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STUDY

IMPACTS AND POTENTIAL BENEFITS OF AUTONOMOUS VEHICLES

FROM AN INTERNATIONAL CONTEXT TO GRAND PARIS

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Summary

OVERVIEW

Autonomous vehicles (AVs) have the potential to transform urban living. By offering the opportunity for safe, efficient, accessible and affordable transportation they promise not only a novel system of mobility, but also a novel approach to the urban lifestyle. Yet these benefits are far from guaranteed. In fact, scholars have shown that AVs have the potential for numerous negative impacts in contraposition to their positive potential, depending, of course, on the form of their implementation. They could combine with other growing trends in the mobility space (such as shared use or mass electrification) to introduce a positive rupture in today's mobility system, or, conversely, they could exacerbate existing trends towards congestion and climate change, further entrenching the negative aspects of today's status quo.

Compounding this duality is a lack of clarity regarding when AV services will be available for public use. Reports from experts in autonomous technology evince a wide range of dates for the arrival of the technology, with some averring high levels of autonomous technology available for widespread use within the next 2 years and others professing that full autonomy can never be fully achieved.

This uncertainty cannot lead to inaction. There is a unique opportunity today to redefine the mobility system before the technology solidifies its own path. Cities have the opportunity to be at the forefront of innovation while simultaneously taking an active role in shaping the form of their cities for the future, pursuing an urban form that is efficient, livable, equitable and sustainable.

In order to capitalize on this opportunity, however, cities need to develop an extensive understanding of the technology as it exists today, the challenges that it presents and the potential benefits that can be realized.

This study strives to offer a primer on international autonomous vehicle development and regulation as applied to the context of Grand Paris. It aims to provide the region and the city with the understanding, insights and tools it needs to enact pertinent policy measures today. In pursuit of those goals, the study includes:

- An overview of the regulatory context in France
- A 'state of the union' of autonomous vehicle technology
- A series of international case studies that offer creative ideas for managing AV experiments and technological development
- An overview of the potential advantages and disadvantages presented by the arrival of autonomous vehicles
- Insights into pertinent regulatory and extra-regulatory levers
- Opportunities for further experimentation in Grand Paris.

Launched in the summer of 2018, this study is the result of a collaboration between APUR and the Massachusetts Institute of Technology's Urban Mobility Lab. Over the course of several months, collaborators interviewed key actors in the Parisian context, including (among others):

- Mairie de Paris
- Navya
- Easymile
- Renault
- Uber
- Mobotiq
- Spirops
- Ile-de-France Mobilités
- SANEF
- IFSTTAR

The interviews contributed to the development of the content of the study as well as to the case studies themselves.

The contents of the study notably build on work conducted by MIT's Automated Mobility Policy Project (AMPP) combined with APUR's expertise on Grand Paris. The primer applies MIT's research to the Parisian context to build a deeper understanding of today's pertinent technological and regulatory developments and their applicability to the City of Light.

This study is part of a larger series to be published by APUR on emerging and innovative mobilities that will examine the potential (and potential drawbacks) of developments within the mobility space, ranging from the sharing economy to mass electrification.

Man and delivery robot waiting at pedestrian crosing in Redwood City, California

Military drone

Waymo self-driving car side view, Googlebil

La Rochelle (France), experimental autonomous shuttle without driver

Uber OTTO autonomous driving truck

Autonomous-rail Rapid Transit train, already in experimental operation in Zhuzhou.

1. Regulation

Regulatory context in France : a nascent question

Albeit not one of the first countries to regulate autonomous vehicles internationally, France has since made the development of autonomous vehicles a national priority both with regards to industrial recovery and urban living. In 2018, the French national government published a strategy for autonomous vehicle development within its borders, addressing the issues raised by autonomous vehicles and presenting a series of ten proposed actions aimed at facilitating the emergence and development of the technology. It aims to help France position itself in the dynamic AV market while simultaneously meeting the challenges posed by their introduction. Figures 1 and 2 as included in the strategy document provide a brief overview of the regulatory timeline in France and in the EU more generally, with a particular emphasis on the years of 2017 and 2018 which have exhibited a particular uptick in action both at the national and international scales.

AV regulation in the United States

The United States offers a unique case study for the regulation of AVs in its juxtaposition of varied regulatory preparedness across different states in combination with extensive testing experience. The National Highway Traffic Safety Administration (NHTSA) has released guidelines for the safety, testing and data management of autonomous vehicles, but, to date, most regulatory activity has occurred at the State level.

In 2012, California became the second State to allow for testing of autonomous vehicles on its roads. Refined in 2018, the state boasts one of the most extensive regulatory systems for the management of AV experimentation and testing on an international scale. The state requires, for example, that all vehicles be equipped with a data recorder for the review of incidents and accidents ex post facto; similarly, the state requires that companies regularly report the number of disengagements they experienced throughout their experimentation process. Despite the comparatively stringent measures, the state has over 50 AV companies working within its borders and over 400 vehicles registered to be tested on public roads. In 2018, California became one of the first locations globally to allow for testing on public roads without a driver present. Nonetheless, the State has come under criticism for its regulations that some companies see as misplaced and others see as excessively stringent.

While Arizona boasts a similar number of autonomous cars operating on its public roads (some estimates are above 600), its regulatory measures regarding AVs are nearly non-existent. After California limited the ability of Uber to operate and test on its streets in 2016, Governor Ducey of Arizona invited the company to come to the Copper State instead. The Governor has since asked the State's DMV to "undertake any necessary steps to support the testing and operation of self-driving cars." The lack of restrictions combined with AV-friendly weather have made the State a popular destination for many companies to test their technology, but also, significantly, resulted in a fatal AV accident in early 2018. The State temporarily suspended Uber's activities there following the crash, but has not adopted any additional regulatory measures since.

The ten national priorities:

1 - Develop the necessary framework to allow for the circulation of autonomous cars, public transport and logistics in France by 2022.

2 - Establish a national regulatory framework for experimentation.

3 - Integrate cybersecurity into regulatory framework.

4 - Define rules for data sharing.

5 - Develop a national program for experimentation of all forms of autonomous vehicles.

6 - Build a framework to encourage the exchange of vehicle data by 2019.

7 - Prepare one or more connected infrastructure deployment plans.

8 - Encourage the development of digital mapping.

9 - Establish the framework for an impact analysis of autonomous vehicles.

10 - Conduct a detailed analysis of the impact of autonomous vehicles on employment.

FIGURE 1 — FRANCE AND EU CONTEXT

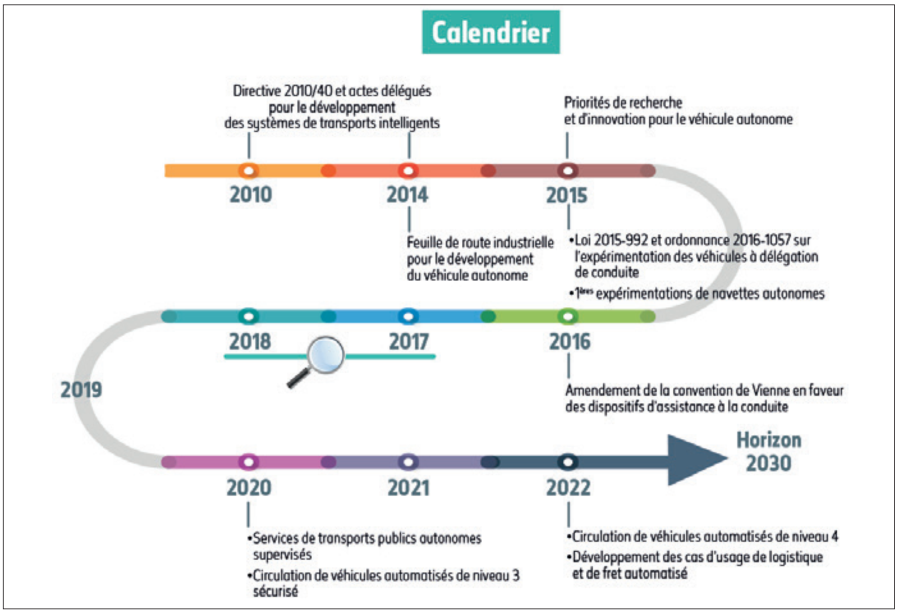

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FIGURE 2 — GOVERNMENT ACTION ON AVS IN FRANCE

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European context

As a member of the European Union, France is also working with the Union and other member states to establish a transnational framework to regulate and support the development of autonomous vehicles. The European Union has outlined a series of goals with the intent to establish Europe as a global leader in connected and automated mobility in pursuit of safer roads and reduced emissions and congestion. In pursuit of those goals, the EU has proposed several categories in which to lend support and expertise:

- Funding for research on autonomous vehicle technology and connected infrastructure.
- Establishing a security approval process for vehicles and infrastructure that is flexible yet strong.
- Ensuring coordination across member states to establish traffic rules and infrastructure development.
- Regulating liability concerns.
- Data Management.
- Analyzing the socio-economic and environmental impacts of driverless mobility.

Significantly, there are also efforts to coordinate an approach to experimenting with autonomous vehicles across EU member states. Countries have agreed to concentrate their efforts on a cadre of coherent and complementary projects that allow for a deeper understanding of its technology and its applications. To that effect, France recently opened a call for autonomous vehicle projects.

Other levers

In addition to traditional regulatory measures that govern the safety of vehicles and testing on public roads, it is important to note that there are many other potential actions that governments can take into consideration when determining their role in preparing for a new global mobility system. Albeit not exhaustive, as part of this study, we outline several other pertinent levers at the level of the state that can be used to incentivize experimentation, to limit potential deleterious impacts and to even help determine the shape of the final product. The application of several of these levers can be found exhibited in the case studies found in chapter 3. At end of this report, we apply this research to the city-specific context, looking into both the regulations and other levers that cities themselves possess that can be used to shape the arrival of autonomous vehicles onto urban streets. The goal of this report is to offer insights into best practices for applying and engaging with those levers. It is important to note that these factors can be applied to the adoption of new technology within the transportation system more generally, but is being applied specifically to the case of autonomous vehicles in this circumstance.

Infrastructure

AVs will require a wide variety of novel infrastructures. Although it remains unclear who will be responsible for building those infrastructures—and in some cases what form the infrastructure itself will even take—there are certain actions that can be taken today in order to prepare for and in some cases shape the future of AVs. To ensure the sustainability of the vehicles and to reduce their impact on the environment, for example, there is widespread agreement that AVs should be electric. That requires **an increased density of electric vehicle charging stations**. Similarly, many AVs are heavily dependent on road markers to ensure that they remain in their lanes and follow the pertinent traffic rules, requiring clear and high-quality road networks. **There is also consensus that the growing connectivity of vehicles (whether autonomous or otherwise) will require next-generation mobile networks in the form of 5G.** Governments today have the opportunity to prioritize the development of these infrastructures to ensure the sustainability of AVs, but also to incentivize experimentation within their borders. The Netherlands has prioritized this route of action, with a commitment to infrastructure in a wide variety of forms. Its road infrastructure is rated among the best in the world by the World Bank, it boasts the highest density of AV charging stations and enjoys a strong wireless network as well.

Fiscal support

Funding in support of research and experimentation for AVs can come in a wide variety of forms. Most directly, governments have the opportunity to fiscally support experiments of vehicles that exhibit characteristics most in line with their priorities for the future of transportation. The city of Helsinki, for example, has clearly outlined emissions reduction goals for 2030 and has thus been involved in supporting AV experimentations that promise to reduce emissions by encouraging more wide-spread public transportation use.

Regulatory clarity

Beyond the content of the regulations themselves, governments have control over the clarity of the regulatory content and the complexity of the process to navigate those regulations. Several of the interviewees that we spoke to as part of this study indicated that they would be supportive of regulations targeted at shaping the introduction of autonomous vehicles onto city streets, but were eager for those regulations to be outlined in

Governments today have the opportunity to prioritize the development of infrastructures to ensure the sustainability of AVs and to incentivize experimentation within their borders.

80 bil. $

Estimated investment in autonomous vehicle technology between 2015 and 2017 as determined by The Brookings Institution [1]

1 — https://www.brookings.edu/research/gauging-investment-in-self-driving-cars/

Countries that have a clearly defined process even if rigorous have an advantage in encouraging experimentation and thus have the opportunity to develop a greater familiarity with the technology and its potential impacts.

94 %

Crashes in the United States attributed to human error [2]

2 — https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115

a clear and comprehensible manner to ease the corporate navigation thereof. Significantly, this also applies to the approval process for AV experiments on public roads: **countries that have a clearly defined process even if rigorous have an advantage in encouraging experimentation and thus have the opportunity to develop a greater familiarity with the technology** and its potential impacts. Singapore, for example, has very clearly defined milestones that companies have to achieve in order to be eligible for experimentations of growing complexity and in more complex environments within the city. Helsinki, meanwhile, has created the position of Chief Design Officer in the city responsible for applying design knowledge to ease and encourage a culture of experimentation across companies and city agencies within Helsinki. This new role is unique and innovative in its attempt to centralize and innovate coordination across bodies, thus easing key regulatory processes for corporate entities, as well as any internal bureaucratic confusion at the city level.

Regulatory responsiveness

Autonomous and connected technologies continue to rapidly develop and evolve, requiring an approach to policy that is responsive and open to evolution. Today, governments are in many ways establishing regulation for autonomous vehicles 'in the dark,' attempting to ensure such necessities as safety and cybersecurity without yet fully comprehending the technology itself. As the technology and its potential continue to become better understood, there is a need for consistent refinement of those rules. Governments that have the ability to be highly responsive to these changes in technology both to support its further evolution and to ensure that it remains on a positive path throughout its evolution have an advantage in attracting experiments and ensuring greater (and continuing) safety and livability for citizens and residents. **California, for example, was one of the first governments to establish a legal structure for the testing of autonomous vehicles in 2012** and has refined several aspects of the law since to incorporate new developments. In 2018, for example, the state added a legal structure under which companies can test without a driver present in direct response to developments within the industry.

Coordination across levels of Government

Building on the need for regulatory clarity, there is often a conflict of responsibility across different scales both nationally and internationally. In the United States, for example, each level of government has overlapping responsibilities with regards to city streets, including in the fields of safety, security and sustainability. Based on research conducted at MIT, lower levels of government in the United States are hesitant to engage in several pertinent regulatory measures out of concern of being preempted by higher levels of government on the matter at a later date. Governments that can coordinate across scales thus have an advantage in establishing greater clarity, but also in ensuring that all necessary aspects of regulation have been covered.

Other

There are a wide range of factors that affect a nation's willingness to experiment with new technology as well as its agility in managing and shaping the introduction of that new technology. In addition to the above enumerated elements, it also important to take consumer acceptance and innovation culture into account. The former can be encouraged through widespread experimentation and engagement with a new technology, for example. The latter, meanwhile, can be developed through fiscal support for innovative enterprises, clarity of regulations regarding new businesses and other related activities that encourage entrepreneurial pursuits.

2. Technology and impacts transport systems

Autonomous technology

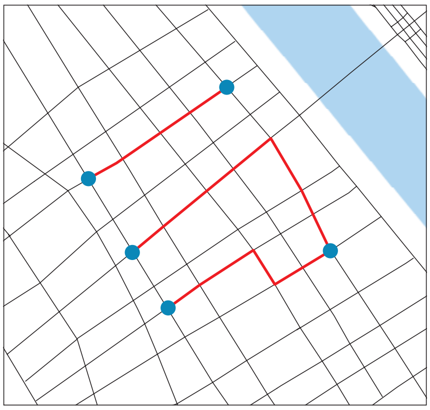
According to SAE International, an engineering standards developing organization, there are five levels of automation. As outlined in Figure 1 below, the levels begin with very limited driver assistance and progress gradually towards full automation in which a steering wheel and driver are no longer required. Most vehicles on the road today contain technology of at least Level 1 autonomy and many boast Level 2 autonomous features as well. It is important to note that the technology will not necessarily progress in a step-wise fashion from level to level. In fact, several companies are experimenting with Level 4 automation today and propose to skip Level 3 automation altogether. Significantly, as a result of the low turnover rate of vehicles, there will be a mix of levels of autonomy in vehicles on the road for the foreseeable future, creating a unique challenge in the transitional period.

