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SHared automation Operating models for Worldwide adoption

SHOW

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Deliverable 12.6: Madrid CCAV demonstrators

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Legal Disclaimer

Executive Summary

The SHOW project aimed to support the migration towards effective and sustainable urban transport through technical solutions, business models and priority scenarios for impact assessment. This was achieved by deploying shared, connected, and electrified fleets of automated vehicles in coordinated Public Transport, Demand Responsive Transport, Mobility as a Service and Logistics as a Service operational chains in real-life urban pilots.

Deliverable *D12.6: Madrid CCAV demonstrators* collects, the full operation demo phase transferring 6,035 PAX in (1) Carabanchel bus depot, in (2) the automated bus transfers at the BACSI (Sustainable and Smart Connected Air Base) event in 2023, and in (3) Madrid city downtown, during 2024's European Mobility Week (EMW 2024), *World Car Free Day*, open traffic public operation. Worth saying at this point that Madrid Mega pilot site has transferred a total of 6,643 PAX, if the pre-demo phase at the depot is also included.

The pilot at Villaverde, despite Madrid pilot's partners effort in obtaining the city council permits to drive in autonomous mode, in this type of urban open traffic scenarios, was finally not operated due to the lack of this mandatory authorisation. Despite this difficulty, EMT's AV two (2) Gullivers demonstrated the bus stop service in autonomous mode during two (2) public events, i.e. (1) BACSI 2023 (in Albacete city) to transfer the Spanish Minister of Defense from the airstrip to the exhibition area as well as base military personnel and general public, in 2023 and (2) the EMW 2024, held in Madrid downtown, on a 700m long round trip giving public transport in downtown city centre, to locals and tourists, in 2024. All the preparatory work in Villaverde and the lessons learned are also included in this document.

The pilot at Carabanchel bus depot involved automated vehicles (AVs) with perception sensors, control mechanisms, and centralized decision-making units, testing services such as the 5 stops (for depot internal transport), auto-parking, and teleoperation, always during weekdays. Over twelve months, the AV fleet performed successfully without incidents, driven by twelve (12) safety drivers.. The autonomous bus depot management use case has focused on process automation to achieve more efficient resource management within the bus depots, with numerous bus driver hours considered as non-productive yet with a high potential for increased efficiency. The bus depot – bus dominant traffic - included a mix of cars (service cars) and trucks, as well as pedestrians (employees and visitors, walking around by foot) interacting under different traffic conditions, as the traffic density varies across the area and across the day, considering depot rush hours very early in the morning and evenings.

- The 5-stops service consisted of an 800m long round trip (circular), giving public transport service to EMT employees, as well as depot external visitors, to Carabanchel's points of interest. The first Tecnobus minibus (Gulliver_1) and one 12m IRIZAR bus (i2eBus) have operated this service inside the depot, where the speed is limited to 10 km/h, dropping to 5 km/h in the bus cleaning area, and 20 km/h on the bus testing circuit.
- The auto-parking has been operated by the 12m i2eBus IRIZAR bus, meant primarily to manage the depot and auto park the e-bus during the day, once the 5 stops service is completed (sometimes in the afternoon). Platoon use case was validated and operative not for the full 12 months due to the fact Madrid local partners prioritised the 5 stops service to be ready for Villaverde scenario. It happened at the beginning of the demo period and was used to move the parked i2eBus to a designated charger, for being charged.

- Teleoperation has been tested with the second Gulliver minibus (Gulliver_2), including both supervision and actuation on the vehicle.

As for the two (2) Renault Twizy provided by TECNALIA, they have been devoted during development phase (in WP7), to transfer AV algorithms verified (in WP11.1) and technically validated (WP11.2) to the minibuses (Gulliver) and the 12m bus (i2eBus). The Twizy does not have the capacity to transport passengers

Subjective data has been collected, via specific questionnaires, to collect the particular view of the safety drivers, the passengers, the PTO and OEMs and have been analysed in the context of *D13.5: SHOW impact assessment on user experience, awareness and acceptance* and *D1.3: Stakeholder & travellers needs evolution through Pilots*. As for Madrid KPIs, this is visualised in SHOW's dashboard (https://show-project.eu/show-dashboard/).

The main objective was to evaluate the technical feasibility of automating operations that are currently carried out manually, to improve the efficiency and to optimize the functioning of the bus depot in many ways, such as reducing the space used for parking, reducing the number of non-productive hours of bus drivers driving inside the bus depot upon arrival at the end of its service, and improving road safety.

In the context of SHOW, a preliminary and brief cost analysis has considered both costs and savings assuming the automation of the bus fleet at a generic bus depot such as the Carabanchel one, exclusively considering the autonomous operations within the bus depot. Despite the evident savings in personnel costs (up to 1 million € per year per bus depot), it is not possible to conclude with a proper cost analysis of costs and savings. The high upfront cost of purchasing the equipment and retrofitting conventional buses, shows a low cost/benefit ratio for adapting existing non autonomous buses (around 26% of the initial cost of an e-bus plus the cost of the e-bus itself), and the uncertainty about some aspects, including depreciation, makes extremely complex to provide concluding figures.

As from the OEM's point of view, Carabanchel's large scale pilots showed that there are potential new business lines, where the effort is focused on industrialization and deployment; whereas PTO's perspective is: (1) that there are potential savings in non-productive hours at bus depots, (2) the importance of training, (3) and that autonomous mobility solutions are mature enough to be deployed in semi-controlled environments (such as bus depots); however, there are still uncertainties about open traffic situations, where further technology development and permissions are needed.

Linked to this, it can be said that SHOW has contributed to the concern towards autonomous transport services, at local level. As a matter of fact, the reborn political support received, at the last stages of the project, thanks to which the two big public events have been used to provide the SHOW service (BACSI 2023 and EMW 2024), have also motivated that EMT Madrid is assessing the possibility of providing autonomous public transport services within *"Casa de Campo"* park, something that could happen, potentially by late 2025.

Hence, SHOW has been extremely useful to open de debate, in Madrid, on which are the needs and requisites of autonomous transport services to be both tested and deployed. The main outcome of this fact is the approval last October 3rd, of Madrid mobility Sandbox[1], ordinance project which will regulate the use of the city as a controlled environment for testing innovative products, services, and projects.

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[1] https://x.com/MADRID/status/1841806664678170635

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Table of Contents

List of Tables

List of Figures

Abbreviation List

Abbreviation	Definition
API	Application Programming Interface
APTA / FTA	American Public Transportation Association / Federal Transit Administration
AV	Automated Vehicle
BASCI	Base Aérea Conectada Sostenible e Inteligente (smart sustainable and connected airbase)
C40	Cities Climate Leadership Group
CCAV	Cooperative Connected Automated Vehicle
CDTI	Centro para el Desarrollo Tecnológico y la Innovación (Centre for Technological Development and Innovation)
CNG	Compressed Natural Gas
CTAG	Centro Tecnológico de Automoción de Galicia (Automotive Technology Centre of Galicia)
CV	Connected Vehicle
DMP	Data Management Portal
DRT	Demand Responsive Transport
EMW	European Mobility Week
HMI	Human Machine Interaction
INSIA	INStituto universitario de Investigación del Automóvil (University Institute of Automobile Research)
KPI	Key Performance Indicator
MLDMP	Madrid Local Data Management Platform
N/A	Not applicable
OEM	Original Equipment Manufacturer
PAX	Passenger
POI	Point Of Interest
PTO	Public Transport Operator
SAE	Servicio Ayuda Explotación (exploitation help service)
SAM	Servicio Ayuda Movilidad (mobility assistance service)
SDMP	SHOW Data Management Platform
TLP	Tactical Leadership Program
UC	Use Case
VRU	Vulnerable road user
V2X	Vehicle to X (everything)

1 Introduction

1.1 Purpose and structure of the document

Deliverable *D12.6: Madrid CCAV demonstrators* mostly compiles the full operation demo phase at Carabanchel bus depot key findings by reviewing the ecosystem, operation setting, fleet and infrastructure for the services operated during the twelve (12) months (Chapter 3). As for the pilot at Villaverde, despite Madrid pilot's partners effort in obtaining the city council permissions to drive in autonomous mode in this kind of urban open traffic scenarios, was finally not operated due to the lack of the mandatory authorisation. Instead, EMT's AV Gullivers demonstrated the bus stop service in autonomous mode in two public demos: (1) BACSI event in the Spanish Army Air Base in Albacete and (2) during the European Mobility Week, held in Madrid downtown, on a 700m long round trip giving public transport in downtown city centre, to locals and tourists. Refer to chapters 4 and 5 for further details. Chapter 3 displays the high-level vision of the site, whereas Chapter 5 the roadmap of the city and the ecocystem.

1.2 Intended Audience

Deliverable 12.6: Madrid CCAV demonstrators is a public document, which mostly presents the conclusions on automated bus depot management, based on the pilot operation performed in Carabanchel.

It offers valuable insights for OEMs and operators across Europe, looking to implement similar solutions. Carabanchel pilot operation demonstrates the potential for automating various depot functions such as vehicle auto parking, dispatch, charging, and maintenance scheduling, which can significantly enhance operational efficiency, reduce human error, increasing efficiency, reducing nonproductive hours of bus drives, and streamline fleet management. It also explores the feasibility of integrating automated systems within existing depot infrastructures, offering a practical roadmap for scaling, and adapting these solutions to other European cities; thus, also relevant for SHOW follower cities interested in the "automated bus depot management" use case, such as Kadikoy, Sarajevo and Braga, based on Eurocities transferability coordinated activities.

