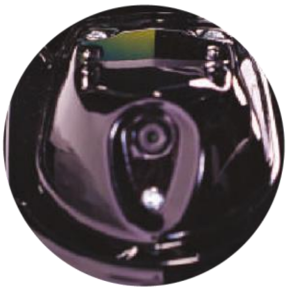
Front top lidar
(each end)

Front lower lidar
(each end)

Front side lidar
(each side)

Camera

Detect obstacles and estimate their position relative to the vehicle. The cameras analyse the vehicle's surroundings, in particular road signs and traffic lights. Thanks to "deep learning" algorithms, the cameras detect and categorise obstacles.



Camera
(each end of vehicle)

GNSS Antenna

Communicates between the GPS sensor and a base station to determine the precise position of the vehicle at any moment. The GNSS antenna are linked to a GNSS RTK system that provides precise positioning, accurate to the nearest centimetre.

GNSS Antenna
(top of vehicle)

Odometer

Measures the displacement and speed of each wheel to estimate the velocity of vehicle and change in vehicle position.

Odometer
(Each wheel)

Internal Measurement Unit (IMU)

The IMU sensors calculate the movements of the shuttle to estimate its sense of direction, its linear speed and its position.

- Gyroscope
  A device used for measuring or maintaining orientation and angular velocity. It is a spinning wheel or disc in which the axis of rotation is free to assume any orientation by itself. When rotating, the orientation of this axis is unaffected by tilting or rotation of the mounting, according to the conservation of angular momentum.

- Accelerometer
  A device that measures proper acceleration. Proper acceleration, being the acceleration (or rate of change of velocity) of a body in its own instantaneous rest frame, is not the same as coordinate acceleration, being the acceleration in a fixed coordinate system.

3.5 Autonom Shuttle: Operation stats

Since the launch of Autonom Shuttle in 2015, the vehicle has been deployed in many pilot projects on private sites and on the open road. All the experience of the Autonom Shuttle is in this section consolidated[4].

One of the latest driverless technologies already on the market

[4] https://navya.tech/wp-content/uploads/documents/Brochure_Shuttle_EN.pdf

130+ vehicles sold worldwide (June 2019)

Presence in 20 countries such as Australia, Austria, Denmark, France, Germany, Japan, Singapore, Switzerland, USA and many others.

350 000+ passengers transported (since April 2016)

Approvals

ASTRA (Switzerland), FTSA (Finland), LTA (Singapore), MDDI (Luxembourg), MFK (Liechtenstein), MTES (France), NTC (Australia), RDW (Netherlands), SAAQ (Canada), SPF M&T (Belgium), STA (Sweden), TÜV Austria (Austria), TÜV Hessen, Nord & Rheinland (Germany), US DoT / NHTSA (USA), Integrated Transport Centre - DoT (UAE), MLIT (Japan), Ministry of State (Monaco), Statens Vegvesen (Norway), DoT (South Africa) (June 2019)

3.6 Consortium experience

There are four operators in the AVENUE consortium, operating out of 4 different countries Switzerland, Denmark, France and Luxembourg. Besides the routes and vehicles included in the AVENUE project, the four operators have prior experience with deploying self-driving vehicles either in demonstration or pilots - on private sites or in public. This experience is illustrated in the following tables introducing and describing each project the operators have conducted.

TPG	
	Route 1
Name of route	XA line (Meyrin, Canton of Geneva, Switzerland)
Type of route (public, private, etc.)	Public
Vehicle: Meaning Navya shuttle or other?	Navya Shuttle
In or out of AVENUE?	Financially out of AVENUE Experience wise in AVENUE
Deployment period (how long did you operate	01.07.2018 - current

that route)	
Route-distance (length)	2.1 Km
Amount of passengers	2474 Passengers with the Navya Shuttle only (back-up with normal Shuttle in case of a problem not counted)
Amount of driven kilometres	3940 Km with the Navya Shuttle only (back-up with normal Shuttle in case of a problem not counted)
Number of shuttles	One autonomous Shuttle (and since June 2019 one autonomous in reserve) + Normal shuttle as back-up
Pricing structure (free or ticket)	Same ticket pricing structure as rest of TPG network
Safety driver present?	Yes

Autocars Sales-Lentz		
	Route 1	Route 2
Name of route	Luxembourg City Pfaffenthal	Contern
Type of route (public, private, etc.)	Public	Public
Vehicle: Meaning Navya shuttle or other?	NAVYA Shuttle	NAVYA shuttle
In or out of AVENUE?	In	In
Deployment period (how long did you operate that route)	Since 24.09.2018	24.09.2018-31.01.2019
Route-distance (length)	1.2 km	2.23 km
Amount of passengers	15629 until week 33 2019	511
Amount of driven kilometres	8619,1 km	1765,1 km
Number of shuttles	2	1
Pricing structure (free or ticket)	Free	Free
Safety driver present?	Yes	Yes

