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Chapter 12

Economic Impact Assessment: Local Service Costs of Automated Vehicles for Public Transport



Fabio Antonialli, Sylvie Mira-Bonnardel, and Julie Bulteau

Abstract While most of the current research on automated public transport focuses on improving operational and technical aspects, as well as tackling policy and user behavioural factors, the integration of these vehicles into public networks is mainly dependent on costs and breakeven points. Research quantifying costs and return on investment specifically in academic settings are sparse. This chapter aims to introduce an economic assessment tool, designed as a decision-making tool to support public policies on the decision of implementing innovative mobility services. The simulation contributes to the Total Cost of Mobility (TCM), a vision that accounts all alternative modes of travel and is therefore more adapted to today's fleets which are evolving towards automated electro mobility, pool management, etc. The presented assessment tool was tested with real data from pilot sites within the AVENUE project, and the results prove it to be a relevant tool to aid decision-makers on whether to adopt services with such vehicles.

12.1 Introduction

Technology and social acceptance are no longer the major obstacles to the deployment of automated vehicles for collective transports (Mira-Bonnardel, 2021). However, the question of their economic impact remains. For that reason, one of the AVENUE project's ambitions was to propose a methodology to assess the economic feasibility of an automated-based public transport service.

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Based on the studies from Bösch et al. (2018), Henderson et al. (2017), and Kalakuntla (2017) as well as by applying the Total Cost of Ownership (TCO) approach as done by Ongel et al. (2019), a simulation tool for assessing the economic impact of services with Automated Mobility (AM) was developed.

The tool, named EASI-AV proposes an *Economic Assessment of Services with Intelligent Automated Vehicles* by providing the fleet dimensioning for the service, calculating the total service costs (accounting both investments (CAPEX) and operating costs (OPEX) and comparing those with a given baseline vehicle, as well as calculating the local external costs for the communities where the vehicles are to be deployed (also in a comparative manner with a baseline vehicle).

EASI-AV was designed with the objective of helping policymakers in cities and regions, Public Transport Operators and Authorities (PTOs and PTAs), and even other interested stakeholders that may wish to implement services with Automated Mobility. The tool aims to assess the economic impact of different implementation scenarios like supply-pushed or demand-pulled strategies, fixed-routes, or geofenced on-demand services. Thus, a comparison between the automated service and other transport modes can be drawn up.

The overall scope, methodology, and previous results obtained with EASI-AV are elaborated in detail in Antonialli et al. (2021). The simulation tool was developed and validated by the PTOs from the demonstrator cities in the AVENUE project and is freely available online on the project's website.¹ In this chapter, we focus on analysing the results of the local economic simulation.

As stated by Nemoto et al. (2021), for the economic impact analysis, the Total Cost of Ownership (TCO), Total Cost of Mobility (TCM), costs and revenues analysis, and calculation of mobility externalities are methods that can support estimating the costs and economic attractiveness for users, public transport operators, transport services providers, and municipalities.

As stated by Nemoto et al. (2021), and PwC (2019), the concept of Total Cost of Mobility brings a more recent and holistic understanding of mobility, which has not been well defined until now, going beyond the fact of owning and operating a fleet of vehicles; it is a response to the changes towards current and future service-oriented mobility and presents a dedicated emphasis on the demand (passenger/citizen and trip) perspective. This change of perspective is closer to the reality of citizen mobility use case. It allows evaluating customer-/citizen-centric business strategies.

The benefits and costs of integrating Automated Mobility in a transport system can be found in Jaroudi (2021) and on part 5 of the AVENUE project deliverable D8.6.²

The chapter is structured as follows. Section 12.2 provides a literature review by presenting a brief overview of AVCT's economic impact assessment for the applicative domain. The tool, EASI-AV, is presented in Sect. 12.3. Section 12.4 presents the

¹EASI-AV web application: <https://h2020-avenue.eu/avenue-economic-calculator/>. Copyright by École CentraleSupélec (Université Paris-Saclay)

²AVENUE D8.6 Economic Impact, available at: https://h2020-avenue.eu/wp-content/uploads/2023/03/20220512_D8.6-Economic-Impact_WP8_final-version_DK-not-approved.pdf.

economic assessment for the four AVENUE demonstrator sites, and different scenarios are discussed, and in Sect. 12.5, a conclusion is derived.

12.2 Theoretical Framework: Automated Mobility Impact Assessment

With automated vehicles expected to be an accepted technology by 2030 (Litman, 2018), their market penetration rate is dependent on investment costs as well as operating costs. By not requiring a driver and with expected lower energy consumption due to smoother driving, AVCTs may have lower operating costs than their human-driven counterparts (Fagnant & Kockelman, 2015; Fournier et al., 2020). However, their current embedded autonomy package constitutes the major cost components—with LIDARs, sensors, cameras, processing unit, and V2X equipment ranging from around 25,000 to 30,000 dollars, not to mention that automated vehicles are generally equipped with an electric battery and powertrain, which also increases the costs and reduces the overall lifecycle of the product to currently around 5 years (Ongel et al., 2019).

On the other hand, it is expected that the prices for the automation package as well as battery prices will decrease over time and that, if necessary, batteries and other fast-moving parts will become replaceable, so that the buses could have a much longer service life. Hence automated vehicles may become cost-effective compared to conventional vehicles in the long term (Bansal & Kockelman, 2017; KPMG, 2015). Consequently, cities and PTOs/PTAs should consider the costs and benefits of implementing a public transport service using automated vehicles over traditional services, and several recent studies have sought to provide answers to these demands.