1.3 Interrelations

Deliverable *D12.6* is related basically to two previous deliverables: [1]: D1.2, SHOW use cases,[2]: D9.3 for the final pilot evaluation's common evaluation framework and methodological approach. Also, as already mentioned, subjective results are analysed in *D13.5: SHOW impact assessment on user experience, awareness, and acceptance* and *D1.3: Stakeholder & travellers needs evolution through Pilots*, whereas performance data are discussed and correlated to subjective data in *D12.9: Real life demonstrations pilot data collection and results consolidation.*

2 Madrid Mega pilot site high level vision and overview

Madrid Mega pilot site main goals have been two: (1) Automated Bus Depot as a mean to optimize management and increase efficiency and (2) CCAM contributing to foster research and innovation, in urban open traffic. So as to enable and provide safe, sustainable and integrated people mobility, by deploying a mixed fleet of AVs, following complex trajectories in various traffic conditions, driving in two different environments: Carabanchel bus depot and Villaverde urban open traffic.

Despite Madrid pilot's partners effort in obtaining the city council permissions to drive in autonomous mode in urban open traffic scenarios, Villaverde was finally not operated due to the lack of this mandatory authorisation. Originally the bus stop service – clustering UC1.1, UC1.2, UC1.3, UC1.6 and UC1.0 - was designed for the urban open traffic area (Villaverde). Finally, it came up to be pilot operated at the bus depot, giving public transport service to EMT employees, as well as depot external visitors, to Carabanchel's points of Interest. Additionally, the use cases dealing with the autonomous bus depot management, i.e. UC 1.7, UC 3.3 and UC 3.5 operated the full period of twelve (12) months. On the contrary, UC1.8[2] was validated and operative not for the full 12 months due to the fact Madrid local partners prioritised the 5 stops service in order to be ready for Villaverde scenario.

Table 1 gives an overview of Carabanchel's bus depot operation. It also outlines the two big public events: BACSI 2023 (in Albacete) and EMW 2024 (in Madrid), where a total of 400 and 280 PAX, respectively, used the stops service. In EMW 2024 public event, the shutle by CTAG is also considered (refer to Figure 24).

Refer to [1] for further details on the UCs mentioned below.

Table 1: Madrid Mega Site: Operation overview

Pilot scenario	**Duration of operation**	**Leader**	**Vehicles**	**Use Cases (by ID and name)**	**Number of passengers transported in PUBLIC OPERATION**
Carabanchel – 5 stops	12 months	TECNALIA	i2eBus (1) Irizar 12m eBus Gulliver_1 (1) Tecnobus minibus	UC1.1[3] UC1.2[4] UC1.3[5] UC1.6[6] UC1.10[7]	5,535 PAX
Carabanchel - teleoperation	12 months	EMT	Gulliver_2 (1) Tecnobus minibus	UC1.7[8]	N/A

[2] UC1.8 Platooning for higher speed connectors in people transport

[3] UC1.1: Automated passengers' mobility in Cities under normal traffic & environmental conditions

[4] UC1.2: Automated passengers' mobility in Cities under complex traffic & environmental conditions

[5] UC1.3: UC1.3: Interfacing non automated vehicles and travellers (including VRUs)

[6] UC1.6: Mixed traffic flows

[7] UC1.10: Seamless autonomous transport chains of Automated PT, DRT, MaaS, LaaS

8 UC1.7: Connection to Operation Centre for tele-operation and remote supervision

Pilot scenario	Duration of operation	Leader	Vehicles	Use Cases (by ID and name)	Number of passengers transported in PUBLIC OPERATION
Carabanchel - auto parking	12 months	IRIZAR, TECNALIA	i2eBus (1) Irizar 12m eBus	UC3.3[9] UC3.5[10]	N/A
BACSI 2023 (Albacete)	2 days	EMT	Gulliver_1 and Gulliver_2 (2) Tecnobus minibuses	UC1.1 UC1.2 UC1.3 UC1.6 UC1.10	400 PAX
EMW 2024 (Madrid)	1 day	EMT, TECNALIA	Gulliver_1 and Gulliver_2 (2) Tecnobus minibuses	UC1.1 UC1.2 UC1.3 UC1.6 UC1.10	280 PAX

9 UC3.3: Automated parking applications

10 UC3.5: Depot management of automated buses

3 Carabanchel, bus depot

3.1 The ecosystem

In Carabanchel bus depot, the Madrid Mega pilot site had four (4) project partners (refer to Table 2).

Table 2: Madrid Mega site: Carabanchel local ecosystem.

Participating Entity	Role
EMT	PTO and operator of demo, - providing two 5m minibuses (Tecnobus - Gulliver) to the demo site.
IRIZAR	OEM, electric bus manufacturer providing one 12m bus (Irizar - i2ebus) to the demo site
TECNALIA	RTO –Madrid Mega Site pilot leader, CCAM decision and control technology, providing two passenger cars (Renault - Twizy) to the test site
INDRA	Communication tech, providing the cooperative infrastructure.

3.2 Operation setting

In Madrid Mega site, Carabanchel bus depot (Figure 1) is a private and semi-controlled environment, own by EMT Madrid. It has a surface area of 65,000m^2 and houses 450 buses to serve 48 bus lines, including CNG and fully electric bus units. It is also where most of the electric fleet of EMT is based. It is indeed a semi-controlled area with interaction with other non-autonomous buses and vehicles, as well as daily operations at the depot (manoeuvring, moving goods, people, etc.). The road type is equivalent to an urban one, with one or two lanes (depending on the area), and 5 intersections.

Operation in Carabanchel focused on the improvement of operations within the bus depot from the perspective of automated bus depots management, exploring the potential of optimising operations and reducing costs and the space needed thanks to introducing automation of bus circulation within the depot, requiring less qualified personnel to manage depot operations and reducing operation times for routineer depot activities like parking, cleaning, charging, etc, but providing at the same time an internal mean of transport for employees. The traffic environment has been like an urban one, with interaction with car/bus/trucks and pedestrians.

Figure 1: Madrid Mega site: Carabanchel bus depot

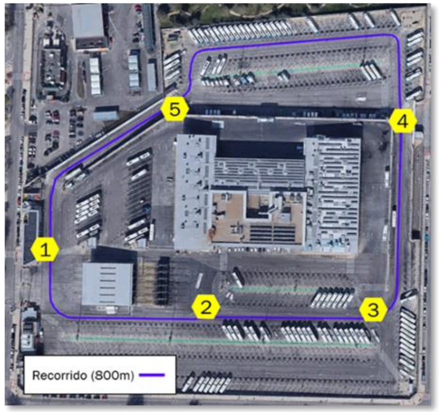
The pilot at Carabanchel bus depot involved automated vehicles (AVs) with perception sensors, control mechanisms, and centralized decision-making units, testing services such as the 5 stops (for depot internal transport), auto-parking, and teleoperation, always during weekdays, on the conditions listed in Table 3.

Table 3: Madrid Mega site: Carabanchel operation conditions

Variable Name	**Value for the Site**
Area type (In- or outside built-up area)	Outside built-up area
Incidents	None.
Traffic composition	Buses are dominant. Mixture of cars (service cars) and trucks, as well as VRU (pedestrians - employees).
Traffic conditions	The traffic density varies across the area and across the day, considering depot rush hours very early in the morning and evenings. Weekdays and usually in the morning (08:00 – 14:00)
Traffic control	N/A in Carabanchel
Road type	Urban road type with one or two lanes (depending on the area), 5 intersections. The speed limit inside Carabanchel is 10 km/h, dropping to 5 km/h in the bus cleaning area, and 20 km/h on the bus testing circuit.
Road works	Ongoing works in the upper terrace for building inverted pantographs charging infrastructure, during the operation.
Sight conditions	Clear, glare depending on time-of-day, but generally good sight conditions. Traffic may be hidden by parked buses.
Weather	Road: Mostly dry. Weather: Mostly clear (sunny)

3.3 Services and use cases

Over twelve (12) months, November 2022 to October 2023, the AV fleet performed successfully without incidents, collecting data throughout the whole operation.



1. Main bus depot entrance
2. Main building personnel entrance
3. Upper terrace bus parking and charging area
4. Secondary bus depot entrance
5. Training area

The ***5-stops*** route consisted of an 800m long round trip (circular), giving public transport service to EMT employees, as well as depot external visitors, to Carabanchel's POIs. One of the Tecnobus minibus (Gulliver_1) and one 12m IRIZAR bus (i2eBus) have operated this service inside the depot, where the speed is limited to 10 km/h, dropping to 5 km/h in the bus cleaning area, and 20 km/h on the bus testing circuit.

Covering UC1.1, UC1.2, UC1.3, UC1.6, UC1.10. (Refer to Table 1 for further details).

Early in the morning, considered rush hour inside the depot, both Gulliver and i2eBus safety drivers drove manually their AV outside boxes, towards the first stop, i.e., Main Building. Once at the first stop, the drivers started the service by using their dedicated HMI, changing to autonomous mode. The 5 stops service collects/drops EMT employees at any of the 5 stops, on a round trip basis. While driving around the depot, always at allowed speeds, it overcomes non-automated vehicles as well as pedestrians.

As soon as a passenger got on the bus, the safety driver took this into account (occupancy); while when he got off the bus, the passenger selected on the dedicated HMI his/her acceptance (refer to Figure 13).

