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To cite this version:

Félix Carreyre, Nicolas Coulombel, Jaâfar Berrada, Laurent Bouillaut. Economic evaluation of autonomous passenger transportation services: a systematic review and meta-analysis of simulation studies. Revue d'économie industrielle , 2022, 178-179, pp.89-138. 10.4000/rei.11536 . hal-04418672

HAL Id: hal-04418672

https://hal.science/hal-04418672v1

Submitted on 29 Jan 2024

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Dans Revue d'économie industrielle 2022/2 (N° 178-179), pages 89 à 138
Éditions De Boeck Supérieur

ISSN 0154-3229
ISBN 9782807398412
DOI 10.4000/rei.11536

Article disponible en ligne à l'adresse
https://www.cairn.info/revue-d-economie-industrielle-2022-2-page-89.htm

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Revue d'économie industrielle

178-179 | 2e et 3e trimestres 2022
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Electronic version
URL: https://journals.openedition.org/rei/11536
DOI: 10.4000/rei.11536
ISSN: 1773-0198

Publisher
De Boeck Supérieur

Printed version
Date of publication: 1 September 2022
Number of pages: 89-138
ISBN: 978-2-8073-9841-2
ISSN: 0154-3229

Electronic distribution by Cairn

Electronic reference
Félix Carreyre, Nicolas Coulombel, Jaâfar Berrada and Laurent Bouillaut, "Economic evaluation of autonomous passenger transportation services: a systematic review and meta-analysis of simulation studies", *Revue d'économie industrielle* [Online], 178-179 | 2e et 3e trimestres 2022, Online since 01 January 2026, connection on 12 April 2023. URL: http://journals.openedition.org/rei/11536 ; DOI: https://doi.org/10.4000/rei.11536

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ECONOMIC EVALUATION OF AUTONOMOUS PASSENGER TRANSPORTATION SERVICES: A SYSTEMATIC REVIEW AND META-ANALYSIS OF SIMULATION STUDIES

EVALUATION ÉCONOMIQUE DES SERVICES DE TRANSPORT DE PASSAGERS AUTONOMES : UNE REVUE SYSTÉMATIQUE ET UNE META-ANALYSE DES RÉSULTATS DES SIMULATIONS

Félix Carreyre[1,2], Nicolas Coulombel[2], Jaâfar Berrada[1], Laurent Bouillaut[3]

Keywords: autonomous vehicles, mobility services, transport modelling, economic evaluation, AV, SAV

Mots-clés : véhicules autonomes, services de mobilité, modèles de trafic, évaluation économique

1. INTRODUCTION

As autonomous vehicles (AV) are becoming more of a reality, with significant technological progress (Pendleton *et al.*, 2017) and numerous experiments (Antonialli, 2019; Stocker and Shaheen, 2019) being led across the world, an increasing number of studies are investigating the economic benefits as well as the costs that can be expected

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from the development of AV services. These studies have shown that the introduction of such services will have relatively diverse impacts (Narayanan *et al.*, 2020). First, by making the act of driving no longer necessary, users will be able to engage in other activities, such as leisure or work, while sitting in their autonomous car. This is predicted to result in a weakening of the value of travel time savings for private mobility (Correia *et al.*, 2019; Kolarova *et al.*, 2019; Berrada *et al.*, 2020), and subsequently in a reduction in the generalized cost of travel. Regarding public transportation (including taxis and ride-hailing), the absence of drivers is similarly likely to result in lower operating costs as the technology matures (Anderson *et al.*, 2016; Bösch *et al.*, 2018). AV services are also expected to improve accessibility for people with limited motility such as the elderly, children, or adults with no driving license (Meyer *et al.*, 2017). Since the autonomous technology should also result in smoother driving and cooperation between vehicles (e.g., platooning), substantial benefits are also expected in terms of emissions (Bauer *et al.*, 2018), accidents (Clements and Kockelman, 2017), and congestion, as shorter headways between autonomous vehicles could allow road capacity to increase (Simoni *et al.*, 2019). These expected benefits remain controversial, however. AV services might also lead to an increase in traffic due to the lower cost of travel—non-monetary through the cost of time for private transport, monetary through lower fares for public transit—(Fosgerau, 2019; Childress *et al.*, 2015) or due to deadheading (Fagnant and Kockelman, 2014). Lower values of travel time savings could also exacerbate congestion by mitigating the peak spreading phenomenon (van den Berg and Verhoef, 2016).[4] Combined with the fact that from a lifecycle perspective, AVs are likely to generate more emissions than conventional electric vehicles due to the additional equipment and data processing they involve, these points make the environmental impacts of AV services highly uncertain (Golbabaei *et al.*, 2020; Wadud *et al.*, 2016). Similarly, there is also strong uncertainty regarding the financial cost of AV services, especially infrastructure costs, which have attracted less attention in the literature.

4 The peak spreading phenomenon corresponds to drivers leaving before or after peak travel time to avoid congestion (Gordon *et al.*, 1990).

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Beyond these uncertainties, there is consensus that AV services will result in many changes to transportation supply—new services, lower operating costs—and travel demand—lower value of time, improved accessibility—, together with complex interactions between them (Bahamonde-Birke *et al*., 2018). In order to better evaluate the (expected) performance of AV services, a growing body of literature therefore relies on mobility simulation models in an attempt to capture these complex factors, ranging from agent-based models—such as MATSim or SimMobility—to direct demand models (Berrada and Leurent, 2017). These studies substantially differ however, be it with regard to the model type used, the way performance is measured, or the services compared within a given study. Many reviews have therefore attempted to synthesize the results of this simulation literature. Berrada and Leurent (2017) provided a short qualitative review of simulation methods and the expected economic impacts (mobility, parking, accidents, environment) of AV services. Jing *et al*. (2020) carried out a systematic review of the agent-based simulation literature with a corpus of 44 papers, focusing on the simulation platforms used and the critical variables and output of the simulations. Golbabaei *et al*. (2020) also carried out a systematic review of the literature (with 81 papers) and discussed the expected impacts on urban mobility (fleet size, traffic, and congestion), urban infrastructure and land use (household location, parking spaces, pick-up/drop-off and charging stations), social and travel behavior impacts (trip and mode choice, vehicle ownership) and environmental impacts. Bahamonde-Birke *et al*. (2018) also discussed what they call the first-order and second-order effects of AV services using a systemic approach. Pernestål and Kristoffersson (2019) reviewed 26 papers and reported their findings on the impacts of AV services, focusing on four specific indicators: the trip (monetary) cost, vehicle kilometers traveled (VKT), fleet size, and waiting time. Other effects have been briefly discussed, such as energy consumption, land-use, and travel behavior. Soteropoulos *et al*. (2019) carried out a systematic review of 37 modelling studies, with a focus on vehicle kilometers traveled, vehicle hours traveled, modal shares, and land use (parking spaces, including fleet size, location choices). Narayanan *et al*. (2019) also conducted a comprehensive review of the literature and the reported impacts on traffic and safety, travel behavior, the economy, transport supply, land use, the environment, and governance.

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Their review focused on shared AV services however, in other words, the so-called "robot-taxis". While several systematic reviews have discussed the expected impacts of AV services, most are qualitative. No meta-analysis has been carried out to date to the best of our knowledge. Furthermore, all the above reviews discuss each impact independently, so the policy implications remain vague due to the wide array of impacts.

This work aims to better understand our current knowledge—and lack of knowledge—of the expected economic impacts of AV services through a systematic two-step review of the simulation literature. Taking cost-benefit analysis (CBA) as a reference evaluation framework (Layard and Glaister, 1994), we first examine which impacts have been studied in the literature and to what extent by examining the prevalence of 22 indicators directly related to CBA. The cost-benefit analysis seeks to evaluate scenarios (e.g., a new infrastructure, transportation policy or mobility service) by assessing the various impacts, monetizing them, and adding them over time using discount rates in order to determine the value of the scenario for society. While other evaluation methods exist (such as multi-criterion analysis), cost-benefit analysis remains to date the standard evaluation framework for transportation policies across the world (Small and Verhoef, 2007). This first step allowed us to establish a shortlist of key performance indicators for which enough studies were found to carry out a meta-analysis, which was conducted in a second step. While the systematic reviews kept the results attached to the articles in question, the meta-analysis provided overall (i.e., decontextualized) forecasts of the AV impacts. Four key performance indicators (KPIs) were taken into consideration: vehicle kilometers traveled (VKT), travel time, fleet size and total costs. Our meta-analysis thus provides a first quantitative estimate of the expected impact of AV services on travel demand, congestion, and system performance.

The literature review focuses on road passenger transportation and the (micro-)economic impacts of AV services for society. Applications of AVs to freight (see Flämig, 2016, for a review) are studied in separate papers, with limited (if any) intersection to date with the (passenger) mobility simulation literature. Similarly, autonomous air and

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rail transportation are not considered in this review due to the specific nature of these modes of transport and the current focus of the simulation literature on road transportation. Our review focuses on (micro-) economic impacts, in other words, all the impacts that may be found in a standard transportation CBA (de Rus *et al.*, 2020). The macroeconomic impacts of autonomous vehicles on economic growth or employment are considered beyond the scope of this paper as they are rarely if ever mentioned in simulation studies and are discussed in other reviews (Clements and Kockelman, 2017; Faisal *et al.*, 2019; Clark *et al.*, 2016). Similarly, other studies offer a broader perspective of autonomous vehicles by considering the state of the art in research as a whole (Gandia *et al.*, 2019), business and management research (Cavazza *et al.*, 2019), and user acceptability (Andersson *et al.*, 2017).

This paper completes the various systematic reviews on simulation studies in two main ways. First, using cost-benefit analysis as a reference evaluation framework, it quantifies the extent to which listed impacts have been studied in the literature, both separately and jointly. This allows us to show which impacts have been largely investigated and are therefore more likely to be correctly appraised, and which impacts have attracted less attention. By also studying the co-occurrence of impacts -seldom done in former reviews -, we show that comprehensive evaluation of AV services, such as using CBA, remain extremely rare to date, as most modeling studies focus on operational and financial performance with significantly less attention to externalities. Second, this paper provides quantitative rather than qualitative estimates of the expected impact of AVs, depending on the service characteristics for four key performance indicators: VKT, travel time, fleet size and total costs. It thus provides better insights into the effects of AV services on demand, operations and system performance, as well as insights into the influence of service characteristics in this regard.

2. METHODOLOGY

This paper investigates the expected economic impacts of autonomous vehicle (AV) services, based on findings in the (passenger) mobility simulation literature. Our methodology relies on two main steps.

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The first step uses a descriptive statistical analysis to determine which impacts are studied in the literature and to what extent. Taking cost-benefit analysis (CBA) as a reference framework for the economic evaluation of mobility services, we establish a list of key performance indicators (KPIs) commonly used in CBA and measure their frequency in a first corpus of AV services modeling studies. In addition to ascertaining the current focus of the relevant literature, this enables us to determine which impacts are studied most frequently and are therefore more likely to be correctly appraised, and which are not.

Next, we carry out a meta-analysis that focuses on the four most frequently considered KPIs in order to evaluate the expected magnitude of the associated impacts, based on the current state of the art.[5] Our first corpus is hence restricted for the sake of the meta-analysis to the subset of relevant studies (i.e., only those featuring at least one of the four KPIs), a subset that we refer to as the second corpus. Through the four KPIs considered (VKT, Travel Time, Fleet Size and Total Costs), the meta-analysis provides a first estimate of the expected impact of AV services on travel demand, congestion, and system performance.

Figure 1 summarizes the methodology used in the paper, including the data collection process. All of these steps were performed on Excel. Data are available as an online appendix.

5 The meta-analysis is "*a subset of systematic reviews; a method for systematically combining pertinent qualitative and quantitative study data from several selected studies to develop a single conclusion that has greater statistical power*" (Himmelfarb Library, Study Design 101).

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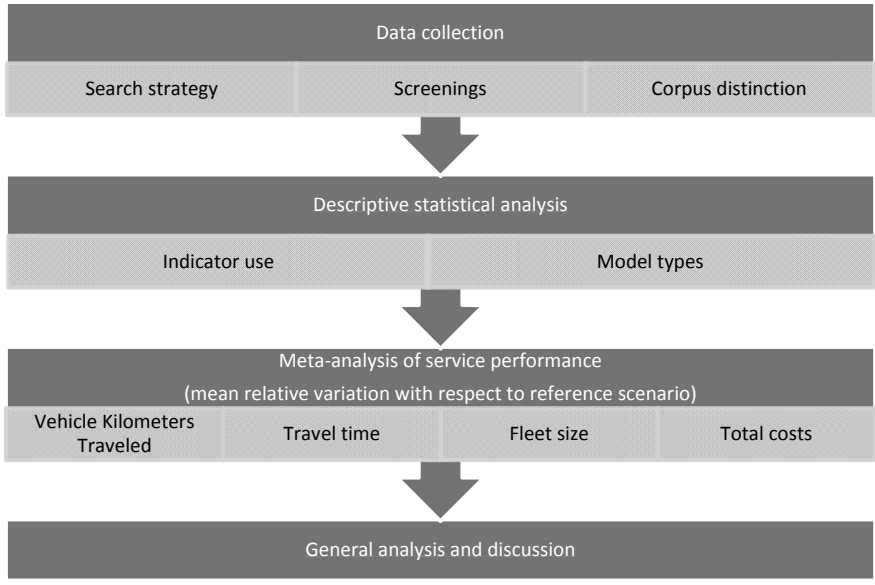
Figure 1. Methodology overview



Source: prepared by the authors.