In order to investigate possible changes in the urban mobility behaviour in the cities of Berlin and Stuttgart (Germany), Fournier et al. (2020) proposed an analytical model that simulates the impacts of a shared automated electric vehicles fleet (AEV) versus private vehicles with an internal combustion engine. Their results showed that a shared AEV fleet system could reduce externalities (accident avoidance, traffic jams, free spaces, parking costs, and lifetime losses) in cities and generate cost benefits for customers.

Kalakuntla (2017) carried out a prospective comparative study of costs and benefits of Automated Mobility fleets versus traditional regular diesel buses for the city of Austin (Texas, USA) with the aim of guiding PTOs/PTAs on the feasibility of Automated Vehicles (AV). The author concluded that AVs could save PTOs/PTAs from capital and operational costs, reduce the environmental effects, and increase the quality of life of the people.

The study carried out by Henderson et al. (2017) aimed at finding useful and efficient ways to use AVs in the campus of the Ohio State University (USA); the authors conducted an analysis to compare the current fleet of traditional vehicles used on campus to the costs of purchasing and maintaining a fleet of AVs (in their

case the shuttle Olli from Local Motors). It was concluded that the automated shuttle exceeded the fleet of traditional vehicles in several categories. The costs and the carbon emissions per mile (0.91 lbs) as well as the annual maintenance costs (\$600/yr) were comparatively lower. However, the automated shuttle was currently not cost-effective due to its high initial price in contrast to traditional shuttles.

Bösch et al. (2018) carried out a substantial cost-based analysis comprising of a bottom-up calculation of the cost structures (including besides the fixed costs, the overhead costs of shared services) for different types of AVs in various operation models, such as dynamic ride-sharing, taxi, shared vehicles fleets and AVs. The authors stated that their methodology allows the determination of different cost components' importance and differentiation of vehicle automation effects on individual cost components. Their results showed that more than half of AVs' fleet operating costs will be service and management costs. Furthermore, they have concluded that automated driving technology will allow taxi services and buses to be operated at substantially lower costs.

At last, the study from Ongel et al. (2019) aimed at determining the Total Cost of Ownership (TCO) of AVs and comparing them to regular internal combustion engine buses and minibuses. Their TCO analysis included three major cost components: acquisition costs, operating costs, and end-of-life costs. Their simulations have shown that, although the acquisition costs of AVs are higher than those of conventional buses, they can reduce the TCO per passenger-km up to 75% and 60% compared to conventional minibuses and regular buses, respectively.

Although bringing several promising and interesting results regarding the economic feasibility of services with AVs, none of the studies proposed a holistic methodology for dimensioning and assessing the economic impact of AVs services, which could be easily applied by decision makers in the economic evaluation of AVs.

Therefore, the simulation tool EASI-AV was designed that helps to assess the economic impact of AVs integration into public transport networks and to simulate different scenarios by allowing the users to adjust cost variables and revenue variables. The next section explains how EASI-AV is structured and how its different parts work.

12.3 The EASI-AV Simulation Tool

12.3.1 Design Methodology

The *Economic Assessment of Services with Intelligent Automated Vehicles* (EASI-AV) tool was developed as a support tool to assist decision-makers in cities, as well as transport operators and other organizations to estimate the economic assessment of implementing a service with AVs. EASI-AV has been developed within the European project AVENUE and in collaboration with the transport operators in charge of the collective transport networks which were responsible for the demonstrators in the four cities of the project (Copenhagen, Geneva, Lyon, and Luxembourg). Their data on the

automated service as well as on traditional human-driven services were collected in order to test the tool and the reliability of its algorithms.

12.3.2 EASY-AV Structure and Implementation in the AVENUE Program

The EASI-AV tool provides different types of assessments in a comparative manner (between the shuttle and different baseline transport modes), such as the total service costs (based on the TCO analysis)—including investment costs and operational costs, the local impact of externalities, as well as the global impact assessment. EASI-AV is composed of five different parts that may be carried out sequentially or independently according to the needs of the user.

12.3.2.1 Part 1: Service Contextualization

This part focuses on qualitatively defining the local context envisioned for the new services with AVs. Contextualizing the service helps to build more accurate scenarios and allows decision-makers to have a holistic view of the service context to be implemented. The tool helps to properly frame the territorial typology (urban, peri-urban, rural), the zoning (residential, commercial, industrial, or mixed areas), and define the public transport supply (if there is already existing public transport in the area) and the area’s population density as well as surface area and extension of roads. Figure 12.1 illustrates the EASI-AV web application data entry for one of the AVENUE project’s testing sites (Antonialli et al., 2021).

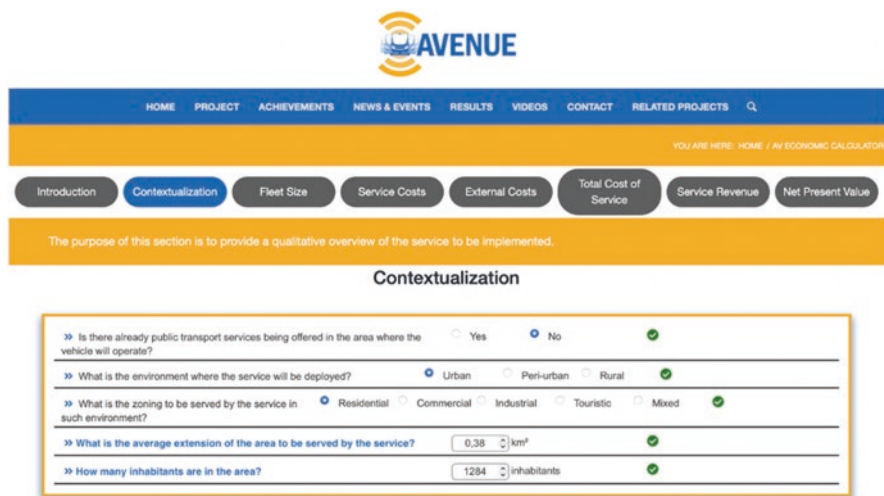


Fig. 12.1 EASI-AV web application data entry—example of an AVENUE testing site. Source: prepared by the authors

