Autonomous shuttles for collective transport: a worldwide benchmark

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Abstract: The present study aimed at performing a comprehensive benchmark on experimentations with autonomous shuttles for collective transport. Data was collected online on both academic and grey literature yielding a research corpus of 176 experimentations. Results show a European lead on both the number of experimentations and manufacturers. The majority of the deployments were aimed towards public transportation being short to mid-term trials, mainly offered free of charge to users. Regular-line transport was the prevailing operational mode adopted, meanwhile, on-demand services were present but incipient, mainly due to legal barriers as well as technological and infrastructural constraints. Eight main typologies of uses able to fulfil both private and public transport offerings were identified, being either focused on solving first- and last-mile issues or microtransit commute. At last, the main common stakeholders were identified, as well as how different forms of value are created and distributed among them.

Keywords: autonomous shuttles; urban mobility; collective transport; business models; typologies of use; autonomous vehicles.

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1 Introduction

With over 55% of the world's population currently living in urban areas and with estimates that this number will rise to 68% by 2050 (United Nations, 2018; European Commission, 2017), mobility has become a key factor affecting citizens' well-being and life-quality.

On one hand, mobility ensures prosperity and social cohesion as well as influences on where people work and live, and consequently, how they commute (Melis et al., 2015; ITF, 2015). On the other, by considering our highly motorised and car-reliant society, urban mobility is also a source of major problems in urban areas, such as: congestion, air pollution, noise and several other externalities associated with moving people and goods around.

As a consequence, cities around the world are coming to terms with the numerous threats posed by these challenges (Clausen, 2017), and are coming to the realisation that they may need to spearhead efforts to develop more sustainable transportation systems (Pancost, 2016; Rosenzweig et al., 2010).

In recent years, innovations in technology and digitalisation have had a great impact on designing sustainable mobility concepts to counteract this trend (Alazzawi et al., 2018). For the authors, on-demand mobility services, automated driving, dynamic pricing algorithms, and vehicle electrification will change the way people experience mobility. Thereby, even an industry as robust and consolidated as the automotive one, could be disrupted by innovations in technology and digitalisation – as the example of several consolidated industries that were disrupted, such as: Kodak vs. digital cameras; Blockbuster vs. Netflix; encyclopaedia Britannica vs. Wikipedia; hotels vs. Airbnb, and so on (Parker et al., 2016).

Furthermore, according to Attias (2017), this possible revolution of urban areas would mainly occur through the arrival of autonomous cars, minibuses, and shuttles, thus building a new paradigm of urban mobility and smart cities.

On the one hand, there is a growing research stream who advocates that such vehicles would facilitate driving; increase road safety; reduce emissions of pollutants (by being electric); reduce traffic jams; as well as would allow drivers to choose to do different things other than driving. Thus, access to fully automated vehicles would also improve mobility for those who cannot or do not want to drive, improving their quality of life (Attias, 2017; Enoch, 2015; Schellekens, 2015; Schreurs and Steuwer, 2015; Poorsartep, 2014). As a result, AVs can provide significant economic, environmental and social benefits (Mutz et al., 2016; Fagnant and Kockelman, 2015).

On the other hand, there is a solid stream of research that questions those promised benefits of vehicular automation. From the technology standpoint there is still a long way to maturity and reliability of autonomous driving technologies, given that no AVs are currently on the level 5 automation proposed by SAE (2016); current AVs require constant human monitoring and intervention and are prone to sudden harsh breaks and speed limitations. There are also many security and reliability issues still to be solved, as well as it is yet unknown the possible impacts of autonomous driving on mobility behaviours and human-machine interactions (Schreurs and Steuwer, 2015; Schellekens, 2015). Not to mention past accidents with self-driving cars (Lubben, 2018; Green, 2018) and shuttles (England, 2020; Krok, 2019) not only put to the test the safety and reliability of AVs but also delay their further market deployment.

Furthermore, issues with autonomous driving go beyond the technology itself, there are still many uncertain aspects regarding consumer acceptance as well as regulatory and liability frameworks (Pakusch et al., 2018; Fagnant and Kockelman, 2015). Not to mention that it is still complex to understand how life will be affected by this disruptive innovation, in a sense that the timing, scale, and direction of the AVs' impacts are uncertain and the opportunities to influence investment decisions and future business models are limited (Guerra, 2015; Cavazza et al., 2019; Gandia et al., 2018).

Thereby, Mira-Bonnardel and Attias (2018) agree that fleets of autonomous cars will not be seen on the roads right away. For the authors, it is likely that fully AVs may firstly be authorised for collective transportation, thus offering a solution for larger cities that struggle to provide adequate public transport to support their residents' needs.

As pointed out by Harris (2018), the emergence of autonomous shuttles for collective transport (ASCTs) promise to harness connected automated vehicles to enable mobility-as-a-service (MaaS) schemes, since their main goal is to fulfill the first- and last-mile requirements as well as microtransit for city centres, central business districts, university campuses, airports, shopping malls, hospitals, etc.

With that, a significant group of entrants have been deploying pilot projects with ASCTs (Mira-Bonnardel and Attias, 2018; Clausen, 2017), among those, two companies have been at the forefront of these demonstrations: Navya and EasyMile. Both French-based companies deserve much credit for the way that they are promoting the advantages of these shuttles, setting the bar for the industry to start (Harris, 2018). Still according to the author, there is still much to learn about the operation ASCTs from both policy and regulation perspective as well as regarding business models and consumer acceptance. Thus, one way to address these questions and overcome these challenges and limitations is through further tests and experiments which allows improvements and advances in technical and navigation aspects of the technology, as well as brings AVs closer to the reality of the cities, allowing a better understanding and possible acceptance by the users and also allows advances in legal and safety aspects.

