Automated Vehicles to Evolve to a New Urban Experience

DELIVERABLE

D7.14 Report on evaluation and assessment of AVENUE solution

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V1.8	19.09.2022	Jakob Puchinger	Final review and final version

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Acronyms

ADS	*Automated Driving Systems*
AI	*Artificial Intelligence*
AMPT	*Automated Minibuses for Public Transport*
API	*Application Protocol Interface*
AV	*Automated Vehicle*
BES	*Business Ecosystem*
BMM	*Business Modelling Manager*
CAPEX	*Capital Expenditures*
CAV	*Connected and Automated Vehicles*
CB	*Consortium Body*
CERN	*European Organization for Nuclear Research*
D7.1	*Deliverable 7.1*
DC	*Demonstration Coordinator*
DI	*The department of infrastructure*
DMP	*Data Management Plan*
DWL	*deadweight loss*
DSES	*Department of Security and Economy Traffic Police*
DTU test track	*Technical University of Denmark test track*
EAB	*External Advisory Board*
EASI-AV©	*Economic Assessment of Services with Intelligent Automated Vehicles*
EC	*European Commission*
ECSEL	*Electronic Components and Systems for European Leadership*
EM	*Exploitation Manager*
EU	*European Union*
EUCAD	*European Conference on Connected and Automated Driving*
F2F	*Face to face meeting*
FEDRO	*Federal Roads Office*
FEDRO	*(Swiss) Federal Roads Office*
FOT	*(Swiss) Federal Office of Transport*
GDPR	*General Data Protection Regulation*
GHG	*GREENhouse gas*
GIMS	*Geneva International Motor Show*
GNSS	*Global Navigation Satellite System*
GWP	*Global warming potential*
HARA	*Hazard Analysis and Risk Assessment*
IPR	*Intellectual Property Rights*
IT	*Information Technology*
ITU	*International Telecommunications Union*
ICEV	*internal-combustion engine vehicles-*
KPI	*Key Performance Indicators*
LA	*Leading Author*
NEEDs	New energy externalities development for sustainability

NMVOC	*non-methane volatile organic compound*
NMT	*non-motorised transport*
NO	Nitrogen oxides
MaaS	*Mobility as a service*
MEM	*Monitoring and Evaluation Manager*
OCT	*General Transport Directorate of the Canton of Geneva*
ODD	*Operational Domain Design*
OEDR	*Object And Event Detection And Response*
OFCOM	*Federal Office of Communications*
OPEX	*Operation Expenditures*
PC	*Project Coordinator*
PCU	*Passenger Car Unit PCU*
PEB	*Project Executive Board*
PGA	*Project General Assembly*
PRM	*Persons with Reduced Mobility*
PRS	*Product related Service*
PSA	*Group PSA (PSA Peugeot Citroën)*
PTO	*Public Transport Operator (French: TPO)*
PTS	*Public Transportation Services*
QRM	*Quality and Risk Manager*
QRMB	*Quality and Risk Management Board*
RN	*Risk Number*
SA	*Scientific Advisor*

SAE Level	*Society of Automotive Engineers Level (Vehicle Autonomy Level)*
SAN	*Cantonal Vehicle Service*
SDK	*Software Development Kit*
SMB	*Site Management Board*
SoA	*State of the Art*
SOTIF	*Safety Of The Intended Functionality*
SUMP	*Sustainable Urban Mobility Plan*
SWOT	*Strengths, Weaknesses, Opportunities, and Threats.*
TCO	*Total Cost of Ownership*
TCM	*Total Cost of Mobility*
TDM	*Transportation Demand management*
TM	*Technical Manager*
TPO	*Transport Publique Operateur (engl. PTO)*
TTW	*Tank-to-Wheel*
UITP	*Union Internationale des Transports Publics*
VAS	*Value Added Service*
VKm	*vehicle kilometre travelled*
VSL	*Value of statistical life*
VOT	*Value of time*
VOLY	Value-of-statistical life
WP	*Work Package*
WPL	*Work Package Leader*
WTT	*WELL-TO-TANK*

Executive Summary

The AVENUE project aims to design and carry out full scale demonstrations of urban transport automation by deploying fleets of automated minibuses in European cities.

An important element in the project is the global evaluation and assessment of the proposed transport solutions. In this regard, this deliverable presents the evaluation framework with its four evaluation categories to assess the overall performance of the AVENUE solution as well as the application of the framework to the AVENUE testing sites (demonstrators and replicators).

This deliverable is structured as follows:

- An overview of on-demand mobility and automated vehicles for public transport (section 1).
- The proposed evaluation framework for automated services for public transport (section 2).
- The application of the proposed framework to the AVENUE demonstrator and replicator sites (section 3).
- An overall conclusion with a summary of the results, the limitations of the framework and its application and hints for future developments (section 4).

The proposed evaluation framework has been designed in an open and flexible manner, with the goal of assessing not only the services on the AVENUE project, but also to be further adapted and expanded by other projects that aim to deploy automated shuttles for collective transport in urban settings.

As a conclusion, the evaluation framework is an useful analytical tool to all involved stakeholders: local governments, public transport operators, users, and third-party partners.

1 Introduction

AVENUE aims to design and carry out full-scale demonstrations of urban transport automation by deploying, for the first time worldwide, fleets of automated minibuses in low to medium demand areas of 4 European demonstrator cities (Geneva, Lyon, Copenhagen, and Luxembourg) and 2 to replicator sites (Sion in Switzerland and, Esch Ville in Luxembourg). The AVENUE vision for future public transport in urban and suburban areas is that automated vehicles will ensure safe, rapid, economic, sustainable, and personalized transport of passengers. AVENUE introduces disruptive public transportation paradigms based on on-demand, door-to-door services, aiming to set up a new model of public transportation, by revisiting the offered public transportation services and aiming to suppress prescheduled fixed bus itineraries.

Vehicle services that substantially enhance the passenger experience, as well as the overall quality and value of the service, will be introduced, also targeting elderly people, people with disabilities, and vulnerable users. Road behavior, security of the automated vehicles, and passengers' safety are central points of the AVENUE project.

At the end of the AVENUE project four-year period, the mission is to have demonstrated that automated vehicles will become the future solution for public transport. The AVENUE project will demonstrate the economic, environmental, and social potential of automated vehicles for both companies and public commuters while assessing vehicle road behavior safety.

1.1 On-demand Mobility

Public transportation is a key element of a region's economic development and the quality of life of its citizens. Governments around the world are defining strategies for the development of efficient public transport based on different criteria of importance to their regions, such as topography, citizens' needs, social and economic barriers, environmental concerns, and historical development. However, new technologies, modes of transport, and services are appearing, which seem very promising to the support of regional strategies for the development of public transport.

On-demand transport is a public transport service that only works when a reservation has been recorded and will be a relevant solution where the demand for transport is diffuse and regular transport is inefficient. On-demand transport differs from other public transport services in that vehicles do not follow a fixed route and do not use a predefined timetable. Unlike taxis, on-demand public transport is usually also not individual. An operator or an automated system takes care of the booking, planning, and organization.

It is recognized that the use and integration of on-demand automated vehicles has the potential to significantly improve services and provide solutions to many of the problems encountered today in the development of sustainable and efficient public transport.

1.2 Automated Vehicles

A self-driving car referred in the AVENUE project as **an Automated Vehicle** (**AV**) is a vehicle that can sense its environment and moving safely with no human input. The choice of Automated vs Autonomous was made in AVENUE since, in the current literature, most of the vehicle concepts have a person in the driver's seat, utilize a communication connection to the Cloud or other vehicles, and do not independently select either destination or routes for reaching them, thus being “automated”. The automated vehicles are considered to provide assistance (at various levels) to the driver. In AVENUE there will be no driver (so no assistance will be needed), while the route and destinations will be defined automatedly (by the fleet management system). The target is to reach a system comprising of vehicles and services that independently select and optimize their destination and routes, based on the passenger demands. In relation to the SAE levels, the AVENUE project will operate SAE Level 4 vehicles (see Figure 1).

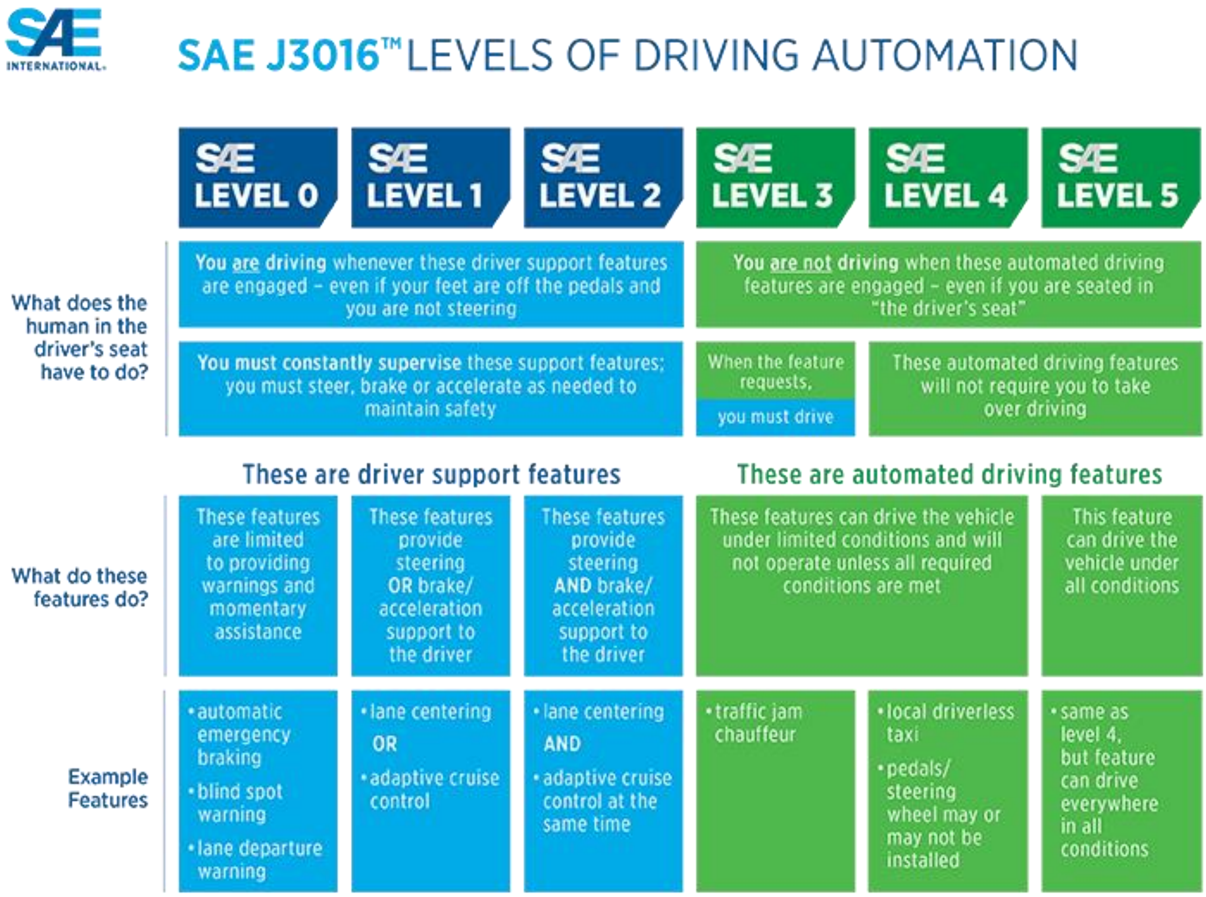


Figure 1. Levels of vehicular automation
Source: ©2020 SAE International

1.2.1 Automated vehicle operation overview

We distinguish in AVENUE two levels of control of the AV: micro-navigation and macro-navigation. Micro navigation is fully integrated into the vehicle and implements the road behavior of the vehicle, while macro-navigation is controlled by the operator running the vehicle and defines the destination and path of the vehicle, as defined by the higher view of the overall fleet management.

For micro-navigation Automated Vehicles combine a variety of sensors to perceive their surroundings, such as 3D video, LIDAR, sonar, GNSS, odometer, and other types of sensors. Control software and systems, integrated into the vehicle, fusion and interpret the sensor information to identify the current position of the vehicle, detect obstacles in the surrounding environment, and choose the most appropriate reaction of the vehicle, ranging from stopping to bypassing the obstacle, reducing its speed, making a turn, etc.

For Macro-navigation, that is the destination to reach, the Automated Vehicle receives the information from either the in-vehicle operator (in the current configuration with a fixed path route) or from the remote-control service via a dedicated 4/5G communication channel, for a fleet-managed operation. The fleet management system considers all available vehicles in the services area, the passenger request, the operator policies, the street conditions (closed streets) and sends route and stop information to the vehicle (route to follow and destination to reach).

1.2.2 Automated vehicle capabilities in AVENUE

The automated vehicles employed in AVENUE fully and automatedly manage the above defined, micro-navigation and road behavior, in an open street environment. The vehicles are automatedly capable to recognize obstacles (and identify some of them), identifying moving and stationary objects, and automatedly deciding to bypass them or wait behind them, based on the defined policies. For example with small changes in its route the AVENUE mini-bus is able to bypass a parked car, while it will slow down and follow behind a slowly moving car. The AVENUE mini-buses are able to handle different complex road situations, like entering and exiting round-about in the presence of other fast running cars, stop in zebra crossings, communicate with infrastructure via V2I interfaces (ex. red light control).

The mini-buses used in the AVENUE project technically can achieve speeds of more than 60Km/h. However this speed cannot be used in the project demonstrators for several reasons, ranging from regulatory to safety. Under current regulations the maximum authorised speed is 25 or 30 Km/h (depending on the site). In the current demonstrators the speed does not exceed 23 Km/h, with an operational speed of 14 to 18 Km/h. Another, more important reason for limiting the vehicle speed is safety for passengers and pedestrians. Due to the fact that the current LIDAR has a range of 100m and the obstacle identification is done for objects no further than 40 meters, and considering that the vehicle must safely stop in case of an obstacle on the road (which will be “seen” at less than 40 meters distance) we cannot guarantee a safe braking if the speed is more than 25 Km/h. Note that technically the vehicle can make harsh break and stop with 40 meters in high speeds (40 -50 Km/h) but then the break would too harsh putting in risk the vehicle passengers. The project is working in finding an optimal point between passenger and pedestrian safety.

Due to legal requirements a **Safety Operator** must always be present in the vehicle, able to take control any moment. Additionally, at the control room, a **Supervisor** is present controlling the fleet operations. An **Intervention Team** is present in the deployment area ready to intervene in case of incident to any of the mini-busses. Table 1 provides and overview of the AVENEU sites and OODs.

Table 1. Summary of AVENUE operating site (+ODD components)

	Summary of AVENUE operating sites demonstrators						
	TPG		**Holo**		**Keolis**	**Sales-Lentz**	
	Geneva		**Copenhagen**	**Oslo**	**Lyon**	**Luxembourg**	
Site	Meyrin	Belle-Idée	Nordhavn	Ormøya	ParcOL	Pfaffental	Contern
Funding	TPG	EU + TPG	EU + Holo	EU + Holo	EU + Keolis	EU + SLA	EU + SLA
Start date of project	August 2017	May 2018	May 2017	August 2019	May 2017	June 2018	June 2018
Start date of trial	July 2018	June 2020	September 2020	December 2019	November 2019	September 2018	September 2018
Type of route	Fixed circular line	Area	Fixed circular line	Fixed circular line	Fixed circular line	Fixed circular line	Fixed circular line
Level of on-demand service*	Fixed route / Fixed stops	Flexible route / On-demand stops	Fixed route / Fixed stops	Fixed route / Fixed stops	Fixed route/Fixed stops	Fixed route / Fixed stops	Fixed route / Fixed stops
Route length	2,1 km	38 hectares	1,3 km	1,6 km	1,3 km	1,2 km	2,3 km
Road environment	Open road	Semi-private	Open road	Open road	Open road	Public road	Public road
Type of traffic	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed	Mixed
Speed limit	30 km/h	30 km/h	30 km/h	30 km/h	8 to 10 km/h	30 km/h	50 km/h
Roundabouts	Yes	Yes	No	No	Yes	No	No
Traffic lights	No	No	No	No	Yes	Yes	Yes
Type of service	Fixed line	On demand	Fixed line	Fixed line	Fixed line	Fixed line	Fixed line
Concession	Line (circular)	Area	Line (circular)	Line (circular)	Line (circular)	Line (circular)	Line (circular)
Number of stops	4	> 35	6	6	2	4	2
Type of bus stop	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Bus stop infrastructure	Yes	Sometimes, mostly not	Yes	Yes	Yes	Yes	Yes
Number of vehicles	1	3-4	1	2	2	2	1
Timetable	Fixed	On demand	Fixed	Fixed	Fixed	Fixed	Fixed
Operation hours	Monday-Friday (5 days)	Sunday-Saturday (7 days)	Monday-Friday (5 days)	Monday-Sunday (7 days)	Monday-Saturday (6 days)	Tuesday & Thursday Saturday, Sunday & every public holiday	Monday - Friday
Timeframe weekdays	06:30 – 08:30 / 16:00 – 18:15	07:00 – 19:00	10:00 – 18:00	7:30 – 21:30	08:30 – 19:30	12:00 – 20h00	7:00 – 9:00 16:00 – 19:00
Timeframe weekends	No service	07:00 – 19:00	No service	9:00 – 18:00	08:30 – 19:30	10:00 – 21:00	No Service
Depot	400 meters distance	On site	800 meters distance	200 meters distance	On site	On site	On site
Driverless service	No	2021	No	No	No	No	No
Drive area type/ODD	B-Roads	Minor roads/parking	B-Roads/minor roads	B-Roads	B-Roads	B-Roads	B-Roads/parking
Drive area geo/ODD	Straight lines/plane	Straight lines/ plane	Straight lines/ plane	Curves/slopes	Straight Lines/ plane	Straight lines/ plane	Straight lines/ plane
Lane specification/ODD	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane	Traffic lane
Drive area signs/ODD	Regulatory	Regulatory	Regulatory, Warning	Regulatory	Regulatory	Regulatory	Regulatory
Drive area surface/ODD	Standard surface, Speedbumps	Standard surface, Speedbumps	Standard surface Speedbumps, Roadworks	Frequent Ice, Snow	Standard surface, Potholes	Standard surface	Standard surface

1.3 Preamble

The AVENUE project is set up to offer on-demand door-to-door solutions integrated within existing public transportation services and evaluates the feasibility of operating fully automated shuttles with routes and schedules based on real-time passenger demand, instead of following fixed itineraries and pre-determined timetables.