FIGURE 1 — LEVELS OF AUTONOMY

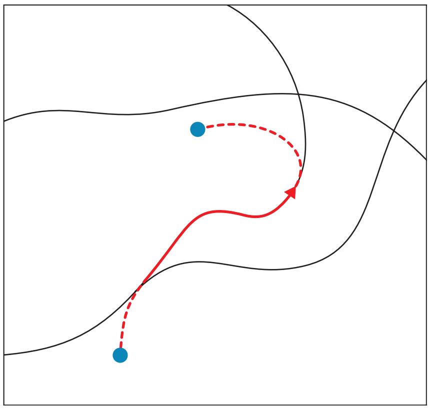
Level		Direction, acceleration and deceleration	Monitoring of environment	Fallback performance of Dynamic Driving Task	System capacity for driving modes
Niv. 5	**Full Automation** All functions performed by the vehicle without the need for a human driver.	System	System	System	All
Niv. 4	**High Automation** Automation fully possible in most road conditions without human intervention; steering wheel still in place in case of emergency.	System	System	System	Some
Niv. 3	**Conditional Automation** The vehicle handles most functions in mapped locations. The human driver must intervene and manage the vehicle in certain scenarios.	System	System	Human	Some
Niv. 2	**Partial Automation** The vehicle is able to manage at least two simultaneous autonomous tasks in specific scenarios.	System	Human	Human	Some
Niv. 1	**Driver Assistance** The vehicle is capable of managing at least two concurrent standalone tasks in specific scenarios.	Human	Human	Human	Some
Niv. 0	**No Automation** A human driver performs all the necessary functions.	Human	Human	Human	Some

Actual level of tested autonomous transport (Niv. 3 and Niv. 2)

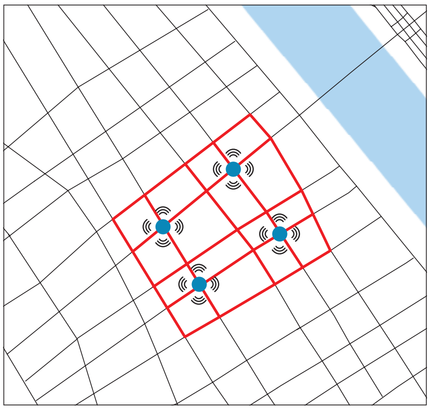
FIGURES 2 –
LEVELS OF AUTONOMY MOBILITY



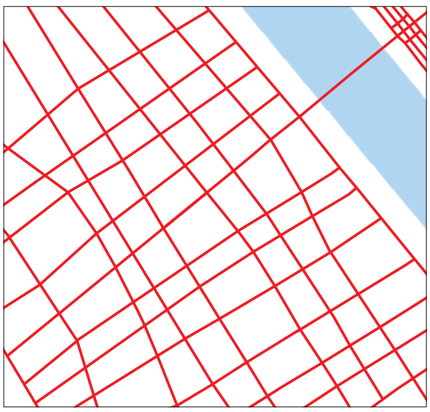
1 – Street, planning route connected



2 – Higtway connected



3 – Urban district connected



4 – Street network connected

Most companies experimenting with automation today rely on Deep Learning to do so. A subfield of Artificial Intelligence within the family of Machine Learning, machines that apply Deep Learning 'learn by example,' relying on extensive data collection to develop ever more complex and hierarchical algorithms for understanding the world around them. Thus, AVs require not only software development to improve the technology used, but also experience driving on roads in order to develop greater familiarity with a wide variety of scenarios and obstacles. Figures 2 represents a natural progression of learning and thus experimentation based on the Deep Learning paradigm.

Today, the vast majority of experiments within the field of autonomous vehicles are fixed single-route experiments as exhibited in picture 1. Vehicles equipped with complex autonomous software learn a specific route by traversing it routinely throughout a test phase and, once the route is fully learned, expand the service to the general public. This approach applies to AV truck testing on highways as well. Trucks are able to learn and execute a fixed route for freight movement—usually straight and unencumbered (picture 2).

As the vehicles develop added experience and thus a greater familiarity with their surroundings through additional miles driven, it is possible to expand the fixed route approach to a fixed district approach (picture 3). Today's robotaxis, for example, apply Deep Learning to a full district within an urban environment: vehicles collect extensive miles driven in a specific district, allowing them to accurately map the area and better understand the pertinent obstacles. Robotaxis are subsequently able to offer service throughout the district. The final stage is to apply this approach to a much broader area—perhaps to a whole city (picture 4).

The structure of service can of course be varied as project partners see fit. Routes can either have defined stops or offer on-demand service based on a user's location, for example. Similarly, AV systems can run on a set schedule (similar to public transportation) or offer service in response to user requests. Further, cities can decide to offer a lane dedicated specifically to the autonomous vehicle, reducing the number of obstacles encountered by the vehicle on a regular basis, or allow the vehicles to operate instead in regular traffic. A dedicated lane notably raises questions regarding the prioritization of autonomous vehicle technology vis-à-vis other modes of transportation.

Service is also affected by the location of the route itself: it could either be within a city in a dense, pedestrian-heavy area (more complex to navigate with an increased number of obstacles) or less dense, suburban areas. Experiments notably vary across public and private property with the latter presenting fewer regulatory limitations.

As the technology continues to develop, a growing number of questions have arisen regarding data ownership, exchange and security. Albeit largely outside of the scope of this primer, there are numerous approaches to exchanging data and experience to support the development of the software and technological capabilities beyond the individual company unit. The value of blockchain as a transparent and secure decentralized ledger for data arose several times during interviews conducted. Nonetheless, blockchain challenges the proprietary and private nature of data as approached today.

Vehicles and transportation systems

To date, autonomous vehicle technology has been combined with diverse systems to serve in a wide variety of contexts. We discuss the forms these experiments have taken briefly below. They are notably explored in-depth in a series of case studies presented in Chapter 3.

Mass of public transportation

The form of autonomous vehicle most widely used for ongoing tests and experimentations is the autonomous shuttle. The two most prolific hardware firms for autonomous shuttles are notably both based in France: Navya and Easymile. Navya boasts over 120 and Easymile boasts over 170 shuttles in circulation. The shuttles range in size, fitting generally between 12 and 15 individuals and, although they are able travel at varying speeds, are largely limited to a walking pace of between 7 km/h and 10 km/h as a result of technological limitations in dense areas.

One of the reasons that these vehicles are widespread is their ideal size for a variety of transportation system solutions. Since autonomous vehicles have the potential to be less expensive than their chauffeured bus brethren, many view shuttles as an ideal solution for replacing routes that are either not as highly trafficked or not as well-suited for traditional public transportation. Shuttles also have the potential to serve as the solution for the first-mile/last-mile conundrum: they offer an on-demand form of transportation that can connect individuals with the closest public transportation stop, thus encouraging greater public transportation use. Shuttles also present an ideal solution for transportation on campuses that are perhaps less trafficked, but are nonetheless in need of transportation options to ease movement throughout the area. Thus, many of the shuttle experiments have been conducted on university campuses, in business districts and in other similar zones of activity.

Albeit smaller than buses, several ongoing experiments are exploring the value of shuttles as a demand-responsive form of mass transportation. These experiments apply the concept of platooning to expand capacity in periods of high demand. Platooning, in short, allows vehicles to travel closely together in a convoy by communicating with each other using connected vehicle technology. Thus, vehicles can be added or subtracted based on demand at any given stop at any given time.

The majority of autonomous shuttle experiments today are fixed-route. This notably fits well with the initial conception of the value of autonomous vehicles: the shuttles serve specific routes that are either underserved or perhaps not ideal for larger-scale public transportation. For this purpose, the shuttles only have to develop experience with one specific route, which, during the early days of experimentation with the technology, allows for earlier deployment and familiarity with the technology and its capabilities.

There ongoing experiments with other forms of mass transportation as well, perhaps most notably with buses. The experiments are targeted at replacing the existing fleet of buses with the novel technology.

Robotaxis

Robotaxis promise to address a different transportation need. The size of a regular passenger vehicle, such taxis are limited to 4 or 5 passengers, making them ideal for more individualized requests, similar to today's TNCs. Applying the Deep Learning approach, many companies engaged in the pursuit of a robotaxi service are collecting thousands of miles of experience in order to be able to serve a district with point-to-point on-demand service. Several cities, such as Singapore and Boston, have offered access to specific

12-15

Individuals generally fit in an autonomous shuttle

4-5

Passengers generally fit in a Robotaxi

3

Trucks hauling freight could be replaced by 1 autonomous truck

Uber's self-driving car test driving in San Francisco

PUBLIC TRANSPORT

Autonomous shuttle, new expectations for nightly public transport

Digital screen in Navya vehicle

Easymile autonomes shuttle, Fahrzeug Bad Birnbach

ROBOTAXI

New service of robotaxi

Googlebil interior by David Castor

Navya autonomous cab in Paris

districts within their borders for robotaxis to develop experience and familiarity with the eventual goal of offering commercial service to the public.

Although their limited size makes them less ideal for the fixed-route, mass transportation service offered by today's autonomous shuttle experiments, some experts view them as compatible with and a possible extension of public transportation. In Rouen, for example, as explored more in depth in a case study in Chapter 3, a group of partners is exploring the value of the Robotaxi for servicing business parks. Typically areas not dense enough to justify the investment of public transportation, business parks are still in need of transportation within the area to discourage workers from bringing their personally-owned vehicles by offering an alternative way to get around once in the park. Others profess the value of platooning for individual vehicles as well, arguing that a platoon of individual vehicles could also serve mass transportation needs.

Today, there can be found a wide variety of actors within this space, experimenting in locations across the globe. Many have announced plans to make the service public by the end of 2018.

Freight and municipal services

The field of freight has a wide variety of functions that are ripe for the introduction of autonomous technology. Highways are notably straight and involve relatively few obstacles, making them prime candidates for first generation, fixed-route experimentation. Several companies have been conducting tests to that effect, ranging from Uber's Otto to Volvo to Waymo. Nonetheless, highway entry and exit and the navigation of complex city streets remain challenging for the autonomous technology of today, limiting the experiments to partial freight routes. Initial studies have shown that the introduction of autonomous technology to this effect would allow the same manpower to be applied to triple the number of trucks as a result of the rest permitted throughout the trip as the autonomous system takes over.

From the urban perspective, there are a large number of municipal and other freight vehicles that travel along fixed routes and traditionally advance at a slow, deliberate pace, thus satisfying the preconditions for today's levels of autonomous technology capabilities. More directly, the autonomous vehicle technology of today could be applied to vehicles such as garbage trucks to ease the manpower required and to reduce emissions. As explored more in-depth in Chapter 3, Hamburg has recently announced plans to introduce autonomous garbage trucks into its fleet in early 2019.

This logic could be applied to other areas within the field of logistics, such as freight parks, airports and logistics centers. Several companies are already experimenting (or have proposed experimenting) with vehicles to service these areas, but experimentation within this area is still relatively inchoate.

Delivery robots

In 2015, start-up company Starship Technologies introduced the novel concept of autonomous delivery robots. The robots are capable of delivering goods from their initial location to a convenient point as determined by the consumer. After testing the robots in 20 countries across the globe, the company announced earlier this year that they would be conducting their first commercial rollout in 2018. Combined with the arrival of drone technology, these robots have the potential to upend the field of last-mile delivery for both freight and consumer goods. They could reduce the need for store fronts as individuals rely increasingly on goods delivery and they also call into question the need for delivery trucks and larger-scale freight movement within the urban context as they offer a smaller-scale, more personalized alternative.

Autonomous trikes

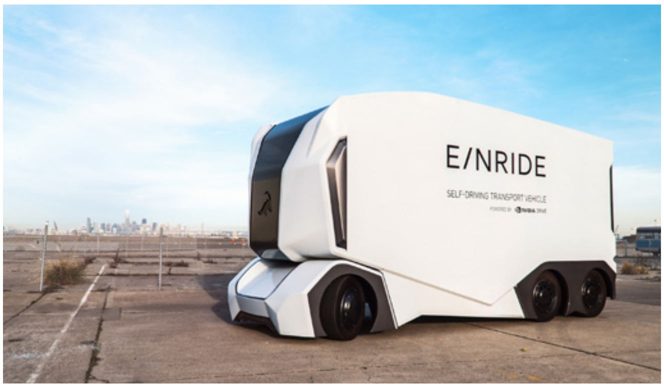
With fewer accidents in an autonomous vehicle future, is there still the need for a large-scale passenger vehicle? Several companies are challenging that notion with the introduction of the autonomous trike. Boston's MIT has introduced what it calls its Persuasive Electric Vehicle (PEV) and a company called Mobotiq has been testing its own version in Romania. These technologies offer a more individualized, small-scale solution to passenger transportation—one with a smaller environmental footprint. Although it might be difficult to imagine these vehicles replacing a full mass transit system, they might, according to MIT, "constitute a new and indispensable category of vehicles in the emerging constellation of mobility systems."

Autonomous drones

Uber has made public plans to actively investigate air taxi service. While scaling back on its autonomous vehicle program, the company has instead announced research into a program it has dubbed Uber Elevate, with demonstration flights planned for 2020 and commercial operations for 2023. The company has partnered with other key actors in the air space to start developing the infrastructure and technology required to make autonomous aerial ride-hailing a reality. Similarly, Airbus is currently conducting experiments whit arial taxis in sevent cities as well. While still in its early stages, these announcements portend a very different future from ground-based autonomous vehicles.

In fact, one can find a wide variety of innovative ideas within the field of autonomous vehicles that present images of the future that are widely divergent with the vehicles and systems that we have in place today across the globe. These conceptions serve as a reminder that the future of AVs might not be as predictable as it might seem at first blush. Nonetheless, experimentations of widely divergent vehicles today are still quite limited in number.

FREIGHT TRUCKS AND TRANSPORT SERVICES



The T-pod in front of San Fransisco, March 2018

Uber Elevate project, skyport design

DELIVERY ROBOTS

Illustration of delivery robot ans connected urban logistic

Illustration of delivery by drone

CONNECTED STREETS AND INFRASTRUCTURES

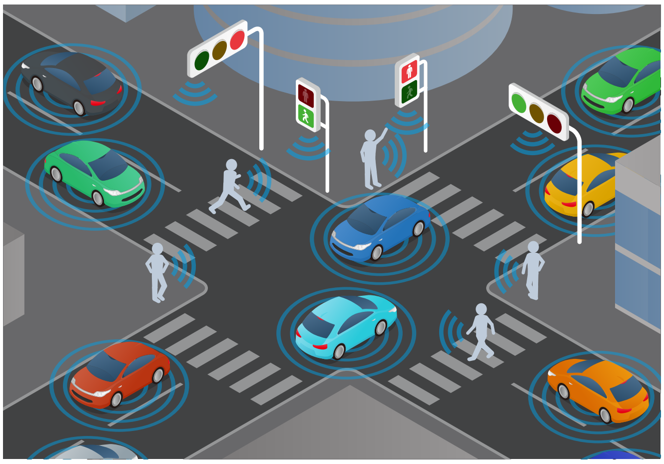


Illustration of connected environment with adapted traffic lights and vehicles

Illustration of artificial intelligence technology

© Mairie de Paris/Christophe Belin

Autonomous shuttle experiment between Austerlitz and Lyon train stations (Paris)

Adapting the city

Although it is perhaps simplest to think of autonomous vehicles in isolation, the technology in fact requires a variety of infrastructural investments to support its inception in addition to the technology within the vehicles themselves. While this field is still shifting as the technology and its requirements continue to develop, there are several areas of infrastructure that are sure to face changes and, in many cases, significant investment and adaptation. The private sector has a significant interest in expanding connected infrastructure in particular to support their experimentations and efforts developing new technology. Nonetheless, governments have a significant role to play in supporting experiments, coordinating across platforms and ensuring standardization.

EV infrastructure

When experts discuss AVs today, they generally do so under the umbrella of connected, autonomous and electric. It is frequently assumed that the future will invariably be electric because the fossil fuel schema of today is not sustainable in the long-term—and electricity is one of the most promising alternatives. Yet the infrastructure hurdles that must be overcome to realize a future of electricity are considerable. An electric future requires first and foremost a high density of electric charging stations that offer routine (and speedy) recharging options. It also, notably, requires an increase in reliable and sustainable power provision. Should governments wish to encourage the adoption of electric vehicles in tandem with the adoption of autonomous ones, then they should start thinking today about densifying and incentivizing the necessary infrastructure.

There is notably much innovation going on in this space that runs parallel to the innovation happening on autonomous vehicles themselves. Nonetheless, as AV technology moves rapidly forward, it should not be assumed that electric vehicle development will keep pace without additional support and incentives.

Connected infrastructure : networks

One of the biggest challenges facing AV development and governments today is the role and form of connected infrastructure. As AV technology has evolved, so too has the approach to connectivity. The challenge lies in how to coordinate connectivity requirements across a wide variety of companies working on a wide variety of projects. And, significantly, governments are asking themselves what connected infrastructure should be invested in, and by whom.