Thereby, the following guiding questions emerged: how have the experimentations with ASCTs been configured across the world? Are we experiencing a shift in urban public transportation? Thus, considering that information regarding the scope of ASCTs' implementations is still scarce, non-structured and pulverised, the present study aimed at answering those questions by performing a comprehensive benchmark on experimentations with ASCT worldwide.

In order to achieve this objective it was sought to:

1. extensively identify experimentations with ASCTs around the world, highlighting the most relevant shuttle manufacturers as well as countries and cities with most deployments
2. propose a relevant typology of uses for ASCTs by evidencing the nature of the deployed experimentations, revenue models, the prevailing business models of the offered services and, their classification within urban transport
3. identify the main stakeholders involved and how different forms of value are created and distributed among them.

This paper is a parallel study alongside the AVENUE project. The autonomous vehicles to evolve to a new urban experience project (AVENUE), is an EU funded project that started on 1 May 2018 that will last for 48 months (the project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 769033). AVENUE aims to design and carry out full-scale demonstrations of urban transport automation by deploying, for the first time worldwide, fleets of ASCTs on mixed-traffic conditions. Providing innovative services, like door-to-door and multimodal transportations, in low to medium demand areas of 4 European demonstrator cities: Geneva, Lyon, Copenhagen, and Luxembourg (AVENUE, 2018).

The results and findings presented in this paper are adequate for the IJATM readers by presenting an original benchmark on experimentations with ASCTs focusing on the macro context of industrial organisation and business management, rather than on pure technical and engineering topics.

Besides this introduction, the present paper is structured as follows. Section 2 presents the research methodology, explaining the necessary steps to perform the benchmark. Section 3 presents and discusses the results following the specific objectives order. Finally, in Section 4, the concluding remarks are presented, summarising the main findings and highlighting the possibilities for future research.

2 Methodology

With the aim of drawing a comprehensive benchmark on experimentations with ASCTs worldwide, the research design adopted in the present study was characterised as qualitative and quantitative of exploratory and descriptive nature (Gil, 2008; Malhotra, 2001). As a starting point for the experimentations' query, the most relevant and up-to-date benchmark publications (by the time this study was written) were taken as references:

- *Hottentot et al. (2015): experiments on autonomous and automated driving*. This report written for ANWB The Hague, listed a range of experimentations with AVs for passengers transport (individual and collective) in 20 countries worldwide.

- Charlet and Chaufrein (2017): *benchmark des experimentations vehicules autonomes et connectes*. Written as a working package for MOV'EO – project TEVAC, the authors listed 64 experimentations worldwide involving autonomous cars and autonomous shuttles for both passengers (individual and collective) and cargo transport.

- Bloomberg Group (2017): *Bloomberg aspen initiative on cities and autonomous vehicles*. It consists of an interactive world map, containing the world's first inventory of how cities around the globe are preparing for the arrival of AVs.

- Mira-Bonnardel and Attias (2018): *the autonomous vehicle for urban collective transport: disrupting business models embedded in the smart city revolution.* In this conference paper presented on the 26th GERPISA International Colloquium, the authors discussed the advances on the development of autonomous public transportation worldwide, listing 6 shuttle manufacturers in the field (newcomers) and highlighted the European project AVENUE H2020.

Based on the aforementioned works, snowball sampling technique (Penrod et al., 2003) was used in order to continue collecting data on both academic and grey literature (both on structured and non-structured data). The online query was carried out from September 3rd to September 18th 2018, and updated from November 4th to November 8th 2019 on both Google and on academic databases (Web of Science, Science Direct, Scopus and, Google Scholar). Saturation criterion was used as a stopping point for data collection (Fontanella et al., 2008). The research corpus consisted of 176 experimentations worldwide with ASCTs. It is important to emphasise that this work represents the reality of the experimentations in the specific temporal context of the data collection. That is, between the years 2018 and 2020, where the autonomous vehicles currently being tested were among levels 3 and 4 of automation (SAE, 2016) and, the current legislation required the presence of a human operator on-board (to retrieve control whether automation failed) and, both speed and operating environments were controlled and limited by respective local regulations.

Furthermore, it is worth noting that different from what was carried out by Charlet and Chaufrein (2017) and Hottentot et al. (2015), it was not in the scope of this study to consider the experiments with driverless cars (up to five occupants) such as the trials provided by Waymo; Uber and Lyft, neither it was considered experiments regarding autonomous vans or trucks for cargo deliveries.

Next, data was structured and analysed via descriptive qualitative analysis (Kim et al., 2016; Sanderlowski, 2000, 2010) and descriptive statistics (such as: frequency distribution, means, and cross tabulations).

3 Results and discussion

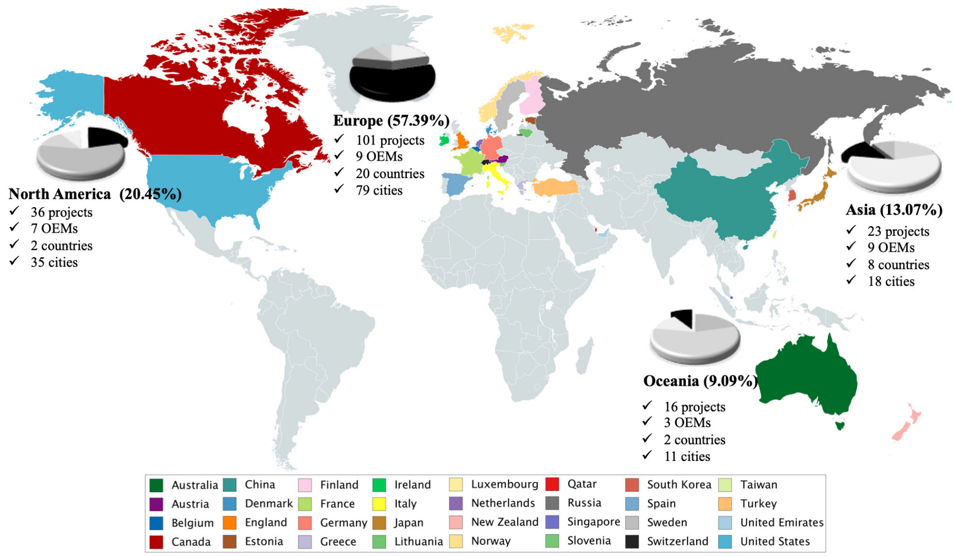
3.1 Worldwide experimentations with autonomous vehicles for collective transport

With the aim of covering as extensively as possible the experiments with Autonomous Vehicles for Public Transport worldwide, this research was not limited to the current (ongoing) experimentations; in this sense, finished projects, as well as projects yet to be started were also considered in the sample.