AVENUE's objective is to showcase these customized transport solutions at demonstrator sites in Copenhagen, Geneva, Luxembourg, and Lyon, and later duplicate them in several other European cities.

Work package **WP7** aims to organize, run, and evaluate these large-scale demonstrators of the fully automated vehicle services for public transport, targeting different user groups, and transport models. The goal is to validate a high-quality, safe service, which will enhance acceptance and adoption of fully automated vehicles for public transport.

With the elaboration of a global evaluation framework, the purpose of task **T7.6** is to perform the assessment of the overall AVENUE services, technologies, and functionalities at large scale demonstrators, considering user experience and evaluation of improvements brought by AVENUE's fully automated urban transport system.

In deliverable **D7.14**, the focus is to present and explain the evaluation framework as well as to apply it to the AVENUE demonstrators' sites.

2 Evaluation framework

As the implementation of more advanced sensors, radars, and navigation technologies in vehicles increases, there is now a potential for large-scale deployment of a new form of publicly available, electrically operated, driverless minibuses for urban environments. If successfully deployed, such vehicles can provide flexible and cost-efficient solutions for serving peak and off-peak demand, parallel and feeders to trunk lines (Ainsalu & et al, 2018).

As advocated by (Poorsartep, 2014), the technology itself is no longer seen as a major hindrance. Automated vehicles for collective transport must now gain wide public acceptance and surpass regulatory frameworks (Enoch, 2015); (Schellekens, 2015). Via large-scale demonstrations involving the public sphere (transport authority and local governments), civil society (users and local businesses), as well as manufacturers, public transport operators, universities, and other institutions, projects such as AVENUE and other EU-funded initiatives, have a central role in helping automated vehicles surpass such roadblocks.

Thus, an essential step towards advancing legal discussions and a better understanding of user acceptance and technological evolution of the systems is the overall evaluation of ongoing projects. Based on the outcomes of D2.16 (Labriga & Mira-Bonnardel, 2018), the research report by the Finish VTT Technical Research Centre (Innamaa & Kuisma, 2018), as well as the former European Commission project CityMobil2 evaluation framework (McDonald, Site, Stam, & Saucci, 2018), we have created a global framework for evaluating projects with automated vehicles for public transport to be applied not only in the scope of the AVENUE project but in any given project that intends to use it.

Given the size and complexity of EU-funded projects such as AVENUE, this evaluation framework proposal is divided into broad categories to be assessed based on data availability and sources and it is classified into various Key-Performance Indicators (KPIs), measured both objectively (e.g., number of passengers per day, battery charging time, number of human interventions) and, subjectively (e.g., semi-structured questionnaires with users, and semi-structured interviews). Whenever possible, we recommend analyzing KPIs considering a set timeframe (monthly, early, etc.) to measure their evolution during the project lifespan.

The evaluation categories listed on the next pages follow the guidelines proposed by (Labriga & Mira-Bonnardel, 2018), in a sense that the framework was built on a systematic comparison between the user side and the service provider side, as shown in Figure 2.

On the user side, the evaluation aims at integrating the users' expectations and perceptions to measure the gap between their cognitive perception and the tangible, measurable data. On the service provider side, service specifications are presented based on well-established objectives and measurable KPIs. Nonetheless, there may be significant differences between targeted specifications and the concrete realization of the service. Therefore, the evaluation must compare initial objectives given to a specific service and the actual performance, the effective performance as well as the perceived performance.

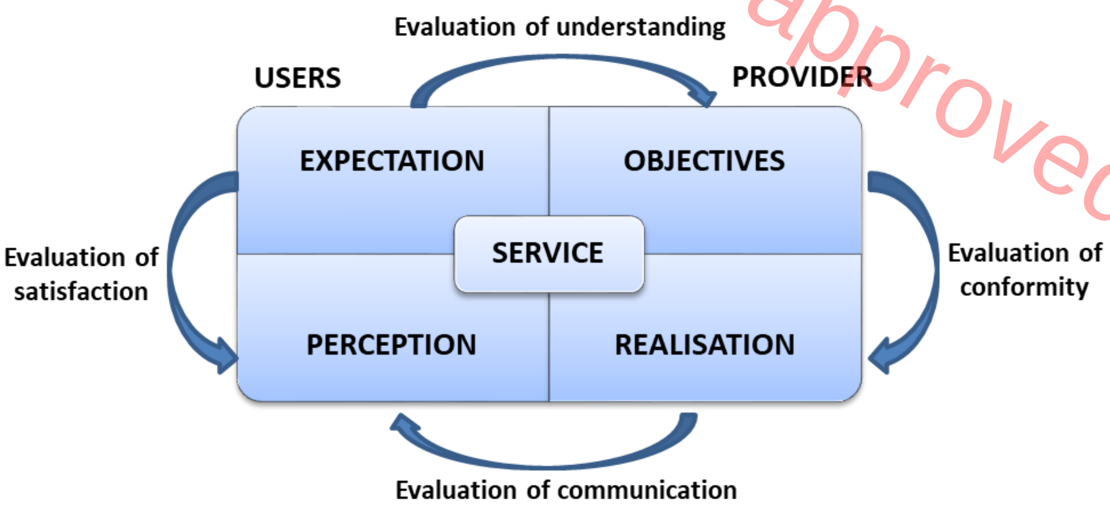


Figure 2. The evaluation process of a given service
Source: (Labriga & Mira-Bonnardel, 2018).

As shown on Figure 2, the evaluation process of any given service should be able to provide:

- **Understanding assessment:** to what extent did the service provider understand users' expectations and succeeded in specifying an adapted service;
- **Conformity assessment:** the difference between the objectives identified by the provider by KPIs and the realization either measured by sensors and other objective indicators;
- **Communication assessment:** to what extent do users perceive and understand the range of proposed services.
- **Satisfaction assessment:** to what extent do users estimate that the service is answering to their expectations

Over the next subsections, the evaluation categories are presented with the proposed KPIs to be assessed. The main evaluation points are divided into a set of KPIs which together aim at providing a comprehensive view of the category. It is worth noting that the categories have been presented and validated by all four PTOs during AVENUE's general meeting discussions.

Furthermore, it is worth noting that data sources and the respective data collection can vary from site to site and project to project, being subjected to availability, confidentiality as well as and unforeseen events (e.g., halt of services due to the COVID pandemic). Ideally, data should be collected at multiple intervals (start, middle, end of the projects) to allow for a historic evaluation, thus showing the KPIs' evolution over time. However, constraints and delays may hinder such a process, thus data collection shall be adapted accordingly.

In the same way as proposed by (McDonald, Site, Stam, & Saucci, 2018), the present evaluation framework may be comparative or absolute. As stated by the authors, comparative evaluations would include factors such as a modal change from car to public transport, induced by an enhanced attractiveness in one or more elements of the new automated service. Factors such as vehicle reliability or the interactions between automated vehicles and pedestrians are unique to the new system, although some comparisons can be made with more conventional existing systems. Evaluation results may also be compared between demonstrations, so as to add a richness of understanding from the range of application contexts.

2.1 Category 1: Operating site features

A brief but complete description of the operating site is a piece of crucial information to contextualize and dimension the service with automated vehicles for public transport. Thus, we have chosen to include this data as an initial category in the evaluation framework to provide a basis for analyzing the other categories.

Table 2 presents the overall proposition for the summary features of the operating sites, illustrated with hypothetical data to detail possible answers to each criterion. We highlight that this analysis can be done in different stages throughout the project (e.g., ex-ante and ex-post; yearly; etc.) to show any possible changes and evolution in the operating site plans.

Table 2. Summary of operating sites

	Operator A		**Operator n**	
	Site A	**Site B**	**Site n**	**Site n+1**
Funding	EU	EU + Operator A		
Start date of project	01.08.2017	01.05.2018		
Start date of site's demonstration	02.07.2018	01.07.2020		
End date of site's demonstration	31.01.2021	ongoing		
Type of route	Fixed circular line	Area		
Level of on-demand service*	Level 1	Level 2		
Routh length	2.1 km	38 hectares		
Road environment	Open road	Semi-private		
Type of traffic	Dedicated traffic	Mixed traffic		
Speed limit	30 km/h	30 km/h		
Roundabouts	No	Yes		
Traffic lights	No	Yes		
Type of service	Traditional bus line	On-demand		
Number of stops	4	>70		
Bus stop infrastructure	Yes	No		
Number of vehicles	2	4		
Timetable	Fixed	On-demand		
Operating days	Monday-Friday (5 days)	Sunday-Saturday (7 days)		
Timeframe weekdays	06h30-08h30 / 16h00-18h30	06h00-19h00		
Timeframe weekends	No service	06h00-19h00		
Depot distance from site	400 m	On site		
Driverless service (Absence of safety driver)	No	Yes		

* *As proposed by* (Antonialli, 2021) *, p.11.*

Source: prepared by the authors

As can be seen, Table 2, although concise, brings key elements for a good contextualization of the service to be implemented in the testing site. However, some minor clarifications are important:

For the type of route, it is important to explain if it is a fixed looped line (like a traditional bus or a metro), if it is a semi-fixed one (allowing some minor route deviations to pickup or drop-off passengers) or if the route is an open geo-fenced area where the vehicles can move freely to according to passengers' demand. This also goes for the level of on-demand service; (Antonialli, 2021) has proposed a typology for on-demand service on public transport (Figure 3), which can be used to increase precision of this criterion.

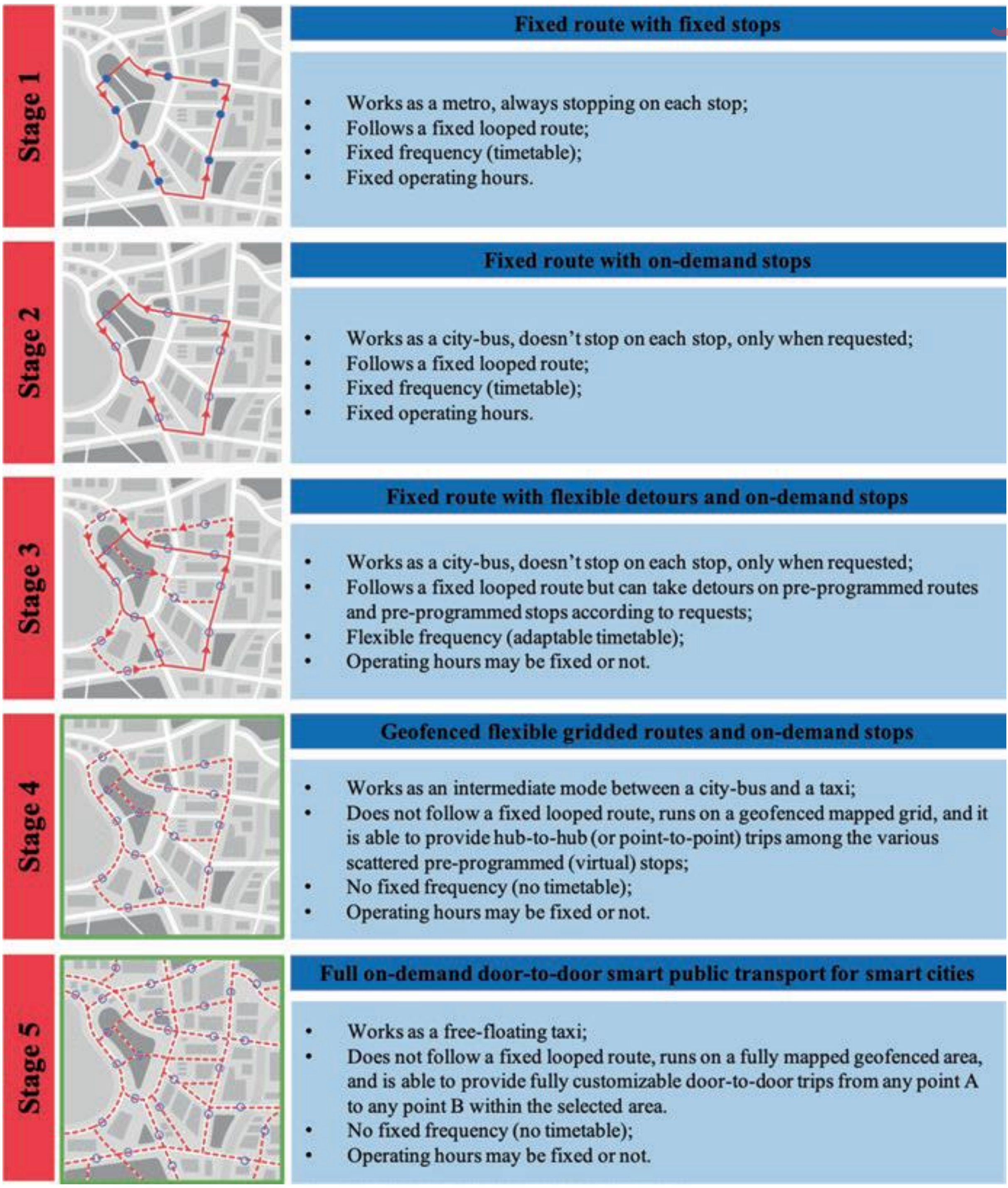


Figure 3. Levels of on-demand service for public transport
Source: (Antonialli, 2021), p.11.

For the road type and type of traffic, it is worth explaining if it is an open or closed road (that is with or without other vehicles) as well as explaining if it is a public or private site. This type of information is important because it will help dictate the needed level of automation in the vehicle as well as the level of infrastructure investment for the service deployment. It is also important to specify if there are roundabouts and/or traffic lights in the operating site, because if yes, Vehicle-to-Infrastructure (V2I) adaptations can be carried out to give priority to the automated vehicles on such crossing points, thus, impacting the investment costs as well. The same goes for the existence of bus stop infrastructure, if the operating sites require the installation of real bus stops with signs, shelter, etc., this will also elevate the investment costs.

At last, it is important to specify whether an onboard safety driver is needed or not, of course, this will also depend on the local legislation, but the presence of safety drivers is a key variable in the service's operating cost. Because one safety operator is needed for one vehicle but one safety operator in an office can remotely monitor several autonomous vehicles and lower the personal costs per vehicle.

2.2 Category 2: Automated vehicle performance

This second category is more technical and oriented towards the evaluation of the vehicle's operational performance. The objective here is not to criticize the quality of the vehicle and/or its manufacturer, but to show the points that may require more technical attention to improve the overall performance of the automated driving systems and consequently the service provided. Table 3 details the main evaluation points for this category and their respective KPIs.

Table 3. Automated vehicle performance assessment

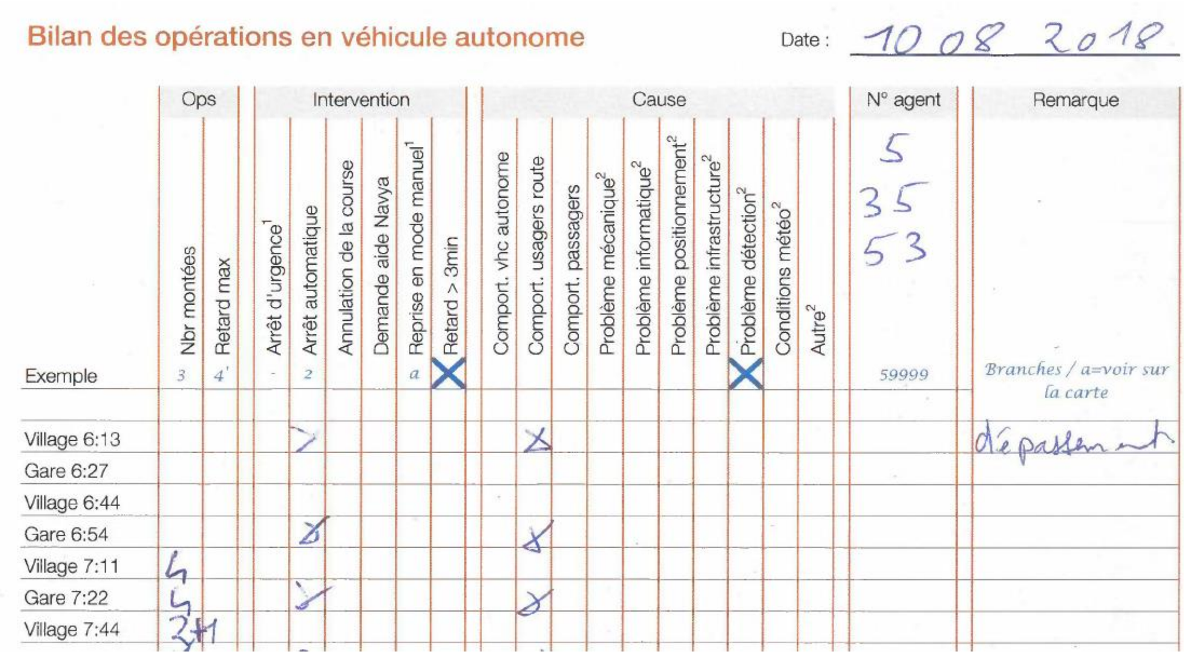
Evaluation criteria	KPIs	Evaluation	
		Year 1	Year n
Vehicle's safety and security	Number of operating days		
	Number of emergency stops		
	Number of automatic stops due to obstacles		
	Number of obstacle detections		
	Number of harsh breaks		
	Number of out of path deviations		
	Number of manual takeovers		
	Number of mis- or dis-communication with other road users		
	Number of instances where other road-drivers abused the safety-first mechanisms in AVs		
	Number of mechanical/sensor failures		
	Number of down time hours due to maintenance or other issues		
	Number of requests for help from OEM		
	Number of crashes/accidents		
	Number of other minor incidents		
Vehicle's energy consumption	Battery autonomy (kW.h/km)		
	Battery charging time (hours)		
Vehicle's comfort and accessibility	Frequency of cleaning (times per week)		
	Temperature control – heating and AC (yes/no)		
	Presence of a wheelchair ramp (yes/no)		
	Presence of a SOS button (yes/no)		
	Audio-visual display of information (yes/no/partially)		

	Presence of in-vehicle wi-fi (yes/no)		
	Presence of in-vehicle infotainment system (yes/no)		

Source: prepared by the authors

Data collection for this category normally may come from two sources: the vehicle manufacturer itself (via its integrated API) or the transport operator in charge of the demonstration. It should be noted here that some of the KPIs listed above contain sensitive information that may be considered strategic to the manufacturer and/or operator. Thus, data may not be available (or disclosed) for all the indicators. The availability and publishing of this data should be discussed internally in the project among the stakeholders involved.

