Chapter

Autonomous Vehicles toward a Revolution in Collective Transport

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Abstract

Autonomous public transport is not a fantasy anymore. At least 92 experimentations with autonomous shuttles for collective transport (ASCTs) have been running in different cities around the world. The deployment of autonomous shuttles opens up a wide range of possibilities in rethinking urban mobility, with a greater focus on users, new services, and reduced urban traffic congestion. The prospective analysis of these possibilities produces original, innovative forecasts with new scenarios for ASPT based on three strong drivers of change, i.e., technological innovation, new mobility behavior, and new business models for public transport. Furthermore, the deployment of ASCTs will considerably modify costs of urban externalities and extend inclusion. The chapter presents how the implementation of autonomous shuttles may revolutionize the public transport.

Keywords: autonomous shuttle, prospective, public transport transformation, autonomous shared mobility

1. Introduction

With 55% of the world's current population living in urban areas and estimates of 68% by 2050, mobility has been playing a fundamental role on our daily lives. It not only affects our well-being and life quality, but it also dictates where people work, were people live, and thereby on how people commute [1–3].

Nevertheless, our current means of transport are reaching their social, economic, and environmental limits. Our car-dependent and fossil-fuel-reliant societies are becoming sources of major problems, such as increased congestion, severe air pollution, noise, and many other externalities associated with transporting people and goods. Thereby, there has been a worldwide consensus that efforts are needed to develop more sustainable transport solutions [4].

Recent advances and innovations in technology and digitalization are presenting significant impacts on designing sustainable mobility concepts to counteract this trend [5]. The complexity of the automotive sector has dramatically grown over the past 10 years, mainly due to technology disruption, changes in regulations, as well as transformations in users' behavior [6].

As highlighted by many authors, on-demand mobility services, autonomous driving, dynamic pricing algorithms, and vehicle electrification will change the way people experience mobility in urban environments. This is clearly highlighted by a 2018 report from PriceWaterhouseCoopers [7]; according to the company's report, the car of the future will be EASCY: electrified, autonomous, shared, connected, and yearly updated.

That is, the mobility of the future will be much easier, more flexible, and user-centered. In this new mobility paradigm, autonomous vehicles (AVs) are expected to play an important role in urban mobility contexts, reducing the number of accidents and pollution, reducing transport costs and time, improving traffic efficiency as well as productivity, and promoting social inclusion for those who cannot or do not want to drive [8–10]. However, the proliferation of AVs is far from guaranteed, since complex issues related to legal aspects, liability, privacy, licensing, cyber-security, insurances, and so on still need to be further addressed and developed [11, 12].

Thereby fleets of private autonomous cars are not likely to be seen on roads and streets in a perceivable feature [13]. The most revolutionary impact of AVs will probably be on collective public transports. The introduction of on-demand mobility in collective public transport will deeply transform collective transport uses and business models, thereby undoubtedly attending to a real paradigm shift [14].

Autonomous shuttles for collective transport (ASCTs) are a technological urban mobility solution aimed at meeting the demand of first- and last-mile commute as well as microtransit. Their emergence promises to take advantage of connected AVs to allow Mobility-as-a-Service (MaaS) schemes [15], with a wide array of scenarios' deployments, such as urban centers, central commercial districts, university campuses, airports, shopping malls, hospitals, etc.

Within this context, a significant group of entrants have been carrying out trials and demonstrations worldwide with ASCTs [16]. However, like many other technology push innovations, there is still much to learn about the operation of such vehicles, not only from policy and regulation perspectives but also regarding business models, impact on communities, user acceptance, and demand [17].

In this sense, this chapter proposes to discuss the most relevant experimentations with ASCTs worldwide, by presenting an overview of the countries and cities with most deployments, the most prominent shuttle manufacturers, and the most recurrent typologies of use, prevailing business models, and so on. It also aims to provide an in-depth view on selected successful deployments of ASCTs, especially regarding their social and economic impacts, and at last, we intend to lay grounds for what will be the future social, economic, and environmental implications of the insertion of ASCTs. We intend to lay grounds on a new paradigm for collective transport, via shared on-demand mobility.