We now detail the corpus selection process, the nomenclature of AV services used in our study, and the methodologies developed in the descriptive statistical analysis and in the meta-analysis.

2.1. Corpus selection

The selection of our two corpuses—the first for the descriptive statistical analysis and the second for the meta-analysis—also comprises two main steps. We began by collecting a preliminary corpus using a standard keyword-based search strategy augmented with a "snowball" search strategy. This corpus was then screened through the successive application of exclusion and inclusion criteria to produce our two final corpuses. As previously mentioned, the second corpus is a strict subset of the first corpus, obtained by considering additional exclusion and inclusion criteria, retaining from the first corpus only studies for which we were able to extract data for the meta-analysis.

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2.1.1. Search strategy

The preliminary corpus was collected using two complementary methods. The primary one was an "All fields" search in the Web of Science database. The keywords used were "(«autonomous vehicles» OR «automated vehicles») AND («Simulation» OR «modelization» OR «modelling» OR «model») AND («passengers» OR «mobility»)". Only papers published between 1990/01/01 and 2020/10/01 were retained, so one trimester is missing for the year 2020.

This set of references was extended using a snowball search based on the survey of Berrada and Leurent (2017), which reviews transportation modeling studies on AV services. The snowball search strategy aims to collect a series of papers on a given topic by considering an initial corpus, then expanding it either with the references listed in the corpus ("reverse snowball search"), or with the papers that reference any one of the papers included in the initial corpus ("forward snowball search") (Francese and Yang, 2021). The starting point can be the result of a search in scientific databases (as in Büchel *et al.*, 2020) or (the solution we chose) an existing review on the topic of interest followed by a search on Google Scholar and Science Direct.

This twofold search strategy allowed us to obtain a large preliminary corpus of simulation studies about AV services, while limiting possible selection bias inherent to pure snowball search strategies. The Web of Science search offers 529 papers published between 1991 and 2020 (Figure 2). From 1991 and 2013, activity was relatively stable, ranging from one to three papers published a year. From 2014 and 2019, activity grew substantially, from 16 papers published in 2014 to 167 papers in 2019. The number of papers fell in 2020 due to the year being incomplete. Given that one trimester is missing, the number of papers for 2020 should be quite close to that of 2019.

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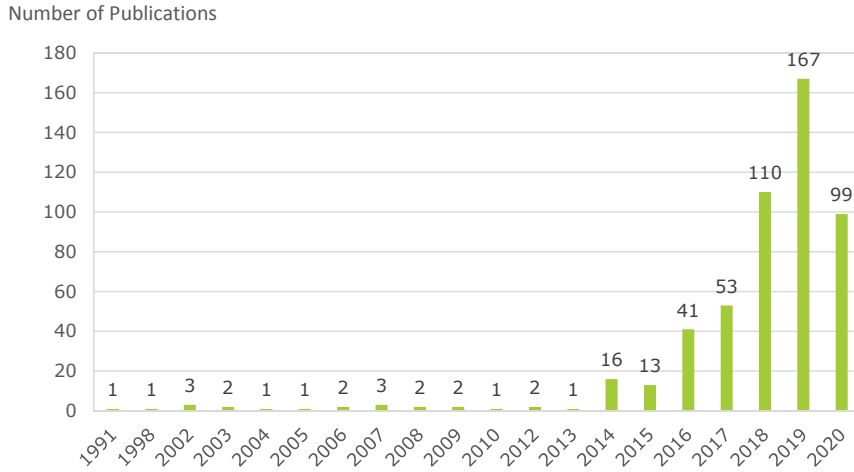
Figure 2. Number of papers per year (preliminary corpus excluding snowball search)



Source: prepared by the authors based on Web of Science query.

The very low number of studies prior to 2014 may be due to the choice of keywords, as "self-driving" or "driverless" might have resulted in older references. On this point, Gandia *et al.* (2019) recommend using "Automated" and "Autonomous" when referring to driverless technology.

2.1.2. Screening

We now detail the exclusion and inclusion criteria applied to the preliminary corpus in order to generate the first and second corpuses.

a. First corpus

The exclusion criteria for the first corpus were:

1. Studies dealing primarily with freight;
2. Parking and traffic optimization studies;
3. Studies focusing on the analysis of autonomous rail or air services (including air taxis, technical developments);

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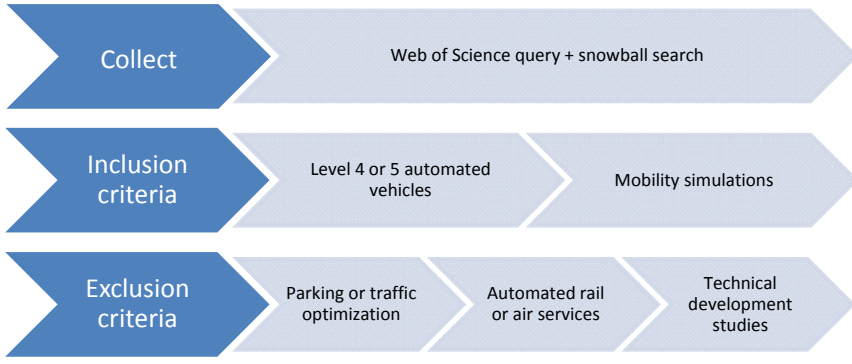
4. All papers using simulation in order to provide technical recommendations on computer driving ability. Research driven by the motivation to make autonomous vehicles a technically mature technology, especially in terms of safety, is not included in the scope of our study.

Conversely, the inclusion criteria for the first corpus were:

1. Mobility simulation studies that consider a scenario with a road-based autonomous vehicle service.
2. The autonomous level considered is SAE level 4 or 5 (see section 2.2 for definitions).
3. Rail services may be included as long as they are only used in the benchmark scenario.

Figure 3. Selection process for the first corpus



Source: prepared by the authors

The exclusion and inclusion criteria (Figure 3) narrow the number of papers from 529 (preliminary corpus) to 84 articles (first corpus). Simulation and evaluation of AVS is a relatively recent topic in the scientific literature. While the first published paper in the corpus dates from 2014 (Zachariah *et al.*, 2014), almost two thirds of the corpus was published in the last three years (Figure 4), reflecting a growing trend in papers on this topic and evincing the results of the query on the Web of Science.

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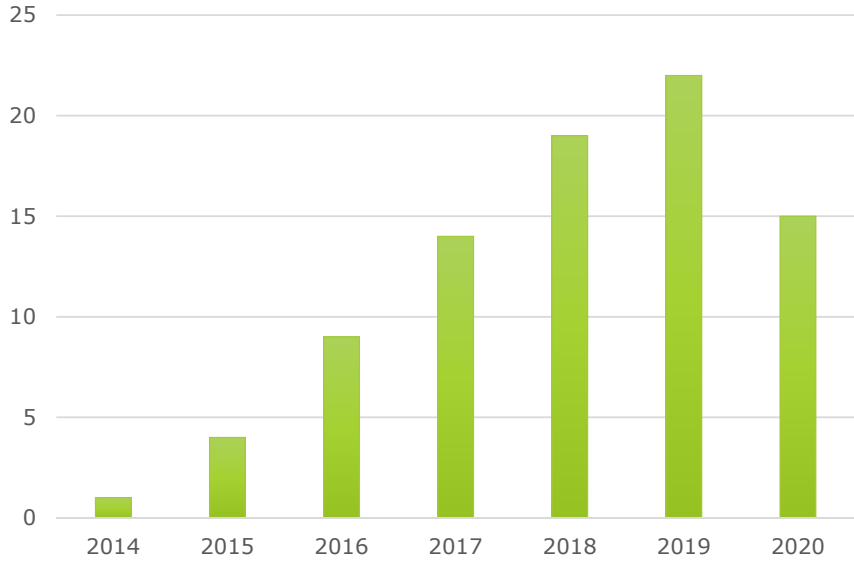
Figure 4. Publication dates



Source: prepared by the authors.

The first corpus consists of 42 papers published in peer-reviewed journals, 1 thesis, 40 conference papers, and 1 technical report. Among the conference papers, the International Workshop on Agent-based Mobility, Traffic and Transportation Models, Methodologies and Applications (ABMTRANS conference) is the most represented, with 5 papers (Figure 5). Among the journal papers, the main source is the Transportation Research Record (the Journal of the Transportation Research Board), with 15 papers published. As expected, a fair number of papers originate from the Transportation Research series, with 7 papers in Part A: Policy and Practice, and 7 papers in Part C: Emerging Technologies.

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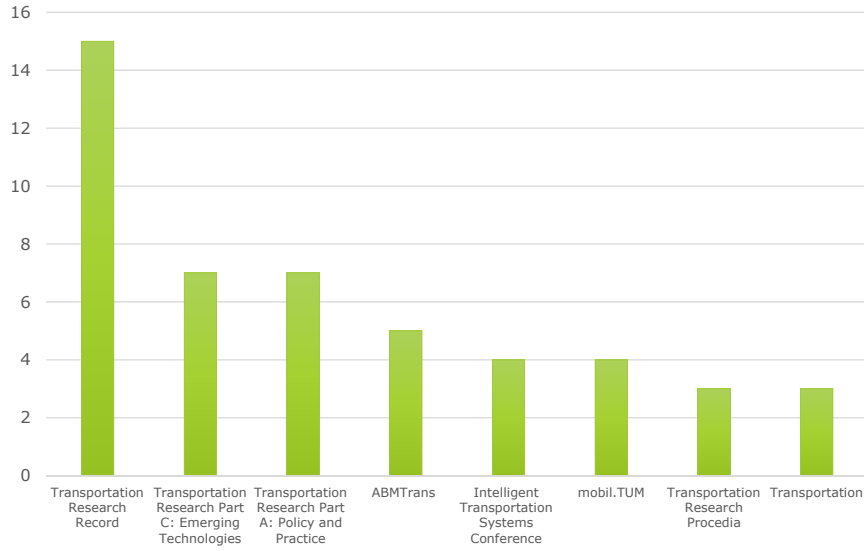
Figure 5. Main publication sources



Source: prepared by the authors. Note: this figure reports all venues with three papers or more.

The full list of reviews and conferences may be found in the Appendix (Fig. A.1).

b. Second corpus

Relative to the first corpus, the following inclusion criteria were added to draw up the second corpus (Figure 6):

1. The study needs to compare two or more mobility services, with at least one involving autonomous vehicles.
2. The paper must evaluate in a quantitative and comparative (across the various scenarios tested in the paper) manner at least one of the four following KPIs:
   - vehicle-kilometers traveled;
   - travel time;
   - fleet size;
   - total costs.

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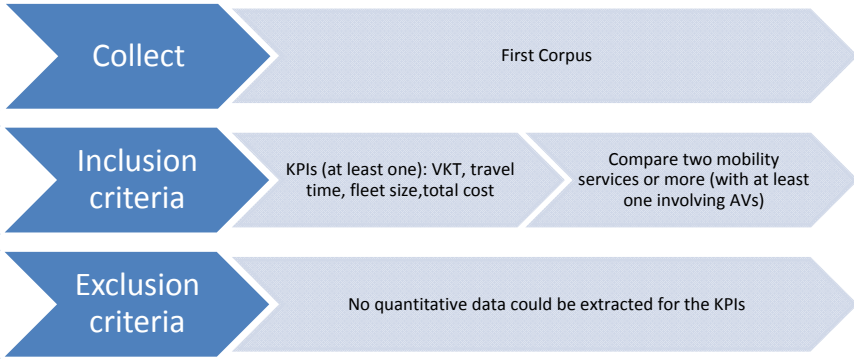
Conversely, studies from which it was not possible to extract quantitative output of any of the four above-mentioned KPIs were not included in the second corpus. More details on the extraction and treatment of KPIs can be found in subsection 2.4.2.

Figure 6. Selection process for the second corpus selection



Source: prepared by the authors.

2.2. Service nomenclature

Current and prospective experiments of autonomous vehicles across the world involve a wide array of services, ranging from short-haul on-demand small autonomous vehicles (the so-called robot-taxis, see Stocker and Shasheen, 2018) to autonomous shuttles that operate on conventional stop-based and schedule-based transit lines (see AVENUE for European project). As the specific characteristics of AV services are likely to strongly influence system performance (Nagel *et al.*, 2019), a nomenclature is a useful way to characterize them, in particular allowing us to control for the effect of service characteristics when assessing the impact of AV services in the meta-analysis.

The following nomenclature was built using the prior work of Antonialli (2019), Földes *et al.* (2016) and Földes *et al.* (2018) on smart mobility services. This classification also bears similarities with that of Becker *et al.* (2020) and Berrada (2019). It is based on the five following features:

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- **Vehicle ownership and usage** reflects the responsibilities of purchasing, maintaining and sharing the vehicle, and potentially providing a service. We distinguished between two types of ownership: individual ownership, where the vehicle is personal, and third-party ownership, where the vehicle is owned by a public or private operator/organization. Similarly, two types of usage were considered: private usage, where the owner uses the vehicle for his/her own mobility needs, and shared usage, where the owner makes the vehicle available to potential individuals to allow them to reach their destination (Berrada, 2019).
- **The ridesharing** feature determines whether the trip may be shared between two passengers or more (Berrada, 2019).
- **Service availability** is considered from two perspectives: space (by distinguishing line-based, stop-based, and door-to-door services) and time (on-demand versus scheduled service). This two-dimensional classification is derived from Berrada (2019) and offers similarities with the two operation models described in Antonialli (2019), distinguishing between Regular-Line Transport and Demand-Responsive Transport.
- **Vehicle type** mostly refers to the vehicle size, with four increasing levels of capacity. The "car category" is used for vehicles with 1 to 5 available seats, shuttles for 6 to 18 seats, and buses for more than 19 seats. The rail vehicle type includes tramways, metros, and trains (inspired by Stocker and Shaheen, 2017).
- **Automation level** describes the vehicles' automation features based on the SAE classification (SAE J3016:201806 "International Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles"). Three main levels are explored in the literature: conventional level refers to the level 0 of automation, semi-autonomous level to levels 3 and 4, and autonomous level to level 5.

