Article

Fully Automated Public Transportation Mobility : A Dream or A Nightmare?

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Abstract: During the past few years many projects and initiatives were undertaken deploying and testing automated vehicles for public transportation and logistics. However in spite of their ambition, all of these deployments stayed on the level of elaborated experimentation deploying no more than 4 maximum 5 AVs in rather small sites (few Kms of roads) and never really reached the level of large scale "commercial" deployment of transport services. The reasons for this are many, but the most important being the lack of economically viability and commercially realistic models, the lack of scalability of the business and operating models, and the lack of inclusive citizen/user centric services required for the large end-user acceptance and adoption of the solutions. In this paper, based on the experience gained in the H2020 AVENUE project, we present the missing pieces of the puzzle, ad which will be addressed in the Horizon Europe project ULTIMO.

Keywords: Public transportation; Automated vehicles; economic viability; business model

1. Introduction

Automated driving : the dream that was born the same day the first cars were moving on the streets. Since the invention of cars, we are dreaming to have a car that can take us to our destination without human intervention. Science fiction writers have imagined different solutions, from mechanical automata [1] to positronic brain robots [2] that can drive a car as a human driver. And the dream, until a decade ago, seemed to be just that : a dream. The processing power required was beyond our reach, the technologies were at the level of laboratory prototypes and the operations models were embryonic. But technologies are evolving very fast, and we have today reached a level where the processing power of the most powerfully supercomputer of the 90's is available in device as small as a mobile phone. At the same time sensor technologies allowing us to "see", analyse and understand the surrounding environment, like LIDAR and high definition cameras, have become readily available and miniaturised, being even available even in smartphones (iPhone 13). As a result, the dream of automated driving seems not to be anymore just as dream, but rather a target we can reach. Throughout the world, from the Americas, to Europe and Asia, companies are investing large amount of funding in the development of automated vehicles, investing billions of Euros, while many cities and mobility actors are experimenting with automated mobility services and solutions [3[4][5][6], deploying automated vehicles for different use cases, like from passenger mobility to urban logistics.

However, the passage from *technology offer* to *service offer* can easily be turned to real nightmare. The major investments today are in the mastering of the technology of automated driving, and it is just recently that the services' requirements and economic social and environmental issues have started to be studied. While in United states the target is mainly to offer automated transport with private cars, in Europe the target is to offer automated transport for public transportation as first and last-mile and mobility gap filler [7][8]. The two models face completely different technical, economic, social and regulatory challenges in order to provide a commercial large-scale deployment of fully automated vehicles in cities. One of the major differences in the deployed of automated vehicles for private cars and public transportation, comes from the fact that the deployment area of a private car is potentially the whole planet, while for the public transportation is a well-defined and limited urban area using supporting existing Public Mass Transports like train, tramways etc.. The first case requires L5 [9] automated driving, while the second can successfully operate with L4 automated driving.

To our opinion the first large scale commercial deployments of automated vehicles will be in well-defined geo-fenced areas, offering shared public transportation services with L4 automated driving integrated with other complementary means of transport of a MaaS (Mobility-as-a-Service). But the dream turns a nightmare when we start considering the real issues, like keeping up-to-date city maps, providing vehicle and passenger safety services, inventing new transport models, creating in-city parking spots and recharging outlets, figuring out how to reuse the unused excess vehicle capacity and how to integrate automated Minibuses in a MaaS or an Intelligent Transport System (ITS).