This study is part of the European project AVENUE, the Autonomous Vehicles to Evolve to a New Urban Experience project [18], an EU funded project which debuted on May 1, 2018, and will last for 48 months. It aims to design and carry out full-scale demonstrations of urban transport automation by deploying, fleets of autonomous shuttles on mixed traffic conditions in low-to-medium-demand areas of four European demonstrator cities: Geneva, Lyon, Copenhagen, and Luxembourg, by providing innovative services, like on-demand door-to-door transportation and multimodal commute solutions.

Besides this introduction, the chapter is structured as follows: Section 2 presents an overall benchmark on 92 experimentations with ASCTs worldwide. Section 3 presents a more in-depth analysis on 11 of these 92 experimentations, divided into three main European projects. At last on Section 4, we propose a prospective view of ASCTs implementation that pictures how it may revolutionize collective transport.

2. Worldwide benchmark with ASCTs

The implementation of ASCTs can be considered as a building block for the urban mobility revolution, in a sense that it involves a wide range of stakeholders from the most diverse fields as well as it pressures policy makers to act on changing and updating regulations [19].

In fact, as pointed out by Harris (2018), there is still much to learn about the operation of ASCTs from policy and regulation perspective as well as regarding business models and consumer acceptance. However, information regarding the scope of the implementations is still scarce, nonstructured, and pulverized.

Thereby, Antonialli [20] carried out an international benchmark study of ASCTs as a way to better understand such issues. The author's research (carried out on September 2018) was not limited to current (ongoing) experimentations; in this sense, finished projects as well as projects yet-to-start were also considered. Over the next pages, we briefly summarize the author's main findings.

In total, 92 experimentations were sampled, of which 50 had already been finished, 31 were currently running, and 11 were still going to be initiated. These 92 projects unfold in 78 cities spread over 32 countries worldwide.

Figure 1 depicts the geographical dispersion of the projects worldwide. Europe is on the lead regarding the total number of experimentations, that is, from the 32 countries that composed the sample, the continent holds 20 and that together comprise a total of 53 from the 92 projects (58%). Next comes Asia with 15 experimentations across 8 countries (16%), followed by North America (14%) with 13 projects divided among the USA and Canada, and, at last, Oceania presents 11 projects spread across Australia and New Zealand (12%). It is worth noting that no country in South America, Central America, and Africa were present in the sample.

Another interesting analysis is that Europe is not only on the lead when it comes to the total number of experimentations, the continent also holds the largest number of shuttle manufacturers. According to the author, Europe holds 9 of the total of 20 OEMs, which are responsible for providing the shuttles for 80 out of the 92 experimentations (a total of 87%).

Notwithstanding, it is important to highlight the relevance of the French startups Navya and EasyMile. The two companies are global leaders regarding both manufacturing and deployments of autonomous shuttles.