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Table 1. Strategic features of a mobility service

Service nomenclature	Features	Source
Vehicle ownership and usage	Individual ownership and private usage Individual ownership and shared usage Third-party ownership and shared usage	Berrada (2019)
Ridesharing	Yes No	Berrada (2019)
Service availability	***Space***	
	Door-to-Door Stop-Based Line-based	Hardt and Bogenberger (2016) Berrada (2019) Antonialli (2019)
	Time	
	Scheduled On-demand	Antonialli (2019)
Vehicle type	Car Shuttle Bus Rail	Stocker and Shaheen (2017)
Automation level	Conventional (Levels 0,1,2) Semi-autonomous (Levels 3&4) Autonomous (Level 5)	SAE classification

Source: prepared by the authors based on above sources.

The on-demand door-to-door system collects passengers from their location and takes them to their final destination. The vehicle can either be shared (ridesharing) or used privately (private ownership or solo car sharing).

The on-demand Stop-Based system is a hybrid between conventional public transit and on-demand door-to-door services. Boarding/alighting is only permitted at stations. Again, the vehicle can be either shared or used privately.

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2.3. Descriptive statistical analysis

The descriptive statistical analysis aims to determine which impacts are considered in the simulation literature, and to what extent, at the same time allowing us to highlight the current focus of the literature and the gaps to be filled.

2.3.1. Selection and classification of the indicators

In order to list which impacts are considered in simulation studies, we took the cost-benefit analysis as the reference evaluation framework, since it is currently standard practice in carrying out an economic evaluation of transportation investments, services, or policies (Boardman, 2006; de Rus *et al*., 2020). We then considered a list of common CBA indicators (de Rus *et al*., 2020; Quinet, 2013; Small and Verhoef, 2007; Victoria Transport Institute, 2009) and classified them into five main categories, related to:

- Service performance: includes indicators that measure service performance from a demand perspective, which are then used to compute consumer surplus,
- Operations: includes indicators that measure the operators' economic performance, which is then used to compute the operator surplus,
- Externalities: includes the main externalities captured in standard CBA: i.e., energy, greenhouse gas emissions, local pollutants, noise, safety, congestion,
- Socioeconomic: used to determine whether the study evaluates the results through the prism of some socioeconomic characteristics such as age or income level,
- Cost Benefit Analysis (CBA): refers to the standard final output of a CBA, such as the net present value.

Table 2 lists the indicators (twenty-two) identified within each category. The aim of this classification is to highlight the focus of the studies, while evaluating the capacity of the different simulation models used in the papers included. Apart from the "Socioeconomic" category,

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these indicators were selected for their use in CBA. The "Socioeconomic" section aims to complete the picture by adding social indicators where a few other studies, such as Tian *et al*. (2018), had a more technological-oriented indicator set (such as pre-collision systems or machine learning approach-based emergency brakes).

The selected indicators are usually simulation outputs. In some specific cases, they may also be considered as operational constraints to ensure a certain quality of service: e.g., fleet size (Berrada, 2019; Vosooghi, 2019) or the required Level of Service (Navidi *et al*., 2017).

Table 2. Indicators

Category	Indicator	Definition	Source
Service performance	Waiting time		Quinet (2013), De Rus *et al*. (2020)
	Patronage		De Rus *et al*. (2020)
	Travel Time	Total travel time is composed of (a) access/egress time (only for line-based and stop-based services), (b) waiting time, and (c) in-vehicle travel time	De Rus *et al*. (2020)
	Vehicle Kilometers travelled (VKT)	Refers to the total distance travelled by empty and loaded vehicles. Also measured by vehicle miles travelled (VMT) in the Anglo-Saxon literature	Quinet (2013), Small (2007)
Operations	Occupancy rate	Corresponds to the average number of passengers per vehicle	Huang *et al*. (2020) *
	Fleet size	Refers to the total number of vehicles deployed for the service production	Bösch *et al*. (2016)
	Total Costs	Production costs, including at least operating costs. Fixed costs are also included in some studies	Bösch *et al*. (2018)
	Profits	Corresponds to the net profit for the operator, as the difference between costs and revenue	Fagnant and Kockelman (2016)
	Fare	Corresponds to the price of usage	Tirachini and Antoniou (2020)

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Externalities	Local pollution	Corresponds to pollutant emissions that contribute to poor air quality, including particulate matter (PM), nitrogen oxides (NOx), and volatile organic compounds (VOCs)	De Rus *et al.* (2020)
	GHG emissions	Mainly include CO2 emissions due to operations. Refers to climate change	De Rus *et al.* (2020)
	Energy	Corresponds to energy consumption required for operations according to the motorization type of vehicle (thermal, electric, etc.)	Bauer *et al.* (2018)
	Noise	Refers to consideration of the noise nuisance	De Rus *et al.* (2020)
	Safety	Corresponds to the level of accidents with injuries and deaths	De Rus *et al.* (2020)
	Congestion	Corresponds to an estimation of the resources wasted in an overcrowded environment	De Rus *et al.* (2020)
Socioeconomic profile	Age		Urbina and Sohaee (2020)
	Gender		Hulse *et al.* (2018)
	Socioeconomic status	Variables describing the socioeconomic status of the household/individual, such as income, job category…	Müller *et al.* (2020)
	People with reduced mobility		
Cost Benefit Analysis	Net Present Value (NPV)	Corresponds to the difference between the present value of inflows and outflows over a certain period of time	Quinet (2013)
	Internal Rate of Return (IRR)	The annual growth rate an investment is expected to generate	Quinet (2013)
	Benefit Cost Ratio (BCR)	The ratio between costs and benefits, expressed in monetary or qualitative terms	Quinet (2013)

Source: prepared by the authors based on above sources.

* *The "occupancy rate" refers to the "average vehicle occupancy" from Huang* et al. *(2020).*

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We investigated the use of indicators in the literature with a statistical descriptive analysis examining 1) the occurrence of each indicator, 2) the occurrences of at least one indicator per category, and 3) the mean numbers of indicators per category in each paper. The analysis is followed by a qualitative discussion regarding the use of indicators in the papers reviewed.

2.3.2. Model types

In addition to the use of indicators, our analysis also investigated the types of simulation models used, providing some insights into the capacity of the various model types to simulate specific AV services or to generate distinctive outputs.

The following model types were considered, using the standard classification of transportation models (Ortúzar and Willumsen, 2011; Soteropoulos *et al.*, 2019):

- Agent-based models are models where "*a system is modeled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules.*" Bonabeau (2002)
- Four-step models are traditional mobility simulation models. They offer an aggregated view of the demand and supply of mobility (McNally, 2007).
- "*Direct demand models can be of two types: purely direct, which use a single estimated equation to relate travel demand directly to mode, journey and person attributes; and a quasi-direct approach which employs a form of separation between mode split and total (O–D) travel demand. Direct demand models are closely related to general econometric models of demand and have long been inspired by research in that area.*" (Ortúzar and Willumsen, 2011, chapter 12; Talvitie, 1973)
- Traffic models represent road traffic flows based on the vehicles' capacity to interact with each other and the infrastructure.
- Land Use/Transport Interaction "*illustrates the spatial organization of the network of socio-economic activities and describes the physical separation between them. The transportation system connects the various activities/land uses*" Gavanas *et al.* (2016)

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- Fleet control models are supply-focused models providing rules to assign vehicles to their goals.
- Mode choice models assign travel demand to specific modes according to their socioeconomic parameters (Ortúzar and Willumsen, 2011, chapter 6).

2.4. Meta-analysis

The meta-analysis completed the descriptive statistical analysis by providing a quantitative estimate of the (expected) impacts of AV services, focusing on the KPIs for which enough studies were reported in the statistical analysis.

2.4.1. Selection of indicators

According to the descriptive statistical analysis, of the twenty-two indicators scrutinized, four KPIs stand out in terms of coverage and quality of treatment.

First, the level of demand was assessed with the Vehicle Kilometers/Miles Traveled (VKT or VMT). This is a paramount KPI for mobility services as it not only relates to travel demand, but also to traffic flows, operating costs and revenues, and virtually all externalities. It is therefore a key driver of economic profitability in a CBA (Small and Verhoef, 2007).

Travel time is a key performance indicator used to measure service quality. Travel time (TT) refers to the total travel time composed of (i) access/egress time (only for line-based or stop-based services), (ii) waiting time, and (iii) in-vehicle travel time. Access/egress time and waiting time may be equal to zero for some services, such as the private car. Travel time is strongly related to consumer surplus and thus to economic profitability (Small, 2012). Conversely, as the service evaluated is autonomous, it has a much smaller impact on operating costs since no drivers are involved (Tirachini and Antoniou, 2020). Similarly, as most AVs are electric, the impact of travel time (or more specifically of speed) on the environmental externalities is greatly reduced.

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Third, fleet size is a widespread key performance indicator in the literature, especially for on-demand services, as many papers study the link between fleet size, dispatch strategies and operational performance (e.g., Hörl *et al.*, 2021). While it is strongly related to capital costs, it also exerts influence on traffic, congestion and/or parking needs, and environmental externalities (from a lifecycle perspective).

Finally, the total cost of a mobility service measures the total production cost of the service, including at least the operating costs and capital costs if available. Unlike Tirachini and Antoniou (2020), we did not consider user costs, as these were already captured by the travel time indicator. In the simulation literature, costs are generally averages per year that are typically derived from more precise total cost of ownership approaches that measure the cost of a vehicle over its entire lifecycle, including purchase, operations, and end of life (e.g., Ongel *et al.*, 2019).[6] For AV public transit services (including taxi and ride-hailing), the absence of drivers could lead to a decrease in operating costs (Bösch *et al.*, 2018). Conversely, if the AV service attracts more demand than the former conventional service, Total Costs could rise as a result. The total costs indicator thus reflects both operational and marketing performance. The choice of a total costs indicator relative to unit cost indicators (cost/km, cost/seat, or cost/passenger) relates to 1) the interest of the study of overall service performance and 2) the constitution of the cost indicators. Unit costs are frequently model inputs, often based on Bösch *et al.* (2018), whereas total costs reflect output from the simulation or result from an economic evaluation based on the simulation output.

2.4.2. Data extraction

The performance of the autonomous vehicle service was measured relative to another service. For each of the four KPIs (VKT, Travel Time, Fleet Size, Total Costs), we computed the mean relative variation between the

6 The total cost of ownership approach is actually highly congruent with the cost-benefit analysis in that both consider discounted cash or monetary flows over a certain period of time.

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reference service and the service compared. Consider for instance an AV service providing rideshared door-to-door trips, and that the VKT for this service is found to be equal to 115% that of the reference service (conventional private cars, for instance). This means that when these two services are compared in the meta-analysis, the AV taxi service will result in a +15% increase in VKT relative to conventional cars. While the usual benchmark against AV services is conventional private vehicles, some studies test AV services against conventional public transit or other AV services (e.g., by comparing AV services that offer private trips versus rideshare trips).

Studies may consider several scenarios regarding the service characteristics or the economic environment (e.g., market penetration, adoption levels). When scenarios consider different shares of Avs within the vehicle fleet, we decided to keep only the scenario with the highest penetration ratio. For instance, Llorca *et al*. (2017) considered two market penetration scenarios, with 20% and 40% share of Avs within the vehicle fleet, respectively. In this case, only the 40% scenario was retained. If more than one scenario with a high penetration rate is considered in a study, the KPI is averaged across the scenarios. In some cases, developed below, the performance variation needed to be estimated to obtain a proxy of the service implementation impact.

To illustrate this methodology, we put forward our main assumptions and the corresponding examples below by considering VKT as the indicator being evaluated. The methodology is similar for Travel Time, Fleet Size and Total Costs. If the scenarios involve varying fare levels, substitution rates of AV/per trip, or modal shares, then the indicator was averaged across scenarios.

