

**AUTONOMOUS MOBILITY**

**THINK BEYOND**

**THE VEHICLE**



**SYSTRA**



# EDITORIAL

Autonomous mobility has been met with extraordinary enthusiasm in recent years which has hardly been dampened by the global health crisis. Hundreds of projects around the world have been carried out to this day, offering an opportunity in this new decade to learn from the experience gained and to prepare for future developments.

Work on autonomous mobility has mainly focused on vehicle technologies. Nevertheless, their performance level progressed more slowly than expected. This is why **we believe that autonomous mobility should be developed and implemented not as an isolated transportation mode, but as a component of a larger and more diverse ecosystem within a holistic approach.** While such an approach brings complexity, we believe that it ensures the sustainability of these new mobility services.

Our 2018 white paper, *“Empowering public transport: possibilities, challenges and technologies”*, focused on the benefits and challenges of autonomous technologies applied to guided modes of transport, such as trains, metros and trams. In this new paper, we have broadened our focus to include road passenger transport services and look at autonomous road mobility, i.e. the various motorised journeys that

use autonomous road vehicles, which we will simplify hereafter with the term “autonomous mobility”.

As transportation engineers and mobility consultants, we have been working on these topics for many years. Here we would like to share our vision of autonomous mobility as an integrated transport system on the one hand, and as a mobility service on the other to examine the feasibility and usefulness of these new solutions in response to the mobility needs of the territories. Moreover, as an international group, we benefit from a global perspective that allows us to offer an overview of the variety of approaches adopted in the different countries that wish to make autonomous mobility a reality. These are all areas of experimentation from which we must learn to prepare the transition to sustainable autonomous mobility.

We hope you enjoy reading our paper.



**Nicolas Massart**  
Chief Technical and Innovation Officer

# EXECUTIVE SUMMARY

Autonomous vehicles promise to bring several benefits to mobility systems, with an increase in safety being the primary driver for autonomous technology development, followed by higher levels of comfort, opportunities for new services and operation optimisation. Motivated by such prospects, manufacturers and mobility and tech players continue to put significant efforts to autonomous vehicle research and are developing increasingly advanced technology to give vehicles the capacity to observe, analyse and then take appropriate action without human intervention.

In order to make this field a success, mobility stakeholders such as public transport authorities and operators must consider the deployment of autonomous vehicles as part of an existing and diverse transport system. In this regard, key concepts should be adopted to support the sound development of autonomous mobility services. We would like to share two complementary approaches to this.

First, a **system engineering approach** is essential to respond to the limits of autonomous vehicles technologies in terms of visibility. This approach highlights in particular the requirement for a fully connected infrastructure to ensure good performance while maintaining safety levels. It is also indispensable for the design of operation and maintenance of the transport systems. Second, a **service-oriented approach** identifies the right use cases of the autonomous vehicle according to the commuter's needs and the urban mobility context. It ensures that autonomous technology operates to serve mobility. This approach must fit in with a comprehensive strategic framework and take into account a broad field of necessary topics to assess the relevance, such as energy policies or urban planning.

Furthermore, such evolutions must be adapted depending on the local context. The implementation of autonomous mobility services strongly depends on the culture, usage, needs and local constraints. Different approaches can be observed between countries, which result in distinctive trends:

- Promotion of fully autonomous cars in the continuation of automotive development, defending values of independence and freedom.
- Emergence of new shared mobility services based on autonomous vehicles to enrich the existing mobility mix.
- Integration of autonomous technology into the existing transport system to respond to efficiency issues.

Even if the first trend is more appealing for the general public and gains more coverage in the media, SYSTRA wants to provide its technical know-how on the second and third. These trends are more likely to ensure a real improvement of mobility in conjunction with other transport systems. We must then learn from experience in shared and public transport systems to make the right choices for tomorrow's mobility.

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SYSTRA is one of the world's leading engineering and consultancy groups specialising in public transport and mobility solutions. For more than 60 years, the Group has been committed to **helping cities and regions to contribute to their development** by creating, improving and modernising their transport infrastructures.

With its 8,200 employees, the Group's mission is to make travel more fluid throughout the world in order to bring populations closer together and facilitate access to employment, education and leisure.

Setting the benchmark for transport solutions, SYSTRA supports its partners and clients throughout the lifecycle of their projects.

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# KEY CONCEPTS

**Autonomous vehicles** are vehicles equipped with ADS (automated driving system) technology that allow them to perform all driving functions with zero human intervention. Here we focus on road-based vehicles intended for public or shared use that are already in use, such as buses, shuttles or driverless taxis.

The **autonomous transport system** brings together all the various components, whether embedded in the vehicles (ADS) or stationary elements (infrastructure, power supply, communication systems, etc.) necessary for the operation of mobility services.

**Autonomous mobility services** refer to the different mobility services available to the passengers that use autonomous technologies.

The **Levels of Driving Automation**: in 2016 the Society of Automotive Engineers (SAE International) classified all road vehicles into six levels of autonomy. Level 0 concerns normal vehicles with no automation system whereas Level 5 indicates full automation. SAE International most recently updated this taxonomy in 2021.



## SAE J3016™ LEVELS OF DRIVING AUTOMATION™

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	SAE LEVEL 0™	SAE LEVEL 1™	SAE LEVEL 2™	SAE LEVEL 3™	SAE LEVEL 4™	SAE LEVEL 5™
What does the human in the driver's seat have to do?	You <b>are</b> driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You <b>are not</b> driving when these automated driving features are engaged – even if you are seated in “the driver’s seat”		
	You <b>must constantly supervise</b> these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
What do these features do?	These are driver support features			These are automated driving features		
	These features are limited to providing warnings and momentary assistance	These features provide steering <b>OR</b> brake/acceleration support to the driver	These features provide steering <b>AND</b> brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	<ul style="list-style-type: none"> <li>• automatic emergency braking</li> <li>• blind spot warning</li> <li>• lane departure warning</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering <b>OR</b></li> <li>• adaptive cruise control</li> </ul>	<ul style="list-style-type: none"> <li>• lane centering <b>AND</b></li> <li>• adaptive cruise control at the same time</li> </ul>	<ul style="list-style-type: none"> <li>• traffic jam chauffeur</li> </ul>	<ul style="list-style-type: none"> <li>• local driverless taxi</li> <li>• pedals/steering wheel may or may not be installed</li> </ul>	<ul style="list-style-type: none"> <li>• same as level 4, but feature can drive everywhere in all conditions</li> </ul>

# 1 THE AUTONOMOUS VEHICLE IN BRIEF



Autonomous systems are different from automated transport systems. We define **automation** as the tasks that a transport mode can perform when given specific information and pre-defined rules, whereas **autonomy** enables systems to take actions based on a deeper understanding of the environment and without any human intervention or remote control. To date research studies of autonomous mobility technologies have put the autonomous vehicle in the spotlight; therefore, we must understand what lies under the hood of an autonomous vehicle and what its benefits are before further investigating the autonomous mobility system.