By the end of our data collection in November 2019 a total of 176 experimentations were identified, of which 104 had already been finished, 57 were currently running and 15 were still yet to start. These 176 projects unfold in 142 cities spread over 32 countries around the world enabled by 20 different autonomous shuttles manufacturers. Figure 1 depicts the geographical dispersion of the projects worldwide.

It is interesting to note that from the data collected in 2018, 33.7% of the total of experiments were ongoing projects, and for the second round of data collection these number changed slightly to 32.4%. However for projects yet-to-start, the total percentage in 2018 was of 12% and that number fell to 8.52% one year later. Furthermore, the number of long-term trial projects rose from 69.23% in 2018 to 80.69% in 2019. Those findings indicates a sense of urgency and proactivity of the involved stakeholders to put in place more quickly and efficiently long-term deployments with autonomous shuttles, bringing the paradigm shift on urban mobility closer to the present reality.

Figure 1 Autonomous shuttles experimentations worldwide (see online version for colours)



Source: Research data

As shown by Figure 1 and detailed in Table 1, Europe is on the lead regarding the number of experimentations. Out of the 32 countries present in our sample, the continent holds 20 that together comprise 101 of the 176 projects (a total of 57.39%), more than half of all experimentations. Such figures may be explained by the fact that the continent is also on the lead when it comes to the number of manufacturers (Table 2) and also currently holds 17 projects related to vehicular automation funded by the European Commission programme Horizon 2020 (European Commission, 2020). However, future studies are needed to better understand and validate the reason for such European leadership.

Next, comes North America, represented by Canada and the United States with a total of 36 experimentations (20,45%), followed by Asia, with 8 countries and 23 projects (13.07%) and Oceania with 2 countries and 16 projects (9.09%). To date, South America and Africa did not present any experimentation with ASCTs.

These results are consonant with the findings by Charlet and Chaufrein (2017) and Hottentot et al. (2015), demonstrating the representativeness of Europe on advancing R&D for autonomous technology deployment as well as the interest of several countries in the continent to approve measures for testing and certifying AVs on public roads (such as: Germany; France; England, Switzerland, among others). The same goes for Asia (especially Japan and China), North America (mainly the US) and Oceania (mainly Australia).

It is also important to highlight the significant advance in the number of experimentations over the approximate one-year interval between the two sets of data collection in our sample. The initial data collected on September 2018 yielded in 92 deployments, with the updates carried out in November 2019, this number rose to 176 deployments, a 91.3% increase.

Table 1 Number of projects in Europe, by city and country

	City	*Country*	*Number of projects**	*Total*
1	Koppl	Austria	2	4
2	Salzburg		1	
3	Vienna		1	
4	Brussels	Belgium	2	3
5	Han-sur-Lesse		1	
6	Aalborg	Denmark	2	5
7	Copenhagen		1	
8	Køge		1	
9	Slagelse Sygehus		1	
10	London	England	3	4
11	Salford		1	
12	Tallinn	Estonia	2	2
13	Espoo	Finland	1	7
14	Helsinki		4	
15	Tamper		1	
16	Vantaa		1	
17	Boulogne-sur-Mer	France	1	29
18	Civaux		1	
19	Clermont-Ferrand		1	
20	Dunkerque		1	
21	Fontevraud		1	
22	Issy-les-Moulineaux		1	
23	La Rochelle		1	
24	Lille		1	
25	Lyon		3	
26	Massy		1	
27	Paris		4	
28	Pribac		1	
29	Reims		1	
30	Rennes		1	
31	Rouen		1	
32	Rungis		1	
33	Saclay		1	
34	Sophia Antipolis		1	
35	Sorigny		1	
36	Toulouse		1	
37	Velizy		1	
38	Verdun		1	
39	Vernon		1	
40	Versailles		1	

Notes: *Table shows finished, running and yet to start projects.
The shaded rows are simply to emphasise the different European countries that composed the study sample, containing experiments with AVCTs.

Source: Research data

Table 1 Number of projects in Europe, by city and country (continued)

	City	*Country*	*Number of projects*	*Total*
41	Bad Birnbach	Germany	1	12
42	Berlin		3	
43	Enge-Sande		1	
44	Frankfurt		2	
45	Hamburg		1	
46	Lahr		1	
47	Leipzig		1	
48	Renningen		1	
49	Sylt		1	
50	Trikala	Greece	2	2
51	Dublin	Ireland	1	1
52	Oristano	Italy	1	1
53	Vilnius	Lithuania	1	1
54	Luxembourg	Luxembourg	2	2
55	Amsteram	Netherlands	1	6
56	Appelscha		1	
57	Delft		1	
58	Rotterdam		1	
59	Scheemda		1	
60	Wageningen		1	
61	Gjovik	Norway	1	5
62	Kongsberg		1	
63	Olso		2	
64	Stavanger		1	
65	Kazan	Russia	1	1
66	Ljubljana	Slovenia	1	1
67	San Sebastian	Spain	1	2
68	Talavera de la Reina		1	
69	Barkarby	Sweden	1	4
70	Gothenburg		2	
71	Stockholm		1	
72	Bern	Switzerland	1	9
73	Cossonay		1	
74	Fribourg		1	
75	Geneva		2	
76	Lausanne		1	
77	Neuhausen Rheinfall		1	
78	Sion		1	
79	Zug		1	

Notes: *Table shows finished, running and yet to start projects.
The shaded rows are simply to emphasise the different European countries that composed the study sample, containing experiments with AVCTs.