1.1 A day in the city in 2035 – a dream of urban mobility!

Our city has a population of 700.000, and the local PTO (Public Transport Operator) deploys 4.000 Km of public transportation services' routes, with 4 tram lines backbones, 8 major backbone large bus/trolley lines, and 340 fully automated multi-manufacturer mini and micro-shuttles in an on-demand, door-to-door shared public transport service (MaaS). The fleet of the 340 automated mini-busses is composed of different vehicle generations and models from different manufacturers, as it was purchased in different batches during the last 12 years (it all started with the first 15 bought by a European project in 2023/24). It is today composed of the first 15 twelve-years old vehicles from manufacturer A, 160 eight-years old vehicles from manufacturer B and 160 two-year old vehicles from manufacturer A, which are the new generation of manufacturer's A vehicles. The last 160 bought vehicles replaced 50 old, driver, thermic busses that reached the end of their life after 18 years in operation. The change from driver large busses to automated mini-buses and from fixed line service to on-demand, door-to-door, was decided 6 years ago, and was based to the great success of the already deployed AV based services in other parts of the city.

The integration of new vehicles in the PTO fleet was done within just a few days, thanks to the now standardised APIs of the automate vehicles connection with the AV fleet management, that allows a plug and operate functionality but also enables the combination of AVs with all other means of transport to offer a seamless citizen centric journey to the smartphones of users. Similarly, the now standardized High Definition (HD) maps between the vehicle manufacturers allowed us to reuse the maps created in the past for the 4.000 Kms of routes of the city, with small adaptations for the new vehicle capabilities. At the same time of the purchase of the last 160 AVs, we also switched to a new AV fleet management service, from another provider, which offers more precise trip time estimations, considering also traffic jams in the city and weather conditions (that affect traffic in the city). The replacement was made within just two weeks ago, thanks to the new standardised interfaces between AV fleet management and PTO MaaS services.

Passengers are now able to reserve on the fly or with pre-reservation trips from one side of the city to another, using the optimal transport mode available including a combination of different public and private transport modes, and having the automated vehicle arriving next (or almost) to their door entrance and bringing them to their final destination or to a backbone transport connection. All trips are offered with reliable and accurate transport and arrival times, based on real time, dynamic and static data and the historical data collected . Many passenger services are available in the AVs via a mobile phone app, adapted to all passengers' needs, from special needs passengers (visually impaired, wheel-chair users, pregnant women, elderly, children), to persons transporting suitcases

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or a baby-stroller, providing adapted information of their trip (where to get-off, PTO general information, and even infotainment, like city related information and historical facts and anecdotes, related to their current position). Weather can be considered as well when wished: the passenger would perhaps prefer a bicycle when the weather is sunny but an automated minibus when it is raining or when he is on business trip.

With the full suppression of on-board operators, automated in-vehicle monitoring provides a multitude of passenger services, which were, and are developed with a continuous collaboration and innovation between users and the PTO. An on-board unit identifies locally (that is, in the bus) incidents and situations, like aggressions, vandalism, forgotten objects, littering etc, and raises incident alarms to the PTO back-office. The PTO officer at the back-office evaluates the incident and decides, based on the operator policies, what action to take: dismiss the incident, or stop the vehicle and call one of the intervention teams to go the vehicle and take the required action. The back-office operator, based on the number of incidents and intervention time legal obligations', can deploy any of the 15 intervention teams available in the city, ready to reach within a few minutes any AV. At the back-end, service operators are able, with one set of screens linked to the fleet management, to follow the vehicle status, reservation, routes chosen, open and closed road segments (due to works, accidents, etc. thus adapting dynamically the trip routings), while in a second set of screens, the back-end operators can follow the passenger services' incidents and the status and location of the intervention teams. The two systems, although independent, are linked so that the back-end operator can transfer incidents to intervention teams and turn-on, when possible and under the local legal restrictions, video connection to inspect the incident.

The public transport services are operating 24/7 with different active vehicles, depending on passenger transport demands. The PTO, being eco-sensible, has defined that the vehicle must have an average occupancy of at least 3 passengers. This of course has implications, especially in off-peak hours, in the transport delays, but it is fully justified for an optimal and eco-responsible operation. Exceptions are made for people with special needs or when the passenger is ready to pay an additional price.