Connected infrastructure notably requires an effective network for vehicles and infrastructure to connect quickly, securely and reliably. There is a debate raging today as to what form that connection should take. ITS G5 has emerged as a frontrunner for the near-term: it does not require extensive infrastructure build-out to be deployed, it doesn't require a licensed spectrum and it is readily available. However, ITS G5 is also much more susceptible to interference and raises numerous cybersecurity concerns. Thus, many are looking to 5G, the next-generation mobile network to address the weaknesses of today's ITS G5 system. 5G offers greater security, longer range, higher speed and low latency. Nonetheless, its build-out is more expensive and more complex, begging the question of its availability (at least initially) in rural or less-dense areas. Limited availability in the near-term could significantly affect access to and the structure of autonomous vehicle technology. Companies have an interest, after all, in strengthening the network in urban areas where demand is highest and less of an interest in ensuring full equity in access to the network. Thus, experts are looking to a range of solutions to ensure broader connectivity such as mesh networking, strengthened Wi-Fi, Li-Fi and more.

Connected infrastructure : roads

Beyond the networks themselves, connectivity will require novel physical infrastructure. First-generation V2X (vehicle-to-everything) experiments are already underway as both companies and governments equip infrastructure with technology to communicate with nearby cars. For traffic lights, the systems are able to warn vehicles in advance as the lights change, for example, or to detect obstacles on the road that might impede a vehicle's progress. Such technology could be embedded within a wide variety of infrastructural forms, ranging from buildings to roads to even toll booths (for more on Sanef's toll booth experiments in partnership with Renault, see Box 2). This connectivity is seen as a way to supplement the autonomy of the vehicle, offering additional information in advance of the vehicle's arrival on the scene via short-range communication, thus easing the vehicle's route. Nonetheless, connected infrastructure is still largely in its experimental phase and, while network standardization has begun, standardization of messaging exchanged between vehicles and infrastructure remains a challenge to be addressed.

There is a need for good infrastructure beyond connectivity. Cities and companies should be weary of focusing solely on technological developments to the detriment of their existing 'low-tech' infrastructure. Today's autonomous vehicles, for example, are still heavily reliant on lane indicators for the accuracy of their routes. Countries that have strong existing road networks have already been proven to be at an advantage in the number of AV experiments being conducted on their roads.

It is above all important to note that investment in infrastructure—who does so and where—raises myriad equity issues for the proliferation of the technology and its promised benefits as well as its potential disadvantages. It is important that cities follow these developments closely and determine their appropriate role therein.

Connected infrastructure : tolls

In June 2016, Renault and Sanef announced a partnership to explore how connected technology could be applied to and enhance the existing infrastructure of the French toll system. They subsequently developed a system that would allow communication between the toll infrastructure and oncoming vehicles using a short-range Wi-Fi network. The system is able to communicate with cars a kilometer before arriving with pertinent details for the vehicle such as which toll booths are open. Cars are thus able to reduce speed as directed and more easily navigate the toll booth area. The experiment is being conducted on a highway in the Normandy region of France and has been proven highly successful thus far.

3. Case studies

Autonomous vehicles present the unique policy challenge of planning for a technology that does not yet exist in its final form. While we have many theories and proposals for how autonomous vehicles should be introduced onto city streets, the result will ultimately depend on the final form that the technology itself takes. It thus behooves policymakers to develop a familiarity with and an understanding of the technology itself; to experiment with its implementation on city streets. The more that policymakers learn about autonomous vehicles, including the functionality of the technology, the response of citizens to its use, and its ability to integrate into larger transit systems, the more prepared they will be to help shape an autonomous vehicle future. There is thus a strong incentive to experiment with autonomous vehicles today and to learn from that experience. Notably, learning also comes from the observation of other cities conducting similar experiments and studies in pursuit of the same goals.

In the past several years, there has notably been a growth in autonomous vehicle experiments taking place across the globe. Chapter 3 highlights a wide variety of those experiments, aiming to consolidate the insights and knowledge gained through diverse experiences. Each case study included in Chapter 3 was selected for specific a reason: each one evinces either a unique approach, a unique set of insights or a unique scenario itself. Cities highlighted (and their defining features) include:

- **AV garbage trucks, Sweden**
  The future of municipal services?
- **Singapore**
  Wide-spread testing of diverse technologies.
- **Wageningen, Netherlands**
  Fixed-route shuttles for last-mile solutions.
- **Helsinki, Finland**
  A targeted, Smart City approach to AVs.
- **Phoenix-area, United States**
  Limited regulations and a car-focused approach.
- **Paris, France**
  Strong consumer feedback in a pedestrian-friendly area.
- **Rouen, France**
  A ride-hailing car service to supplement public transportation.
- **Shenzhen, China**
  An eager interest in new technologies combined with a high consumer acceptance.
- **Sion, Switzerland**
  A tourist attraction in a dense, pedestrian-heavy area.

AV garbage rucks, Sweden

The future of municipal services?

▶ **Location**
Gothenburg, Sweden

▶ **Testing dates**
May - December 2017

▶ **AV mode**

Overview

In mid-2018, Volvo unveiled its next-generation autonomous garbage trucks. The vehicles have the opportunity to improve the efficiency, safety and sustainability of waste management in cities. As a low-speed, traditionally fixed route, garbage trucks are notably ripe for early adoption of autonomous technology. Volvo's designs offer insights into the potential of autonomous technology for freight within the urban context specifically beyond to the much-discussed opportunity for autonomous trucks on straight, long-distance highways. From may to december 2017, Volvo Group, together with Swedish waste and recycling specialist Renova, tested during 6 months a pioneering autonomous refuse truck that has the potentiel to be used across the urban environment. This refuse truck could enhance efficiency of municipal service, reduce urban congestion and improve safety and working conditions.

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A garbage autonomous truck

10 %
up to 10 % reduction of fuel use as a result of truck platooning

3→1
trucks hauling freight could be replaced by 1 autonomous truck

4 000
trucks accidents in 2012 in US, of which 90 % were human error

50/70 %
of trucks drivers could be replaced by 2030

Context

In addition to human transportation, autonomous technology presents a unique opportunity for the hauling of freight in a wide variety of use cases. The context of highway driving in fair weather conditions has been perhaps the most widely discussed: while human drivers are limited in the hours they are permitted to work, an autonomous truck could theoretically drive itself while the driver rests. Under some calculations, an autonomous truck combined with a human driver could complete the work of three non-autonomous trucks. Similarly, auonomous trucks on highways could serve as a prime use case for the concept of platooning: decreasing the distance between trucks in order to improve gas mileage and streamline travel on roads. Eased by the autonomous technology and connected infrastructure, several trucks could drive in short succession to increase the load delivered while decreasing emissions and congestion. Beyond the much-discussed highway use cases, however, autonomous trucks show much promise for urban context as well, particularly for slow-moving vehicles (such as garbage trucks) or vehicles with a fixed, pre-determined route.

Project spotlight

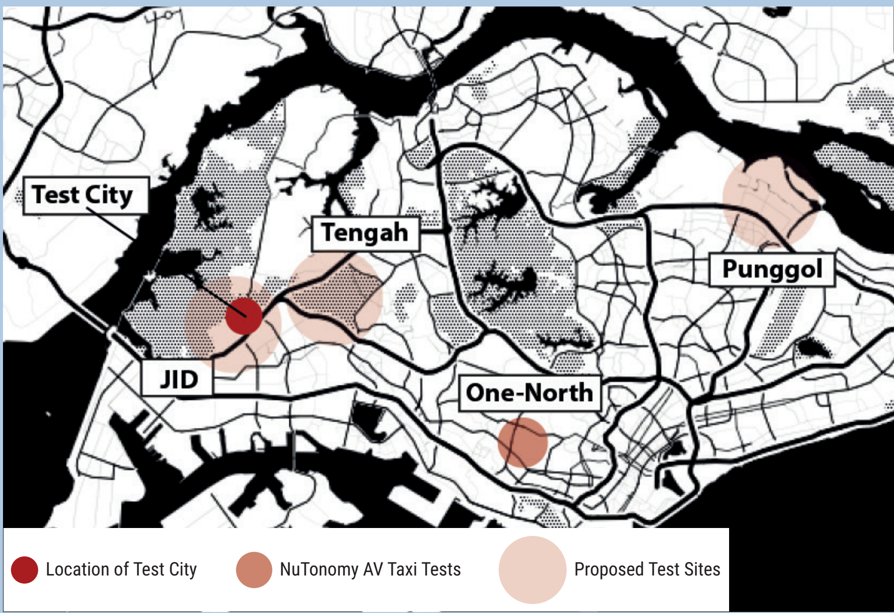
In May of 2017, Volvo introduced its radical new idea of an autonomous garbage truck tested in Gothenburg in Sweden with Renova. According to the concept, debuted later that year at the Volvo Innovation Summit in Brussels, the vehicle is parked at the top of a street and subsequently backs up slowly as the garbage man walks ahead and deposits the various receptacles into the vehicle as it progresses down the road. The concept thus saves time (and physical impact) for the garbage man who no longer has to continuously climb up into the driver's seat between bins; Volvo also anticipates that the vehicle will be able to reduce emissions by offering a smoother trip along the street with more limited braking and acceleration. The truck uses LIDAR sesors to detect obstacles in its environment, but Volvo has announced that initial prototypes will operate in areas where the company has fully mapped the streets that make up the truck's route. Despite the many potential positive impacts, concerns remain about the vehicles' ability to navigate dense urban contexts, particularly when moving against the flow of traffic.

AV actor spotlight

• **Volvo**
Volvo has been bullish with its ambitions for autonomous vehicles for several years. The company announced its Drive Me pilot program in 2014 with the intent to provide 100 self-driving cars to the public by 2017. While the company has scaled back its ambitions in recent months, Volvo continues to experiment with a wide variety of vehicles including, notably, trucks. The company has conducted several highway tests in recent years (on the Triange Expressway in the United States for example) and is looking into the technology's application in urban environments and other contexts as well. Volvo is testing large-scale trucks for other purposes such as mining, for example, in the Kristineberg Mine in northern Sweden.

Singapore

Widespread testing of diverse technologies



Overview

Known as one of the world's most autonomous vehicle-friendly countries, Singapore has allowed testing of autonomous vehicles on its streets since 2015. The city has expressed itself open to experimentation with a wide variety of autonomous vehicle formats ranging from autonomous taxi fleets to buses to shuttles serving both private use and public transportation. Its strong and diverse partnerships and extensive testing offer unique insights into the juxtaposition of a wide variety of potential technologies and system structures.

- **Location** -------- Singapore
- **Testing dates** ---- 2015 - present
- **AV mode** -------- 

67 km of trial routes on public roads

10+ companies testing vehicles in city

15 % car ownership rate within city

2 hectares test city complex dedicated to testing

NuTonomy vehicle

Nanyang Technology University's Centre of Excellence for Testing & Research of Autonomous Vehicles (CETRAN)

Context

Singapore is well-positioned for the introduction of autonomous vehicles into a larger transportation system. Car ownership rates for the city state are an impressively low 15 percent as a result of the taxes and fees associated with ownership. A wide-range of alternative mobility options is a thus high priority for the city and its citizens. Officials view autonomous vehicle fleets as an opportunity to increase access to affordable transportation for citizens while simultaneously establishing the city-state at the forefront of international innovation. Similarly, the country sees autonomous vehicles as a key opportunity to reduce congestion, address labor shortage within several key industries and to reduce the cost of municipal activities such as street sweeping. To that effect, the country has engaged in a wide variety of partnerships and has established itself as a hub for the testing of a wide variety of AVs.

In addition to opening up specific neighborhoods for testing on public roads, the city also has an extensive test city specifically dedicated to AV testing.

The city has developed an extensive regulatory system consisting of milestones required for testing at various locations throughout the city.

Project spotlight

In 2017, Singapore released a Request for Information designed to inform a future Request for Proposals. The city intends to operate fleets of autonomous vehicles in the form of buses or on-demand shuttles in three districts (Punggol, Tengah and the Jurong Innovation District (JID)) by 2022. The extensive RFI included a wide variety of questions regarding data, mobility networks, infrastructure requirements, vehicle design, business model and integration with existing public transportation systems. The RFI will provide the government with extensive insights into the state of autonomous capabilities today and serves as one of the most articulated plans for AV integration into a public transportation system to date.

Significantly, the city has a wealth of partnerships and companies operating on its streets and testing grounds, allowing for a wide variety of concepts and experiments including individual vehicles, on-demand shuttles, freight and utility operations such as street sweeping. The majority of these tests are still being conducted in a cordoned-off test city that closely mimics the cityùs roads, but several can be found on public streets One North District.

NuTonomy, an MIT spin-off, has been running tests of an autonomous ride-hailing taxi service in Singapore in partnership with Southeast Asian ride-hailing services company Grab. The tests are currently being conducted on public roads and the companies have announced plans to introduce a commercial version of the service by the end of this year.

Future trajectory

The city has made it a clear priority to be at the forefront of AV technological innovation and implementation. As a result of their strong and varied partnerships, the city has truly become one of the world's most AV-friendly cities. The city's RFI notably established a clear intent to integrate AVs into public transportation, but the technologies that are currently testing in Singapore would indicate that the city will be a hotbed for a wide variety of services, both public and private. As a result, all eyes are on Singapore for the best way to handle the dangers and address the technological needs for AVs, ranging from connected infrastructure to safety regulations.

AV actor spotlight

- **NuTonomy**

The first private company to receive approval for public road testing, nuTonomy vehicles have been on public roads in Singapore since 2016. An MIT spin-off, the company became the world's first company to offer invite-only driverless taxi rides and has since partnered with ride-hailing company Grab to make hailing driverless rides a reality in the country in the coming years. The company is owned by software supplier Aptiv.

- **SMART (Singapore-MIT Alliance for Research and Technology)**

Testing autonomous golf carts since 2010, the SMART partnership produced the second autonomous vehicle approved for circulation on public roads.

- **A*STAR's Institute for Infocomm Research**

One of the original players in the field of autonomous vehicles in Singapore, I2R produced the first vehicle approved for public road testing in Singapore in 2015.

ST Kinetics

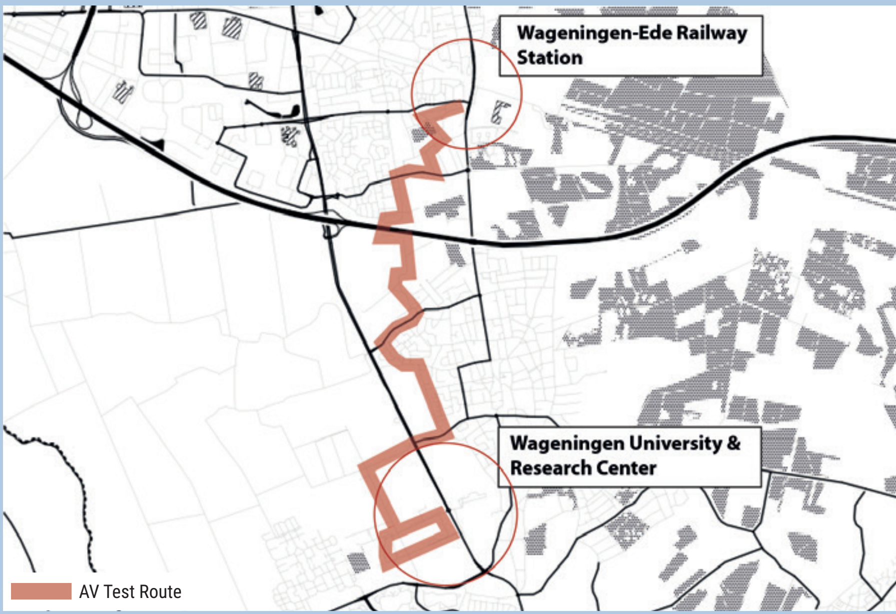
ST Kinectics has partnered with Singapore's Land Transport Authority to develop a 40-seater bus that is both autonomous and electric with the intent of offering a larger scale public transportation supplement.

- **Other**

The city has on-going partnerships with Toyota and Scania to develop technologies for effective platooning, as well with Katoen Natie to develop autonomous trucks and other heavy-duty vehicles including city service vehicles for such tasks as street sweeping. More than ten companies are now testing vehicles at the country's Nanyang Technological University AV testing facility, including French firm Navya.

Wageningen

Fixed-route shuttles for last-mile solutions



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Overview

Starting trials in early 2016, Wageningen can boast the first autonomous shuttle trip to operate without a driver on a public road. The trial has since expanded according to plan and now the electric, driverless shuttle bus regularly ferries individuals across a fixed route at Wageningen University and Research Centre. Albeit a first-generation shuttle experiment, using a system with limited autonomous dexterity, the system offers insights into the benefits of the autonomous shuttle as well as the Dutch prowess within the field of autonomous vehicle development and testing.