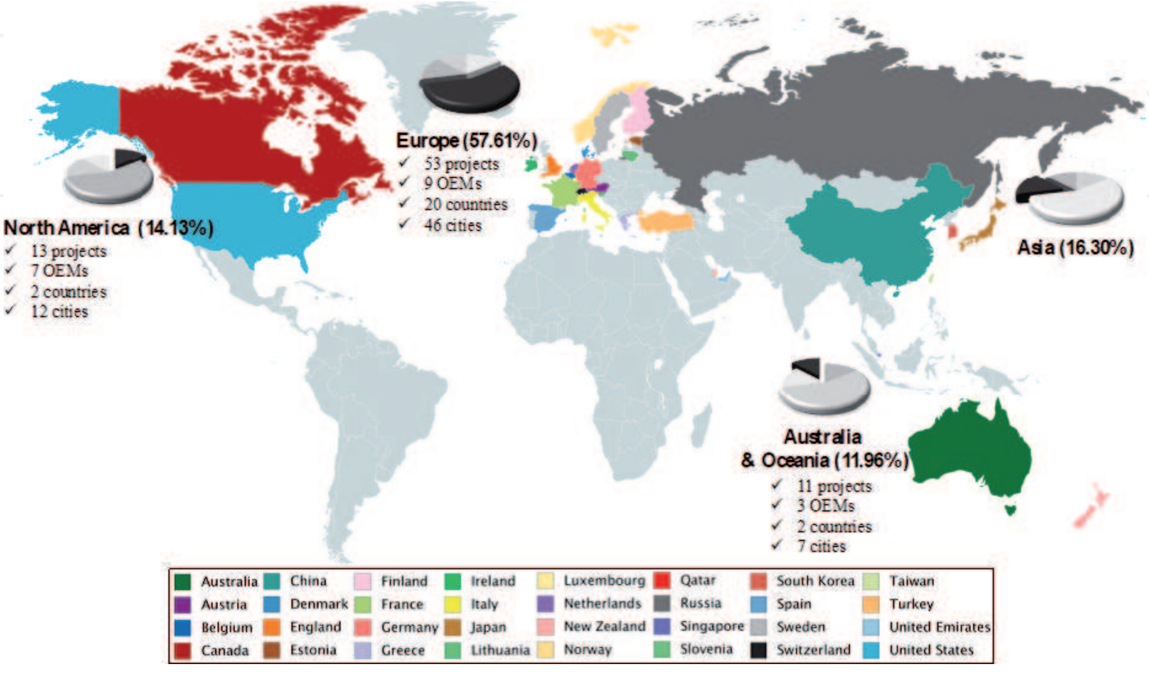

Figure 1.
Experimentations with ASCTs worldwide. Source: [20].

	EZ10 by EasyMile	ARMA by Navya
Capacity:	12 passengers (6 sitting and 6 standing)	15 passengers (8 sitting and 7 standing)
Cruising speed:	20 km/h	25 km/h
Maximum speed:	40 km/h	45 km/h
Propulsion engine:	Electric	Electric
Length:	3,93 meters	4.75 meters
Width:	1,99 meters	2.05 meters
Height:	2,75 meters	2.55 meters
Vehicle cost:	200,000 to 220,000€. ($223,180 to $245,498)	200,000€ ($223,180)
Maintenance costs:	30,000€/year ($33,477/year)	90,000€/year ($101,511/year)

Figure 2.
Navya's ARMA and EasyMile's EZ10 technical specifications. Source: [20].

With the greatest number of ongoing projects and projects yet-to-start (16 and 2, respectively), Navya is the current market leader. The company was founded in 2014 in Lyon and launched their ARMA shuttle (with capacity of 15 passengers) in October 2015. On November 2017, they launched a new product, named "Autonom Cab," which they claim to be the first robot-taxi in the market. The vehicle, with capacity for six passengers, was designed to work as an on-demand service, for both hide-hailing and shared hide-hailing (which would be autonomous counterparts of services like Uber and UberPool).

EasyMile, on the other hand, is seen as Navya's main competitor [21]. The company is the result of a joint venture between Ligier (vehicle manufacturer) and Robosoft (high-tech robotics company). It was also founded in 2014 with its headquarters in Toulouse, and their autonomous shuttle, the EZ10 (with capacity for 12 passengers), was developed with the help of the CityMobil2 project, and it has been deployed on projects in Australia, Canada, China, Estonia, Finland, France, Germany, Ireland, Japan, the Netherlands, Norway, Singapore, Spain, Sweden, Switzerland, the United Arab Emirates, and the United States.

Figure 2 depicts the main technical features of both shuttles.

Autonomous shuttles can be described as a "technology push" innovation. In this sense, in order for ASCTs to succeed in the market, it is essential for the general public to be acquainted with the technology and its use forms, not only to cease their inherent human curiosity but also as a way to build trust.

In this sense, the benchmark shows a predominance of:

- Showcases (21%): Where ASCTs are demonstrated to potential consumers in hopes of (1) getting them acquainted to it and/or (2) getting them to acquire it

- Trials (69%): Temporary offering (mainly in fixed, looped routes in controlled environments) allowing consumers to examine, use, or test the ASCT prior to fully committing company resources to a full launch

- Regular services (10%): permanent (paid) transportation service from point A to B via an ASCT

Thereby, due to this inherent "technology push" nature of the deployments, most of the experimentations were mainly offered free of charge to riders (94% of the total sample). As for the road environment, 52% of the deployments were set to take place in closed/controlled areas (e.g., university campuses, parks, hospitals, resorts, airports, and other designated roads); the remaining 48% were set to run in mixed traffic conditions with low-to-medium-demand areas.

Since the testing with autonomous vehicles is not yet legal in all countries and regions, it is worth highlighting that in all 92 sampled deployments, a human operator was required to be onboard the vehicle at all times as well as the operating speeds were not higher than 15 km/h.