Keolis		
	Route 1	Route 2
Name of route	NAVLY, Confluence	Groupama Stadium
Type of route (public, private, etc.)	Public. Limited circulation.	Public, open road.
Vehicle: Meaning Navya shuttle or other?	NAVYA Shuttle	NAVYA Shuttle

In or out of AVENUE?	Out	In
Deployment period (how long did you operate that route)	Since Sept 2016	This project will be open at the end of 2019
Route-distance (length)	1.3 km	1.3 km
Amount of passengers	55 000	-
Amount of driven kilometres	+/- 35 000km	-
Number of shuttles	2	2
Pricing structure (free or ticket)	free	Free
Safety driver present?	yes	Yes

Autonomous Mobility				
	Route 1	Route 2	Route 3	Route 4
Name of route	SUH Køge	Gothenburg, Lindholmen	Oslo, Akershus	Helsinki, Aurinkolahti
Type of route (public, private, etc.)	Private	Public	Public	Public
Vehicle: Meaning Navya shuttle or other?	Navya Shuttle	Navya Shuttle	Navya Shuttle	Navya Shuttle
In or out of AVENUE?	Out	Out	Out	Out
Deployment period (how long did you operate that route)	4 months from Maj 2018 to August 2018	April 2019 to October 2019 (still going)	Maj 2019 to Maj 2020 (still going)	Juni 2019 to September 2019 (still going)
Route-distance (length)	800 m	1.8 km	1.3 km	2.5 km
Amount of passengers	6.000 passengers	2.500 passengers so far	18.000 so far	3.300 passengers so far
Amount of driven kilometres	980 km	3.300 km so far	6.700 km so far	2.200 km so far
Number of shuttles	1	2	4	1
Pricing structure (free or ticket)	Free	Free	A part of Ruter pricing structure	Free
Safety driver present?	Yes	Yes	Yes	Yes

3.7 What can we learn from other projects and operators

As a part of the SoA it is crucial to discover and learn from others who have attempted to achieve the same as the AVENUE project, ensuring that mistakes made in the past can be avoided, or that learnings can be made/gained in the AVENUE project.

This section seeks to introduce the main learnings gained from external prior projects and demonstration, e.g. non-AVENUE-partners, conducted with autonomous vehicles, more specifically with autonomous shuttles. Relevant projects and demonstrations are in the following section described and the major learnings and recommendations from each are consolidated and presented.

3.7.1 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 the 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

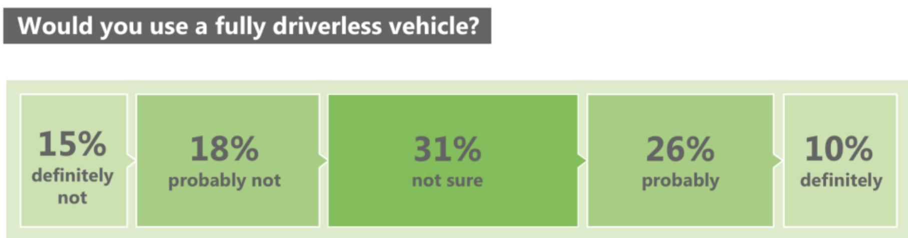
- Enforcement of the laws applied to car/truck drivers is necessary to make sure that the operation of the ARTS vehicles was not detrimentally impacted by illegal parking, etc.

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.

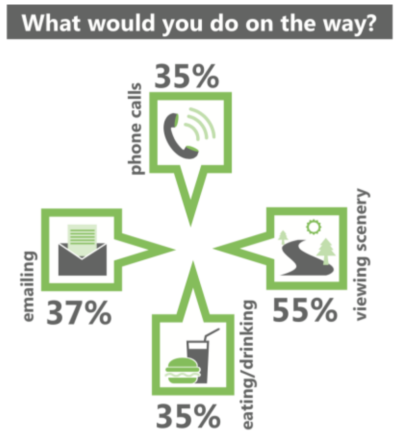
3.7.2 UK Autodrive[6]

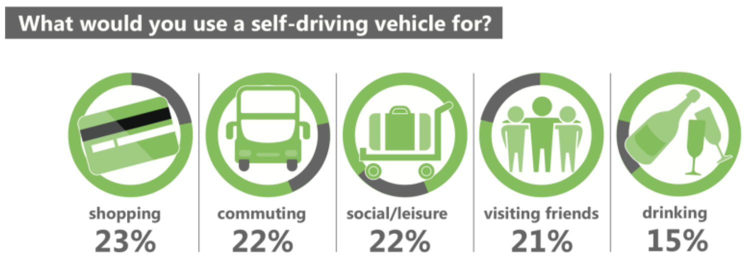
UK Autodrive is the largest of three separate consortia that are currently trialling automated vehicle technology in the UK. All three consortia projects are part of a government-backed competition that supports the introduction of self-driving vehicles into the UK. The project will run for three years (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 are summarized below.