12.3.2.2 Part 2: Fleet Size Dimensioning

EASI-AV proposes four alternatives for the fleet size calculation (Table 12.1) that are guided by two main drivers: (1) service type (supply-push or demand-pull), and (2) road environment (fixed-routes or geofenced-on-demand). The tool allows the fleet size to be calculated for all combinations of service type/route environments. Once the category is selected, decision-makers enter data on selected cells if they work with the spreadsheet tool or ask for data collection online if they work on the web application (Antonialli et al., 2021).

As explained by Antonialli et al. (2021), each scenario prompts the algorithms to calculate both the local service costs (CAPEX and OPEX) and well as the local external costs (such as accidents, pollution, noise, and congestion). In addition, each scenario allows the simulation of different revenue models, not only based on ticketing or subsidies (as the current public transport offerings) but also innovative tariffs for on-demand with different revenue sources, such as custom commute to schools, hospitals, and private companies with different onboard services integrated into a mobility app, allowing new revenue streams, and a different economic balance.

For the scenario with option type 1 (fixed-route), the fleet size dimensioning is based on traditional fleet size calculations. Besides the usual general parameters characterizing the territory (route length, average speed, layover time, capacity, etc.) and specific parameters characterizing local mobility uses (percentage of public transport users in the area or numbers of operating hours per day), we considered some other specific for parameters as a way of leading to a finer calculation, such as the average operational speed (taking into account the idle time on each stop), as well as the battery autonomy and its charging time (which allows us to make a time differential to integrate in the calculation for how long a vehicle will be out of service to recharge). Simple algorithms compute these data and propose an optimum fleet size. The scenario with option type 2 (geofenced on-demand) is more complex since the algorithms must evaluate how many kilometres the vehicle may drive across the serviced area to comply with any user's demand for any direction at any time. Key elements of calculation in that option are the passenger waiting time (i.e. how long should a requester wait before a vehicle arrives) and the maximum distance between the requester and the vehicle at the time of the request. After computing these elements in addition to all elements considered for option 1, EASI-AV proposes an optimum fleet size (Antonialli et al., 2021).

Still according to the authors, for service type 1 (demand-pull), EASI-AV proposes calculations via the demand side, that is, for the cases where the demand for mobility

Table 12.1 Service scenarios encompassed by EASI-AV; Source: adapted from Antonialli et al. (2021)

	Service 1: demand-pull	Service 2: supply-push
Option 1: Fixed-route	Copenhagen (Nordhavn) Luxembourg (Contern)	Lyon (Groupama Stadium) Geneva (Meyrin) Luxembourg (Pfaffenthal)
Option 2: Geofenced on-demand	Lyon(Groupama Stadium)	Geneva (Belle-Idée)

is known (i.e. areas where public transport is already in place). Three calculation scenarios are proposed depending on the degree of knowledge of data concerning the existing transport demand (the number of passengers or the expected percentage of passengers during the peak and off-peak hours, etc.). The objective is to offer a flexible, modular tool depending on the transport demand and/or the future transport service offer. It is worth noting that from an economic standpoint, incentives will certainly be different depending on the type of vehicle chosen (e.g. one large bus versus several small buses), thereby, the input demand variables for this service type proposal must always be adjusted accordingly. For service type 2 (supply-push), the tool offers calculations via supply (i.e. areas where public transport is not yet available); thus, where demand on public transport is unknown or the service will be offered as a new transport offering in a supply-pushed strategy (Antoniali et al., 2021).

With the tool being tested with data from several testing sites in the AVENUE project, the EASI-AV-simulated presented results are consistent with the field data. For instance, the fleet size simulations carried out on EASI-AV for the Groupama Stadium testing site in Lyon (KEOLIS), the Nordhavn testing site in Copenhagen (Holo), and the Ormøya testing site in Oslo (Holo) yield the same fleet size and the real number of shuttles used for the operators. Figure 12.2 illustrates the results for one of the AVENUE testing sites yielded by the EASI-AV's web application.

12.3.2.3 Part 3: Local Service Cost Assessment

In the scope of the Total Cost of Mobility as presented by Nemoto et al. (2021), the service cost assessment can be used as the follow-up of part 2 (fleet size dimensioning), or for cases where the fleet size is already known, it can be started by entering the current fleet size the users seek to evaluate.

For this part, information about the lifetime of the vehicles as well as the number of onboard safety drivers and off-board supervisors are requested. The former will allow for the calculation of vehicle depreciation, while the latter two will allow a better characterization of operating costs and possible economies of scale in terms of required staff.



Results for the Supply Side	
Number of passengers for peak hours	80 users/hour
Number of passengers for off-peak hours	30 users/hour
Fleet size for peak hours calculation	2 vehicles
Fleet size for off-peak hours calculation	1 vehicles
Maximum daily total of kilometers per vehicle	83 km
Maximum monthly total of kilometers per vehicle	2 140 km
Maximum yearly total of kilometers per vehicle	25 740 km
Estimated Fleet Size	2 vehicles

Fig. 12.2 EASI-AV web application fleet size results—example of an AVENUE testing site. Source: prepared by the authors

The main internal costs are investment costs (or capital expenditures (CAPEX)) and operations expenditures (OPEX), both must be determined. Once all cost sources are registered, EASI-AV calculates useful KPIs such as the costs per passenger/km and per vehicle/km as well as other indicators. These ratios will be used afterwards for a detailed comparison between transport modes (Antonialli et al., 2021).

