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International benchmark on experimentations with Autonomous Shuttles for Collective Transport

Fabio Antonialli[1]

Abstract: Based on an exploratory and descriptive quali/quanti research design, the present study aimed at performing a worldwide benchmark on experimentations with Autonomous Shuttles for Collective Transport (ASCT). Data was collected online on both academic and grey literature yielding a research corpus of 92 experimentations. Results show a European lead on both the number of experimentations and manufacturers, with highlights to the French startups Navya and EasyMile. Most of the sampled deployments have their services aimed towards public transportation business models being either showcases or trials, mainly offered free of charge to commuters (paid regular services were a minority). Regular-line transport system was the prevailing operational mode adopted, meanwhile, on-demand platform services were still present, but incipient. Eight main typologies of uses able to fulfill both private and public transport offerings were identified, being either focused on solving first- and last-mile issues and/or microtransit commute. Nine key-performance indicators were selected and divided into economic – and user-centered. At last, the main common stakeholders among all experimentations were identified, as well as how different forms of value (financial; usage; research; data) are created and distributed among them in order to promote sustained growth and evolution of the ecosystem.

Keywords: Autonomous shuttles; Urban mobility; Collective transport; Business models; Typologies of use.

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1. Introduction

Currently, 55% of the world's population is living in urban areas and estimates are that this number will rise to 68% by 2050 (United Nations, 2018; European Commission, 2017). With that, mobility has become a key factor affecting citizens' well-being and life-quality, by ensuring prosperity and social cohesion as well as influencing on where people work and live, and consequently, how they commute (Melis et al., 2015; International Transport Forum, 2015).

On the other hand, by considering our highly motorized 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 realization 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 digitalization 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, autonomous driving, dynamic pricing algorithms, and vehicle electrification will change the way people experience mobility in urban environments. Furthermore, according to Attias (2017), this revolution of urban areas will mainly occur through the arrival of autonomous cars, minibuses, and shuttles, thus building a new paradigm of urban mobility and smart cities.

Such vehicles are expected to fundamentally change – for the better – urban mobility in cities, by reducing the number of accidents and pollution, lowering transportation costs and time, as well as improving traffic efficiency, productivity and, promoting social inclusion for those who cannot drive (Alazzawi et al., 2018; Lang et al., 2016; Mutz et al., 2016). On the other hand, AVs' proliferation is far from guaranteed, since complex questions related to legal aspects, liability, privacy, licensing, security, and insurance regulation still remain to be solved (Gandia et al., 2018; Fagnant & Kockelman, 2015; Schellekens, 2015).

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 autonomous cars may firstly be authorized 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 schemes, since their main goal is to fulfill the first- and last-mile requirements as well as microtransit for city centers, central business districts, university campuses, airports, shopping malls, hospitals, etc.

With that, a significant group of entrants has been testing ASCTs (Mira-Bonnardel & 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.

With that, the following guiding question emerged: how have the experimentations with ASCTs been configured across the world? Thus, considering that information regarding the scope of ASCTs' implementations is still scarce, non-structured and pulverized, the present study aimed at performing a worldwide benchmark on the experimentations with Autonomous Shuttles for Collective Transport.

In order to achieve this objective it was sought to: 1) identify all 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, their classification within urban transport and, most relevant key-performance indicators; and 3) identify the main stakeholders involved and how value is created and distributed among them.

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, summarizing the main findings and highlighting the possibilities for future research.

2. Methodology

With the aim of drawing a worldwide benchmark on all experimentations with ASCTs, the research design adopted in the present study was characterized as qualitative and quantitative of exploratory and descriptive nature (Gil, 2008; Malhotra, 2001). As a starting point for the experimentations' query, we took as references the following publications:

- **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;
- **Hottentot, Meines, and Pinckaers (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;
- **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, we used the snowball sampling technique (Penrod et al., 2003) in order to continue collecting data on both academic and grey literature (both on structured and non-structured data). Our on-line query was carried out from September 3rd to September 18th, 2018 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, Ricas & Turato, 2008). The research corpus consisted of 92 experimentations worldwide with ASCTs.