The service runs until the afternoon. One of the two Gullivers (Gullliver_1) buses was manually driven back to boxes for charging and/or maintenance. While i2eBus was parked automatically in its designated parking spot, until late afternoon, when it was manually driven back to boxes for charging.

Wednesdays have been a particular day at the depot as it is students' day visit. SHOW took profit of this (almost) weekly event to present the project to young generations as well as a tour around the depot, visiting the different areas (training, boxes, main building, etc …).

The ***auto-parking*** has been operated by the 12m i2eBus IRIZAR bus, meant primarily to manage the depot and auto park the e-bus during the day, once the 5 stops service is completed (sometime in the afternoon).

Covering UC1.8, UC3.3, UC3.5. (Refer to Table 1 for further details).

i2eBus' safety driver selected in his dedicated HMI the designated parking spot. Next, the 12m eBus could drive in automated mode to the selected slot, prior to performing the parking manoeuvre; and next to park in the selected slot automatically (no driver's intervention). This auto parking use case has successfully run in weekdays.

UC1.8 was validated and operative not for the full twelve (12) months due to the fact Madrid local partners prioritised the 5 stops service to be ready for Villaverde scenario. Occasionally, at the beginning of the demo period, the platoon was used to move the parked i2eBus to boxes, for being charged.

Teleoperation has been tested with one Gulliver minibus, including both supervision and actuation on the vehicle.

Covering UC1.7. (Refer to Table 1 for further details).

The operative is taken inside the depot's main building, from a remote-control desk, where the technical personnel in charge is remotely controlling the second Gulliver (Gullliver_2) inside boxes. This use case has successfully run in weekdays.

This control desk could be potentially integrated into the central control centre (Servicio de Ayuda a la Explotación, S.A.E.) that EMT has at its main headquarters, from which all the on-street bus operations are managed

Moreover, mobility pattern identification was developed by the Hellenic Institute of Transport (HIT)/Centre for Research and Technology Hellas (CERTH), based on the dataset collected in the 5 stops service, inside Carabanchel depot. Refer to [4] for further details.

During the operation phase in Carabanchel, the C-ITS service "Speed Limits" has been used to provide information to vehicle fleets operating in the area. Given that the bus depot is a low-speed environment, various speed limits have been tested, ranging from 10 km/h to 20 km/h, which is the maximum allowed within the parking zone of the depot. This approach ensures that the speed limit information is tailored to the specific operational context, enhancing safety and compliance among the vehicles.

The goal of this service is to enhance driver awareness, promote safer driving behaviour, and support the development of autonomous driving systems by providing reliable, real-time speed limit data directly to vehicles.

Once the equipment was set up and communication with the C-ITS Hub was successfully verified, it was possible to conduct the different use cases of the Madrid pilot with the support of the Speed Limit service. These tests aimed to evaluate various aspects of the system, including data transmission accuracy, responsiveness of the speed limit notifications, and the effectiveness of safety alerts. Each test was designed so as to assess the performance of the automated bus fleet in a real environment.

Figure 2: Madrid Mega site: Speed limit C-ITS service RSU equipment deployed

Throughout the testing process, the key metrics such as vehicle behaviour, communication reliability, and system integration were monitored.

To facilitate this, in addition to the equipment related to the RSU and the necessary setup, i2eBus Irizar bus was utilised, which was equipped with an On-Board Unit (OBU) and a Human-Machine Interface (HMI). The HMI allows for the visualization of the speed limits transmitted from the C-ITS Hub, ensuring that the safety driver receives in real-time updates on applicable speed restrictions.

Figure 3: Madrid Mega site: AV HMI used and speed limit notification visualization.

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3.4 The fleet and infrastructure

Madrid has operated three (3) AVs: one (1) IRIZAR 12m bus (i2eBus, Figure 4 upper left), and two (2) Tecnobus minibuses, i.e. one to operate the 5 stops service (Gulliver_1, Figure 4 upper right) and another other to operate UC1.7 (Gulliver_2, Figure 4 below). Refer to Table 4 for further details.

Figure 4: Madrid Mega site: The fleet in Carabanchel

As for the two (2) Renault Twizy provided by TECNALIA, they have been devoted during development phase (in WP7), to transfer AV algorithms verified (in WP11.1) and technically validated (WP11.2) to the minibuses (Gulliver) and the 12m bus (i2eBus). The Twizy do not have the capacity to transport passengers.

The functionalities developed for SHOW fleet correspond with SAE L4 behavior and compliance in the ODD selected and ambition of the tests. As for the SAE level reached on the field trials, the vehicles maintain a SAE L4 behavior when in their specific ODD; in the scope and scale of the operation provided several transitions were issued whenever any part of the automated driving system was unavailable, or with a reduced performance, triggering a transition to manual, and ending the SAE L4 operation, until manually restored.

The vehicles have not been certified to a L4 level according to Instruction 15 / V-113 (now obsolete and substituted by Instruction VEH-2022-07), due to the fact the instruction is not completely suited for the kind of vehicles that were selected for the Madrid site, which dynamic behavior cannot achieve the specifications required by the instruction.

SHOW AVs are being stored and serviced alongside the rest of the vehicles, that EMT manages on daily basis. The infrastructure to charge, store and service site’s fleet is hence provided by EMT. Several charging points are available in the training area and in the general parking area.

As for the C-ITS service "Speed Limits", a hybrid V2X (Vehicle-to-Everything) Roadside Unit (RSU) has been deployed in the Carabanchel area, covering the part of the routes of the automated fleets of vehicles, enabling the communication between infrastructure and vehicles, and the exchange of information to improve the overall safety of the autonomous driving during the execution of the different use cases.

Figure 5: Madrid Mega site: Infrastructure - RSU location in Carabanchel.

Table 4: Madrid Mega site: Characteristics of the operated fleet

Test/Use Case	Deployed fleet characteristics								
	Vehicle brand & model	**Vehicle type**	**SAE Level reached for the field trials [1-5]**	**TRL level reached for the field trials [1-9]**	**Summary of upgrades held during the project (in consistency with D7.2)**	**HMI and Hand-over strategies (in consistency with D7.2)**	**Maximum speed reached during the trials (km/h)[11]**	**Average speed during the trials (km/h)**	**Maximum capacity of vehicle**
UC1.1,1.2,1.3,1.6, 1,10 UC1.7	TECNOBUS - Gulliver	Minibus	4	6	Enhanced environment and perception (TECNEP01/02) Enhanced AV decision and driving functions (TECND01/02) Enhanced V2 comms protocols (TECNV201)	Shared control: managing the transition manual & automated driving modes, via the safety driver's HMI[12]	12.5 km/h	9.9 km/h	10 PAX + 1 safety driver
UC1.1,1.2,1.3,1.6, 1.10 UC1.8 UC3.3, 3.5	IRIZAR – i2eBus	Bus	4	6	Same as above	Same as above	15.65 km/h	11.9 km/h	25 PAX + 1 safety driver

[11] Maximum and average speed values are acording to current calculations. Following the detailed filtering applied in WP13 impact assessment, differentiations may occur.

[12] In compliance with the override tests considered at the ***instruction 15 / V-113(***15.V-113-Vehiculos-Conduccion-automatizada.pdf (dgt.es)***)***

3.5 Passengers and safety drivers

The service including passengers in Carabanchel bus depot was the 5-stops service (refer to Table 1). And the most important goal of the 5-stops service at the depot was to improve automated driving to reach SAE L4 experience both for the users (passengers: basically, EMT employees and visitants) and the safety drivers, encompassed in the public transport sector.

To ensure the continued service within the Carabanchel scenario, the safety drivers have been trained – by means of theoretical and practical sessions - in the operation of the services and in the safe use and basic troubleshooting of the integrated technology.

For this purpose, EMT Madrid organized comprehensive in-person training sessions aimed at educating its personnel about automation from multiple perspectives, including technical, operational, and strategic aspects. The training took place at the Carabanchel bus depot training centre and was led by experienced EMT Madrid managers. Through a series of detailed PowerPoint presentations, employees, including bus drivers (from whom EMT and IRIZAR selected the twelve (12) safety drivers), mechanics, technicians, etc., gained valuable insights into the implementation and management of automated systems, preparing them for future roles in a more technology-driven operational environment.

Figure 6: Madrid Mega site: Safety drivers

For the operation period, there was a total of twelve (12) safety drivers and 5.535 PAX. The number of passengers varied from day to day, giving public transport service to EMT employees, as well as depot external visitors.

Figure 7: Madrid Mega site: Carabanchel bus depot end-users

In addition to EMT employees, a significant number of scholars also used the 5 stops service during Wednesdays school visits. Through the year, on Wednesdays, EMT often receives school visits under a Corporate Social Responsibility policy agreement, to show children how the buses they normally see on the streets of the city and pick to go to school are operated and maintained. During SHOW project life, 14 schools have visited Carabanchel bus depot.

Figure 8: Madrid Mega site: Carabanchel bus depot school visit[13]

[13] Faces covered for legal reasons

3.6 Data collection

The Madrid site employed a variety of tools to gather and stream key data (e.g., vehicle location, speed, number of passengers, etc.) in real time. These data were logged in the Madrid Local Data Management Platform (MLDMP) and later utilized for KPI (Key Performance Indicator) calculations and impact assessments. The collected data were displayed on dashboards for monitoring and analysis purposes. In addition to vehicle data, external information such as weather conditions was incorporated via the OpenWeatherMap API, enhancing the dataset and supporting KPI development. Data streams from the fleet, including vehicle information, location, speed, passenger count, and mileage, were transmitted in real time.