As for the AVENUE operating sites, each PTO has deployed its own mechanism to assess such performance. In Geneva and Luxembourg, TPG and Sales-Lentz have given each of its on-board safety drivers a formulary to be filled in with their findings and interventions during every service (see TPG's example in Figure 4). In Copenhagen and Lyon, HOLO and Keolis have chosen a more digitalized approach. Holo has created a mobile application for the safety drivers to fill in, as well as an operation dashboard that is based on inputs from both the safety drivers' app and Navya's API (see Figure 5). Sales-Lentz uses the app since May 2022 in Esch and Contern. Keolis has also developed an online application to be accessed via a tablet, where the safety drivers could log their daily operational reports.



Bilan des opérations en véhicule autonome

Date : 10 08 2018

N° agent : 5, 35, 53

	Ops		Intervention						Cause										N° agent	Remarque
	Nbr montées	Retard max	Arrêt d'urgence[1]	Arrêt automatique	Annulation de la course	Demande aide Navya	Reprise en mode manuel[1]	Retard > 3min	Comport. vhc autonome	Comport. usagers route	Comport. passagers	Problème mécanique[2]	Problème informatique[2]	Problème positionnement[2]	Problème infrastructure[2]	Problème détection[2]	Conditions météo[2]	Autre[2]		
Exemple	3	4'	-	2			a	X								X			59999	Branches / a=voir sur la carte
Village 6:13				✓						X										dépassement
Gare 6:27																				
Village 6:44																				
Gare 6:54				✓						✓										
Village 7:11	4																			
Gare 7:22	4			✓						✓										
Village 7:44	3+1																			

Figure 4. TPG's form for vehicle's performance assessment
Source: (Beukers & Vlajki, 2021)

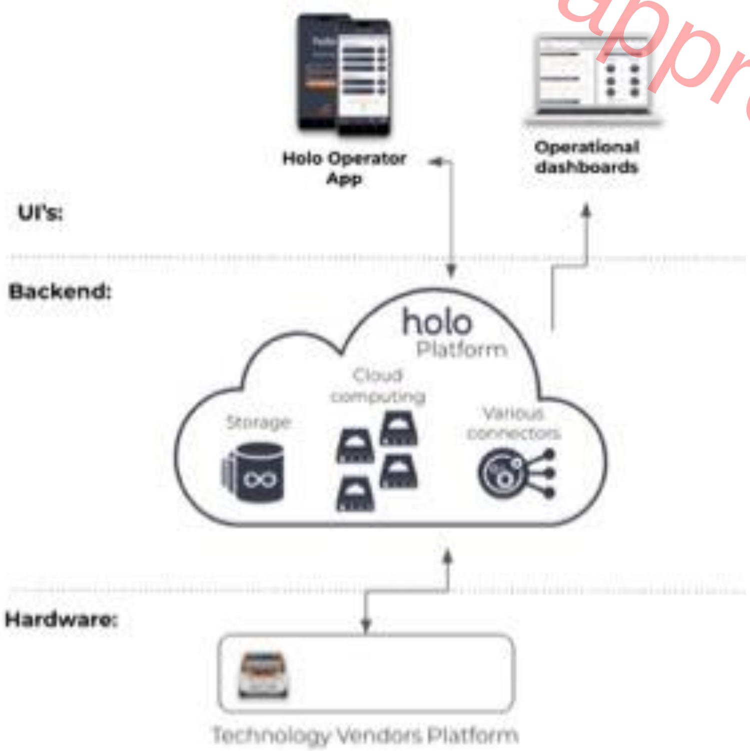


Figure 5. Holo's operational dashboard architecture
Source: (Zinckernagel, 2021)

At last, it is worth noting that the forms and dashboards put in place by the AVENUE project's operators, contain KPIs that fit not only on this second category but are also useful for assessing the overall quality and performance of the service, which is the next category of this evaluation framework.

2.3 Category 3: Service performance

This category entails the assessment of the overall quality and performance of the transportation service itself on each operating site, as well as key surrounding aspects of the service, such as its safety and security, comfort and accessibility, and economics. KPIs are presented in Table 4.

Table 4. Transportation service performance assessment

Evaluation criteria	**KPIs** *(Specify if the data provided is for a single shuttle or for the entire fleet)*	**Evaluation**	
		Year 1	Year n
Transportation service	Average operating speed (km/h)		
	Average number of trips (day)		
	Total number of trips (year)		
	Average distance traveled (km/day)		
	Total distance traveled (km/year)		
	Average distance traveled by autonomous driving (km/day)		
	Total distance traveled by autonomous driving (km/year)		
	Average distance traveled by manual driving (km/day)		
	Total distance traveled by manual driving (km/year)		
	Average detour time (min) *– for on-demand service*		
	Average waiting time (min) *– for on-demand service*		
	Average occupancy rate (passengers/day)		

	Total number of passengers (passengers/year)		
Service's safety and security	Presence of on-board safety-driver (yes/no/partially)		
	Presence of off-board supervision (yes/no/partially)		
	Shuttle surveillance system (yes/no/partially)		
	Site surveillance system (yes/no/partially)		
Service's comfort and accessibility	Accessibility to people with reduced mobility (yes/no/partially)		
	Integration to the city transport network (yes/no/partially)		
	Timetables at the stops/stations (yes/no/partially)		
	Timetables online (yes/no/partially)		
	Availability of on-line application (yes/no/partially)		
	Integration of route-planning apps (yes/no/partially)		
Economics	Total yearly capital expenditures – CAPEX (euros)		
	Total yearly operating expenditures – OPEX (euros)		
	Total yearly revenues (euros or % of OPEX coverage)		
	Cost per shuttle/km (euros/year)		
	Cost per passenger/km (euros/year)		

Source: prepared by the authors

For the first three evaluation criteria presented in Table 4: i) the transportation service itself, ii) service's safety and security, as well as iii) service's comfort and accessibility; most of the data should come from the PTO itself with any complementary information to be provided by the vehicle's manufacturer via its API.

For the economics criteria, the goal is to analyze the viability of deploying the autonomous transport service when compared to its traditional human-driven counterparts. PTOs are free to use their own calculation modes and metrics, however, we highlight that within AVENUE WP8, a simulation tool (EASI-AV©) has been developed to assist decision-makers in calculating the economic feasibility of implementing services with automated vehicles when compared to traditional collective urban transport modes. The EASI-AV© simulation tool is free of charge and can be accessed on the AVENUE project website (see Figure 6). Guidelines on its utilization can be found on (Antonialli, Mira-Bonnardel, & Bulteau, 2021) as well as on the D8.4 – Second Iteration Economic Impact (Antonialli, et al., D8.4 Second Iteration Economic Impact, 2021).

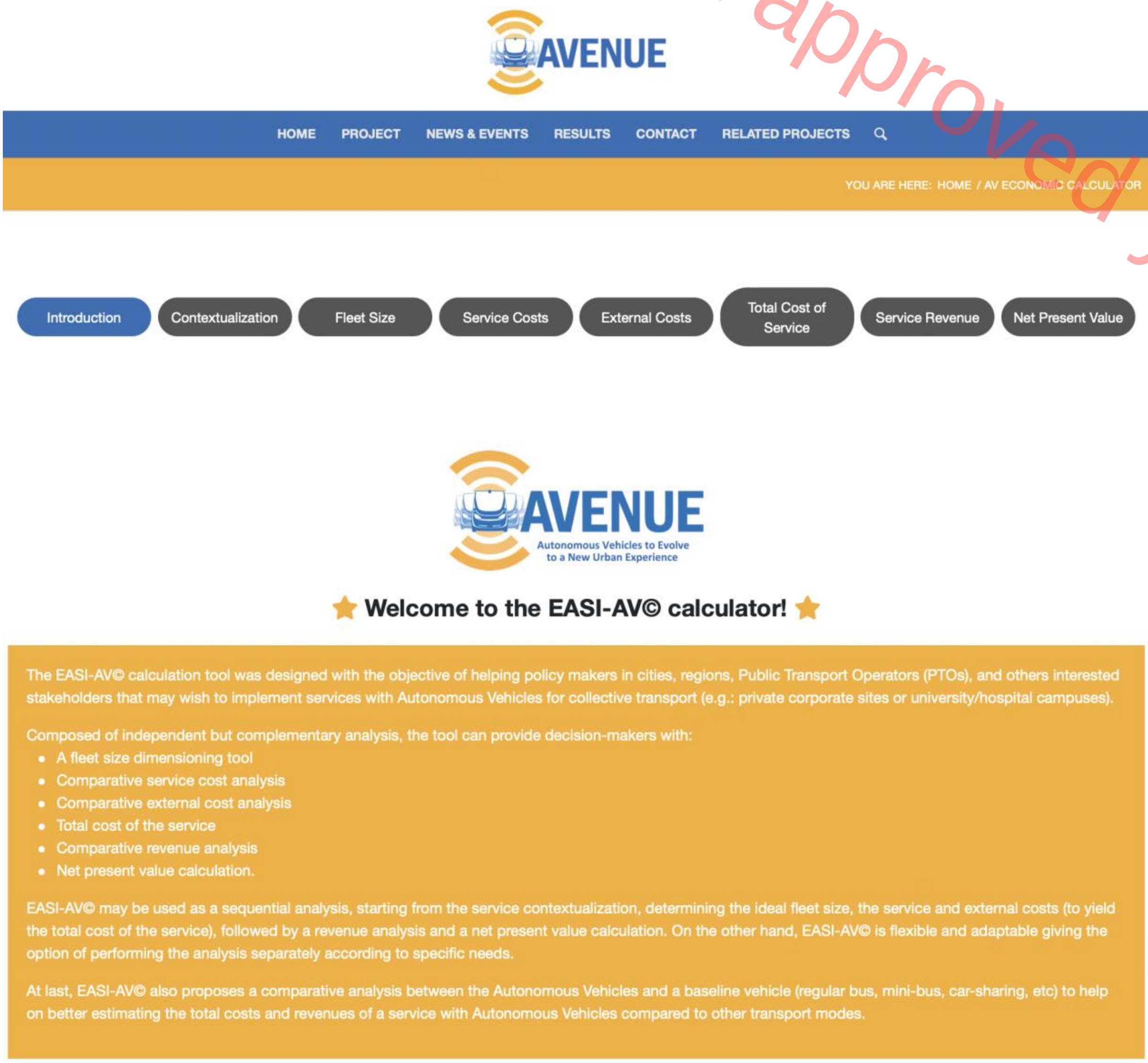


Figure 6. EASI-AV calculation tool
Source: https://h2020-avenue.eu/avenue-economic-calculator/

At last, it is worth recapping that the suggested metrics for each KPI presented in Table 4 (e.g.: km/h; km/day; passengers/day; yes/no/partially, etc.) can be adapted according to the service's requirements, and the same goes for the data collection interval which can also be adjusted according to the project's needs. Over the next subsection, the final category of this evaluation framework is presented.

2.4 Category 4: Users' perceptions and satisfaction, toward the vehicle and service

A crucial part of evaluating projects with automated shuttles for collective transport is gathering users' feedback regarding both the automated vehicles and the provided service. This category aims to evaluate the users' level of feedback (their perceptions, satisfaction, and attractiveness toward both vehicle and service), and it relates to Task.

8.3 – Social impact evaluation (Korbee, Naderer, & Nemoto, 2019), and Task 2.2 – Passenger needs, including People with Reduced Mobility – PRM (Dubielzig, Mathé, Lindemann, & Labriga, 2019). The main evaluation points to be measured are listed in Table 5.

Table 5. Assessment of users' perceptions and satisfaction toward the vehicle and service

Evaluation criteria	KPIs *(Specify if the data provided is for a single shuttle or for the entire fleet)*	Evaluation	
		Year 1	Year n
Users' retention	Frequency of use of the service (times per week)		
	Intention to use the service again (5-point scale)		
Satisfaction with the automated vehicle	Comfort in the vehicle (5-point scale)* ** This KPI can be the result of average scores of several items (e.g.: cleanliness, temperature, noise level, interior lighting, internal space, seats, handles, ramps for PRM, audiovisual information, etc.).*		
	Feeling of safety and security in the vehicle (5-point scale)* ** This KPI can be the result of average scores of several items (e.g.: presence of surveillance system, presence of on-board operator, presence of seatbelts, presence of handles, etc.).*		
	General satisfaction with the ride (5-point scale)		
Satisfaction with the service	Reliability of the service (5-point scale)		
	Punctuality of the service (5-point scale)		
	Efficiency and effectiveness of the service (5-point scale)* ** This KPI can be the result of average scores of several items (e.g.: waiting time, speed, frequency).*		
	Location of the operating site (5-point scale)		
	Location of the stops/stations (5-point scale)		
	Willingness to pay (in euros)		
	Importance of additional services (5-point scale)		
Other road users' perceptions	Road system usage safety: Are other road-user perceiving the automated minibus service as threatening (yes/no) or (5-point scale)		
	Road system usage efficiency: Are other road-user perceiving the automated minibus service as slowing down traffic (yes/no) or (5-point scale)		
	Are other road-user perceiving the automated minibus service as causing any other problems or inconveniences (yes/no) if yes: what are they?		

Source: prepared by the authors

This category has been widely discussed in the academic literature (Nordhoff, et al., 2018), (Feys, Rombaut, & Vanhaverbeke, 2020) (Mouratidis & Serrano, 2021), (Piatkowski, 2021), (Bellone, et al., 2021), among others, have studied the users' perceptions, acceptance and willingness to use services with automated vehicles for public transport, thus, the KPIs, data collection methods and data treatment techniques are quite diverse. Meaning that our proposal from Table 5 is not exhaustive, but rather a generic guideline on the main criteria and KPIs to be considered while assessing users' perceptions.

It is also important to note that the availability of the data is subject to the users' willingness to take part in the surveys and interviews. Which in turn, must be very well written and validated through pre-tests to avoid bias in the answers and indirect influence of the investigators.

In the AVENUE project, the work related to this category was mainly carried out within WP8, with a combination of longitudinal, representative and user surveys.

3 AVENUE project operating sites assessment

In the following subsections, we sought to apply each category from our evaluation framework to the AVENUE project sites. However, we do emphasize beforehand that not all KPIs proposed for the categories could be evaluated, due to several external factors, such as 1) lack of homogeneous data for all sites; 2) service interruptions due to the COVID pandemic (which directly affected all project sites); 3) legal and regulatory barriers to start demonstrations which delayed and hampered the start of services – especially in Copenhagen, for further details see: D7.7 (Zinckernagel, Guldmann, Lytzen, & Simonsen, 2019), D7.8 (Zinckernagel, 2021), and (Konstantas, 2021); 4) data confidentiality restrictions; among other limiting factors.

3.1 Category 1: AVENUE Operating sites summary

TPG: Geneva, Switzerland

AVENUE operations in Geneva, Switzerland, were led by TPG (Transports Publics Genevois) that operated two pilot sites within the project's scope: the XA-Line in the community of Meyrin, and the Belle-Idée site in the community of Thonêx. Both test sites are in the Canton of Geneva. Further details on each site's description, constitution, operations, and constraints can be found on (Beukers & Vlajki, 2021). Table 6, presents the summary of TPG's test sites for the project.

Table 6. Summary of TPG's operating sites in Geneva, Switzerland

	XA-Line (Meyrin)	Belle-Idée (Thônex)
Funding	TPG	EU + TPG
Start date of project	01.08.2017	01.05.2018
Start date of site's demonstration	02.07.2018	01.07.2020
End date of site's demonstration	31.01.2021	Ongoing[1]
Type of route	Fixed circular line	On-demand
Level of on-demand service	Level 1	Level 4
Routh length	2.1 km	38 hectares
Road environment	Open road	Open road (semi-private)
Type of traffic	Mixed traffic	Mixed traffic
Speed limit	30 km/h	30 km/h
Roundabouts	Yes (between track and depot)	Yes
Traffic lights	No	No
Type of service	Traditional bus line	On-demand
Number of stops	4	75
Bus stop infrastructure	Yes	5 regular bus stops, 70 virtual ones
Number of vehicles	1	3-4
Timetable	Fixed	On-demand
Operating days	Monday-Friday	Sunday-Saturday

	(5 days)	(7 days)
Timeframe weekdays	06h30-08h30 / 16h00-18h30	06h00-19h00
Timeframe weekends	No service	06h00-19h00
Depot distance from site	400 m	On site
Driverless service (Absence of safety driver)	No	Yes (end of 2021)

[1] *Demonstration was still running by the time this deliverable was written.*
* *As proposed by* (Antonialli, 2021) *, p.11.*
Source: adapted from (Beukers & Vlajki, 2021)

Keolis Lyon: Décines, France

In the metropolitan region of Lyon, the demonstration was led by Keolis Lyon which ran one pilot site in the city of Décines, in the region know as Parc OL next to Groupama stadium. Further details on the so-called Line N1 can be found in (Zuttre, 2021). Table 7, presents the summary of Keolis' operating site.