Source: Research data

It is also worth emphasising that Europe is not only ahead in the number of experimentations, but it is also on the lead regarding the representativeness of ASCTs manufacturers.

Table 2 Overview of manufacturers of autonomous shuttles for public transport (see online version for colours)

Shuttle provider		*Shuttle name*	*Country of origin*	*Experimentation*				
				Finished	*Running*	*Yet to start*	*Sum*	*Total by continent*
1	Shenzhen Haylion	n/a	China	1	0	0	1	5
2	Yutong	n/a		1	0	0	1	
3	Hino Motors	n/a	Japan	0	0	1	1	
4	AICT	n/a	South Korea	1	0	0	1	
5	IETT	n/a	Turkey	0	0	1	1	
6	TRL (Greenwich)	Harry	England	1	0	0	1	155
7	Ultra Global PRT	HeatrowPods		0	1	0	1	
8	*EasyMile*	*EZ10*	France	*56*	*23*	*1*	*80*	
9	*Navya*	*Arma*		*27*	*27*	*4*	*58*	
10	Lohr	i-Cristal		0	1	1	*1*	
11	Robosoft	n/a		4	0	0	4	
12	IAV	n/a	Germany	0	0	1	1	
13	2getthere	Parkshuttle	Netherlands	2	2	4	8	
14	Kamaz	SHATL	Russia	1	0	0	1	
15	HMI	Ohmio LIFT	New Zealand	1	0	0	1	1
16	Auro Robotics	Polaris GEM	USA	1	0	0	1	14
17	Fisker	Orbit		0	0	1	1	
18	Local Motors	Olli		4	0	0	4	
19	May Mobility	GEM e6		3	0	0	3	
20	Optimus Ride	n/a		1	3	1	5	
Total				104	57	15	176	

Notes: The shaded rows represent the different continents:
green: Asia; blue: Europe; yellow: Oceania; orange: North America.

Source: Research data

As shown in Table 2, from the total of 20 shuttle manufacturers in our sample the continent holds 9, which are responsible for providing the shuttles for 155 out of the 176 experimentations, that is, a total of 88.06%. Even more important is to highlight the relevance of the French manufacturers; EasyMile – holding 80 out of the 176 experimentations and, Navya – with 58 experimentations.

Regarding Asia, the continent holds 5 manufacturers: Shenzhen Haylion Technologies and Yutong in China; Hino Motors in Japan, AICT in South Korea and IETT in Turkey. Each Asian manufacturer holds only one project, which deployment takes place in the same origin countries of the manufacturers; thus, they still have a low representation in the global scenario. This same analysis applies for Oceania – with only one manufacturer from New Zealand manufacturer (HMI) running a single project and North America, with fivr manufacturers (Auro Robotics; Fisker; Local Motors; May Mobility and, Optimus Ride) running a total of 14 projects.

Even with a total of 20 manufacturers identified in our study, the relevance of the French start-ups EasyMile and Navya is undeniable. The two companies together represent a total of 78.5% of the total number of shuttles used in the sampled experiments. As for the other 18 manufacturers, it can be seen that the projects they work on are mostly punctual and often single or binary projects that are restricted to their cities and regions of their OEM itself (with some minor exceptions of the American based companies Local Motors and May Mobility which are gradually expanding their experimentations). This finding raises a number of questions about the viability of their business models and their long-term sustainability, however further studies are needed to better understand this phenomenon.

Founded in 2014 with headquarters in Toulouse, EasyMile is the result of a joint venture between Ligier (vehicle manufacturer) and Robosoft (high tech robotics company and former autonomous shuttle manufacturer – as depicted in Table 2) (Mira-Bonnardel and Attias, 2018; Pessaro, 2016). Their autonomous shuttle, the EZ10 was developed with the help of the European Commission funded project CityMobil2 (Alessandrini, 2018). The company has also recently launched a new product, as a result of a partnership with the TLD group (specialised in airport ground support equipment). They announced in October 2017 a driverless baggage tractor named 'TractEasy', which is a solution meant to transfer baggage and freight from the terminal to the aircraft area (Apron) with a fully driverless approach, by operating in normal traffic, without infrastructure modification, and in all weather conditions (TLD, 2017). Hence, in addition to autonomous passengers' transportation, EasyMile is now seeking to expand its portfolio to other market segments.

On the other hand, as pointed out by Fluhr (2017), Navya can be seen as EasyMile's main contender. Also founded in 2014 with headquarters in Lyon and Paris, Navya launched their ARMA autonomous shuttle in October 2015 (Mira-Bonnardel and Attias, 2018; Pessaro, 2016). On November 2017, the company launched a new product called 'Autonom Cab', which is claimed to be the first robot-taxi in the market (Navya, 2018). With capacity for six people, the vehicle is 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 Uber pool). Similarly to EasyMile, Navya is also expanding their portfolio to other market segments. In October 2018, the company joined forces with Charlatte Manutention (one of the world's leading manufacturers of electric and thermal industrial and airport vehicles) and created Charlatte Autonom, to develop autonomous tractor solutions for industrial sites and airports (Navya, 2018). Figure 2, summarises the main features of Navya's ARMA and EasyMile's EZ10.

Also worth highlighting is the growing relevance of the American market-newcomer Local Motors (Fluhr, 2017), founded in 2007 with headquarters in Phoenix, Arizona, the company developed their vehicle OLLI, using 3D printing technology, designs co-created and crowd-sourced by their online community (Mira-Bonnardel and Attias, 2018; Randazzo, 2014), in addition, the shuttle is equipped with IBM's Watson artificial intelligence.