## WHICH VEHICLES ARE WE TALKING ABOUT?

In this document, autonomous vehicles (AV) correspond to Levels 3, 4 or 5 of the SAE International classification. They are also called "self-driving" or "driverless" and offer automated driving features that partially or fully remove the driver. AVs are not the same as more straightforward support features, which would instead assist the driver in their driving.

AVs for passenger transportation services are imagined in different forms. Today, the three main modes are:



### A driverless car

A vehicle used as an individual taxi with automation Level 4 or 5. Many experiments have been carried out with Level 3 or 4 vehicles and commercial services are already being trialled in geo-fenced areas in the USA and China.

### A shuttle

A small capacity public transport conceived without a driver (Levels 4 to 5). Shuttles are being trialled worldwide, mostly using safety drivers (Level 3). A few Level 4 trials were launched in 2020.



### A public bus

A bus meant to operate with a driver assistance (Level 3) or later without a driver (Levels 4 to 5). Autonomous buses are not as developed as the other modes, but a few prototypes have been trialled first in 2016 (Netherlands) and more recently in 2020 and 2021 (Singapore, China, UK, USA or France).



Other vehicle types also exist, but these remain at a less advanced stage of development (i.e. autonomous pods with capacity for 2-4 seats.)

## HOW DOES AN AUTONOMOUS VEHICLE WORK? A MATTER OF TECHNOLOGY

### Sensing technologies

Sensing technologies create a "safety bubble" around the vehicle to avoid potential accidents. This mechanism is similar to the guided transportation system that has been developed over many years in aviation and rail transportation. The main sensing technologies are the following:

- The **CAMERA** provides line-of-sight detection.
- The **RADAR** uses radio waves to detect objects, e.g. in bad weather or at night.
- The **LIDAR** is similar to a radar but uses laser light pulses to scan the environment and detect small objects.
- **ULTRASONIC SENSORS** can detect at close range using high-frequency sound waves.

### Communications technologies

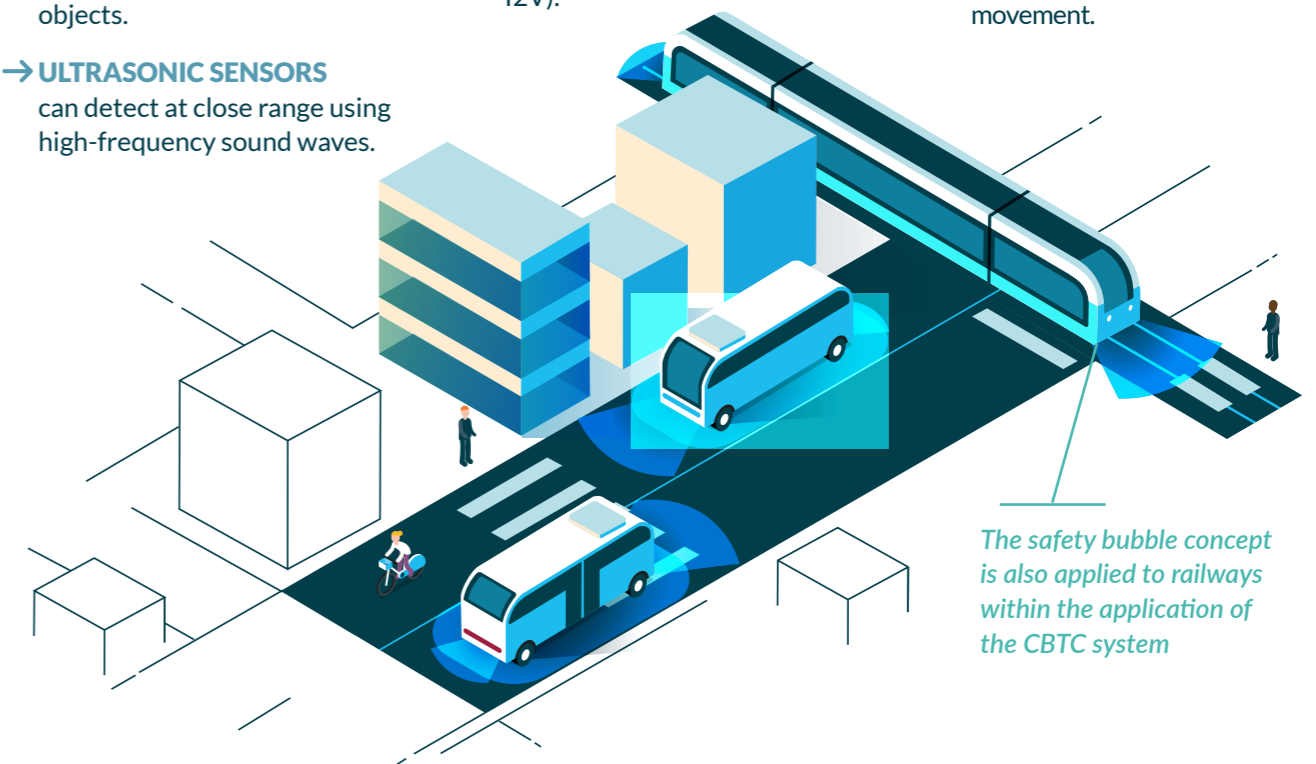
Communication technologies allow the vehicle to locate its position and collect extensive data on the local environment.

- **GNSS paired with RTK**: GNSS is a satellite-based navigation system, often referred to as GPS, used to position the vehicle. RTK (real-time kinematic) greatly improves the positioning of GNSS using 4G and 5G networks.
- **V2X technologies** enable the autonomous vehicle to communicate with surrounding vehicles (V2V) and infrastructure (V2I/I2V).

### Control system

The control system uses artificial intelligence (AI) technology to process the data collected and make decisions. Its functions are essentially:

- **SENSE**: An environment detection system (EDS) mainly uses statistical algorithms and was at the heart of major R&D investment in the last decade.
- **ANALYSE**: A decision-making control loop uses the laws of physics and discrete mathematics that turns into algorithms.
- **ACT**: Actuators which consist mainly of a powertrain control system safely execute the planned movement.



The safety bubble concept is also applied to railways within the application of the CBTC system

Whereas the technology concepts are well defined, there are still different approaches competing for the best vehicle functioning. For example, should an environment be completely mapped? Or does the vehicle work out what to do for the first time every time? Or maybe a combination of the two?