- **Location** -------- Wageningen, Netherlands
- **Testing dates** ---- January 2016 - present
- **AV mode** --------

11 km of trial routes on public roads

2 Easymile EZ10 vehicles

3G/4G 2x4G + 3G 3 wifi-P communication

25 km/h maximum speed permitted

© Alwin Bakker

WePods vehicle

© Norbert Voskens - www.vosfoto.nl

WePods vehicle

Context

The Netherlands was deemed the easy winner in KPMG's Autonomous Vehicle Readiness Index re-leased in early 2018. Beyond the extensive testing that can be found in cities throughout the coun-try, the Index highlights the country's advantages in a wide variety of other key categories as well, ranging from 5G connectivity to density of elec-tric vehicle charging stations to a well-used and well-maintained road network to the number of AV companies based in the country as adjusted for population to, notably, private investment in AV technology. Wageningen was one of the first public trials ofautonomous shuttle technologies, and thus served as one of the first proof cases of their value withregards to transporting groups of individuals along fied routes. The project has been executed with a strong coalition of partners, including both city and province participation, university leader-ship and extensive private sector involvement. More generally, it is of note that Dutch government has taken an active role in funding and encouraging autonomous and connected tech-nologies, ranging from traffic light adjustmentsto fiscal support or companies working in the AV space.

Project spotlight

SpotlightLaunched in January 2016, Wageningen has a strong case for the world's first autonomous shutle without a driver on a public road. The shuttles are fully electric and fully autonomous and are now permitted to circu-late without a driver. The university town's ongoing trial consists of multiple Easymile EZ10 vehicles dubbed WEpods which circulate between the Wageningen railway station and the Wageningen University and Research Cen-tre campus. The test has offered key lessons for other cities eager to experiment with autonomous shuttles, setting the example of a successful firs-mile/last-mile solution along a fied route in an area not as traditionally served by public transportation. The vehicles notably face a diversity of conditions including dense pedestrian zones, cyclist interaction and even a trafficlight. A second phase has expanded the number of obstacles faced by the vehicles. Since Wageningen's trailblazing test, there have been a num-ber of autonomous shuttle trials both in the Netherlands and internationally evincing the value of the vehicle as a way to address firs-mile/last-mile gaps in transportation as well as to serve fied, pre-determined routes.

Future trajectory

TrajectoryAs one of the world's first autonomous shutle tests, the WEpod experiment boasts a considerable longevity that proves its value as a service. The experiment has been very successful, realizing its goal of offering a firs-mile/last-mile solution. It has been expanded over time to include additional obstacles--and there are currently no plans to end it. Nonetheless, it is important to note that the solution offered is very specific tothe suburban, low-density context.

AV actor spotlight

- **Province of Gelderland, City of Wageningen and City of Ede**

Initiated by the Province of Gelderland, the WEpod project was launched as a knowledge development opportunity. Both the province and the two cities have been actively involved in the project, working with the university and project partners to better understand the technology and its application and to refinea strategy for AV use targeted at improving quality of life for citizens in the future.

- **Wageningen University and Research Center**

The university served not only as a base of operations for the route, but also as a contributor to the technology used as part of the project.

- **Future Mobility Network**

Alwin Bakker, project manager for the WEpods project, subsequetly founded the Future Mobility Network. The company offers guidance for cities and companies eager to launch their own AV experiments.

- **Other key actors in the WEpod project include :**

Spring Innovation Management (project management); Robot Care Systems (system integration); Mapscape (high definition map) TU Delft (contract partner); Elek-trobit (system translation).

Other national actors

- **AmberAn**

Eindhoven University of Technology spinoff that promises to be the next-generation car-sharing service. Expected to launch in 2018, the companies is striving for an electric car within walking distance regardless rof location.

- **TomTom and HERE Technologies**

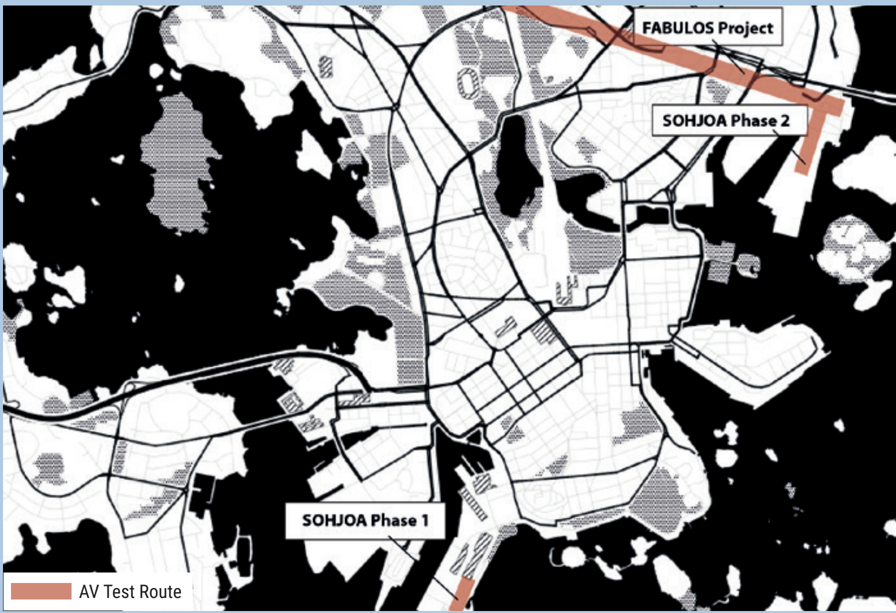
Two navigation, mapping and locational data companies offering a wide variety of next-generation solu-tions for autonomous driving and connected vehicles.

- **2getthere**

With extensive experience in autonomous technology, 2getthere is a key Smart City player that helps cities coordinate implement autonomous technology into ther transit systems .

Helsinki

A smart city, emissions-reducing approach



Overview

Well-known for its efforts to establish itself as a leading smart city, Helsinki is well-positioned to be an early AV mover. The city has been experimenting with autonomous shuttles to solve first-mile/last-mile limitations, aiming to increase public transportation use and thus reduce emissions. What sets the city apart in its approach is its openness to EU-wide partnerships, its centralization of integration under a Chief Design Officer and the establishment of clear priorities to be achieved by AV experimentation.

- **Location** -------- Helsinki, Finland
- **Testing dates** ---- 2016 - present
- **AV mode** -------- 

6
different areas of experimentation within Helsinky region

18 km/h
operating speed for SOHJOA project

25+
smart city projects being developed in Kalasatama district

2050
target date to phase out use of private cars

Helsinki RobobusLine project

SOHJOA project

Context

In 2016, Helsinki was selected as one of three EU smart city experimentation locales, dubbed 'lighthouse cities,' as part of the EU's mySMARTLife project. In its role, Helsinki will integrate a wide variety of smart city solutions targeting smart infrastructure, electricity grids and mobility. Helsinki was seen as fertile ground for experimentation in electricity, smart homes and next-generation mobility as a result of its investments in open, digital technologies and agility with regards to the city's electric grid. A key aspect of the mySMARTLife project is the reduction of carbon emissions; Helsinki has thus been experimenting with AVs in an effort to reduce emissions by easing access to (and subsequently use of) public transportation. The city is also home to a wide variety of innovative transportation companies, including transportation platform MaaS Global.

In 2016, the city introduced the role of Chief Design Officer with the missive to integrate across platforms and apply design knowledge to ease and encourage a culture of experimentation across companies and city agencies within Helsinki. This new role has received widespread international attention in its unique attempt to centralize and innovate coordination across platforms.

Project spotlight

In 2016, Helsinki launched its 2-year, 1.2 million Sohjoa autonomous vehicle pilot project: fixed-route Easymile autonomous shuttles in a suburb north of Helsinki and in the city's Hernessaari district. A cooperation between several universities and supported by funds from both domestic governmental agencies and the EU, the shuttles have traversed several low-density routes to experiment with the technology as a first mile/last-mile solution. The successful pilot was closed in May 2018 and is being transitioned to the next phase of experimentation on more complex routes.

Today, the city has a variety of experimentations in the pipeline boasting a wide variety of partnerships. The Helsinki RobobusLine for example, part of the city's mySMARTLife project, uses Navya shuttles to traverse public roads in the Kivikko suburb of Helsinki. The tests will last three years with the ultimate goal of regular autonomous bus service upon its completion--it has notably already been incorporated into the Helsinki Regional Transport network and is displayed on the network's journey planner. Also of note is the coming experiment along the Pasila and Kalasatama axis as part of the Forum Virium Helsinki's FABULOS project.

Future trajectory

Helsinki and Finland more generally have laid out very concrete goals as part of their experimentation strategy. The city aims to be both a leader in smart city technology and to become carbon neutral by 2035; autonomous vehicles have the opportunity to play a unique role in helping the city to realize both those goals. Helsinki is thus experimenting with the vehicles specifically to address first-mile/last-mile access to public transportation as well as to supplement the existing bus system.

AV actor spotlight
Project partners

• **Metropolia University of Applied Sciences**

A key partner in the first generation of the Sohjoa project and continuing on with the next phase, Metropolia University of Applied Sciences owns and manages the shuttles used for the experimentation.

• **Navya and Easymile**

After completing the first phase of the project with an Easymile shuttle, the second generation RobobusLine will be using a shuttle supplied by Navya.

• **Helsinki Innovation Fund and mySMARTLife program**

The project is supported by domestic funds supplied by the Helsinki Innovation Fund and international funds provided as part of Helsinki's involvement in the mySMARTLife program.

• **Trafi**

Although current Finnish legislation already permits the testing of autonomous vehicles on open roads, Trafi, the city's road safety agency, plays a key role in facilitating and managing tests.

• **MaaS Global**

MaaS Global is a next-generation company offering transportation as a service for a monthly fee. Their Whim app allows users to travel to their destination with a wide variety of services ranging from public transport to taxi to car.

• **InfoTripla**

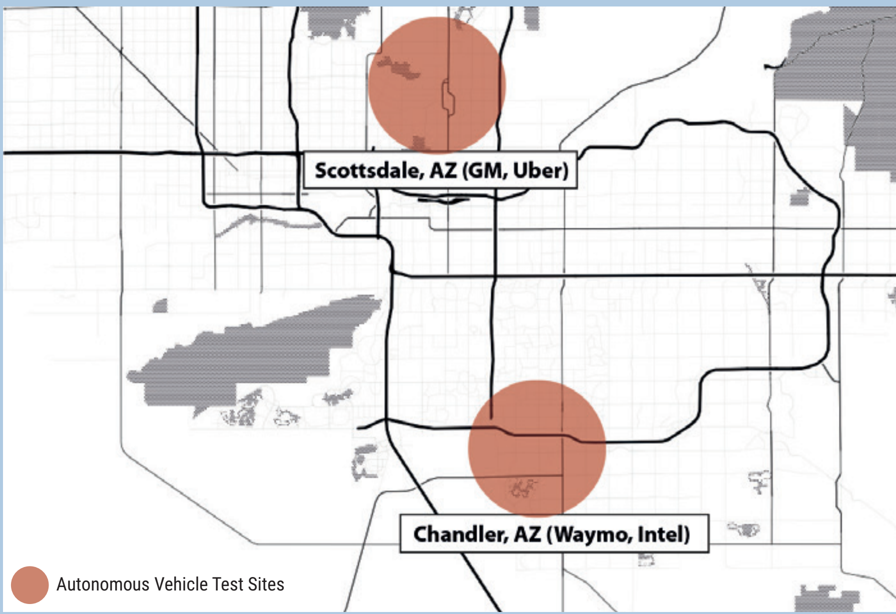
A data company, InfoTripla is an established player in the field of information and data management, analysis and exchange, paving the way for the integration of connected mobility and smart mobility technologies.

• **Fleetonomy**

A platform for coordinating fleets, Fleetonomy uses artificial intelligence to offer data analysis and fleet management services that are 'autonomous-ready solutions'.

Phoenix-area

Limited regulations and a car-focused approach



Overview

Taking advantage of the sunny weather and limited regulations, a wide variety of companies have been testing their autonomous vehicles on Arizona streets. In late 2017, Alphabet subsidiary Waymo began testing vehicles without a human safety driver in Chandler in anticipation of introducing a ride-hailing service in the area by the end of this year.
Waymo's efforts in the Phoenix suburb provide interesting insights into company-driven experimentation and individual autonomous vehicle technology development.

- **Location** ——————— Phoenix, Arizona, USA
- **Testing dates** ———— 2016 - present
- **AV mode** ——————— 

62 000
vehicles behing purchased by Waymo for future service

600
cover 600 autonomous vehicle operating on AZ roads

25+
D+ grade for AZ's road infrastructure from ASCE'S infrastructure Report Card

7+
million miles logged in Waymo's autonomous test vehicles

Waymo's fully self-driving Chrysler Pacifica Hybrid minivan on public roads

World's first fully self-driving ride on public roads: Steven Mahan 1

Context

Although a high proportion of autonomous vehicle technology development in the United States occurs in California, many companies have been attracted to Arizona as a direct result of its weather and relaxed regulations. Unlike California, a center of AV technology innovation and development, Arizona does not require data disclosure such as the number of times that human drivers were forced to take control of a vehicle or the number of accidents involving the vehicles themselves. The state gave Waymo permission to test its vehicles without a human safety driver in late 2017.

Phoenix was one of the first cities in the nation to consider zoning changes to regulate curb management and parking requirements with an eye towards autonomous vehicles.

Despite its reputation for relaxed testing laws, Arizona Governor Ducey suspended Uber's testing in the state following a crash that involved a fatality in March. Uber had been testing its vehicles in the area since 2016.

Although a wide variety of companies are testing vehicles on Arizona streets, this case study focuses primarily on Waymo's experimentations, as the company has been at the forefront of autonomous vehicle development, testing individual vehicles starting as far back as 2009.

Project spotlight

Waymo, an Alphabet subsidiary, has been testing individual autonomous vehicles since 2009. According to reports, the company had has logged over 7 million miles on public roads thus far. The company launched an Early Rider program in Chandler, AZ in late April of 2017 that allows individuals to sign up for free on-demand AV service. As of publication, test drivers remain at the wheel at all times and participants are carefully screened to help the company collect data on usage habits, enabling them to better understand individuals' habits with regards to the vehicles.

In early 2018, the company announced that it will be opening up its on-demand AV ride-hailing service to all individuals in the Phoenix area by the end of the year. In collaboration with Fiat-Chrysler, the company indicated that it had ordered 'thousands' of vehicles to prepare for the service and expects to expand the service to California following a successful Arizona rollout.

Albeit allowed under Arizona regulations and sanctioned by the government, the rollout of the program is not in collaboration with the city or the state.

There are numerous other companies currently testing autonomous vehicles on the streets of Chandler and the Phoenix region more generally, including GM, Intel and, until recently, Uber.

Future trajectory

As described in a Medium post published in 2018, the Waymo team paints its image of the future as follows: "Imagine a world where you can take a self-driving minivan to the baseball game with family, and a self-driving I-PACE home after a night out — in both cases, a car perfectly suited for your needs. That's the world we're building." The company has been experimenting solely with individual vehicles and has announced plans to take their ride-hailing service public by the end of 2018.

AV actor spotlight

• **Waymo**

A Google spin-off, Waymo is a subsidiary of Google's parent company Alphabet, Inc. Waymo has been testing a ride-hailing service in Arizona in recent years with plans to make the service public by the end of 2018. Albeit partnering with a wide variety of OEMs for the vehicle hardware, Waymo has sourced a large percentage of its vehicles from partner Fiat-Chrysler and announced in early 2018 that its new car service would include 62,000 Fiat-Chrysler vehicles.

• **General Motors**

The company has been testing autonomous vehicles (Chevy Bolts) on the roads of Scottsdale, AZ since 2016. Early that year, GM notably acquired Cruise Automation, an autonomous vehicle technology company, which has its headquarters in the Phoenix area. GM has announced plans to commercialize their vehicles as early as 2019 as well as to invest 100 million dollars into several AV production plants.

• **Intel**

A technology company, Intel debuted its first autonomous test vehicle in a fleet of 100 at the CES show in January of 2018. The company notably purchased Mobileye, which makes software for autonomous driving, in 2017.