While at peak-hours the full 340 strong fleet of AVs is in service for public transportation, in the off-peak and night hours, due to the reduced transportation needs, part of the fleet is not serving passenger transportation. However, because having a vehicle waiting idly is a waste of resources, the PTO has signed an agreement with *Logistics as a Service (LaaS)* Service providers. During the off-peak hours the unused vehicles are dynamically *chartered* by the different LaaS providers to be used for other types of incidental transport of goods. Local shops and enterprises use the service, on demand, to offer home delivery of on-line purchases, or B2B delivery of goods from an urban consolidation center to the distribution center (hub, many to one or one to many) or the before mentioned store [6]. This way they can deliver the goods to their customers in the city, with a delay of just 60 minutes to affordable price as the last mile is most inefficient part of the delivery chain. The goods send can include books from local bookshops or libraries, supermarket bags or even documents exchanged between companies or waste. The local shops are even using the service in early hours (5 o'clock in the morning) for re-provisioning their shops for the day. The so chartered AVs are "returned" to the PTO for public transport at the peak-hours automatically, at the end of the chartered time period. Combined transport of goods and persons can be imagined as well like in Air transport.

1.2. From dream to nightmare and back to the dream

The above described mobility dream represents an economically realistic and plausibly economically viable model for deployment of automated vehicles in public transportation. However, if we look closely, we can see that many issues still need to be addressed so that the dream can become reality, before turning to a nightmare. Many issues are today well known and well documented, like the technical and regulatory requirements, where different approaches are being taken by different authorities and manufacturers [4][5].

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However, the current approaches for a viable service solution cover only the tip of the iceberg, addressing the most "obvious" problems (legal and regulatory, passenger acceptance, services, technical shortcomings), ignoring the more complex issues, deeper in the iceberg (figure 1) that are related to large scale full deployment of commercial services. In the above described dream, every simple element down the iceberg can become a nightmare: from how to scale from a few kms of deployment to thousands of Kms, to what are the required investment and operational costs to cover recharging stations in the city, parking spots for inactive vehicles, city street mappings, as well as and how to avoid the business trap for a PTO to be customer-locked to a single technology provider due to the fine tuning of the IT infrastructure or due to the excessive costs in adopting another technological solution.

Figure 1 The iceberg of deploying AVs in public transportation

2.1 Challenges for the realisation a mobility dream

The ultimate target in any deployment of automated vehicles in public transportation is to create a sustainable, economically viable and commercially realistic deployment of citizen- and user-centric public transportation service. This should be based on proven business models and concepts, like valorisation and preservation of past investments, promotion of competition between technology providers, suppression of customer lock-in situations, and development of cross-section business models and partnerships for the creation of viable, sustainable and optimized business ecosystems.

From an economic perspective, the use of AVs cannot be made profitable today due to the elevated costs linked to the deployment of AVs in an urban environment. Although the major visible costs today in full scale deployment of AVs are the costs of the on-board safety operator (due to the small capacity of AVs the cost ratio per passenger is too high), other very important costs are not yet fully being taken into account by the operators due to fact that all of today's deployments are small scale and last a relatively short time. We have identified 8 major issues that are not yet fully understood by the PTOs and have a major impact in any large scale deployment of AVs in public transportation.

2.2.1 Life time of Automated vehicles

It is expected that in a large-scale deployment the PTO will deploy hundreds of AVs in the city, this being one of its major capital investments. However, AVs are based on IT systems which are evolving and will continue to evolve relatively fast for the next decades. With the evolution of the technology, it is to be expected that the regulatory requirements will also be adapted in order to consider the new IT and AVs (e.g. lidars) capabilities. This will create the risk of making the "older technology" vehicles technologically obsolete and possibly "unusable". Today the expected lifetime of an AV does not exceed 6 or 7 years, while a traditional thermic bus or electric trolley has a life time of 15 years and more. If the PTOs need to replace their AV fleet every 7 years instead of every 15, this creates a major obstacle for an economically viable deployment.