In cases where the KPI evolution was combined with other modes, a ratio was used to estimate the KPI evolution. In Oh *et al*. (2020), VKT are estimated for two adoption level assumptions: a) a High adoption scenario and b) a Moderate adoption scenario. Again, only scenario a) was used. Moreover, the VKT for AMOD (Autonomous Mobility On Demand), which encompasses AV (autonomous taxi) and SAV (shared autonomous taxi) services, was computed as a single synthetic mode (Fig. 7). Thus, to differentiate the performance of the two modes, a ratio from their

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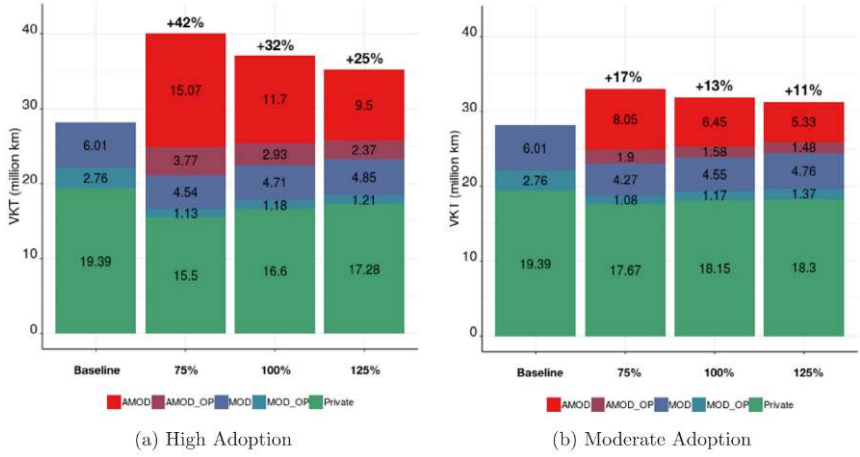
respective modal shares was used to assign a proxy of the VKT of each mode.

Figure 7. Results of simulation for vehicle kilometers travelled



(a) High Adoption (b) Moderate Adoption

Fig. 13. Vehicle-Kilometres Travelled (VKT).

Source: Figure 13 from Oh *et al.* (2020)

The average rise in AV and SAV VKT were extracted from the average of AMOD VKT (4), in other words, AV + SAV VKT, with the average of the 3 price scenarios of the high adoption scenario, in other words:

(+42% + 32 % + 25%)/3 = + 33%, with the average ratio of modal share for AV (6.27%) and SAV (8.83%) on total AMOD modal share (15.10%) from Fig. 8.

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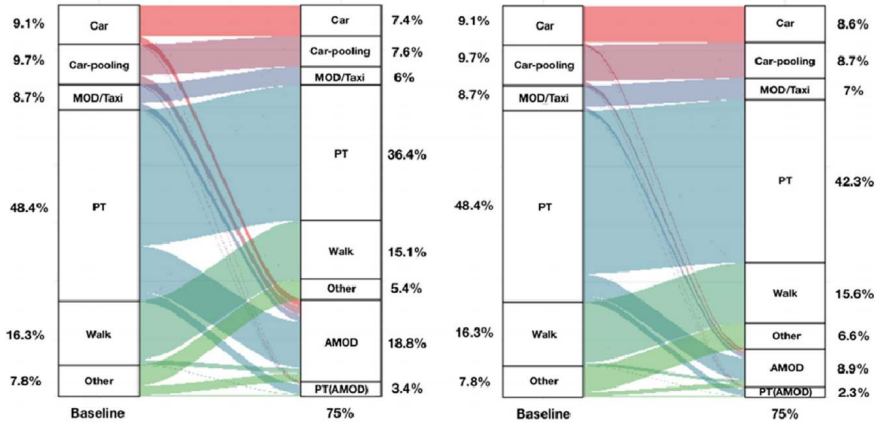
Figure 8. Simulation results for modal shifts



(a) High Adoption (b) Moderate Adoption

Fig. 12. Mode shifts.

Source : Oh *et al.* (2020), Figure 12

The average share of the rise of VKT from the AV and SAV is respectively: 33% x 6.27 % / 15.1% = +14% and 33% x 8.83%/15.1% = +19%.

3. RESULTS AND DISCUSSION

3.1. Descriptive statistical analysis

3.1.1. KPI occurrences

a. Results

The two categories of indicators investigated in all 84 papers of our first corpus (apart from one paper on operations) cover service performance and operations (Figure 9). They also feature the highest average number of indicators per paper. For service performance, the mean number of indicators per paper is 3.37 (from 4 possible indicators), and only 12 papers (14%) use less than 3 of these indicators. Surprisingly, the VKT indicator is the least represented, yet still has over 76% of

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occurrence (Figure A.2A in Appendix). The VKT indicator may be straightforwardly computed by multiplying total ridership by the mean travel distance, which might explain why it is not always reported. Regarding operations, the average number of indicators per paper was 2.64 (from 5 possible indicators), and 43 papers (51%) use fewer than 3 of these indicators. Fare and profit are the least represented within this category, while fleet size, total cost and utilization rate are present in respectively 83%, 73% and 55% of the corpus (Figure A.2B in Appendix). In fact, a large number of papers deal with optimal fleet size and dispatching strategies (e.g., Fagnant and Kockelman, 2016; Loeb and Kockelman, 2019; Vosooghi *et al.*, 2019). The latter three indicators—fleet size, utilization rate, and total costs—tend to form the crux of the analysis, while fares and profits may be disregarded in that they are more related to demand.

Externality indicators are considered at least once in fewer than two-thirds of the papers reviewed (68% of occurrence). Usage is more heterogeneous than for the two previous types of indicators (Figure A.2C in Appendix): the prevalent KPI within the category is congestion (61% of occurrence), followed by energy (33%) and climate change (26% of occurrence). Local pollution (21% of occurrence) always appears together with a climate change indicator, reflecting the fact that no paper in our corpus focuses on air quality, while climate change is given slightly more attention. Noise and safety KPIs have significantly lower occurrence rates (1% and 6% respectively), and again always appear in combination with climate change KPIs (e.g. Simoni *et al.*, 2019).

Socioeconomic profile indicators appear at least once in 21% of the corpus, with 0.31 indicators per paper on average. Moreover, only four papers include more than one socioeconomic category indicator (e.g. Berrada, 2019).

Finally, just two papers in the whole corpus (2% of the corpus) include CBA indicators, with a single indicator each time (Figure A.2D in Appendix): either the BCR (Gelauff *et al.*, 2019) or the IRR (Fagnant and Kockelman, 2016).

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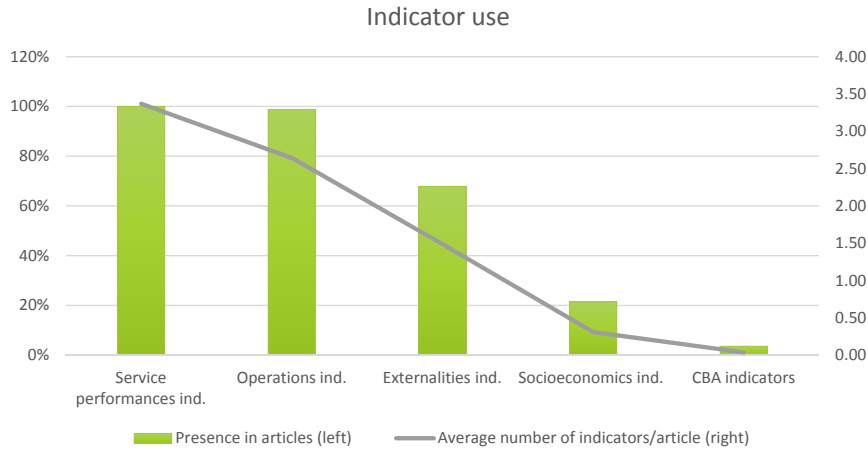
Figure 9. Occurrence of indicators per category



Source: prepared by the authors.

b. Discussion

The analysis shows a very strong prevalence of service performance and operational indicators, reflecting the fact that most papers focus on performance from the perspective of the user or the operator, but seldom that of society as a whole. Since most AVS tested in the papers are on demand, fleet control and optimal dispatching strategies attract considerable interest (again, to cite just a few, Ben-Dor *et al.*, 2019; Fagnant and Kockelman, 2016; Farhan and Chen, 2018; Loeb and Kockelman, 2019; Vosooghi *et al.*, 2019). As result, the most frequently investigated KPIs are supply oriented, including, on the operator side, the VKT, fleet size, utilization rate, and costs, and on the user side, waiting time and travel time. Conversely, KPIs that are demand-oriented such as fares or more elaborate KPIs such as profit are covered less in the corpus.

In addition to being underrepresented compared to service performance and operational KPIs, the indicators relating to externalities tend to be those where the analysis is the least thorough. In some papers, pollutant emissions (GHG and local pollutants) and congestion are mentioned but not analyzed (Simoni *et al.*, 2019; Zachariah *et al.*, 2014; Heilig *et al.*, 2017, Jäger *et al.*, 2018). In others (Navidi *et al.*, 2018;

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Wang *et al.*, 2018; Childress *et al.*, 2015), pollutant emissions and congestion are repeatedly proxied by the distance traveled, which indicates the general trend but not the intensity of the trend. Furthermore, while VKT is a key driver of pollutant emissions, vehicle type (especially if the AV service is electric), average speed and congestion also have a strong influence (Grote *et al.*, 2016), which is not captured when VKT is used as a proxy for emissions.

Socioeconomic category indicators (age, gender, income class, people with reduced mobility) are often mentioned but seldom analyzed. For instance, people with reduced mobility are mentioned once (Sieber *et al.*, 2018), but they do not fulfill any role in the simulation process. In Meyer *et al.* (2017), age acts as an important parameter of the demand simulation with AV taxis since people with limited access to mobility increase the overall demand by 16%. Similarly, Puylaert *et al.* (2018) do not distinguish travel behavior between age or social categories, but include these parameters to determine the type of car owned. Truong *et al.* (2017) proceed in a similar way. In these papers, age only serves as a segmentation variable in the demand model. Only one paper carries an in-depth analysis by investigating the impact of AV service on the mobility of the age brackets with mobility issues (Kamel *et al.*, 2018).

Cost-benefit analysis indicators are extremely infrequent: only two papers (2% of the corpus) feature them, with a single indicator in each case. Moreover, in Fagnant and Kockelman (2016), the IRR is used as a financial indicator, meaning that only the study of Gelauff *et al.* (2019) actually engages in a welfare analysis of AV services. Moreover, the latter study focuses on consumer surplus, and does not consider either the operator surplus or externalities such as congestion, safety and pollutant emissions. This virtual absence of cost-benefit analysis indicators is not surprising if we consider that CBA is a step further from environmental indicators which are already poorly represented within the corpus (with only 21% of occurrence). This confirms that the focus of the AV simulation literature is currently strongly oriented toward the operational design of AV services (including fleet size, dispatch and pooling strategies), rather than their strategic design, which would involve a welfare analysis (in most cases involving the computation of CBA indicators).

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3.1.2. Model types

a. Results

Agent-based models (ABMs) represent the large majority (75% of the corpus) of the models used for AV simulation (Table 3). Within this category, the MATSim open-source framework is used in more than half the agent-based model papers (41%). While in most cases, including all MATSim instances, travel demand is determined endogenously, some ABMs tend to treat travel demand as exogenous, and focus on fleet control. The agent-based modeling paradigm is then used to consider user-vehicle interactions regarding waiting times and/or pooling decisions in the matching process between users and vehicles.

Four-step models represent the second largest category, yet account for only 10% of the second corpus. Activity-based (i.e., non agent-based ones) models are an intermediate form between agent-based and four-step models: while their representation of demand is identical to that of activity-based ABMs, the transportation supply is represented in a simpler and more aggregate manner than in four-step models. This aggregate representation of supply precludes representing vehicle dispatching strategies, and thus finely analyzes the operational performance of the AV service. When four-step or activity-based models are used, the performance of the AV service is often evaluated through the lens of modal shares (Levin and Boyles, 2015) or trip characteristics, such as the mean trip length or duration (Childress *et al.*, 2015; Zhao and Kockelman, 2018). Berrada (2019) is an exception as in this case a four-step model running in VISUM is coupled with VIPSIM, an agent-based fleet control-oriented model, resulting in a range of indicators closer to ABMs than to four-step and activity-based models.

Direct Demand Models are the third largest category of models, representing 6% of the papers. These models are used to generate travel demand based on supply and demand characteristics, but with no or very limited representation of spatial interactions (Anderson *et al.*, 2006). They are often used when considering aggregate trips at the level of a country, a region, or a specific origin-destination (Ortúzar and Willumsen, 2011).

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Table 3. Models used in the first corpus

Models	Use
Agent-based	75%
Four Steps	10%
Direct Demand model	6%
Traffic model	2%
LUTI	2%
Fleet control model	2%
Mode choice model	2%

Source: prepared by the authors

Other models used in the corpus were only exploited twice, but not enough papers were gathered to provide conclusive evidence. This category included the use of Discrete Choice Models. Like direct demand models, these models are often preferred to four-step models—which add the generation, distribution and assignment steps to the mode choice—when spatial interactions and network effects (as when users switch from one service to another, since a change in the transportation supply or in travel conditions leads to a new supply-demand equilibrium) are not the focus of the paper. For instance, Truong *et al.* (2017) provide a rough estimate of the impacts of AVS in Victoria, Australia, with no spatialization of the results. Sun *et al.* (2020) estimate a mixed-logit mode choice model to investigate user preferences and assess whether cost savings or travel time savings are more important for users when comparing AVS with Conventional Public Transit services, meaning that, once again, spatial interactions are not a central issue. Other models were also identified in our corpus that target very specific issues that are not part of our study. For instance, LUTI (Land Use and Transport Integrated) models highlight the interaction between land use (mostly job locations and residential areas) and transportation. Fleet control models are a type of model that focus on the supply side of transportation. When simulating on-demand services, ABMs often use a fleet control module, such as the DRT module for MATSim. Lastly the traffic model provides an analysis of interactions between infrastructure and vehicles through the infrastructure characteristics and the vehicle capacities. There is less focus on the service level than

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on the infrastructure level, which is mainly why this type of model does not appear much in our corpus.

b. Discussion

There is thus a strong focus on agent-based models in the literature. These models emphasize analysis at tactical level, with relatively close attention to fleet optimization (compared to the four-step models). They aim to optimize operational efficiency by maximizing the utilization rate (Fagnant and Kockelman, 2016; Vosooghi and al., 2019; Llorca *et al.*, 2017) and/or the level of service for a given fleet (Wang *et al.*, 2018; Lu *et al.*, 2018).