Table 7. Summary of Keolis' operating site in metro-Lyon, France

	Parc OL (Line N1)
Funding	EU + Keolis Lyon + Sytral
Start date of project	01.06.2018
Start date of site's demonstration	15.11.2019
End date of site's demonstration	01.09.2020
Type of route	Fixed circular line
Level of on-demand service	Level 1
Routh length	2.6 km
Road environment	Open road
Type of traffic	Mixed traffic
Speed limit	30 km/h
Roundabouts	Yes (two in total)
Traffic lights	Yes (four in total)
Type of service	Traditional bus line
Number of stops	2
Bus stop infrastructure	Yes
Number of vehicles	2
Timetable	Fixed
Operating days	Monday-Saturday (6 days)
Timeframe weekdays	06h30-08h30 / 16h00-18h30
Timeframe weekends	06h30-08h30 / 16h00-18h30
Depot distance from site	On site (Groupama Stadium Parking)
Driverless service (Absence of safety driver)	No

Source: adapted from (Zuttre, 2021)

Holo: Copenhagen & Slagelse, Denmark, and Ormøya, Norway

In the Scandinavian region, Holo (former Amobility) set to run three test sites within the AVENUE project, two in Denmark (Nordhavn and Slagelse) and one in Norway (Oslo). As explained by (Zinckernagel, 2021), the Ormøya route was originally initiated without being a part of AVENUE, but an agreement has been made to include the site. The Norwegian site ended in December 2020, and the new Danish site in Slagelse

Hospital was set to begin in September 2021, with focus on on-demand services. The summary of Holo's operating sites is depicted on Table 8.

Table 8. Summary of Holo's operating sites in Scandinavia

	Nordhavn site	Ormøya site (Norway)	Slagelse site
Funding	EU + Holo	EU + Holo + Ruter	EU + Holo + Movia
Start date of project	May 2017	August 2019	August 2019
Start date of site's demonstration	September 2020	December 2019	August 2021
End date of site's demonstration	Ongoing[1]	September 2020	Ongoing[1]
Type of route	Fixed circular line	Fixed circular line	Fixed circular line
Level of on-demand service	Level 1	Level 1	Level 2
Routh length	2.6 km	1.6 km	5.0 km
Road environment	Open road	Open road	Open road
Type of traffic	Mixed traffic	Mixed traffic	Mixed traffic
Speed limit	30 km/h	30 km/h	30 km/h
Roundabouts	No	No	No
Traffic lights	No	No	No
Type of service	Traditional bus line	Traditional bus line	On-demand service
Number of stops	6	6	6
Bus stop infrastructure	Yes	Yes	Yes
Number of vehicles	1	2	2
Timetable	Fixed	Fixed	On-demand
Operating days	Monday-Friday (5 days)	Monday-Sunday (7 days)	Monday-Friday (5 days)
Timeframe weekdays	10:00-18:00	7:30-21:30	07:00-18:00
Timeframe weekends	No service	9:00-18:00	Only for special events
Depot distance from site	800 m	200 m	200 m
Driverless service (Absence of safety driver)	No	No	No

[1] *Demonstration was still running by the time this deliverable was written.*

Source: adapted from (Zinckernagel, 2021)

Sales-Lentz: Pfaffenthal, Contern & Esch-sur-Alzette, Luxembourg

As summarized in Table 9, within the AVENUE framework, Sales-Lentz has been set to run two demonstrator sites (Pfaffenthal and Contern), and later on, one replicator site (Esch-sur-Alzette). Details on each site's operations are available at (Marrafa & de Vera, 2021).

Table 9. Summary of Sales-Lentz's operating sites in Luxembourg

	Pfaffenthal site	Contern site	Esch site
Funding	EU + Sales-Lentz	EU + Sales-Lentz	EU + Sales-Lentz + Ville d'Esch
Start date of project	01.07.2018	01.07.2018	01.02.2021
Start date of site's demonstration	19.09.2018 restart: 04.04.2022	19.09.2018 Restart expected for August 2022	September 2021
End date of site's demonstration	31/08/2020 ongoing since restart	01.01.2020	Ongoing[1]
Type of route	Fixed circular line	Fixed circular line	Fixed circular line

Level of on-demand service	Level 1	Level 1	Level 1
Routh length	2.1 km	3.0 km	1.0 km
Road environment	Open road	Open road	Open road / Pedestrian zone
Type of traffic	Mixed traffic	Mixed traffic	Mixed traffic
Speed limit	50 km/h	50 km/h	20 km/h
Roundabouts	No	No	No
Traffic lights	No	No	No
Type of service	Traditional bus line	Traditional bus line	Traditional bus line / on demand
Number of stops	4	2	3
Bus stop infrastructure	Yes	Yes	Yes
Number of vehicles	2	1	1
Timetable	Fixed	Fixed	Fixed / On-demand
Operating days	Tuesday, Thursday & weekends (4 days)	Monday-Friday (5 days)	Monday – Saturday (6 days)
Timeframe weekdays	12:00-16:00 16:45-20:00	7:00-09:00 16:00-19:00	11:00 – 18:00
Timeframe weekends	10:00-21:00	No service	11.00 – 18:00
Depot distance from site	On site	On site	500m away
Driverless service (Absence of safety driver)	No	No	no

[1] *Demonstration was still running by the time this deliverable was written.*

Source: adapted from (Marrafa & de Vera, 2021)

Car Postal: Sion, Switzerland

By the time this deliverable was written, data regarding the replicator site of Sion (Switzerland) had not yet been made available by the transport operator.

3.2 Category 2: AVENUE automated vehicles performance

For this category, not all KPIs could be evaluated, partly due to data confidentiality, and partially due to lack of data for shuttles at the operating sites. Thus, the results presented are based on the data that were available and whose dissemination has been authorized by both the PTOs and the shuttle manufacturer (Navya).

The data sources for this category were primarily provided by Navya from the period of April 2018 to October 2021 for the sites of: Belle Idée (PTG, Geneva); Parc OL (Keolis, Lyon); Holo (Nordhavn, Denmark and Ormøya, Sweden), and Sales-Lentz (Pfaffenthal, Luxembourg). At the time of writing this deliverable, data for the remaining project sites had not yet been made available (or were in raw larger formats and could not be processed in time). Among the KPIs suggested in Table 3, Navya provided us with the following:

- Number of operating days
- Number of emergency stops
- Number of obstacle detections
- Number of automatic stops due to obstacles

- Number of manual takeovers
- Number of out of path deviations

Some data for other KPIs in this category were obtained from the deliverables already published by the PTOs, available on the ISI AVENUE platform.

Belle Idée – TPG: Geneva, Switzerland

For the Belle Idée site, the data provided by Navya concerned the test period (without passengers) for the on-demand service. This testing lasted 35 days during the months of July (16 days) and August (19) in 2020.

During this period, no emergency stops (emergency press button) were recorded. The shuttle's sensors detected a total of 4510 obstacles during the 35-day test, of which it stopped moving 358 times. In percentage terms, for every 100 obstacles detected the shuttle stopped an average of 7.79% of the time. As for manual takeover during the driving, the daily average for July 2020 was 58 times, and it went down to 54 times in August. A similar reduction was noted for out-of-path deviations, moving from a daily average of 19 times in July 2020 to 16 times in August. Table 10 gives an analytical overview of these KPIs.

Table 10. Belle Idée shuttle performance - analytical overview

Year	**Month**	**Operating days**	**Emergency stops**	**Detected obstacles**	**Automatic stops**	**Manual takeovers**	**Out-of-path deviations**
2020	July	16	0	1954	133	925	302
		Normalized values	0	122	8	58	19
	August	19	0	2556	225	1025	297
		Normalized values	0	135	12	54	16
Sum	**2 months**	**35**	**0**	**4510**	**358**	**1950**	**599**
		Normalized values	**0**	**129**	**10**	**56**	**17**

Source: prepared by the authors based on Navya's data

It is worth noting that due to the short time span of the database for the Belle Idée site, no long-term inferences can be made on the performance of these indicators, hence a more comprehensive database is needed. At last, regarding Meyrin's testing site, the available data site provided did not contain vehicle data for the testing site. Thus, results could not be presented in this deliverable.

Parc OL – Keolis: Lyon, France

In Lyon, the data provided refers to 134 days of operations over 10 months between July 2019 and September 2020, resulting in an average of 13 days of service per month. During this period, only two emergency stops have been recorded. Table 11, brings an analytical overview of these KPIs.

Table 11. Parc OL shuttle performance - analytical overview

Year	Month	Operating days	Emergency stops	Detected obstacles	Automatic stops	Manual takeovers	Out-of-path deviations
2019	July	9	0	995	61	551	219
		Normalized values	0	111	7	61	24
	August	11	1	1404	46	305	244
		Normalized values	0	128	4	28	22
	November	22	0	5200	360	2298	772
		Normalized values	0	236	16	104	35
	December	20	0	2803	210	2325	595
		Normalized values	0	140	11	116	30
2020	January	26	0	7024	334	4347	902
		Normalized values	0	270,2	12,8	167,2	34,7
	February	25	0	4677	253	4490	1056
		Normalized values	0	187	10	180	42
	March	12	1	804	38	908	281
		Normalized values	0	67	3	76	23
	July	3	0	234	13	113	91
		Normalized values	0	78	4	38	30
	August	5	0	273	9	118	233
		Normalized values	0	55	2	24	47
	September	1	0	0	0	0	0
		Normalized values	0	0	0	0	0
Sum	**10 months**	**134**	**2**	**23414**	**1324**	**15455**	**4393**
		Normalized values	**0**	**175**	**10**	**115**	**33**

Source: prepared by the authors based on Navya's data

A total of 23414 obstacles have been detected, yielding in 1324 full stops of the vehicle, that is, at every 100 obstacles detected the shuttle fully stopped 5.65% of the time. Manual takeovers averaged at 115 times per day while out-of-path deviations averaged 33 times.

Figure 7 summarizes these KPIs' evolution over time for Lyon's site, from which the COVID impacts can be clearly observed from March 2020 onwards – the month which the official lockdown has started in the country.

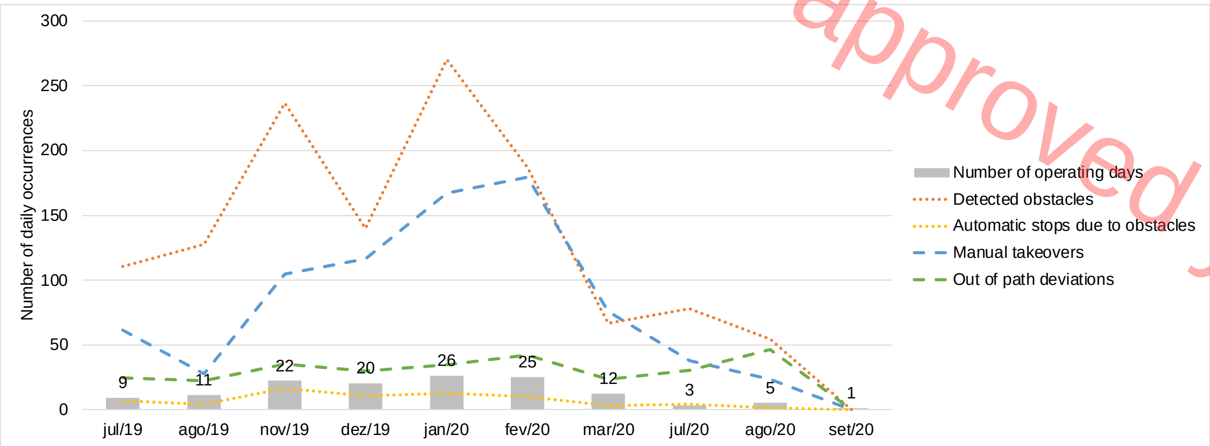


Figure 7. Parc OL shuttle performance overtime
Source: prepared by the authors based on Navya's data

Nordhavn – Holo: Copenhagen, Denmark

Similarly, to the Belle Idée site, Navya's available database for Nordhvan comprised only few months of entries. There were in total 27 days of registered operations, being 5 in July 2020, 21 in August, and a single day in September. Emergency stop data was not available for this dataset.

As observed in Table 12, for the total of 202 detected obstacles by the shuttles' sensors, there were only 6 automatic stops (2.97%). The daily average of manual takeovers was 36, being highest in the month of August (862 total, 41 daily avg.), justified by the number of operation days, notably higher in August than in the other two months. The number of out of path deviations followed accordingly, with a daily average of 31, and the highest values being registered in August (862 total, 41 daily average).

Table 12. Nordhavn shuttle performance - analytical overview

Year	Month	Operating days	Emergency stops	Detected obstacles	Automatic stops	Manual takeovers	Out-of-path deviations
2020	July	5	0	777	35	103	97
		Normalized values	0	155	7	21	19
	August	21	0	4588	118	862	723
		Normalized values	0	218	6	41	34
	September	1	0	76	1	20	19
		Normalized values	0	76	1	20	19
Sum	**3 months**	**27**	**0**	**5441**	**154**	**985**	**839**
		Normalized values	**0**	**202**	**6**	**36**	**31**

Source: prepared by the authors based on Navya's data

Ormøya – Holo: Oslo, Sweden

The Swedish site of Ormøya operated for 10 months (just as Lyon's site). The registered dataset contains entries of 189 operating days between December 2019 and September 2020. Emergency stops have not been registered for this dataset. As for the detected obstacles, the daily average for the whole operation was 118 times/day with an average of 6 full stops daily (6.8%). As for manual takeovers, the daily average was 95 times from which 41 times were caused by out-of-path deviations. Table 13, brings an analytical overview of these KPIs.

Table 13. Ormøya shuttle performance - analytical overview

Year	Month	Operating days	Emergency stops	Detected obstacles	Automatic stops	Manual takeovers	Out-of-path deviations
2019	December	6	0	1643	72	227	217
		Normalized values	0	274	12	38	36
2020	January	24	0	2814	243	2380	1402
		Normalized values	0	117	10	99	58
	February	29	0	4920	337	3608	1921
		Normalized values	0	170	12	124	66
	March	20	0	1619	171	1708	595
		Normalized values	0	81	9	85	30
	April	3	0	273	1	3	15
		Normalized values	0	91	0	1	5
	Mai	27	0	4486	76	4003	1159
		Normalized values	0	166	3	148	43
	June	23	0	1861	76	1199	480
		Normalized values	0	81	3	52	21
	July	28	0	1811	155	1935	504
		Normalized values	0	65	6	69	18
	August	28	0	1708	2	2200	1040
		Normalized values	0	61	0	79	37
	September	1	0	12	0	33	10
		Normalized values	0	12	0	33	10
Sum	**10 months**	**189**	**0**	**22252**	**1187**	**17992**	**7658**
		Normalized values	**0**	**118**	**6**	**95**	**41**

Source: prepared by the authors based on Navya's data

Figure 8 summarizes the KPIs' evolution overtime for Ormøya's site. With the lockdown imposition in Sweden in April, we can observe its immediate impact in the shuttles' daily operations. However, with governmental actions, the service was able to restart briefly regaining momentum from May 2020 onwards.

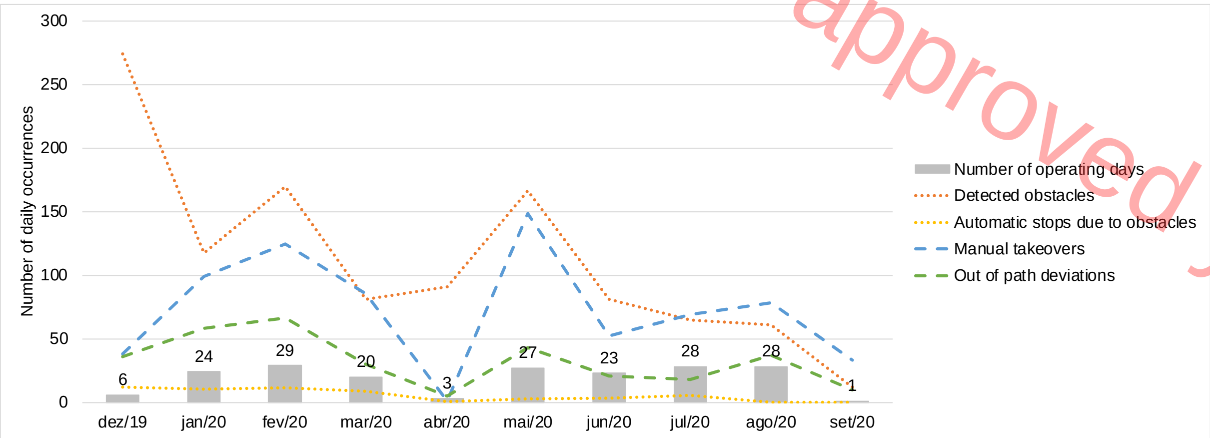


Figure 8. Ormøya shuttle performance overtime
Source: prepared by the authors based on Navya's data

At last, it is worth noting that by the time of writing this deliverable, no shuttle data was available for the replicator site of Slagelse.

Pfaffenthal – Sales-Lentz: Luxembourg city, Luxembourg

Regarding the sites operated by Sales-Lentz, the database contains, for the time being, only data for the Pfaffenthal site. Of all the sites present in the database, Pfaffenthal's experimentation was the longest, with a total of 269 registered days divided into 15 months from September 2018 to January 2020.