To help the user of the tool, based on an extensive literature review and benchmark with the PTOs, a list was created that explains the most relevant CAPEX and OPEX cost sources on a specific side document and via drop-down menus for the web application. In order to integrate economies of scale, the user can choose if the cost applies to a single vehicle or to the entire fleet (e.g. infrastructure works is CAPEX applied to the whole fleet, whereas acquisition is a per vehicle cost). In case the user does not know the exact cost values for the automated shuttle, the calculator also provides the option of using the standard costs (determined based on the average results obtained in the AVENUE project).

As shown in Fig. 12.3, with the summary results for one of the testing sites on the AVENUE project (anonymized due to confidentiality agreements), currently services with automated minibuses are not economically viable when compared to the baseline vehicle (6 meters human-driven bus). Since the fleet size service for this site was comprised of a single shuttle, the capital expenditures are 67% higher, and the operating costs are 29% higher as for CAPEX and the main cost differences between the Automated Vehicle and the baseline vehicle lie in commissioning costs (1567% higher) and in the purchase price of the vehicle (73% higher), in addition, it is worth mentioning the economies of scales that exist for the baseline vehicles due to their higher number on the roads.

As Konstantas (2021) explains, due to current regulatory limitations in some countries (such as Switzerland and Denmark) as well as to the experimental nature of the current projects of Automated Mobility, the commissioning costs for automated vehicles, besides being expensive (the extreme difference in commissioning costs depends very much on the test character and the innovativeness of the mobility approach), are imperatively carried out individually for each vehicle in the fleet, while for traditional human-operated vehicles, the legislation allows such costs to be applied to the whole fleet. As for the acquisition cost, it is evident that automated vehicles are currently more expensive (mainly due to the onboard automation technology and the electric powertrain and batteries). However, as Heineke et al. (2022), Cortright (2017), and Fagnant and Kockelman (2015) have pointed out, the expectation is that the costs of these vehicles will gradually decrease in the next years.

Regarding operating costs (OPEX), the major factor to be considered (in the current state of affairs) is the salary of onboard safety drivers. Since legislation still requires them inside AVs, this raises personnel costs, bringing this expense in line with that of traditional human-driven vehicles. Once the legislation waives the requirement for such professionals, this expense will be eliminated for automated vehicles, rendering them more cost-competitive (more details on these aspects are presented in Session 5). Furthermore, it should be noted that currently, the taxes and fees and maintenance costs are higher than the ones of

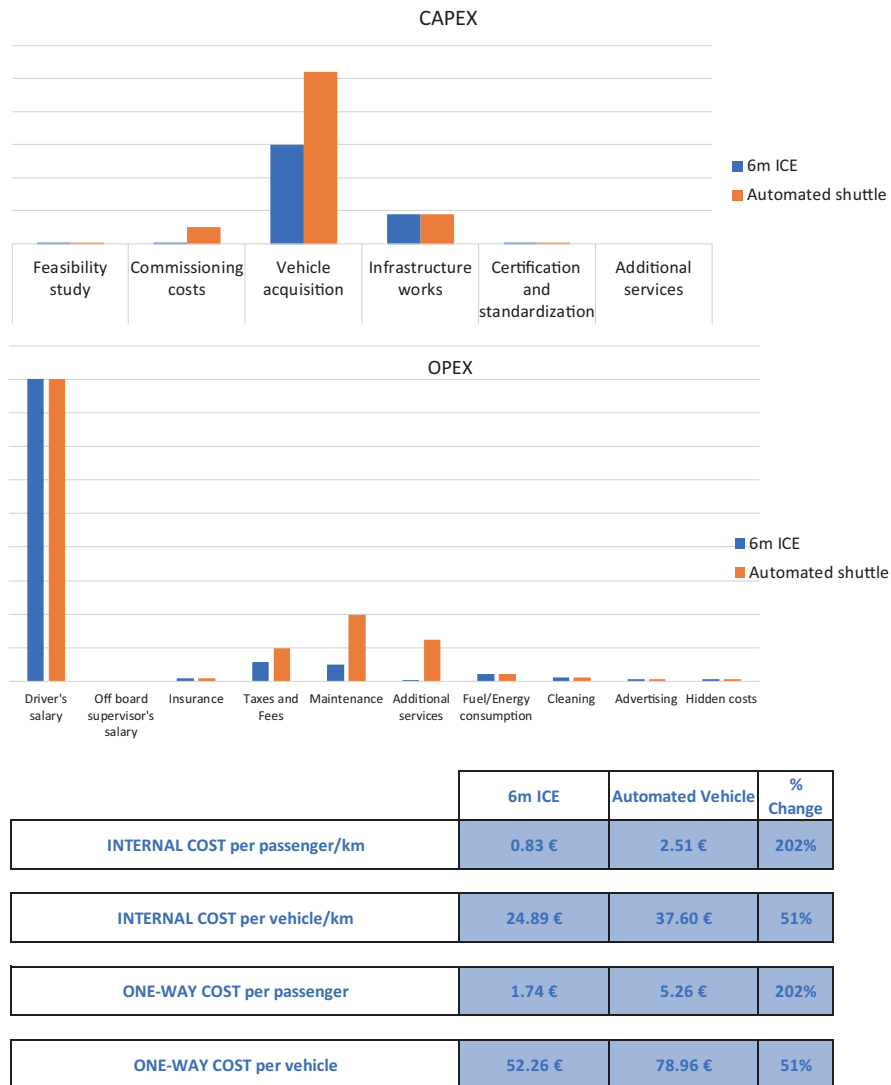


Fig. 12.3 Service cost assessment results—example of an AVENUE testing site. Source: prepared by the authors on EASI-AV

the baseline vehicle (73% and 296%, respectively). Finally, there is a high value of additional services (3.025% higher for AVs), which is due to the choice of the transport operator to offer the testing of additional services to the user (such as the Follow-my-Kid application of the start-up and partner of the Mobile Thinking project).