Agent-based models are more suitable to describe dynamic availability of mobility services and interactions between agents compared to four-step models. As mentioned in 2.2, the corpus is primarily composed of on-demand services: of the 63 studies made with agent-based models, 61 consider on-demand services. Thus, it is no surprise to see such widespread use of these models in the corpus.

In addition, studies that use agent-based models do not take different classes of demand into consideration (depending on their socioeconomic profile, for instance), which represents a future research path, especially since AVS show promise in improving accessibility of age brackets with mobility issues.

3.2. Meta-analysis of AV Impacts

For the second corpus, the papers selected use a least one of the four KPIs (VKT, travel time, fleet size and/or total costs) in a comparative form. The number of documents dropped from 84 documents in the first corpus to 48 documents in the second. The total number of services compared is 80, however, since several papers evaluate more than one AVS.

3.2.1. Results

Based on the service nomenclature defined in 2.2, we generated combinations of services that were investigated in our second corpus. Ten

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combinations of services were finally identified and named, as presented below in Table 4.

Table 4. List of services considered in the meta-analysis

Service features					Service Name
PO*	No RS*	D2D*	Car	Conv.	Private car
PO	No RS	D2D	Car	Aut.	Private AV
Public	RS	D2D	Car	Conv.	Shared Taxi
Public	No RS	D2D	Car	Aut.	AV
Public	RS	D2D	Car	Aut.	SAV
Public	RS	SB*	Car	Aut.	Stop Based AV
Public	RS	D2D	Shuttle	Aut.	Door-to-Door Shuttle
Public	RS	SB	Shuttle	Aut.	Stop Based Shuttle
Public	RS	Line Based Schedule based	Bus or rail	Conv.	Conventional Public Transit
Public	RS	Line Based Schedule based	Shuttle	Aut.	Line Based Shuttle

** PO stands for "Private Ownership ; RS stands for "Ride-sharing" ; D2D stands for Door-to-door ; SB stands for Stop Based*

Source: prepared by the authors.

The performance comparisons between autonomous and conventional services show strong differences depending on the service of reference. When compared to private cars, autonomous services offer overall performance variations of +/- 50% on the four indicators (Figure 10). The variations are much larger (up to +700%) when the service of reference considered is Conventional Public Transport (Figure 11).[7]

The number of papers covering comparisons between two (or more) services also indicates the interest of the academic community in such comparisons. In the corpus collected, the three most frequently compared service pairs are:

7 Note that the methodology adopted for data extraction, which averages indicators in the case of multiple scenarios, reduces the occurrence of extreme values in the results. It also artificially reduces data variability associated with scenario parameters, which is why the meta-analysis focuses on service characteristics only.

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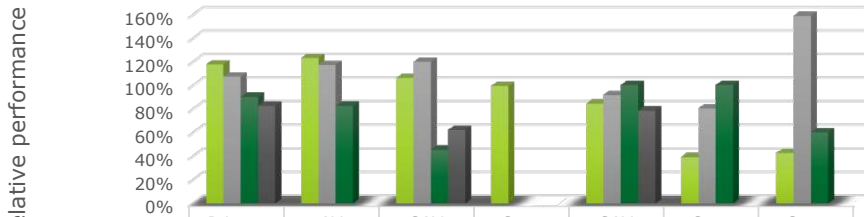
- the replacement of private cars by Private AV,
- the replacement of private cars by autonomous vehicles (AV), corresponding to autonomous taxis (shared vehicles but no ride-sharing),
- the replacement of private cars by shared autonomous vehicles (SAV).[8]

Figure 10. AV On-demand service performance against conventional counterparts



	Private AV	AV	SAV	Stop Based SAV	SAV	Stop Based SAV	Stop Based Shuttle
	Private Car				AV		SAV
Average VKT perf.	117%	123%	106%	99%	84%	39%	42%
Average TT perf.	107%	117%	120%		92%	80%	159%
Average FS perf.	90%	83%	45%		100%	100%	60%
Average TC perf.	83%		62%		78%		

Acronyms: VKT = Vehicle Kilometers Traveled, TT = Travel Time, FS = Fleet Size, TC = Total Costs

Example of interpretation: here the first comparison on the left is the performance of Private AV vs. Private Car. The four indicators (VKT, Travel Time, Fleet Size and Total Costs) are covered by the literature, and the replacement of private cars by private Avs should result, on average, in a rise of VKT and Travel Time (by respectively +17% and +7%), but also in a reduction of Fleet Size and Total Costs (respectively by 10% and 17%).

Source: prepared by the authors.

These three categories represent the majority of comparisons. The next major comparison is between conventional public transit and AV/SAV (~15% of comparisons).

8 There is no clear consensus in the literature on the definition of "Shared Autonomous Vehicles", as shared may refer either to carsharing, ridesharing, or both (Narayanan *et al.*, 2020). Here we distinguish private AVs, AVs (carsharing) and SAVs (carsharing and ridesharing).

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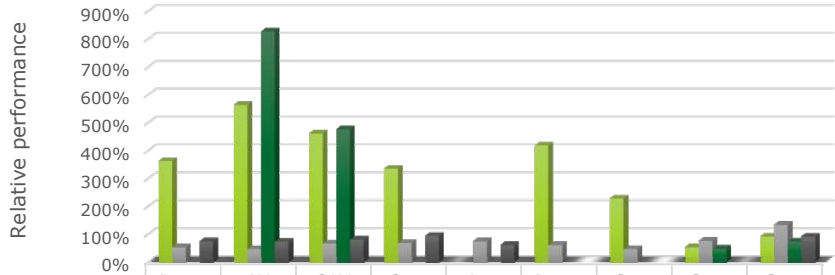
According to Stocker and Shaheen (2019), AV and SAV services are the main autonomous vehicle business models projected by the major manufacturers (Ford, Tesla, Daimler) and tech developers (Google or Uber). It is not surprising that academic attention also focuses on these service types. On the other hand, shuttle-based services are explored to a greater extent by public transport operators via several experiments worldwide (see SAM project).

Figure 11. AV service performance against Conventional Public Transport



	Door-to-Door Shuttle	AV	SAV	Stop Based Shuttle	Aut. Bus	Door-to-Door Shuttle	Stop Based SAV	Stop Based SAV	Stop Based Shuttle
	Conventional Public Transit					Line Based Shuttle		Door-to-Door Shuttle	
Moyenne de VKT	363%	564%	461%	335%		419%	229%	55%	92%
Average TT perf.	55%	48%	68%	70%	76%	62%	48%	78%	134%
Average FS perf.		827%	477%					50%	75%
Average TC perf.	76%	74%	82%	95%	62%				92%

Source: prepared by the authors.

3.2.2. Discussion

Focusing first on the comparison between AV-based services and private cars, it clearly appears that the three most studied AVS (Private AV, AV and SAV) are three steps from the same ladder, trading the VKT and travel time performance of private cars against their fleet size performance at different intensities (Table 5).

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Table 5. Performance comparison of conventional and autonomous services

Reference	New Service	VKT	Travel Time	Fleet Size	Total Costs
Private car	Private AV	+17%	+7%	-10%	-17%
Private car	AV	+23%	+17%	-17%	N/A
Private car	SAV	+6%	+20%	-55%	N/A
Public transit	AV	+464%	-52%	+727%	-26%
Public transit	SAV	+361%	-32%	+377%	-18%
AV	SAV	-16%	-8%	No variations	-22%

**Regarding comparisons with public transit, SAV is found to be more costly than AV (-18% versus -26%), based on 3 and 4 occurrences respectively. On the other hand, the direct comparison of AV and SAV leads to the opposite result, in other words, SAV is less costly (-22%) but based on only one occurrence. These results should thus be considered with care.*

Source: prepared by the authors.

Private AV services offer the best performance regarding Travel Time, which increases by only +7% compared to Private Car, as opposed to +17% for AV and +20% for SAV. This is mostly due to the fact that private AV do not involve waiting time as is the case for AV or SAV (Fagnant *et al.*, 2016). If VKT and Travel Time are greater for private AVs than for Private cars (+17% and +7% respectively), it is probably because the marginal generalized cost of the former is lower than that of the latter. The expected decrease in the value of travel time savings from not having to drive (Kolarova and al., 2019; Fosgerau, 2019; Singleton, 2019; Szimba and Hartmann, 2020; Gao *et al.*, 2019) should result in both more frequent and longer trips.

The marginal operating cost could also be lower for autonomous vehicles operated by a third party than for conventional ones. This should have a considerable impact on mobility services in which drivers' wages are an important component (Bösch *et al.*, 2018; Bauer *et al.*, 2018; Loeb and Kockelman, 2019). However, these analyses rely on forecasts not confirmed as yet by empirical data. Similarly, the cost analysis of Leich and Bischoff (2018) is based on assumptions that cannot be validated based on real data, which would have a significant impact on their findings.

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The effect on VKT is relatively similar for AV (+23%) and SAV (+6%) as for Private AV (+17%), but the fleet size is smaller due to ridesharing. The effect on fleet size is even greater for SAV (-55%) than for AV (-17%) since ridesharing also makes vehicles not fully loaded available to passengers (Farhan and Chen, 2018). Similarly, VKT are lower for SAV than for AV (-16%) since fewer vehicles are assigned through a centralized dispatcher, while maximizing their loading. In addition, SAV would attract at least the same number of passengers since they usually charge lower fares than AV (Simoni *et al.*, 2019; Vosooghi *et al.*, 2019), reducing their total generalized cost, even for less comfort and additional detours (Golbabaei *et al.*, 2020). Ridesharing can also help to further reduce waiting times, especially during peak times, by increasing vehicle availability (Hörl, 2017). However, given that travel times include waiting times as well, the literature notes that the increase in travel time is greater for SAV (+20%) than for AV (+17%), indicating that the extra Travel Time resulting from detours exceeds the reduction in waiting times (Vosooghi *et al.*, 2019; Farhan and Chen, 2018).

Regarding vehicles' capacity, the optimal capacity providing shared door-to-door trips is found to be between two and four seats per vehicle (Leich and Bischoff, 2018; Berrada, 2019; Zachariah *et al.*, 2014; Gurumurthy *et al.*, 2019; Farhan and Chen, 2018; Vosooghi *et al.*, 2019). In fact, in general, the average occupancy is found to be about two persons per vehicle. These numbers should be taken with caution. The effect of empty kilometers traveled was not assessed in this meta-analysis and their role in the occupancy rate might be important. The average occupancy per vehicle also decreases with fleet size (Winter *et al.*, 2018). That being said, Wang *et al.* (2018) published a paper on the ridesharing potential of Singapore, based on real taxi booking data, where 40% of the trips were shared by six passengers or more in taxis, showing the potential of this type of service in densely populated urban areas. Winter *et al.* (2018) and Navidi *et al.* (2017) also presented evidence of the ability of AV and SAV to take advantage of economies of scale, even if the leverage seems weaker than the conventional public transit leverage. This shows that benefits from a reduced Fleet Size are more an outcome of sharing vehicles (sequentially or simultaneously) than the effect of automation. Zhu (2019) exposed that the extrinsic monetary incentive did not provide leverage to support ridesharing

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policies. The automation innovation might help to promote societal changes.

We now turn our attention to the comparison between conventional public transit and autonomous services. Shuttle-based services provide a vehicle capacity of eight to fifteen seats, allowing more passengers to board than car-based services, while offering greater flexibility than conventional public transit. In this configuration, a shuttle service would save passengers time (Sieber *et al.*, 2020; Bischoff *et al.*, 2018; Viergutz and Schmidt, 2019), but would also offer both the service provider and passengers savings at the cost of a larger fleet (in number of vehicles, though not of the same size). This topic has attracted less attention in the academic community and even fewer studies that would correspond to the methodology established for the second corpus.

From our results (Figure 11), stop-based routing seems to be the best autonomous alternative to conventional public transit to limit externalities (here proxied by fleet size and VKT). In addition, a stop-based SAV service is also more likely to benefit from economies of scale than a door-to-door shuttle (fewer detours, thus shorter travel times and waiting times, and less congestion).

The comparison of AVS with conventional public transit suggests that AVS could be interesting in peri-urban or rural areas where conventional public transit might struggle to benefit from economies of scale, or as a feeder (first mile and last mile) service. The expected decrease in operating costs from the drivers' salaries could allow smaller and more flexible vehicles to operate, reducing both passenger waiting time and the overall system costs (Berrada and Poulhes, 2021; Schlüter *et al.*, 2021). Another alternative is to operate buses with a higher level of service but reduced capacity (Bösch *et al.*, 2018; Winter *et al.*, 2018). However, these reductions come at the price of a larger fleet size and more VKT (Sieber *et al.*, 2019; Bischoff *et al.*, 2018; Leich and Bischoff, 2018; Bösch *et al.*, 2018b; Merlin, 2017; International Transport Forum, 2015; Imhof *et al.*, 2020) which might be less of a problem in rural areas, where the space dedicated to mobility has a lower opportunity cost, and the externalities generated by transport are less of an issue than in urban areas. In addition, most of the publications in our corpus focus on urban and

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peri-urban areas, with only two articles specifically dealing with rural areas (Viergutz and Schmidt, 2019; Sieber *et al.*, 2020).