91% of the experimentations were classified as regular-line transport (RLT). On the other hand, only 4.5% of projects were fit under demand-responsive transport (DRT), and the last remaining 4.5% were offered in both RLT and DRT modes. Thereby, as stated by the author, as more countries and cities begin to allow testing the circulation of AVs, the percentage of DRT autonomous mobility is likely to increase, since the major value proposition claimed by ASCTs' manufacturers is to facilitate the first- and last-mile commute as well as microtransit.

Based on the aforementioned elements, a set of typologies of use for ASCTs can be synthetized in **Table 1**.

Regarding the business models toward private transportation (in blue), only three experimentations were found, all within the scope of regular-line transport, those being: May Mobility (American shuttle manufacturer) transporting Quick Loans workers in Detroit from parking lots to their office buildings; (typology 2) and Navya transporting workers in the Civaux nuclear power plant in France and in Sydney Olympic Park in Australia (typology 3).

Regarding public transportation offerings, a total of 89 experimentations were identified, covering all 8 of the typologies proposed. 79 of these experiments (89%) fit RLT, with 23 (26%) projects in typology 1 (first- and last-mile RLT in closed traffic), 17 (19%) in typology 2 (first- and last-mile RLT in mixed traffic), 18 (20%) in typology 3 (microtransit RLT in closed traffic), and 21 (24%) within typology 4 (microtransit RLT in mixed traffic). The remaining projects (11%) in public transportation contexts were identified as belonging to DRT.

Some relevant examples were Navya's trials at the confluence district in Lyon (France), the last-mile commute at the Swiss city of Sion, and in Las Vegas offering a looped microtransit commute downtown. Also worth mentioning are EasyMile's

Typologies of uses for ASCTs		Number of experiments	%
1	First- and last-mile RLT in closed traffic	23	26
2	First- and last-mile RLT in mixed traffic	17	19
3	Microtransit RLT in closed traffic	18	20
4	Microtransit RLT in mixed traffic	21	24
5	First- and last-mile DRT in closed traffic	1	1
6	First- and last-mile DRT in mixed traffic	1	1
7	Microtransit DRT in closed traffic	4	4.5
8	Microtransit DRT in mixed traffic	4	4.5
Total		**89**	**100%**

Source: [20].

Table 1.
Classification of experimentations with typologies of use.

efforts in Calgary and Edmonton (Canada), offering a looped closed-road microtransit commute for tourists, as well as their deployments in Germany (Ioki project), in Norway (Kolumbus project), and in the United States (GoMentum station project).

As for DRT examples, it is worth highlighting the shuttle service offered by Navya on Paris Charles de Gaulle Airport, connecting passengers from the RER train station to the airport's terminals and the Schöneberg's district experimentation in Berlin, where Local Motors (American Shuttle Manufacturer) has tested an on-demand ride-hailing service based on their shuttle's (OLLI) artificial intelligence system.

As a final analysis on the benchmark study, a framework was drawn with the aim of identifying the main common stakeholders for all experimentations by listing four main groups, (1) private entities, (2) public entities, (3) communities, and (4) others, and also by describing how different forms of value (financial, usage, research, and data) is likely to flow among to and from stakeholders.

By doing so, the author concluded that ASCTs are embedded in a business ecosystem [22, 23] in which growth and evolution depend on the synergy and value flows among all stakeholders. Therefore, under the upright policy, large urban centers could strongly benefit from the introduction of ASCTs [24]. For the authors, besides of being the first- and last-mile connection to mass transit, ASCTs could compete with automobiles by price and be more effective than traditional public transport busses (by taking 10 instead of 150 passengers), being on-demand instead of on-schedule and moving on flexible routes instead of fixed ones.

Nevertheless several issues and assumptions regarding the social and economic impacts of these experimentations could be raised. In this sense, over the next section of this chapter, an in-depth analysis of three selected European project is made in order to address the aforementioned impacts with the aim of learning from these existing experimentations and understanding what could be applied and/or avoided in future projects and deployments.

3. Social and economic analysis of ASCT

For now, the technology itself is no longer the major hindrance for autonomous shuttle implementation, and the deployment speed is very much liked to the socioeconomic impacts of ASCTs on the transport system. It is therefore essential to explore the degree to which these shuttles may prove beneficial or adverse in achieving common societal and economic goals and achieve a better understanding of how transport users and society at large perceive and value their future use.