The data infrastructure at the Madrid site was built using a containerized architecture based on Docker, chosen for its flexibility, modularity, and ease of maintenance. Several containers were deployed, including the Mosquitto broker, which uses the MQTT protocol to facilitate lightweight communication between connected IoT devices, the architecture described is shown in Figure 9 . This broker was configured in bridge mode to connect the local system to the SHOW Data Management Platform (SDMP), ensuring seamless real-time data transfer between the vehicles and the central platform for project-wide analysis.

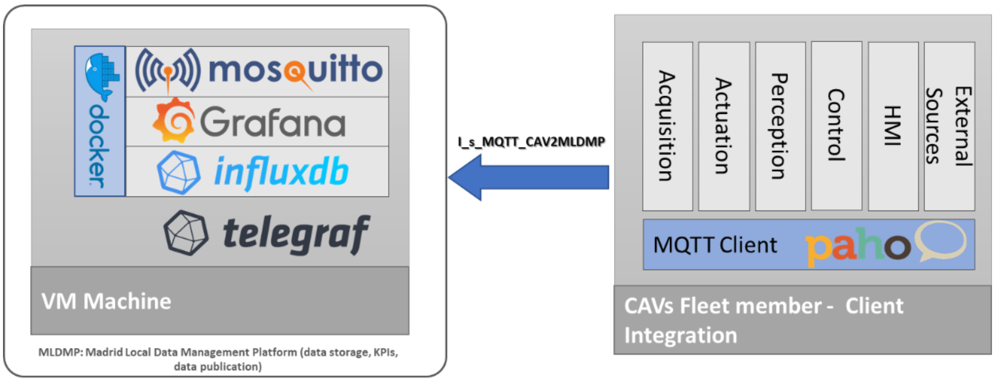

Figure 9: Madrid Mega site: MLDMP main technologies used.

The messages transmitted by the vehicles were stored in InfluxDB, a time series database chosen for its ability to handle the project's specific data formats (JSON) and protocols (MQTT). Storing the data in this way facilitated further analysis and enabled detailed visualizations through Grafana, an open-source platform for creating custom dashboards. Grafana’s compatibility with the backend systems at Madrid allowed for efficient KPI monitoring.

In addition to InfluxDB, Telegraf was installed to manage data flow between the Mosquitto broker and InfluxDB, while also monitoring the overall performance of the server infrastructure. On the client side, each autonomous vehicle in the fleet was equipped with Paho C++ libraries, integrated into the AUDRIC® automation system to ensure consistent data formatting in line with project specifications. The clients collected data from various subsystems within the vehicles (such as acquisition, perception, and control) and sent this information to the MLDMP broker for central processing.

Query for occupancy data

```
occupancy_query = '''from(bucket: "SHOW-TECNALIA")
  |> range(start: <START_TIME>, stop: <END_TIME>)
  |> filter(fn: (r) => r["topic"] == "show/2ae2ed0c-84cf-442f-8ba8-1fd01a49acc3/<VEHICLE-ID>/passengers")
  |> filter(fn: (r) => r["_field"] == "passengerData_occupancy" or r["_field"] == "switchToManual")
  |> pivot(rowKey:["_time"], columnKey: ["_field"], valueColumn: "_value")
  |> group()
  |> sort(columns: ["_time"], desc: false)
  |> fill(column: "switchToManual", usePrevious: true)
  |> fill(column: "passengerData_occupancy", usePrevious: true)
  |> fill(column: "switchToManual", value: false)
  |> fill(column: "speedValue", value: "0")
  |> map(fn: (r) => ({ r with switchToManual: float(v : r.switchToManual) }))
  |> map(fn: (r) => ({ r with passengerData_occupancy: float(v : r.passengerData_occupancy) }))
  |> map(fn: (r) => ({ r with occupancyAutomated: (1.0 - r.switchToManual) * r.passengerData_occupancy }))
  |> filter(fn: (r) => r["switchToManual"] == 0)
  |> yield(name: "last") '''
```

Figure 10: Madrid Mega site: Data collection query

Throughout the project, connectivity between the MLDMP and SDMP was maintained using secure cryptographic keys. These certificates had to be manually updated each year, which occasionally led to periods of data loss. A certificate administrator is recommended to maintain continuous, secure connectivity. Additionally, issues with data collection emerged during operations. For instance, battery data was often dependent on manual input, leading to incomplete or inaccurate reporting in some cases. Location data also faced challenges due to GPS misconfigurations or poor weather conditions, affecting the accuracy of satellite corrections. These factors resulted in some erroneous data being transmitted. To minimize data loss caused by intermittent connectivity, the Mosquitto broker container was configured to automatically restart every day.

For further data processing and sanitization, a custom Python script was implemented to query the InfluxDB database. This script played a critical role in filtering out irregular values, such as abnormally high speeds, negative data entries, or readings from geofenced areas—typically caused by faulty sensor inputs. The data was queried from influxDB depending on the vehicle, and timeframe to be processed, an example of one of the queries used in this process is depicted in Figure 10. The raw data was then flattened into a standardized format using the Pandas library, a well-established tool for data manipulation and analysis. By processing the various data streams into cohesive packets, this step ensured that the information was clean and structured for downstream analysis, contributing to more reliable KPI calculations. An snippet of the speed data filter used for one of the vehicles is shown below in Figure 11, visualized via Pandas library.

Speed Data Automated

```
frame_speed_automated = frame_speed
frame_speed_automated = frame_speed_automated[frame_speed_automated['switchToManual']==0].copy()
frame_speed_automated = frame_speed_automated[frame_speed_automated['speedValue']>0.1].copy()
print("Speed average value: " + str(round(frame_speed_automated["speedValue"].mean()*3.6,2)))
frame_speed_automated.describe()
```

✓ 0.0s

```
Speed average value: 7.26
```

	speedAutomated	speedValue	switchToManual
count	4956.000000	4956.000000	4956.0
mean	2.017232	2.017232	0.0
std	0.881903	0.881903	0.0
min	0.110000	0.110000	0.0
25%	1.420000	1.420000	0.0
50%	2.110000	2.110000	0.0
75%	2.860000	2.860000	0.0
max	8.760000	8.760000	0.0

Figure 11: Madrid Mega pilot site: Data collection filter

Additionally, the Python script facilitated the creation of detailed visualizations, helping to further refine the dataset and support project reporting. These visualizations provided insight into the cleaned data and offered stakeholders a clearer understanding of the performance metrics being evaluated. By integrating real-time data collection with these post-processing techniques, the Madrid site was able to maintain the accuracy and integrity of its KPIs reporting and analysis throughout the project. An example of visualization is shown below in Figure 12, where it is depicted, on the left, the speed data from the Gulliver and the geolocation for i2eBus, on the right.

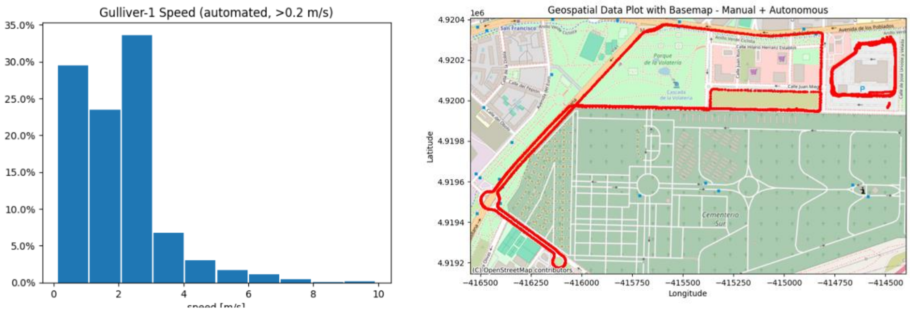

Figure 12: Madrid Mega site: Data collection visualization[14]

So as to be able to assess the impact on user experience, awareness and acceptance, passengers were asked to express their experience by filling in the dedicated surveys, using the QR located at the exit door of the bus or by simply pressing the touch screen when leaving the bus (Figure 13). As for Madrid KPIs, this is visualised in SHOW's dashboard (https://show-project.eu/show-dashboard/).