# WHAT COULD BE THE POSITIVE IMPACTS OF AUTONOMOUS VEHICLES?

## A better safety



A main aim of autonomous technologies is to improve road safety. Road injuries represent a huge cost on societies worldwide. These technologies would initially enable the vehicle to assist the driver when dealing with difficult situations, and later would be in full control of the steering functions to ensure the safest driving.

## An opportunity to optimise operations



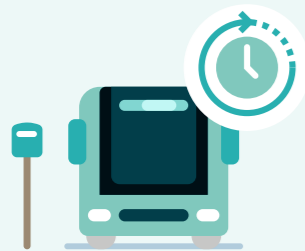
AVs would allow operators to significantly improve operations management. In fact, the first cases of AV deployment may take place out of the sight of the travelling public; for example, autonomous technologies offer the possibility of automating manoeuvres during maintenance operations in an optimal way within new, adapted intelligent depots.

## An improved service quality

Another potential benefit of AVs is the improvement of the travel experience. In the context of a mobility service, AVs offer an opportunity to enhance the passenger's experience by converting drivers into customer service agents. This position could increase the accessibility of the service, especially for people with disabilities. Onboard agents could also be an enabler for early deployment, as they could solve difficult situations that obstruct the route and facilitate users' acceptability.



## An extension of the transport network



AVs open doors for operators to develop new mobility services and complete the existing transport network. For example, they could reach underserved areas where a traditional public transport service is not feasible for financial reasons or extend operating hours by means of a more flexible service adapted to demand.



Autonomous mobility offers multiple benefits such as travel safety, transport services efficiency (better fleet management, flexibility, cost optimization, etc.)

and inclusiveness and accessibility of territories with the development of new services. But these benefits will only be meaningful if the technologies for automation are integrated within the public transport service. Only then will it be an interesting enabler for the improvement of quality of life, contributing to the reduction of congestion, the reduction of the environmental impact of our travel and the preservation of public space.

However, several technological and regulatory challenges must still be met such as improving the vehicle speed and managing data interoperability between vehicles and the infrastructure. The removal of the safety driver from the vehicle is also a key issue to guarantee the economic viability of autonomous mobility. This is why it is essential to continue experimenting. In Europe, we are increasing the number of pilot projects in progressively more complex contexts, for instance in the framework of the Horizon Europe funding programme from the European Commission.



**Henriette Cornet**  
Senior Manager, Connected and Cooperative Automated Mobility, UITP



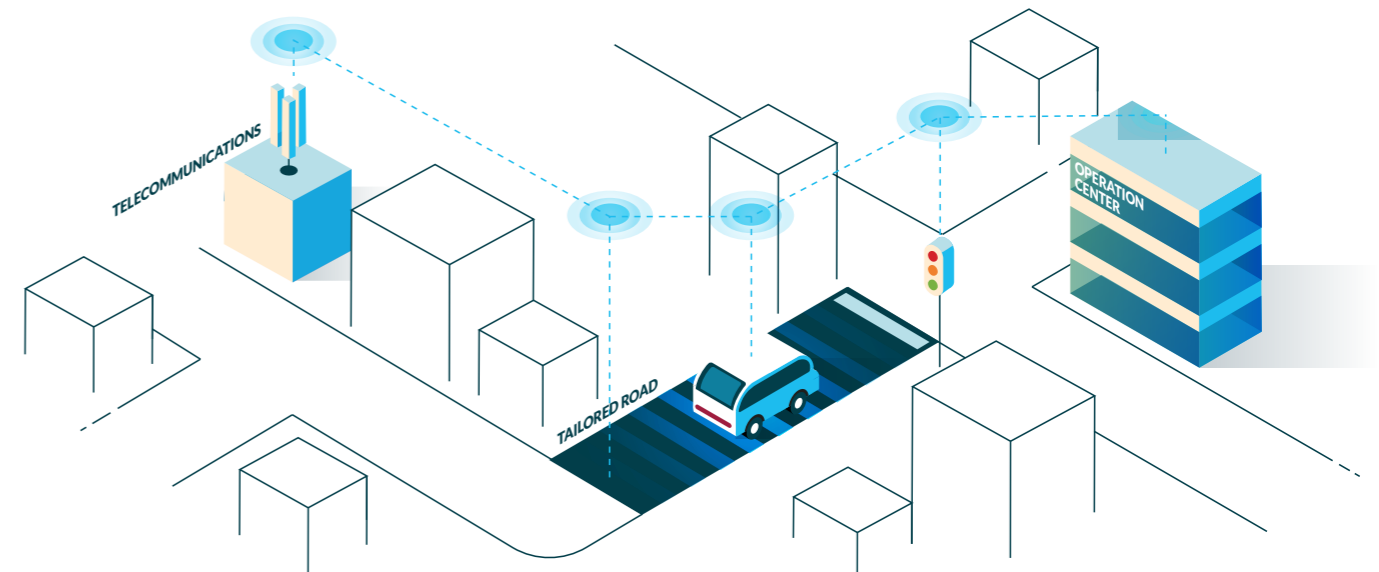
# 2

## LEARN FROM PUBLIC TRANSPORT SYSTEMS

Autonomous mobility is more than just a fleet of autonomous vehicles. Several technical factors must be considered to successfully develop an autonomous transport system, as vehicles encounter difficulties when trying to reach a high level of performance while maintaining the maximum levels of safety. Alongside technological research and development of vehicle capabilities, a system engineering process brings technical solutions that meet the requirements of the desired service.



## WHAT CAN WE LEARN FROM TRANSPORT SYSTEMS ENGINEERING?



The transport system is made of several interoperable subsystems

### The basics of the autonomous transport system

An autonomous mobility service needs an **integrated transport system approach** to meet the required levels of safety and performance.

An autonomous transport system relies on several subsystems, typically:

- Vehicles equipped with autonomous technologies.
- Tailored urban infrastructure with supporting “wayside” systems and urban furniture using telecommunications to help orientate the vehicles.
- Operation and maintenance organization and procedures to deliver a high-level of service and a good customer experience.
- A traffic control system, such as intelligent traffic light management.

These subsystems must interface with each other and with other external systems (i.e. charging stations networks) to enable the service to be operational.

### System Engineering applied to autonomous mobility

System engineering ensures that **all the needs of a transport system are covered from a technical standpoint** so that, in the end, the desired service is made possible. It defines each function and requirement at the global transport system level and allocates them to develop each individual subsystem. It implements the necessary processes to integrate the different subsystems, to demonstrate their capability as a whole and to enable a smooth transition in its operation.

System engineering includes the design of the system and its subsystems, and the development, integration, testing (verification, validation and certification) and commissioning phases. It **requires an interdisciplinary approach that combines several engineering skills** (urban infrastructure, telecommunications, security system, road signalling, energy, data science, etc.) and **transversal competencies** (System Assurance, Interfaces, Integration, Requirement Management, Operation & Maintenance, etc..)