During the trial period, only four emergency stop requests were registered. The daily average of detected obstacles was 116, with an average of 8 full stops of the shuttle (6.9%). There has been an average of 96 daily manual takeovers, from which 35 were caused by out of path deviations. Table 14, brings an analytical overview of these KPIs.

Table 14. Pfaffenthal shuttle performance - analytical overview

Year	Month	Operating days	Emergency stops	Detected obstacles	Automatic stops	Manual takeovers	Out-of-path deviations
2018	September	14	0	525		1394	1210
		Normalized values	0	38	0	100	86
	October	21	0	1354		3033	2205
		Normalized values	0	64	0	144	105
	November	21	0	1889		4713	1189
		Normalized values	0	90	0	224	57
	December	17	1	763	39	1427	739
		Normalized values	0	45	2	84	43
2019	January	5	0	224	61	512	239
		Normalized values	0	45	12	102	48
	February	17	0	1352	130	991	243
		Normalized values	0	80	8	58	14

	March	21	0	2305	174	1165	290
		Normalized values	0	110	8	55	14
	April	20	0	1986	192	1337	409
		Normalized values	0	99	10	67	20
	May	19	0	1585	197	1581	294
		Normalized values	0	83	10	83	15
	June	23	1	2924	267	2805	483
		Normalized values	0	127	12	122	21
	July	20	1	1302	151	1578	609
		Normalized values	0	65	8	79	30
	August	21	0	2425	202	2246	1057
		Normalized values	0	115	10	107	50
	November	22	0	10087	400	1573	227
		Normalized values	0	459	18	72	10
	December	18	1	2325	234	1271	223
		Normalized values	0	129	13	71	12
2020	January	10	0	125	18	92	87
		Normalized values	0	13	2	9	9
Sum	**15 months**	**269**	**4**	**31171**	**2065**	**25718**	**9504**
		Normalized values	**0**	**116**	**8**	**96**	**35**

Source: prepared by the authors based on Navya's data

Figure 9 summarizes the KPIs' evolution over time for Pfaffenthal's site. Differently from some of the other AVENUE sites, the experimentations in Pfaffenthal ended in January 2020, thus prior to the lockdowns imposed by the pandemic. Thus, alongside Geneva's XA line in Meyrin, these were the only two test sites among all in the AVENUE project that were not affected by the pandemic. At last, Figure 9 shows a peak of detected obstacles in November 2019, which were the result of different factors, among those, obstacle detection tests carried out by the Sales-Lentz and Navya, which, as shown by the other indicators, have not impacted the overall performance of the shuttle.

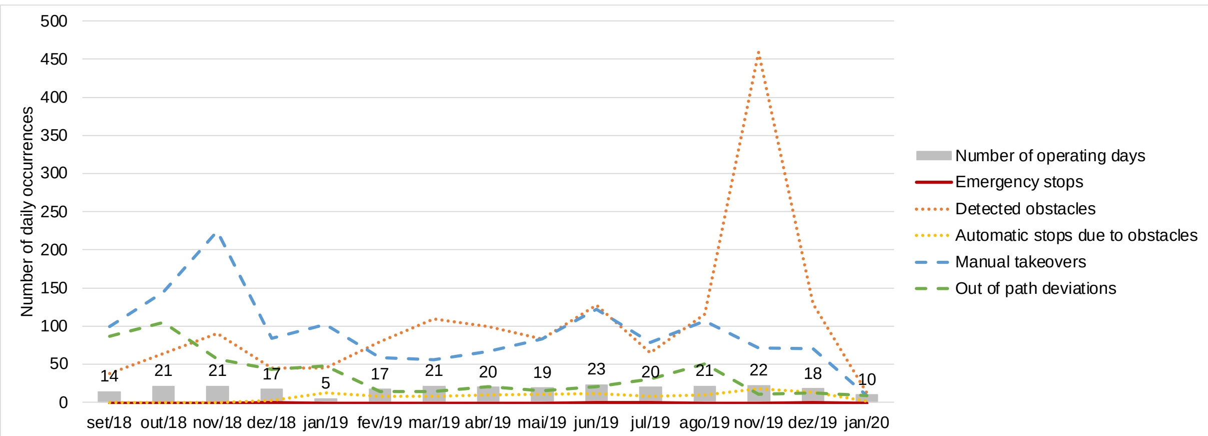


Figure 9. Pfaffenthal shuttle performance overtime
Source: prepared by the authors based on Navya's data

By the time of writing of this deliverable no data concerning the shuttles' performance had been made available for the testing site of Contern and the replicator site of Ecsh ville. The same can be side by the replicator site of Sion (Switzerland), where no data had been yet shared on these KPIs.

3.3 Category 3: AVENUE services performance

As for category 2, for the AVENUE services evaluation, not all KPIs could be assessed. Thus, the results presented here are based on the data available and which dissemination had been authorized by the PTOs.

Data sources for this category were primarily provided by each PTO and for each respective testing site, and they varied in quantity and format. That is, 1) some PTOs were able to provide most of the data for the KPIs suggested in Table 4, while others were not able to do it in time for this deliverable and/or didn't disclose the information, and 2) some PTOs provided data in a monthly basis, while others provided it on a yearly basis.

Table 15 summarizes the list of KPIs accessed from each operator by the time of writing of this deliverable.

Table 15. KPIs to assess the transportation services provided by the PTOs

KPI	PTO			
	Holo	TPG	Keolis	Sales-Lentz
Avg. operating speed	✓		✓	
Total number of trips		✓		
Avg. daily distance	✓			
Total distance travelled	✓	✓	✓	✓
Avg. daily distance on autonomous driving	✓			
Total distance on autonomous driving	✓		✓	
Avg. daily distance on manual driving	✓			
Total distance on manual driving	✓		✓	
Avg. daily occupancy rate	✓	✓		✓
Total number of passengers	✓	✓		✓

Source: prepared by the authors

By the time of writing, Holo was the operator which was able to provide the most data for the KPIs proposed in Table 4 – that is: besides their already published results from D7.8 (Zinckernagel, 2021). Thus, the analysis of this section starts with their testing sites, followed by TPG, Keolis, and Sales-Lentz. For the replicator site of Sion, Car Postal was not able to provide us with the data in time for the writing of this deliverable.

Nordhavn – Holo: Copenhagen, Denmark

The service demonstrations in Nordhavn were carried out with one Navya ARMA shuttle and lasted for six months (from August 2020 to February 2021). During this period a total of 1579 passengers were transported, and a total of 2446 km were driven (being 64% in autonomous mode and 36% in manual driving). Table 16 details the KPIs for the service. It is worth noting that the data provided was on a yearly basis.

Table 16. Nordhavn service performance - analytical overview

Year	Avg. operating speed (km/h)	Avg. daily distance (km)	Total distance travelled (km)	Avg. daily distance on autonomous driving (km)	Total distance on autonomous driving (km)	Avg. daily distance on manual driving (km)	Total distance on manual driving (km)	Avg. daily occupancy rate	Total number of passengers
2020	7,5	11,5	1757	8	1184	3,5	573	8	1225
2021	7,9	16	689	9	388	1	301	8	354

Source: prepared by the authors based on Holo's data

Ormøya – Holo: Oslo, Sweden

Demonstration in the Swedish site of Ormøya were the longest carried out by Holo during the AVENUE project, lasting the entire year of 2020. During the trials, two Navya ARMA shuttles were used, and a total of 6475 were transported in a total of 22412 km driven (being 91% in autonomous mode and 9% in manual driving). Table 17 details the KPIs for the service. It is worth noting that the data provided was on a yearly basis.

Table 17. Ormøya service performance - analytical overview

Year	Avg. operating speed (km/h)	Avg. daily distance (km)	Total distance travelled (km)	Avg. daily distance on autonomous driving (km)	Total distance on autonomous driving (km)	Avg. daily distance on manual driving (km)	Total distance on manual driving (km)	Avg. daily occupancy rate	Total number of passengers
2020	10,7	61	22412	56	20478	5	1934	17	6475

Source: prepared by the authors based on Holo's data

Slagelse – Holo, Denmark

The replicator site in Slagelse started its operations on September 2021, and is set to run until August 2022, thus by the time of writing, data was available for the months from September 2021 to March 2022 (six months), thus, not for the full 10 months of the demonstrations. The service follows a fixed route with on-demand stops, thus being different from the sites of Nordhavn and Ormøya that worked as a metro, following a fixed looped route, with the shuttle stops at each station (as explained in Figure 3).

As detailed in Table 18 from September 2021 to March 2022, the service has transported 748 passengers and driven 2172 km (being 94% in autonomous mode and 6% as manual drive).

Table 18. Slagelse service performance - analytical overview

Year	Avg. operating speed (km/h)	Avg. daily distance (km)	Total distance travelled (km)	Avg. daily distance on autonomous driving (km)	Total distance on autonomous driving (km)	Avg. daily distance on manual driving (km)	Total distance on manual driving (km)	Avg. daily occupancy rate	Total number of passengers
2020	7,3	20	1520	18	1433	1	87	7,5	577
2021	7,5	16	652	15	618	0,8	34	4	171

Source: prepared by the authors based on Holo's data

While certainly present, the impacts and disruptions caused by the pandemic were not detailed by the PTO in the data provided for the elaboration of this deliverable. More details on these issues will be provided in D7.9 to be delivered at the end of the project.

Regarding the qualitative evaluation categories proposed in Table 4: service's safety and security and service's comfort and accessibility, Holo has stated that an on-board safety driver was always present during the shuttle's operators, as well as an off-board supervisor. The shuttle was also equipped with a surveillance system and the testing site was partially surveilled as well. As for accessibility to people with reduced mobility, the shuttle was equipped with a wheelchair ramp. As for integration to the city transport network, the service had no direct links to it. As for the service timetables, they were partially available at the shuttle stops and online.

Meyrin – TPG: Geneva, Switzerland

The service in Meyrin ran from July 2018 until the end of January 2021, however, the available data provided by TPG regarded the full year of 2019 with monthly figures. The demonstrations were carried out using one Navya ARMA shuttle and for the operating year of 2019 transported a total of 1787 passengers and traveled over 3856 km. Table 19, and Figure 10 provide an overview of the service performance based on the available KPIs.

Table 19. Meyrin service performance - analytical overview

Year	Month	Total number of trips	Total distance traveled (km)	Avg. daily occupancy rate	Total number of passengers
2019	jan/19	329	348,9	6,04	151
	fev/19	60	63	4,42	106
	mar/19	210	220,5	7,85	204
	abr/19	266	279,3	5,92	142
	mai/19	440	462	5,66	164

	jun/19	352	369,9	5,71	137
	jul/19	228	239,4	4,78	110
	ago/19	401	421	5,67	119
	set/19	304	319,2	7,8	156
	out/19	376	394,8	7,26	167
	nov/19	327	343,3	8	168
	dez/19	376	394,8	7,76	163

Source: prepared by the authors based on TPG's data

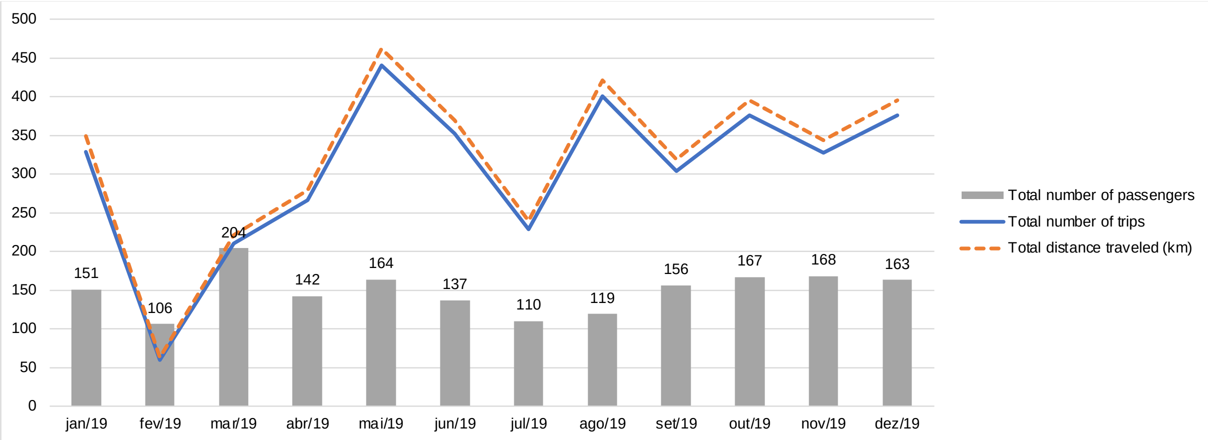


Figure 10. Meyrin service performance overtime
Source: prepared by the authors based on TPG's data

As for COVID since the trials in Meyrin finished prior to the pandemic, no pandemic-related disruptions to the services were observed. As for Belle Idée, details can be found in (Beukers & Vlajki, 2021).

Regarding the qualitative evaluation categories, according to TPG, an on-board safety driver was always present during the shuttle's operation. The shuttle was also equipped with a surveillance system. As for accessibility, the shuttle was equipped with a wheelchair ramp. As for integration to the city transport network was able to connect the local train station with the main TPG tram lines at Meyrin Village. As for the service timetables, they were available at the shuttle stops and on TPG's website.

At last, it is worth nothing that for Geneva's operating sites, the available data was gathered from D7.2 (Beukers & Vlajki, 2021), and no further updates have been made available by the PTO by the time of writing of this deliverable. Thereby, data for the Belle Idée site was not available. Further details shall be found on D7.3 to be delivered at the end of the project.

Parc OL – Keolis: Lyon, France

Experimentations in Parc OL in the Décines (metropolitan Lyon) were carried out from November 2019 until January 2021. However, due to the imposed lockdown in France in March 2017, the service didn't work from mid-March to late August 2020. Thus, the monthly service data presented on Table 20, corresponds to a total of 10 months of operations.

Table 20. Parc OL service performance - analytical overview

Year	Month	Average operating speed (km/h)	Total distance traveled (km)	Total distance traveled by autonomous driving (km)	Total distance traveled by manual driving (km)
2019	nov/19	9,6	1244	73,95%	26,05%
	dez/19	9,8	1301	73,97%	26,03%
2020	jan/20	9,9	1906	77,77%	22,23%
	fev/20	10,1	1717	75,91%	24,09%
	mar/20	10	486	58,56%	41,44%
	set/20	9,2	354	71,77%	28,23%
	out/20	9,7	1474	61,73%	38,27%
	nov/20	10,2	2039	67,83%	32,17%
	dez/20	9,9	501	56,69%	43,31%
2021	jan/21	9,8	620	56,21%	43,79%

Source: prepared by the authors based on Keolis' data

The operations were carried out with two Navya ARMA shuttles. Over 4000 passengers have been transported (available data from November 2019 to March 2020) and over 11642 km were coved by the shuttles (available data from November 2019 to January 2021) with an average of 67.44% in autonomous mode and 32.56% in manual drive. Figure 11, depicts the overtime evolution of the service based on the available KPIs.

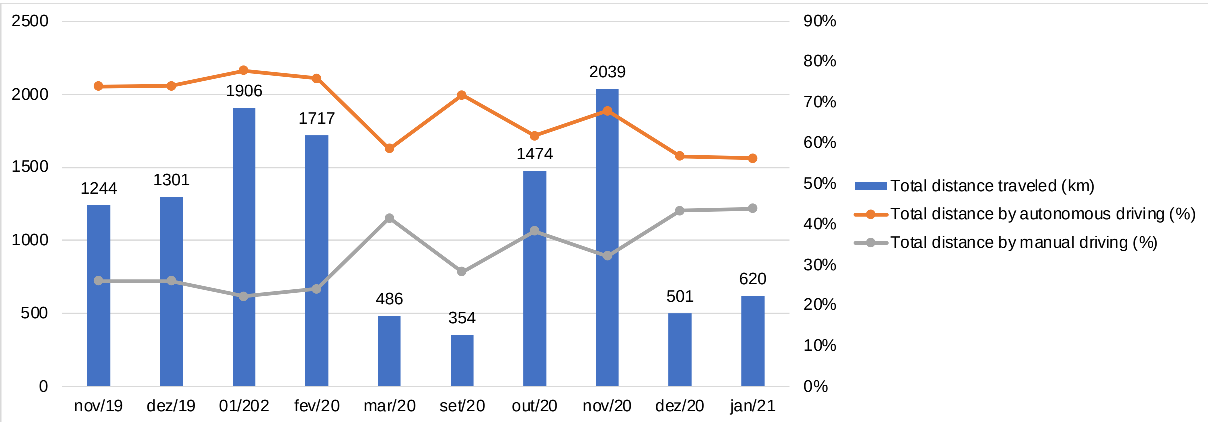


Figure 11. Parc OL service performance overtime
Source: prepared by the authors based on Keolis' data

Regarding the qualitative evaluation categories proposed in Table 4: service's safety and security and service's comfort and accessibility, an on-board safety driver was always present during the shuttle's operations. The shuttles were also equipped with a surveillance system. As for accessibility to people with reduced mobility, they were equipped with a wheelchair ramp. As for integration into the city transport network, the service had a direct connection with TCL's tramway line T3 at the station of Décines Grand Large and acted as a complement to the bus line 85. As for the service timetables, they were partially available at the shuttle stops and online on TCL's site and application.

Pfaffenthal & Contern – Sales-Lentz: Luxembourg

For Luxembourg's operating sites, the available data was gathered from D7.11 (Marrafa & de Vera, 2021), and no further updates have been made available by the PTO by the time of writing of this deliverable. The data gives a brief description of the operational experience for the sites of Pfaffenthal and Contern, however, no results have yet been made available for the replicator site of Esch Ville.

For Pfaffenthal, services were carried out with two Navya ARMA shuttles from 24/09/2018 to 01/01/2021, carrying over 25060 passengers and over 9000 km driven by both vehicles. For Contern, services were provided with a single Navya ARMA shuttle from 24/09/2019 to 01/01/2020 transporting 650 passengers over 1900 driven kilometers.

