Automated Vehicles to Evolve to a New Urban Experience

DELIVERABLE

D2.3 Final Gap analysis and recommendations on autonomous vehicles for public service

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Acronyms

ADS	Automated Driving Systems
AI	Artificial Intelligence
AM	Automated Mobility
API	Application Protocol Interface
AV	Automated Vehicle
BM	Bestmile
BMM	Business Modelling Manager
CAV	Connected and Automated Vehicles
CB	Consortium Body
CERN	European Organization for Nuclear Research
D7.1	Deliverable 7.1
DC	Demonstration Coordinator
DI	The department of infrastructure (Swiss Canton of Geneva)
DMP	Data Management Plan
DSES	Department of Security and Economy - Traffic Police (Swiss Canton of Geneva)
DTU test track	Technical University of Denmark test track
EAB	External Advisory Board
EC	European Commission
ECSEL	Electronic Components and Systems for European Leadership
EM	Exploitation Manager
EU	European Union
EUCAD	European Conference on Connected and Automated Driving
F2F	Face to face meeting
FEDRO	(Swiss) Federal Roads Office
FOT	(Swiss) Federal Office of Transport
GDPR	General Data Protection Regulation
GIMS	Geneva International Motor Show
GNSS	Global Navigation Satellite System
HARA	Hazard Analysis and Risk Assessment
IPR	Intellectual Property Rights
IT	Information Technology
ITU	International Telecommunications Union
LA	Leading Author
LIDAR	Light Detection And Ranging
MEM	Monitoring and Evaluation Manager
MT	MobileThinking
OCT	General Transport Directorate of the Canton of Geneva
ODD	Operational Domain Design
OEDR	Object And Event Detection And Response
OFCOM	(Swiss) Federal Office of Communications
PC	Project Coordinator
PEB	Project Executive Board
PGA	Project General Assembly
PRM	Persons with Reduced Mobility
PSA	Group PSA (PSA Peugeot Citroën)
PTO	Public Transportation Operator
PTS	Public Transportation Services
QRM	Quality and Risk Manager
QRMB	Quality and Risk Management Board
RN	Risk Number
SA	Scientific Advisor

SAE Level	Society of Automotive Engineers Level (Vehicle Autonomy Level)	TM	Technical Manager
SAN	(Swiss) Cantonal Vehicle Service	TPG	Transport Publics Genevois
SDK	Software Development Kit	UITP	Union Internationale des Transports Publics (International Transport Union)
SLA	Sales Lentz Autocars	V2I	Vehicle to Infrastructure communication
SMB	Site Management Board	WP	Work Package
SoA	State of the Art	WPL	Work Package Leader
SOTIF	Safety Of The Intended Functionality		
SWOT	Strengths, Weaknesses, Opportunities, and Threats.		
T7.1	Task 7.1		

Executive Summary

The final Gap analysis is conducted as a follow-up on the first and second deliverable. The purpose of the Gap analysis is to specify in detail the potential of the AVENUE services and solutions, while at the same time propose new and state-of-the-art features and recommendations for the AVENUE project and the EU commission.

The Gap analysis and the recommendations are based on the work of the project partners, with both inputs from academic research and real demonstrations of the technology. The recommendations are also based on in-depth investigation and analysis of the barriers and obstacles that arise during the deployment of automated vehicles in public transport and urban areas, via the real pilots in the AVENUE projects.

The obstacles are defined in categories identified by the project partners; Technical, Legal, Economic, social and more. The recommendations and obstacles are based on the work so far and will be used to improve and further develop the services and technologies in the project. The official public recommendations will be presented at the end of the project in WP9 as a complete results of all the initiatives in the project, both technical, legally, economically and so forth. Hence 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 Automated minibuses in low to medium demand areas of 4 European demonstrator cities (Geneva, Lyon, Copenhagen and Luxembourg) and 2 to 3 replicator cities. The AVENUE vision for future public transport in urban and suburban areas, is that Automated vehicles will ensure safe, rapid, economic, sustainable and personalised transport of passengers. AVENUE introduces disruptive public transportation paradigms on the basis of on-demand, door-to-door services, aiming to set up a new model of public transportation, by revisiting the offered public transportation services, and aiming to suppress pre scheduled fixed bus itineraries.

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

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

1.1 On-demand Mobility

Public transportation is a key element of a region's economic development and the quality of life of its citizens.

Governments around the world are defining strategies for the development of efficient public transport based on different criteria of importance to their regions, such as topography, citizens' needs, social and economic barriers, environmental concerns and historical development. However, new technologies, modes of transport and services are appearing, which seem very promising to the support of regional strategies for the development of public transport.

On-demand transport is a public transport service that only works when a reservation has been recorded and will be a relevant solution where the demand for transport is diffuse and regular transport is inefficient.

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

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

1.2 Fully Automated Vehicles

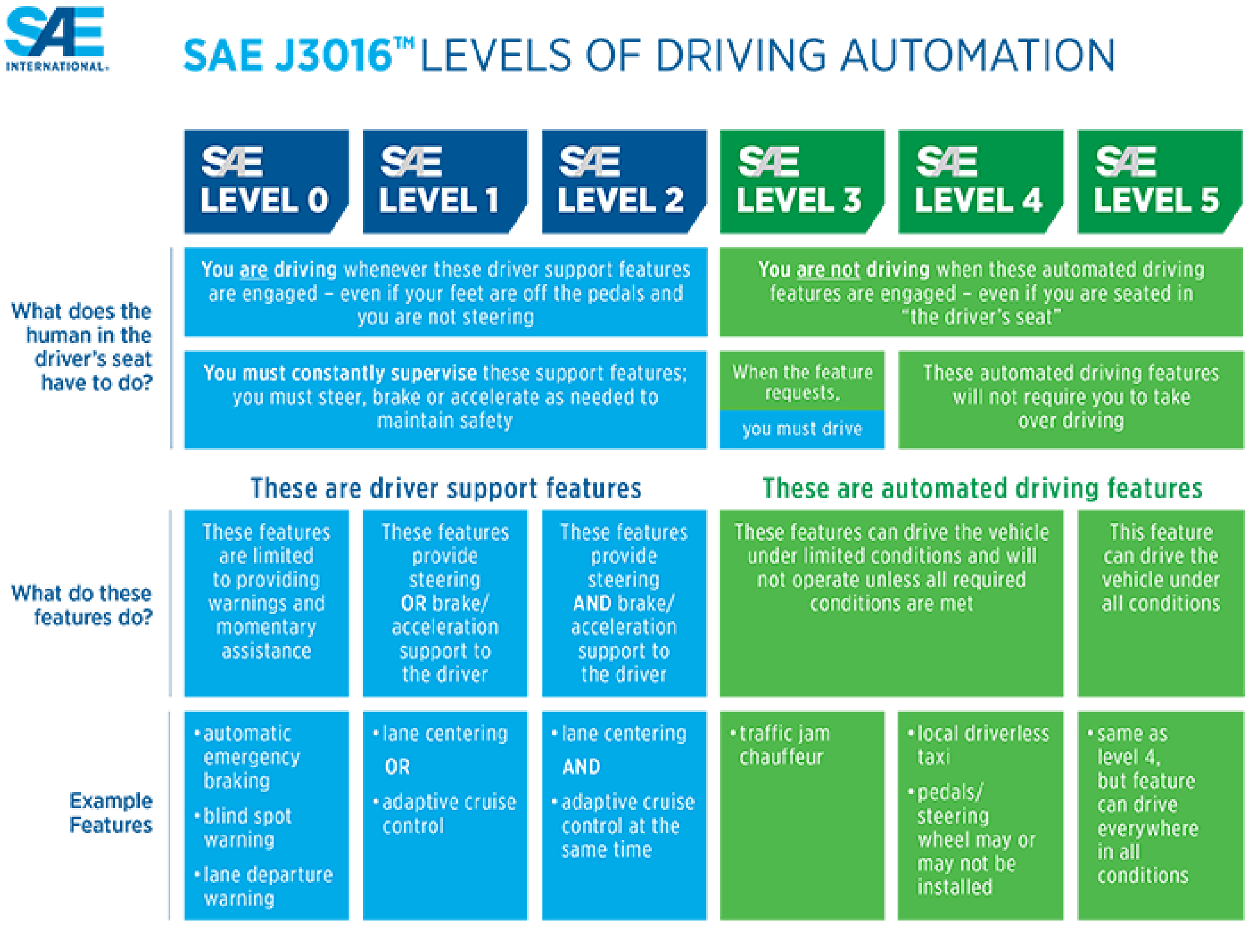
A self-driving car, referred in the AVENUE project as **an Fully Automated Vehicle** (AV), also referred as autonomous vehicle, is a vehicle that is capable of sensing its environment and moving safely with no human input.