The "nightmare" is thus how to valorise "older" AVs and extend their useful service life time (Preservation of Past Investment). One possible solution, fully compatible with the concept of dynamic, on-demand public transport services, would be to dispatch AVs based on the use case and the require vehicle capabilities. For example, if the older generation vehicle is slower, then it will be dispatched only in areas with lower speed limits

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(like the city center where the speed limits are in general no more than 30 Km/h), or for passengers that require lower speed are not pressed by the time duration of the trip, or even provide a price differentiation based on the speed of the trip required by the passenger. This type of use-case/capabilities-based vehicle dispatching requires a detailed identification of the target use cases and their correlation to the different vehicle capabilities. The fleet management and orchestration service will need to handle this service provision, while the PTOs will need to identify the policies for differentiated service levels.

2.2.2 City HD- maps

One of the key requirements for the deployment of AVs in a city, is the compilation of High Definition (HD) Maps, with annotations and information for the smooth and safe operation of the AVs. Each vehicle manufacturer creates its own maps, scanning the deployment roads and making its own annotations. These maps with the inserted annotations are proprietary to each manufacturer.

From one hand, today the majority of the AV deployments operate in small areas with just a few Kms of routes. As a result, the cost for the creation of the HD maps is relatively low, compared to the other costs of deployment, bust still quite important. We have seen prices ranging from 5.000 EUR to 25.000 EUR for a Km of road (depending on the associate services).

On the other hand, today public transportation buses are deployed in a small percentage of the total roads' network of the city. For example, in a city of a population of 500.000 (example Geneva, Switzerland) the public transportation road network is 420Km, whereas the total road network of the canton is roughly 1500 Km. Passing from fixed line to on-demand, door-to-door, the public transportation road network of the AVs will eventually cover the complete road network, but we can safely consider that only 50% of the unserved roads will be served. This means that the public transportation road network of AVs deployment will cover at least 1.000 Km of roads. The cost of creating HD maps will thus be very high (in the order or a several million EUR).

The nightmare is that each vehicle manufacturer has today its own standards for HD maps. As a result, the PTO will be forced to either use a single AV manufacturer (resulting in customer lock-in to the vehicle vendor) or pay the mapping of roads twice (or even more times). But the nightmare does not stop there: the city roads are constantly modified, changed, blocked. These changes *must* be integrated to the HD maps in a very short time (hours maybe). Keeping the HD maps up to date will require a continuous re-scanning, analysis and manual annotations of the roads. And if the PTO has opted for multiple vendors, keeping the HD maps of the different vendors synchronized is by itself a major challenge (or nightmare!).

The challenges are how to keep the HD-maps up to date and how to reuse the HD maps for different vehicle manufactures. Creating a standard for HD-maps will require that all the vehicle manufactures join forces and come up with a common open model. How feasible this is, is not yet known, the different manufactures do not really communicate details. Keeping the HD-maps up to date, might be an "easier" task. Each AV when operated scans the area around it. A comparison of the dynamically scanned area by the AV and static scan, would be able to identify differences and with an intelligent system, create the required HD map updates. Another option is to have a permanent mobile unit visiting "incident" spots and rescanning and manually updating the HD maps. All these solutions however, have cost and require a fine tuned methodology and logistics.

2.2.3 Plug and play of AVs in MaaS/ITS systems

The current model for traditional bus deployment is that the PTO identifies the new bus model/manufacturer (based on some procurement process with clear specifications) and the new vehicles are adapted (by the manufacturer or by the technical services of the PTO) and deployed in the public transportation network.

On-demand, door-to-door AVs require, among others, to be guided and connected to the operator fleet management and MaaS/ITS services. However, each AV model has

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its own interface (API) and its own capabilities. As a result, each AV fleet management provider provides a custom integration of fleet management services, based on the special capabilities of a specific type of vehicle.

If the PTO wishes to change to a more performant service, the integration cost and adaptation can be prohibitive (in budget and time to develop and test). Furthermore, the new service provider might not support the PTOs older vehicles and will be required to develop new interfaces, thus increasing the transition costs. The challenge is how the PTO can switch fleet management services and integrate them to it MaaS service with minimal costs (Customer Lock-in to the service provider).