System engineering is especially relevant for autonomous mobility because:

- It demonstrates how the **safety of the autonomous transport system is guaranteed** prior to and during its operation.
- It covers **nominal and degraded situations** (i.e. situations where the system encounters internal or external events that degrade its nominal performance) to ensure a useful and profitable service at all times and under any traffic conditions.

→ It considers the way that **the transport system will gradually be rolled out**. The system may go through transition phases because of the technology's scalability (e.g. system partially deployed during a first phase, infrastructure evolving, customer acceptance, operations improvement etc.), and these transition phases are necessary steps before reaching a final configuration.



*The system engineering approach to autonomous mobility is critical to building trust, just as important as certifying the Artificial Intelligence of vehicles.*

**Thomas Bruel**  
Group Digital Director, SYSTRA



### 5G as a key to connectivity needs?

While rail systems use their own telecommunications networks, autonomous road vehicles will be connected to existing networks. Autonomous transportation systems will have high technical requirements and 5G will play a key role in meeting these. Sustained coordination between transport engineers and telecom players will be vital to the smooth operation of the system.

### Safety vs performance: an unachievable “dream zone”?

Transportation systems need to **achieve the best compromise between cost and performance while maintaining the highest safety standards**. This is the “dream zone”.

Today, autonomous vehicles are struggling to reach the dream zone all by themselves. **The importance of safety makes slowing down the most socially acceptable and rational decision** when a situation is encountered near or within the safety bubble. Such situation usually happens in one of these three cases:

- In areas considered dense due to the urban furniture and the behaviour of other vehicles and vulnerable road users.
- In the case of curves or junctions where visibility is reduced.
- On straight roads mainly as a result of being close to other vehicles.

In such situations, the limited visibility of the safety bubble leads to degraded performance compared to what is expected for a human driver. Thus, system engineering is a key approach to deploy an integrated transport system that will help **extend the sensing technologies of autonomous vehicles**.





# ENSURE SAFETY AND PERFORMANCE THANKS TO CONNECTED INFRASTRUCTURE



*We believe that connected infrastructure will be at the heart of autonomous mobility.*

**Mathieu Melenchon**

System Engineering and Integration Expert, SYSTRA



## Connected infrastructure to increase the vehicle's vision

Connected infrastructure mainly consists of sensors along the road and urban furniture such as traffic lights. They use I2V (Infrastructure to Vehicle) technologies to communicate with the surrounding vehicles and extend the sight of the "safety bubble".

Therefore, **connectivity is a solution to communicate more information to the vehicle** about its surroundings. This additional information will increase the vehicle's vision and enable it to understand obstacles or events happening on its route better and faster.

## Connected infrastructure to improve service quality

Frequent and sudden reductions in speed caused by the vehicle's safety levels being breached are a major negative feedback from autonomous mobility service experiments.

The inconvenience caused degrades the commercial speed and passenger's comfort, and reduces the attractiveness of autonomous mobility services.

In this context, connected infrastructure and I2V technologies will lower sudden braking as much as possible and increase the overall commercial speed and passenger comfort while keeping its safety standards at the highest level.

## Architectures for the decision-making process

I2V improves the vehicle's vision by means of additional data and enhances the decision-making process. Various protocols can be used to do this, for instance:

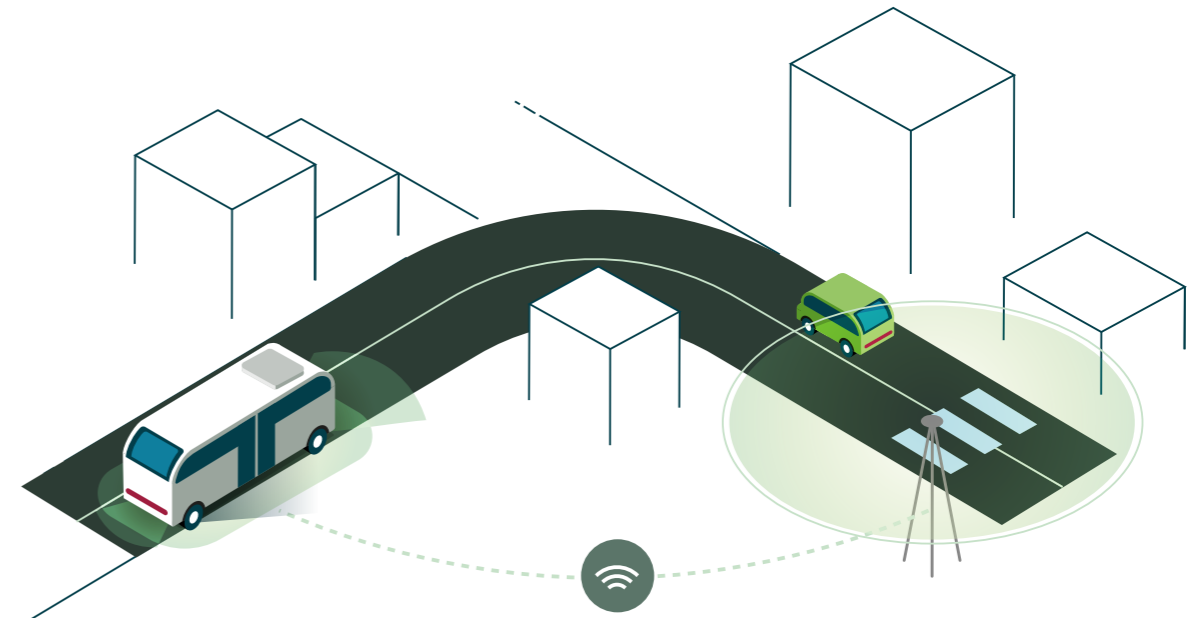
→ The infrastructure will transmit only raw data to the vehicles which categorise it alongside its own data.

→ Infrastructure sensors can process data upstream and communicate enhanced information to add to the vehicle's own processed data so that it may take the right action.