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

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

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

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



1.2.1 Automated vehicle operation overview

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

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

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

1.2.2 Automated vehicle capabilities in AVENUE

The Automated vehicles employed in AVENUE fully and automatically manage the above defined, micro-navigation and road behaviour, in an open street environment. The vehicles are Automatically capable to recognise obstacles (and identify some of them), identify moving and stationary objects, and Automatically decide to bypass them or wait behind them, based on the defined policies. For example with small changes in its route the AVENUE shuttle is able to bypass a parked car, while it will slow down and follow behind a slowly moving car. The AVENUE vehicles are able to handle different complex road situations, like entering and exiting round-about in the presence of other fast running cars, stop in zebra crossings, communicate with infrastructure via V2I interfaces (ex. red light control).

The shuttles used in the AVENUE project technically can achieve speeds of more than 60Km/h. However this speed cannot be used in the project demonstrators for several reasons, ranging from regulatory to safety. Under current regulations the maximum authorised speed is 25 or 30 Km/h (depending on the site). In the current demonstrators the speed does not exceed 23 Km/h, with an operational speed of 14 to 18 Km/h. Another, more important reason for limiting the vehicle speed is safety for passengers and pedestrians. Due to the fact that the current LIDAR has a range of 100m and the obstacle identification is done for objects no further than 40 meters, and considering that the vehicle must safely stop in case of an obstacle on the road (which will be “seen” at less than 40 meters distance) we cannot guarantee a safe braking if the speed is more than 25 Km/h. Note that technically the vehicle can make harsh break and stop with 40 meters in high speeds (40 -50 Km/h) but then the break would too harsh putting in risk the vehicle passengers. The project is working in finding an optimal point between passenger and pedestrian safety.

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

1.3 Preamble

The final Gap analysis is, as the first and second deliverable, structured in 4 sections; AVENUE goals, State-of-the-Art 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.i. 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 automated 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.

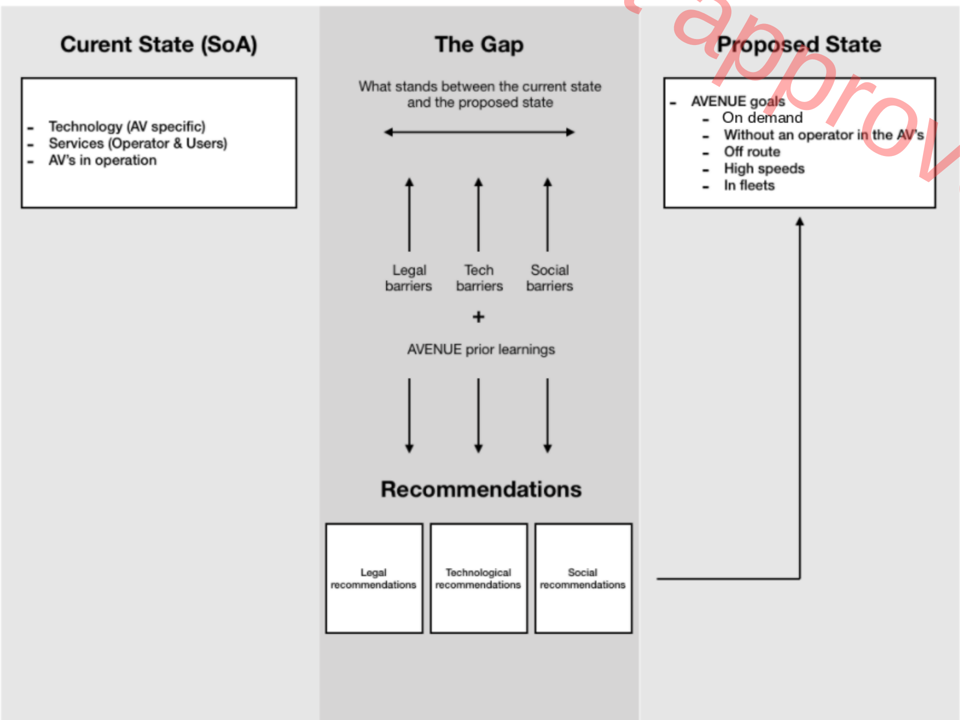


Figure 1 - The gap visualised

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 automated 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 automated vehicles for public transport, e.g. demonstrations and pilot projects.
- Academic reports and articles based on existing pilot projects and demonstrations with automated vehicles in and out of public transport.

1 AVENUE goals

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

1.1 Proposed state

The purpose of the AVENUE project is to demonstrate and pilot the adaptability and efficiency of the deployment of small and medium automated 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 automated 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 automated vehicles.

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

[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

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.

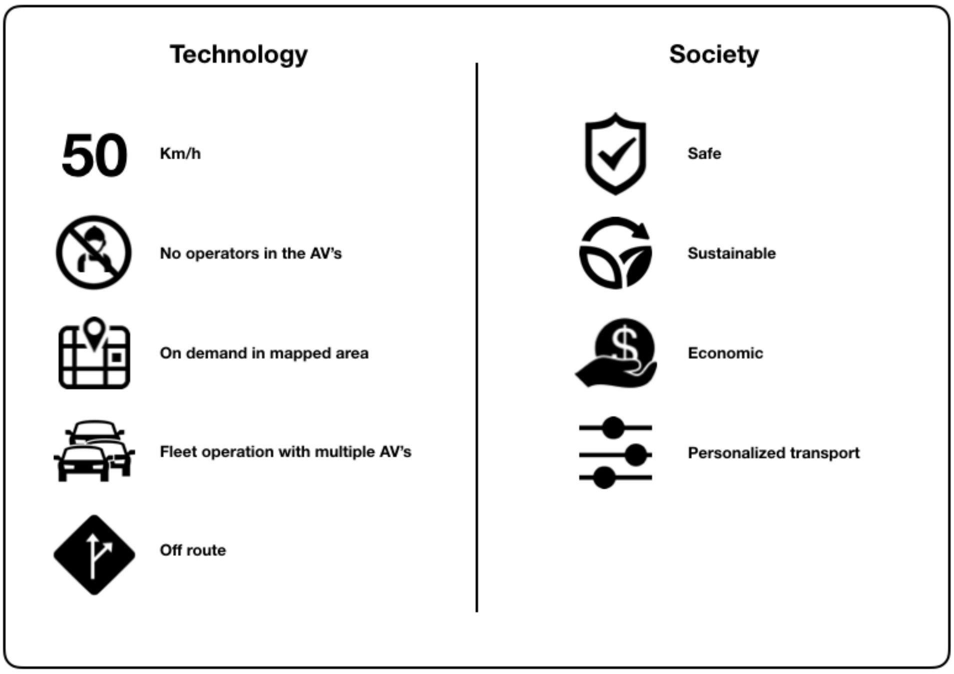


Figure 2 - AVENUE goals

1.2 Basic description of on-demand

On-demand transportation or Demand Responsive Transportation (DRT) are terms referring to non-fixed routes. Where the travellers pickup and dropoff locations are determining the route driven by the vehicle. It is a valid term for both manual and automated vehicles. But with the present state of known automated vehicles, the DRT for automated vehicles are restricted to: Geographic area, specific roads already mapped, specific driving behavior (Ex no U-turns), etc. Where manual drivers are still more flexible in terms of satisfying on-demand requests from travellers.