• **Arizona Government**

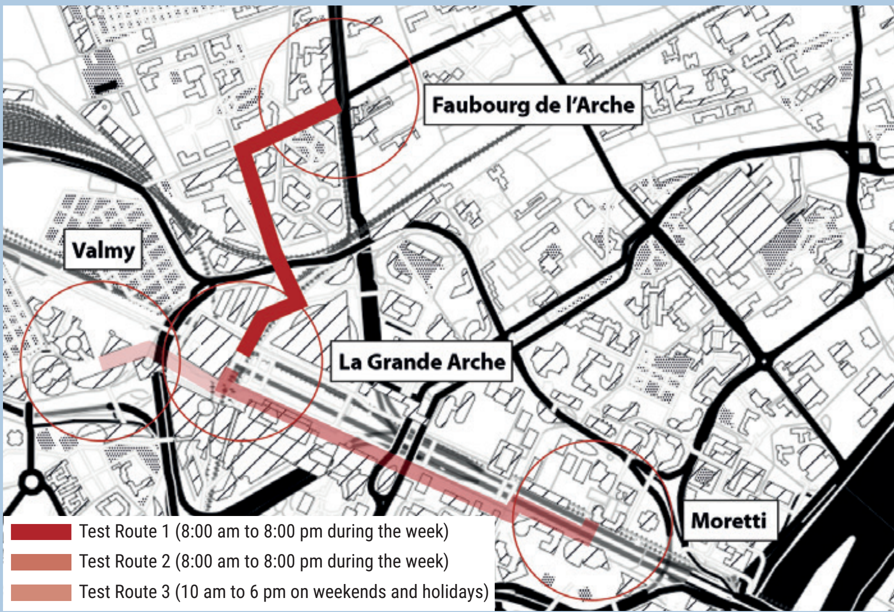
The state government has made it clear that their open regulatory policies are intentional and that they are eager to serve as a testing ground for the technology.

• **Uber**

The ride-hailing company had been testing vehicles in the area starting in 2016. In early 2018, one of the company's vehicles was involved in a crash that caused a fatality and the Governor temporarily revoked the company's ability to operate in the state. The company has yet to resume testing.

Paris, La Défense

Strong consumer feedback in a pedestrian-heavy area



Overview

Beginning in July 2017, Paris business district La Défense boasted continuous service from 3 autonomous shuttles traveling 3 distinct routes. The experiment, launched by Ile-de-France Mobilités in collaboration with several other partners, serves as a proof-of-concept for the value of the autonomous shuttle as a last-mile solution as well as its continuing efficacy even in dense, pedestrian-heavy areas. As part of the project, users (and non-users) were interviewed to better understand their reactions to the new technology, offering key insights for future projects.

- **Location** -------- Paris, France
- **Testing dates** ---- July 2017 - December 2017
- **AV mode** -------- 

3
number of vehicles

7 km/h
speed permitted

560 ha
of area

500 000
individuals travel to and from La Défense each day

Autonomous shuttle Navya

Autonomous shuttle Navya

Context

Conducted on private roads within the capital, the La Défense experiment is unique in its ability to test autonomous shuttles without a driver present on French roads. The experiment is one among a growing number of autonomous shuttle experiments within France after a slow start due to regulation-imposed limits on testing until 2015.

France is rated 13th internationally in preparedness for AVs, according to KPMG's Autonomous Vehicles Readiness Index. The company is commended for its excellent roads, its research infrastructure and contributions to technology and innovation. Nonetheless, France receives relatively lower scores on such items as wireless infastructure, legislative agility, government capability and technology use more generally.

The proof-of-concept experiment was launched to specifically assess consumer/shuttle interactions as well as the technology's use in a dense, pedestrian-heavy zone. While user feedback was generally quite positive and the experiment itself proven of value, technological limitations result in the vehicles still being quite sensitive to any obstacles, raising questions about their efficacy in areas that are perhaps more dense or more complex.

Project spotlight

In July of 2017, Ile-de-France Mobilités launched an autonomous shuttle experiment in Paris' La Défense business district. Completed in partnership with companies Defacto (local partner), Keolis (transport management) and Navya (shuttle technology), the project provided first-mile, last-mile service for the 500,000 individuals traveling to and from the district on a daily basis. Since the roads within the district are private, the vehicles were permitted to operate without a driver present, signifying one of the first fully driverless autonomous vehicle experiments within France.

Each shuttle can accommodate up to 15 passengers (11 seated and 4 standing), is fully electric and, during its trial period, offered service both during the week and on weekends. Although the vehicles are capable of traveling up to 20 km/h, they were limited to a maximum of 7 km/h for this experiment as a result of the density of pedestrians in the La Défense area. Transport management company Keolis describes this experiment as a proof-of-concept and has identified a wide-variety of sites where similar shuttles could offer service, ranging from university campuses to tourist attractions.

Key actors and partnerships La Défense experimentation

- **Ile-de-France Mobilités**

Responsible for organizing and financing public transportation within France, Ile-de-France Mobilités initiated this project as part of its mission to innovate within the field of transportation, working consistently to improve the service its provides to its passengers.

- **Paris La Défense**

Responsible for the management and promotion of the La Défense business distract, DEFACTO manages the private roads on which the experiment is conducted.

- **Keolis**

Keolis served as the management company for this project. The company is an international leader in public transportation, offering mobility solutions specifically adapted to a locality's needs. Keolis operates in over 15 countries and boasts over 58,000 collaborators.

- **Navya**

Navya provides the vehicles and the technology used as part of the experiment in the La Défense business district. The company is an international leader in electric autonomes vehicle development with operations on 5 continents and more than 170,000 passengers transported on their autonomous shuttles.

Consumer acceptance

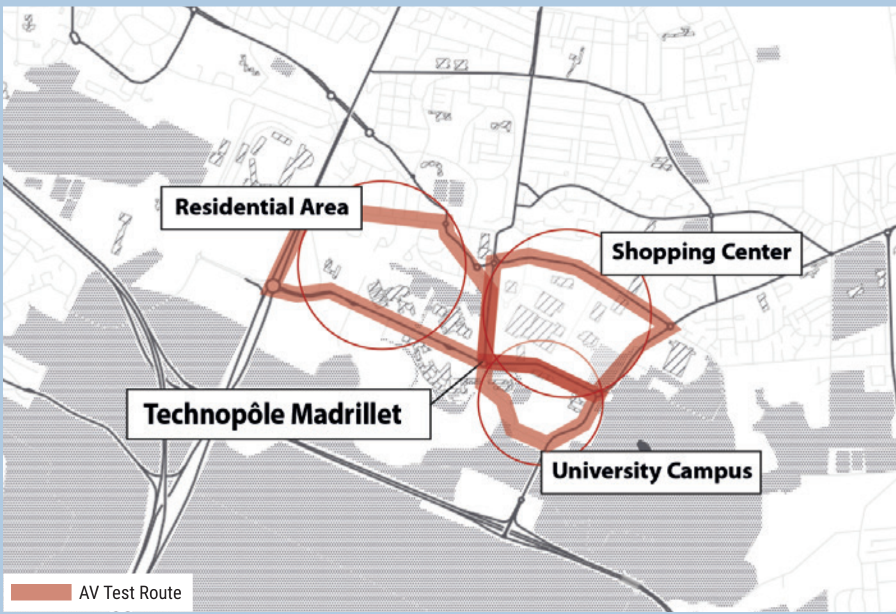
One key feature of the project was analysis of consumer comfort throughout the journey on the autonomous shuttles. Throughout the experiment, users and non-users were surveyed to determine their reaction to their experiences with the vehicle as well as to better understand those individuals who chose not to use the vehicles. Feedback was very positive: 97 percent of users expressed satisfaction with their journey, 98 percent felt safe onboard and 97 percent felt comfortable. Nonetheless, only 68 percent felt satisfied with the speed of the vehicle, which is limited to a walking pace. Representatives of the project expressed an eagerness to increase the speed in future experiments, while simultaneously ensuring the safety of users and pedestrians.

Other experiments

Ile-de-France Mobilités is currently conducting a second experiment in the Château de Vincennes vicinity in collaboration with partners RATP and EasyMile. That project offers a connection between the end of Line 1 and the Bois de Vincennes. Using fully electric shuttles provided by EasyMile, the connection is free for users and operates during the day between Friday and Sunday. The experiment notably applies platooning--the juxtaposition of multiple shuttles--for times of higher demand.

Rouen

A ride-hailing service to supplement public transportation



Overview

In mid-2018, the Rouen Normandy Autonomous Lab Initiative announced that it was testing the first on-demand shared mobility service to use open roads in Europe. The initiative intends to open up service to the public in late 2018, offering four autonomous, electric Renault cars for on-demand service in Rouen's Technopôle du Madrillet business district. Despite the use of individual vehicles, the goal of the project is to offer a novel mobility option to serve routes not ideally suited for existing public transit options. The experiment also offers an interesting public-private partnership case study.

- **Location** -------- Rouen, France
- **Testing dates** ---- 2018 - present
- **AV mode** --------

17
pick-up/drop-off zones

50 km/h
speed limit

11
million euro budget

10 km
3 routes covering 10 km

2018 Rouen Normandy Autonomous Lab - Expérimentation Renault ZOE robot taxi

2018 Rouen Normandy Autonomous Lab - Expérimentation Renault ZOE robot taxi

Context

Although France can boast a wide variety of autonomous vehicles tests over the past several years, this experimentation is the first of its kind in the country: individual vehicles offering an on-demand ride-hailing service in a dense, urban-like environment.
The location was notably strategically chosen: the partners were looking for a wide variety of challenges similar to those offered by urban environments, but also one that exhibited the sprawl that has long posed a challenge for public transportation networks. With a university, research laboratories and a number of enterprises, there is a demand for transportation services, but perhaps not enough of one to justify a full transportation system. More concisely, it is well-suited for a complementary on-demand ride-hailing service.
Further, the project is a good example of a strong public-private partnership within the context of autonomous vehicle experimentation. The city of Rouen and the region of Normandy more generally are eager to bring technological innovation and autonomous vehicle testing to the region, while each of the private partners brings an expertise in a key area of AV technology that promises to result in an innovative, sustainable solution.

Project spotlight

In June of 2018, the Rouen Normandy Autonomous Lab initiative announced the final testing phase of their autonomous on-demand shared mobility service. The partners that formed the initiative, Métropole Rouen Normandie, Transdev Group, Groupe Renault and Matmut with the support of Normandy Region and Banque des Territoires, hope to make the service public by the final quarter of 2018.
The experiment is located outside of the city of Rouen in the Technopôle du Madrillet business park. It connects 17 locations within the business park to the Technopôle public transportation stop, with 4 autonomous electric vehicles made by Renault. The area that is covered by the tests totals 3 km within the Madrillet district. It thus serves as a form of first-mile/last-mile connectivity--the initiative sees the experiment as a proof of concept for the value of a shared mobility service to provide connections via routes that are not ideally suited for existing public transportation options. The service will thus eventually be connected to the public transportation system in order to provide supplemental on-demand service for the region.
Throughout the tests and once the service goes public in late 2018, the vehicles are monitored by a remote control center with the ability to slow the vehicles should any concerns arise as well as by an engineer seated in the back in charge of monitoring the performance of the vehicle as it traverses local streets.

Key actors and partnerships

• **Renault**
A leader in the manufacturing of electric vehicles, Renault is providing the vehicles for the test. These efforts notably build on the company's strategy to offer autonomous, on-demand mobility by 2022.
• **Matmut Group**
Based in Rouen, Matmut is an insurance provider, offering insights into the nuances of liability within the project.
• **Transdev**
A transport provider based in France with extensive experience, Transdev serves as the manager of project for operation, fleet and customer relations. Additionally, the company is in charge of the tracking system for the vehicles enabling the remote monitoring, the smart infrastructure discussed below and the security of the telecommunications for the vehicles.
• **Banque des Territoires**
A subsidiary of Caisse des Dépots, Banque des Territoires is partially funding the experiment in pursuit of its 'Smart City' goals rolled out in late 2016. The bank played a key role in bringing together the partners and launching the experimentation.
• **City of Rouen and Normandy Region**
Both governments are eager to to become hubs of technological innovation more generally and to attract autonomous vehicle experimentations specifically. The region of Normandy is thus offering financial support for the project, with the City of Rouen playing a key role in permitting and allowing for the experimentation on public roads.
• **Métropole de Rouen Transit Authority**
Since the intent of the project is to integrate the service into the existing public transportation system, the Métropole de Rouen Transit Authority has been intimately involved in the project.

Connected infrastructure

The project notably involves a wide variety of connected vehicle technologies to help realize its goals, including roadside Wi-Fi sensors/terminals for vehicle communications, connected traffic lights and a control center that allows for remote monitoring of vehicles (albeit currently limited to slowing down the vehicles).

Shenzhen

An eager interest in new technologies combined with a high consumer acceptance

- **Location** -------- Shenzhen, China
- **Testing dates** ---- December 2017 - present
- **AV mode** --------

Overview

Known as China's tech hub, Shenzhen recently became the country's third city to issue a license for AV testing on open roads. This announcement came closely on the heels of a report in December 2017 that the city is testing a small fleet of autonomous buses for eventual use in the public transit systems if approved. China generally and Shenzhen specifically present an interesting case study in the race for AVs, boasting actors with a particular eagerness to be at the forefront of technological innovation combined with considerable legal agility to support technological innovation and a populace with a high technological readiness rating.

1,2 km
route for bus tests in Shenzhen technology district

4
buses being tested in Shenzhen technology district

500 000
yuan : cost of buses

40 km/h
possibility of speed

Company ZTE in the Shenzhen High-Tech Industrial Park

Context

As announced in 2017, China views AVs as a key pillar in its 3-year strategy to be at the forefront of developments in artificial intelligence. The goal is to boast a safe and reliable platform for AVs by 2020. The country is pushing for 20% of its cars to be highly autonomous by 2025 and 10% to be fully autonomous by 2030.
In pursuit of that goal, China's Ministry of Industry and Information Technology (MIIT) released national guidelines for smart internet-connected cars earlier this year which notably allow for considerable freedom for local authorities to arrange AV tests on public roads. Following in the footsteps of Beijing and Shanghai, Shenzhen, the 'Silicon Valley of Hardware,' has since granted Tencent a license to operate on public roads in addition to several other ongoing experiments on private loops by technology companies based in the city.
Based on several polls conducted on readiness for AV technologies, Chinese consumers are notably more open to AVs than their brethren in other countries. According to a 2016 survey by Boston Consulting Group, for example, 75% of Chinese respondents favored autonomous vehicles as compared to 52% of Americans who responded and only 36% of Japanese respondents. This, combined with a willingness to cede data, positions the country well for early adoption of AV technology.

Project spotlight

In December 2017, public transit operator Shenzhen Bus Group started testing four self-driving, electric buses on the streets of Shenzhen in China's Guangdong Province. The buses move along a pre-determined loop in the Futian district that is 1.2 kilometers in length. The vehicles are notably larger than shuttles being tested elsewhere, fitting up to 19 passengers. They are also capable of moving faster than most shuttle tests with speeds up to 40 kilometers per hour. The city has also announced plans to open up a second route for testing in the proximity of the Southern University of Science and Technology that is 3 kilometers long with ten pre-planned stops.
While the buses still have a driver behind the wheel ready to take over if necessary, there have been numerous demonstrations without human intervention necessary. The vehicles are capable of speeding up, slowing down, turning, avoiding obstacles and pedestrians, responding to traffic lights and making emergency stops.

Future trajectory

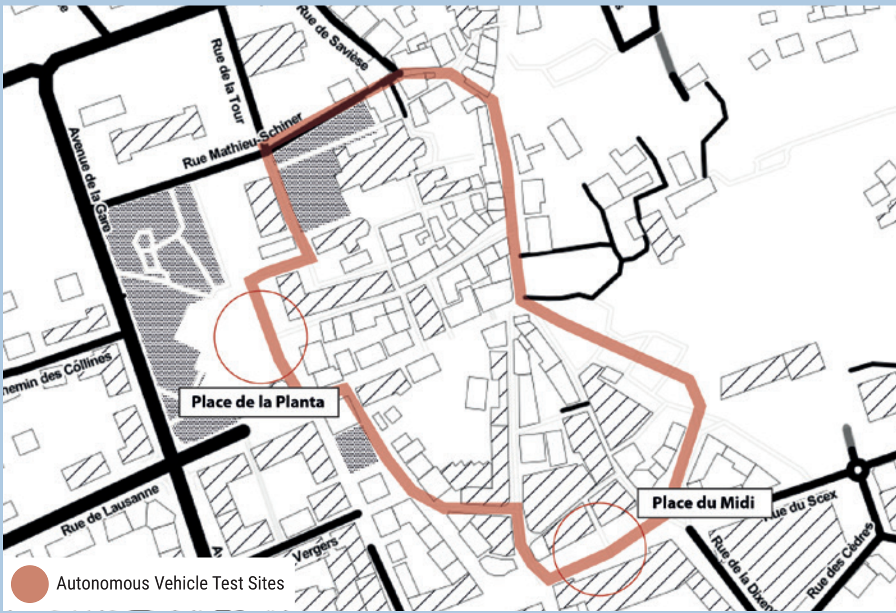
Shenzhen is globally renowned as a hub for technology development, making the city eager to place itself at the forefront of both AI and AV development. Unsurprisingly, as permitted by new MIIT guidelines, the city was one of the first to allow for and encourage testing on public roads. While Shenzhen boasts several ongoing tests, however, the city has not yet released a concrete plan for the integration of AVs into its public transportation system or for regulating the adoption of autonomous vehicles. Thus the case study of Shenzhen is one of encouragement and adoption of technology instead of clear and carefully considered integration and/or regulation.