However, the study by Leich and Bischoff (2018) warns of the dangers of competition between conventional public transit and AVS, since AVS would take over the public transit passengers and reduce its profitability. This could result in a reduction in the level of service for public transit, which would exacerbate the modal shift toward AV services. The study of ride hailing firms by Carballa Smichowski (2018) shows that the ride hailing companies might be prone to use predator price, which would strengthen the threat if these companies were the ones developing the autonomous vehicles. The authors therefore recommend conventional public transit operators switching to autonomous vehicles. Hatzenbühler *et al.* (2020) compared the performance of conventional and autonomous buses and found that autonomous bus services were less expensive to operate and provided better travel times to boot.

The idea of public transit lines being substituted by autonomous flexible vehicles is discussed not only in the academic field, but also in private industry. Rau *et al.* (2020) investigated the effect of autonomous shuttle pods driving through Singapore in dedicated lanes. These pods could be linked together to create little trains to absorb demand during peak hours and then divided into multiple vehicles to provide attractive Level of Service, even during off-peak times. This idea is similar to the Loop Aix-Marseille project and some Hyperloop projects (see Loop Aix Marseille and Urbanloop references).

4. CONCLUSION

The regulator is the actor interested in the analysis of the externalities. As a complement to simulation models, tools have been developed (cost-benefit analysis and multicriteria analysis) to assess these issues. However, very few studies offer an analytical framework that allows the economic appraisal of AV to be carried out *in situ*.

In order to make the best strategic choice (i.e., to define the "best" mobility service with respect to the given mobility and sustainability

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objectives), we cannot rely on an eclectic set of indicators. The regulator needs a comparative base between projects, with the potential to rank them. The average methodology could overshadow concerns about the heterogeneity of demand during the day (peak and off-peak time), the type of territory (urban, peri-urban and rural), or the field of application of the mobility service (First and Last Mile service, for example).

The sample of articles provides interesting opposing trends between Private Car and Private AV, AV and SAV services, but the comparison of other service pairs is less robust. If autonomous taxis (AV and/or SAV) were to replace conventional private cars, they should increase VKT between +23% and +6% and Travel Time between +17% and +20% but reduce Fleet Size by 17% to 55%. The replacement of Conventional Public Transit (traditionally operated with high-capacity vehicles and with a line and schedule base) by AV or SAV could reduce Travel Time by half and might also help to reduce overall costs. This transition to on-demand services would also extend the required Fleet Size and the VKT by three to six times the initial value.

Future studies could provide more accurate results from the mobility simulation of the type of territories or specific impact of one of the service features, such as ridesharing. In the meantime, the literature could benefit from an extended analysis of the impact of Autonomous vehicles through the socioeconomic prism.

REFERENCES

ANDERSON, Michael, Khalid SHARFI, et Sampson GHOLSTON. "Direct Demand Forecasting Model for Small urban Communities Using Multiple Linear Regression". Transportation Research Record 1981 (2006): 114-17. https://doi.org/10.3141/1981-18.

ANDERSON, James, Nidhi KALRA, Karlyn STANLEY, Paul SORENSEN, Constantine SAMARAS, and Oluwatobi OLUWATOLA. Autonomous Vehicle Technology: A Guide for Policymakers. RAND Corporation, 2016. https://doi.org/10.7249/RR443-2.

ANDERSSON, Jan, Christopher PATTEN, Clemens KRAETSCH, and Johanna TAKMAN. 'Literature Review on the Acceptance and Road Safety, Ethical, Legal, Social and Economic Implications of Automated Vehicles', 2017, 76.

© De Boeck Supérieur | Téléchargé le 19/04/2023 sur www.cairn.info via Université Gustave Eiffel (IP: 137.121.86.171)

ANTONIALLI, Fabio. International benchmark on experimentations with Autonomous Shuttles for Collective Transport. 27th International Colloquium of Gerpisa, Feb 2019, Paris, France. Hal-02489797v2

AVENUE PROJECT: "Demonstrator Sites", H2020 AVENUE, URL: https://h2020-avenue.eu/demonstrator-sites/

BAHAMONDE-BIRKE, Francisco J., Benjamin KICKHÖFER, Dirk HEINRICHS, et Tobias KUHNIMHOF. "A Systemic View on Autonomous Vehicles". disP—The Planning Review 54, n° 3 (2018): 12-25. https://doi.org/10.1080/02513625.2018.1525197

BAUER, Gordon S., JEFFERY B. GREENBLATT, and BRIAN F. Gerke. 'Cost, Energy, and Environmental Impact of Automated Electric Taxi Fleets in Manhattan'. *Environmental Science & Technology* 52, no. 8 (17 April 2018): 4920–28. https://doi.org/10.1021/acs.est.7b04732.

BECKER, Henrik, Felix BECKER, Ryosuke ABE, Shlomo BEKHOR, Prawira F. BELGIAWAN, Junia COMPOSTELLA, Emilio FRAZZOLI, *et al*. "Impact of Vehicle Automation and Electric Propulsion on Production Costs for Mobility Services Worldwide". Transportation Research Part A: Policy and Practice 138 (2020): 105-26. https://doi.org/10.1016/j.tra.2020.04.021.

BEN-DOR, Golan, Eran BEN-ELIA, and Itzhak BENENSON. 'Determining an Optimal Fleet Size for a Reliable Shared Automated Vehicle Ride-Sharing Service'. *Procedia Computer Science*, The 10th International Conference on Ambient Systems, Networks and Technologies (ANT 2019) / The 2nd International Conference on Emerging Data and Industry 4.0 (EDI40 2019) / Affiliated Workshops, 151 (1 January 2019): 878–83. https://doi.org/10.1016/j.procs.2019.04.121.

BERRADA, Jaâfar. 'Technical-Economic Analysis of Services Based on Autonomous Vehicles'. Paris-Est, 2019.

BERRADA, Jaâfar and Fabien LEURENT. 'Modeling Transportation Systems Involving Autonomous Vehicles: A State of the Art'. *Transportation Research Procedia* 27 (2017): 215–21. https://doi.org/10.1016/j.trpro.2017.12.077.

BERRADA, Jaâfar, Ilyes MOUHOUBI, et Zoi CHRISTOFOROU. "Factors of Successful Implementation and Diffusion of Services Based on Autonomous Vehicles: Users' Acceptance and Operators' Profitability". Research in Transportation Economics, Thredbo 16 conference, 83 (2020): 100902. https://doi.org/10.1016/j.retrec.2020.100902.

BERRADA Jaâfar, Alexis POULHÈS, Economic and socioeconomic assessment of replacing conventional public transit with demand responsive transit services in low-to-medium density areas, Transportation Research Part A: Policy and Practice, Volume 150, 2021, Pages 317-334, ISSN 0965-8564, https://doi.org/10.1016/j.tra.2021.06.008.

BISCHOFF, Joschka, Karoline FUHRER, and Michal MACIEJEWSKIA. 'Impact Assessment of Autonomous DRT Systems'. Munich: ScienceDirect, 2018. https://doi.org/Transportation Research Procedia 00 (2018) 000–000.

BONABEAU, Eric. "Agent-Based Modeling: Methods and Techniques for Simulating Human Systems". Proceedings of the National Academy of Sciences 99, n° suppl 3 (2002): 7280-87. https://doi.org/10.1073/pnas.082080899.

© De Boeck Supérieur | Téléchargé le 19/04/2023 sur www.cairn.info via Université Gustave Eiffel (IP: 137.121.86.171)

BOARDMAN, Anthony E., David H. GREENBERG, Aidan R. VINING, et David L. WEIMER. Cost-Benefit Analysis: Concepts and Practice. Cambridge University Press, 2017.

BÖSCH, Patrick M., Felix BECKER, Henrik BECKER, and Kay W. AXHAUSEN. 'Cost-Based Analysis of Autonomous Mobility Services'. *Transport Policy* 64 (May 2018): 76–91. https://doi.org/10.1016/j.tranpol.2017.09.005.

BÖSCH, Patrick M., Francesco CIARI, and Kay W. AXHAUSEN. 'Autonomous Vehicle Fleet Sizes Required to Serve Different Levels of Demand'. *Transportation Research Record* 2542, no. 4 (2016): 111–19. https://doi.org/10.3929/ethz-b-000104743.

BÖSCH, Patrick M., Francesco CIARI, and Kay W. AXHAUSEN. 'Transport Policy Optimization with Autonomous Vehicles'. *Transportation Research Record* 2672, no. 8 (1 December 2018): 698–707. https://doi.org/10.1177/0361198118791391.

BÜCHEL B and CORMAN F (2020) Review on Statistical Modeling of Travel Time Variability for Road-Based Public Transport. Front. Built Environ. 6 :70. DOI : 10.3389/fbuil.2020.00070

CAVAZZA, Bruna Habib, Rodrigo Marçal GANDIA, Fabio ANTONIALLI, André Luiz ZAMBALDE, Isabelle NICOLAÏ, Joel Yutaka SUGANO, et Arthur DE MIRANDA NETO. "Management and business of autonomous vehicles: a systematic integrative bibliographic review". International Journal of Automotive Technology and Management 19, n° 1-2 (2019): 31-54. https://doi.org/10.1504/IJATM.2019.098509.

CARBALLA SMICHOWSKI, Bruno "Is ride-hailing doomed to monopoly? Theory and evidence from the main U.S. markets", Revue d'économie industrielle, 162 | 2018, 43-72.

CHILDRESS, Suzanne, Brice NICHOLS, Billy CHARLTON, and Stefan COE. 'Using an Activity-Based Model to Explore Possible Impacts of Automated Vehicles'. *Submitted for Presentation at the Transportation Research Board 2015 Annual Meeting, Washington, D.C.*, 2015, 18.

CLARK, Ben, Graham PARKHURST, and Miriam RICCI. 'Understanding the Socioeconomic Adoption Scenarios for Autonomous Vehicles: A Literature Review', 1 January 2016. https://uwe-repository.worktribe.com/output/917906/understanding-the-socioeconomic-adoption-scenarios-for-autonomous-vehicles-a-literature-review.

CLEMENTS, Lewis M., and Kara M. KOCKELMAN. 'Economic Effects of Automated Vehicles'. *Transportation Research Record* 2606, no. 1 (1 January 2017): 106–14. https://doi.org/10.3141/2606-14.

CORREIA, Gonçalo Homem DE ALMEIDA, Erwin LOOFF, Sander VAN CRANENBURGH, Maaike SNELDER, et Bart VAN AREM. "On the Impact of Vehicle Automation on the Value of Travel Time While Performing Work and Leisure Activities in a Car: Theoretical Insights and Results from a Stated Preference Survey". Transportation Research Part A: Policy and Practice 119 (2019): 359-82. https://doi.org/10.1016/j.tra.2018.11.016.

FAGNANT, Daniel J., et Kara M. KOCKELMAN. "The Travel and Environmental Implications of Shared Autonomous Vehicles, Using Agent-Based Model

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Scenarios". Transportation Research Part C: Emerging Technologies 40 (2014): 1-13. https://doi.org/10.1016/j.trc.2013.12.001.

FAGNANT, Daniel J., and Kara M. KOCKELMAN. 'Dynamic Ride-Sharing and Optimal Fleet Sizing for a System of Shared Autonomous Vehicles', 2016. https://trid.trb.org/view/1337372.

FAISAL, Asif, Tan YIGITCANLAR, Md KAMRUZZAMAN, and Graham CURRIE. 'Understanding Autonomous Vehicles: A Systematic Literature Review on Capability, Impact, Planning and Policy'. *Journal of Transport and Land Use* 12, no. 1 (28 January 2019). https://doi.org/10.5198/jtlu.2019.1405.

FARHAN, J., and T. Donna CHEN. 'Impact of Ridesharing on Operational Efficiency of Shared Autonomous Electric Vehicle Fleet'. Transportation Research Part C: Emerging Technologies 93 (1 August 2018): 310–21. https://doi.org/10.1016/j.trc.2018.04.022.

FLÄMIG, Heike. "Autonomous Vehicles and Autonomous Driving in Freight Transport", 365-85, 2016. https://doi.org/10.1007/978-3-662-48847-8_18.

FÖLDES, Dávid, et Csaba CSISZAR. "Conception of future integrated smart mobility", 1 6, 2016. https://doi.org/10.1109/SCSP.2016.7501022.

FÖLDES, Dávid, et Csaba CSISZAR. "Framework for planning the mobility service based on autonomous vehicles", 2018. https://doi.org/10.1109/SCSP.2018.8402651.

FOSGERAU, Mogens. 'Automation and the Value of Time in Passenger Transport'. ITF, 7 October 2019. https://www.itf-oecd.org/automation-and-value-time-passenger-transport.

FRANCESE, R., YANG, X., 2021. Supporting autism spectrum disorder screening and intervention with machine learning and wearables: a systematic literature review. Complex Intell. Syst. https://doi.org/10.1007/s40747-021-00447-1.

GAO, Jingya, Andisheh RANJBARI, and Don MACKENZIE. 'Would Being Driven by Others Affect the Value of Travel Time? Ridehailing as an Analogy for Automated Vehicles'. Transportation, 6 August 2019. https://doi.org/10.1007/s11116-019-10031-9.