An interesting topic for automated vehicles is dynamic routing (Or simply routing). Which is adjustments to the selected route while driving. This is an important feature for DRT solutions with automated vehicles to really make a good product both for the traveller and the supplier. With this ability the route can be adjusted while driving and travellers can request to get off quickly. Where in a scenario without, a destination is loaded into the vehicle's software. And there would be no elegant way to diverge from the destination once in execution mode.

1.3 Higher speed

In order to reach higher speeds both software and hardware needs to accommodate this. With higher speeds introduced, a need to measure the surroundings further away is needed. Time for processing sensor input needs to be low, such situations can be analyzed and handled correctly in time. The quicker processing time, the quicker a decision can be made and the quicker the vehicle can go to a full stop.

Generally higher speeds calls for better sensors, better software and better processing equipment. These three components will need to be measured on its worst scenarios, which will dictate its minimum performance. The minimum performance is an important measure in the game of automated vehicles. As there is no room for errors, 99% 'uptime' is not a thing once it's on the road. In a scenario where the system can not measure the surroundings, process its data in time or cant process the data at all, will lead to a scenario similar to that of a manual driver not having eyes, ears or focus on the road.

The first figure surrounding this text will show the importance of the 'Reaction distance'. This is the time for the sensor to measure and the system to process and find a way to handle the situation.

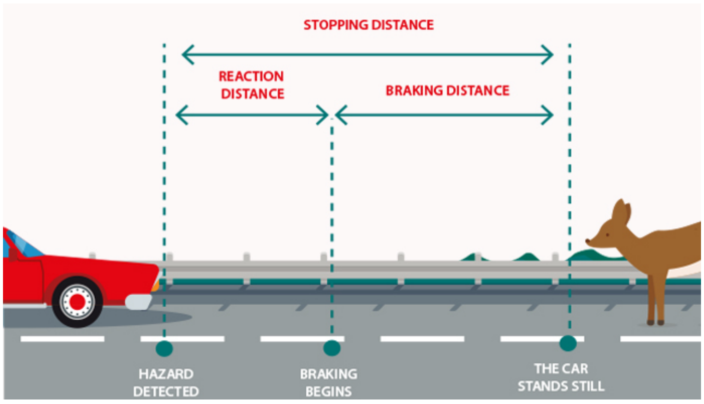


Figure 3 - Reacting distance

The second figure shows the concept of exponential braking distance that is attached to higher speeds. The figure indicates that the stopping distance is exponentially defined by the speed of the vehicle. This means that the sensory system has to extend the radius exponentially as much as the speed increases to ensure visibility of other vehicles, road users, pedestrians etc. when driving at a higher speed.

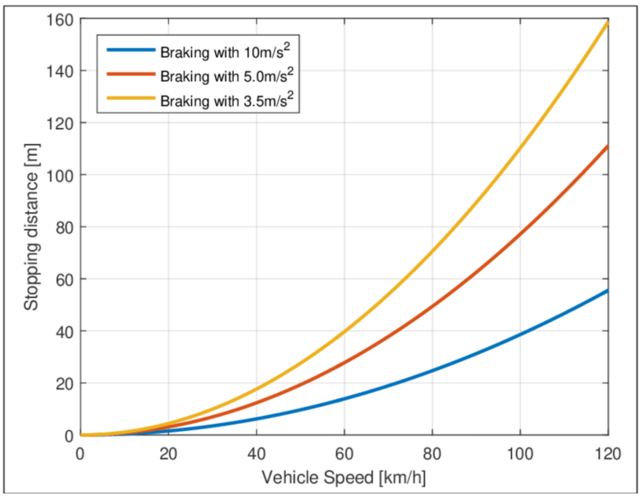


Figure 4 - exponential braking[3]

[3] https://www.researchgate.net/figure/Stopping-distance-vs-speed-for-three-different-levels-of-deceleration_fig1_332838232

2 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.

2.1 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 automated 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[4]

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

2.1.1 Status of the AVENUE goals

- Reach 50 km/h (later agreed to be 30-40 km/h)
  - **Software**: No development activity initiated. Navya even states that their improved shuttle, the Navya EVO, will reach speeds no higher than 25 km/h.
  - **Hardware**: No real development activity initiated. Navya even states that their improved shuttle, the Navya EVO, will reach speeds no higher than 25 km/h. Currently, the sensors used on the Navya Autonom shuttle will not support those kinds of speeds. LiDAR sensors' resolution is too low.
  - **Legal**: No update (not relevant)

- No Safety operator in the shuttle
  - **Software**: No real development activity initiated as this functionality needs to build on top of the vehicle vendor API. Navya has not added remote control features to API, that can handle the tasks the inside vehicle operator/safety operator is performing. At the same time it seems like there is a need for the safety steward (As of Q1 2021) to assist the vehicle. A need that should be limited before remote control features makes sense to try and replace. The operators within Avenue have received a lot of data from the daily operations from all Navya vehicles, enabling them to understand the vehicle better and to initiate design and development activities to take the first small steps towards remote monitoring and control. As an example: Video from inside and outside vehicle, events from vehicles when issues happen that need assistance, location updated every second.
  - **Hardware**: Currently the vehicle has limited visibility in comparison to a regular driver such as blindspots in front of the vehicle. The Safety Operator is therefore necessary in order to assist the automated vehicle in detecting obstacles and braking accordingly. Moreover, the low resolution of LiDAR sensors prevents vehicles from detecting moving obstacles more than approximately 40 metres away. Hence, AVs cannot detect moving obstacles in time when entering unregulated intersections and alike.
  - **Legal**: In Denmark it is allowed to take out the Safety Operator from the vehicle. However, such projects would have to document and prove that this would not add increased risk to the traffic safety, compared to e.g. a minibus driving on the same route and with the same speeds and stops. As of now, the technology is not ready to comply with this requirement for documentation.

- On-demand in mapped areas
  - **Software**: Assigning missions through Navya API is possible. In Q1 2021 an important 'Partner mode' update to the API and vehicles is released. This enables some basic on-demand functionality to take place. Maturity is still an important aspect to stabilize and make on-demand a fully functional product for all operators of Navya vehicles. Multiple operators (Amobility and TPG) within Avenue have been trying to use the automatic assigning missions features and received important learnings to prepare and organize for this future way of orchestrating vehicle start and end destinations.
  - **Hardware**: No update (not a challenge)
  - **Legal**: No update currently

- Fleet operation with multiple vehicles
  - **Software**: With the ability to assign missions through Navya API, it is possible to manage the operation of multiple vehicles intelligently. For example the fleet management can make sure the vehicles are distributed evenly on the route, that the vehicle's capacity matches the passenger request throughout the route and so on. These are complex features which implementation/integration are not broadly tested within Avenue. For the first wave of on-demand testing, each vehicle is treated separately, this means no fleet management is added to optimize the vehicle behavior. This will be tested during the reminding period of the AVENUE project. Once the on-demand functionality is matured, the fleet management is the obvious next step to build on top. There are many products of fleet management software available, both existing software mainly used for taxi and public transport coordination, but also new tech approaches like Bestmile, who is targeting automated vehicles. It's a matter of time before the bridge can be fully built between a software like the one from Bestmile and the vehicles from Navya, enabling a whole new set of important features. For the AVENUE project the Bestmile solutions will be used and tested by the operators.
  - **Hardware**: No challenges (hence no update)
  - **Legal**: No challenges (hence no update)

- Off route (being able to drive in new areas - mapping as is goes)
  - **Software**: No activities has been initiated in this area
  - **Hardware**: Navya LiDAR sensors are likely not able to map an area precisely enough when only driving the route once - i.e. mapping as it goes.
  - **Legal**: It is only possible for authorities to approve pre-defined routes. The legal framework is not ready for this type of update.