AV actor spotlight

• **Haylion Technologies**
A Shenzhen-based technology company, Haylion Technologies equips the buses being tested by Shenzhen Bus Company with the software and sensors required for the vehicles to operate autonomously. The company recently partnered with Volkswagen's Scania to further their efforts to develop autonomous, electric vehicle technology.
• **Baidu**
A technology giant specializing in artificial intelligence, Baidu recently announced the completion of the 100th autonomous shuttle in its AV fleet. The company has announced plans to offer autonomous bus services both domestically and internationally (partnering with SB Drive, for example, to bring Apolong shuttles to Japan in 2019) and has created an open-source platform to support the exchange of AV technology innovation.
• **Tencent**
Headquartered in Shenzhen, the internet and technology company was the first to receive approval to test its vehicles on public roads in the city. It has since been testing its individual vehicles on the city's streets.
• **Alibaba**
Albeit late to the game, the e-commerce giant and technology company announced in early 2018 that it had been testing its own autonomous vehicles. The company views autonomous vehicles as a key part of its larger connected and smart city efforts.
• **Didi**
The ride-hailing giant recently opened up a US-based lab for AV experimentation and received permission to operate and test its vehicles on California streets in May of this year.
• **Other**
Shanghai-based SAIC, partner of Alibaba, and electric vehicle company NIO, were the first two companies to receive the green light for testing autonomous vehicles in Shanghai earlier this year. Roadstar.ai, a chinese AV technology start-up, meanwhile, set a single round private funding record among Chinese startups in its series-A funding round.

Sion

A tourist attraction in a dense, pedestrian-heavy location



- **Location** -------- Sion, Switzerland
- **Testing dates** ---- June 2016 - present
- **AV mode** -------- 

Overview

Launched in 2016, the Sion autonomous shuttle was the first of its kind in Switzerland and one of the first autonomous shuttles to offer regular service on public roads in Europe. The experiment proves the value of autonomous shuttles in dense, pedestrian-heavy areas and on routes not ideally suited for public transit or with roads that are difficult to navigate without assistance from technology. The experiment has allowed the participating partners to refine the technology over the course of its duration and has given regulators a chance to better understand the technology and how best to approach its regulation.

1,5 km
route in the center of Sion

6 km/h
average speed

15 %
yuan : cost of buses

40 km/h
possibility of speed

SmartShuttle Sion

SmartShuttle Sion

Context

Playing host to one of the first autonomous shuttle experiments in Europe in 2016 in the town of Sion, Switzerland can boast a number of additional experiments in the years since. The town of Neuhausen Rheinfall, for example, has introduced the world's first electric self-driving bus to be integrated into a regular public transit timetable. Launched as a public service in March 2018, the shuttle ferries riders to the nearby Rhine Falls, a popular tourist destination. These experiments indicate that the country is eager to better understand the opportunities associated with the technology, primarily as a complement to (or in some cases replacement for) public transit services.

The country notably has a long history of innovation in transportation. Switzerland is credited with one of the world's first carsharing programs, for example, with the Selbstfahrergenossenschaft launched in 1948. This history is reflected today in the wide acceptance and enthusiasm expressed by Swiss citizens with regards to AVs.

Nonetheless, Switzerland is still limited in the extent of its AV experiments as a result of legal limitations. Experiments are still required to have a driver physically present to take over the wheel should it be necessary, for example. Further, the country has yet to outline a concrete approach for how to integrate the technology onto its streets and transportation systems going forward.

Project spotlight

As part of a project launched in December of 2015, the Swiss city of Sion boasts two bright-yellow autonomous shuttles navigating its streets. The buses carry up to 11 passengers along a fixed 1.5 kilometer route through the city's dense, pedestrian-heavy Old Town area. As of mid 2018, 60,000 people had traveled on the buses. In the first year alone, the shuttles operated for 312 days and covered more 4,500 kilometers, averaging a speed of 6 km/h. Nonetheless, they had to be taken off the road for several weeks in September 2016 after an incident in which the shuttle collided with a delivery truck (albeit no injuries were sustained). The algorithms used by the shuttles have been consistently refined since the test was launched improving the efficacy of the vehicles. Of particular note is the operation of the vehicle along narrow streets and among distracted pedestrians, proving the value of the vehicles for greater accuracy in navigation and in pedestrian-heavy areas as an alternative form of transportation.

In 2018, the town announced plans to expand the pioneering shuttle service to Sion's main train station adding additional complexities (such as regular traffic) and obstacles (such as traffic lights). The town has notably introduced connected traffic lights to the route which communicate with the vehicles as they approach the intersection.

Future trajectory

One of the first of its kind in Europe, the Sion autonomous vehicle experiment has played a key role in encouraging other cities and countries to adopt experiments of their own. Partners in charge of Paris' La Défense business district AV experiment, for example, worked closely with Sion to launch their own iteration of the project. After the successful completion of the anticipated 2 years, the experiment has been expanded to encompass more obstacles and further challenge the technology and its applications. Nonetheless, the city has not announced plans to conduct experiments or integration beyond the aforementioned expansion of the existing project.

AV actor spotlight

• **PostBus**

A subsidiary company of the state-owned Swiss Post, PostBus offers regional and rural bus service throughout Switzerland and beyond. PostBus views the purpose of the experiment as an opportunity to "understand the added value of the autonomous shuttles" as a new solution for underserved or complex routes.

• **BestMile**

A spin-off from Lausanne's Federal Institute of Technology (EPFL) BestMile is a start-up company offering 'vehicle agnostic' mobility services to convert human-powered vehicles into autonomous vehicles. They are responsible for the software used in Sion's PostBus vehicle to make it autonomous. EPFL is notably one of the universities at the forefront of autonomous vehicle research globally, working on developing the mathmatical algorithms that allow vehicles to accurately navigate roads as well as offering policy insights for pertinent regulations and management of autonomous vehicles.

• **Navya**

The French-based autonomous vehicle hardware developer, Navya is responsible for the buses being used as part of the experiment in Sion. Navya shuttles, now found across the globe, traditionally fit between 10 and 12 individuals and drive at speeds up to 20 km/h. The company is also starting to experiment with Robotaxis.

• **Federal Road Office**

The Federal Road Office is Switzerland's federal authority in charge of road infrastructure and private road transport. The federal body was in charge of approving PostBus' request to expand the trial onto trafficked roads as part of the second phase of the experiment.

4. Autonomous vehicles and the city

Potential benefits for urban areas

The potential benefits presented by autonomous vehicles are numerous. Although they have been explored at length by a wide variety of experts, here is a list of those potential benefits as of interest to Paris in particular.

Safety

Hundreds of individuals are killed on French roads every year. Studies have found that over 90 percent of road accidents can be attributed to human error. The elimination of human error through the widespread adoption of autonomous vehicles is thus expected to significantly reduce accidents, with some experts putting the reduction as high as 90 percent.

Reduced congestion

Autonomous vehicles promise to reduce the human error that contributes to congestion on city streets. A traffic congestion study at the University of Illinois at Urbana-Champaign found, for example, that even the roadway penetration of autonomous vehicles by 5 percent in a simulation could eliminate stop-and-go waves caused by human error in driving. Even the simple reduction in traffic accidents will likely mean fewer jams on city streets. In addition to smoother driving as a result of vehicle-to-vehicle communication, autonomous vehicles will also be able to use digital mapping tools to optimize routes and thus spread out traffic in a more effective manner.

Mass transit optimization

Autonomous vehicles have the potential to serve as a complement to mass transit. Today, larger cities have the perpetual challenge of providing adequate public transportation both within the city and between the city and its surrounding area. Cities are forced, at times, to put valuable resources towards routes with limited ridership and, in other cases, are not able to adequately serve less dense areas. Further, in areas with more limited access to transportation, the first-mile/last-mile conundrum presents barriers for more widespread transit use. Vehicles without a chauffeur promise to be less expensive and more flexible than chauffeured vehicles in the long run, making smaller-scale AVs a natural solution for either public transportation routes that are over/under-served today or as a way to connect individuals with the closest transit station to address the first-mile/last-mile problem.

Improved transportation service

Autonomous vehicles and the accompanying technological advancements promise to improve the experience of transportation more generally by both expanding the concept of Mobility as a Service and allowing for more free time for transportation users everywhere. As a flexible addition to public transit, autonomous vehicles can support the

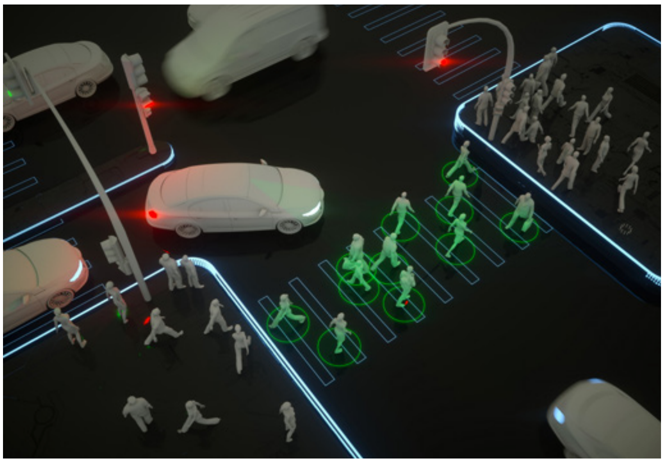


Illustration of impacts on pedestrian safety

Illustration of connected cars and smart hightway

Autonomous shuttle in Vincennes wood and platooning experiment

New perspectiv of transportation in airport area

Man and delivery robot waiting at pedestrian crosing in Redwood City, California

Illustration of platooning organization for freight introduction of novel services (such as shuttles and drones) and more flexible hours (greater responsiveness to demand on nights and week-ends). Communication between vehicles could also allow for platooning, thus increasing the ability of transport systems to add vehicles as needed. This reduces scenarios of over-supply of transit, operating instead in response to demand. Autonomous vehicles could have a serious impact on behaviour.

In the future, there could be no need for city dwellers to use or even buy individual private cars. Thanks to the diversity of transport services, shared and free-floating mobility, the need to park could totally evolve affecting the daily use of parking lanes and streets.

Lower emissions

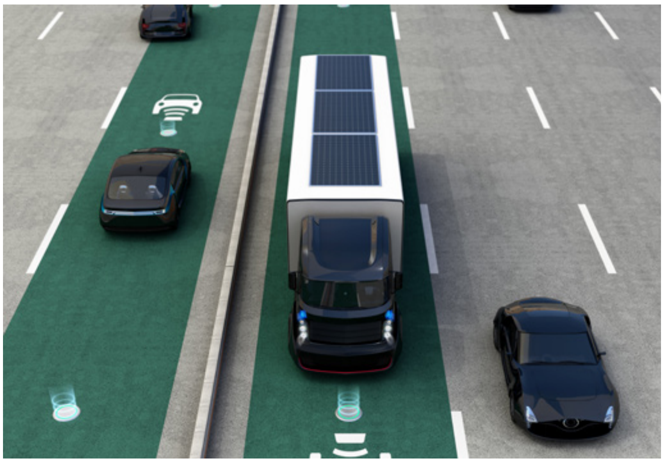
AVs promise to improve the fuel economy of driving as compared to human drivers simply by accelerating and decelerating more smoothly. Similarly, platooning can increase roadway capacity and improve fuel economy through improved aerodynamics. Safer travel, in turn, means lighter and perhaps smaller, more fuel-efficient vehicles. But most importantly, the transportation system rupture presented by the introduction of autonomous vehicles could allow for wide-spread adoption of electric vehicles reducing the impact of fossil-fuel based vehicle infrastructure and emissions.

Social impact

Postings for jobs in the field of autonomous vehicles have been increasing steadily over the last several years. Several experts expect that autonomous vehicles will result in an uptick in engineering-related positions as well as in other positions related to the integration of autonomous vehicles into society.

10%

Up to 10 percent reduction of fuel use as a result of truck platooning.



© istockphoto.com/Chesky_W

The future of hightway : dedicated lane for substainable cars and trucks?

© Michaël Gounon – Naya

Tomorrow, cities with mobility 100% substainable and autonomous?

Potential negatives

The aforementioned benefits associated with the adoption of autonomous vehicles are far from guaranteed. In fact, concerted action is required to ensure that they are, in fact, realized. Each potential positive scenario can be juxtaposed with a potential negative one; each perhaps equally as likely, depending on regulatory action taken and the form of technology introduced.

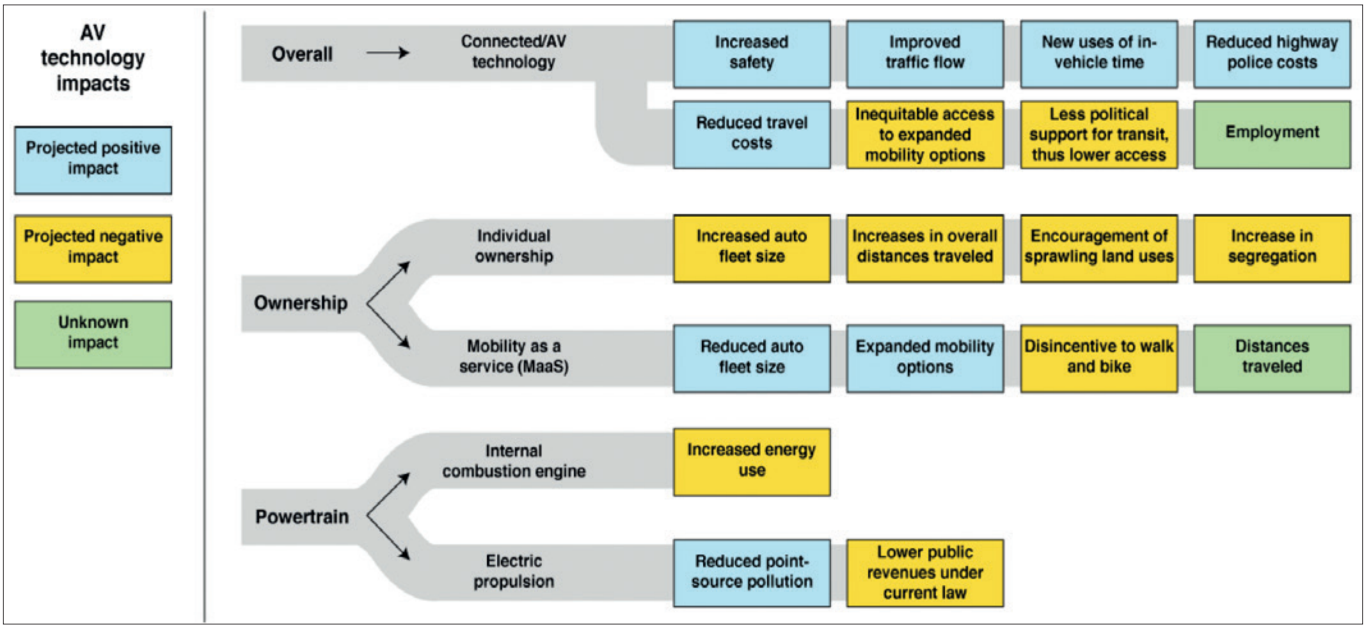
Figure 3 below, created by MIT's Urban Mobility Lab, summarizes the potential positive and negative impacts as affected by several determining factors with regards to the introduction of technology. Overall, as discussed above, autonomous vehicles promise to increase safety, improve traffic flow, allow for more free time and reduce travel costs. Yet they also have the potential to allow for inequitable access to the technology and in its accompanying opportunities. This, in turn, could be accompanied by even greater deleterious effects if higher AV usage should be accompanied by decreased support for transit. Employment, meanwhile, will also surely be affected, yet questions remain about whether the result will be positive with new, higher-level jobs or negative, with the replacement of existing jobs by the technology.

While the use of autonomous vehicles within a larger Mobility as a Service (MaaS), shared system of transportation could reduce auto fleet size and expand mobility options, it could also disincentivize active forms of transportation such as biking and walking, while increasing distances traveled as a result of increased ease of transportation. Individual ownership of autonomous vehicles, on the other end of the spectrum, is accompanied by myriad potential negative impacts, including increased fleet size, and thus an increase in overall distances traveled. Growing ease of individual transportation also promises to encourage sprawl and increased segregation as those who can afford the vehicles settle in areas further removed from urban centers which may, in turn, find themselves increasingly fiscally strained for infrastructure maintenance.