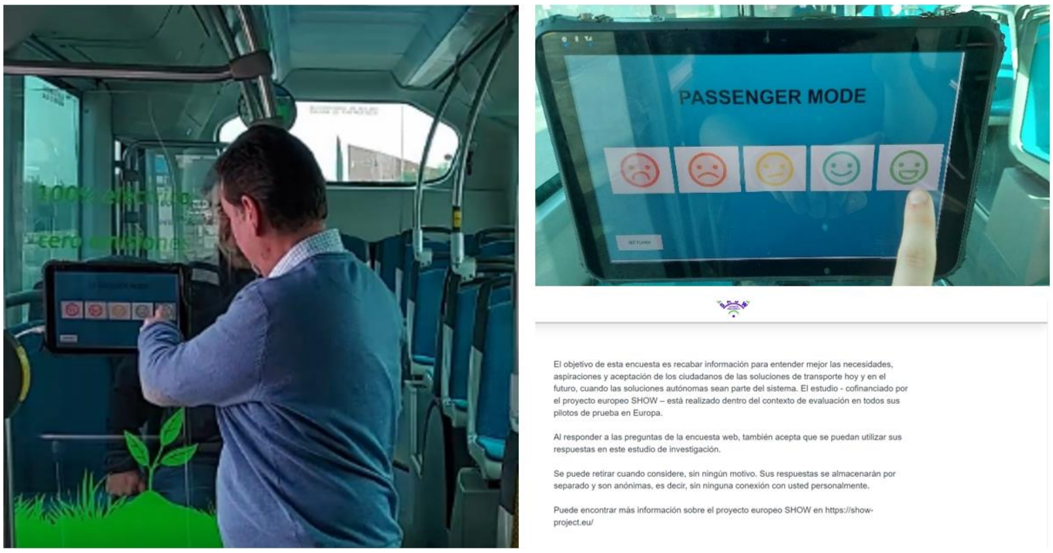

Figure 13: Madrid Mega site: End-user subjective data collection tools

[14] Source: Madrid MLDMP collected data

3.7 Pilot operation key findings

Pilot operation key findings per Use Case

High level findings per Use Case		
Use Cases	Overall qualitative performance score (1-3[15])	Justification
UC1.1: Automated passengers/cargo mobility in Cities under normal traffic & environmental conditions UC1.2: Automated passengers/cargo mobility in Cities under complex traffic & environmental conditions UC1.6: Mixed traffic flows UC1.10: Seamless autonomous transport chains of Automated PT, DRT, MaaS, LaaS	3	Satisfactory operation of the 5-stops service, with more than 5,000 passengers. Both safety drivers and passengers found the service useful and acceptable. There were no events between the AVs and non-AVs nor travellers within the boundaries of the Carabanchel Depot. The AVs, clearly identified as demo vehicles, travelled at safe speeds and within know routes and timetables, ensuring safe operation, satisfaction in the service and good acceptance level. No incidents occurred.
UC1.7: Connection to Operation Centre for tele-operation and remote supervision	3	The remote controlling or teleoperation service was found very interesting internally at EMT, and there is the intention to potentially integrate EMT's the central control centre that EMT has at its main headquarters, from which all the on-street bus operations are managed, with the remote-control desk.
UC1.8: Platooning for higher speed connectors in people transport	2	The platooning service was found interesting internally at EMT due to the possible implications in reducing the cost of operation (1 CV as leader, AV as followers) for an automated bus depot management. Further testing and development required to better assess the cost-savings of the solution.
UC3.3: Automated parking applications UC3.5: Depot management of automated buses	2	Safety drivers demonstrated the auto-parking manoeuvre via a dedicated HMI. Reported occasional localization drift and missing parking slot. Moderate satisfaction.

[15] 1 [Low] – 2 [Medium] – 3 [High]; success qualitative score, considering all aspects (technical, user acceptance).

Key challenges and mitigations outcomes

There were no incidents during the operation at Carabanchel. The key challenge was mostly positioning errors, which have been improved in Carabanchel environment.

Table 5: Madrid Mega site: Carabanchel key challenges

Challenge	**Type** (Operational, Technical, Business, Other)	**Mitigation**	**Mitigation outcome**
Localization errors.	Technical	Updated vehicle perception SW as well as additional LiDAR and GNNS.	Reduce localization errors, with an increased satisfaction of the safety driver .
Actuator reliability - HW	Technical	Reworked the actuator and replaced several components that were degraded due to the continuous usage.	HW problems were almost completely removed from the system, some comms error remained.
Actuator reliability - comms	Technical	Reworked comms to reduce latency and ensure easy and reliable hand-over and re-start in fail events.	Reduced the fail rate of the comms, not completely removed. Drivers satisfied with hand-over strategies.
Acceptability by bus drivers	Business	Training courses	Quite surprisingly, the acceptance and interest from most bus safety drivers and EMT employees has been very high. Notable interest on CCAM issues and less reluctance than expected

The passengers´ and safety driver's point of view

In the case of safety drivers and general users most of the feedback has been gathered through the questionnaires and surveys defined by the project.

Operating the 5-stops service in Carabanchel has denoted clear acceptance and satisfaction from the end-users, both the passengers and the safety drivers (refer to section 3.5 for further details).

- The first ones, mostly *EMT employees*, used the service when moving around the depot and enjoyed the ride. Many of them are bus drivers and want to know about the driving “driverless” mode. Pleasantly there have been no mistrust on the service nor the system.

- *Passengers* generally perceive autonomous buses operating within such contexts (with a safety driver on board) as a safe and innovative step forward. However, there remains a certain level of caution regarding fully autonomous buses (without a driver) or also operating in open traffic, where interactions with other vehicles and pedestrians are more unpredictable. This caution, combined with the novelty of the technology, means that public acceptance is still evolving, but education and transparency about the safety, reliability, and benefits of autonomous systems can enhance user trust over time.

- *School children* enjoyed the fact that the safety driver was not holding the steering wheel and question “why is there a driver, then?”. It was explained to them during the visit that Spanish law obliges to have a driver always on board. Visitors – familiar with the public transport sector – were curious about the maturity of the technology. All these profiles depicted positive responses on perceived comfort and safety.

- *Safety drivers* were trained with the system and service(s) before the pre-demo phase. This was a very relevant action. Both IRIZAR and EMT safety drivers have been very much involved and cooperative during the whole process, as they were there from the very beginning. It is true to say that with the auto-parking service – which does not involved passengers – they were not that confident due to the localization errors. From their comments it can be derived that is difficult for them to understand why there were times when the service worked perfectly and others not that well.

- Interestingly, the acceptance among professional drivers has also had a positive impact on passengers' views. Knowing that drivers are not largely opposed to autonomous buses (as they currently need safety driver as well) helps ease concerns among users about job displacement and the overall reliability of the system.

- Ultimately, users appear ready to embrace autonomous buses in carefully controlled environments, as long as safety remains a priority and transparency about the technology continues. Public acceptance will likely grow in parallel with technological maturity, further integration into urban transit systems, and user education initiatives.

The stakeholders’ point of view

As from the PTO’s point of view, Carabanchel’s large scale pilots showed: (1) that there are potential savings in non-productive hours at bus depots, (2) the importance of training, (3) autonomous mobility solutions are mature enough to be deployed in semi-controlled environments (such as bus depots); however, there are still uncertainties about open traffic situations, where further technology development is needed.

On the other hand, OEMs believe that there are potential new business lines, where the effort is focused on industrialization and deployment. In Spain, and from the public administration’s perspective, they are not prepared for the time being to cope with the sector's demands in terms of autonomous mobility due the rigidity of the current regulatory framework and would need to enable field testing without the current complex and costly procedures.

3.8 Key local pilot events

SHOW Madrid Mega site activities have been widely visited during the project life. As Carabanchel bus depot is also the flagship of EMT Madrid in terms of electrification, most of the site visits included visiting and explaining EMT's CCAM activities. Refer to [3] for further details on Madrid's overarching activities.

The following are some of the key local events taken place in Carabanchel bus depot:

- [Oct. 18th and 19th, 2022]: SHOW Demo Board meeting and 3rd Pan-European workshop in Madrid with site visit to the Carabanchel bus depot. UITP general secretary, Mohammed Mezghani, during the site visit to Carabanchel bus depot.

Figure 14: Madrid Mega site: 3rd PanEuropean workshop

- [Jun. 1st, 2023]: APTA/FTA delegation visit.
- [Jun. 10th, 2023]: UITP members' delegation visit during UITP Global Summit in Barcelona (UITP Study Tour).

Figure 15: Madrid Mega site: UITP delegation visit

- [Sept. 19th, 2023]: Visit of CDTI delegation (Spanish Centre for the Development of Industrial Technology) to EMT Carabanchel bus depot to learn about the SHOW initiatives in Madrid and the automated buses, with nine (9) participants from CDTI and INSIA (University Institute for Automotive Research), to explore further opportunities for automation of buses.
- [Jan. 10th, 2024]: Madrid-Mumbai Knowledge Exchange visit.
- [Jan. 10th, 2024]: C40 Cities Finance Facility, with Mumbai Public Transport Authority.
- [Apr. 11th, 2024]: SHOW MAMCA workshop.

Figure 16: Madrid Mega site: MAMCA workshop

- [May 30th, 2024]: Delegation from Uzbekistan Transport Ministry.
- [Sept. 24th – 26th, 2024]: UITP training course on e-bus operation and maintenance.

3.9 Lessons learned & Recommendations

The focus of the Madrid Mega Site pilot in SHOW has finally been to explore the potential optimization of bus depot operations while at the same time making AVs more attractive to users by deploying public transport services.

Despite the difficulties in deploying the urban open traffic demo, the main and extremely relevant impact is the learning and research on how automation can help improving efficiency in bus depot management, and the confirmation that technology is mature enough to be deployed in semi-controlled environments such as a bus depot, bringing also further possibilities with additional operations such as charging processes.

For this reason, public and private cooperation is key in this process, and operators, manufacturers and other stakeholders involved need to maintain it to help the market providing more (and cheaper) autonomous solutions; research and innovation projects with more realistic funding schemes can play a key role in this process.

Finally, amongst the lessons learnt and recommendations in Carabanchel bus depot, it is worth mentioning the following ones:

Technical:

- Confirmation that technology is mature enough to be deployed in semi-controlled environments such as a bus depot, bringing also further possibilities with additional operations, such as automated charging processes.
- Improve hard braking, to be able to predict what is going to happen next on board. The main cause of hard brakes is regular and repeated, when caused by weather and environmental issues. The properties of leaves and dust particles must be possible to distinguish from those of pedestrians and real obstacles by machine learning, to be totally filtered out.
- Develop towards a technology that is easier to integrate into existing infrastructure, physical as well as digital, with lower requirements for adaptations and maintenance.
- Make sure there is a standard of the use of sound and visual information for the other road users: Persons with hearing problems do not know if the AV is close behind or is about to stop, and blind persons do not understand what the sound stands for.
- Events describing activation of emergency brake might be hidden by the fact that this is information comes from the (manually written) event recording only, e.g., where the LiDAR sensors did not register a VRU but the safety driver. The vehicle will most probably not have any recording of the event, since the VRU was not “seen”.
- A “black box” function in the vehicle system could be used to recall detailed information after a critical event which is of large importance.