Therefore, we analyzed more deeply three main European projects (CityMobil2, SOHJOA, and GATEway) by identifying the most relevant social and economic findings as well as understanding how such results may contribute to future projects and trials.

We selected these three projects based on four criteria, in a sense that experimentations should have been (1) finished/completed, (2) deployed in mixed traffic conditions (not on exclusively dedicated roads), (3) mid- to long-term trials and/or regular services (short-time showcases were not considered due to their limited data-gathering potential), and (4) easy accessible (with public available final reports, academic papers, news, videos, blogs, and etc.).

The CityMobil2 project was a European Commission-funded project carried out from September 2012 to August 2016. It aimed at fostering the implementation of ASCTs in seven European cities spread across six countries; the general objectives included the study of long-term socioeconomic impacts of automated mobility and the definition of a legal framework that would allow ASCTs on urban roads.

CityMobil2 covered more than 25,000 km driven by the autonomous shuttles and carried over 60,000 passengers. The project is—to date—the most extensive trial with ASCTs worldwide [24].

The physical and virtual innovation platform of autonomous last-mile urban transportation (SOHJOA project) was a Finnish consortium—funded by the European Regional Development Fund—lead by the Metropolia University of Applied Sciences, from June 2016 to May 2018. The project was the first of its kind to introduce ASCTs in mixed traffic conditions on Finnish roads. It aimed at utilizing an enterprise- and area-based approach to creating new innovations and understanding related to the use of autonomous minibusses in last-mile transportation for the benefit of both the public sector and companies. Trials were carried out on three demonstrator cities (Espoo, Helsinki, and Tamper) carrying passengers over small mixed traffic looped routes (no longer than 1 km) and having to face Finland's harsh weather conditions.

The Greenwich Automated Transport Environment (GATEway project) was a British-founded consortium—jointly funded by the government and industry—that took place from July 2014 to the end of 2017 in London at the Greenwich Peninsula. It was divided into three main experimentations: (1) an autonomous shuttle service, (2) simulations and trials on how automation is supporting accessibility for disabled people, and (3) simulations and trials with autonomous delivery of goods [25]. The shuttles' project ran during April 2017 in a 1.6 km mixed traffic route (among pedestrians and cyclists) on the Greenwich Peninsula. A total of 2310 trips carrying a total of 320 were completed yielding in a total distance covered of 3700 km. It is worth noting that different from the other two projects described here, the shuttles used on GATEway, had a capacity of transporting a maximum of four passengers at a time, while the shuttles on CityMobil2 and SOHJOA could carry two or three times more passengers.

All shuttles deployed in the three analyzed projects were in accordance with SAE level-4 vehicles [26], which, for legal and safety reasons, were only allowed to drive at slow speeds (no more than 15 km/h) and were required to have a human operator on board at all times—in case automation failed.

3.1 Social impacts of autonomous shuttles' deployments

Over the past years, there has been a large number of studies aimed to investigate the acceptance of automated vehicles by gathering social-demographic, mobility, psychological, functional-utilitarian, and symbolic-affective characteristics [24]. However, most studies have focused on AVs with steer and pedals, as a result, knowledge on the factors that drive the acceptance of ASCTs in real environmental conditions is still limited [27].

Thereby, the three sampled projects were mainly focused on gathering such social insights from users, regarding acceptance, trust, willingness to use, shuttles' interactions with pedestrians, cyclists and other vehicles, and so on. Furthermore, all three projects were consistently safety-focused. Since in order to be socially accepted (and thereby used), ASCTs will need to be reliable and safe.

The main social results obtained in the sampled trials have shown positive attitudes toward the implementation of ASCTs, with the general public perceiving the vehicles as convenient, accessible, and safe. About two-thirds of the respondents stated that they would choose an automated bus if both automated and conventional busses were available in a route [28]. Most participants were positive about the safety benefits, believing that ASCTs would be either safer than or as safe as human-driven vehicles, hence considering useful to implement ASCTs services on a permanent basis.

People's first impressions were a mix of curiosity, amusement, and an urge to try something new. As reported by [29], most users made their trips to test the shuttles, that is, occasional trips were much more frequent than systematic ones. Thereby, the provided services will have to meet people's actual mobility needs in order for ASCTs to be accepted and used.