A solution would be to standardize the AV APIs and protocols, in the same way that web services were standardized, allowing an open model that will be able to adapt and accommodate new capabilities of the future vehicles. This will require collaboration between vehicle manufacturers, and the possible create of a neutral entity that will be the "guardian" of the open interfaces, operating a similar way as the W3C [10] . First steps towards this direction are undertaken by the MaaS Aliance [11] and comkpnies, like the Trapeze group [12] have identified the issue and started working toward this direction.

2.2.4 Critical mass

A major point in the deployment of large-scale public transport services is the deployment of a critical mass of AVs that will allow real transportation services (and not just a "tourist attraction service"). Based on past experience, we have estimate that the minimal critical mass is 15 AVs serving a single site, under a common management service. However, it is clear that not many PTOs have the budget to purchase 15 AVs (in view of their high cost) for a service that has not proven its commercial value. As a result the demand of AVs is very low, the prices are very high, and this drives the demand to be low!! We somehow need to break this circle and boost the mass development of AVs, bringing the prices down and allowing the deployment commercially viable services. This where the support of the European Commission can provide the required funding, by allowing the PTOs to purchase the initial seed vehicles with Horizon Europe funding.

2.2.5 Scaling up the Automated vehicles' transport services

Currently the city public transportation operates on well-defined itineraries. As mentioned above, in a medium size city like Geneva the public transportation routes, with fixed bus lines, is about 420. Passing to an on-demand door to door service, means covering at least 1000Km of roads. In addition, today the public transportation in Geneva is served with 472 vehicles (tramways, trolleybus, autobus) and 4 automated vehicles. Scaling up to cover the full Geneva area will require at least 200 to 300 automated vehicles with the parallel decommissioning of 150 to 250 traditional vehicles. This transition will require a long-term planning and a detailed transition plan (assuming that there is an offer from vehicle manufacturers for this very high numbers of vehicles!).

Fist of all it must be decided which routes will be served and under which type of services: door-to-door, near-door-to-door, 24/24 vs 18/24 hours of service etc. Once the deployment area is defined the PTO should identify and organize the required city infrastructure: charging points in the area or depot, parking space for vehicles that are on stand-by chosen to minimize energy consumption (like under shade to minimize the use of air-condition), installation of required V2I technologies for traffic light control, or other needs, ramps for wheel-chair passengers, etc.

Furthermore, the PTO should create a new IT center for the management of the AVs, and a vehcile maintenance center and of course train the personnel to the new technologies and transport models.

The choice of the AVs in such high number will also be a challenge, depending on the available offers and how to compare the quality of the automated drivers and their adequacy to the local city and weather conditions (narrow roads, frequent rains, vegetation, etc).

2.2.6 Transport services

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The driver in a public transportation vehicle is not simply drives the vehicle, but offers a number of formal and information services, from controlling the status of the vehicle, resolving small incidents, providing information to passengers and offering a safety feeling to the passengers. Its suppression means that all these services must continue being offered, otherwise we will have radical quality of service degradation. Many solutions are proposed and are implemented, based on live surveillance of the vehicle and its passengers. Systems that are able to identify aggression in the vehicle, vandalism, as well small malfunctions, are developed and tested. However, this can very fast turn to a regulatory nightmare, since it is based in video surveillance of passengers. Do we store the video for later analysis? Do allow the back-office operator to see the live video and decide of an action to take? In a service like "follow my kid" where a parent will be able to track the presence a depended person in the bus using face recognition, how we handle the need that we will scan all faces trying to identify one of them?