It is worth noting that different from what was carried out by Charlet and Chaufrein (2017) and Hottentot, Meines and Pinckaers (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 did we consider experiments regarding autonomous vans or trucks for cargo deliveries.

Next, data was structured and analyzed via descriptive qualitative analysis (Kim, Sefick & Bradway, 2016; Sanderlowski, 2000; 2010) and descriptive statistics (such as: frequency distribution, means, and cross tabulation).

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; finished projects, as well as projects yet to be started were also considered in the sample.

In this sense, by the time this research was carried out, a total of 92 experimentations were identified, 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 around the world enabled by 20 different autonomous shuttles manufacturers. Figure 1 depicts the geographical dispersion of the projects worldwide.

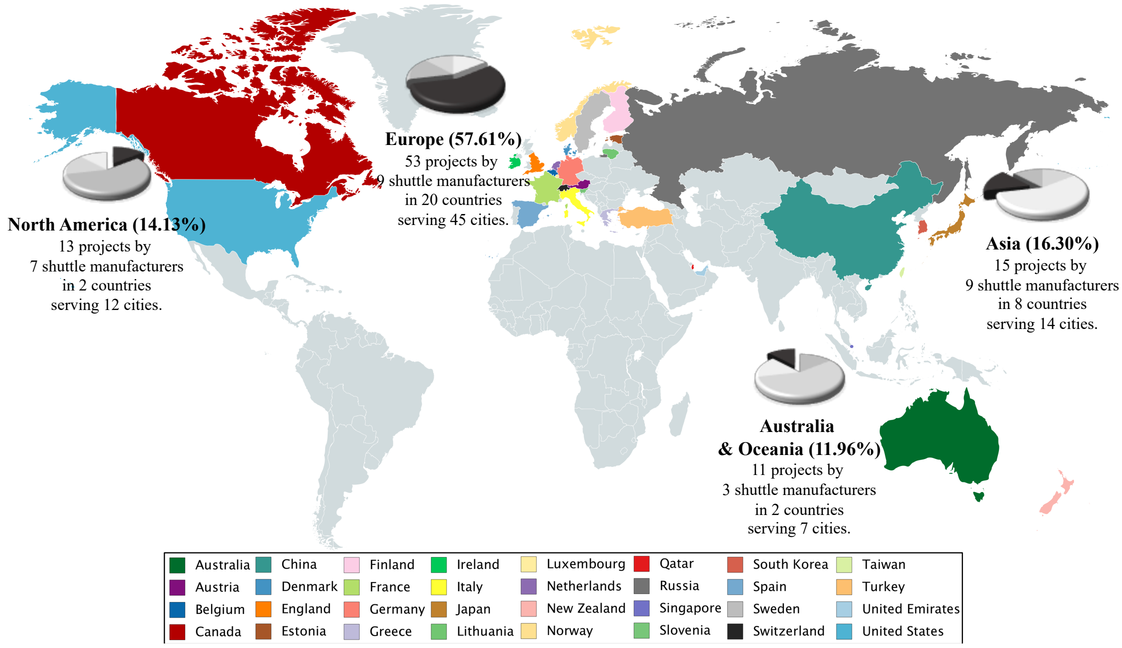

Figure 1. Autonomous shuttles experimentations worldwide.
Source: prepared by the author based on research data.

As shown by Figure 1 and detailed in Table 1, Europe is on the lead regarding the experimentations. Out of the 32 countries present in our sample, the continent holds 20 that together comprise 53 of the 92 projects (a total of 57.61%), more than half of all experimentations.