Levels of distrust and fear have also been reported. According to GATEway's final report, building the public's confidence in the technology will be a critical factor in ASCTs' successful adoption. However, as depicted by [30], trust formation is a dynamic process that starts long before a user's first contact with the system and continues long thereafter. One good experience already enhances the personal feeling of safety considerably [31], but according to the authors, people still have hesitations about the general safety of ASCTs, in a sense that opposite to a human driver, mistakes will not likely be so easily accepted.

In this sense, quality of service was an indicator that clearly needs improvements: lower operational speeds, abrupt braking, and occasional localization problems, longer waiting times, better locations and routes, comfort complaints (limited seats), information availability, etc. are all issues that require urgent attention. In addition, providing the correct infrastructure and increasing public engagement and awareness of the vehicle's capabilities are also likely to increase the acceptance of these AVs.

Furthermore, as people become more familiar with ASCTs, the excitement and enjoyment of using them may decrease [32]. Hence, in order to maintain higher satisfaction levels, manufacturers and service providers will need to ensure that these systems perform to an optimum level and are reliable, along with optimizing their connectivity with other transport services [33].

The pathway to adoption and social acceptance of ASCTs should be incremental and iterative, providing users with hands-on experience of the systems at every stage, thereby removing unrealistic and idealized expectations which can ultimately hamper acceptance.

The private semiautomated vehicle available today and in the near future provides a level of convenience and comfort which is perhaps superior to ASCTs. Therefore, for those kinds of vehicles to be considered a serious alternative to privately owned vehicles, city authorities will need to work with manufacturers and suppliers to enable the development of some—if not all—of the current features offered by privately owned vehicles.

3.2 Economic impacts of autonomous shuttles' deployments

Results on economic impacts were not widely explored in the projects in the same way as social acceptance impacts were. Hence, robust results on economic aspects were not addressed or were not disclosed on the projects' publications. The few results found were mainly concerned with users' willingness to pay for the services and the potential to reduce fares (due to the lack of a human driver).

The majority of respondents on the CityMobil's trials were positive about ASCTs if the service was offered at a lower price (with fares compatible to those of public transport) [34].

On the GATEway project, participants stated that they would be willing to pay an average price of around £2 to use ASCTs (less than the average price of a single-journey ticket in London), also believing that the shuttles have the potential to be more economical (regarding fuel/energy consumption) and therefore better for the environment.

Results from SOHJOA also state the elimination of drivers' wages as a positive outcome. However interestingly, users were not hoping for a consequent reduction on fare costs; it was hoped that the funds saved would be used to improve the quality of the mobility services (e.g., more frequent lines, on-demand services, and operations around the clock). Thereby, the authors stated that reduced costs are not necessarily considered to improve customers' quality of life but that better services are more likely to do that.

Taking into account all the aforementioned results, an interesting discussion arises. Most of the autonomous shuttle pilots aimed mostly on (1) integrating their services into the public transportation system, (2) testing the technology and circumstances, and (3) looking at people's standpoint on autonomous vehicles—since one of the biggest concerns, along with the technical performance, is to see how the general public accepts autonomous shuttles.

Exposing commuters to the technology at very early stages on a small-scale and under controlled conditions makes it possible to gradually and slowly expose and familiarize them with ASCTs' technology [34]. In this way, the introduction of automated vehicles can be linked to the creation of realistic expectations, which have been defined as a key driver of acceptance [35].

We agree with the assertions made by the authors. However, we believe that the relevance of the economic impacts are not receiving the deserved attention and thereby are somewhat being neglected. We believe that it is indeed pivotal to understand social acceptance for proper implementation of ASCTs; however, we also advocate that economic aspects also comprises the concept of acceptance.

Nevertheless, we argue that economic aspects shall not be treated as "ceteris paribus" in the data collection of experimentations with ASCTs. Their implementation requires synergy and alignment of value flows among multiple stakeholders (e.g., shuttle manufacturers, transport operators, client cities or firms, end users, digital service providers, local transport bodies, and R&D centers). Thereby, understanding economic aspects, such as costs structures, revenue flows, taxes, subsidies, investments, etc., in this business ecosystem is fundamental for successfully implementing ASCTs.