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





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

7.3 Future driving, Autonobus, La Trobe University[7]

La Trobe Autonobus Pilot Project was established with a focus on showcasing and testing a Level 4 autonomous shuttle (Navya Shuttle) in real traffic environment, trying to demonstrate long-term commercial benefits - regarding both passenger uptakes and potential safety and traffic enhancements. There were 6 key partners in the project: Vic Roads, Keolis Downer, La Trobe University, RACV, HMI Technologies and ARRB. The pilot project was conducted from summer 2017 to summer 2018 resulted in

[7] https://www.latrobe.edu.au/technology-infusion/autonobus

multiple recommendations and learnings regarding the deployment of the self-driving shuttle in real traffic. These recommendations and learnings are presented in the following sections; Safety, Technology, Operations, Customer adoption, AV readiness, Legislation and regulation and Commerciability and liability.

Safety

IN SUMMARY

Recommendations for the future deployment of Autonomous Vehicles:

- ✓ The shuttle was safe for customers and road users, and ready to be deployed at the speeds used in this type of precinct; however further testing is required:
  - At speeds above 20km/hr;
  - Connectivity between the AV and other infrastructure (such as traffic signals) – in a signalised environment;
  - Use of a remote monitoring management platform for operational areas;
- ✓ Establish an Operational Control Centre which would also look at the remote operation of AVs, as well as its integration with other modes of transport, to ensure safety across the whole public transport network;
- ✓ La Trobe University have a nominated "shared space" driving route;
- ✓ Raise awareness of the local community - with a campaign educating people – on how to behave around Autonomous Vehicles; and
- ✓ It is recommended that from a regulatory perspective a formal accreditation be developed for AV operators and precincts.

Technology

IN SUMMARY

For future operations, an AV at SAE Level 4 would require:

- ✓ Suitable physical and digital infrastructure for connectivity, precise positioning and battery charging;
- ✓ Stakeholders in the local environment to embrace an overarching operational framework which requires a revised concept of operations for all movements within the road corridor (pedestrians, cyclists, light vehicles, commercial vehicles, heavy vehicles and shuttles) as well as a campaign informing other road users of this concept; and
- ✓ An overall safety assurance, traffic management and incident management response plan for all manual and automated operations.

Operations

IN SUMMARY

Conditions which were valuable to the operational success of this project and are recommended for future deployments:

- ✓ Safety management and traffic management plans are in place, with all relevant emergency personnel trained in how to attend to a situation relating to electric AVs (not just conventional vehicles);
- ✓ Advice to other road users about AV operators;
- ✓ Managing the inter-operation with public transport (i.e. bus or light rail);
- ✓ Repeater station infrastructure for precise positioning around the operational precinct (which is set to roll out in the future, following the Federal government's 2018/19 budget which committed funds to overhauling this infrastructure in Australia); and
- ✓ Starting with a slow speed to enable all road users to familiarise themselves with AV shuttle operations and progressively increasing speed to desired operational levels.

Additional recommendations include:

- ✓ Upskilling current bus drivers to learn how to use AV technology and future ICT systems;
- ✓ Telecommunication companies increasing their commitment to better quality service and ICT infrastructure to provide reliable 4G mobile coverage and other operational aspects of Autonomous Vehicles; and
- ✓ Government bodies reviewing current road rules, regulations and legislation to accommodate the future deployment of AVs – such as seat belt exemptions for AV operators, having dedicated lanes to overcome the speed issue and/or sharing bus lanes for this alternative mode of transport.

Customer adoption

IN SUMMARY

Recommendations for the future deployment of Autonomous Vehicles:

- ✓ Deeper understanding and testing is required of how elderly people or users with a disability can engage with Autonomous Vehicles, as well as people with English language barriers or families travelling with prams;
- ✓ Development of a pricing framework to ensure commercial viability. Passengers indicated they would be willing to pay between $1.50-$2.50 to use the service based on the conditions of the pilot;
- ✓ Public awareness campaign to maintain importance and a positive attitude, by communicating messages associated with benefits of the service, the alleviation of potential concerns, and how to behave around this new technology;
- ✓ Vehicle's interior is 'designed for purpose' by the manufacturer, to ensure social inclusion; and
- ✓ Conduct a commercial trial which could provide insight into the potential uptake and value participants place on the service.

AV readiness

IN SUMMARY

Recommendations for the future deployment of Autonomous Vehicles:

- ✓ Autonomous shuttles are ready for commercial deployment within a controlled environment, accompanied by appropriate risk, safety and incident management plans;
- ✓ Australia ranked 14 out of 20 countries evaluated in the "2018 KPMG Autonomous Vehicle (AV) Readiness Index";
- ✓ Australia needs more electric charging stations;
- ✓ A consistent regulatory platform of standards across all state and federal authorities needs to be developed to support AV deployments nationally; and
- ✓ More widespread communication is required to familiarise the community and all road users.