The potential for lowered emissions that has been promised should AVs be electric is not guaranteed. If they are not electric nor shared, they promise to in fact increase emissions as both the users and the VMT increase. There also notably remain questions about municipal fiscal security under an electric vehicle regime, as significant municipal revenues are derived from gas taxes today.

Finally, positive economic/social impacts are not guaranteed. While many see autonomous vehicles as ultimately expanding the number of jobs, particularly in the field of engineering, others worry that the decreased need for workers in positions ranging from drivers to mechanics will affect a large portion of society: in 2015, it was estimated that 15.5 million workers find themselves in jobs related to driving. The replacement of human beings by robots also brings with it concerns regarding the impact of dehumanization: will humans act different in a bus without a driver present ?

FIGURE 3 — IMPACTS OF AVS



Municipal levers for preventing projected negative impacts

As discussed in Chapter 1, governments have a wide variety of tools at their disposal for ensuring that the aforementioned positive effects are realized, and the negative ones avoided. Many, albeit not all, of those tools apply to municipal governments as well and should be closely considered. For the purposes of this primer for Grand Paris, we seek to explore two broad categories of municipal actions that can be taken to prepare for an autonomous vehicle future: municipal regulatory measures and design interventions.

Municipal regulatory measures

Although autonomous technology is still in its early stages, cities have a unique opportunity to introduce regulatory measures today to help shape the eventual arrival of autonomous vehicles tomorrow. Far from requiring a novel set of policies and regulations targeted specifically at autonomous vehicles (particularly since our understanding of the technology remains inchoate), cities can and should consider expediting a cadre of more general practices that achieve the widespread goals of efficiency, equitability, sustainability and livability. As discussed in the previous section, should cities not start thinking about this today, autonomous vehicles promise to in fact undermine those goals in the absence of proper policy pushing them in the right direction.

MIT's Urban Mobility Lab has developed a set of policies that can be applied to the mobility system of today, but which also promise to set in place the proper structure to shape the arrival of autonomous vehicles tomorrow. A brief overview of the policy proposals is as follows :

- **Lowered parking provision :**
Lowered parking provision could be an effective instrument in combatting increased VMT and sprawling land uses, since underpriced parking contributes to automobile use.

- **Distance and congestion-based road pricing :**
A per-kilometer fee associated with congestion pricing would encourage higher vehicle occupancy, particularly at peak times.

- **Integrated AV and transit system :**
A policy approach that pits AV services against transit would produce an urban environment with more travel, congestion and energy use because of multiple transportation options providing similar services, none at their optimum capacity. A more efficient approach would encourage collaboration between AV services and transit.

- **Minimum levels of service :**
To ensure equitable and efficient geographic distribution of high-quality service, local governments could develop service standards or offer subsidies to incentivize service provision.

- **Income-base subsidies :**
An AV-system with high fares relative to transit will not increase mobility for many low-income individuals, resulting in a less equitable city. A subsidy instrument potentially implemented through a data clearinghouse could fill the gap.

- **Data clearinghouse :**
A data clearinghouse would allow riders to choose between varying operators and connect to multimodal trips offered by the transit system, allowing them to find best-cost travel options, thus diminishing the potential of AVs lowering transit use and supporting the goal of more efficient cities.

- **Zero-emissions vehicles :**
Cities could require that AVs providing publicly accessible services are zero-emissions to meet sustainability goals.

- **Education programs :**
Cities could support efforts by their citizens to educate themselves in anticipation of on evolution in jobs available.

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Ponkawall, experiment of connected screens on A86 hightway (Ile-Saint-Denis, France)

© OneSITU

© OneSITU

Sensors «OneSITU», a technology already tested to optimize freight's and sidewalks's uses

Design interventions

Beyond the implementation of regulatory measures, cities can also turn to design to help structure their streets according to their priorities, thus helping to mold the arrival of autonomous vehicles. In 2017, the National Association of City Transportation Officials (NACTO) released a Blueprint for Autonomous Urbanism, laying the groundwork for a design approach to streets in anticipation of autonomous vehicles. They outline principles for an autonomous future, design approaches that can be applied to achieve those principles and areas of intervention. Their principles are relevant for any urban context and highlight numerous actions that governments can start considering now in preparation for the arrival of autonomous vehicles. Building on NACTO's work and the interviews conducted for this study, we present three broad areas of design that should be considered for interventions as Paris begins to prepare itself for the arrival of autonomous vehicles.

Curbside management (Figure 4)

Curbside management presents one of the greatest opportunities—and the greatest challenges—of the future city. As cities are able to reduce curbside parking in response to more efficient transportation opportunities offered by AVs, the curb will be freed up for alternative uses. Demand for curb space is already high and only promises to grow as more uses arise in the future. Bikes, pedestrians, buses, taxis, TNCs, restaurants and freight all have a claim to the space and there are myriad other potential uses that could be imagined (or have already been put into practice) ranging from stormwater management to park space to mobility infrastructure. Rather than allowing the curb to go to the highest, the largest or the first bidder, cities have the opportunity to manage access in an equitable manner that achieves the widespread goals of efficiency, livability and sustainability.

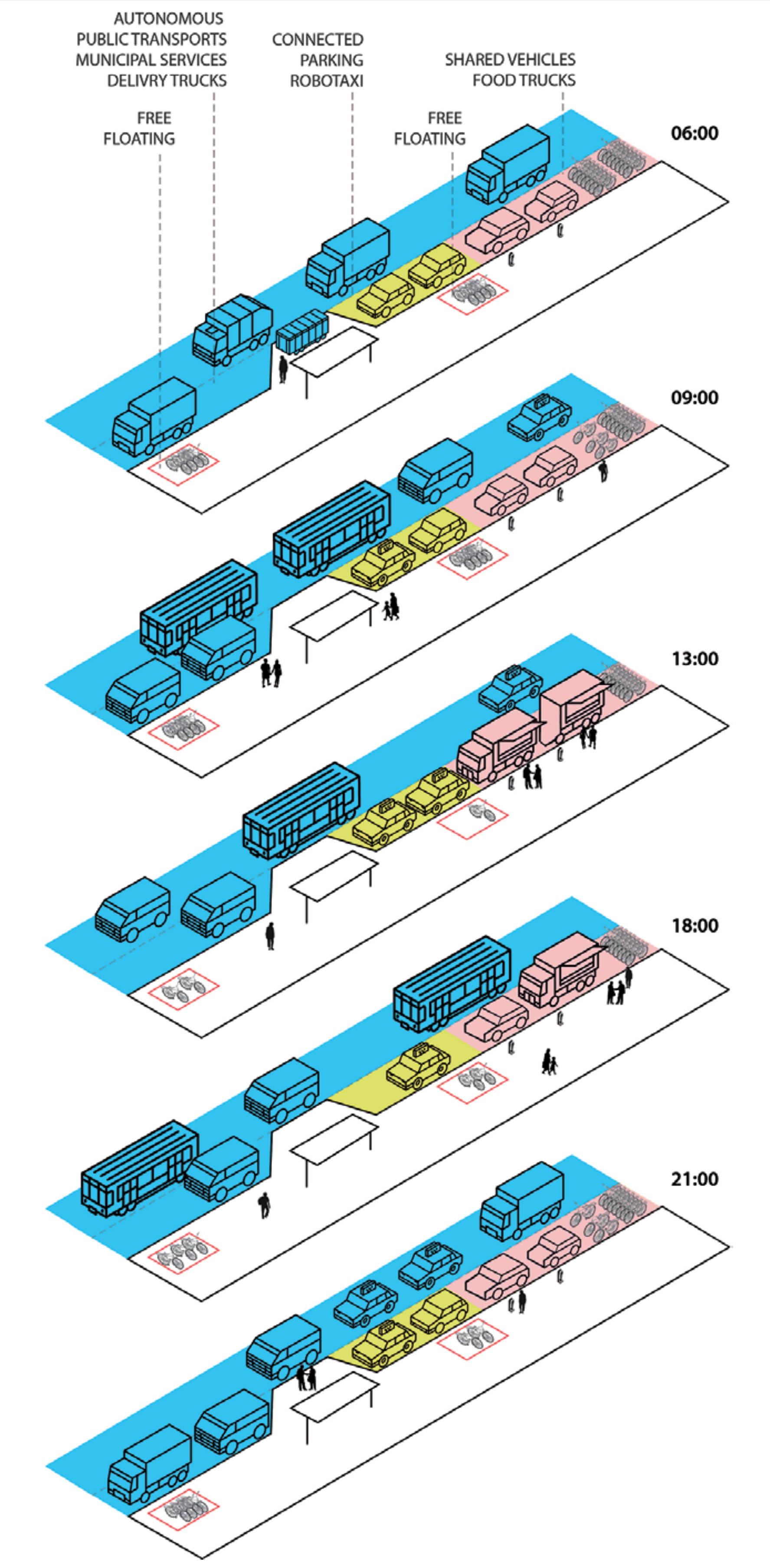
Figure 4 presents a vision for how the curbside might be managed throughout a given weekday. Technological advances will permit more advanced signage that indicates clearly (either on the curb itself or on a vertical sign) which use is permitted along the curb at what time. In the morning, freight could be given priority, as trucks or other delivery vehicles seek to deliver their goods in a timely manner. A section of the curb could meanwhile be a flex-use space that prioritizes shared forms of transportation (such as an electric car-sharing service or shared bicycles) as well as social engagement at varying times of day (such as food trucks over lunch). Similarly, there could be a designated section of the curb for TNC use to encourage safe and efficient drop-off of passengers. Significantly, cities could choose to prioritize public transportation along the curb to ensure easy access to and salience of the service, thus encouraging use.

Looking towards the future, there are a wide variety of potential approaches to curbside management that cities could consider. Significantly, many of the issues that cities will be facing with AVs will simply be exacerbated versions of the ones that they are facing with new mobility services today. There is thus an opportunity to strategize and address these issues in a timely manner today, thus preparing for the future while simultaneously addressing growing concerns in the present.

Street Design (Figure 5)

Once the vehicles leave the curb, there remains the question of what design awaits them on a city's streets. Should policies encouraging shared use be implemented, autonomous vehicles promise to move individuals in a more efficient manner, taking up less space and creating less congestion in doing so. This offers an immense opportunity for the reallocation of street space: cities can choose to advantage certain

FIGURE 4 — CURBSIDE MANAGEMENT: FLEXIBLE USE AND AUTONOMOUS VEHICLES



modes over others by managing lanes, speeds and right-of-way. Cities could consider expanding sidewalks and reducing speed permitted. Perhaps there could be a lane dedicated to mass transit and another to shared mobility. Perhaps speeds could differ across lanes to ensure vehicles are moving more slowly should they be in proximity to pedestrians.

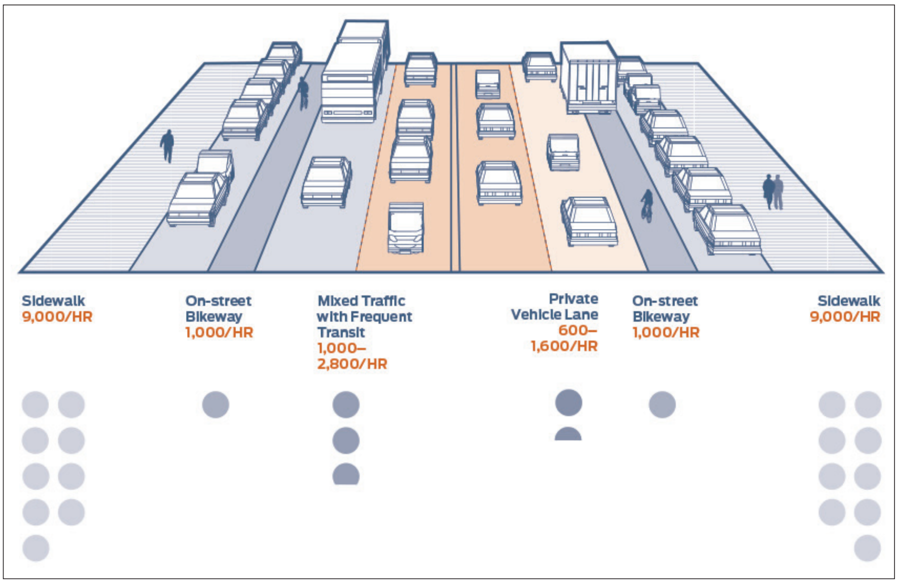
Design should notably be different across different types of streets, with residential streets prioritizing pedestrians to the greatest extent and other major thoroughfares allowing for efficient albeit safe movement of transit and transportation.

Data management

Connected vehicles, connected streets, connected infrastructure and public space as discussed in Chapter 2, offer the unique opportunity of access to vast amounts of data, which could in turn be used to better manage city streets. The data, if managed properly, could in fact be used for real-time management of city streets in response to fluctuations in demand as well as efficiency, equity and/or safety concerns. This can be used to assist in both curbside management and street design itself, but can also be applied for implementing novel pricing schemes such as distance- and congestion-based road pricing to replace today's gas tax.

Already tested, the installation of roadway sensors ("One Situ" sensors with the City of Paris) along parking areas enables an optimal use of delivery spaces and provides information in real time about available parking spaces in streets.

FIGURES 5 — STREET DESIGN / STREET CAPACITY : MOVE MORE PEOPLE WITH FEWER VEHICLES



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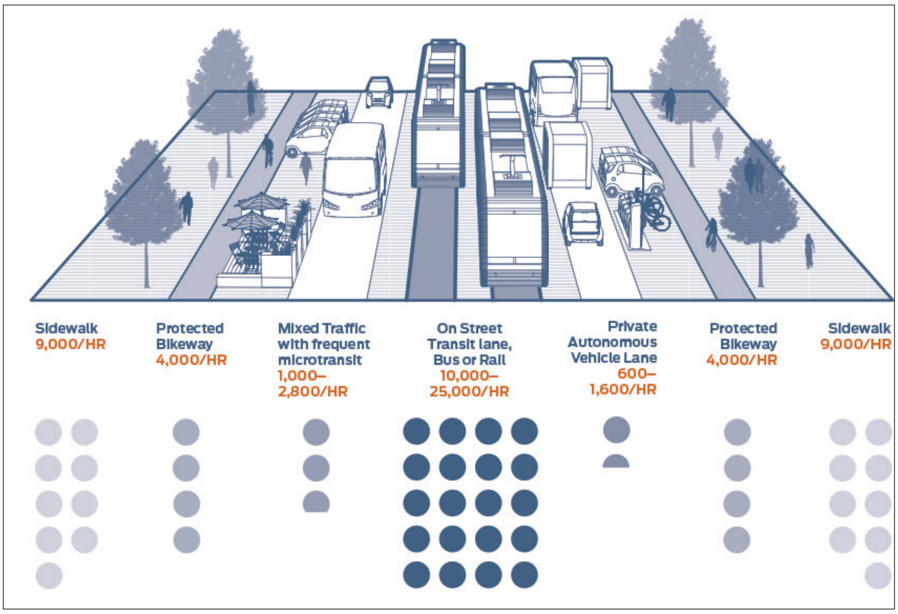
Before



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After

Conclusion

While much uncertainty still surrounds the timeline and ultimate form of autonomous vehicles, multiplication of experiences for innovation in mobility and freight is the best option to pursue in a substainable pathway for cities. There are numerous actions that municipal governments can take today to ensure that the former are realized. Governments can indeed help shape the ultimate outcome, while simultaneously improving the present.

In addition to the aforementioned tools and approaches to AV regulation and design, there is also the important step of increased experimentation of autonomous vehicles. Experimentation supports not only technological advancements, but also societal familiarity and comfort with the technology as well as government understanding of its opportunities and potential. Allowing for controlled experimentation in specific contexts results in insights, awareness and comfort with autonomous vehicles and encourages companies to develop the technology for projects encouraged by governmental bodies. This arguably gives the government and, significantly, the people a voice in the evolution of the technology. As was explored in the case studies in Chapter 3, those cities that boast extensive experimentation in the field of autonomous vehicles also have the most developed and impressive regulatory systems and networks with key AV companies to date. The benefits of the creation of a test city or a test area on public roads are numerous.