Further precisions on the operating details for Luxembourg's testing sites, including results for the replicator site of Esch Ville may be found on D7.12 by the end of the project.

As for the qualitative evaluation categories proposed in Table 4: service's safety and security and service's comfort and accessibility, data from (Marrafa & de Vera, 2021) stated that an on-board safety driver was always present during the shuttle's operations in all Sales-Lentz sites. The shuttles were also equipped with a surveillance system. As for accessibility to people with reduced mobility, the shuttles were equipped with a wheelchair ramp.

As for integration into the city transport network, for Pfaffenthal's site, the service was conceived to connect Pfaffenthal's residential area, the multimodal station, and the public elevator. The core objective was to fill this lack of transportation to connect the different means of transportation to each other as well as the different areas of Luxembourg City with each other. As for the industrial zone of Contern, the core objective was to provide a mobility solution for people arriving by public transport to the different companies in the industrial zone and to provide a mobility solution within the zone. As for the service timetables, for both sites, they were partially available at the shuttle stops and online.

Economic assessment of the AVENUE services

In the previous (second) iteration of the economic deliverable (D8.4), Antonialli et al. (2021) presented the preliminary Excel version of the **EASI-AV©** simulation tool to access, at the local level, the economic impact of services with Automated Shuttles for Collective Transport. Further details on how the tool was conceived can also be found on (Antonialli, Mira-Bonnardel, Bulteau, 2021).

The <u>E</u>conomic **<u>A</u>**ssessment of **<u>S</u>**ervices with **<u>I</u>**ntelligent **<u>A</u>**utomated **<u>V</u>**ehicles simulation tool (EASI-AV©) was designed with the objective of helping policy makers in cities, regions, Public Transport Operators (PTOs), and even others interested stakeholders that may wish to implement services with Automated Shuttles (e.g.: private corporate sites or university/hospital campuses).

The tool aims to evaluate the economic impact of different implementation scenarios - supply-pushed or demand-pulled strategy, for both fixed road sites (as the Avenue sites of Lyon, Luxembourg, and Copenhagen) or geofenced on-demand service (as

Geneva's Belle Idée site) – offering a comparison between an automated service and any other transport mode. The preliminary version of EASI-AV© detailed on D8.4., was designed using a spreadsheet software with manual data entry and automated calculation of results, allowing for:

- Service contextualization.
- Fixed route fleet size dimensioning.
- Total cost of ownership assessment.
- Local externalities assessment.

Figure 12, depicts D8.4's global results from the AVENUE demonstrator sites based on the simulation outcomes from EASI-AV©.

	Luxembourg (Sales-Lentz)		Geneva (TPG)	Copenhagen/Oslo (Holo)		Lyon (Keolis)	AVERAGE
	Pfaffenthal	Contern	Meyrin	Nordhavn	Ormøya	Décines	Avenue
CAPEX							
Single shuttle							
Fleet total							
OPEX							
Single shuttle							
Fleet total							
KPIs**							
Cost passenger/km							
Cost shuttle/km							

These data are not public

Figure 12. Total Cost of Ownership of the AVENUE service calculated on EASI-AV©
** Values comprise the Total Cost of Ownership considering the CAPEX, OPEX and Local externalities.
Source: (Antonialli, et al., 2021).

These results show us that the cost per passenger/km for the current demonstrators are still higher than other traditional public transport offerings (AVENUE average: [redacted] euros per passenger/km), which is justifying by the current need of an onboard safety driver in the vehicles, thus increasing the services' operating costs. These results in line with the findings by (Henderson, Veder, Li, & Johnson, 2017) in their feasibly study for a shuttle-service trial in Ohio State University Campus where the authors also concluded that the automated shuttle is indeed currently not cost-effective relative to traditional buses.

However, as technology and legislation evolve, it is expected that in the coming years an onboard safety driver will no longer be needed (thereby drastically reducing the costs with personnel), which assures that our tool is also aligned with the results of the prospective studies carried out by (Fagnant & Kockelman, 2015), (Bösch, Becker, Becker, & Axhausen, 2018) and, (Ongel, et al., 2019).

At last, it is worth highlighting that by the time of writing of the present deliverable, the web version of EASI-AV© tool has been completed. Users can access it via the AVENUE project website[1] and simulate the total cost of services with automated shuttles according to their needs and specificities as well as compare the service's feasibility with a baseline vehicle of their choosing. Further details on the web application version of the tool can be found on D8.6 (Antonialli, et al., 2022).

3.4 Category 4: Users' perceptions and satisfaction, toward AVENUE's vehicles and services

A crucial part of the evaluation plan of the AVENUE services is to gather the feedback from the users regarding their perceptions, satisfaction and attractiveness towards the shuttle and the services. This category is aimed at evaluating the user's level of feedback and it relates to Task. 8.3 – Social impact evaluation, and Task 2.2 – Passenger needs (including People with Reduced Mobility - PRM). Further details and a complete analysis of the social impact assessment in the AVENUE project can be found in D8.9 (Naderer, et al., 2022). Following the guidelines proposed on Table 5, the main evaluation points to be measured are:

- Retention rate of users
- The level of satisfaction with the automated minibus
- The level of satisfaction with the services offered
- The perception of impacts of other road users?

Sample description

By the time this deliverable was written, the survey has been ongoing in Sion, and it started in October 2021 in Esch and Contern, and in the new site in Copenhagen and Belle Idee in November 2021.

We present the results from the user survey in Copenhagen (July/August 2020) and those respondents from the representative survey that indicated to have used an automated minibus before (May/June 2021).

Copenhagen: 68 users
Representative survey: 126 (partial total of respondents from the sites below)

- Copenhagen: 21
- Geneva: 22
- Luxembourg: 40
- Lyon: 43

3.4.1 Retention rate

[1] Link for the web version of the EASI-AV© simulation tool: https://h2020-avenue.eu/avenue-economic-calculator/.

KPI: Frequency of the service

As shown on Table 21, users use the shuttle on an occasional basis, the majority has only travelled 1 or 2 times with the shuttle. Only a small part of the users (1,4% for the users from the representative survey, and 2% of the Copenhagen users) regularly use the automated minibus.

Table 21. Shuttle's frequency of use (based on the representative survey)

The use of the service	Users from the representative survey (n=126)	Copenhagen (n=68)
1 to 2 times	65,4%	94%
3 to 5 times	21,3%	4%
6 to 10 times	8,7%	-
11 times and more	4,7%	2%

Source: prepared by the authors

KPI: Intention to use the shuttle again

In the representative survey, 62,2% are willing to use the automated minibus again (33,9% are very willing, and 28,3% are willing). We also asked whether the respondents would be willing to reduce or give up the use of their own car, if the automated minibus would offer an on-demand service, see Figure 13. The respondents were also asked whether they would recommend the service to friends and family; **76,2%** would recommend the use of the shuttle to friends and family.

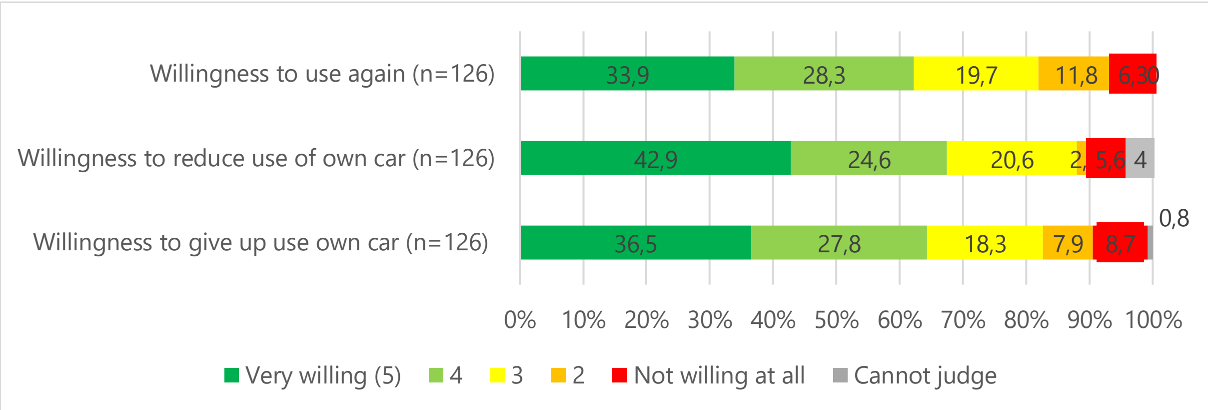


Figure 13. Willingness to use again, users from representative survey (n=126)
Source: prepared by the authors

In Copenhagen, the willingness to use the automated minibuses again is extremely high; 76% are very willing to use the automated minibus again, as is indicated in the first bar of Figure 14, only 4% of the users hesitate to use it again, and none of the users indicate that they are not willing to use it again.

Interestingly, while respondents indicate high willingness to reuse the service, actual reuse numbers are relatively low in both surveys.

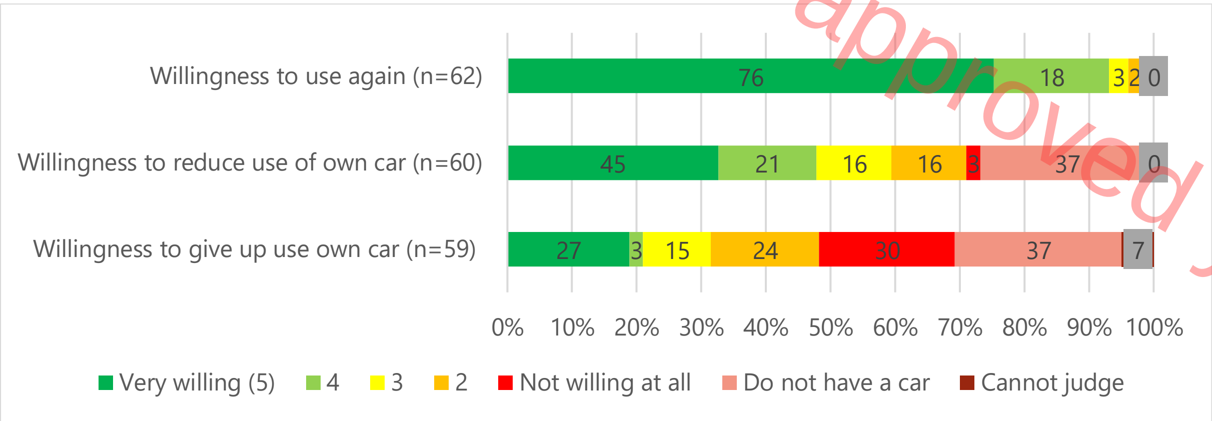


Figure 14. Willingness to use again, Users Nordhavn, Copenhagen
Source: prepared by the authors

3.4.2 Level of satisfaction with the automated minibus

KPI: Comfort in the shuttle

Users from the representative survey are positive about the level of comfort in the shuttle (see Figure 15). They especially rate the cleanliness and noise level high, the same goes for the users in Copenhagen, their impressions were positive about the level of comfort in the shuttle (see Figure 16). They especially rate the cleanliness, the temperature and noise level high.

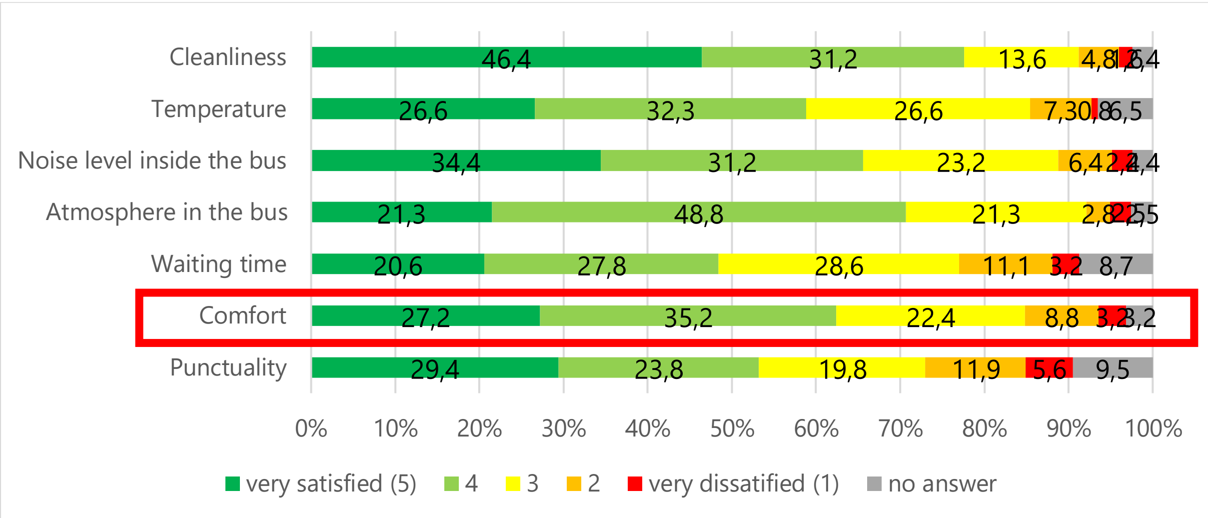


Figure 15. Detailed satisfaction with last ride; users from representative survey (n=126)
Source: prepared by the authors

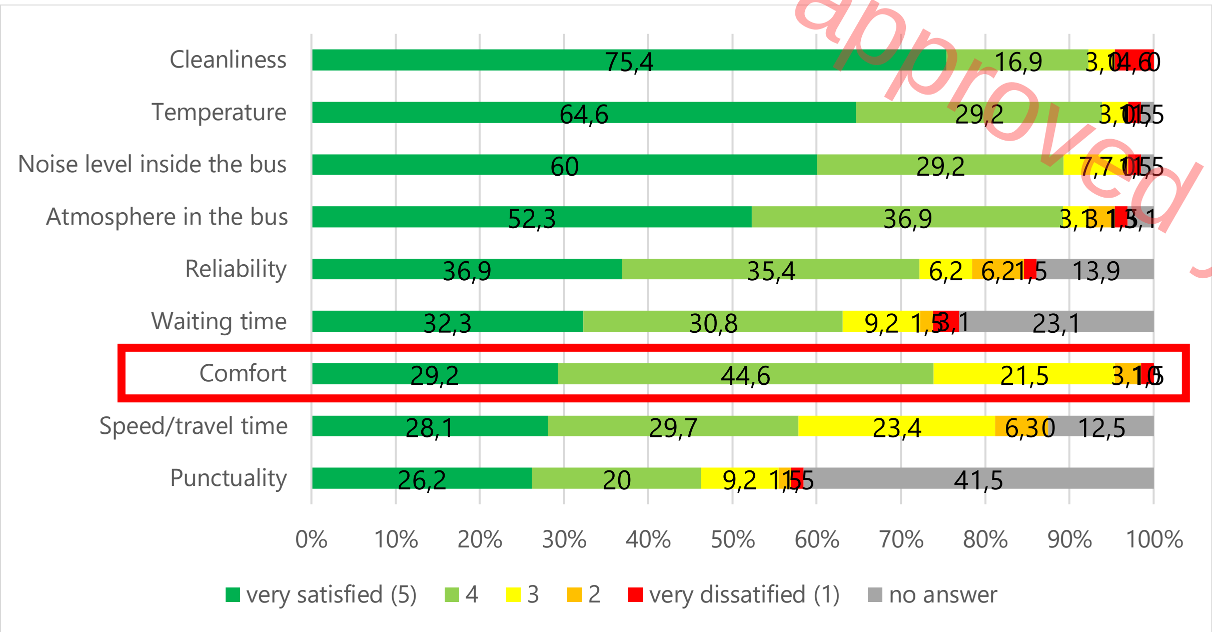


Figure 16. Detailed satisfaction with last ride; Nordhavn, Copenhagen (n=68)
Source: prepared by the authors

KPI: Feeling of safety and security in the shuttle

Both in the representative survey (Figure 17) and the user survey in Copenhagen (Figure 18), safety and security are ranked high. This result is specially interesting for the *in-loco* user survey in Copenhagen, since after testing the service, 52,3% of users are very satisfied with the security from outside the bus, and 46,2% are very satisfied with the safety in the bus.

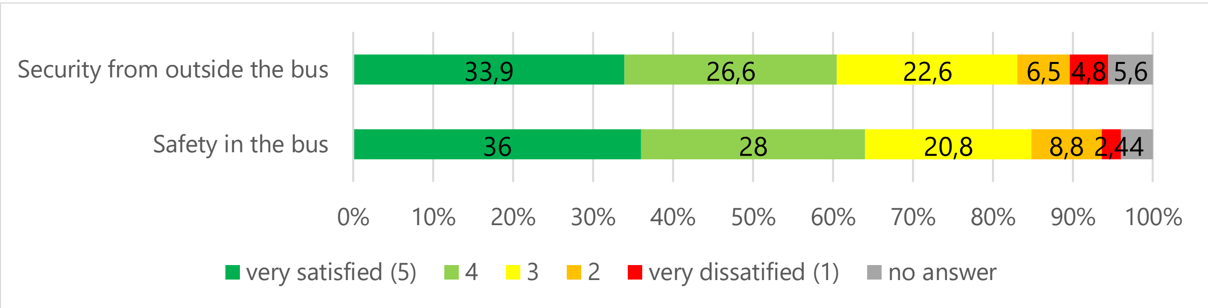


Figure 17. Safety and security; users from representative survey (n=126)
Source: prepared by the authors

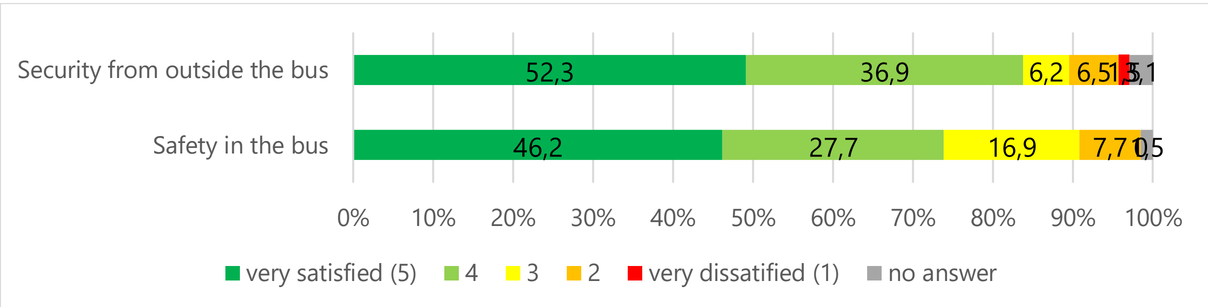


Figure 18. Safety and security; Nordhavn, Copenhagen (n=68)
Source: prepared by the authors

KPI: Ease of use of the shuttle

The users in Copenhagen perceive the use of the shuttle as easy. However, as shown on Figure 19, most users indicated that they do not have an opinion on four of the categories; the signal and announcements, the stop-button, the visual and acoustic passenger information, and the ease of transfer.