Legislation and regulation

IN SUMMARY

Recommendations for the future deployment of Autonomous Vehicles:

- ✓ Introduce a more formalised mechanism led by Transport for Victoria (but involving all stakeholders), which captures lessons learnt and knowledge associated with Autonomous Vehicles and their future deployment;
- ✓ Adapt regulations following subsequent deployments, based on learnings and recommendations with a 'loop-based' learning process, managed by Government;
- ✓ Consider several factors which apply to both public and private roads, including the vehicle registration process, safety management plan, incident management and reporting, traffic management and driver certification processes, as well as the current regulations and road rules which impact the enablement of modern transport solutions to be deployed. This also applies to future trials and the governance associated with passenger safety;
- ✓ Enable more flexible ethical requirements and compliance processes until more formalised structures are defined, so that future projects of similar nature can be executed;
- ✓ Develop appropriate regulations relating to the management, administration, availability and access of data by stakeholders delivering and operating AV technology; and
- ✓ Create a more comprehensive approach at the national level, which develops guidelines around what the vehicle can do / be allowed to do and how the operation of the vehicle can be programmed, which the states must follow. Encourage the Australian Government to initiate this, in consultation with technology experts, academics, ethicists, transport operators and state representatives.

Commerciability and liability

IN SUMMARY

Recommendations for the future deployment of Autonomous Vehicles:

- ✓ Develop a clear commercial framework (similar to the Collaborative Research Agreement signed by this project's partners) for future commercial operations;
- ✓ University to conduct further work to see whether a permanent Autonobus service is viable (in conjunction with the existing Glider service);
- ✓ The operator of the Autonomous Vehicle be the sole party liable for any incidents that may occur, and that appropriate insurance be provided to cover all instances – including the AV's storage, operation and whilst charging;
- ✓ Greater discussion amongst the technology, legal and political communities surrounding this previous matter – including an AV malfunction and whether the manufacturer or operator should be liable – and to decide on the ultimate course of action;
- ✓ Current Public Liability Insurance policies (for precincts such as Universities) be extended to allow for the operation of Autonomous Vehicles, on both private and public roads, which clearly outline factors to be considered in establishing liability;
- ✓ Australian Government take charge of this public liability requirement and encourage insurance companies to introduce policy cover which enables the future deployment of AVs in Australia; and
- ✓ Well-documented procedures (including for safety, incident and traffic management), consistent with regulatory guidance (and emerging best practice), combined with regular training and clear communication with staff, passengers and the community, will ensure risks are minimised and safety is maximised.

3.7.3 J.D. Power, Mobility Confidence Index Study[8]

J.D. Power, a global leader in consumer insights and data analysis, conducted a Mobility Index Study from 2018-2019 with the purpose of identifying and describing the market readiness and acceptance of self-driving and battery-electric vehicles. J.D. Power conducted the study in collaboration with survey software company SurveyMonkey. The study is based on 5700 consumers. From the study the following key findings were identified:

- Low level of confidence regarding comfort about riding in a self-driving vehicle and comfort about being on the road with others in a self-driving vehicle.
- Industry experts emphasize that the perfection of self-driving technology is tougher and more challenging than originally expected.
- Experts expect that self-driving services - like public transport, taxi services and delivery services will arrive within 5-6 years, where self-driving vehicles for personal purchase will arrive in 12 years. Consumers expect both types of use to be available in closer to 10 years.

[8] https://www.jdpower.com/business/press-releases/2019-mobility-confidence-index-study-fueled-surveymonkey-audience

- In general consumers are more optimistic than worried (64 % vs. 34 %) about how self-driving vehicles can benefit their lives. Most consumers are worried about tech failures (71 %), risk of being hacked (57 %) and legal liability as a result of collision (55 %).
- The vast majority of the respondents (66 %) admit to having no or little knowledge about self-driving vehicles.
- In general consumers are not sure whether self-driving vehicles with improve traffic safety (40 % vs 40 %). Consumers who say that they know "a great deal" or "a fair amount" about self-driving vehicles expect that self-driving vehicles will improve traffic safety (59 % and 52%, respectively).

4 The gap

The gap can be described as the space between the current state (SoA) and the proposed state (AVENUE goals). This space is defined and understood by the barriers that stand between reaching the desired goals. These barriers are in this deliverable defined in three categories representing together what is necessary to accomplish in the AVENUE consortium, in order to meet the project's vision. These categories are legal, social and technical.

Based on these barriers, actionable recommendations can be defined as steps that the AVENUE consortium has to take to minimise the gap that stands between the current state and the proposed state. These recommendations also include insights from in-depth investigations performed by other AVENUE partners, with experience and expertise within the three categories:

- Legal barriers - ECP
- Social barriers - SAG
- Technical barrier - PTO's, Bestmile & Mobile Thinking

This gap analysis will continue on the basis of the first deliverable, D2.1, in combination with learnings and experience gained by the PTO's and other relevant partners.

Based on the SoA analysis the current state (what are we capable of doing so far) is briefly defined:

- SAE level 3 vehicle driving
  A security-driver is needed to compensate for blind angles and to overtake unknown obstacles on the road.