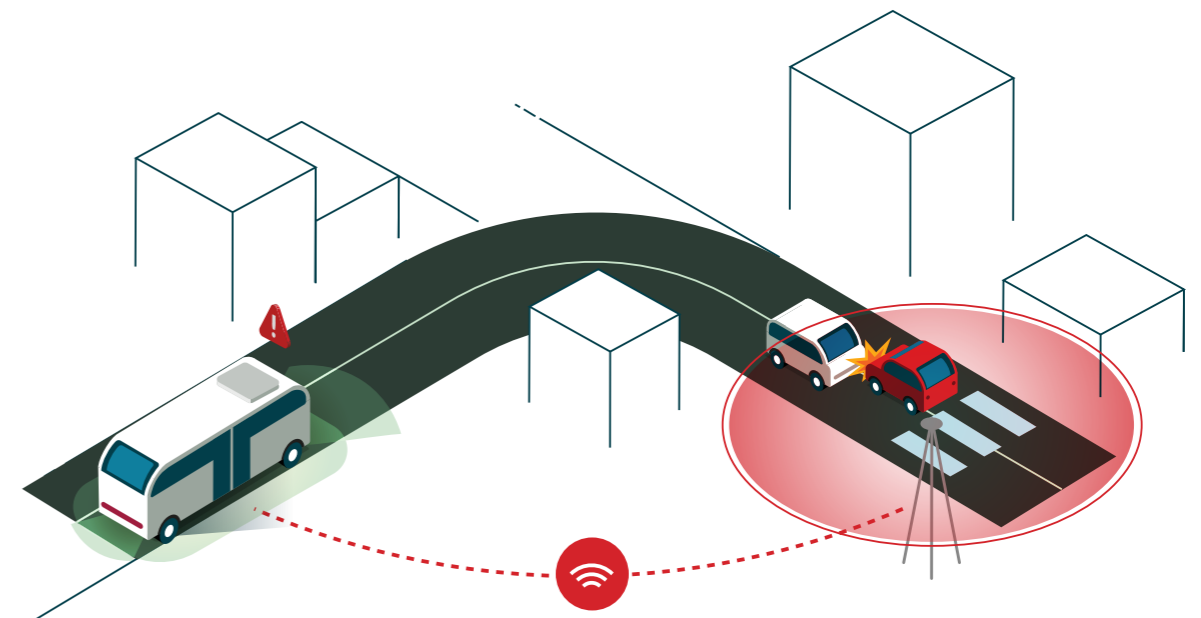
In addition, vehicles could also combine I2V with V2V (Vehicle to Vehicle) technologies to improve their vision even further and anticipate actions in any circumstances.

All these concepts give rise to several technical questions which can be solved with system engineering, such as how to standardise data and interfaces to ensure interoperability, or how to gauge the system to optimise its cost.

With connected infrastructure, speed is tailored to maximize both safety and commercial speed.



Connected infrastructure makes it possible to combine speed and safety even with reduced visibility



Connected infrastructure makes it possible to anticipate incidents in any situation and to better regulate the speed

# ENVISION YOUR AUTONOMOUS MOBILITY SERVICES

# 3



Autonomous mobility should aim to create a more fluid, accessible and inclusive mobility that meets the needs of its users . Several questions must be considered to successfully define and set up an adapted mobility service that uses autonomous technologies. Besides the technological aspects, a sound transition towards autonomous mobility will depend on the service design with the right use cases and the adoption of a local common development strategy.



# IDENTIFY THE RIGHT USE CASES



In addition to their applications for freight services, autonomous technologies are relevant for next-gen mobility services. Application areas are vast and could either materialise in the **development of new services** for shared mobility (last-mile solution, local mobility service, etc.) or the **improvement of existing services** (autonomous bus line, driverless taxi service, etc.). Mobility authorities and operators may consider various mobility services according to the operational constraints, local opportunities and the user's needs.

**A user-centred approach is essential** for the creation of autonomous mobility services as they must meet the needs and expectations of all citizens. Such an approach provides appropriate solution to the users demand according to the feasibility of the autonomous technology and brings out the best advantages of autonomous mobility.

Let's look at three examples of what an autonomous mobility service could look like:

## 1 A driverless taxi service

Driverless taxi solutions can extend the range of mobility services to underserved areas and enable better access to the public transport network.

Driverless taxis also have the potential to be more affordable for users, thus improving their accessibility (in suburban areas). However, a service that relies on small capacity vehicles could generate new congestion issues in urban areas. Integration with public transit solutions and proper service design are essential to avoid negative effects.

The service design of urban driverless taxis should include, inter alia, a ridesharing strategy adapted to the user's needs and fleet management process in order to optimise service performance while maintaining traffic fluidity.

Driverless taxis are currently adapted from existing cars, but in the future manufacturers will design new models.



**Réza Vosooghi**  
Senior Modeler,  
SYSTRA

*Properly designed robotaxi services can help open up underserved areas.*



*Experiments in the USA and China*



**Michael Gregorevic**  
Senior Consultant,  
SYSTRA Scott Lister

*Depending on the location and use case, autonomous shuttles can feasibly complement or replace existing mobility services.*



*Experiments in Europe, the USA, Australia, and Singapore*

## 3 An autonomous bus line

Same line, new rolling stock: autonomous buses could be a significant step towards upgrading a transit line to replace traditional buses. Technological possibilities and safety requirements give us a realistic picture of this use case in the short term in a dedicated lane, such as bus rapid transit (BRT).

Innovation on a BRT line can significantly improve performance and quality of service and help to optimise operation costs.

For example, autonomous buses can allow for fleet rebalancing to reduce turnaround time; vehicle platooning at peak times to increase capacity; or wider schedule flexibility to increase availability.

However, its economic and operational relevance will depend on several criteria determined by the service design. In certain situations, investment costs could exceed operational savings without bringing a greater added value to the service.



**Marie Cleuet**  
Mobility  
Consultant, SYSTRA

*The economic benefit of autonomy is conditioned by the performance and tends to increase with the commercial speed and the distance run.*



*Experiments in Singapore, China, Europe and the USA*

## 2 A local shuttle service

Autonomous shuttles can be relevant in areas where demand is not high enough for a regular public transport service.

Local shuttle services are intended for short trips or first- and last-mile services at a low speed. For example, they may operate within a vast university campus or across a neighbourhood that needs connection with a nearby mass transit service.

Shuttles are currently designed to carry very few passengers in a combination of seated and standing

configurations and can be specifically adapted for people with reduced mobility.

Shuttles may operate on predetermined routes in addition to demand-based dynamic routing within a defined network. In the latter case, an online platform will be specifically developed to calculate the optimised routes according to the commuter's demand and allowing for acceptable detour time.

## Each situation needs its own model

Autonomous transport systems do not offer an off-the-shelf solution for mobility services and must be adapted to the type of service required. In every use case a service design approach can validate relevance and determine the best service depending on the user's needs, the operator's requirements and the background context.

Cost-effectiveness is a key question in the development of services, and this must be considered carefully by operators. Investment cost will strongly depend on local contexts; for instance, length and complexity of a line and road quality will determine the costs of infrastructure, while transport demand and the manufacturer's market will determine the costs of rolling stock. Meanwhile, operational savings will vary depending mostly on labour costs, maintenance costs and working conditions.

A detailed socioeconomic study will help find the right balance between investment costs and operational savings while ensuring the best service to meet the user's needs.