The KPIs on cost per passenger/km and cost per vehicle/km also corroborate the current economic infeasibility of the services with AVs, being 201% higher in terms

of cost per passenger/km compared to the baseline vehicle and 51% higher considering cost per vehicle/km.

12.3.2.4 Part 4: Local External Cost Assessment

At both local and global scales, public actions are considered in terms of sustainability. In this regard, the transport sector is no exception (Bulteau, 2016). The objective of policymakers is to reduce negative externalities of transport for the community, such as congestion, environmental pollution, and accidents. Therefore, the economic assessment takes into account externalities generated by the transport service implemented in the area, as well as at the macro-city level.

On EASI-AV, several sources of external costs for the cities are considered: congestion, accidents, air pollution (NOx and particulate matter), and noise. The monetized values of these externalities come from the handbook of the externalities of transport (European Commission, 2019) being adjusted for inflation for the year 2020 and adapted to fit AVs. To get the results for externalities valuation, all that needs to be done is to select the country of where the shuttle will be deployed. Everything else is automatically calculated. A comparative analysis is provided between the external costs generated by the fleet size of shuttles and the chosen baseline vehicle (Antonialli et al., 2021).

It is worth noting that since this assessment is based on secondary data from the handbook of externalities of transport (which data was compiled for the year of 2016), the analysis is an approximation and only available for the countries listed in the handbook. However, the results do already provide an overview of the possible impacts (and eventual gains) of implementing AVCTs services.

Figure 12.4 exemplifies the local externalities gains for the same AVENUE testing site exemplified on Fig. 12.3. In comparison with the 6-meter internal combustion engine baseline bus, a 69% local externality cost reduction is observed in all

	6m ICE	Autonomous Shuttle	% Change		6m ICE	Autonomous Shuttle	% Change
EXTERNAL COST per passenger/km	0.04 €	0.01 €	-69%	ONE WAY COST per passenger	0.09 €	0.03 €	-69%
EXTERNAL COST per vehicle/km	0.83 €	0.26 €	-69%	ONE WAY COST per vehicle	1.73 €	0.54 €	-69%
Vehicle DAILY cost	28.42 €	8.78 €	-69%	Fleet DAILY cost	28.42 €	8.78 €	-69%
Vehicle MONTHLY cost	625.23 €	193.19 €	-69%	Fleet MONTHLY cost	625.23 €	193.19 €	-69%
Vehicle YEARLY cost	7,502.74 €	2,318.31 €	-69%	Fleet YEARLY cost	7,502.74 €	2,318.31 €	-69%

Fig. 12.4 Local external costs assessment results—example of an AVENUE testing site. Source: prepared by the authors on EASI-AV

	Luxembourg (Sales-Lentz)		Copenhagen/Oslo (Holo)		Geneva (TPG)	Lyon (Keolis)	AVENUE average	Baseline vehicle 6m-EV (AVENUE average)	
	Pfaffenthal (2 vehicles)	Contern (2 vehicles)	Nordhavn (1 vehicle)	Ormøya (2 vehicles)	Meyrin (1 vehicle)	Groupama (2 vehicles)			
KPIs									
Cost per passenger/km	0.73 €	0.79 €	1.35 €	1.01 €	2.52 €	1.22 €	1.27 €	0.63 €	
Cost per vehicle/km	11.01 €	11.78 €	20.33 €	15.21 €	37.86 €	18.29 €	19.08 €	9.48 €	

NOTE: detailed figures on CAPEX and OPEX have been omitted due to confidentiality requirements.

Fig. 12.5 Total cost of services (CAPEX and OPEX)—AVENUE demonstrator sites. Source: prepared by the authors on EASI-AV

listed KPIs. This results in significant long-term savings for local taxpayers, especially regarding accident costs (94% lower for AVs), local pollution costs (99.7% lower), and noise costs (100% reduction).

The next section details the global results obtained for each testing site of the AVENUE project for which data was provided by the PTOs. Finally, an analysis of scenarios considering service offerings without onboard safety drivers and with commissioning costs applied to the entire AVs fleet is also performed.

12.4 Global Impact Evaluation and Scenarios

12.4.1 Overall AVENUE Results: KPIs

Figure 12.5 depicts the global results for the AVENUE demonstrator sites based on the simulation outcomes from EASI-AV. The presented results are from the demonstrator sites where the operators were able to provide detailed data (results have been adjusted for inflation (December 2022)).

The variations in the CAPEX values among the operating sites differ due to individual prices and levels of investments needed mainly on feasibility studies, commissioning costs, infrastructure works, and certification and standardization for each country. Those values vary according to the specificity of each site as well as based on local legislation.

The variations seen in the OPEX values are mainly due to the costs of personnel. The average salary paid for the operators and supervisors in each country varied as well as the number of operators needed for the daily operation of a single shuttle. For Lyon and Switzerland, the reported average annual salary for the safety drivers is about 90.000,00 euros, while for Luxembourg the values are around 43.133,48 euros, for Denmark around 48.000,00 euros, and for Sweden 55.700,00 euros.