- Public and shared transport
  In pre-mapped areas the shuttles can transport up to 11 people in public transport.

- Solve real mobility needs
  In urban areas with no existing transport option, the shuttles can be used to move people on a pre-mapped route.

- Drive safe under the right conditions with low speeds

The shuttles can drive safe, in autonomous mode, under the right conditions with low speeds up to 18 km/h.

- Sustainable transport
  The shuttles are used for shared transport and run on the cleanest energy source.

Based on the AVENUE project proposal and desired goals from the PTO's, the proposed state (what do we want to be able to do) is briefly defined:

- SAE level 5 driving
  Driving everywhere with no security driver. Fully autonomous no need for human interference.

- Drive fully on demand
  No need for pre-mapped routes, autonomous driving everywhere based on live mapping and sensor systems.

- Drive off routes (door to door transport)
  Ability to stop everywhere and pick up passengers

- Drive without safety drivers
  Fully integrated systems allow people to experience the same level of service from apps, AI, screens etc.

- Drive with higher speeds (50 km/h)
  The ability to drive on all roads in urban areas demands the vehicle to be able to drive up to 50 km/h

- Integrate with existing public transport system
  The vehicles are fully integrated with public transport and works as links between trains, subways, metros and other means.

- Drive with multiple vehicles in fleet mode
  The ability to use vehicles after demand in specific areas require that the vehicle can communicate in fleet mode, ensuring efficient routes with multiple passengers from different pick-up points.

- Be fully sustainable (green electricity - positive rebound effects)
  The vehicles are shared and km effective. 100 % green electricity is used during all hours.

- Reach a more competent economic setup (no operators & easier application processes)
  No drivers and shared autonomous vehicles will be able to reduce the cost of transport in urban areas.

- Personalised transport
  Fully autonomous vehicles will enable new and more personalised transport options, introducing new ways to spend time during transport.

- Automatic vehicle changes
  The vehicles are fully autonomous and can drive back and forth from charging station ensuring transport 24/7 without any human interference.

It can clearly be seen that there is a gap between the current state and the proposed state. This gap is caused by both legal -, social - and technological obstacles, which are perceived as barriers describing what needs to be accomplished for the AVENUE project goals to be met.

The legal -, social - and technological barriers are in the following sections, 3.1, 3.2 and 3.3, described while emphasising that legal - and social barriers are further elaborated on in task T2.4 and T2.2. The proposed state (the goals of the AVENUE project) is defined.

4.1 Legal barriers

From deliverable D2.10 and the beginning of deliverable D2.11, the following legal barriers were identified, based on research and interviews with the operators in Luxembourg, Copenhagen, Lyon and Geneva. For in depth understanding, please see the deliverables.

With the purpose of understanding the legal barriers, it is necessary to describe the three legal branches that legal AV issues can occur within; Administrative law, Civil law and Criminal law. These will be shortly described in the following sections.

Administrative law
This includes road traffic laws like licensing, technical controls, road traffic rules and so forth. Relevant questions within this branch of law can be: Shall an AV driver/user be required to have a driver's license? Should there be dedicated lanes for AVs? Should AVs be allowed everywhere? And many more.

Civil law
This includes a broad range of legal areas like civil liability, injuries, damages and so forth. The main challenge in this legal branch is to define the liability setup between, manufacturers, operators, passengers and the rest of the public transport system.

Criminal law
This includes legal areas like protection of passengers, protection against cybercrimes and hackers. This area very much affects the civil law, since if a crime is committed against the AV or a passenger inside/outside the vehicle, who is held responsible?

The following barriers has not yet been defined in terms of the three different legal branches, but merely describes some of the initial barriers experienced in the AVENUE project so far. The work of defining in which legal branch the barriers belong, will be introduced in the next deliverable D2.12.

Barriers

- The lack of precise regulation
  The regulatory focus thus far has been on enabling testing of autonomous vehicles and providing guidelines for the development of autonomous vehicles. Both are positive steps,

however, there is a risk that without clear legislation stakeholders may opt not to follow the guidelines, leading to a discordant development.

- Low progress of EU legislation
  Considering that it took five years from the request for a Mandate until the adoption of the 'Release 1 specifications', EU legislation may progress too slowly to be of assistance in coordinating and synchronising development.

- Cross-border use of connected cars, ITS related.
  The ITS Directive allows each Member State "to decide on deployment of […] applications and services on its territory" which may give rise to situations where car owners cannot use their vehicles outside their home jurisdictions.

- Interoperability
  AVs contain supreme information systems that use sensors and machine learning to drive. These systems need to interact with each other as well as with the surrounding systems. These systems must have interoperability to ensure the systems to be safe and smart.

- Liability issues - Attributing liability
  Who should be held liable in the case of an incident with the AVs? This issue is not fully defined and can cause some major publicity problems, if an incident occurs.