# BUILD THE BEST STRATEGIC FRAMEWORK



*By aligning autonomous mobility deployment use cases with strategic objectives, we can better control and optimise the resulting impact on cities and communities.*

**Mathieu Martin**, New Mobilities Project Leader, SYSTRA



## Forge a vision with a strategic framework

A strategic framework is a key element to guide the deployment of autonomous mobility services on a delimited territory. The following steps are typical for the upstream planning and strategic decision-making phase:

1. To define future mobility objectives aligned with national and regional priorities and values regarding sustainability, social inclusivity, safety and economic efficiency.
2. To conduct different studies to assess the mobility needs especially the one not satisfied by public transport, and the potential impacts of the new autonomous mobility solutions for the area of interest, such as:
  - Transport and traffic studies
  - Energy and environmental studies
  - Safety and security studies
  - Financial analysis
3. To be part of a master plan in line with the existing mobility plan and spatial planning programmes for territorial cohesion between regions.

## Adopt an urban planning strategy

Autonomous mobility should serve the users and improve quality of life, especially in the city. Its development must fall within urban planning objectives to improve mobility and increase service accessibility.

### Support public transit

Bringing autonomous technologies into public transit reinforces its attractiveness and stimulates modal transfer towards public transport services.

### Complement with ridesharing

Autonomous driving technologies are likely to increase the appeal of services such as driverless taxis and generate saturation of small vehicles on the roads. Shared mobility services should be promoted with a view to encouraging ridesharing and to complementing public transit. A pricing strategy based on zones or time of day can contribute to that.

### Optimise the fleet operation

In terms of shared and on-demand mobility services, free passenger detours and improper fleet relocation strategies with empty journeys can have a negative impact on energy consumption as well as congestion. The fleet needs to be managed properly by means of rebalancing and allocation strategies to optimise routes, maximise the vehicle occupancy rate and minimise the waiting time for the user.



## Energy transition objective

Alongside the development of autonomous mobility comes the rise of electromobility. These topics are not codependent but should be considered as strongly linked as new technologies must address energy transition, thereby reducing the use of fossil fuels. It is expected that most AVs will be electric, and an autonomous mobility strategy must be linked to a sustainable energy strategy.

## A dynamic ecosystem with public-private collaboration

Stakeholders must cooperate upstream with decision-makers and legislators to contribute towards improving policies and legislation. This is essential in part to help define the right allocation of responsibility, and overall such cooperation is key to enable the sound development of new mobility systems.

## Design services with the right tools

Mobility engineers and consultants use a wide range of planning tools to help public authorities provide the right solutions to their strategic objectives.

### Measuring the impact of new mobility services

New transport services can generate new demand while also capturing the actual demand served by current modes of transport. In turn, demand modelling and traffic flow simulations can anticipate these specific impacts. At a macroscopic scale, transport models consider modal shifts and demand evolution to target the best

solutions, while also integrating user acceptance as an important parameter of mode choice. At the mesoscopic and microscopic scale, traffic simulations study the fluidity of the transport network in the light of the specific behaviour of AVs in traffic.

### Suitable fleet sizing

New transport modelling approaches, such as agent-based models, are used to better calibrate the fleet according to the demographic structure of the region of interest along with the various needs of its inhabitants. For instance, a fleet of autonomous buses with varied-capacity vehicles could potentially perform better.

## Public consultation for better acceptance

*General public support is also key to the success of autonomous mobility and is as important as technical feasibility and territorial relevance. It is therefore essential to include future users early in the service design process to measure their needs, expectations and concerns. Public consultation methods effectively serve this purpose and are regularly employed by mobility consultants.*





# BE INSPIRED BY INTERNATIONAL VISIONS

# 4

Mobility has taken various forms across the world depending on the local culture, environment and resources. The development of autonomous mobility systems will heavily depend on these features as well as the technological opportunities. Three countries have been selected to illustrate these differences, driven by strategic objectives and public will, and depending on the local ecosystem: Singapore, the United States of America and France.





**SINGAPORE**

## Autonomous Mobility within a public vision of the Smart Nation

The will, the means, the appetite of the population for new technologies and the development of necessary frameworks all explain how Singapore has become a leading nation in autonomous mobility.

### A response for land planning optimisation

Singapore is a dense city with major space issues. The road network currently uses 12% of the land, which is considered the maximum acceptable limit. Authorities are looking to manage land development while eliminating cars, optimising logistics and increasing public transport modal shares (90% of peak-hour journeys using Walk-Cycle-Ride modes of transport to be completed in less than 45 mins). Therefore, autonomous transport technologies are seen as a way to improve the public transport system and goods delivery. The main desired effects are the reduction in number of private vehicles on the roads and the reduction of parking size.

### A key part of the Smart Nation programme

One of the key transport projects within the Smart Nation programme is the development and deployment of autonomous vehicles. In 2014, the Committee on Autonomous Road Transport for Singapore (CARTS) was created to lead and provide guidance for the research and deployment of AVs in Singapore, including regulation and safety aspects. CARTS is strongly involved with the Singapore's Land Transport Authority (LTA) in its work, which ensures that the programme remains relevant to land development objectives.

**Demographics:** 5.686 million inhabitants (2020)  
**Density:** 7,810 inhab./km<sup>2</sup>  
 Rank in the 2020 Autonomous Vehicles Readiness Index (KPMG): **#1**

### A strategy focused on experiments and frameworks development

Several pilots have taken place since 2010, which focused on public transport and mobility-on-demand services, freight on last-mile and long-distance services, and utility operations such as road sweeping and rubbish collection. Meanwhile, the CARTS developed safety, regulatory and liability frameworks to make Singapore the number one city in this respect, which facilitated trials to prepare for future "mass" deployment. In 2017, the LTA and the Nanyang Technological University (NTU) also created the Centre of Excellence for Testing and Research of

Autonomous Vehicles (CETRAN) as the leading player in developing technical references and international standards for AV deployment. NTU and the CETRAN developed several partnerships with public authorities and private stakeholders around the world.



### A LARGE-SCALE INVESTMENT PROGRAMME

At the end of 2020, Singapore launched its most recent plan to sustain investments, investing 25 billion Singapore dollars (€15.6 billion) between 2021 and 2025 in research, innovation and business activities. This new plan is a continuation of the RIE2020 plan (19 billion Singapore dollars invested in the period 2016-2020).

### TR68: the magic ingredient?

The Technical Reference 68 (TR68) is intended to support the development of AV technology and deployments in the areas of basic behaviour, safety, cybersecurity, and vehicular data types and format. Through Singapore's participation in the ISO, the TR68 efforts also contribute to the global effort towards the harmonisation of technical requirements for AV technology.