	City	Country	Num. of projects	Total
1	Salzburg	Austria	1	2
2	Vienna		1	
3	Brussels	Belgium	1	2
4	Han-sur-Lesse		1	
5	Aalborg	Denmark	1	2
6	Copenhagen		1	
7	London	England	3	3
8	Tallinn	Estonia	1	1
9	Espoo	Finland	1	5
10	Helsinki		2	

	City	Country	Num. of projects	Total
24	Trikala	Greece	1	1
25	Dublin	Ireland	1	1
26	Oristano	Italy	1	1
27	Vilnius	Lithuania	1	1
28	Luxembourg	Luxembourg	1	1
29	Amsterdam	Netherlands	1	4
30	Delft		1	
31	Rotterdam		1	
32	Wageningen		1	
33	Kongsberg	Norway	1	3

11	Tamper		1		34	Olso		1	
12	Vantaa		1		35	Stavanger		1	
13	Civaux	France	1	8	36	Russia	Kazan	1	1
14	La Rochelle		1		37	Ljubljana	Slovenia	1	1
15	Lyon		1		38	San Sebastian	Spain	1	2
16	Paris		4		39	Talavera de la Reina		1	
17	Sophia Antipolis		1		40	Stockholm	Sweden	1	1
18	Bad Birnbach	Germany	1	7	41	Fribourg	Switzerland	1	6
19	Berlin		1		42	Geneva		1	
20	Enge-Sande		1		43	Lausanne		1	
21	Frankfurt		2		44	Neuhausen Rheinfall		1	
22	Hamburg		1		45	Sion		1	
23	Lahr		1		46	Zug		1	

Table 1. Number of projects in Europe, by city and country.
Source: prepared by the author based on research data.

Next, comes Asia with a total of 8 countries holding 15 experimentations (16,30%), followed by North America and Oceania both with 2 countries each. North America, however, presents more projects - 13 overall (14,13%) while Oceania presented 11 (11.96%). 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, Meines and Pinckaers (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 U.S.) and Oceania (Australia and New Zealand).

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

As shown in Table 2, from the total of 20 shuttle manufacturers in our sample the continent holds 9, being those: Westfield and Ultra Global PRT (England); EasyMile, Navya, Robosoft and, Lohr (France); IAV (Germany); 2getthere (Netherlands) and; Kamaz (Russia), which are responsible for providing the shuttles for 80 out of the 92 experimentations, that is, a total of 86.86%. Even more important is to highlight the relevance of the French manufacturers; EasyMile – holding 34 out of the 92 experimentations and, Navya – with 31 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 5 manufacturers (Auro Robotics; Fisker; Local Motors; May Mobility and, Optimus Ride) running a total of 6 projects.

	Shuttle provider	Shuttle name	Continent of origin	Country of origin	Experimentations				
					Finished	Running	Yet to start	Sum	Total by continent
1	Shenzhen Haylion Tech.	n/a	Asia	China	0	1	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	0	1	0	1	

5	IETT	n/a		Turkey	0	0	1	**1**	
6	Westfield	Harry	Europe	England	1	0	0	**1**	80
7	Ultra Global PRT	HeatrowPods			0	1	0	**1**	
8	***EasyMile***	***EZ10***		France	***26***	***7***	***1***	***34***	
9	***Navya***	***Arma***			***13***	***16***	***2***	***31***	
10	Lohr	i-Cristal			0	0	1	**1**	
11	Robosoft	n/a			4	0	0	**4**	
12	IAV	n/a		Germany	0	0	1	**1**	
13	2getthere	Parkshuttle		Netherlands	1	2	3	**6**	
14	Kamaz	Kamar 1221 Shatl		Russia	1	0	0	**1**	
15	HMI	Ohmio LIFT	Oceania	New Zealand	0	1	0	**1**	1
16	Auro Robotics	Polaris GEM	North America	United States	1	0	0	**1**	6
17	Fisker	Orbit			0	0	1	**1**	
18	Local Motors	Olli			2	0	0	**2**	
19	May Mobility	GEM e6			0	1	0	**1**	
20	Optimus Ride	n/a			0	1	0	**1**	
	Total				**50**	**31**	**11**	**92**	

Table 2. Overview of manufacturers of autonomous shuttles for public transport.
Source: prepared by the author based on research data.