- Liability issues - Attributing fault
  With the increase in event data recorders (also known as insurance black boxes) in vehicles it should become easier to determine exactly what the cause of the accident was (subject to the privacy implications), however, the fault for the accident will still need to be attributed and there is still no common agreement on that.

- Liability issues - Responsibility for insurance:
  There is the question of who should insure the vehicle. Should all relevant parties contribute to the insurance or should the driver or manufacture do it? There is still no common agreement on that.

- Energy consumption
  The green aspect of AV could be jeopardised and stronger rules applied if LCA were to be applied or if digital pollution regulation were to be stronger.

- Anonymity and personal data protection hardening

- Lack of European normalisation
  This is linked to the various aspects of the AV: homologation process, test authorisation, AV level accepted on open roads even for tests, data sharing and common platforms

- Urban planning and legal aspects / public transport organisation

4.2 Social barriers & motivators

From deliverable D2.4 and the beginning of deliverable D2.5, the following social barriers were identified during the consolidation of user interviews in Luxembourg, Copenhagen, Lyon and Geneva. For in depth understanding, please see the deliverables.

Barriers

- People prefer to drive their own car
- Passengers want to talk with a driver
- Passengers rely on a driver to help them
- Doubts that the technology is mature enough to be trusted up to the absolute refusal to trust in this technology
- Stories about accidents with autonomous vehicles
    - Passengers need to be convinced that the vehicles are absolutely safe
    - Possible indicator: The amount of time or km a vehicle has been running without accidents
    - Even little incidents or accidents are likely to destroy any trust passengers have developed
- Worries that other road users will not be able to anticipate the behaviour of autonomous vehicles
- Autonomous busses in the field will lead to more delays and failures and more traffic jams for other road users
- Traffic situation is very complex:
    - Too complex to be handled by technology in general
    - A driver can flexibly react to all unforeseen situations and interfere if necessary
    - The autonomous bus will have accidents without a driver
- Risk of cyber-attacks: hackers could make the bus go faster or drive off a bridge or into oncoming traffic
- Passengers do not like the idea that there could be no supervisor in the shuttle:
    - No one in the bus to perform first aid if required
    - Feeling uncomfortable all alone in the bus at night, especially in certain neighbourhoods
    - Even robberies or assaults
    - No authority figure present to keep passengers calm (-> school kids)
    - Vandalism
    - No information if there are any problems
    - No communication (chatting with the driver is quite common in some areas)
    - No support during the trip/on board and especially no support to get on and off (passengers are worried that they might not have enough time to get on and off the shuttle and the doors could close too soon)
    - No support to reach a connection

During the interviews and user observation several motivators were also identified and described. These social motivators are included in this section, since the social acceptance of the autonomous vehicles will be defined by the balance between motivators and barriers that needs to be solved.

Motivators

- Presence of a supervisor in the bus
    - Someone who can interfere or take over (if the technology fails)
    - Someone to act as an authority figure
    - Someone who can answer questions, provide information and help with getting on or off the bus when necessary
- Better coverage of an area with public transport; bus connections where there are none today (because it is not profitable today)
- More destinations
- Higher frequency of service
- Public transport anytime of the day/night
- Bus on demand: no rigid timetable but being able to call the bus whenever needed
- More flexibility regarding the stops / door-to-door Service
- Reliable service that is on time
- Cheaper tickets
- Clean vehicles
- Sufficient seating, maybe "even guaranteed seats for people with special needs"
- Better information than today: more, accurate, accessible
    - e.g. acoustically understandable announcements, correct announcement of the upcoming stop, information when the bus will actually arrive, information where the bus is at every moment and where it is going (considering flexible routes)
- Expected advantages if the bus is not operated by human driver:
    - A smooth driving style as there is no impatient driver
    - Gentle braking, no more sudden braking manoeuvres
    - Clear announcements, no more mumbling, no cursing

4.3 Technical barriers

The technical barriers are defined by two processes as follows:

- A master thesis project, written by Tim Bürkle, called "Autonomous Shuttles - Technical Obstacles for the Diffusion, Implementation and Deployment" at Hochschule Pforzheim: School of Engineering. Acting supervisor: Prof. Dr. Guy Fournier. The results of the master thesis derive from a thorough investigation process involving the four operators of the AVENUE project: Keolis, TPG, Autocars Sales-Lentz, Amobility and the consortium vehicle manufacturer: Navya.

- Feedback from technical development partners in the AVENUE project, e.g. Bestmile and Mobile Thinking due to their participation in generating the technical solutions. Both partners were asked to provide the technical barriers and obstacles based on what they perceived as important for their work in the AVENUE consortium.

Barriers

Based on interviews with the operators and vehicle manufacturer the following technical barriers were identified, in the master thesis, and defined in two categories: Shuttle capabilities and Shuttle environment:

Shuttle capabilities:

- Construction Quality
  Lack of experience and knowledge on construction of vehicles

- Traffic Regulation & Choice of Roadway
  Not as flexible as a driver - need of operator to move the shuttle manually. Vehicle give way to all other road participants, regardless of the rules due to fixated sensory system.