GANDIA, Rodrigo Marçal, Fabio ANTONIALLI, Bruna Habib CAVAZZA, Arthur Miranda NETO, Danilo Alves DE LIMA, Joel Yutaka SUGANO, Isabelle NICOLAI, et Andre Luiz ZAMBALDE. "Autonomous vehicles: scientometric and bibliometric review". Transport Reviews 39, n° 1: 9-28. https://doi.org/10.1080/01441647.2018.1518937.

GAVANAS, Nikolaos, Goergia POZOUKIDOU, et Eleni VERANI. "Integration of LUTI models into sustainable urban mobility plans (SUMPs)". EUROPEAN JOURNAL OF ENVIRONMENTAL SCIENCES 6 (2016): 11-17. https://doi.org/10.14712/23361964.2016.3.

GELAUFF, George, Ioulia OSSOKINA, and Coen TEULINGS. 'Spatial and Welfare Effects of Automated Driving: Will Cities Grow, Decline or Both?' *Transportation Research Part A: Policy and Practice* 121 (2019): 277–94. https://doi.org/10.1016/j.tra.2019.01.013.

GOLBABAEI, Fahimeh, Tan YIGITCANLAR, and Jonathan BUNKER. 'The Role of Shared Autonomous Vehicle Systems in Delivering Smart Urban Mobility: A Systematic Review of the Literature'. *International Journal of Sustainable*

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Transportation 0, no. 0 (2020): 1–18. https://doi.org/10.1080/15568318.2020.1798571.

GROTE, Matt, Ian WILLIAMS, John PRESTON, and Simon KEMP. 'Including Congestion Effects in Urban Road Traffic CO2 Emissions Modelling: Do Local Government Authorities Have the Right Options?' *Transportation Research Part D: Transport and Environment* 43 (2016): 95–106. https://doi.org/10.1016/j.trd.2015.12.010.

GURUMURTHY, Krishna MURTHY, Kara M. KOCKELMAN, and Michele D. SIMONI. 'Benefits and Costs of Ride-Sharing in Shared Automated Vehicles across Austin, Texas: Opportunities for Congestion Pricing'. *Transportation Research Record* 2673, no. 6 (2019): 548–56. https://doi.org/10.1177/0361198119850785.

HARDT, Cornelius, and Klaus BOGENBERGER. "The Price of Shared Vehicles–On current and future Pricing Strategies in Mobility Sharing Systems." In Proceedings of the 95th annual meeting of the Transportation Research Board. 2016.

HATZENBÜHLER, Jonas, Oded CATS, and Erik JENELIUS. 'Transitioning towards the Deployment of Line-Based Autonomous Buses: Consequences for Service Frequency and Vehicle Capacity'. *Transportation Research Part A: Policy and Practice* 138 (2020): 491–507. https://doi.org/10.1016/j.tra.2020.06.019.

HEILIG, Michael, Tim HILGERT, Nicolai MALLIG, Martin KAGERBAUER, et Peter VORTISCH. "Potentials of Autonomous Vehicles in a Changing Private Transportation System—a Case Study in the Stuttgart Region". Transportation Research Procedia, Emerging technologies and models for transport and mobility, 26 (2017): 13-21. https://doi.org/10.1016/j.trpro.2017.07.004.

HÖRL, Sebastian. 'Agent-Based Simulation of Autonomous Taxi Services with Dynamic Demand Responses'. *Procedia Computer Science*, 8th International Conference on Ambient Systems, Networks and Technologies, ANT-2017 and the 7th International Conference on Sustainable Energy Information Technology, SEIT 2017, 16-19 May 2017, Madeira, Portugal, 109 (2017): 899–904. https://doi.org/10.1016/j.procs.2017.05.418.

HÖRL, Sebastian, Felix BECKER, et Kay AXHAUSEN. "Simulation of price, customer behaviour and system impact for a cost-covering automated taxi system in Zurich". Transportation Research Part C Emerging Technologies 123 (2021): 102974. https://doi.org/10.1016/j.trc.2021.102974.

HUANG, Yantao, Kockelman KARA, Venu GARIKAPATI, Lei ZHU, et Stanley YOUNG. "Use of shared automated vehicles for first-mile last-mile service micro-simulation of rail-transit connections in Austin, Texas" Transportation Research Record (2020). https://www.caee.utexas.edu/prof/kockelman/public_html/TRB20FMLMforAustinSUMO.PDF.

HULSE, Lynn M., Hui XIE, et Edwin R. GALEA. "Perceptions of Autonomous Vehicles: Relationships with Road Users, Risk, Gender and Age". Safety Science 102 (2018): 1-13. https://doi.org/10.1016/j.ssci.2017.10.001.

IMHOF, S., FRÖLICHER, J., & VON ARX, W. (2020). Shared Autonomous Vehicles in rural public transportation systems. Research in transportation economics, 83, 100925.

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JÄGER, Benedikt, Carsten BRICKWEDDE, et Markus LIENKAMP. "Multi-Agent Simulation of a Demand-Responsive Transit System Operated by Autonomous Vehicles". Transportation Research Record: Journal of the Transportation Research Board 2672, n° 8 (2018): 764-74. https://doi.org/10.1177/0361198118786644.

JING, Peng, Hanbin HU, Fengping ZHAN, Yuexia CHEN, and Yuji SHI. 'Agent-Based Simulation of Autonomous Vehicles: A Systematic Literature Review'. *IEEE Access* 8 (2020): 79089–103. https://doi.org/10.1109/ACCESS.2020.2990295.

KAMEL, Joseph, Reza VOSOOGHI, Jakob PUCHINGER, Feirouz KSONTINI, et Göknur SIRIN. "Exploring the Impact of User Preferences on Shared Autonomous Vehicle Modal Split: A Multi-Agent Simulation Approach". Transportation Research Procedia, 21st EURO Working Group on Transportation Meeting, EWGT 2018, 17th—19th September 2018, Braunschweig, Germany, 37 (2019): 115-22. https://doi.org/10.1016/j.trpro.2018.12.173.

KOLAROVA, Viktoriya, Felix STECK, and Bahamonde-Birke FRANCISCO J. 'Assessing the Effect of Autonomous Driving on Value of Travel Time Savings: A Comparison between Current and Future Preferences', Transportation Research Part A, no. 129 (2019): 155–69. https://doi.org/10.1016/j.tra.2019.08.011.

LAYARD, Richard, et Stephen GLAISTER, éd. Cost-Benefit Analysis. 2e éd. Cambridge: Cambridge University Press, 1994. https://doi.org/10.1017/CBO9780511521942.

LEICH, Gregor, and Joschka BISCHOFF. 'Should Autonomous Shared Taxis Replace Buses? A Simulation Study', 2018. https://doi.org/10.14279/depositonce-8478.

LEVIN, Michael W., and Stephen D. BOYLES. 'Effects of Autonomous Vehicle Ownership on Trip, Mode, and Route Choice'. *Transportation Research Record: Journal of the Transportation Research Board* 2493 (January 2015): 29–38. https ://doi.org/10.3141/2493-04.

LOOP AIX MARSEILLE, web site URL : https ://loopam.fr/

LLORCA, Carlos, Ana Tsui MORENO, and Rolf MOECKEL. 'Effects of Shared Autonomous Vehicles on the Level of Service in the Greater Munich Metropolitan Area. Pdf', Vol. Transportation Research Procedia 00 (2016) 000–000, 2017.

LOEB, Benjamin, and Kara M. KOCKELMAN. 'Fleet Performance and Cost Evaluation of a Shared Autonomous Electric Vehicle (SAEV) Fleet: A Case Study for Austin, Texas'. *Transportation Research Part A: Policy and Practice* 121 (1 March 2019): 374–85. https://doi.org/10.1016/j.tra.2019.01.025.

LU, Miaojia, Taiebat MORTEZA, Xu MING, and Hsu SHU-CHIEN. 'Multiagent Spatial Simulation of Autonomous Taxis for Urban Commute: Travel Economics and Environmental Impacts'. *Journal of Urban Planning and Development* 144, no. 4 (1 December 2018): 04018033. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000469.

MCNALLY, Michael G. "The Four-Step Model". In Handbook of Transport Modelling, edited by David A. Hensher et Kenneth J. Button, 1:35-53. Emerald Group Publishing Limited, 2007. https://doi.org/10.1108/9780857245670-003.

MERLIN, Louis. 'Comparing Automated Shared Taxis and Conventional Bus Transit for a Small City'. *Journal of Public Transportation* 20, no. 2 (1 June 2017). https://doi.org/10.5038/2375-0901.20.2.2.

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MEYER, Jonas, Henrik BECKER, Patrick M. BÖSCH, and Kay W. AXHAUSEN. 'Autonomous Vehicles: The next Jump in Accessibilities?' *Research in Transportation Economics* 62 (2017): 80–91. https://doi.org/10.3929/ethz-b-000118781.

MÜLLER, Johannes & STRAUB, Markus & NAQVI, Asjad & RICHTER, Gerald & PEER, Stefanie & RUDLOFF, Christian. (2021). MATSim Model Vienna: Analyzing the Socioeconomic Impacts for Different Fleet Sizes and Pricing Schemes of Shared Autonomous Electric Vehicles.

NAGEL, Kai, Joschka BISCHOFF, Gregor Leich, et Michal MACIEJEWSKI. "Simulation-based analysis of the impacts of fleets of autonomous vehicles on urban traffic", 2019. http ://www.vsp.tu-berlin.de/publications/vspwp.

NARAYANAN, Santhanakrishnan, Emmanouil CHANIOTAKIS, et Constantinos ANTONIOU. "Shared Autonomous Vehicle Services: A Comprehensive Review". Transportation Research Part C: Emerging Technologies 111 (1 février 2020): 255-93. https://doi.org/10.1016/j.trc.2019.12.008.

NAVIDI, Zahra, Nicole RONALD, and Stephan WINTER. 'Comparison between Ad-Hoc Demand Responsive and Conventional Transit: A Simulation Study'. *Public Transport* 10, no. 1 (1 May 2018): 147–67. https://doi.org/10.1007/s12469-017-0173-z.

OH, S., R. SESHADRI, C.L. AZEVEDO, N. KUMAR, K. BASAK, and M. BEN-AKIVA. 'Assessing the Impacts of Automated Mobility-on-Demand through Agent-Based Simulation: A Study of Singapore'. *Transportation Research Part A: Policy and Practice* 138 (2020): 367–88. https://doi.org/10.1016/j.tra.2020.06.004.

ONGEL, Aybike, Erik LOEWER, Felix ROEMER, Ganesh SETHURAMAN, Fengqi CHANG, et Markus LIENKAMP. "Economic Assessment of Autonomous Electric Microtransit Vehicles". Sustainability 11, n° 3 (janvier 2019): 648. https://doi.org/10.3390/su11030648.

ORTÚZAR, Juan de Dios, et Luis G. WILLUMSEN. "Modal Split and Direct Demand Models", Chapter 6 In Modelling Transport 4th edition, 207-25. John Wiley & Sons, Ltd, 2011. https://doi.org/10.1002/9781119993308.ch6.

ORTÚZAR, Juan de Dios, et Luis G. WILLUMSEN. "Simplified Transport Demand Models", Chapter 12 In Modelling Transport 4th edition. John Wiley & Sons, Ltd. https ://doi.org/10.1002/9781119993308.ch12.

PENDLETON, Scott Drew, Hans ANDERSEN, Xinxin DU, Xiaotong SHEN, Malika MEGHJANI, You Hong ENG, Daniela RUS, et Marcelo H. ANG. "Perception, Planning, Control, and Coordination for Autonomous Vehicles". Machines 5, n° 1 (2017): 6. https://doi.org/10.3390/machines5010006.

PERNESTÅL, A. and Ida KRISTOFFERSSON. "Effects of driverless vehicles: Comparing simulations to get a broader picture." European Journal of Transport and Infrastructure Research 19 (2019): 1-23.

PUYLAERT, S., Maaike SNELDER, Rob NES, et B. AREM. "Mobility impacts of early forms of automated driving—A system dynamic approach". Transport Policy 72 (1 avril 2018). https://doi.org/10.1016/j.tranpol.2018.02.013.

QUINET, Emile. « L'évaluation socioéconomique des investissements publics ». Commissariat général à la stratégie et à la prospective, 2013. https://www.

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strategie.gouv.fr/espace-presse/levaluation-socioeconomique-investissements-publics.

RAU, Andreas, Madhur JAIN, Meng XIE, Teron NGUYEN, Tao LIU, Xiaodong LIU, Yuan ZHOU, and Zain UL ABEDIN. *Planning and Design of a New Dynamic Autonomous Public Transport System: The DART System in Singapore*, 2019.

RUS, Ginés de, M. SOCORRO, Javier CAMPOS, Daniel GRAHAM, Jorge VALIDO, et Per-Olov JOHANSSON. "Economic evaluation of transports projects and policies: methodology and applications", September 2020.

"SAE J3016 AUTOMATED-DRIVING GRAPHIC". https://www.sae.org/site/news/2019/01/sae-updates-j3016-automated-driving-graphic.

SCHLÜTER, Jan, Andreas BOSSERT, Philipp RÖSSY, et Moritz KERSTING. "Impact Assessment of Autonomous Demand Responsive Transport as a Link between Urban and Rural Areas". Research in Transportation Business & Management, Urban Transport Planning and Policy in a changing world: bridging the gap between theory and practice, 39 (2021): 100613. https://doi.org/10.1016/j.rtbm.2020.100613.