2.2 Autonomous technology (AV specific)

To set the framework of the SoA, regarding the automated 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.

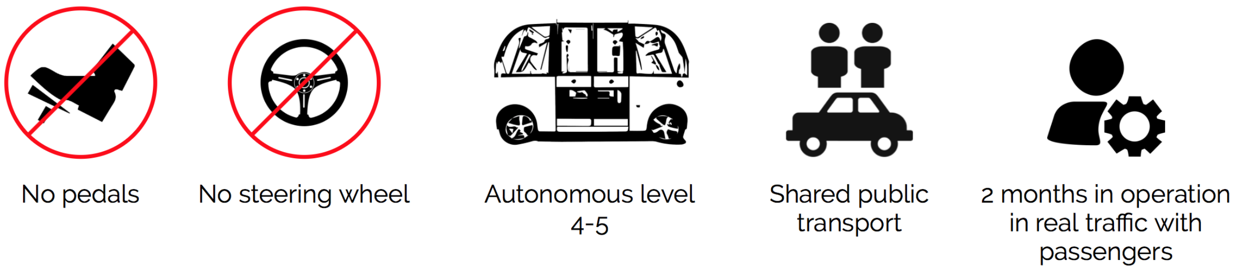


Figure 5 - AVENUE AV scope

Based on the automated vehicle scope, desk research on automated 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	
No vehicles	No vehicles
Table 2 - In system - not in scope - in consortium	

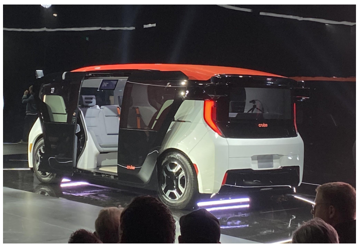
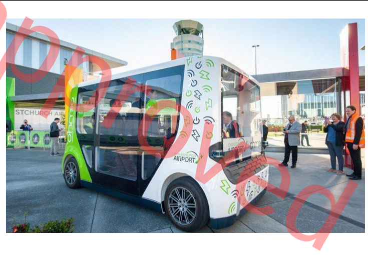
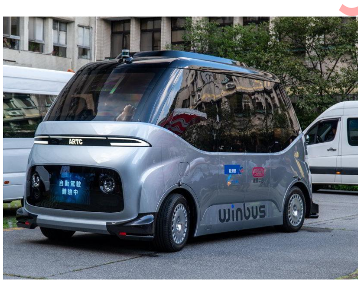
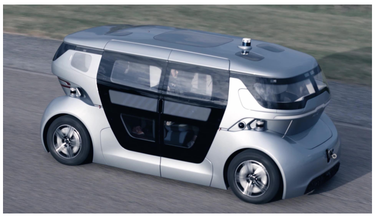
Navya Autonom Shuttle	
Navya Autonom Shuttle EVO	
Table 3 - In system - in scope - in consortium	

In system - in scope Not in consortium but relevant			
2getthere GRT		2getthere PRT	
Baidu Apolong		EasyMile EZ10	

Ohmio Hop		Sensible 4 Gacha	
Yutong 5G		HEAT	
Local Motors Olli		Local Motors Olli Gen 2	
Dongfeng Sharing Van		ZERO shuttle	

Table 4 - In system - in scope - not in consortium

In system - not in scope Not in consortium but relevant			
COAST Autonomous		Toyota e-Palette	

Cruise Origin		Ohmio Lift	
Transdev/Lohr i-Cristal		WinBus	
NEVS PONS			
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	

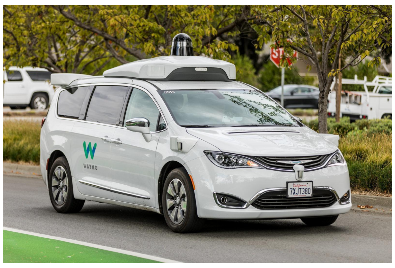
Streetdrone		Tesla	
Uber		Voyage	
Waymo		Yandex	
Sensible 4 / Toyota Motor Europe		Zenuity	

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 fourteen (14) vehicles that fit the AVENUE AV scope shown in Table 3 and Table 4; Navya shuttle, Navya shuttle EVO, 2getthere GRT, 2getthere PRT, Baidu Apolong, EasyMile EZ10, Ohmio Hop, Sensible 4 Gacha, Yutong 5G, HEAT, Olli 1.0, Olli 2.0, Dongfeng Sharing Van and ZERO shuttle. As a part of the consortium are only the shuttles from Navya, the rest is outside the consortium.

- System
  There are multiple automated 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. Toyota's e-Palette 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 automated vehicles.

2.3 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.

3.3.1 Navya Shuttle EVO

The EVO shuttle from Navya is based on the preceding and thus has similar construction and capabilities. It is able to transport up to 15 people and has a theoretical autonomous top speed of 25 km/h.

2.4 Technical description of Navya Shuttle

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

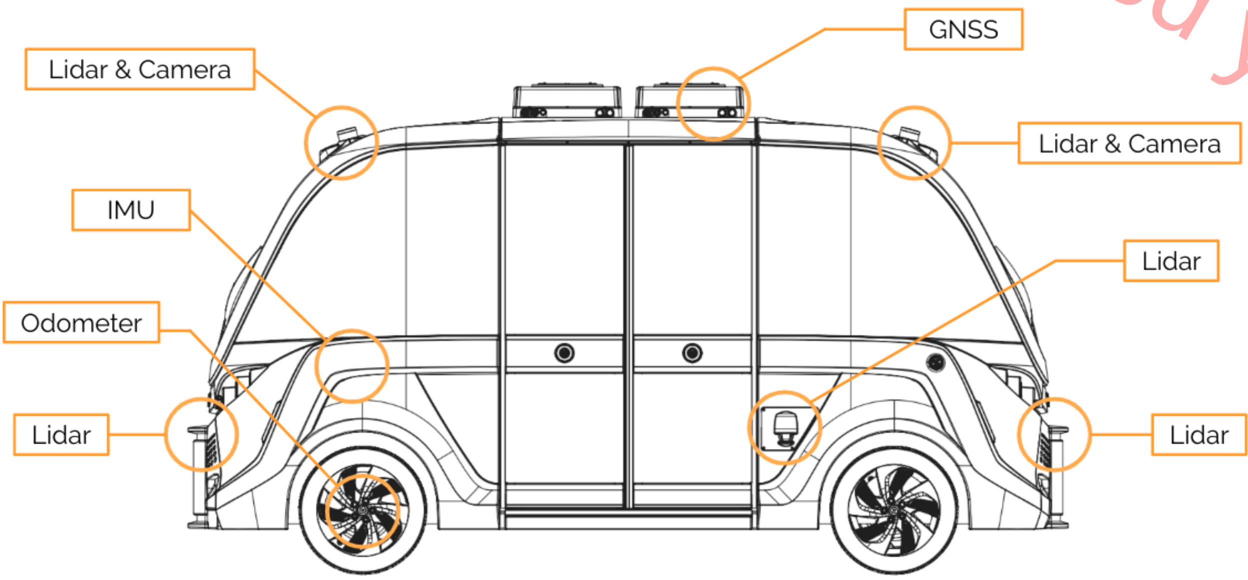
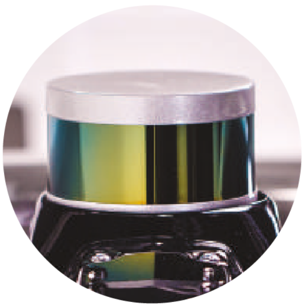


Figure 6 - Technical drawing Navya Shuttle

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
Used for surveillance only.