- Perception & Ability to Determine
  No classification of traffic lights and signs yet fully integrated and the shuttles cannot distinguish between the obstacles, e.g. people versus animals, snow flakes versus big rain drops etc.

- Driving Strategy
  Unnatural driving behaviour (hard braking, different acceleration) could cause issues in traffic. Need of onboard attendant to overcome all situations.

- Interoperability
  Isolated system. Needs to be comparable with other systems like regular cars etc.

- Sensor-Position (LIDAR 360°)
  Some minor blind spots and no-detection areas

- Sensor-Resolution (VLP16 LIDAR)
  No reliable detection of moving object and its direction

- UMTS & 3G-Modem
  Problematic transfer of pictures and videos due to lack of bandwidth of the modem

- Charging Time
  Charging time of the vehicle is more than 4 hours

- HitRatio
  The shuttle relies on a high hit ratio, meaning that the shuttle is seeing what was recorded when the route was mapped. Since roads change a lot in urban areas due to construction, snow, etc. the shuttle experiences a low HitRatio and cannot continue.

Shuttle environment:

- Mapping & Modification of Routes
  Operation is limited to pre-mapped routes and pre-defined stops.

- Sensor-Related
  Detection of rain and snow as an obstacle, or aberrancy between camera/sensor perception and 3D-Map (low HitRadio) causes the shuttle to stop.

- Batterie-Related
  Charging and de-charging problems in cold weather (0 degrees celsius or lower)

- Power-Related
  Breakdown of shuttle in very warm weather (40 degrees celsius or higher)

- Reference Points Road Markings
  Reference point are needed to ensure that the shuttle know its position. Problematic in areas without big buildings etc.

- Surface of Roadway
  The shuttle cannot drive on roads with a grade of more than 12 degrees. Shiny buildings and glass surfaces can cause low hit ratio or sudden brakes.

- GPS & GNSS Signal
  Can disappear without live base station (local antenna setup by operator). Base station can lose signal from time to time and cause low HitRatio (no driving).

- 3G/4G Signal
  City infrastructure and bad signal-areas, can cause the shuttle lo lose 3G/4G meaning low HitRatio (no driving).

- Data Transfer & Updates
  Internet need for transfer and updates on the shuttle. Files have to be transferred manually from USB drive to computer.

Based on insights from Mobile Thinking and Bestmile the following technical barriers were identified. The technical barriers are based on what the two companies perceive as technical obstacles regarding the development of fleet management system and in-and-out-of-vehicle services:

- Lack of means to count passengers to estimate occupancy (as this is crucial for a real on-demand system, and without safety driver there need to be automatic means to do so)

- Lack of algorithms or other means to determine capacity left out of occupancy (occupancy does not equate always to capacity)

- Missing APIs in order to be able to send missions to the vehicle remotely

- Lack of optimized detection systems and algorithms to be able to drive fluidly and without heavy braking (to be able to go to speeds over 40km/h)

- Low battery capacity to sustain faster driving, more sensors, more computations

- Not being able to really avoid obstacles without the aid of a safety driver

- Not being able to drive on uncharted routes/without pre-mapping, not following a predefined line/path
- Not being able to operate in bad weather conditions (snow, heavy rain...)
- Lack of means to identify passengers who go in (authorization, who can really ride in the vehicle)
- Lack of integration into the PTOs ecosystem (with legacy systems, route planners, existing applications and interfaces, etc)
- Barriers related to the use of technology itself (elderly people, people not familiar with smartphones or not at ease with the use of technology/apps), which will exclude certain population groups
- Vehicle capacity to operate in any weather conditions, including snow and fog, which today confuses lidar lasers and obscure road signs
- Vehicle capacity to operate in hilly conditions (without engine overheat) and hot/cold temperatures
- Accessibility and usability for disabled people
- Vehicle / embedded technology price
- Vehicle production limited capacity
- Lack of anticipation capabilities of embedded decision-making algorithms as regards the behaviour of pedestrians, cyclists and unconnected vehicles
- Lack of standardized mapping technology that all vehicles can use and that can easily be updated
- Limitation of sensors to render accurate 3D images of surroundings and high latency of image processing that would slow decision-making
- Limitation of sensors to see far enough to get the needed understanding of surroundings to go to speeds over 40 km/h
- Lack of ability to isolate and heal system failures such that vehicles can either continue to operate while failure is overcome or to know how to stop safely in the current environment
- Battery capacity and weight of the vehicles when equipped with all the hardware involved in the self-driving technology
- Teleoperations to enable remote safety driving of vehicles in specific situations (with no latency and perfect understanding of surroundings for the remote operator)

- Lack of fleet orchestration capability to ensure the right mission is sent to the right vehicle at the right time in split seconds

- Lack of fleet orchestration capability to move vehicles in and out of service in a safe and efficient manner to manage charges and maintenance

- Lack of operational knowledge to deal with incident management (additional vehicles taking over passengers from out-of-service vehicles).