The French startups EasyMile and Navya are the global leaders when it comes to manufacturing and deployment of autonomous shuttles experimentations worldwide. According to David Fluhr, journalist and owner of the digital magazine "Autonomes Fahren & Co":

> "Both companies have a similar concept: provide autonomous minibuses with a capacity of around 12 people. The shuttles are powered by electricity and reach a top speed of 20 km/h. They navigate independently and recognize obstacles (...)." (Fluhr, 2017).

Navya is the current market leader by having the greatest number of projects currently running and yet to be started (16 and 2 respectively). Founded in 2014 with headquarters in both Paris and Lyon, the company launched their ARMA autonomous shuttle in October 2015 (Attias & Mira-Bonnardel, 2018; Pessaro, 2016) and ever since, the company has held projects in Australia, Austria, Belgium, Canada, China, Denmark, England, France, Germany, Lithuania, Luxembourg, New Zealand, Qatar, Singapore, Slovenia, Switzerland and, United States. On November 2017, the company launched a new product called "Autonom Cab", which the company claims to be the first robot-taxi in the market (Navya, 2018). With capacity for 6 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).

On the other hand, as pointed out by Fluhr (2017), EasyMile can be seen as Navya's main contender. Also founded in 2014 with headquarters in Toulouse, the company 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) (Attias & Mira-Bonnardel, 2018; Pessaro, 2016). Their autonomous shuttle, the EZ10 was developed with the help of the CityMobil2 project (co-funded by the European Union's Seventh Framework Programme); and it has been deployed on projects in Australia, Canada, China, Estonia, Finland, France, Germany, Ireland, Japan, Netherlands, Norway, Singapore, Spain, Sweden, Switzerland, United Emirates and, United States.

EasyMile has also recently launched a new product, as a result of a partnership with the TLD group (specialized 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.

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 develops vehicles using 3D printing technology and utilizes vehicle designs co-created and crowd-sourced by their online community (Attias & Mira-Bonnardel, 2018; Randazzo, 2014). Launched in 2016, their autonomous shuttle OLLI – equipped with IBM's Watson artificial intelligence – has so far been deployed in the United States (National Harbor) and Germany (Berlin) for trial runs (Attias & Mira-Bonnardel, 2018; Warren, 2016, DPA/The Local, 2016). Figure 2, better highlights the main features of Navya's ARMA, EasyMile's EZ10 and Local Motor's OLLI.

	 **EZ10 by EasyMile**	 **ARMA by Navya**	 **OLLI by Local Motors**
Capacity:	12 passengers (6 sitting and 6 standing)	15 passengers (8 sitting and 7 standing)	12 passengers (6 sitting and 6 standing)
Cruising speed:	20 km/h	25 km/h	12km/h
Maximum speed:	40 km/h	45 km/h	40 km/h
Propulsion engine:	Electric	Electric	Electric
Length:	3,93 meters	4.75 meters	3.90 meters
Width:	1,99 meters	2.05 meters	2.05 meters
Height:	2,75 meters	2.55 meters	2.50 meters
Vehicle cost:	200,000 to 220,000€. ($223,180 to $245,498)	200,000€ ($223,180)	212,690€ ($250,000)
Maintenance costs:	30,000€/year ($33,477/year)	90,000€/year ($101,511/year)	n/a

Figure 2. Technical specifications of EasyMile, Navya, and Local Motors shuttles.
Source: prepared by the author based on Pierce (2017), Pessaro, (2016) and Molitch-Hou (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 (20.88% 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 (69.23%):** 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; Gu & Wu, 2016; Wright & Stern, 2015).
- **Regular services (9.89%):** permanent and (normally paid) offering aimed at providing a solution for consumers' needs (Lian; Gu & Wu, 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 (20.88%) or short to mid-term trials (69.23%) they were mainly offered free of charge to riders (94.05% of the total sample), being subsidized either by the shuttle manufacturer, the service provider and/or other stakeholders. In the other few sampled cases were the commute was paid to a transport service provider (5.95%), the adopted revenue model was similar to what traditional urban transport companies usually do: 1) pay-as-you-go or 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 52.17% of the projects. In the second scenario (47.83%), shuttles were able to circulate among mixed traffic – for these cases the routes were mainly pre-determined for city-centers and areas with a slow-speed circulation of regular vehicles.