2.2.7 Transport policies

Assuming that the above logistic, technology and infrastructure issues have been resolved, the PTO will face a new challenge, due to the radical paradigm change, from fixed line operation to on-demand, door-to-door driverless operation. New transport policies need to be designed, that will be socially acceptable and support the economic viability of the service. Some examples of the required transport policies that need to be defined include: a) what is the minimal distance a passenger can order a trip? Do we allow trip of 50m? (considering that ordering a vehicle to divert its route by 200m to serve a 50m trip will be highly expensive and might end up degrading the service quality). b) Do we differentiate trip price based on trip distance (going away of today's flat rate models)? c) What should we do for no-shows? Do we allow the passenger to order a trip and not use it? Do charge the trip at all cases? d) how long should the vehicle wait the passenger? 1 minute, 5 minutes? Knowing that any delay will affect the service quality and might end up to "no -show" situations, e) how do we make exceptions for elderly, people with special needs etc? f) do we provide for special services, like if a passenger wants to be alone in the vehicle ? this can be the case for night service when we transport vulnerable passengers. g) how do we handle false reservations? For example, a passenger reserves for one person, but enters with two large suitcases, taking up all the space in the vehicle, h) how we react to incidents (from small vehicle malfunctions, to passenger related incidents)? We need to have intervention teams roaming the city, but what are the delays to intervene? How we distinguish of different types of incidents the urgency to intervene? i) what we do in case of incidents in the vehicle, like vandalism, aggression etc? do we stop the service and send an intervention team? Do we store the video and refer to the authorities?

The PTO will need to define new policies, in coordination with passenger associations and of course state authorities and these policies should be integrated in the fleet management services via an incident service dashboard. Some of the incidents (but which?) would be able to treated automatically, while other will require human intervention. Furthermore, the modification of policies and reactions should be very simple to introduce, so that the back-office operator can change them dynamically.

2.2.8 Idle vehicles during off-peak hours

One of the advantages of using automated vehicles in public transportation, is that the vehicle is operating only when there is a need. This means that during off-peak hours an important number of vehicles will be sitting idle in a parking spot waiting for the demand to go up. This saves energy, from one hand, but has high cost (we cannot have vehicles that are used just 30% per day (7 hours /24)). We thus need to find ways to reuse the vehicles. This can be done by making the vehicles available for non-public transport usage. Since the vehicles have all the authorization to operate in the city streets, we can use them for services like urban logistics or private transport. This can be done by creating a platform implementing *Vehicle as a Service* model, where the excess capacity of the AV

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fleet becomes available to be used by other service providers (like LaaS). The control of a vehicle can be passed to another urban transport provider (Logistics or person), under well defined Service Level Agreements (SLAs). This way we can have virtual operators, using the excess capacity and offering non-public transportation services. This can become an important revenue source for the PTOs, allowing them to better valorize their vehicles.

3 Making a dream come true

Today, as we have seen from past projects and initiatives, we are in the crossroad for the deployment of AVs in public transportation. From one side many PTOs have experimented with AVs for short or long periods, identifying the possible advantages in adopting the technology, but can not afford to continue small demonstrator deployments and thus they terminate the experiments, while from the other side the vehicle manufactures need to increase the number of AVs deployed (and thus their revenue) in order to be able to work and improve the shortcomings identified in the experimental deployments. The net result is that the lack of a market does not allow manufacturers to invest to vehicle improvements and the lack of improved vehicles does not allow the PTOs to large scale deployments. The evolution is thus very slow. This is where, in Europe, the support of European commission can play a major role, but providing the seed money required. In this direction the European Commission is funding a large number of projects under the Horizon 2020 and Horizon Europe frameworks.

3.1 The H2020 AVENUE project

One of the major and successful deployments of on-demand, door-to-door public transportation was achieved within the Horizon 2020 project AVENUE [13]. AVENUE, is a four and a half years H2020 project financed by the European Commission. The project started in May 2018 and will be completed in October 2022. With 22 partners and a 15.5MEUR funding, the project has designed and carried out full-scale demonstrations of urban public transport services with fully automated vehicles, in 6 European demonstrator sites (Geneva, Lyon, Copenhagen, Luxembourg, Sion, Esch-sur-Alzette). The project deployed, for the first time worldwide, small fleets of automated minibuses in low to medium demand areas offering fully automated on-demand, door-to-door, shared public transportation services. The AVENUE vision for future public transport in urban and suburban areas is that automated vehicles will ensure safe, rapid, economic, sustainable and personalised transport of passengers. AVENUE introduced disruptive public transportation paradigms on the basis of on-demand, door-to-door services, aiming to set up a new model of public transportation, by revisiting the offered public transportation services, and aiming to suppress prescheduled fixed bus itineraries.