### Wee shann Lam

Chief Innovation & Transport technology Officer, LTA



LTA's vision is to create a Car-Lite Singapore where people choose to walk, cycle and ride public transport and we believe Autonomous vehicles (AVs) can bring about new opportunities especially for public transport. Hence, autonomous buses have been our focus since we embarked on our AV journey in 2014 and we are also examining shared, on-demand services on smaller platforms. We also believe the successful deployment of AVs depends on two key factors. Firstly, the technology must be reliable, safe, and customized to the local environment, e.g. to face specific weather conditions. Secondly, we must ensure that public safety and interest are of paramount consideration to promote public acceptability to AV.

Promoting the use of AVs in Singapore at this point can help to prepare our eco-system and workforce to support AV deployment when the technology is ready. R&D activities, AV trials and pilot deployments will create new job roles and opportunities such as remote fleet controllers, technicians, engineers, and data scientists.



### Progress report

- Passengers cars and shuttles have been tested since 2010
- First autonomous bus pilot route opened in 2021
- Policy and legal framework established as the most advanced in the world in 2020



### Strengths

- In-depth work on policies, legislation and safety framework
- Good quality of mobility infrastructures
- Great user acceptance



### Challenges

- Local market size could limits the interest of technology stakeholders
- Limited space to develop new services





**USA**

## A vehicle-centric approach of autonomous mobility

The technological capabilities of its stakeholders make the USA a major player in the development of autonomous mobility. Such development is primarily focused on technologies within the vehicle in the pursuit of the ideal scenario of an all-terrain, self-driving car.

### The private sector takes over developments

Following an early development plan promoted by the US Department of Defense in the mid-2000s, AVs quickly gained the attention of OEMs and tech companies as well as private universities that now run their own programmes. By early 2010s, few stakeholders stood out besides Waymo, Tesla or Uber, but by 2018, more than 40 competitors had entered the race of autonomous technology development.

Such interest and commitment in the development of AV technologies are followed by considerable investments. Therefore, the US is the world's leading nation in terms of investment, for a total of \$55 billion in the period 2010-2018. Despite a slowdown in the subsequent years, investment continues.

### Focus on individual vehicles with SAVs and delivery services

Autonomous mobility is developing in a context of individual freedoms and in large cities with space mostly given to roads. Therefore, it comes as no surprise that research and development activities lean more towards individual transport options, with most automotive companies at the heart of the action. Individual vehicles and taxis count for more than half of the autonomous testing projects in the country, while remaining passenger transport tests use shuttles and are predominantly furnished by two French



companies, EasyMile and Navya. Local Motors, a US shuttle company, is roughly involved in one fifth of experiments.

Shared Autonomous Vehicles (SAVs) and autonomous delivery services also promise to bring automakers access to new revenue streams, while financial benefits from optimised individual transport services are the main draw for investment.

### A fragmented regulatory framework

Individual States remain the leading regulators when it comes to licensing, registration, traffic law enforcement, safety inspections, infrastructure, and insurance and liability.

Each State develops its own legislation and regulatory framework to authorise autonomous driving on roads, with Nevada leading the way in 2012. Various States therefore have created their own taskforces or strategic committees to investigate and consider future legislation for autonomous vehicles, while others still have no legislation in place. As of 2021, around three quarters of US States have enacted legislation or executive orders relating to the testing and driving of autonomous vehicles.



### NHTSA DEFINES SAFETY STANDARDS AT THE FEDERAL LEVEL

The National Highway Traffic Safety Administration (NHTSA) has outlined a roadmap for States wanting to move ahead with testing and eventually deploy AVs. It offers steps that a State could consider rather than detailed legislation. NHTSA is also a strong advocate for I2V and V2V technology for safety.



**Susan Shaheen**

Professor in Civil and Environmental Engineering, UC Berkeley



Shared AVs are expected to have a transformative impact on mobility. Passenger vehicles like taxis and transportation network companies have the potential to reduce vehicle ownership as well as reduce parking needs. Other innovative services can emerge as efforts are underway to develop automated micromobility devices (e.g., three-wheeled scooters) that could be e-hailed and delivered directly to a user. However, shared AVs can also lead to increased vehicle kilometers traveled due to empty vehicles that “room” instead of parking. This risk should be carefully examined, particularly from a public policy perspective. Safety and societal adoption are also key challenges for shared AVs, such as the absence of “eye contact” with human drivers, which would change nearly a century of human behavior on the streets. Additionally, steps will need to be taken to ensure social equity, privacy, data protection, and building trust in this emerging technology.



### Progress report

- Robotaxis have been tested since 2017, despite a fatal accident with Uber in 2018
- First pilot driverless taxi service opened in 2020
- 16 States authorise full deployment and 12 States authorise testing



### Strengths

- Cutting-edge tech companies and manufacturers dominate AV industry
- An accelerated pace of development
- Strong investment capacity



### Challenges

- Disparities between States on autonomous regulations
- Development mainly focused on the car does not address congestion issues
- Consideration of road infrastructure in autonomous mobility development





**FRANCE**

## A national strategy specific to autonomous mobility development

As a later participant in the race, France developed a national comprehensive strategy and launched several AV experiments with a large focus on public transportation. Today, France shares its vision of autonomous mobility with the world and is trialling its technologies in several countries.

### A specific roadmap for 2022

Public authorities adopted a national strategy in 2018, with a broad public action plan to support AV development under the concepts of safety (of systems), progressiveness (of technologies) and acceptability (of users). It established a solid framework to address all the main requirements of AV development.

However, technological and regulatory complexities – on top of the global health crisis – slowed down initial ambitions to have AVs in circulation by 2020. In December 2020, public authorities updated the roadmap and set 2022 as the new horizon.

### Main focus on legal framework and public transport trials

France entered the race on legislation early but fell behind when the buzz was at its peak. Up to 2018, the lack of framework to standardise licensing conditions slowed the launch of AV trials, although private actors were eager to develop autonomous mobility technologies.

Once the national strategy was released, new regulatory tools facilitated the delivery of authorisations as of 2018. In 2019, the French Agency for Ecological Transition (ADEME) also launched a centralised and government-

**Demographics:** 67.39 million inhabitants (May 2021)

**Density:** 118.27 inhab./km<sup>2</sup>

Rank in the 2020 Autonomous Vehicles Readiness Index (KPMG): **#19**

funded trial programme known as EVRA (in french, Expérimentation du Véhicule Routier Autonome). Two consortiums covering 16 experimentations nationwide were selected (named SAM and ENA), of which 10 were orientated towards public transport services mostly in suburban areas.

Since then, public authorities continue to put the regulatory framework in place, and in July 2021 a decree was published to authorise autonomous vehicle circulation on open roads by 2022, thanks to adapted traffic regulations.