Operational:

- Passengers and safety drivers clearly accepted the autonomous driving services. They consider the speed to be slow and understand, at the same time, it is safer.
- Training the safety drivers is compulsory, by means of theoretical and practical sessions, in the operation of the services and in the safe use and basic troubleshooting of the integrated technology.
- The remote controlling or teleoperation service was found very interesting internally at EMT, and there is the intention to potentially integrate EMT’s central control centre, based in its main headquarters, from which all the on-street bus operations are managed, with the remote-control desk.
- As for replicability, the cost-benefit ratio for adapting existing non-autonomous buses is relatively low, approximately 26% of the initial cost of an e-bus plus the cost of the e-bus itself. Evolution in technology will make this cost-increment even smaller, therefore, there is significant potential for scaling up, making it worthwhile to initiate discussions with bus manufacturers to test further solutions on new automated bus models.

Business model:

In the context of SHOW, a preliminary and brief cost analysis has considered both costs and savings assuming the automation of the bus fleet at a generic bus depot such as the Carabanchel one, exclusively considering the autonomous operations within the bus depot. It is important to remark that this is a rough initial calculation which, potentially, could be much more elaborated:

- Bus drivers:

According to the collective agreement with the human resources department, the trade unions and the operational requirements established in the company, bus drivers have up to 13 minutes to enter and 13 minutes to leave the bus depot upon arrival at the end of their journey (this is the official time they have allocated within their labour journey). That is a total of 26 min/day per driver. On average, there are 350 drivers per bus depot, and 22 working days in a month. That makes a total of 9,120 min/day (152 h/day), 200,220 min/month (3,337 h/month) that potentially could be saved if operations become autonomous. To translate that into euros and considering an average salary of a bus driver with 14 years in the company, the salary is 43,178.47 €/year without considering social security, and 57,155.34 €/year considering social security; this second salary including social security is the cost for the company. Considering an average of 22 working days a month and an average of 8 hours a day, drivers work a total of 2,112 h/year. If we divide the salary by the hours, this results in an average salary cost of 27.06 €/h. Going back to the saved hours and multiplying them by the hourly cost, automation could save up 4,113.2 €/day per bus depot for the specific role of bus driver waiting at the depot (90,488.64 €/month for a bus depot like Carabanchel). Safety drivers' costs are not included as within the bus depot they would not be necessary.

- Remote operators (teleoperation)

  If the autonomous bus encounters a situation where it cannot act, a remote operator will take control. Remote operations could be performed by the current "vehicle-movers" staff. This specific category of staff takes care of moving buses around the depot, for whichever reason needed. That makes 6 persons per day that should be trained to upgrade their skills in order to become remote operators. These workers have an average salary 20% lower than that of the bus drivers, so we can consider a cost for the company of 45,724.27 €/year per each. Considering those 6 persons, remote operators would mean a total cost of 274,345.62 €/year. However, this is already existing personnel, and therefore this cost is not included within the savings calculation. Simply, vehicle movers will be turned into remote operators after the proper training. The clear advantage of this change is that, since vehicle-movers (now teleoperators) would not need to physically go to the vehicle, more manoeuvres could be performed in less time. Also, since less people would be moving around in the depot, safety concerns would be reduced.

- Engineering costs:

  Assuming that the retrofitting of buses would be done "in-house", the company assumes an average dedication of 950 hours/year dedicated to defining, plan and execute the automation tasks from our engineers. Engineers have an average salary of 27.06 €/h, meaning a cost of 25,707 €/year for the engineering process. This task and cost would affect only at the beginning of the retrofitting project (just one time) as this initial development would serve as the foundation for future developments on other bus models.

- Mechanic workers:

  The mechanics are responsible for assembling the components on the bus and also for repairing them when breaking down or misaligning. A similar average salary as for the "vehicle movers" is considered, as well as an average dedication of 40% of their time for these tasks. It should also be noted that dedication hours are higher at the beginning of the process (learning curve). Therefore, for the "in house" automation of vehicles there would be an average cost of 18,289.71 €/year per mechanic worker.

- Equipment:

  For the current calculation, the investment on equipment for retrofitting one single bus is estimated in approximately 75,000 €/vehicle. This cost includes the purchase of the equipment indicated in chapter 4.1., but not the hypothetical maintenance of it.

- Total cost

  Despite the figures, the calculation of the total cost analysis is not evident nor easy to obtain, as it is important to consider the following limitations and considerations:

  - Occupations of workers: the 26 min "saved" at the depot cannot be transferred that easily to another occupation. "Rigidity" of the contracts and laws, made this option not that flexible nor possible. However, one of the purposes of this paper is to highlight the potential for more efficiency in bus depot operations by automation.
  - Price of technology is not entirely predictable. It is envisioned that technology will become cheaper as soon as more manufacturers engage. However, this has not happened yet.
  - The initial upfront cost of purchasing the equipment for 450 buses (average amount of buses in one bus depot) is considerably high and makes the calculation quite complex as it should consider the correspondent depreciation. With the 75,000 € considered per bus, the total cost to retrofit the whole fleet at Carabanchel bus depot would sum up to 33,75 million euro plus mechanic and engineering costs (roughly estimated in 8.2 additional million €).
  - It is important to consider that in the Madrid bus depot pilot, vehicles have been retrofitted by the partners involved. The costs reflect the hurdles and challenges of retrofitting a vehicle for the first time, and in this case, it should also be considered that the retrofitted vehicles were already quite old and therefore giving extra issues which demanded more man-hours than expected.
  - In the future, EMT Madrid (as a public transport operator) is considering on directly acquiring the autonomous vehicles from the manufacturer. According to Ongel et al (2019) [5], it is suggested that the acquisition prices are estimated to be 20% for buses with autonomous functions in 2030.

Therefore, despite the evident savings in personnel costs (up to 1 million € per year per bus depot), it is not possible to conclude with a proper cost analysis of costs and savings. The high upfront cost of purchasing the equipment and retrofitting conventional buses, shows a low cost/benefit ratio for adapting existing non autonomous buses (around 26% of the initial cost of an e-bus plus the cost of the e-bus itself), and the uncertainty about some aspects, including depreciation, makes extremely complex to provide concluding figures.

4 Villaverde preparatory work and lessons learned

Villaverde environment covers the urban open traffic area defined in Madrid Mega pilot site. Despite Madrid pilot's partners effort in obtaining the city council permits to drive in autonomous mode, in this type of urban open traffic scenarios, was finally not operated due to the lack of this mandatory authorisation.

To address the requests from Madrid city council and to avoid being dependent of charging stop while in service, the initial route defined for La Nave innovation hub was updated to the *"Islazul"* mall. From the passengers' point of view, it was considered very positive. The itinerary included a round trip of 4,13 km connecting *"Avenida de Los Poblados"* area (where there is a high concentration of services), with *"Islazul"* shopping mall, which, beyond its attractiveness as a commercial and shopping hub, it belongs also to the Park and Ride network of the city, as it is by the M40 ring road. Refer to Figure 17 for Villaverde urban open traffic route, which holds the following advantages:

- Closer to Carabanchel bus depot, and therefore, more battery range to operate with, and easier intervention if needed.
- Better road surface condition in general (less need for municipal 'repairs').
- Left turns with traffic lights
- Easier contact with the current company managing the traffic light infrastructure in the area.
- Maintains usefulness as a means of transport (connects with the Mall and includes six (6) bus stops)
- High visibility towards users, who are visiting the shopping centre

Figure 17: Madrid Mega site: Villaverde route, connecting *Islazul* shopping mall

The manually driven zones were necessary due to the complexity of interactions with other vehicles and vulnerable road users (VRUs) in the area. This design allowed the pre-testing of the vehicle's capabilities in both controlled and dynamic environments, providing a comprehensive assessment of its performance. By simulating real-world conditions, it was possible to gather valuable data on how the vehicles respond to various challenges, ensuring that they can operate safely and effectively in diverse traffic scenarios.

Although the solution originally thought for the vehicles has been fully realized, tested, and improved upon the 5 stops service, which took place in the Carabanchel bus depot, moving towards activities in open traffic required further improvement. Hence, from the technical point of view, there were two key points to be enhanced in the vehicles:

- Firstly, the laser-based localization system, which needed to be updated and improved upon, to better suit the requirements of the urban environment of piloting area
- Secondly, an upgrade of the installed LiDARs, substituting the Velodyne sensors (that were enough for the Carabanchel site), with OUSTER sensors in the case of the Irizar 12 meters long bus, which provide a denser point cloud and up to longer distances.

This, of course, helped improving the obstacle detection algorithms, which were brought to a level more in line with the necessities of the urban environment.

Once the itinerary was defined, and while waiting for the permit, some tests were conducted in manual driving mode, in order to 3D map the environment and fine tune the solutions. All AVs were clearly identified as testing vehicles.