5. An approach to experimentation in Grand Paris

Priorities for Paris with regards to AV experimentation

In pursuit of a future that boasts the full slate of benefits that autonomous vehicles can bring, Paris is today looking towards a more extensive cadre of experimentations. The city seeks to develop a greater familiarity with the technology as it exists today and as it continues to develop into the future. Nonetheless, as the city looks towards increasing the number of experiments on its streets, it should seek to prioritize ones that fulfill the city's overarching goals, build on existing projects within the EU, and push towards a more sustainable, efficient and equitable future. In analyzing proposed experiments; the city of Paris should seek to address the below priorities:

- **Sustainability**

According to the Air Quality, Energy & Climate Action Plan adopted by the city earlier this year, Paris aims to be carbon neutral and fully powered by renewable energy by the year 2050. The plan includes ambitious goals for reducing both energy consumption and greenhouse gas emissions in the coming years. Any AV experimentation should thus also support these goals through the prioritization of electric vehicles or other forms of sustainable travel.

- **Promote mass transit compatibility and shared use mobility**

In order to avoid the dangers of increased VMT leading to increase emissions and congestion, AV experimentation should have a component that explores their compatibility with public transportation or that supports a schema of shared use mobility. There are many opportunities for expanding the efficacy of public transportation through the use of novel technologies such as AVs and experimentations could and should explore those prospects.

- **Expand service, increase equity**

AVs have the opportunity to expand service to less dense areas traditionally underserved by public transit. By reducing the need for a driver and allowing for a greater diversity of vehicles, AVs have the potential to increase equity through offering a larger network of on-demand service. This form of service could also be expanded to areas of activity such as business districts that have limited hours and a lower density, but a distinct population that is today underserved. The city of Paris should examine a wide variety of potential applications for underserved populations and prioritize experiments that address their needs.

AUTONOMOUS SHUTTLE BY NAVYA AND ILE-DE-FRANCE MOBILITÉS, EXPERIMENTED ON LA DÉFENSE PEDESTRIAN AREA

© Apur

• Encourage the cohabitation of modes

In recent years, cities have been increasingly reorienting their transportation policies from a car-centric approach to one that prioritizes offering diverse modes of travel to improve choice and quality-of-life. Multi-modal streets increase the efficiency and livability of cities. As AVs arrive, it is important not to lapse into old habits of prioritizing the new technology over other modes. Thus, experimentations that take a multi-modal approach to their design and implementation should be advantaged.

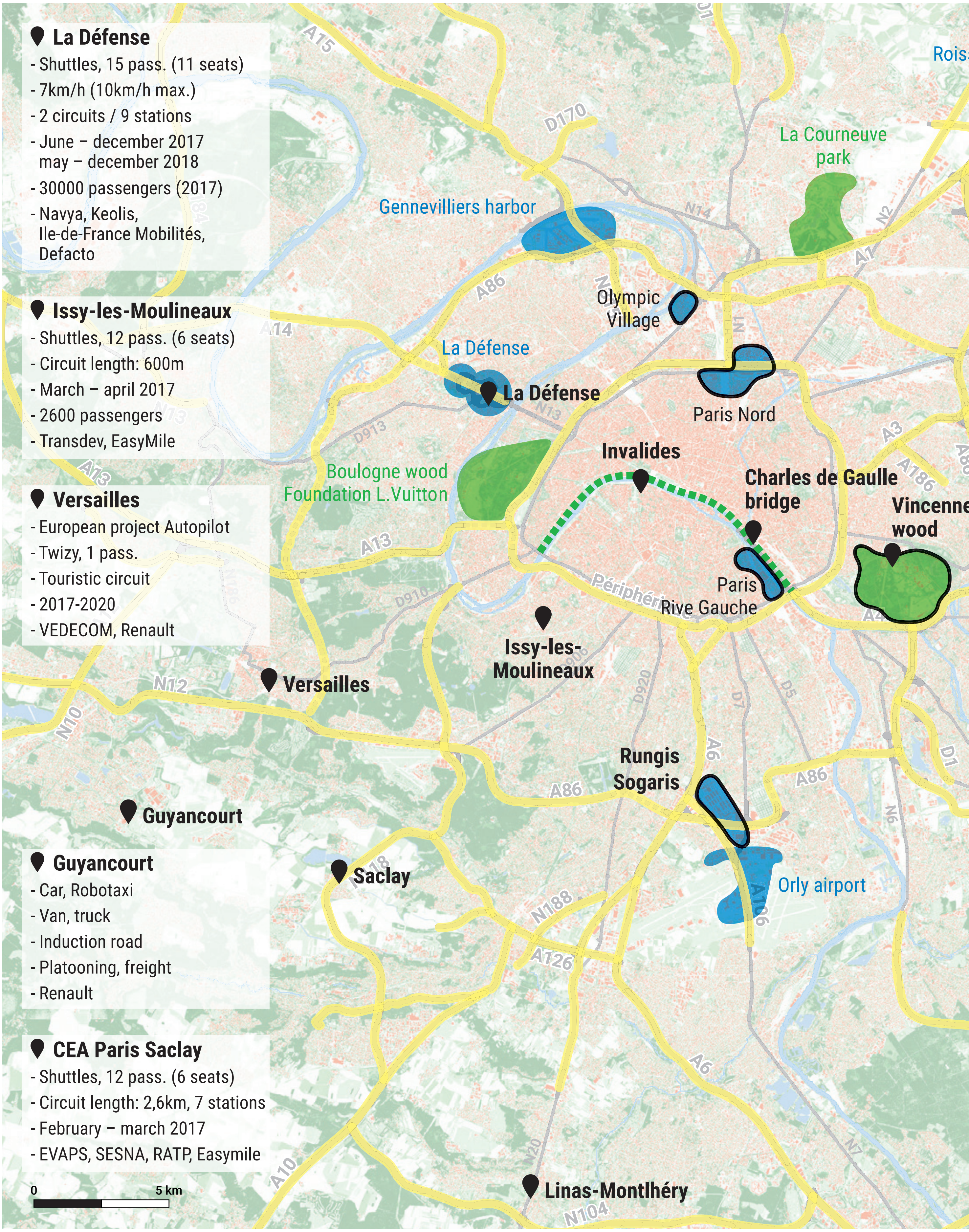
• Optimize data use for coordination across platform and informed consumer choice

In pursuit of more effective multimodality and the democracy of choice across modes, experimentations that offer solutions for data management and coordination across platforms should be prioritized.

• Expand support for tourist activities

In 2017, 89 million tourists visited the city of Paris. Unsurprisingly, tourism plays a significant role in the Parisian economy. Autonomous vehicles have the potential to support the city's tourist efforts both through expanding access to attractions and easing challenges faced by tourists and citizens attempting to circumnavigate the city today. Instead of individual tourist buses, for example, the city could have an AV bus route that consistently runs for a wide variety of tourists, reducing the need for bus parking throughout the city. The city has a particular opportunity to expand this category in particular during the upcoming Olympic Games in 2024.

Experimentation supports not only technological advancements, but also societal familiarity and comfort with the technology as well as government understanding of its opportunities and potential. Cities that boast extensive experimentation in the field of autonomous vehicles also have the most developed and impressive regulatory systems and networks with key AV companies to date. The benefits of the creation of a test city or a test area on public roads are numerous.


La Défense
- Shuttles, 15 pass. (11 seats)
- 7km/h (10km/h max.)
- 2 circuits / 9 stations
- June – december 2017 may – december 2018
- 30000 passengers (2017)
- Navya, Keolis, Ile-de-France Mobilités, Defacto
Issy-les-Moulineaux
- Shuttles, 12 pass. (6 seats)
- Circuit length: 600m
- March – april 2017
- 2600 passengers
- Transdev, EasyMile
Versailles
- European project Autopilot
- Twizy, 1 pass.
- Touristic circuit
- 2017-2020
- VEDECOM, Renault
Guyancourt
- Car, Robotaxi
- Van, truck
- Induction road
- Platooning, freight
- Renault
CEA Paris Saclay
- Shuttles, 12 pass. (6 seats)
- Circuit length: 2,6km, 7 stations
- February – march 2017
- EVAPS, SESNA, RATP, Easymile
0
5 km
Gennevilliers harbor
La Courneuve park
Olympic Village
La Défense
La Défense
Paris Nord
Invalides
Boulogne wood
Foundation L.Vuitton
Charles de Gaulle bridge
Vincenne wood
Paris Rive Gauche
Périphérique
Issy-les-Moulineaux
Versailles
Guyancourt
Saclay
Rungis Sogaris
Orly airport
Linas-Montlhéry
A15
D170
N14
N2
A1
A86
A14
N13
D913
A13
A13
D910
N12
N10
A3
A186
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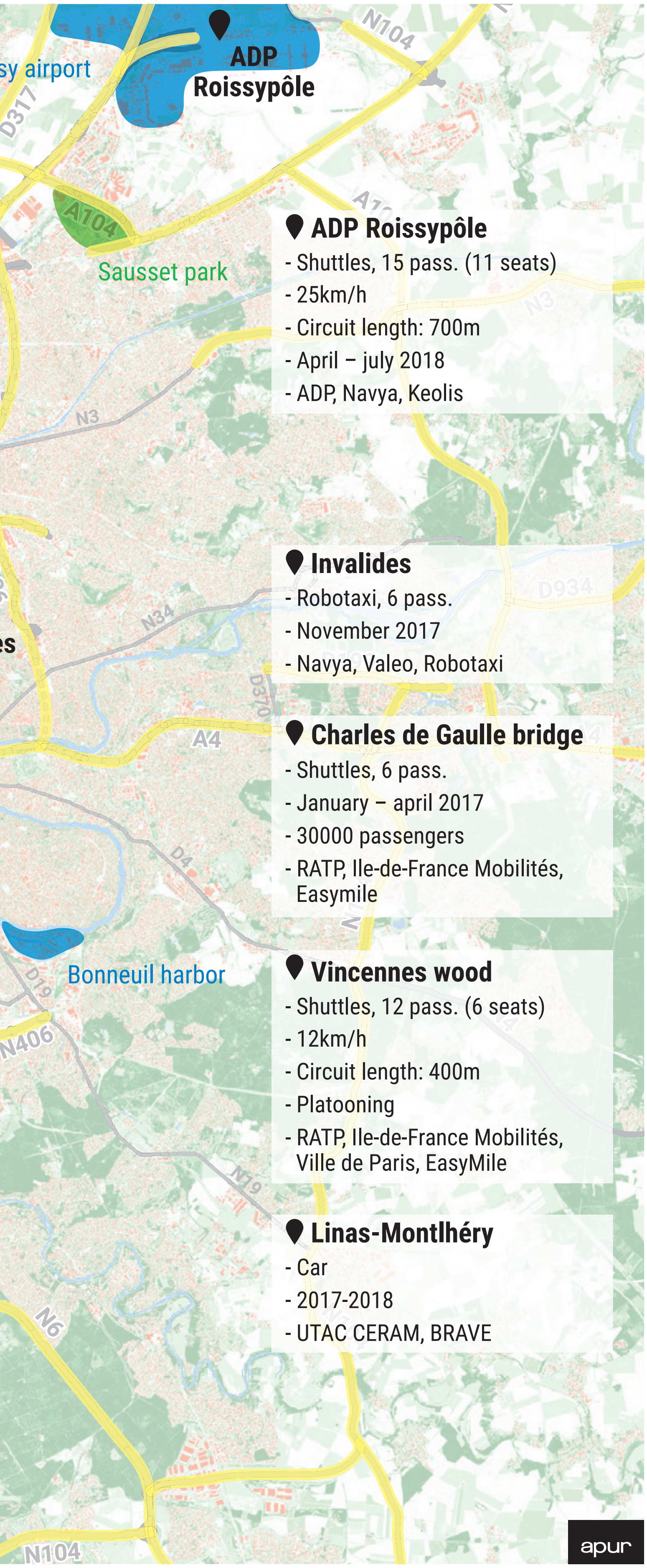

AUTONOMOUS VEHICLES IN GRAND PARIS

Experimentation: carried out or planned

- Test completed, in progress or already planned
- New mobility or logistics hubs
- Landscape and leisure sites

Other experimentation routes and places to be studied (Apur proposals)

- Potential Olympic links
- Potential economic sites
- Potential landscape and leisure sites
- Expressway network (International consultation on the future of expressways in Grand Paris)
- Motorways, Bd Périphérique ring road, expressways
- Main structuring roads

Apur July 2018
Source: Bd TOPO IGN

This map thus explores initial potential sites to expand the cadre of experiments in Grand Paris :

- **On mobility and logistics hubs already identified:**
  - In the **Olympic and Paralympic village** "Pleyel-Bords de Seine" which is planned to accommodate autonomous shuttles,
  - In **urban innovation districts** (Paris Rive Gauche and Paris Nord) as well as the logistics site of Rungis - Sogaris.
- On part of the **motorway network and the Boulevard Périphérique** ring road: the International Consultation on the future of the Périphérique and Grand Paris urban highways launched in the summer 2018 by the Metropolitan Forum will provide an opportunity to consider the "intelligent motorways of the future", integrating autonomous vehicles with three dates in view: 2014 linked to the Olympic road network, 2030 and 2050. Four international teams were selected in September 2018 to put together an exhibition in the summer of 2019.
- On the **Banks of the Seine**: experiments could be developed along this iconic site notably on the higher banks.
- On **territories with specific mobility demands** such as the airport zones of Roissy and Orly and business and job zones (the CBD at La Défense, the MIN Rungis - Sogaris logistics platform, the Millénaire Park, Left Bank districts and the Gare du Nord…).
- In **large green spaces** like the Bois de Boulogne and Vincennes and the Georges Valbon Park.

Autonomous mobility and guidelines for the future of Grand Paris...

The possible benefits of autonomous vehicles on mobility

- Improved road safety.
- Reduction in road congestion.
- A reduced demand for parking spaces, notably in public spaces.
- Development of an alternative, complementary, public transport network such as autonomous shuttles.
- New services in zones which are sparsely populated, under serviced or with irregular timetables.
- More flexible economic models like “platooning”, a cooperative adaptive cruise system for a series of vehicles and a service on demand.
- Logistic solutions and municipal urban services, including household waste collection.
- Maintenance of infrastructures and information exchanges between vehicle, user, urban environment and public space.

Guidelines for continuing experimentation in the city

- To take into consideration the exemplary sustainability and environmental aspects.
- The support of large capacity, collective and shared autonomous vehicles including on motorways, and their efficient articulation with public transport.
- The development of mobility services (MaaS) and integrated portals for travellers (tickets, reservations, flexibility…).
- Thoughts on the sharing and management of the streets aiming for a greater cohabitation of modes according to their different speeds (pedestrians at less than 10km/h, bikes and light vehicles at less than 20km/h, shared vehicles and public transport at less than 30km/h).
- Motorway and public space facilities using “connected infrastructures” (roadway sensors, signs, traffic lights…) linked to the production of digital maps.
- Support of the development of Open Data, strong networks for exchanging and for the flow of data (ITS G5, 4G/5G, Wifii, Lifii…)and electrical recharge systems (stations, dynamic induction…).
- Optimisation of parking on streets and delivery in the city from connected to redistribution centres (valet,robot, drone…).


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Smart city, a future for mobility in Grand Paris

Impacts and potential benefits of autonomous vehicles

FROM AN INTERNATIONAL CONTEXT TO GRAND PARIS

Autonomous vehicles (AVs) have the potential to transform future of urban living. By offering the opportunity for safe, efficient, accessible and affordable transportation they promise not only a novel system of mobility, but also a novel approach to the urban lifestyle and urban design. Yet these benefits are far from guaranteed. Scholars show that AVs have the potential for numerous negative impacts in contraposition to their positive potential, depending, of course, on the form of their implementation. They could combine with other growing trends in the mobility space (such as shared use or mass electrification) to introduce a positive rupture in today's mobility or, conversely, they could exacerbate existing trends towards congestion and climate change, further entrenching the negative aspects of today's status quo.

Whereas the number of experiments has greatly increased in recent years in France and around the world, French Government will authorize from early 2019 autonomous vehicles tests without human driver on national roads. Impacts of autonomous mobility could affect a wide field of domains, from urban transportation to freight organization systems. The foreseeable arrival of drone, delivery robot, robotaxi, shuttle or autonomous garbage truck…, in our streets imposes to better identify the fallout for major cities.

The challenge - and the opportunity - of today is to redefine the mobility system before the technology solidifies its own path. In pursuit of that goal, this study, registered in the program of work of Apur in 2018 and carried out in connection with the MIT, strives to offer a primer on international autonomous vehicle development and regulation, applying its lessons to the context of the Paris metropolitan area. It aims to provide public actors with the understanding, insights and tools it needs to enact pertinent policy measures today to shape the arrival of autonomous vehicles tomorrow.

L'Apur, Atelier parisien d'urbanisme, est une association loi 1901 qui réunit autour de ses membres fondateurs, la Ville de Paris et l'État, les acteurs de la Métropole du Grand Paris.
Ses partenaires sont :