Figure 2 Technical specifications of EasyMile and Navya shuttles (see online version for colours)

	 **EZ10 by EasyMile**	 **ARMA by Navya**
Capacity:	up to 12 passengers (6 sitting and 6 standing)	up to 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
Purchase price:	225,000€	260,000€
Lease price:	starting at 7,235€/month (5-year contract)	starting 9,500€/month (5-year contract)
Maintenance costs:	30,000€/year	90,000€/year

Source: Navya (2018), Pierce (2017), Rogers (2017) and Pessaro (2016)

Another important contender on autonomous vehicles for collective transport is the Dutch company 2getthere, however, differently from Navya's, EasyMile and Local Motors, their shuttles have been so far operating only on dedicated lanes and controlled areas. Even so, the company's deployments have been successfully running as regular paid services in cities like Rotterdam and Masdar and are yet to start in Singapore and Brussels (2getthere, 2018).

It is also worth mentioning the imminence of incumbents such as the American companies: AuroRobotics; May Mobility; Fisker; the Asian ones: Hino Motors and Yutong and the New Zealander: HMI. Despite their current small presence in the autonomous shuttle market today, such companies could become important international players in a perceivable future.

3.2 Typologies of use and key-performance indicators (KPIs)

In order to draw a set of use typologies for ASCTs, we first identified the following key elements:

1 the nature of deployed experimentations – encompassing the revenue sources and deployed road environment

2 the prevailing business model and its respective target audience

3 the classification within urban transport.

Nature of deployed experimentations

As for the experimentations' nature, three distinct forms were identified:

- *Showcases (13.14% of sampled projects):* entails a promotion where a product (ASCT) is demonstrated to potential consumers in hopes of:
  1. getting them acquainted to it and/or
  2. getting them to acquire it (Debelak, 2005; Lempert, 2002).
- *Trials (81.15%):* also known as 'experience service' it consists of a temporary offering intended to provide the service supplier with market information by allowing consumers to examine, use or test a product prior to fully committing the company resources to a full launch (Lian et al., 2016; Wright and Stern, 2015).
- *Regular services (5.71%):* permanent and (normally paid) offering aimed at providing a solution for consumers' needs (Lian et al., 2016). In the case of urban transportation: getting to point A to point B.

As for the revenue models, since the majority of experimentations were either showcases or short to mid-term trials they were mainly offered free of charge to riders (95.73% of the total sample), being subsidised either by a public transport operator, a municipality a research project and/or other stakeholders. In the other few sampled cases were the commute was paid to a transport service provider (4.27%), the adopted revenue model was similar to what traditional urban transport companies usually do:

1. pay-as-you-go
2. unlimited rides for a determined time-period (e.g., Navigo card in Paris and Oyster card in London).

Regarding the road environment, two distinct scenarios were observed. In the first, shuttles circulate in closed/controlled areas (such as university campuses, parks, hospitals, resorts, airports, and other designated roads); this kind of deployment comprised 48.87% of the sampled projects. In the second scenario (51.13%), shuttles were able to circulate among mixed traffic – for these cases the routes were mainly pre-determined for city-centres and areas with a slow-speed circulation of regular vehicles. It is worth highlighting that for the first round of data collection in 2018, the percentage of experimentations in closed-roads was higher than in mixed traffic conditions (52.17% versus 47.83%), and as shown, this figures are now inverted, which indicates that such trials are getting a step closer to becoming part of the multimodal set of urban transportation in cities.

However, it is important to emphasise that mixed traffic testing with AVs is not yet legal in all countries and regions (Peng and Sarazen, 2018; Threlfall, 2018; Parker et al., 2017; Fagnant and Kockelman, 2015; Schellekens, 2015), so even if the ASCT fits SAE's (2016) higher levels of automation (4 and 5), there is still a need for human intervention whenever needed.

Prevailing business model and target audience

By analysing the dominant business models in the experimentations, two main service approaches were observed:

- *Private transport (5.84%):* shuttles are sold (or leased) to private firms or instead, to transport operators to offer commute services to such firms. In this context, shuttles' usage is restricted to employees (workers) of a given firm or entity, and the revenue model is often managed by the contracting firm itself.
- *Public transport (94.16%):* shuttles are sold (or leased) to public transport operators which offer public commute to citizens of a given city/region/area. In this business model, commuters are the main revenue source for the transport operator. Moreover, unlike private transport models, the shuttles here described can be seen as an additional transport mode to the current public urban transport networks (hence, mainly acting as first- and last-mile solutions as well as microtransit).

Still regarding public transport services, some different target audiences were identified: commuters' transport (in both closed and mixed traffic – 65.83%); fair visitors' transport (during shuttles' showcases in closed roads – 4.34%); tourists' transport (mainly in closed trial areas – 9.94%); travellers' transport (connecting parking lots to airport terminals mainly in dedicated closed lanes – 6.83%) and; transport of university students, faculty and staff (in looped routes within campuses or to/from campuses – 13.07%).

It is important to highlight that peer-to-peer (P2P) business models have not been identified in the sampled ASCTs. In such business models, vehicle' ownership is normally in the hands of ordinary peers (e.g., drivers) which by the use ride-haling platform-companies provide services to other peers (e.g., commuters) (Macmurdo, 2015).

Classification within urban transport

The complexity and variety of transport modes available to urban commute have led to a wide range of different operation modes, encompassing both individual and shared transport schemes as well as both public and privately owned vehicles or fleets (Jin et al., 2018; Shaheen et al., 2016). Based on the sample's scope, two primary operation models were identified:

1. *Regular-line transport (RLT):* this type of service fits the traditional model offered by transport operators who provide services to cities, in which existing models of transport (buses, metros, trains, tramways, etc.) have predetermined routes and stops at regular intervals between vehicles and with preset hours of operation (Cross, 2016; Wardman, 2001).
2. *Demand-responsive transport (DRT):* in this model, shuttles do not circulate at fixed intervals of time, but rather respond to users' demands. As for the routes, they can be fixed with pre-defined stops or lines (as in the RLT model) or they can be geofenced and flexible.