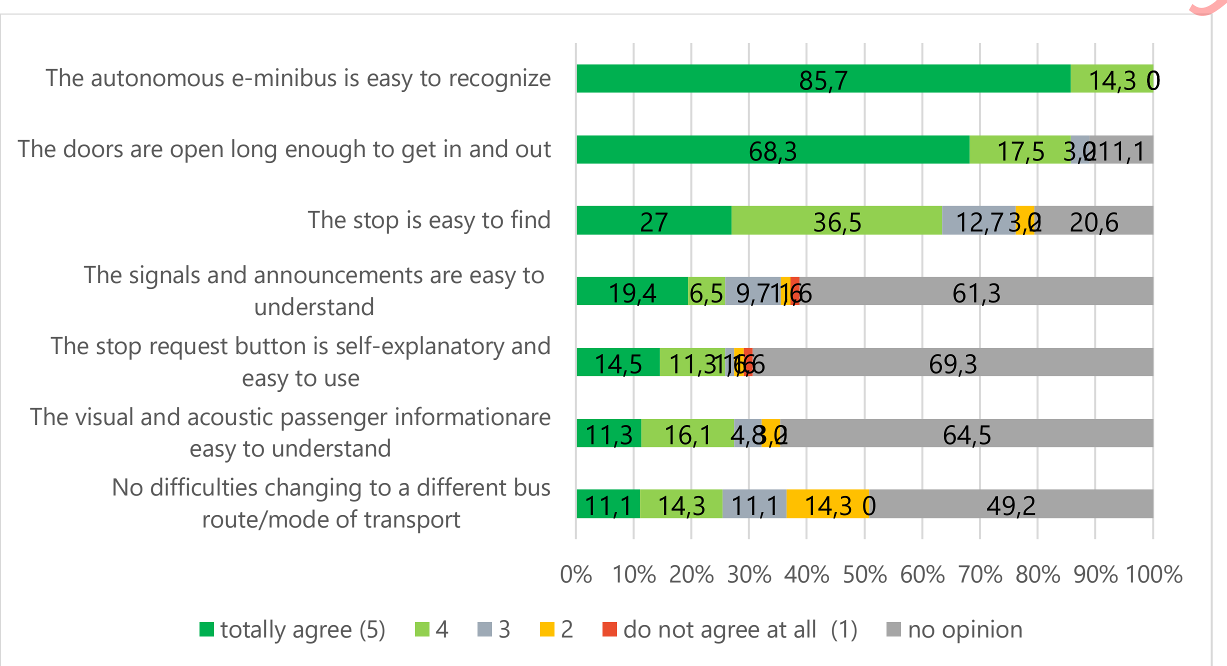


Figure 19. Ease of use of the shuttle; Nordhavn, Copenhagen (n=68)
Source: prepared by the authors

User satisfaction and perceived safety are very high in both surveys. The major topics with regards to the ease of use of the shuttle are highly appreciated. However the questions regarding the interactions with the uses as well as the information within the shuttle did receive no opinion from the respondents, possibly pointing at an absence of these services or that the users did not notice them. The means of interacting with the users (signals, announcements, visual and acoustic passenger information) need to be further refined and examined in future experimentations.

3.4.3 Level of satisfaction with the service

Figure 20, depicts the main KPIs from the survey in Copenhagen regarding the users' satisfaction with the service. Regarding the service's reliability, users are highly satisfied with its overall performance, with 36,9% being very satisfied, and 35,4% satisfied. This pattern also applies to the users' satisfaction with the location of stops (35.9% very satisfied and 32.8% satisfied), accessibility to the service (35.4% very satisfied and 33.8% satisfied), as well as waiting time (32.3% very satisfied and 30.8% satisfied).

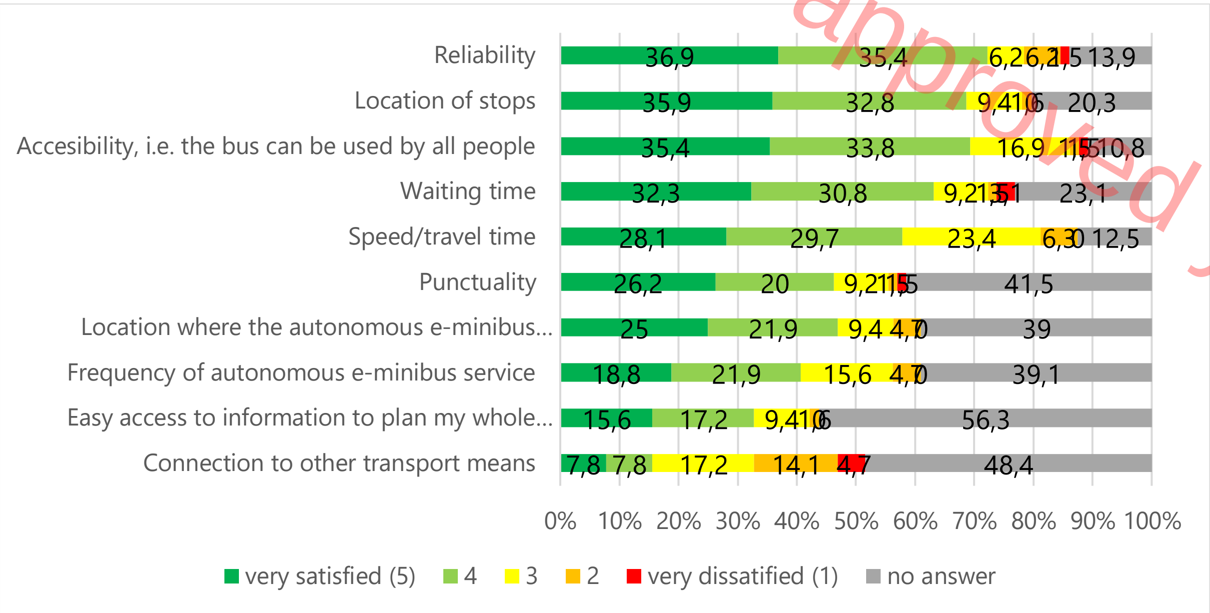


Figure 20. Satisfaction with the service; Nordhavn, Copenhagen (n=68)
Source: prepared by the authors

As for the shuttle speed and the total travel time, satisfaction rates are still positive but are lower than the previous KPIs (with 28.1% of users being very satisfied and 29.7% satisfied). This also applies to the service's punctuality (26.2% very satisfied and 20% satisfied), and the location of the service in the city (25% very satisfied and 21.9% satisfied).

The remaining three KPIs for this category (frequency of the service, ease of access to information about the service, and connection to other transport means) displayed lower satisfaction rates among the surveyed users (see Figure 20). They were also the KPIs with the highest rates of non-responses. Thus, PTOs shall pay closer attention to these indicators in future projects.

KPI: Willingness to pay

Most users from the representative survey (n=126) are willing to pay more (31,3%) or the equivalent (40,9%) to the current public transport fares to use the automated minibus service (Figure 21).

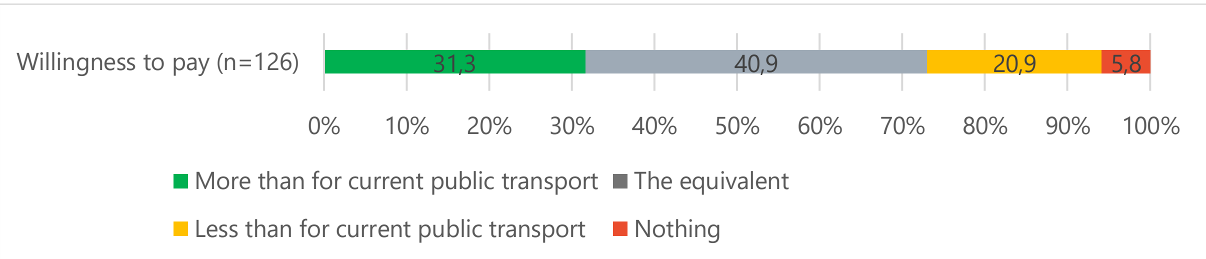


Figure 21. Willingness to pay; representative survey (n=126)
Source: prepared by the authors

This result is corroborated by the user survey from Copenhagen. When asked about the importance of the ticket price as a deciding factor to use the service with the automated shuttles (Figure 22), a majority of 58% state that the price is (very) important for the decision to use the automated minibus. No one stated that price is not important at all.

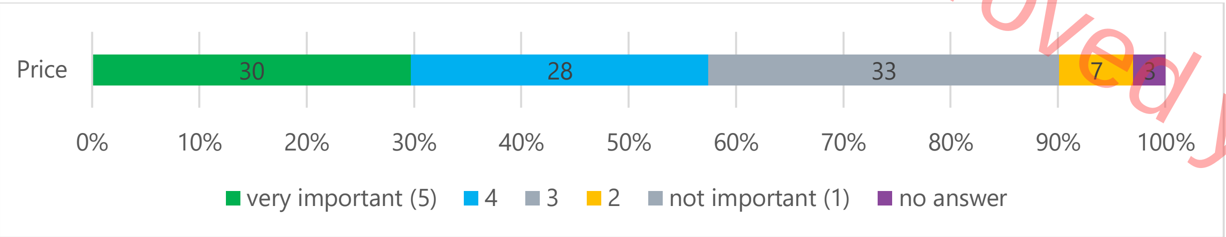


Figure 22. Pricing importance of the service; Nordhavn, Copenhagen (n=59)
Source: prepared by the authors

To investigate the possibilities for future use and business cases, a question was included to compare the willingness to pay for the services with the automated minibus compared to other means of transport (Figure 23). While around a third (35%) of the potential users are not willing to pay at least the same amount or even more for using the automated minibus as for regular public transport, only 24% refuse to pay the same even more. Nevertheless, only 11% of the users are willing to pay more shows that users do not see such a great improvement that would justify a higher willingness to pay. This can again be interpreted to mean that the automated minibus cannot completely replace other systems, but this is seen as an obvious necessity that does not justify the additional cost for the user.

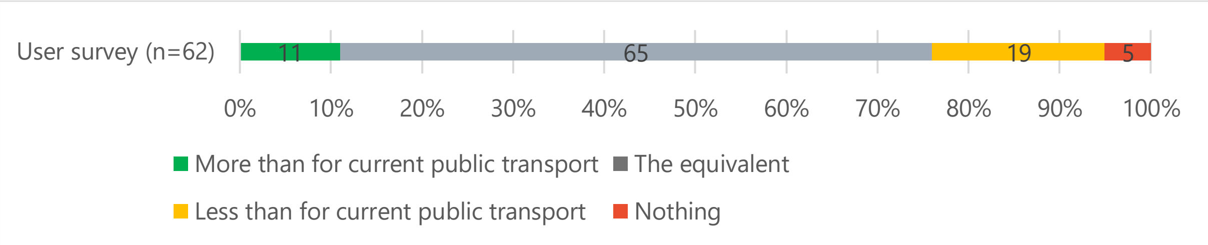


Figure 23. Willingness to pay for the service; Nordhavn, Copenhagen (n=62)
Source: prepared by the authors

3.4.4 Perception of impacts on other road users

This category aimed at understanding the perception of an autonomous shuttle service by other road users, such as pedestrians, cyclists, and drivers. The assessment of this category was carried out in the AVENUE project's replicator site of Sion, with the aid of 22 students in risk management at the University of Applied Sciences and Arts Western Switzerland (HES-SO), who conducted (in October 2021) a field research by doing observations and interviews of other road users.

The methodology adopted was semantic sentiment analysis, which is a Natural Language Processing (NLP) for automating the synthesis of multiple opinions to obtain an overview of opinions on a given topic. An expression of opinion has a polarity, which can be positive, negative, or neutral. The semantic sentiment analysis determines the opinions expressing a sentiment, a judgment, or an evaluation in the whole corpus. It specifies the tone of the text by situating the nature and intensity of the opinions expressed in relation to a repertoire of feelings.

Using integrated technologies and methodologies, Sphinx Quali determines which quotes express a feeling, judgment, or evaluation and identifies their orientation (positive/negative/neutral). Sphinx Quali is dedicated to the processing of textual data and semantic sentiment analysis. It integrates recent advances in knowledge engineering (ontology, semantic networks, etc.) and is at the forefront of innovative technologies. The assessed KPIs for this category are presented as follows.

KPI: Road system usage safety

This KPI was analyzed by questioning if the other road users perceive the autonomous shuttle service as a threat. As shown from the compiled results from Figure 24, with 22 responses, 68,2% of respondents do not perceive the autonomous shuttle service as a threat, while 31.8% do. All answers remarks, comments and suggestions were evaluated by the Sphinx software through a semantic sentiment analysis. The results show that 40.9 % of all the answers have a tendency towards a positive connotation. On the other hand, 22.7% of the comments have a negative connotation (18.2% clearly negative and 4.5% rather negative). 31.8% of the answers are identified with no positive nor negative connotations and 4.5% with both positive and negative connotations.

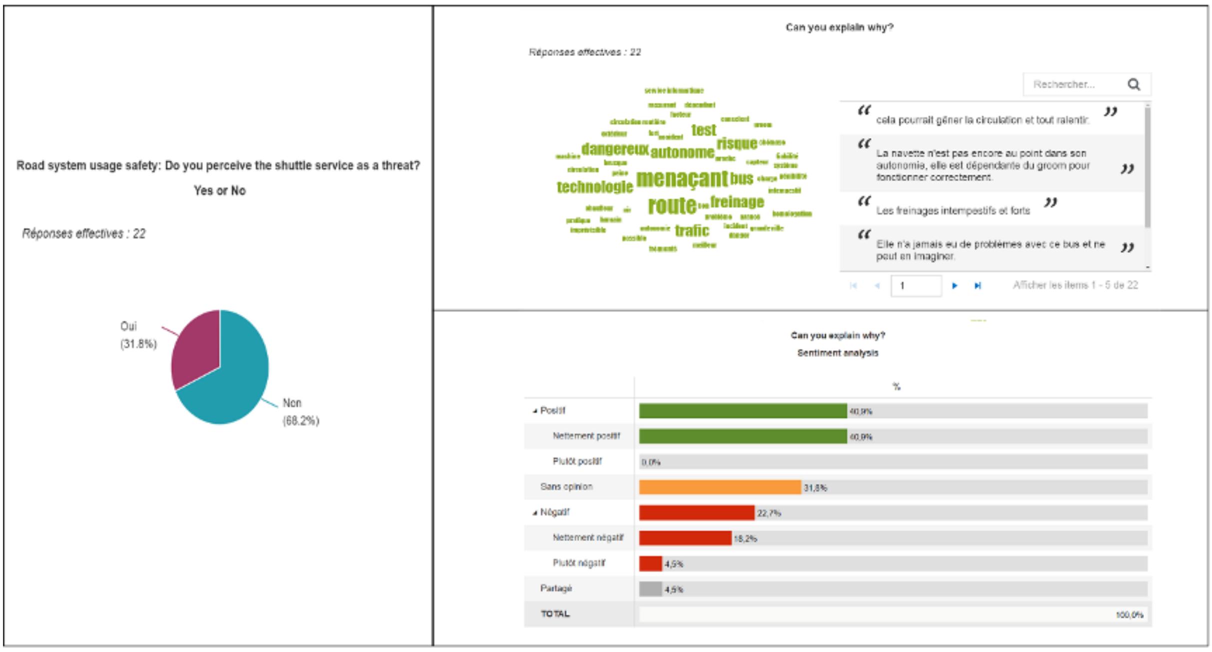


Figure 24. Other road users' perceptions about the safety of the service
Source: prepared by the authors

KPI: Road system usage efficiency

By asking the respondents if they fell that the automated shuttle service slows down traffic, 54.5% of the people agree that service slows down the traffic, against 45.5% who perceive it otherwise. According to a semantic sentiment analysis, a tendency (22.7%) towards a clearly negative connotation was detected while 18.2% of the remarks are clearly positive. 50% of the answers have no positive nor negative connotations and 9.1% of answers have both positive and negative connotations. Results are summarized on Figure 25.