As the end of the AVENUE project is near (at the time of writing this paper), the mission to have demonstrated that automated vehicles will become the future solution for public transport and provide recommendations and guideline for the different actors, was largely achieved. The AVENUE project has demonstrated the economic, environmental and social potential of automated vehicles for both public transport operators and commuters, and we were able to identify the needs for a successful service deployment of automated vehicles in public transportation[14].

3.1.1 Overview of the AVENUE project results

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

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In the AVENUE project we are operating SAE Level 4 vehicles (NAVYA Autonom Shuttle [15], with a capacity of 14 persons, and authorized to operate at a maximum speed of 25-30 km/h), depending on the local regulatory framework. In the current demonstrators the speed does not exceed 23 Km/h, with an average operational speed of 14 to 20 Km/h. Another, more important reason for limiting the vehicle speed is safety for passengers and pedestrians. Due to the fact that the current LIDAR has a range of 100m and the obstacle identification is done for objects no further than 40 meters, and considering that the vehicle must safely stop in case of an obstacle on the road (which will be "seen" at less than 40 meters distance) we cannot guarantee a safe braking if the speed is more than 25 Km/h. Note that technically the vehicle can make harsh break and stop with 40 meters in high speeds (40 -50 Km/h) but then the break would too harsh putting in risk the vehicle passengers. The partners in the project are working in finding an optimal point between passenger and pedestrian safety.

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

A series of passenger services were introduced and validated in the project [16]. With the use of an on-board computer and on-board cameras microphones, we developed and tested several safety services. The system installed was able locally identify aggressions, vandalism, forgotten objects, number of passengers, available space, and send a incident notification to the back-end operator for further action.

In addition with the collection of real data from long term deployments, and by incorporating known data from traditional public transportation service, we were able to develop a economic analysis tool [17], that allowed us to estimate the deployment of a public transportation service, given the different options (from site size, quality of service level (waiting delays, transport delays), number of vehicles, costs of vehicles etc).

3.2 The road ahead - the Horizon Europe ULTIMO project

Strong with the experience gained in the AVENUE project a more ambitious project was launched in the Horizon Europe Framework, the ULTIMO project. A 4 years project (October 2022 to September 2026), with 23 partners and a total contribution of 40 MEUR (24MEUR from the European Commission and 16 MEUR from the Swiss Federal Government) targeting to create and deploy in three sites in Europe the very first viable, economically feasible and sustainable integration of Automated Vehicles in user centric Public Transportation services, with integrated LaaS urban goods transportation. The ULTIMO project aims in resolving all the issues presented above, making the dream come reality.

Within ULTIMO we will deploy SAE L4 AVs into large scale (3 sites, each with 15 or more multi-vendor AVs per site), user-centric, on-demand, door-to-door, shared, seamless-integrated in a MaaS with economically viable public transportation and logistics services, with target the operation without safety driver on-board, in fully automated, mission management mode and with the support of innovative user centric passenger services. All aspects for improving the services for citizen to offer a real alternative to privately owned cars will be addressed. A further focus will be to enable viable economic deployments, ranging from valorization of past investments (older vehicles), development of economically sustainable passenger and transport services without safety driver, and introducing the concept of vehicle chartering for vehicle reuse in LaaS services.

In the ULTIMO project we will develop and integrate standardised APIs for vehicles and fleet management services, validate the dynamic change of fleet management service provider, integrate multi-vendor vehicles in a plug and play model, and most of all, design passenger service in direct collaboration with the service users.

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