It is worth noting that the KPIs calculations (Fig. 12.5) are based on the OPEX for the service and on the maximum daily mileage that a shuttle can run, which is dependent on the route length, operating hours, and frequency of the service. Consequently, the KPIs (cost passenger/km and cost shuttle/km) vary accordingly. For instance, in the Meyrin site and in Pfaffenthal the shuttles are operated much

less than on the other sites (an average of 31.66 km/day and 43,27 km/day respectively versus the average of 72.73 km for the other four testing sites).

At the current state of affairs, it is safe to say that services with AVs are not yet cost-effective. The KPIs for all demonstrator sites, as well as the averages for the project (column in green on Fig. 12.5), have higher costs than the 6 m EV human-driven baseline vehicle³ used here to provide a global comparison to the AVENUE services (column in red on Fig. 12.5). The costs of the automated vehicles used in the project are 50.39% higher in terms of cost per passenger/km and 50.31% regarding the costs per vehicle/km, considering an average occupancy of 15 passengers. In the following subsection, different scenarios are presented to show the potential economic viability of the services once certain regulatory barriers are overcome.

12.4.2 Simulation of Scenarios

12.4.2.1 CAPEX Savings

As for possible CAPEX reductions, a possible evolution in the regulatory framework can lead to a reduction in costs for certification and standardization, feasibility studies, as well as commissioning costs. As pointed out by Konstantas (2021) feasibility studies and commissioning costs deserve special attention according to the local legislation of each country. According to the author, in Denmark, due to the lack of clear legal requirements, feasibility studies were not only time-consuming but also more cost-intensive than planned. In Switzerland, on the other hand, current legislation requires commissioning costs to be incurred for each vehicle individually and not for the fleet as a whole, leading to higher capital expenditures (particularly for the Belle Idée site, where two shuttles were used and not just one as in Meyrin). Secondly, as pointed out by Fagnant and Kockelman (2015), not only do the acquisition costs of these vehicles tend to decrease in the next years, but also their life cycle is assumed to decrease due to more modern sensors and cameras. Thus, it is possible to consider an important reduction in fleet acquisition costs.

Overall, the current average CAPEX values for the AVENUE project presented in the green column in Fig. 12.5 (both for a single AV and for the fleet) are not disproportionately higher than the average calculated for the human-driven baseline vehicle (red column in Fig. 12.5), being only 8.41% higher for a single vehicle and 21.71% higher for the total fleet.

In fact, by analysing each demonstrator site individually, (apart from Groupama in Lyon—due to its particularities that rendered the CAPEX higher than the AVENUE average), all other demonstrators already present—for a single vehicle—CAPEX values lower than the average calculated for the baseline vehicle. Therefore, even with a

³Values for the baseline vehicle were calculated based on the baseline average for the AVENUE demonstrator sites, considering a 6-meter Bolloré electric bus (<https://www.bluebus.fr/bluebus-6-metres>) with an average occupancy of 15 passengers (maximum capacity 30 passengers)

potential margin for investment cost reductions, CAPEX is not the main elements that make the current offering of services with AVs unfeasible, these fall on operating costs. The following subsection describes the possible ways to reduce these costs.

12.4.2.2 OPEX Savings

Undoubtedly, the main competitive advantage in terms of operating costs for AVs when compared to traditional vehicles is the absence of drivers. However, the current regulatory framework in most countries does not allow services and projects without the presence of an onboard safety driver. Thus, the constant presence of this professional inside the vehicle suppresses their competitive promise in terms of cost reduction.

However, advances are being made in the legal frameworks, and in some countries, legislation is starting to allow trials of these services without the presence of a full-time onboard safety driver. In these cases, an off-board supervisor in a control room is responsible for ensuring the safety and operation of the service for the AV fleet. Within the scope of the AVENUE project, the first tests of this type began in Geneva at the Belle Idée site and were scheduled to begin at the Lyon site. In a medium to long-term horizon, considering technological and regulatory advances, one can imagine a 100% automated service (SAE level 5), where the vehicle would not require either an onboard safety driver or off-board supervisors (SAE, 2016).

Figure 12.6 presents the OPEX and KPIs results from the AVENUE project as well as simulation results for a (1) short-term scenario without an onboard safety driver and with an off-board supervisor and (2) a medium to the long-term scenario without any human intervention (either inside or outside the vehicle) for the operation of the service. It is worth noting that for both scenarios, all other operating costs were kept unchanged, meaning that further savings can still be made when

		Luxembourg (Sales-Lentz)		Copenhagen/Oslo (Holo)		Geneva (TPG)	Lyon (Keolis)	AVENUE average	Baseline vehicle 6m-EV (AVENUE average)
		Pfaffenthal (2 vehicles)	Contern (1 vehicles)	Nordhavn (1 vehicle)	Ormøya (2 vehicles)	Meyrin (1 vehicle)	Groupama (2 vehicles)		
AVENUE results	KPIs								
	Cost per passenger/km	0.73 €	0.79 €	1.35 €	1.01 €	2.52 €	1.22 €	1.27 €	0.63 €
	Cost per vehicle/km	11.01 €	11.78 €	20.33 €	15.21 €	37.86 €	18.29 €	19.08 €	9.48 €
Scenario 1	KPIs								
	Cost per passenger/km	0.49 €	0.79 €	1.18 €	0.63 €	1.86 €	0.82 €	0.96 €	0.63 €
	Cost per vehicle/km	7.39 €	11.78 €	17.81 €	9.22 €	27.95 €	12.37 €	14.42 €	9.48 €
Scenario 2	KPIs								
	Cost per passenger/km	0.41 €	0.57 €	0.84 €	0.48 €	1.20 €	0.69 €	0.70 €	0.63 €
	Cost per vehicle/km	6.19 €	8.66 €	12.75 €	7.23 €	18.04 €	10.29 €	10.53 €	9.48 €

NOTE: detailed figures on CAPEX and OPEX have been omitted due to confidentiality requirements.