DRT fits into the steadily-growing business platforms model (Gawer and Cusomano, 2015, 2002; Parker et al., 2016), that has allowed the emergence of the ride-sourcing or ride-hailing companies, such as Uber, Lyft, Didi Chuxing (Choudary, 2015; Rayle et al., 2016). In this model, by using an app on their smartphones, users can hail a vehicle according to their specific travel needs (Winter, 2015). In here we may have:

- The transport operator managing the transport system itself as well as managing the online on-demand platform service or.
- The transport operator managing only the transport system and a third-party company (digital service provider) managing the online on-demand platform as well as other possible additional services to be offered during the commute.

Among the sampled experimentations, 94.18% have fallen within the RLT. Such a fact is likely to be justified due to the large percentage of showcases and short- to mid-term trials found, as well as due to legal challenges and barriers for testing and deploying autonomous driving technologies on open public roads. On the other hand, only 2.91% of projects were fit under DRT, and the last remaining 2.91% were offered in both RLT and DRT modes.

Thereby, as more countries and cities begin to allow testing the circulation of AVs on their roads and highways, the percentage of DRT autonomous mobility is likely to increase, since the major value proposition claimed by ASCTs' manufacturers is to facilitate the fist- and last-mile commute as well as microtransit. Over the next paragraphs, such concepts are better detailed.

1. *First- and Last-mile commute (50.28%):* as pointed out by Scheltes and Correia (2017), these concepts in ordinary public transport are known to bring a large disutility for passengers, since conventional transport modes for these stages of the commute can, in many cases, be rather slow, inflexible and not provide a seamless experience to passengers. Therefore, ASCTs could act as a first mile/last mile connection (feeders) to mass public transport modes (Ainsalu et al., 2018).
2. *Microtransit commute (49.72%):* aims to provide a ride-sharing shuttle service that can have fixed routes and schedules, as well as flexible routes and on-demand scheduling (Jin et al., 2018; Shaheen et al., 2016). For the authors, microtranist mainly provides commuting services that connect residential areas with urban and suburban working and commercial areas. As stated by Mira-Bonnardel and Attias (2018), in cities that struggle to provide adequate public transport, ASCTs could partially fill the gap by fulfilling the promise of personal rapid transit and offering a personalised point-to-point service.

It is worth recapitulating that for first/last-mile as well as microtransit, both RLT and DRT operation modes are applicable. Regarding the latter, it is important to explain that its operation mode normally requires the assistance of a digital service provider in order to manage the on-demand platform services via multi-sided business platforms schemes.

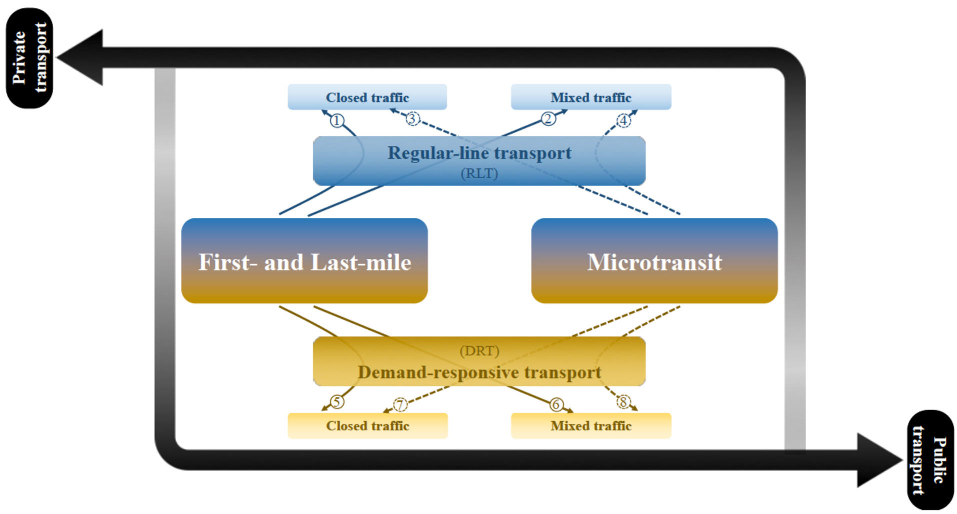
Since, P2P models where not found in our sample, instead, we identified B2B and B2C on-demand models (both ride-hailing and shared ride-hailing) wherein such cases the digital service provider (and its partners – transport operator) subsidise on side of the platform (in the case: commuters) in order to attract riders and thereby generate the desired network effects and positive feedback loops. This type of platform is commonly referred as 'one-way multisided platforms'. (Parker et al., 2016; Choudary, 2015;

Osterwalder and Pigneur, 2010). We highlight that, whenever a critical mass of users is formed on both sides of the platform, subsidies can be lifted, transforming 'one-way platforms' into 'two-way platforms'.

Typologies of uses for ASCT

Based on all the aforementioned key-elements as well as on (Antonialli et al., 2018; Jin et al., 2018; Shaheen et al., 2016), Figure 3 depicts a framework of the main usage typologies identified for the ASCTs.

Figure 3 Framework of ASCTs usage typologies (see online version for colours)



Source: Research data

As shown in Figure 3, a total of eight typologies for ASCTs have been identified, which can all be offered either for private and public transport solutions, therefore summing up 16 typologies of use.

Regarding the business models towards private transportation, only ten experimentations were found, nine within the scope of RLT; and one offered both as RLT and DRT: Navya privately transporting workers in Dunkerque (France) within the Total Factory campus.