The technological evolution of the area is evident. However, it is still necessary to understand broader aspects of the industry, such as the market factors surrounding them and other economic and managerial issues [36].

Within this context, we can identify a possible gap between such technological advancements on vehicular automation and its eventual market insertion and consolidation as business models play an extremely important role in the events that precede AVs' market introduction [37].

The ultimate success of ASCTs will only be achieved following an effective collaboration between the manufacturers and local and central government, to provide citizens with the most suitable options for each specific environment.

4. A new paradigm for collective transport: Shared on-demand mobility

While the shift toward shared AV operation could indeed have a significant impact on safety, as more than 90% of road accidents are caused by human error, a shift toward shared mobility has the potential of significantly reducing the urban space allocated to parking, as well as pollution and congestion. Combining AV and collective transport may be the solution for a more citizen friendly urban space.

Besides, commuters and city's inhabitants are more and more expecting a new type of mobility that is more sustainable but also more flexible than the everyday mobility they have been used to for a long time. If they claim to be ready to share their mobility, they also require a customized mobility. In the framework of Mobility-as-a-Service, the city's authorities have to supply their voters with shared on-demand mobility.

An evolution of this type goes beyond seeing an autonomous shuttle simply as a new product but rather as a new system, the product-service system (PSS), combining technological innovation with service and market innovation. The PSS may be developed within new business models [38].

New business models are emerging from the transformation of the mobility ecosystem largely supported by digitalization. "Digitalization is a sociotechnical process that leverages the technical process of the encoding of analog information in a digital format (digitizing) applied to broader social and institutional contexts, transforming their sociotechnical structures, thus rendering digital technologies infrastructural" [39].

In the automotive industry, the potential transformation enforced by digital innovation is inducing business model innovation that can widen horizons and business paths that may impact companies' strategies toward greater sustainability and more customer services.

> *"MaaS predicts a paradigm with service providers offering travelers easy, flexible, reliable, well-priced, and environmentally sustainable everyday travel, mixing public transport, car-sharing, car leasing, and road use, with more efficient goods shipping and delivery possibilities" ([40], p. 248). "It opens up opportunities for greater customer service and potential reductions in public subsidy for public transport service; it has the very real opportunity to match customer needs more closely to service supply" ([41], p. 90).*

Indeed, as RethinkX's report [42] states: "by 2030, within 10 years of regulatory approval of autonomous vehicles, 95% of passenger miles traveled will be served by on-demand autonomous electric vehicles owned by fleets, not individuals, in a new business model called "transport-as-a-service."

Transportation-as-a-Service (TaaS) sits at the intersection of four macro trends: the technology that offers autonomous vehicles, the social demand for energy transition that pushes electrified vehicles, the overall connectivity, and the sharing economy that transfers property to usage. It involves a shift away from ownership of modes of transport toward mobility solutions that are consumed as a service.

As Mulley ([40], p. 249) states: "one of the biggest hurdles for transition to a Mobility as a Service business model is the need for a cultural shift, away from personal car ownership and reliance, toward the multiple, often shared and public mobility offerings."

That is the reason why the transition can only be started with public transport targeting specific customers, such as younger or older people, people with reduced mobility, and disabled people. For these targets, MaaS will widely increase their mobility because it will offer "mobility-on-demand," ensuring a completely new perspective in terms of mobility for people in need, reducing costs and time spent in transportation systems, and offering comfort to those who do not want to or cannot drive.

ASCT will potentially enable communities of citizens to gain greater access to opportunities for employment, education, health, and social interaction. These social benefits are likely to be particularly relevant for travelers with additional needs, such as those who are elderly, persons with disabilities, and those living in areas that are underserved by the existing transport provision.

In fact, the most remarkable asset for MaaS will undoubtedly be the portfolio of demand-responsive services, "using big data to innovate entirely new operations models to deliver new products and services based on a closer understanding of customers' on-going needs" ([43], p. 4).