*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.

3.4.1 Technical description of Navya Shuttle EVO

The EVO shuttle from Navya is based on the preceding autonomous shuttle from Navya - i.e. similar chassis, bodywork, components, etc. Like the preceding shuttle, the EVO uses LiDAR sensors as the only sensor type for obstacle detection and for positioning, it also uses LiDARs, RTK GNSS, IMU sensor, and odometry sensors.
The LiDAR sensors on the EVO are upgraded from the preceding shuttle and consequently the vehicle has a higher resolution LiDAR image and improved mitigation towards black spots.

2.5 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[5].

One of the latest driverless technologies already on the market

180+ vehicles sold worldwide (Dec 2020)

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

Presence in 23 countries such as Australia, Austria, Denmark, France, Germany, Japan, Singapore, Switzerland, USA and many others

~1M passengers transported (since April 2016)

Approvals

ASTRA/OFROU/OFT (Switzerland), FTSA (Finland), LTA (Singapore), MDDI (Luxembourg), MFK (Liechtenstein), DGEC/MTES (France), NTC/TFNSW (Australia), RDW (Netherlands), SAAQ (Canada), SPF M&T (Belgium), STA (Sweden), TÜV Austria/MA 46 (Austria), TÜV Hessen, Nord, Sud & Rheinland (Germany), US DoT / NHTSA (USA), Integrated Transport Centre - DoT (UAE), MLIT (Japan), Ministry of State (Monaco), Statens Vegvesen (Norway), DoT (South Africa), DRD/DRSA (Denmark), ERA (Estonia), FTSA/Traficom (Finland)

(June 2019)

2.6 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	DETAILS	ROUTE 1	ROUTE 2
PLANNING	Name of route	XA Line	Belle-Idee
	Location (city)	Meyrin (Geneva, CH)	Thônex (Geneva, CH)
	Type of route (public, private, etc.)	Public	Public
	In or out of AVENUE?	In	In
	Vehicle: Meaning Navya shuttle or other?	Navya	Navya
OPERATION	Deployment period (how long did you operate that route)	30 months	8 month commissioning and testing no customers yet
	Route-distance (length)	2.1 km	38 acres
	Number of shuttles	1 + 1 reserve	3 + 1 reserve

	safety operator present?	yes	yes
	Supervision setup?	yes	yes
	Navya API integration?	yes	yes
	Traffic systems integration	no	no
	V2X integration	no	not yet
	Pricing structure (free or ticket)	ticket	free
OPERATIONAL DATA	Uptime (average during the project)	73% due to Covid	-
	Amount of passengers	9000	-
	Amount of driven kilometres	18000	-

Table 7 - TPG driving experience

KEOLIS	**DETAILS**	**ROUTE 1**	**ROUTE 2**
PLANNING	Name of route	NAVLY	N1
	Location (city)	Lyon	Decines
	Type of route (public, private, etc.)	Public	Public
	In or out of AVENUE?	Out	In
	Vehicle: Meaning Navya shuttle or other?	Navya	Navya
OPERATION	Deployment period (how long did you operate that route)	Oct 2016 - Mars 2020	Nov 2019 - Now
	Route-distance (length)	1.2 km	1.3 km
	Number of shuttles	2	2
	safety operator present?	yes	yes
	Supervision setup?	yes (navya first, then keolis)	yes (keolis)
	Navya API integration?	no	no
	Traffic systems integration	no	no
	V2X integration	no	yes
	Pricing structure (free or ticket)	free	free
OPERATIONAL DATA	Uptime (average during the project)	-	-
	Amount of passengers	65000	5500
	Amount of driven kilometres	40000	12500

Table 8 - Keolis driving experience

SLA	DETAILS	ROUTE 1	ROUTE 2
PLANNING	Name of route	Campus Contern	City Shuttle Pfaffenthal
	Location (city)	Contern	Pfaffenthal
	Type of route (public, private, etc.)	Public	Public
	In or out of AVENUE?	In	In
	Vehicle: Meaning Navya shuttle or other?	Navya	Navya
OPERATION	Deployment period (how long did you operate that route)	Since 09/2018	Since 09/2018
	Route-distance (length)	0.8 km	2.3 km
	Number of shuttles	1	2
	safety operator present?	yes	yes
	Supervision setup?	yes	yes
	Navya API integration?	yes	yes
	Traffic systems integration	not yet	not yet
	V2X integration	not yet	not yet
	Pricing structure (free or ticket)	free	free
OPERATIONAL DATA	Uptime (average during the project)	90%	85%
	Amount of passengers	1280	115
	Amount of driven kilometres	9000	1000

Table 9 - SLA driving experience

Amobility 1/2	DETAILS	Route 1	Route 2	Route 3	Route 4	Route 5
PLANNING	Name of route	SUH Køge, Denmark	Gothenburg, Sweden	Akershusstranda, Norway	Aurinkolahti Finland	Talinn, Estonia
	Location (city)	Køge	Gothenburg, Sweden	Oslo	Helsinki	Talinn
	Type of route (public, private, etc.)	Private	Public	Public	Public	Public
	In or out of AVENUE?	Out	Out	Out	Out	Out
	Vehicle: Meaning Navya shuttle or other?	Navya	Navya	Navya	Navya	Navya
OPERATION	Deployment period (how long did you operate that route)	May 2018 to August 2018	April 2019 to October 2019	May 2019 to october 2019	June 2019 to Sep 2019	July 2019 - December 2019
	Route-distance (length)	0.8 km	1.8 km	2,3 km	2.5 km	1.8 km
	Number of shuttles	1	2	2-4	2	1
	safety operator present?	Yes	Yes	Yes	Yes	Yes
	Supervision setup?	No	Yes	Yes	Yes	Yes
	Navya API integration?	No	Yes	Yes	Yes	Yes
	Traffic systems integration	No	No	No	No	No
	V2X integration	No	No	No	No	No
	Pricing structure (free or ticket)	Free	Free	Ticket	Free	Free
OPERATIONAL DATA	Uptime (average during the project)	-	-	-	-	-
	Amount of passengers	6000	3000	20000	3500	3200
	Amount of driven kilometres	1000 km	3000 km	7000 km	2500 km	4000 km