It is important to emphasize that mixed traffic testing with AVs is not yet legal in all countries and regions (Peng & Sarazen, 2018; Threlfall, 2018; Parker, Shandro & Cullen, 2017; Fagnant & 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 analyzing the dominant business models in the experimentations, two main service approaches were observed:

- **Private transport:** 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. Such a model was identified in only 3.45% of our sample.

  Public transport: shuttles are sold (or leased) to 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).

Public transport services comprised the majority of the sampled projects (96.55%), where some different target audiences were identified: commuters' transport (in both closed and mixed traffic – 65.52%); fair visitors' transport (during shuttles' showcases in closed roads – 3.45%); tourists' transport (mainly in closed trial areas – 8.05%); travelers' transport (connecting parking lots to airport terminals mainly in dedicated closed lanes – 10.34%) and; transport of university students, faculty and staff (in looped routes within campuses or to/from campuses – 9.20%).

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, Cohen & Zohdy, 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 flexible (as in: Uber and taxis).

DRT fits into the steadily-growing business platforms model (Gawer & Cusomano, 2015; 2002; Parker, van Asltyne & Choudary, 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., 2014). 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, 91.21% have fallen within the Regular-line Transport (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 4.40% of projects were fit under Demand-Responsive Transport (DRT), and the last remaining 4.40% 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 (44.57% of sampled projects):** 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 (55.43% of sampled projects):** 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, Cohen & Zohdy, 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 personalized point-to-point service.

It is worth recapitulating that for First/Last-mile as well as Microtransit, both Regular-line transport (RLT) and Demand-responsive transport (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.

The premise behind such digital service providers (business platforms) is to act as “orchestrators of interactions”, connecting supply (e.g., transport operators with their ASCTs) with demand (e.g., commuters) (Evans & Gawer, 2016). As aforementioned, for the current traditional ride-hailing services, this type of business model is generally offered as P2P business models, where the service provider does not own any transacted assets, such model is commonly called in the literature as "two-way multi-sided platforms" (Osterwalder & Pigneur, 2010). That is, in order to achieve network effects and positive feedback loops (Shapiro & Varian, 1999), the platform provider subsidizes neither sides (nor supply or demand). Some successful examples of two-way platforms are: Uber; Lyft, Blablacar, Airbnb, Tinder, Spotify, TripAdvisor, among others.

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) subsidize 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, van Asltyne & Choudary, 2016; Choudary, 2015; Osterwalder & Pigneur, 2010), some examples are: video game companies (Playstation; Xbox), printer companies (HP, Epson) and even newspaper companies (such as the Swedish company Metro International). 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 Autonomous Shuttles for Collective transport