SIEBER, Lukas, Sebastian HÖRL, Claudio RUCH, Kay W. AXHAUSEN, et Emilio FRAZZOLI. "Autonomous mobility-on-demand providing superior public transportation in rural areas", Research Collection, 2018. https://doi.org/10.3929/ethz-b-000279530.

SIEBER, L., C. RUCH, S. HÖRL, K. W. AXHAUSEN, and E. FRAZZOLI. 'Improved Public Transportation in Rural Areas with Self-Driving Cars: A Study on the Operation of Swiss Train Lines'. *Transportation Research Part A: Policy and Practice* 134 (1 April 2020): 35–51. https://doi.org/10.1016/j.tra.2020.01.020.

SIMONI, Michele D., KARA M. KOCKELMAN, KRISHNA M. GURUMURTHY, and Joschka BISCHOFF. 'Congestion Pricing in a World of Self-Driving Vehicles: An Analysis of Different Strategies in Alternative Future Scenarios'. *Transportation Research Part C: Emerging Technologies* 98 (January 2019): 167–85. https://doi.org/10.1016/j.trc.2018.11.002.

SINGLETON, Patrick A. 'Discussing the "Positive Utilities" of Autonomous Vehicles: Will Travellers Really Use Their Time Productively?' *Transport Reviews* 39, no. 1 (2 January 2019): 50–65. https://doi.org/10.1080/01441647.2018.1470584.

SMALL, Kenneth A. "Urban Transportation Policy: A Guide and Road Map", Unraveling the Urban Enigma: City Prospects, City Policies, 2007. URL: https://www.economics.uci.edu/files/docs/workingpapers/2006-07/Small-24.pdf

SMALL, Kenneth and Erik VERHOEF. "The economics of urban transportation." (2007).

SOTEROPOULOS, Aggelos, Martin BERGER, et Francesco CIARI. "Impacts of automated vehicles on travel behaviour and land use: an international review of modelling studies". Transport Reviews 39, n° 1 (2019): 29-49. https://doi.org/10.1080/01441647.2018.1523253.

STOCKER, Adam, et Susan SHAHEEN. "Shared Automated Vehicles: Review of Business Models", 2017. https://doi.org/10.1787/11bcbc7c-en.

STOCKER, Adam, et Susan SHAHEEN. "Shared Automated Mobility: Early Exploration and Potential Impacts". In Road Vehicle Automation 4, edited

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by Gereon Meyer et Sven Beiker, 125-39. Lecture Notes in Mobility. Cham: Springer International Publishing, 2018. https://doi.org/10.1007/978-3-319-60934-8_12.

STOCKER, Adam, et Susan SHAHEEN. "Shared Automated Vehicle (SAV) Pilots and Automated Vehicle Policy in the U.S.: Current and Future Developments". In Road Vehicle Automation 5, edited by Gereon Meyer et Sven Beiker, 131-47. Lecture Notes in Mobility. Cham: Springer International Publishing, 2019. https://doi.org/10.1007/978-3-319-94896-6_12.

STUDY DESIGN 101 "Meta-Analysis", Himmerlfarb, Health Sciences Library, URL: https://himmelfarb.gwu.edu/tutorials/studydesign101/metaanalyses.cfm

SUN, Shanshan, Yiik Diew WONG, and Andreas RAU. 'Economic Assessment of a Dynamic Autonomous Road Transit System for Singapore'. *Research in Transportation Economics*, 22 April 2020, 100843. https://doi.org/10.1016/j.retrec.2020.100843.

SZIMBA, Eckhard, and Martin HARTMANN. 'Assessing Travel Time Savings and User Benefits of Automated Driving—A Case Study for a Commuting Relation'. *Transport Policy*, 26 March 2020. https://doi.org/10.1016/j.tranpol.2020.03.007.

TALVITIE, Antti. "A Direct Demand Model for Downtown Work Trips", Transportation 2 (1973) 121-152.

TIAN, Danyang, Guoyuan WU, K. BORIBOONSOMSIN, et M. BARTH. "Performance Measurement Evaluation Framework and Co-Benefit\/Tradeoff Analysis for Connected and Automated Vehicles (CAV) Applications: A Survey". IEEE Intelligent Transportation Systems Magazine, 2018. https://doi.org/10.1109/MITS.2018.2842020.

TIRACHINI, Alejandro, et Constantinos ANTONIOU. "The economics of automated public transport: Effects on operator cost, travel time, fare and subsidy". Economics of Transportation 21, n° C (2020). https://econpapers.repec.org/article/eeeecotra/v_3a21_3ay_3a2020_3ai_3ac_3as2212012219300802.htm.

TRUONG, Long T., Chris DE GRUYTER, Graham CURRIE, and Alexa DELBOSC. 'Estimating the Trip Generation Impacts of Autonomous Vehicles on Car Travel in Victoria, Australia'. *Transportation* 44, no. 6 (1 November 2017): 1279–92. https://doi.org/10.1007/s11116-017-9802-2.

URBANLOOP, website URL: http://urbanloop.univ-lorraine.fr/

URBINA, Sara, et Negar SOHAEE. "Influence of Autonomous Vehicles on Travel Behavior of 50+ Years Population". ITE Western District Student Paper Award, 2020. https://scholar.google.com/citations?view_op=view_citation&hl=en&user=XJowaLsAAAAJ&citation_for_view=XJowaLsAAAAJ:qjMakFHDy7sC.

"VICTORIA TRANSPORT INSTITUTE—TRANSPORTATION COST AND BENEFIT ANALYSIS, 2009" Todd Litman, and Eric Doherty. https://www.vtpi.org/tca/.

VIERGUTZ, Kathrin, and Clemens SCHMIDT. 'Demand Responsive—vs. Conventional Public Transportation: A MATSim Study about the Rural Town of Colditz, Germany—2019', Volume 151:69–76. April 29—May 2, 2019, Leuven, Belgium: ScienceDirect, 2019. https://www.sciencedirect.com/science/article/pii/S1877050919304740.

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VOSOOGHI, Reza, Jakob PUCHINGER, Marija JANKOVIC, and Anthony VOUILLON. 'Shared Autonomous Vehicle Simulation and Service Design'. *ArXiv:1906.07588 [Cs]*, 18 June 2019. http://arxiv.org/abs/1906.07588.

WADUD, Zia, Don MACKENZIE, et Paul LEIBY. "Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles". Transportation Research Part A: Policy and Practice 86 (2016): 1-18. https://doi.org/10.1016/j.tra.2015.12.001.

WANG, Yazhe, Baihua ZHENG, and Ee-Peng LIM. 'Understanding the Effects of Taxi Ride-Sharing—A Case Study of Singapore'. *Computers, Environment and Urban Systems, ISSN: 0198-9715* Vol: 69 (2018): Page: 124-132. http://dx.doi.org/10.1016/j.compenvurbsys.2018.01.006.

WINTER, Konstanze, Oded CATS, Gonçalo CORREIA, and Bart VAN AREM. 'Performance Analysis and Fleet Requirements of Automated Demand-Responsive Transport Systems as an Urban Public Transport Service'. *International Journal of Transportation Science and Technology* 7, no. 2 (1 June 2018): 151–67. https://doi.org/10.1016/j.ijtst.2018.04.004.

ZACHARIAH, Jaison, Jingkang GAO, Alain KORNHAUSER, and Talal MUFTI. 'Uncongested Mobility for All: A Proposal for an Area Wide Autonomous Taxi System in New Jersey', 2014. https://trid.trb.org/view/1288288.

ZHAO, Yong, and Kara M. KOCKELMAN. 'Anticipating the Regional Impacts of Connected and Automated Vehicle Travel in Austin, Texas'. *Journal of Urban Planning and Development* 144, no. 4 (December 2018): 04018032. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000463.

ZHU, Dianzhuo "The Limits of Money in Daily Ridesharing: Evidence from a Field Experiment in Rural France", Revue d'économie industrielle, 173 | 2021, 161-202.

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APPENDIX

In order to promote transparent science, the authors made the data of both the Bibliometric analysis and the Meta-analysis available publicly.

Online Appendix 1. Autonomous Vehicles Impacts—Bibliometric analysis and Meta-analysis from mobility simulations. URL: https://figshare.com/projects/Autonomous_Vehicles_Impacts_from_mobility_simulations/125386

Table A. 1. Publications

Journals	Occurrences
Transportation Research Record	15
Transportation Research Part C: Emerging Technologies	7
Transportation Research Part A: Policy and Practice	7
ABMTrans	5
mobil.TUM	4
Intelligent Transportation Systems Conference	4
Transportation Research Procedia	3
Transportation	3
International Conference on Traffic and Transport Engineering (ICTTE)	2
International Journal of Transportation Science and Technology	2
Transport Policy	2
Transportmetrica A: Transport Science	2
Transportation Research Part A: Policy and Practice	2
Journal of Advanced Transportation	2
Computers, Environment and Urban Systems	1
Research in Transportation Economics 62	1
Advanced Microsystems for Automotive Applications	1
Transportation Research Part D: Transport and Environment	1
EURO Working Group on Transportation (EWGT)	1
Journal of Urban Planning and Development	1
ANT 2016	1
Journal of Public Transportation	1
2015 IEEE 7th International Conference on CIS & RAM	1
Urban Rail Transit	1

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Journals	Occurrences
European Transport Research Review	1
International Symposium of Transport Simulation	1
Environmental Science & Technology	1
Thesis	1
Arbeitsberichte Verkehrs- und Raumplanung	1
International Conference on Transportation	1
Advances in Transport Policy and Planning	1
The 10th International Conference on Ambient Systems, Networks and Technologies (ANT)	1
Springer Nature	1
International Conference on Internet of Vehicles	1
Intelligent Transportation Systems Conference	1
Sustainability	1
Institute of Electrical and Electronics Engineers Access	1
Technical report	1
Grand Total	**84**

Figure A.2A. Service performance indicator use

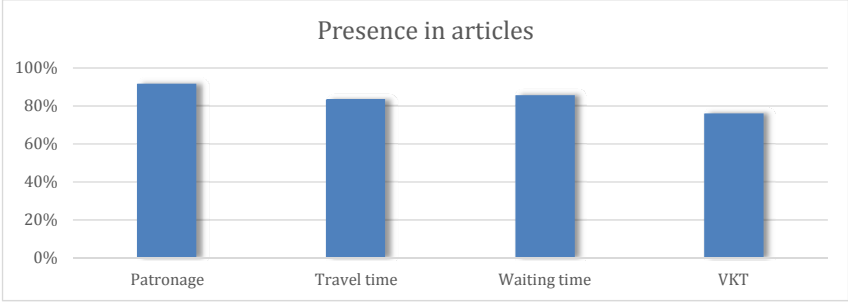

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Figure A.2B. Operational indicators use

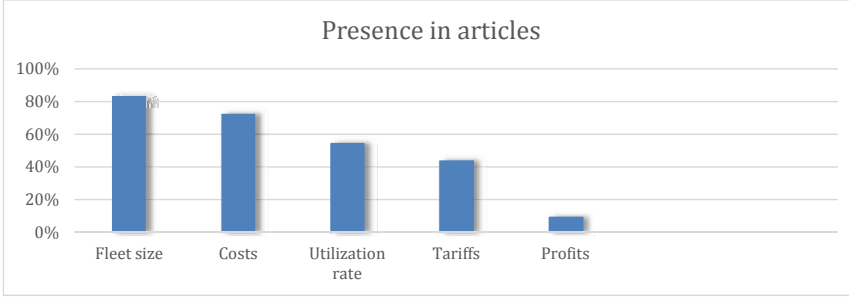

Figure A.2C. Externalities indicators use

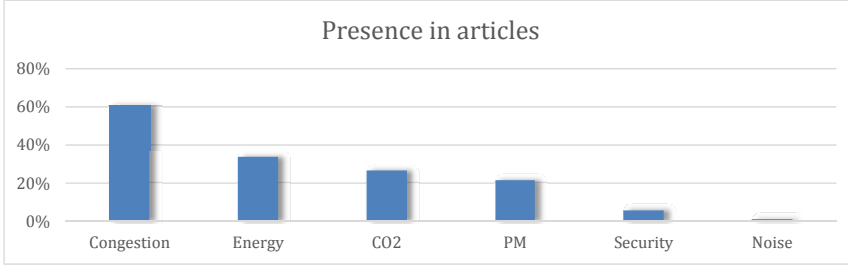

Figure A.2D. Socioeconomics indicators use

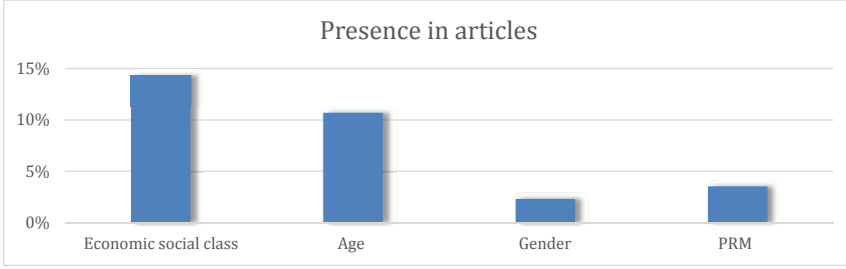

Figure A.2E. CBA indicator use

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