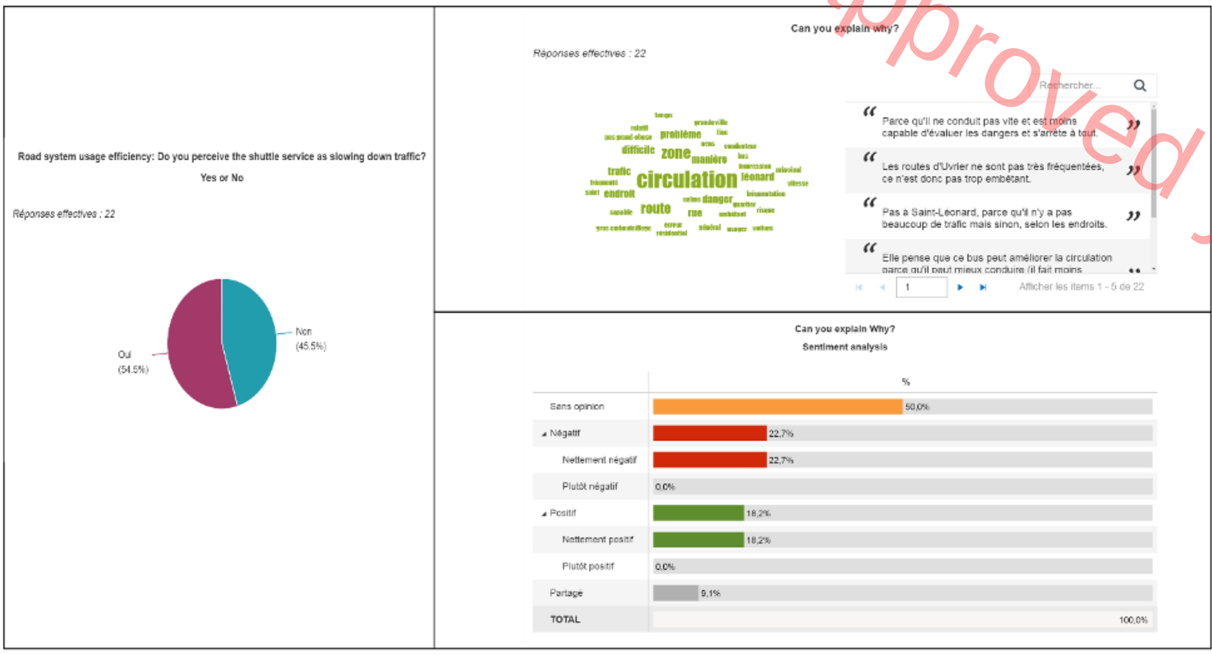


Figure 25. Other road users' perceptions about the traffic efficiency of the service
Source: prepared by the authors

KPI: Problems and inconveniences with the service

When asked if the service with the shuttle causes any problems and inconveniences to them, 55.6% of the interviewed group of other road users do not perceive any problems nor inconveniences with the autonomous shuttle service against 44.4% who perceive it otherwise. According to a semantic sentiment analysis, a tendency (35.0%) towards a negative connotation was detected while 5.0% of the remarks are clearly positive. These results presented on Figure 26 may be explained by the fact that while respondents did not observe any problems or inconveniences in their current experience, their responses reflect their projection into the future when further problems and complications are expected. 55% of the answers have no positive nor negative connotations and 5.0% with both positive and negative connotations.

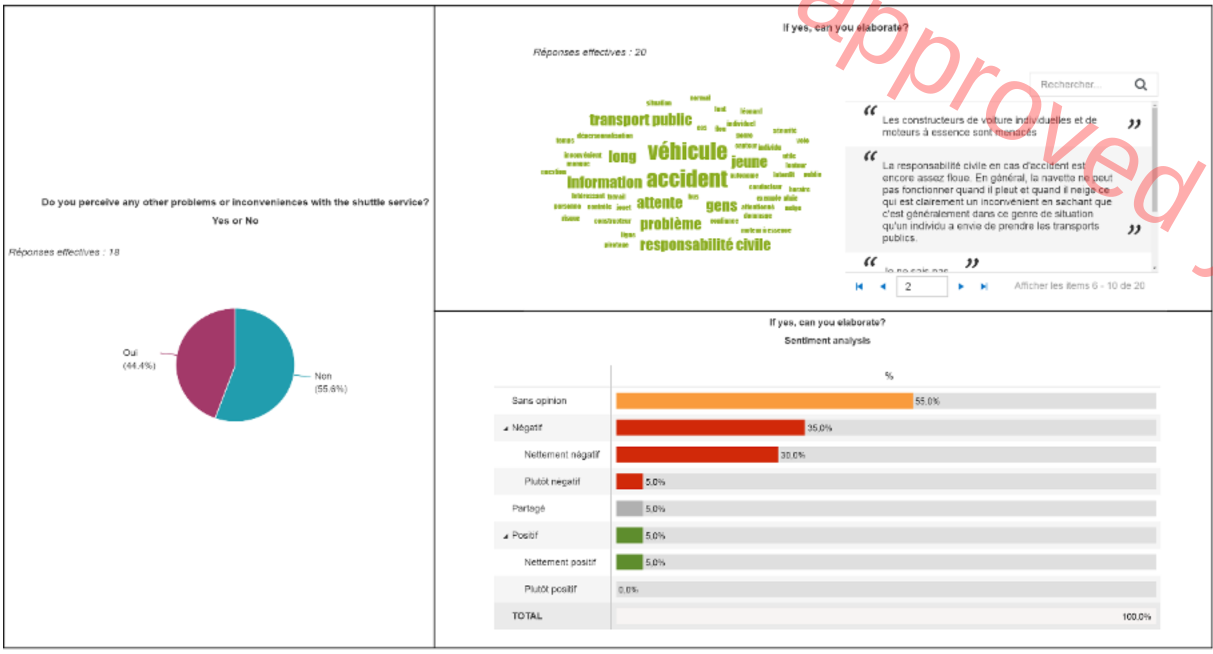


Figure 26. Other road users' perceptions about the traffic efficiency of the service
Source: prepared by the authors

KPI: Communication with the shuttle

As show on Figure 27, according to 31.8% of the people interviewed, their answers regarding communication between the autonomous shuttle and the users have a positive connotation (22.7% clearly positive and 9.1% rather positive). However, 22.7% of the answers had a clearly negative connotation. Sphinx Software also detects 40.9% of the answers with no positive nor negative connotations and 4.5% with both positive and negative connotations.

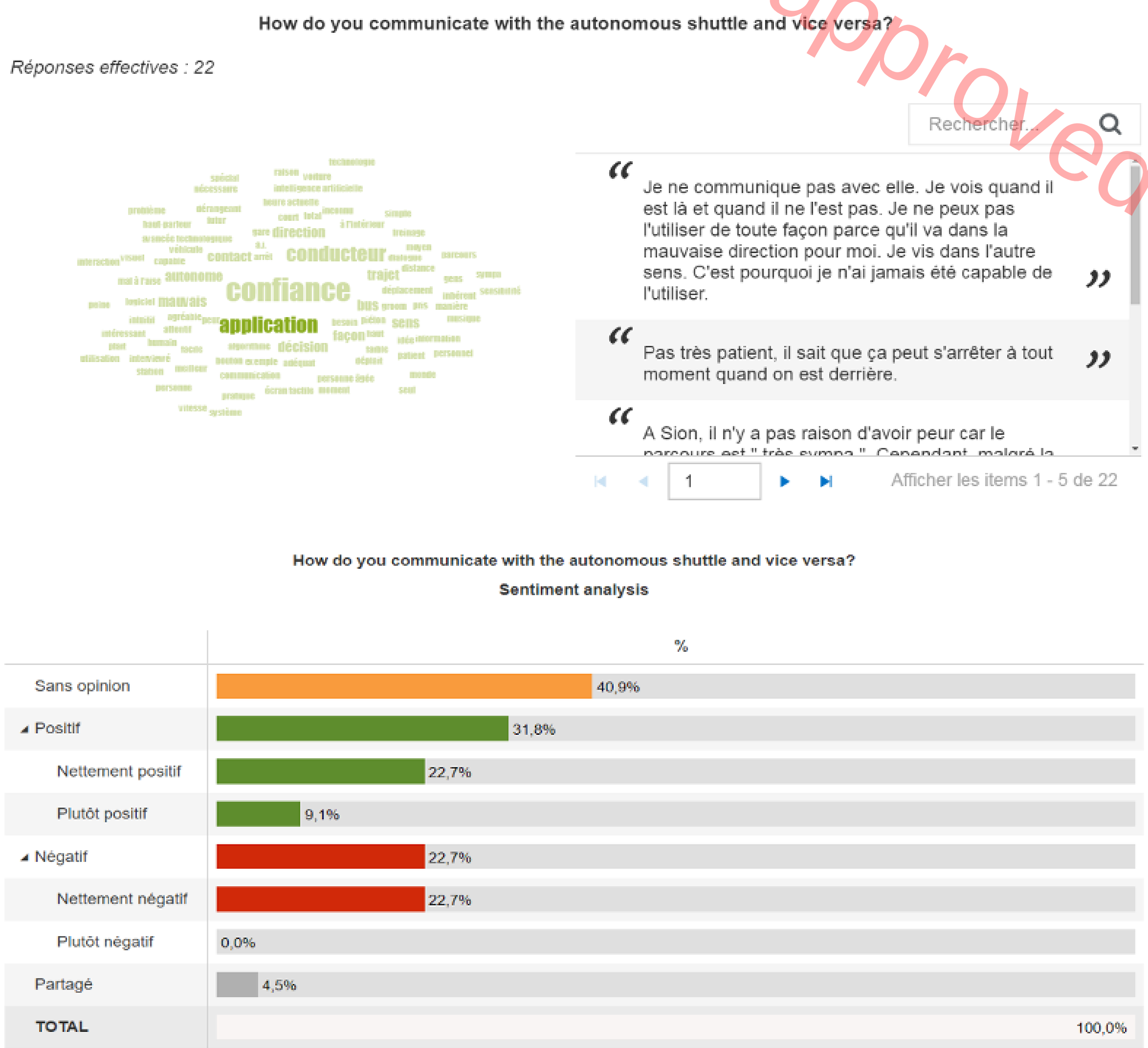


Figure 27. Other road users' communication with the shuttle
Source: prepared by the authors

KPI: Behavior near the shuttle

As for their behavior near (or in front of) the shuttle, 19.0% of the people regard their behavior with the shuttle have a positive connotation (14.3% clearly positive and 4.8% rather positive). However, 14.3% of the answers had a clearly negative connotation. Sphinx Software also detects 57.1% of the answers with no positive nor negative connotations and 9.5% with both positive and negative connotations. A summary of the results is depicted on Figure 28.

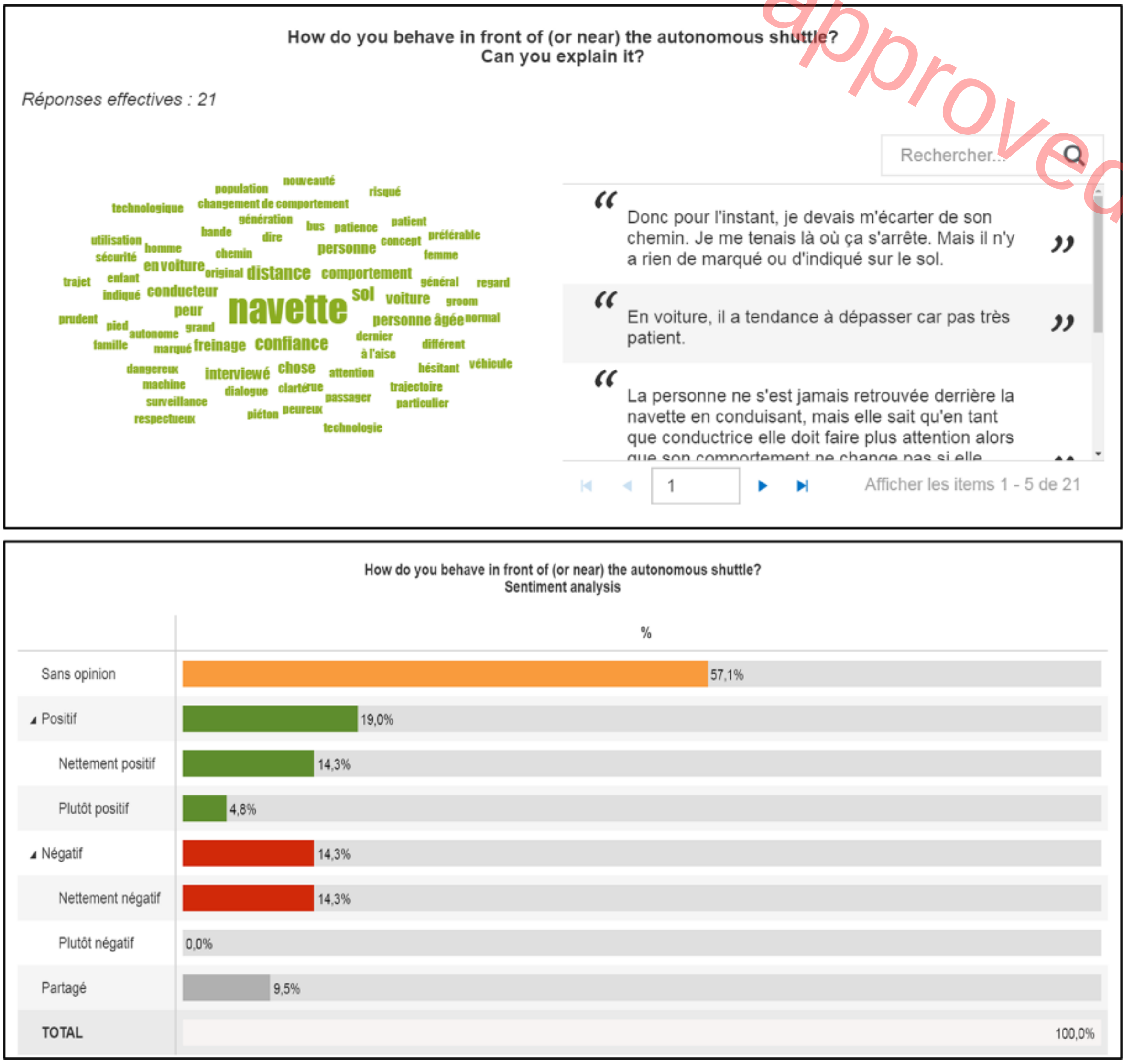


Figure 28. Other road users' behavior near the shuttle
Source: prepared by the authors

4 Concluding remarks

With the aim of performing the assessment of the overall services, technologies, and functionalities at large-scale demonstrators, the present deliverable presented and applied a global evaluation framework capable of measuring on a flexible and data-available basis the demonstrators and replicators sites in the AVENUE project.

The proposed evaluation framework was conceived with four macro-categories, each divided into categories of KPIs (both quantitative and qualitative ones). The first one brings an overview of the operating site, the second assesses the performance of the automated shuttles, the third the performance of the services with the automated shuttles, and the fourth aims at gathering the users' perceptions and satisfaction toward both the vehicle and the service.

With four transport operators (TPG, Keolis, Holo, and Sales-Lentz), six demonstrator sites (Meyrin and Belle-Idée in Geneva - Switzerland, Décines in Lyon - France, Nordhavn and Ormøya in Scandinavia – Denmark and Sweden, and Pfaffenthal and Contern in Luxembourg), and two replicator ones (Esch Ville in Luxembourg, and Sion in Switzerland), the AVENUE services ran from July 2017 (with the debut of the Meyrin site in Geneva) until October 2022 (some sites like Esch or Contern will continue even after the end of the AVENUE project).

From the total of the eight test sites (including the demonstrators and replicators), 6 ran as a fixed route with fixed stops (stage 1 of Figure 3 as proposed by (Antonialli, 2021): Meyrin, Décines, Pfaffenthal, Contern, Nordhavn, and Ormøya), one ran as a fixed route with on-demand stops (stage 2 of Figure 3: Esch Ville), and one with geofenced flexible gridded routes and on-demand stops (stage 4 of Figure 3: Belle-Idée).

By the time of writing this deliverable a total of 40.299 passengers have been transported across all AVENUE sites, with the shuttles covering over 53.428 kilometers, with an average rate of 76.78% automated driving and only 23,22% manual drive by the on-board operators.

All AVENUE shuttles were equipped with ramps, signs, and seatbelts for people with disabilities as well as with an onboard surveillance system to assure user safety. Timetables were mostly available at the shuttle stops as well as online either on the PTOs' webpages or applications. By the time of writing, at last four of the eight AVENUE testing sites provided a connection with their city's transport network, while all of them were deployed in areas with poor and/or absent public transport services.

For their economic assessment, the results provided by the calculation tool EASI-AV© (developed within the scope of the project in WP8) show that currently – due to the need for an onboard safety driver – the operating costs of service with automated shuttles are not yet cost-effective compared to a traditional human-driven counterpart. However, as legislation and technology evolve, these figures are bound to change in favor of automated shuttles soon.

As for users' perceptions and acceptance, results show that the frequency of use of the service is still low, with less than 2% of users making regular trips with the shuttles. Due to the novelty and innovative approach of the service, most users tried it out of curiosity, although over 62% claimed a willingness to use the services again and

76.2% would recommend them to friends and family. As for the service price, 58% of users claim that this is a deciding factor. With 41% willing to pay the same fare as current public transport while 31.3% were willing to pay more. Users also perceive the service as comfortable, safe, and easy to use. The main pressing points to be improved according to users are the shuttle speed and the service frequency and reliability.

Regarding other road users who interact with the shuttle (drivers, pedestrians, and cyclists), the main results highlight that 68.2% of other road users do not perceive the shuttles as a threat, 54.2% agree that the service slows down traffic (corroborating the need of increasing the service speed), and 55.6% do not perceive any problems nor inconveniences with the shuttle service.

At last, regarding the limitations, we highlight the difficulty and uniformity in data collection regarding the PTOs and other stakeholders, which in turn limited the analytical power of the proposed framework. Moreover, the interruptions and other disturbances caused by the COVID pandemic were a limiting and delaying factor for data collection and analysis, thus preventing a uniform analysis among all the testing sites of the project.

It is therefore suggested for future studies and projects not only to apply, but also to extend the proposed framework (refining and/or adding categories and KPIs), as well as to establish ex-ante a standard and schedule for data collection with the PTOs and OEMs, which in turn will allow more robust and complete analysis of the services with autonomous shuttles, thus allowing, at the end of the analysis, more precise and timely recommendations for the stakeholders involved.

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