Figure 18: Madrid Mega site: Testing vehicles identification

Figure 19 illustrates the quality of localization using a GNSS solution across different areas of the route. The green areas indicate the highest quality of localization, with a covariance under 5cm. However, in one of the streets, the quality diminishes drastically, with precision dropping to approximately 30cm. This reduction in quality is attributed to a low number of tracked satellites, which hampers the localization capabilities and disables automated functions in a small part of the route. The presence of foliage in this area might be the cause, as it obstructs the satellite signals, reducing the accuracy of the localization data. This finding highlights the importance of considering environmental factors when designing and deploying automated vehicle systems.

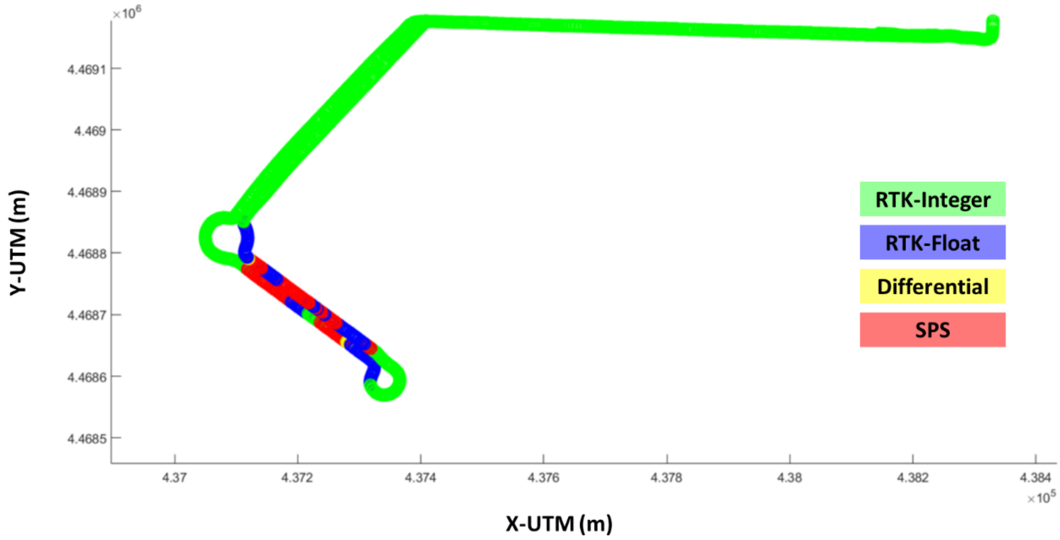

Figure 19: Madrid Mega site: Villaverde localization quality

EMT Madrid proposed the Madrid City Council the following operational program to minimize any inconvenience from the traffic management point of view:

- Service running from as early as possible, until the end of June 2024.
- 2 departures per week (each lasting approximately 1 hour), both buses (this means more or less a couple of laps of the route).
- At times of lower traffic intensity during working hours, based on traffic capacity provided by Madrid City Council. It is estimated that the most suitable time slots were around 11 a.m. and 4 p.m.
- Marking out the stretches where SHOW buses would circulate in autonomous mode (cones or any other solution established by the Madrid City Council), only one lane of traffic in each direction, the rest being regular bus lanes.

Despite the fact that everything was ready for the real traffic piloting phase in February 2024, and after many requests done by EMT, on July 16th, Madrid City Council indicated that the permit was not going to be issued and therefore, the real traffic piloting could not be carried out.

However, quite surprisingly, on August 21st, Madrid City Council showed sudden interest in organizing a public event during the European Mobility Week to demonstrate the innovation behind SHOW automated services. Refer to section 5.2, for further details.

In summary, the main lesson learned in Madrid Mega pilot site with Villaverde scenario is that, locally speaking, in Madrid the current ecosystem is not ready to fully support and manage the complexities of CCAM, highlighting the need for more proactive governmental engagement, infrastructure upgrades, and public-private collaboration to pave the way for future mobility innovations, with a very special role to play with regards regulation rigidity to enable testing and piloting this type of services.

5 Public demos

Madrid Mega pilot site has demonstrated two big public demos during its project's life:

- BACSI 2023 run right after the demo phase in Carabanchel bus depot, and it was a request from the Spanish Air Force.
- EMW 2024 public event directly requested from Madrid municipality, to demonstrate the innovation behind SHOW automated services.

5.1 Sustainable and Smart Connected Air Base (BACSI 2023, Albacete)

While preparing Villaverde demo phase, on October 18th and 19th 2023, EMT provided automated bus transfers at the BACSI event in the Spanish Army Air Base in Albacete (*"La Maestranza"*). At the request of the Spanish Air Force, EMT designed and deployed two (2) autonomous bus lines within the base by using the two automated Gulliver microbuses (Figure 20).

A total of 400 PAX made use of the automated transfer service, with a great acceptance by the users, covering a total route of 1.5km (Figure 21). The first automated service (lower, red 1 stop route) moved the Spanish Minister of Defense from the airstrip to the exhibition area; and the second (upper, orange round route), which was open to the public, transported the passengers from the exhibition area to the Tactical Leadership Program (TLP) zone.

Figure 20: BACSI 2023: Spanish Air Force stop service

Figure 21: BACSI 2023: Spanish Air Force tested routes (left) and passengers (right).

5.2 European Mobility Week (EMW 2024, Madrid)

EMW is an awareness campaign promoted by the European Commission aimed at raising public awareness of the use of public transport, cycling and walking, and encouraging European cities, institutions, organisations and companies to promote these modes of transport and to invest in the new infrastructure needed to do so. EMW takes place every year from 16 to 22 September. The theme chosen by the European Commission this year 2024 is 'Shared Public Space', and the motto of the initiative remains 'Combine and move! Shared public space brings many benefits to society. A place where people, transport modes and activities have their own space is a place with more social equity, more road safety, less noise and air pollution and a better quality of life. EMW invites to share public space and that citizens can move safely and comfortably in a pleasant environment, especially pedestrians and cyclists. EMT Madrid participates annually in the EMW with different proposals and initiatives.

In the framework of the 2024 edition, last September 22nd, 'World Car Free Day', SHOW project was presented by Madrid City Council Urbanism, Mobility and Environment Councillor, Mr. Borja Carabante, including the testing on public roads with public. While, Madrid Mega Site partners organized a real traffic presentation of SHOW project to public, including an urban traffic demo with the Gullivers, Madrid City Council - local authority external to the consortium – provided all the necessary actuation in the public space (road infrastructure).

Figure 22: EMW 2024: Users at the World Car Free Day

The service included an itinerary of 1,4Km (Figure 23) between *"Cibeles"* Square (Madrid Town Hall) to *"Colón"* square (Calle de Villanueva) and back, along the *"Paseo de Recoletos"* avenue, with one single bus stop (drop-on, drop off) at *"Cibeles"* square.

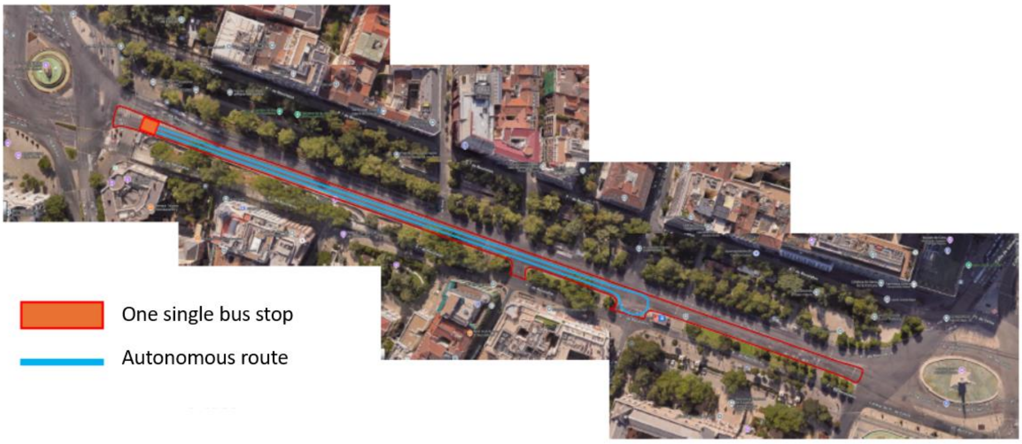

Figure 23: EMW 2024: AVs route, Madrid city centre

In addition to the EMT's minibus, the operations have also been done with the "ShuttlebyCTAG" automated shuttle, developed by the Galician Automotive Technology Centre (CTAG), with whom EMT Madrid signed a Memorandum of Understanding on the 14th September 2022, to keep pushing forward research and innovation as a result of SHOW achievements in the first Madrid Scenario: Carabanchel bus depot, as well as foster cooperation amongst european projects. Regarding the "ShuttlebyCTAG", it is also a 100% electric. With a capacity of 12 passengers and is 5.2 metres long. This shuttle has been developed as part of the European 5G-Mobix project: https://www.5g-mobix.com/ , in which also some SHOW partners participate (i.e. Valeo, ERTICO, Ericsson, Sensible4, among others).

Figure 24: EMW 2024: Shuttle, by CTAG

Figure 25: EMW 2024: SAE L4 Gulliver, by EMT

The preparatory demo testing involved Madrid partners and other collaboration entities (EMT, TECNALIA, Universidad Carlos III, INSIA and CTAG) working both at Carabanchel bus depot and on-site, in order to calibrate the itinerary and to double check the perception and rest of systems. Madrid police service cut the traffic on-site in three occasions:

- September 13th, between 00:00 and 05:00, manually drive both AVs to recognise the route.