Table 10 - Amobility 1/2 driving experience

Amobility 2/2	DETAILS	Route 6	Route 7	Route 8	Route 9	Route 10
PLANNING	Name of route	Ormøya, Norway	Aalborg, Denmark	Kongensgate, Norway	Nordhavn, Denmark	Ski, Norway
	Location (city)	Oslo	Aalborg	Oslo	Copenhagen	Ski
	Type of route (public, private, etc.)	Public	Public	Public	Public	Public
	In or out of AVENUE?	In	Out	Out	In	Out
	Vehicle: Meaning Navya shuttle or other?	Navya	Navya	Navya	Navya	Toyota / Sensible4
OPERATION	Deployment period (how long did you operate that route)	Dec 2019 - Dec 2020	Since Jan 2020 - still going	June 2020 - sep 2020	August 2020 to March 2021	January 2021 - still ongoing
	Route-distance (length)	3 km	1.8 km	2,6 km	1.2 km	2 km (will be expanded)
	Number of shuttles	3	4	2	3	2 (will be expanded)
	safety operator present?	Yes	Yes	Yes	Yes	Yes
	Supervision setup?	Yes	Yes	Yes	Yes	Yes
	Navya API integration?	Yes	Yes	Yes	Yes	No (Sensible 4)
	Traffic systems integration	No	No	Yes	No	No
	V2X integration	No	No	Yes	No	No
	Pricing structure (free or ticket)	Ticket	Free	Ticket	Free	Ticket
OPERATIONAL DATA	Uptime (average during the project)	55.2% (Aug-Dec 2020)	61.3% (Aug 2020-Jan 2021)	54.5% (Aug-Sept 2020)	81.5% (Aug 2020-Jan 2021)	-
	Amount of passengers	6700	9500	1500	1500	-
	Amount of driven kilometres	22500 km	14500 km	2700 km	2400 km	-

Table 11 - Amobility 2/2 driving experience

2.7 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 automated 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.

2.7.1 CityMobil2[6]

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 automated 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:

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

- 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.

- 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

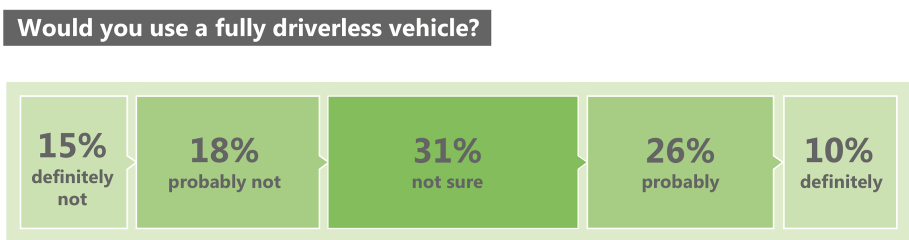
- Enforcement of the laws applied to car/truck drivers is necessary to make sure that the operation of the ARTS vehicles was not detrimentally impacted by illegal parking, etc.

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 operator during the project.

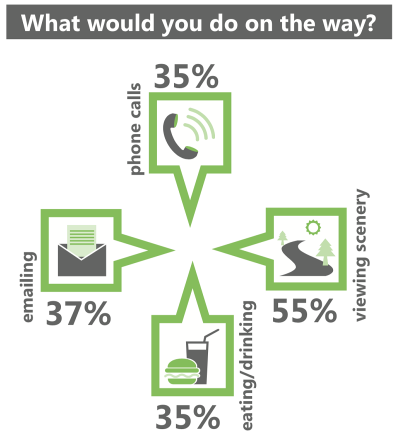
2.7.2 UK Autodrive[7]

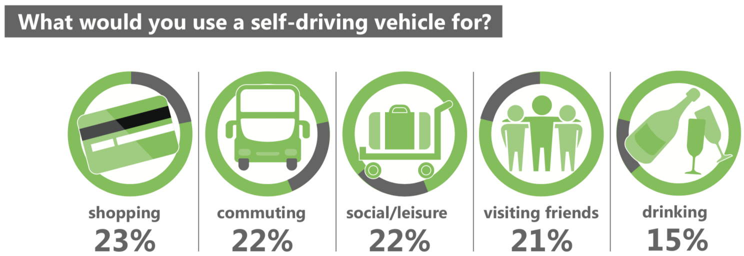
UK Autodrive is the largest of three separate consortia that are currently trialling automated vehicle technology in the UK. All three consortia projects are part of a government-backed competition that supports the introduction of self-driving vehicles into the UK. The project will run for three years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



[7] 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.

2.7.3 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:

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

- 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.
- 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).

2.7.4 Future driving, Autonobus, La Trobe University[9]

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 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.

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

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.

2.7.5 Autonomous Shuttle Bus for Public Transportation[10]

A review, Published: 6 June 2020

This paper examines the evolution of autonomous technology that has made it possible to implement automated vehicles in public transport. Vehicles in focus are shuttles with the capacity of around 15 people, hence vehicles like Navya and EasyMile. Even though the shuttle bus capacity is seen as low (15 people) the paper examines the benefits of these shuttles in large urban areas. The paper dives into how the technology affects scientific evolution, with links directly to both legal and social aspects of public transport. One of the major learnings from the paper is that the legal framework of automated vehicles are very uneven across the european and international countries having a direct and important impact on the overall implementation of the technology in public transport. The overall learnings are summed up as follows:

- The technology still demands the presence of a human safety operator inside the shuttles
- The current capacity is "only" 15 people (not taking COVID into account)
- The vehicles have limited scenarios and use cases due to low speed (maximum 25 km/h)
- The market price of acquiring the shuttles are around 300.000 euros.

The above highlighted points are in the paper argued to be major barriers in regards to fully implementing the shuttles in public transportation.

[10] file:///media/fuse/drivefs-1ac7ca4c87068887049aade1ac5c9e50/root/Downloads/energies-13-02917.pdf

2.7.6 MnDOT Autonomous Bus Pilot Project[11]

Testing and demonstration summary, published: June 2018

The Minnesota Department of Transportation (MnDOT) tested and demonstrated an EasyMile vehicle during the winter in Minnesota - to test the AVs behavior in actual winter environments, something at the point in timer never done before. The operational goals of the pilot project were: (copied from report)

- Identify the challenges of operating automated vehicle technologies in snow/ice conditions and test potential solutions through field testing.
- Identify the challenges and strategies of having third parties safely operate automated vehicles on the MnDOT transportation system.
- Identify infrastructure gaps and solutions to safely operate automated vehicles on the MnDOT transportation system.

The results of the pilot project can be seen in the following cut-outs from the final report:

6.1.1 Clear Weather

The automated shuttle bus operated as expected under clear weather conditions. There were a few sensor activated slowdowns and emergency stops due to external stimuli picked up by the vehicle sensors, but in general the shuttle moved along its intended route and performed controlled stops at locations designated for passenger pick up and at intersections.

6.1.2 Falling and Blowing Snow

The automated shuttle bus experienced sensor activated slowdowns/stops and emergency stops when operating in falling snow, blowing snow (especially during snowmaking operations), and from loose snow kicked up from the test track. The vehicle sensors detected snow particles and performed multiple successive sensor-activated stops assuming there were obstacles in the drive path. Once the shuttle had passed the snow-making areas, it resumed normal operations.

6.1.3 Snow Cover on Pavement

The automated shuttle bus navigated through several inches of snow/slush on the pavement but lost its location on the programmed path if the tires slipped. The automated shuttle bus course-corrected once back on dry pavement if conditions caused it to slip from the preprogrammed path.

[11] file:///media/fuse/drivefs-1ac7ca4c87068887049aade1ac5c9e50/root/Downloads/201904.pdf

6.1.4 Temperature/Battery Correlation

Testers observed that temperatures below 0° F drained the battery at a faster rate than temperatures above 0° F. At times, the automated shuttle bus required mid-demonstration battery charges during the MnROAD sessions, and the interior heating system, internal lights, and cold weather drained the battery at a noticeably faster rate. Lower battery levels are directly correlated to a reduction in shuttle system performance.

6.1.5 Vehicle, Pedestrian, Bicycle and Obstruction Detection

The automated shuttle bus performed well in detecting other vehicles, pedestrians, and bicycles on the MnROAD test track. It detected and reacted to static obstacles placed in its path. The automated shuttle bus also showed more conservative braking behavior and increased stopping distances as speed increased or as pavement conditions worsened.