As for the business models aimed to address public transportation solutions, a total of 166 experimentations were identified, covering all eight of the typologies proposed. As detailed in Table 3, 151 of these experiments (88,82%) are fit within RLT, with 39 (24.38%) projects in typology 1 (first- and last-mile RLT in closed traffic), 43 (26.88%) in typology 2 (First- and Last-mile RLT in mixed traffic), 37 (23.13%) in typology 3 (Microtransit RLT in closed traffic) and, 32 (20.00%) within typology 4 (Microtransit RLT in mixed traffic).

Some relevant examples are: Navya's trials at the confluence district in Lyon (France) – offering both RTS and DTS last-mile commute; 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 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 (Kolombus project) and in the United States (GoMentum station project).

The remaining projects (11.18%) in public transportation contexts, were identified as belonging to DRT. Within typology 5 (First- and Last-mile DRT in closed traffic), is the example of the shuttle service offered by Navya on Paris-Charles-de-Gaulle airport, connecting passengers from the RER train station to the airport's terminals (the on-demand service is offered by pushing a button in the shuttles' stops). Next, within typology 6 (first- and last-mile DRT in mixed traffic) is Schöneberg's district experimentation in Berlin, where Local Motors has tested an on-demand ride-hailing service based on their shuttle's (OLLI) artificial intelligence system.

As for DRT microtransit experimentations, 1 projects was found for closed traffic and also 3 in mixed traffic. As for closed traffic, we highlight EasyMile's initiative in Dubai, that during 2017 offered a looped on-demand service around Dubai World Trade Center. At last – regarding DRT microtransit for mixed traffic – in early 2020 (via project AVENUE), Navya will deploy at Nordhavn industrial port in Copenhagen a fleet of their Arma shuttle running on a selected route with bus stops and regular scheduling; however, in off-peak hours, the service will be offered on-demand via an app provided by Holo and Mobility Thinking (Transport operator and the digital service provider). Table 3 classifies the sampled experimentations within the range of identified typologies.

Table 3 Classification of ASCTs experimentations within the eight proposed typologies (see online version for colours)

Typologies of uses for ASCTs	*Private transport*		*Public transport*	
	Number of experiments	*%*	*Number of experiments*	*%*
1 First- and Last-mile RLT in closed traffic	0	0.00%	39	24.38%
2 First- and Last-mile RLT in mixed traffic	1	10.00%	43	26.88%
3 Microtransit RLT in closed traffic	3	30.00%	37	23.13%
4 Microtransit RLT in mixed traffic	5	50.00%	32	20.00%
5 First- and Last-mile DRT in closed traffic	0	0.00%	1	0.63%
6 First- and Last-mile DRT in mixed traffic	0	0.00%	4	2.50%
7 Microtransit DRT in closed traffic	1	10.00%	1	0.63%
8 Microtransit DRT in mixed traffic	0	0.00%	3	1.88%

Notes: The shaded rows are colour-coded to the typologies shown on Figure 3.
The blue shades are the typologies within RLT (regular-line transport) and the yellow ones are the typologies within DRT (demand-responsive transit).

Source: Research data

3.3 Main involved stakeholders and value flow

Identifying urban mobility stakeholders and understanding their potential role and position in the value chain is crucial to achieve the overall goals of sustainable urban mobility planning (Doe, 2015).

Thus, by considering the wide array of experimentations in our sample as well as the different deployment natures and typologies of uses, the task of describing the main involved stakeholders is quite complex. In this sense, it was chosen to generically exemplify the main common stakeholders among all experimentations, trying to describe the underlying interrelationship among them as well as the main interactions regarding value flows.

As depicted by Kopanezou (2004), there are typically four groups of stakeholders involved in transportation projects (each one of them encompassing a range of other stakeholders who are constantly interacting and co-evolving). As shown in Figure 4, those groups are:

1 private entities (e.g., transport operators/providers consultants, business associations, financers, retailers, utility services, contractors)

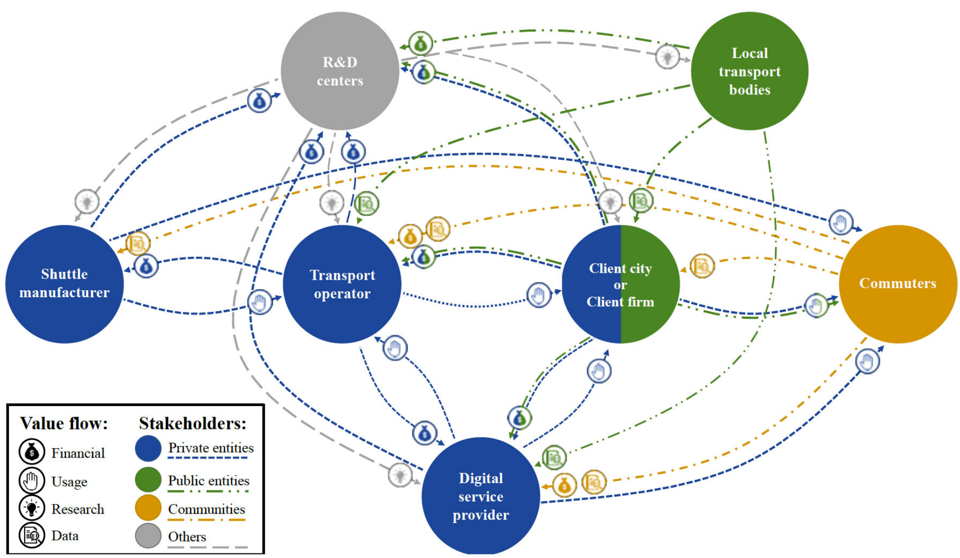
2 public entities (e.g., local governments and local authorities, neighboring cities, traffic police, emergency services)

3 communities (e.g., end consumers, trade unions, media, landowners, NGOs)

4 others (e.g., research institutions, universities, foundations, etc.).

Among such groups, different forms of value flow can occur (WDS, 2018), Figure 4 depicts four possible (generic) value flows: financial, usage, research, and data. Thus, the main interactions among the stakeholders are shown by coloured-coded arrows which indicate the direction of the flow and the main value being exchanged.