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

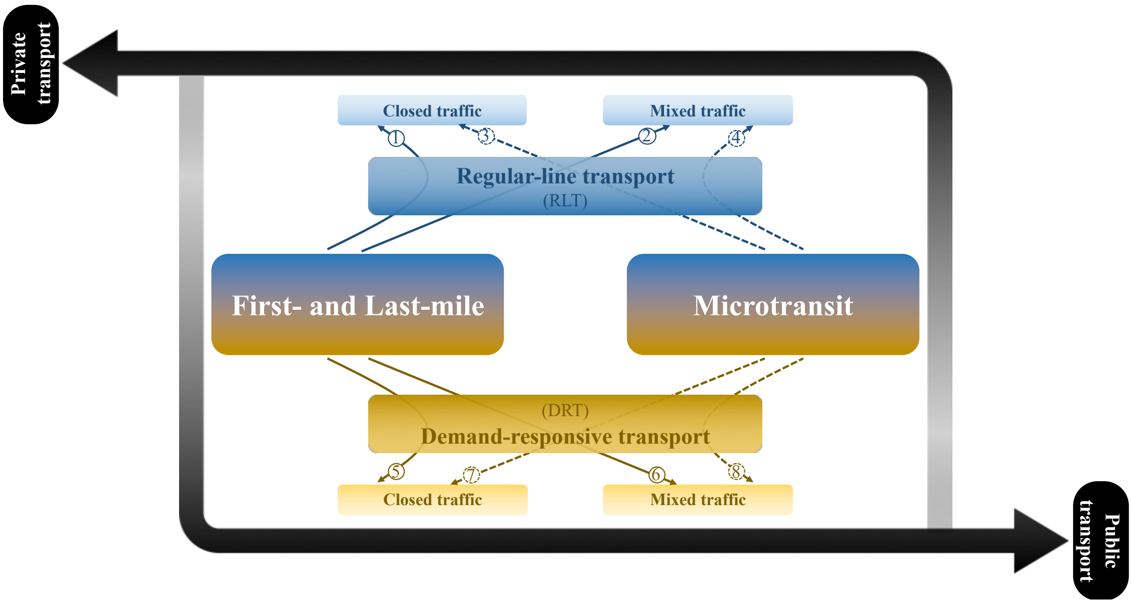

Figure 3. Framework of ASCTs usage typologies
Source: prepared by the author based on research data.

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 three experimentations were found, all within the scope of Regular-line Transport (RTS); being one project in typology 2 (First- and Last-Mile RTS in mixed traffic): May Mobility privately transporting Quick Loans workers in Detroit from parking lots to their office buildings; and two in typology 3 (Microtransit RTS in closed traffic): Navya privately transporting workers in France (EDF Civaux nuclear powerplant) and in Australia (Sydney Olympic Park).

As for the business models aimed to address public transportation solutions, a total of 89 experimentations were identified, covering all eight of the typologies proposed. As detailed in Table 3, 79 of these experiments (88,76%) are fit within RLT, with 23 (25.84%) projects in typology 1 (First- and Last-mile RLT in closed traffic), 17 (19.10%) in typology 2 (First- and Last-mile RLT in mixed traffic), 18 (20.22%) in typology 3 (Microtransit RLT in closed traffic) and, 21 (23.60%) 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 (11.24%) 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, 4 projects were found for closed traffic and also 4 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 2019 (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 Amobility (digital service provider). Table 3 classifies the 92 sampled experimentations within the range of identified typologies.

	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%	23	25,84%
2	First- and Last-mile RLT in mixed traffic	1	33,33%	17	19,10%
3	Microtransit RLT in closed traffic	2	66,67%	18	20,22%
4	Microtransit RLT in mixed traffic	0	0,00%	21	23,60%
5	First- and Last-mile DRT in closed traffic	0	0,00%	1	1,12%
6	First- and Last-mile DRT in mixed traffic	0	0,00%	1	1,12%
7	Microtransit DRT in closed traffic	0	0,00%	4	4,49%
8	Microtransit DRT in mixed traffic	0	0,00%	4	4,49%
	Total	**3**	**100,00%**	**89**	**100,00%**

Table 3. Classification of the 92 ASCTs experimentations within the 8 proposed typologies. Source: prepared by the author based on research data.

Key-Performance Indicators (KPIs)

Due to the inherent complexity regarding each experimentation and each of the listed typologies, we sought to discuss in this session a group of factual Key-Performance Indicators that most likely would impact the overall technical implementation of ASCTs. We listed 9 KPIs (Table 4), and subdivided them into economic-centered (related to best usage of resources) and user-centered (related to the user experience).