Fig. 12.6 OPEX and KPIs—simulation of scenarios Source: prepared by the authors on EASI-AV

considering future reductions in fees and charges, maintenance, additional services, advertising, etc.

Considering the average values for the AVENUE project (green column in Fig. 12.6), it is noted that for scenario 1 (with an onboard safety driver and without an off-board supervisor), there is a 24.41% reduction in the cost per passenger/km (dropping from an average value of 1.27€ to 0.96€) and a similar 24.42% reduction in the cost per vehicle/km (dropping from 19.08€ to 14.42€). However, these average values are still above the average values found for the baseline vehicle (red column in Fig. 12.6).

On the other hand, this scenario is already economically feasible for two of the six demonstration sites studied. In Pfaffenthal (Luxembourg) and Ormøya (Oslo), the replacement of onboard safety drivers with off-board supervisors has resulted in lower costs per passenger/km and vehicle/km than the average values for the baseline vehicle (even without considering a reduction in the other listed operating costs). This represents a 32.87% reduction for both costs per passenger/km and vehicle/km in Pfaffenthal. In Ormøya a 37.62% reduction in costs per passenger/km and 39.38% reduction in costs per vehicle/km was recorded.

The results observed for scenario 2 (no onboard safety drivers and no off-board supervisors) bring the operational costs to competitive values when compared to the baseline vehicle. Although the overall average costs within the project are still above the values observed for the baseline vehicle (0.70€ versus 0.63€ for the cost per passenger/km, and 10.53€ versus 9.48€ for the vehicle/km cost), it is worth noting that in half of the demonstration sites studied, the service would prove to be economically competitive.

Both sites in Luxembourg show average values lower than those of the baseline vehicle. For Pfaffenthal, the cost per passenger/km would drop to 0.41€ and per vehicle/km to 6.19€, a respective reduction of 34.91% and 34.70% compared to the baseline vehicle. In Contern, the reductions would be 9.52% regarding the cost per passenger/km and 8.64% for vehicle/km. When comparing the figures to the actual results of the project, in Pfaffenthal the potential for reductions in cost per passenger/km would drop from 0.73€ to 0.41€ (a reduction of 43.83%) and from 11.01€ to 6.19€ in cost per vehicle/km (reduction of 43.77%). In Contern, the reductions would be 27.84% for the cost per passenger/km and 26.48% for the cost per vehicle/km.

The Ormøya site in Oslo also provided results that would make it feasible to implement the service with AVs. With respect to the baseline vehicle, the cost per passenger/km would be 0.48€ (23.8% less than the baseline vehicle) and the cost per vehicle/km would be 7.23€ versus 9.48€ for the baseline EV (23.73% reduction). When comparing the results with the actual values obtained in the AVENUE project, the savings in terms of cost per passenger/km would be 52.47% (falling from 1.01€ to 0.48€) and 52.46% regarding the cost per vehicle/km (falling from 15.21€ to 7.23€).

It is important to emphasize the following for the three other project sites considered in the analysis: in Nordhavn (Copenhagen), Meyrin (Geneva), and Groupama Stadium (Lyon), high operating costs such as insurance, taxes and fees, maintenance, and additional services have pushed the average costs up, causing the KPIs

to yield higher values than those obtained for the baseline vehicle (0.84€ and 12.75€ for Nordhavn; 1.20€ and 18.04€ for Meyrin; and 0.69€ and 10.29€ for Groupama Stadium).

Nevertheless, when comparing the results of scenario 2 for these sites with the actual results obtained in the AVENUE project, a significant reduction in costs can also be observed. For the Nordhavn site, costs per passenger/km would fall from 1.35€ to 0.84€ (a 37.77% reduction) and from 20.33€ to 12.75€ for costs per vehicle/km (37.28% reduction). At Meyrin, the reductions would be 52.38% for the cost per passenger/km and 52.35% for the cost per vehicle/km. Finally, for Groupama Stadium the reductions would be 43.44% for costs per passenger/km and 43.73% for costs per vehicle/km.

Therefore, there is a high potential in both the short and medium to long term for the economic viability of AV services. Once technological advances (allowing reductions in vehicle prices, maintenance costs, insurance, and fees) and regulatory framework advances (eliminating the need for safety-driver and/or off-board supervisor, as well as better accommodating feasibility studies and commissioning costs) are accomplished, the potential gains for passengers, transport operators, and consequently for cities are undeniable.

The main expected results would then be an important increase in the number of passengers commuting in the automated vehicles, thus rendering the services not only viable but attractive to the general public. On the other hand, if none in-vehicle services and reliable safeguard systems are provided, privacy and security issues can lower the number of passengers willing to use the service.

12.5 Conclusion

The large-scale deployment of automated collective vehicles, combined with online services, user profiling, and dynamic itinerary optimization, will have a disruption effect on today's public transport. The disappearance of drivers will allow transport operators to deploy more vehicles, resulting in a scaling down of vehicles. This, in turn, will allow vehicles to divert from the predefined itineraries and start offering on-demand, door-to-door services (based on dynamic online reservations and optimization), transforming public transport into a personalized transit service.

This transformation will require a high level of investments. Anticipating the economic impact of investments is a usual task for any decision-maker or investor. Therefore, the tool was developed in collaboration with transport operators and local city governments to enable an economic assessment of the implementation of automated vehicles into their transport network and the valorisation of deployment scenarios.