## French shuttles are everywhere

France leads the autonomous shuttle market worldwide. Among the dozens of companies that build and test shuttles, the two French companies EasyMile and Navya are conducting the most trials at a global level. Other companies have also developed their own shuttles, such as 2gether (Netherlands) or Local Motors (USA).



### INTEROPERABILITY WITH EUROPEAN INFRASTRUCTURE

With open borders and free traffic flows, AVs will raise the issue of harmonised and connected road infrastructure across Europe.

This is not seen as a priority as AVs are expected to circulate freely across Europe in the long term. However, the European Commission has already launched research projects (e.g. InterCor and C-Roads) to publicise technical and regulatory issues.



### Come Berbain

Innovation Director, RATP Group



If we want to reduce congestion and build cities with a better quality of life we have to continue developing shared mobility and multi-modality. Autonomous shuttles offer a great opportunity to do so. This is why RATP has been experimenting shuttles for public transport and for service to companies with continuous progress since 2017. In 2021 we opened the first fully operating autonomous shuttle service in the Paris region (Arval transport service) and we are pursuing our experimentation program in Paris region as well as in different cities in France.

However, the economic model of such services is still to be validated to demonstrate rentability. To do so, removing the safety operator onboard is a key step and will be the next challenge.



### Progress report

- 50+ authorisations for testing delivered up to 2018
- Autonomous vehicles testing programme launched in 2019, still ongoing in 2021
- Regulatory framework started in 2015 remains under development in 2021



### Strengths

- A strong national strategy for autonomous mobility
- An advanced thinking about key issues : frameworks, cybersecurity, acceptability, etc.
- AV manufacturers export and test abroad



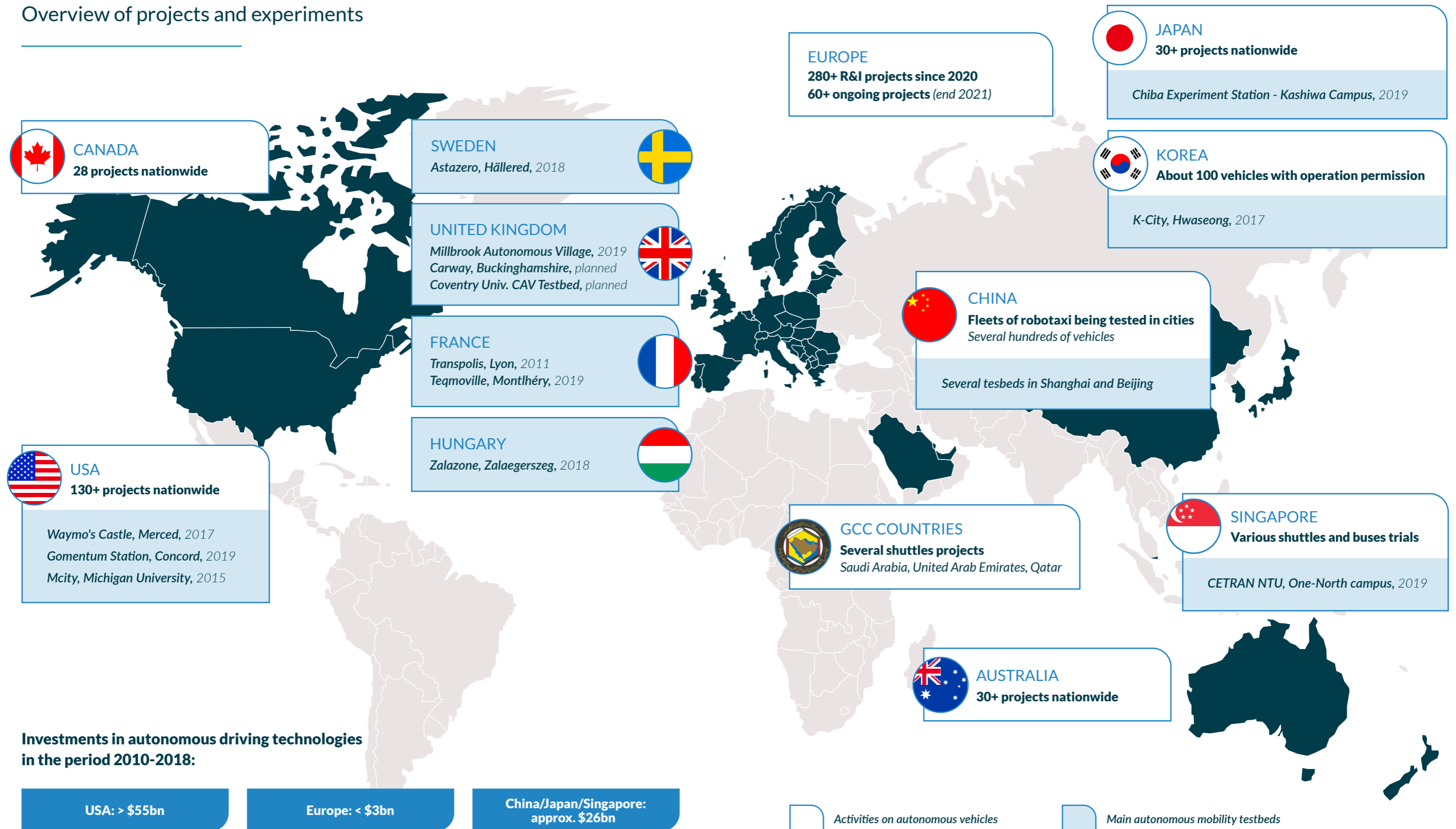
### Challenges

- Mixed acceptance and adoption of AVs by users
- Modest involvement from large digital companies
- European context brings complexity and extra requirements in term of regulation and standardisation



# AUTONOMOUS MOBILITY IN THE WORLD

## Overview of projects and experiments



Source: McKinsey

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## PUBLICATIONS ON SYSTRA.COM



### Automated and Autonomous Public Transport: Possibilities, Challenges and Technologies

2018



### The future of the metro as seen by SYSTRA and Usbek & Rica

2020



### Mobility as a Service as seen by SYSTRA and Usbek & Rica

2021

## INTERVIEW



### Autonomous shuttles and bus rapid transit: understanding the value and risks

Maud Bernard, innovative transportation systems program director at SYSTRA

The Future of Transportation World Conference

2019

[www.thefutureoftransportconference.com](http://www.thefutureoftransportconference.com)

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The background is a solid red color. It features several thin white lines that are mostly straight but have rounded ends. Some of these lines are solid, while others are dashed. Small white dots are placed at various points along these lines, some appearing as simple dots and others as dots enclosed in small white circles. The overall composition is minimalist and geometric.

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