3 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 safety operator 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 operators
  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 30 to 50 km/h

- Integrate with existing public transport system
  The vehicles are fully integrated with public transport and work 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 requires 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 automated vehicles will be able to reduce the cost of transport in urban areas.

- Personalised transport
  Fully automated 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 the 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.

3.1 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 concerns either the use or the user of an automated vehicle.
Regarding the use, many questions are still unanswered like: Should automated vehicles be allowed everywhere? Should it be allowed only on special roads or dedicated lanes? Does autonomous driving have to follow all traffic rules? If an automated vehicle violates a traffic rule, does it have to self-report to authorities? Should there be an external indicator on the vehicle when operated on autonomous mode?

Regarding the users, still many issues are unsolved like: Which is the most appropriate terminology between "driver and "user" describing the person guiding the automated vehicle? Do we need any age requirement for automated vehicle users? Does autonomous driving require a special driving license? If so, shall it be national or international? Shall an automated vehicle driver ("user") be required to have a driving license at all?

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. Hence, the legislation should introduce an irrefutable presumption of a defect in a highly or fully automated vehicle that causes an accident, unless the manufacturer can prove that the automated vehicle functionality was not the cause of the accident.

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?

Autonomous driving-inspired legal challenges in the area of criminal law include especially the issue of criminal responsibility as well as protection against cybercrime and hackers. Many situations still need to be analysed like: What crimes may be committed with automated vehicles? Who should be held responsible in case, when using an automated vehicle, a crime is committed: the owner; the person who is sitting in the driver's seat (if there is any kind of it), the vehicle manufacturer, the software designer or another entity? Will the responsible subject change according to the circumstances and if so, how? How should the law react, if the criminally responsible subject is a legal entity? As for the criminal responsibility for harm caused by an automated vehicle, according to most European states' criminal codes, the driver (or vehicle owner) may be charged with negligence even if the automated vehicle was in control (in autonomous mode). In case of no proved negligence, the crimi-nally responsible entity is the manufacturer. Since in most cases, a vehicle manufacturer is a legal entity, it is highly important to consider the issue of corporate criminal responsibility. The European Union countries do not have an identical legislation in this area. Personal guilt is the basement of criminal codes in most countries; these codes would need an amendment.

The following barriers have 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 automated vehicles and providing guidelines for the development of automated 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 synchronizing 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. Many questions related to liability attributing remain open. Indeed, in the absence of specific legislation, vehicle owners, i.e. transport operators, will remain liable in the first instance for incidents caused by their Fully autonomous vehicles. However, if an accident occurs in an autonomous bus as a result of an error or shortcoming in the system as opposed to resulting from carelessness on the part of the owner, in some cases it might be considered unfair to attribute the incidents to the vehicle owner.

- *Liability issues - Attributing fault*
  Liability issues are linked with data collection and protection. It should be treated with the event data recorder (EDR) and the Data Storage System for Automated Driving vehicles (DSSAD). These tools are built to establish the cause and the responsibility in case of a crash. EDR collects and records the necessary data to understand what or who was controlling the driving in case of a crash. DSSAD collects and records the necessary data to reconstruct the last moment before a crash and identify the status of the driving system. With EDR and DDSAD, 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. One option being considered is expanding compulsory insurance to cover product liability, another one is the manufacturer takes all responsibility for its products.

- *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.

- *Cybersecurity and personal data protection*
  Cybersecurity issues go along with anonymity and personal data protection hardening as well as system’s hacking. automated vehicles should be protected against cyberattacks in accordance with established best practices for cyber vehicle physical systems. Vehicle manufacturers should ensure that system updates occur as needed in a safe and secure way and provide for after-market repairs and modifications as needed.

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

- *Urban planning*
  The main issue surrounding the regulatory and political aspects of the deployment of autonomous buses in urban planning concerns the confrontation and convergence of political will at national and local levels and the distance between the executive and the legislative bodies which also refers to the complexity of the political systems of the various states composing Europe.

- *Public transport organization*
  The existence of transport and mobility policies has a positive impact for the implementation of new services as well as the existence of public service delegation. The existence of an integrator policy organization at local level implementing local mobility policy has a direct impact on operation efficiency. In that case, the local government can fully delegate operations to the integrator and concentrate on needs anticipation and innovation deployment. Therefore, the

level of power of a public transport organization may be considered either a barrier or a facilitator.

3.2 Social barriers & motivators

From deliverable D2.4, the beginning of deliverable D2.5 and deliverable D8.7 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 automated 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 automated 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 automated 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

3.3 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. The PTOs in the project, hence the operators have also contributed with the definition and identification of technical barriers.

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 safety operator to move the shuttle manually. Vehicles 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 an 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 (4G/5G)
  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.

- Lack of means to count passengers to estimate occupancy (as this is crucial for a real on-demand system, and without safety operator 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)

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

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 systems and in-and-out-of-vehicle services. PTOs, hence the operators have provided feedback as well.

- Missing features in Navya APIs in order to be able to cancel 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 operator
- 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 supervisor)
- 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 management capabilities of recharging infrastructure
- Video feed from cameras inside the shuttle not externally available (yet)

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.

3.3.1 Technical barriers with driving on-demand and reaching higher speeds

3.3.1.1 Higher speeds

Below are listed some of the barriers that prevent the Navya Autonom Shuttle from driving at higher speeds than what is currently achievable:

- The range and resolution of LiDAR sensors prevent the Navya vehicles from detecting obstacles confidently at higher speeds. Already currently, the Navya vehicles have issues detecting and reacting to incoming vehicles at intersections if speeds are above approximately 30 km/h.
- The braking system of the Navya vehicles is not able to decelerate at a rate good enough to comply with UN ECE regulations. Hence, the Navya vehicles would not be able to safely drive at higher speeds.

- The Navya vehicles do not have approved seat belt anchorages and cannot be retrofitted with such. The current seat belt anchorage solution is both too weak and at a wrong angle meaning that higher operating speeds would be unsafe. In some countries this seat belt solution must even be removed before operation.

- The Navya vehicles have never been crash tested and therefore it is unknown how the structure will react under these circumstances. At higher speeds than currently, this unknown factor would make it unsafe.

- The autonomous software installed in the Navya shuttles is not able to predict the movement of obstacles. Therefore, the vehicle does not react to incoming obstacles in the same way that humans would - e.g. it would not detect an obstacle before it enters the safety zone of the Navya vehicle. At higher speeds, this missing ability would make operation unsafe.

The consortium is currently waiting for a detailed and documented explanation from the vehicle manufacturer, Navya, on how they expect to develop the necessary improvements to move forward in reaching higher speeds. The plan for developments is critical in order to anticipate when we can expect to further develop the potential business models and to plan how to also be able to approve higher speeds in the different countries in the project.

3.3.1.2 On-demand

- No overwriting of an ongoing mission is possible (canceling an ongoing mission / dynamic mission change). Operational impact: Key limitation for shared rides is that when a mission is already being executed, no other mission can be injected to modify the vehicles plan regarding its current route. Example: If traveler 1 is going from A to C via B, and traveler 2 requests a ride from B to C while traveler A has already started from A, the vehicle is not able to update its plan to stop at B and pick up traveler 2 as well.