- Lack of integration with Smart City infrastructure (connectivity with emergency services for example)

- Lack of green electricity source to fuel the electric shuttles

- Lack of understanding of the waste cycle of lithium ion batteries

- Lack of management capabilities of recharging infrastructure

- Too comfortable, entertaining and efficient on-demand rides that people won't mind long commutes and traffic will get worse.

As seen, some of the technical barriers from the master thesis overlaps with the technical barriers provided by Bestmile and MobileThinking. The reason for keeping them separate - and not consolidate the barriers - is that we want to provide a transparent picture of the barriers and their origin.

5 Recommendations

This chapter introduces the Legal -, Social - and Technological recommendations, based on the above introduced and described barriers and obstacles. Each set of recommendations will be presented in the three following sections. The recommendations should be understood as actions that needs to be conducted to ensure further development of the AVENUE project, but also the self-driving technology itself.

The Legal recommendations are mostly targeted at the international and domestic law-makers, hence not directly something that the AVENUE partners can solve. At the end of the AVENUE project, the legal recommendations will be collected and drafted into one resulting proposal, recommending how the AVENUE learnings can be implemented in the overall EU legal framework to establish a more proactive AV setup. The Social recommendations are targeted at the AVENUE partners, emphasizing actions that need to be done, to ensure customer adoption and satisfaction. The Technical recommendations are targeted at the technical partners of the AVENUE project, mostly the manufacturer of the shuttle and mostly highlight technical features that need to be in place to reach the proposed state.

5.1 Legal recommendations

- One common EU based AV law department, that centrally can ensure state-of-the-art knowledge regarding type approvals (in this case not only type approvals of the vehicles but also approvals of routes, software etc. across EU borders - one legal framework to accommodate all approvals necessary to implement AV's), energy consumption requirements, liability distribution. Most importantly one agile department with the ability to constantly update the legal framework to ensure safety, innovation and agile development of AV deployment in public transport. THis common EU law framework

- Data-driven (meaning using data from operations, customers satisfactions etc., to form and guide future aspects and decisions) legislation on public transport with AVs, hence using vehicle and traffic data to govern new laws and standards.

- Central governance on standards regarding connectivity and interoperability. Meaning one platform of standards and regulations that manufacturers can use as guidance regarding communication between vehicles and communication with the rest of the traffic environment (signs, lights etc.).

5.2 Social recommendations

- Ensure a user-centred approach. Including the users in testing, ensuring insights regarding potential barriers and obstacles, hence being proactive in the user approach. Ask and observe to ensure honest insights from the users.

- Show users the benefits of AV deployment in public transport. User promotional videos and flyers to describe a futuristic image of how the users' lives can change for the better due to the introduction of self-driving vehicles in urban transport.

- Show the users how the technology is working. Bring them into the environment and avoid misunderstanding and unnecessary opinions regarding the technology. Work against the "zero tolerance industry" concept, where no mistakes are allowed. As with other transport industries some mistakes cannot be avoided in the process of shaping the future.

- Keep the safety driver in the shuttle until user surveys show that they have enough confidence in AV driving technology that the presence of a safety driver is not necessary anymore..

- Use data from pilots and real operations to show the users the progress of the technology. Data can be used to remove any misunderstanding or negative perceptions about the technology.

5.3 Technical recommendations

[FOR INTERNAL READING]

The Technical recommendation will be based on the barriers and obstacles introduced in section 3.3. Before being able to define the recommendations the technical partners and operators of the AVENUE project must meet and define a technical roadmap, e.g. a timeline on how to tackle and solve the presented barriers. This means sorting, categorising and prioritising the barriers.

6 Conclusions

The gap analysis clearly indicates that there are many barriers and obstacles to overcome in order to move from the current state to the proposed state (AVENUE goals). These barriers are divided into legal, social and technical obstacles that need to be addressed to move forward. Based on these barriers and the consortium's technical knowledge this gap analysis proposes some recommendations to move forward on.

The gap analysis shows that both legal, social and technical advancement is necessary to reach the goals, but that specifically the technical barriers propose a hard challenge. Based on Operator knowledge, specifically the technical features of the autonomous shuttle has to advance in order for the Operators to provide the necessary urban mobility that is demanded at the four pilot sites. Here with focus on maintaining the current safety level, but to reach higher speeds at the same time.

Therefore the technical barriers presented in this gap analysis is seen as critical focus points of the AVENUE consortium. As the development of the technical capabilities of the shuttle progress, the social and legal barriers will be indirectly targeted, as they both represent issues caused by the limitations of autonomous technology.

It is though important to be aware of the fact that not only the manufacturer of the shuttles need to continue developing the technology, but also the sub-manufacturers like lidar and sensory system companies need to progress in order to reach the AVENUE goals.