Key-Performance Indicator	Possible metrics	Category
Battery range	Number of kilometers traveled on a single charge	Economic-centered
Vehicle's traveled distance	Number of kilometers traveled per shuttle	Economic-centered
Shuttle's occupancy	Number of passengers per shuttle and per ride	Economic-centered
Commute costs	Overall costs involved in operating and maintaining the shuttle per kilometer traveled	Economic-centered
Safety	Number of accidents/incidents per kilometer traveled	User-centered
Commute travel time	Average time spent in the commute	User-centered
Commute price	Average price per trip	User-centered
Waiting time	Average waiting time (in minutes) to get on board the shuttle	User-centered
Travel time efficiency	Expected departure and arrival time	User-centered

Table 4. Key performance indicators for ASCTs.
Source: prepared by the authors based on research data.

It is worth noting that the listed KPIs far from being exhaustive. Further studies are needed to better understand and develop relevant metrics for assessing ASCTs performance not only from technical and economical standpoints but also from social-psychological ones.

Regarding the latter, the Unified Theory of Acceptance and Use of Technology – UTAUT (Davis, 1989) seems to be appropriate. Madigan et al. (2017) used theory to delineate constructs to investigate users acceptance of ASCT during the CityMobil2 trials in Lausanne (Switzerland). The construct definitions used by the authors were:

- **Performance expectancy:** degree to which using an ASCT provides benefits to consumers in their commute.
- **Effort expectancy:** degree of ease associated with ASCTs use.
- **Hedonic motivation:** fun or pleasure derived from using ASCTs.
- **Facilitating conditions:** consumers' perceptions of the resources and support available to use ASCTs.
- **Social influence:** extent to which consumers perceive that important others (e.g., family or friends) would use ASCTs.
- **Price value:** value for money
- **Habit:** extent to which an individual believes a behavior to be automatic.

The final topic of this session of results and discussion will better detail the role played by the main stakeholders in each nature of deployed experimentations as well as the value creation and distribution.

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) and 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 colored-coded arrows which indicate the direction of the flow and the main value being exchanged.