With public transport being a complex ecosystem, not only transport operators, passengers, and policymakers are included but a lot of different stakeholders such as software providers, mobility platforms, vehicle manufacturers, insurance companies, telecom companies, infrastructure construction companies, maintenance

companies, and data provider companies. Each stakeholder may facilitate or hinder the deployment of automated collective transport. Therefore, they should be able to analyse scenarios from their own economic viewpoint. EASI-AV was successfully tested on the AVENUE experimentation sites in four European cities and proved to be a relevant support tool for decision-making in designing new mobility solutions.

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References

- Antonialli, F., Mira-Bonnardel, S., & Bulteau, J. (2021). Economic assessment of services with intelligent autonomous vehicles: EASI-AV. In S. Mira-Bonnardel, F. Antonialli, & D. Attias (Eds.), *The robomobility revolution of urban public transport* (1st ed.). Springer Nature.
- Bansal, P., & Kockelman, K. M. (2017). Forecasting Americans' long-term adoption of connected and automated vehicle technologies. *Transportation Research Part A: Policy & Practice*, 95, 49–63.
- Bösch, P. M., Becker, F., Becker, H., & Axhausen, K. W. (2018). Cost-based analysis of automated mobility services. *Transport Policy*, 64, 76–91.
- Bulteau, J. (2016). Revisiting the bottleneck congestion model by considering environmental costs and a modal policy. *International Journal of Sustainable Transportation*, 10(3), 180–192.
- Cortright, J. (2017). *What price for autonomous vehicles?* City Observatory. Available at: http://cityobservatory.org/what-price_autonomous_vehicles. Accessed 2 May 2023.
- European Commission. (2019). Handbook on the external costs of transport. *Publications Office of the European Union [online]*. <https://op.europa.eu/en/publication-detail/-/publication/9781f65f-8448-11ea-bf12-01aa75ed71a1>. Accessed 15 Jan 2021.
- Fagnant, D. J., & Kockelman, K. (2015). Preparing a nation for automated vehicles: Opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy & Practice*, 7, 167–181.
- Fournier, G., Boos, A., Wörner, R., Jaroudi, I., Morozova, I., & Nemoto, E. H. (2020). Substituting individual mobility by mobility on demand using autonomous vehicles - A sustainable assessment simulation of Berlin and Stuttgart. *International Journal of Automotive Technology and Management*, 20(4), 369–407.
- Heineke, K., Heuss, R., Kampshoof, P., Kelkar, A., & Kellner, M. (2022). *The road to affordable autonomous mobility*. McKinsey & Company. Available at: <https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-road-to-affordable-autonomous-mobility#/>. Accessed 2 May 2023.
- Henderson, H., Veder, A., Li, L., & Johnson, M. (2017). *Feasibility of electric automated vehicles on Ohio State University Campus*. Available online: www.kb.osu.edu/bitstream/han

- [dle/1811/81632/1/ENRAEDE4567_ElectricAutomatedVehicles_au2017.pdf](#). Accessed 14 Apr 2020.
- Jaroudi, I. (2021). What is the potential impact of the transition from traditional transport to new mobility models (electric automated minibuses) in European cities? In *Proceedings of the 29th international colloquium of Gerpisa: The transformations of the global auto industry*. Available at: <https://www.gerpisa.org/node/6370>. Accessed 2 May 2023.
- Kalakuntla, S. P. (2017). *Adopting automated bus to a transit agency: a cost-benefit analysis*. Available online: www.academia.edu/34636124/ADOPTING_AUTOMATED_BUS_TO_A_TRANSIT_AGENCY_A_COST-BENEFIT_ANALYSIS. Accessed 14 Apr 2020.
- Konstantas, D. (2021). From demonstrator to public service: The AVENUE experience. In S. Mira-Bonnardel, F. Antonialli, & D. Attias (Eds.), *The robomobility revolution of urban public transport* (1st ed.). Springer Nature.
- KPMG. (2015). *Connected and automated vehicle - The UK economic opportunity*. Available online: www.smmmt.co.uk/wp-content/uploads/sites/2/CRT036586F-Connected-and-Automated-Vehicles-%E2%80%93-The-UK-Economic-Opportu...1.pdf. Accessed 13 Apr 2020.
- Litman, T. (2018). Automated vehicle implementation predictions. Implications for Transport Planning. Available online: www.vtppi.org. Accessed 13 Apr 2020.
- Mira-Bonnardel, S. (2021). Robomobility for collective transport: A prospective user centric view. *International Journal of Automotive Technology and Management*, 21(1/2), 99. <https://doi.org/10.1504/IJATM.2021.113353>
- Nemoto, E. H., Issaoui, R., Korbee, D., Jaroudi, I., & Fournier, G. (2021). How to measure the impacts of shared automated electric vehicles on urban mobility. *Transportation Research Part D: Transport and Environment.*, 93, 1–18.
- Ongel, A., Loewer, E., Roemer, F., Sethuraman, G., Chang, F., & Lienkamp, M. (2019). Economic assessment of automated electric microtransit vehicles. *Sustainability*, 11(648), 1–18.
- PwC. (2019). The 2019 strategy & digital auto report: Time to get real: Opportunities in a transforming market. Available online: www.strategyand.pwc.com/gx/en/insights/2019/digital-auto-report/digital-auto-report-2019.pdf. Accessed 2 May 2023.
- SAE. (2016). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles J3016_201609, Available online: www.sae.org/standards/content/j3016_201609/. Accessed 14 Apr 2020.

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