Thus, we can imagine usage scenarios for an autonomous shuttle fleet operating in an urban area, bringing both more flexibility to the users and a larger variety of

Time slot	Mobility services
6–9 AM Point-to-point	Transportation with predetermined stops for regular, fixed time mobility (employees and schoolchildren)
9–5 PM On-demand	Transportation of goods (last mile) in city centers for retailers and individuals, with booking and connection to track the delivery process in real time
	Transportation for targeted needs (people with reduced mobility, leisure centers, care centers, specific goods, etc.)
	Transportation for disabled people at set times
	Transportation for city tours and outings
5–8 PM Point-to-point	Transportation with predetermined stops for regular, fixed time mobility (employees and schoolchildren)
8–6 AM On-demand	Night transportation for specific and emergency requests (like injured or sick people, delivery, deliveries for hospitals, tourist trips, etc.) Specific requests should be privately funded (individuals, travel agencies, retailer associations, etc.)

Table 2.
Scenario for a typical week day for the autonomous fleet.

business models for the transport operator. For each use, the operator may find a specific funding: subsidiaries for citizen mobility, companies for freight, Ministry of Health for disabled people, Ministry of Education for pupils, etc.

The list of user requirements for traditional forms of transport in urban centers is quite infinite: school journeys, home-to-work journeys, transport for disabled people, last-mile delivery, transport for medical care, sports and cultural activities, tours, goods deliveries, etc.

In a prospective vision featuring a totally autonomous shuttle (level 5), mobility services operate nonstop (24/7) without additional wage costs. All users are connected to the shuttle's navigation system, which must be constantly updated to ensure the service quality.

Three scenarios are currently possible: shuttle fleet management alternating predetermined journeys with request journeys, shuttle fleet management adapted to specific weekend needs, and shuttle fleet management based entirely on request journeys.

The scenarios allow a wide range of journey requests that have to be optimized by alternating point-to-point journeys, characterized by predetermined and fixed stops supporting high passenger flows, with on-demand journeys, characterized by mobile stops supporting shifting times and specific requests (**Table 2**).

Mobility-on-demand (for people or for goods) is the cornerstone of autonomous fleet deployment that could easily be combined with conventional, regular transport management featuring predetermined stops and times. A different schedule could be available during holiday periods, with more frequent shuttles during the day for tourists or citizens' leisure activities in the city.

The optimum scenario for urban mobility involves designing shared and optimized mobility-on-demand based on a constant connection between the shuttle's navigation system and the users' digital interface (smartphone or computer) in a sharing perspective.

Shared mobility-on-demand will be designed with data mining technologies using personal data to create digital people-grouping pick-up stops and common traveling time slices that will optimize autonomous fleet management. Data management and machine learning should help integrate unanticipated requests into a global optimized system. This definitively anchors mobility within a MaaS perspective.

5. Conclusion

By aiming at forecasting the future for autonomous collective transport, we conducted a benchmark on experimentations with ASCTs worldwide; the present study identified 92 deployments, spread across 78 cities in 32 countries, being enabled by 20 different shuttles' manufacturers. Figures show that Europe is at the forefront not only in experimentation numbers but also on shuttles' R&D.

By analyzing the prevailing business models, we observed that the vast majority of experimentations fit B2C models, that is, toward public transportation with ordinary commuters consisting as the main revenue source for the service provider.

Regular-line transport system comprised the vast majority of operation models; however, demand-responsive transport and mixed models comprising both regular and on-demand models are increasing, as more countries and cities begin to allow testing and circulation of AVs. Business typologies picture a range of models including first- and last-mile mobility or microtransit commute mostly within the regular-line transport system. All experimentations are part of the Mobility-as-a-Service paradigm.

The strength of the MaaS perspective is definitely its user-centric approach that allows integrating the latest technologies and the user needs for a new urban mobility. It offers a fully personalization of services based on user profiling, vehicle's localization, and dynamic itinerary optimization. Experts agree that robomobility will provide autonomous vehicle public transport services à la carte, anytime, anywhere, and for anybody, with optimal service costs and with full integration and coordination with existing public transport services. Besides, robomobility may positively impact social inclusion and well-being and give users the opportunities for social interaction offered by shared mobility.

The new transport offer will bring various innovative in- and out-of-vehicle services for passengers that will be designed with users in mind to ensure acceptance and promote the smooth integration of these novel technologies into an everyday lifestyle. In cooperation with vehicle manufacturers, public transport operators will focus on including both users in good health and users with special needs. They will develop services and solutions to accommodate these specific needs, such as children and adults who have special requirements, people with reduced mobility, and young children and elderly people who require supervision.

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