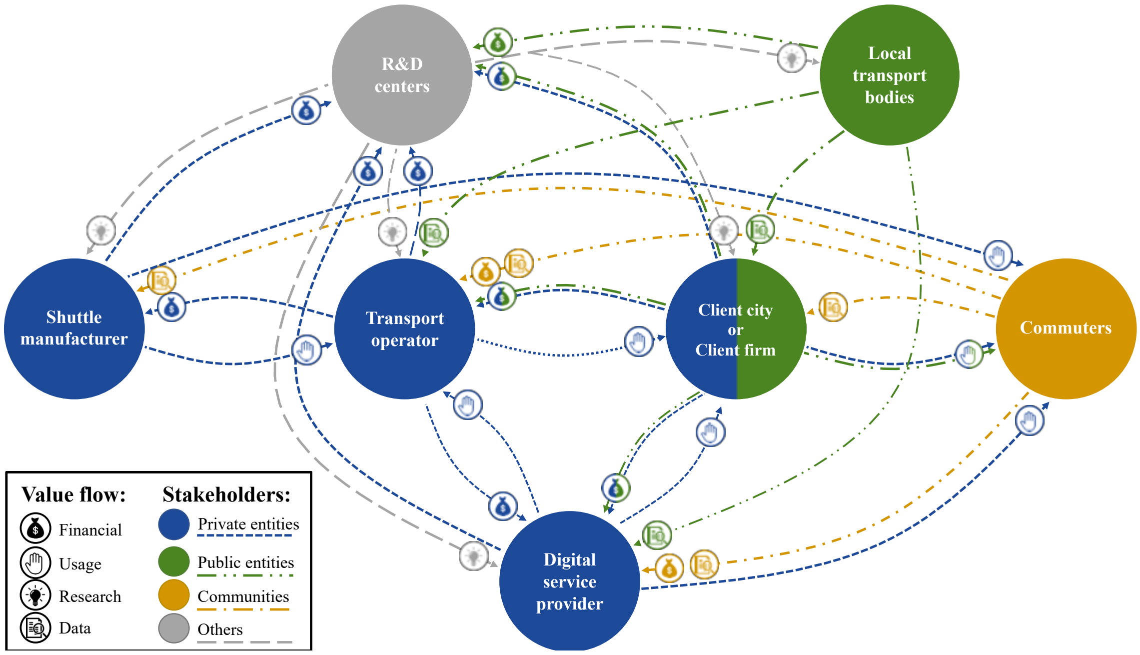

Figure 4. ASCTs' generical stakeholders and value flows.
Source: prepared by the author based on WDS (2018) and Kopanezou (2004).

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) or 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 customized 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, Souza, and Castro (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 centers 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

By aiming at performing a worldwide benchmark on experimentations with Autonomous Shuttles for Collective Transport, the present study identified 92 deployments, spread across 78 cities in 32 countries; being enabled by 20 different shuttles' manufacturers.

Europe has been at the forefront not only in experimentation numbers (57.61% of the projects) but also on shuttles' R&D. The continent holds 9 manufacturers that together respond to 80 of the 92 experimentations, and within this figure, more than three quarters were carried out by the French startups Easymile and Navya (34 and 31 experimentations respectively). Other newcomers such as the American Local Motors, the New Zealander HMI and the Japanese Hino Motors have great potential on becoming relevant contenders for Navya and Easymile.

From the total of experimentations, the majority of 69.23% was classified was trials, followed by 20.88% classified as showcases and only 9.89% as regular services, and due to that, they were mainly offered free of charge to commuters (94.05% of the total). As for the deployed road environment, they were either on closed/controlled areas (52.17%), or, mixed-traffic routes (47.83%); such results might be explained by the fact that testing with autonomous vehicles on mixed-traffic and open roads is 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 & Sarazen, 2018; KPMG, 2018; Parker, Shandro & Cullen, 2017; Clausen, 2017).

By analyzing the prevailing business models, we observed that the vast majority of experimentations tackle public transport schemes (96.55%) with daily commuters as the main revenue sources for the transport operator. With that, only 3.45% were aimed at private transport schemes.

Regular-line transport systems comprised the vast majority of operation models among the sampled projects (91.21%) while demand-responsive transport answered to only 4.40% and a mixed approach comprising both operation models was present in the other 4.40%. 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.

As for the business typologies, eight usage forms were identified, four focusing on the first- and last-mile issue and four focusing on microtransit commute (all applicable for both public and private transport business models). From the 92 experiments, 79 were fit within the regular-line transport system, with 23 projects covering first- and last-mile in closed traffic,17 first- and last-mile in mixed traffic, 18 with microtransit in closed traffic and, 21 with microtransit in mixed traffic. The remaining were either private regular-line systems (3 cases) or on-demand public transport (10 cases) where, in such cases, multi-sided one-way business platforms were applicable.

Regarding the key-performance indicators, we listed 9 (battery range, vehicle's traveled distance, shuttle's occupancy, commute costs, safety, commute travel time, commute price, waiting time and, travel time efficiency) that aimed at covering all typologies of uses and were divided into economic- and user-centered. Further studies are however needed to test the feasibility of such KPIs as well as to elucidate if they are enough metrics for evaluating the business models or whether more KPIs need to be ranked.

At last, we attempted to identify 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, we've concluded that ASCTs are embedded in a business ecosystem in which growth and evolution depends on the synergy and value flows among the stakeholders. Nevertheless, several issues and assumptions 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 challengers to all stakeholders involved, therefore further in-depth studies should be valid to tackle such strategic matters.

The main limitation of this study was the difficulty in obtaining data. Much of the data 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 analyze. In addition, some sets of information could not be obtained through the adopted technique of 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.

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) may come to answer and fulfill the main issues and constraints found in the present study.

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