Figure 4 ASCTs' generical stakeholders and value flows (see online version for colours)



Source: Prepared by the author based on WDS (2018) and Kopanezou (2004)

To briefly illustrate, starting from the shuttle provider, it has the option to sell (or lease) their autonomous shuttles to a transport operator, which in turn will financially compensate the manufacturer (data is also exchanged in a multidirectional way). Next, by possessing the shuttles, the transport operator will offer transportation services to

1 a client city (which by means of a concession will allow the transport operator to offer services to the end consumers-commuters)

2 a client firm (which by means of a transport contract will provide commute to its employees).

A second alternative is the transport operator partnering with a digital service provider to enhance users' experience by offering customised mobility services whether in relation to route planning, forms of payment, infotainment features, and so on. Thus, the digital service provider will act as a platform operator for online mobility services.

It is also important to highlight the role of local transport authorities – responsible for legislation and supervision of other stakeholders involved in the ecosystem, and also the importance of R&D centers for the technical and marketing advances of the whole ecosystem.

Thus, this web of interactions among the stakeholders depicted in Figure 4, is known in the literature as a business ecosystem (Moore, 1998, 1993); in which businesses are not viewed as belonging to a single industry, but rather as part of an ecosystem that crosses a variety of industries, including customers, suppliers, competitors, governments, etc., who coevolve their capabilities and roles, tending to align themselves with how a focal firm (e.g., transport operator) creates, captures and distributes value (Muegge, 2013; Kamargianni and Matyas, 2017).

With this, the process of growth and evolution of this ecosystem depends on the synergy and value flows among the stakeholders. As highlighted by Mineiro et al. (2018) as well as by Gandia et al. (2017), the public sphere plays a fundamental role in catalyzing the interactions, since it has the power to make laws and rules feasible for the implementation of ASCTs schemes. On the other hand, private stakeholders should align their interests with the common good (urban mobility fluidity and collective well-being) in addition to individual growth and profit. R&D centres also play a pivotal role in advancing the ecosystem by promoting innovations through research in both technical and humanities areas regarding AVs. Finally, in order to close the cycle of growth and evolution of the ecosystem, it is up to civil society to understand the advantages and benefits of ASCTs over individual and traditional means of transport, as a way of fostering a more enduring and sustainable urban mobility.

4 Concluding remarks

The present benchmark study described a wide range of 176 experimentations with ASCTs worldwide that were spread across 142 cities in 32 countries; being enabled by 20 different shuttles' manufacturers. By considering the one-year time difference between the two sets of data collection, results have shown a significant advance in numbers of projects (92 in 2018 versus 176 in 2019) as well as an increase in number of long-term trials (69.23% in 2018 versus 81.15% in 2019), which indicates a trend and greater interest from governments and cities for further testing and advances in autonomous mobility technologies for public transport.

Europe has been at the forefront in experimentation numbers (57.39%), which could be explained by the several projects with vehicular automation under the H2020 grants (European Commission, 2020), by the interest of several European countries to approve measures for testing and certifying AVs on public roads, and also by the great number of shuttle manufacturers (9 out of 20), with highlights to the French startups Easymile and Navya. On the other hand, other non-European newcomers (such as: Local Motors, May Mobility, HMI and Hino Motors) have great potential on becoming relevant contenders for Navya and Easymile, however further studies are needed to better understand and evaluate the feasibility of their business models in the long-run, in a sense that at the current stage, their deployments are scarce and somewhat limited to their specific cities and regions.

The majority of experimentations (81.15%) was classified as trials, mainly offered free of charge to commuters (95.73%), deployed either on closed/controlled roads (48.87%) or mixed-traffic (51.13%), on fixed looped-routes (94.16%). A set of eight business typologies was also identified as well as the prevalent stakeholders involved in the experimentations and the value types of value that flows among them.

The results of this study corroborates the advancements made by PTOs, municipalities and the European Commission to foster further trials with autonomous vehicles on mixed-traffic conditions and open roads. Even if such operations are not yet legal in all countries and regions, therefore, it is difficult to empirically gauge the ways in which this technology will develop once it matures (Peng and Sarazen, 2018; KPMG International, 2018; Parker et al., 2017; Clausen, 2017). Notwithstanding, as more countries and cities begin to allow testing and circulation of AVs, the percentage of on-demand autonomous mobility is likely to increase, however further studies are needed to corroborate this assumption.

Nevertheless, several issues and hypothesis could be raised by considering this ecosystemic approach for ASCTs, such as: an ASCTs' ecosystem is mainly dominated by newcomers, will these newcomers override traditional vehicles manufacturer? Or will traditional manufacturers regain control of such an ecosystem? Furthermore, may the increase in ASCTs experiments be symptomatic of the emergence of a new business ecosystem? Those questions posit challenges to all stakeholders involved, therefore further in-depth studies should be carried out to tackle such strategic matters.

An important limitation of this study was the difficulty in obtaining data, much of it came from secondary sources such as news sites and blogs and in many cases, the information was not structured (presented as videos and photos and in several different languages) making it difficult to codify and analyse. In addition, some sets of information could not be obtained via secondary data collection, such as: data on investor strategies regarding ROI (it was not possible to calculate the expected revenue even though we had data for Navya's and Easymile's shuttles and maintenance costs); as well as on the ways of evaluating how stakeholders participate in the development of the business models.

It is also important to note that the data collection was done in order to obtain as many experiments as possible to compose the study sample, however, due to the speed at which the field is evolving it is not feasible to cover 100% of the deployments with ASCTs and the results presented here show the temporal reality at the time the data were collected (years 2018 and 2019).

Thus, in addition to the already previously suggested future studies, we believe that studies which data collection is carried out via primary sources (in-depth interviews and questionnaires with stakeholders directly involved in the experimentations) and, with a longitudinal time-span may come to answer and fulfill the main issues and constraints found in the present study.

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