- It is currently not possible for the fleet management platform to control the routing of the vehicle (= which route to take to get from A to B)

- Detect that the person that enters the vehicle actually booked his/hers place

- Automatically know that the person came in the vehicle so that the shuttle knows when to close its door and start its mission

- Ensure that the right person exits the shuttle before starting a new mission (or go back to it’s garage)

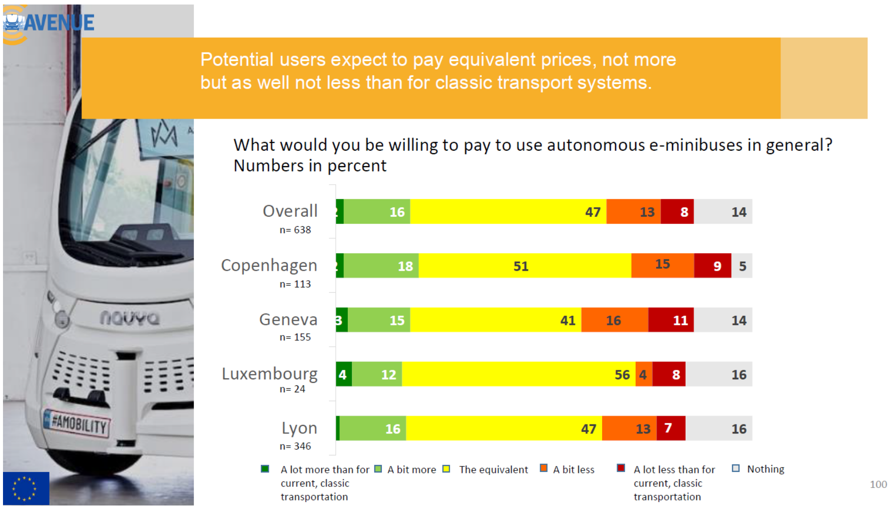
- Maturity is still an important aspect to stabilize and make on-demand a fully functional product for all operators of Navya vehicles

3.4 Economic barriers/learnings

Here are some of the initial economic barriers and learnings[12]

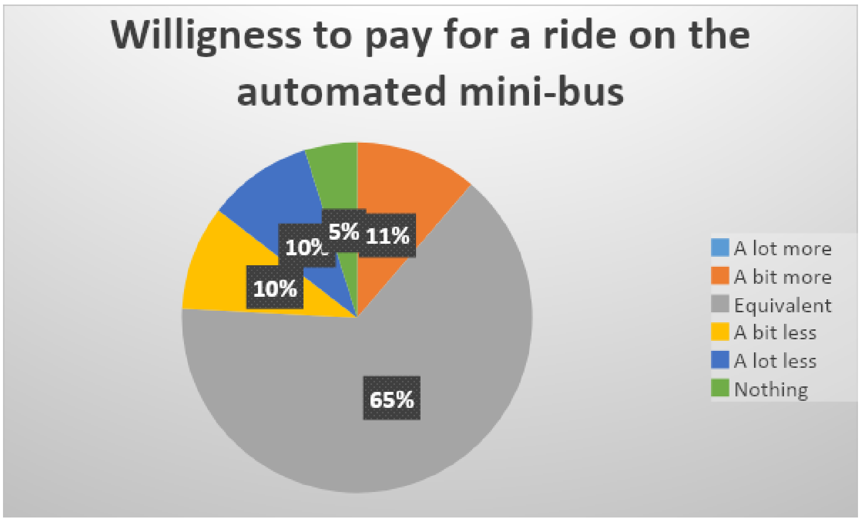
- Willingness to pay for the automated e-mini bus in comparison with the public transport price (From the representative survey)

  Most people are willing to pay the equivalent of public transport.
  This is not seen as a barrier, but a result for the economic analysis



- Willingness to pay for the automated e-mini bus in comparison with the public transport price (From the user survey – Nordhavn, n=62)

  64% are willing to pay the equivalent price of public transport



[12] Information gathered from Pforzheim University and École Centrale de Lyon

- Preliminary TCO: CAPEX, OPEX and main KPIs for the testing sites

  Learnings from the Second Iteration on Economic Impact Assessment Section 2 – Micro economic analysis and Total Cost of Ownership (TCO) (copied sections)

TCO[13]	Luxembourg (Sales-Lentz)		Geneva* (TPG)	Copenhagen/Oslo (Holo)		Lyon (Keolis)	AVERAGE
	Pfaffenthal	Contern	Meyrin	Nordhavn	Ormøya	Décines	Avenue
CAPEX							
Single shuttle	346,250.00 €	346,250.00 €	333,000.00 €	380,200.00 €	380,200.00 €	356,000.00 €	642,650.00 €
Fleet total	626,950.00 €	346,250.00 €	333,000.00 €	380,200.00 €	680.200,00 €	712,000.00 €	797,766.67 €
OPEX							
Single shuttle	108,290.15 €	136,033.48 €	326,860.00 €	347,000.00 €	249.975,97 €	71,103.00 €	219,973.27 €
Fleet total	194.557,11 €	136,033.48 €	326,860.00 €	347.000,00 €	796.951,94	142,206.08 €	348,367.76 €
KPIs**							
Cost passenger/km	3.66 €	4.31 €	5.27 €	4.47 €	1.78 €	4.06 €	3.93 €
Cost shuttle/km	55.14 €	64.78 €	79.21 €	67.07 €	26.75 €	60.99 €	58.99 €

- The internalization of costs from mobility externalities

  Internalization of external costs of transport helps mitigate the effects on the transport system on the society through taxes, traffic restrictions, and safety restrictions. These boundaries could limit the extended deployment of SAEV. The pricing regulations carried by the users might mean higher ticket prices as well and reduced accessibility

[13] * By being an on-demand site, values for the Belle Idée (Geneva) were not calculated yet.
** Values comprise the Total Cost of Ownership considering the CAPEX, OPEX and Local externalities.

4 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.

4.1 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.

- 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.).

4.2 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 operator in the shuttle until user surveys show that they have enough confidence in AV driving technology that the presence of a safety operator 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.

4.3 Technical recommendations

4.3.1 Higher speeds recommendations

In order for the Navya vehicles to operate autonomously at higher speeds, the platform would need to be fitted with sensors enabling better and more accuracy with a longer view.

4.3.2 On demand recommendations

In order to update an ongoing mission, a workflow needs to be created such that the update can be requested from the vehicle. The vehicle will accept or reject the update based on its state and location, such that it would have time to smoothly transition to the new destination point. A hard but important constraint is that the vehicle needs to do the transition while driving, it cannot stop while doing this.

In order to solve barriers with passenger entrance, exit and door closed/open situations. It is recommended to solve this through the app wherein the passenger has ordered the vehicle. This can lower the complexity greatly and move so tasks away from the vehicle vendor.

It will be beneficial if vehicle vendors follow communication standards for On-demand. Such the on-demand will be implemented with a vehicle vendor API who follows an approach like the SUTI standard, as an example. Much time and trouble will be avoided if proven communication protocols are used as building blocks and unification in the market.

Bestmile protocol
The Hermes autonomous vehicle protocol is used to establish the communication between a vehicle and the AVENUE fleet orchestration platform. It is a bidirectional protocol allowing both the vehicle to report its status, defects, and telemetry data and the AVENUE Platform to send missions to the vehicle.

The protocol target users are both vehicle manufacturers who want to be compatible with the AVENUE fleet orchestration platform as well as fleet monitoring software providers who wish to benefit from the

AVENUE fleet orchestration services. More information about the Hermes protocol can be found here: https://developer.bestmile.com/hermes-vehicle-protocol.html

5 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, economic 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, economic and technical advancement is necessary to reach the goals, but that specifically the technical and legal barriers propose a hard challenge. Based on Operator knowledge, specifically the technical features of the autonomous shuttle have 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. In specifically Denmark, the legal framework has posed a very challenging task - the approval process is very time consuming and costly.

As the technical limitations for the shuttles are posing a real challenge in terms of the widespread deployment of self driving vehicles in public transport, 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 progresses, the social and legal and economic barriers will be indirectly targeted, as they to some extent 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.