- September 21st, between 01:00 and 05:00, autonomous driving of both AVs.
- September 22nd, between 00:00 and 04:00, autonomous driving of both AVs

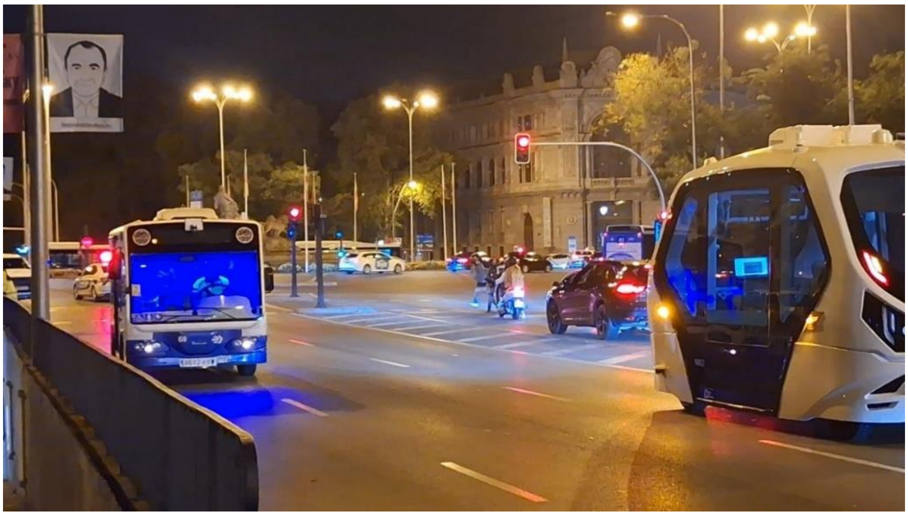

Figure 26: EMW 2024: Preparatory demo testing

In all three occasions all AVs had to return to the depot since the on-site area was not guarded by the police, plus they needed to be charged.

Additionally, and to avoid interference with the 8th edition of the Naval Week 2024 race, taking place on the 22nd of September in the surroundings, Madrid City Council fencing service department, with the support of the municipal Police department, marked out the route.

During the EMW day demo on September 22nd, the users waited at the bus stop upon the arrival of the AVs. The bus stop had information on (1) real time the position of buses and their itinerary and (2) AV's different maximum capacity: Gulliver: 8 PAX, and shuttle by CTAG: 12 PAX. (Figure 27).

The personnel involved in providing both assistance and information to public, was identified with the following badge. EMT Madrid also provided additional staff from its SAM service ("*Servicio de Ayuda a la Movilidad*" - Mobility Assistance Service) to help managing the flow of passengers. (Figure 28).

The service was operational and open to public between 12:00 and 14:00. A total of 14 rounds of trips were done by each AV, with a total of 280 PAX. The overall acceptance and interest were very high, and many passengers asked about the CCAV initiatives in Madrid.

The average speed of the vehicles during the testing was between 10 km/h and 15 km/h for both EMT Gullivers and ShuttlebyCTAG.

Figure 27: EMW 2024: Bus stop real time information.

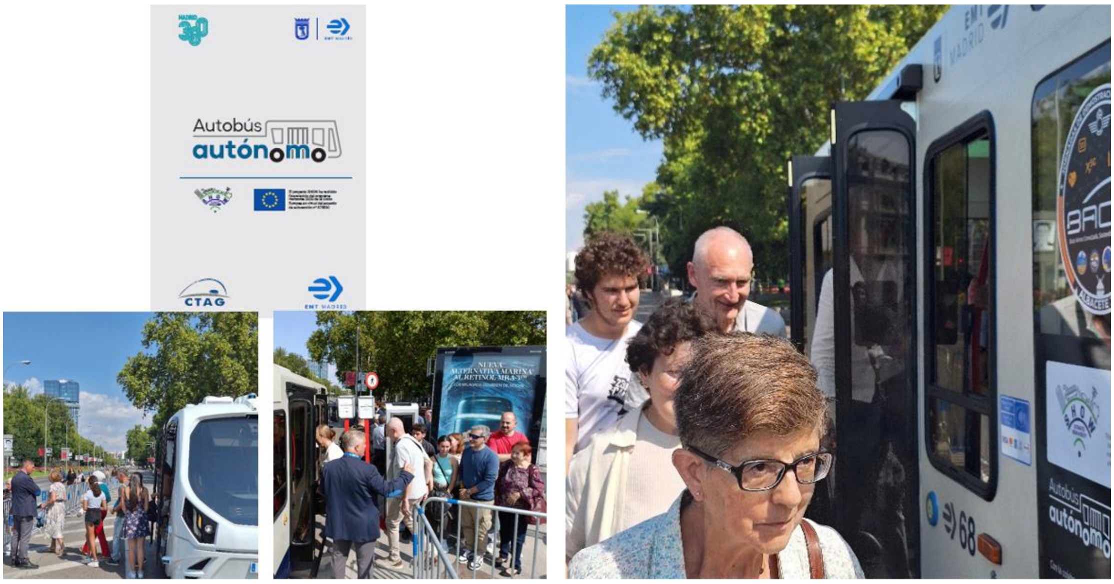

Figure 28: EMW 2024: Service drop-on/off (and badge).

Figure 29: EMW 2024: Both vehicles performing the service at the initial bus stop.

The demo had the opportunity to get together Madrid city and EMT authorities such as Madrid City Council Urbanism, Mobility and Environment Councillor, Madrid City Council Mobility Coordinator, Salamanca District Councillor and EMT Madrid General Manager. (Refer to Figure 30).

Figure 30: EMW 2024: Madrid city and EMT authorities

César Chacón from EMT provided technical explanations of the autonomous service to Madrid City Council Urbanism, Mobility and Environment Councillor, Madrid City Council Mobility Coordinator and EMT Madrid General Manager (refer to Figure 31).

Figure 31: EMW 2024: Autonomous service technical explanations to authorities

6 Madrid roadmap beyond SHOW and replicability

SHOW project has been able to set a roadmap towards automation in Madrid, capital city of Spain. Despite the difficulties for deploying the open traffic pilot in Villaverde scenario, and precisely due to that fact, SHOW has showcased the difficulties of testing AV services in open traffic, helping the city to develop the Mobility Sandbox to overcome them. As a result of last months of awareness work, finally, the ordinance project of the Madrid Mobility Sandbox[16] was approved by the City Board on October 3rd, 2024, and will be fully developed in the upcoming months, paving the way for CCAM testing and deployments.

However, the aforementioned achievement, thought one of the most relevant, is not the main one.

On one hand, there is a clear compromise by both the PTO (EMT Madrid) and the OEM (IRIZAR) to continue working towards automation within the boundaries of a bus depot. As a matter of fact, the focus of the Carabanchel pilot in SHOW was on the exploration of the potential optimization of bus depot operations.

The main impact has been the learning on how automation can help improving efficiency in bus depot management, and the confirmation that technology is mature enough to be deployed in semi-controlled environments such as a bus depot, bringing also further possibilities with additional operations such as automated charging processes.

To achieve this goal, public/private cooperation is key in this process, where operators, manufacturers and other stakeholders involved need to maintain it to help the market provide more (and low-priced) autonomous solutions. Two examples:

1. In September 2022, EMT Madrid signed a Memorandum of Understanding with CTAG, the Galician Technological Automotive Centre, for three (3) years (up to September 2025, renewable on an annual basis) to test the automated shuttle they have developed - commercially called ShuttleByCTAG – which was present at EMW 2024.
2. EMT and IRIZAR are in conversations to stablish a cooperation framework so as to test the OEM's CCAM products.

On the other hand, EMT Madrid is also committed to exploit the potential of automation and it is currently assessing the possibility of providing an autonomous shuttle service in Casa de Campo Park in Madrid which potentially could be deployed by the end of 2025.

Last, but not least, Madrid Mega Site is committed to further research and innovation projects In this regard, EMT, TECNALIA, CERTH, and other partners, are involved in AUGMENTED CCAM[17] EU funded project, to develop and test innovative services to go beyond the current state of the art regarding CCAM functionalities.

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[16] https://x.com/MADRID/status/1841806664678170635

[17] Home (augmentedccam.com)

7 Conclusions

Deliverable *D12.6: Madrid CCAV demonstrators* collects, the full operation demo phase transferring 6,035 PAX in (1) Carabanchel bus depot, in (2) the automated bus transfers at the BACSI (Sustainable and Smart Connected Air Base) event in 2023, and in (3) Madrid city downtown, during 2024's European Mobility Week (EMW 2024), *World Car Free Day*, open traffic public operation. Worth saying at this point that Madrid Mega pilot site has transferred a total of 6,643 PAX, if the pre-demo phase at the depot is also included.

The pilot at Villaverde, despite Madrid pilot's partners effort in obtaining the city council permits to drive in autonomous mode, in this type of urban open traffic scenarios, was finally not operated due to the lack of this mandatory authorisation. Despite this difficulty, EMT's AV two (2) Gullivers demonstrated the bus stop service in autonomous mode during two (2) public events, i.e. (1) BACSI 2023 (in Albacete city) to transfer the Spanish Minister of Defense from the airstrip to the exhibition area as well as base military personnel and general public, in 2023 and (2) the EMW 2024, held in Madrid downtown, on a 700m long round trip giving public transport in downtown city centre, to locals and tourists, in 2024. All the preparatory work in Villaverde and the lessons learned are also included in this document.

The pilot at Carabanchel bus depot involved automated vehicles (AVs) with perception sensors, control mechanisms, and centralized decision-making units, testing services such as the 5 stops (for depot internal transport), auto-parking, and teleoperation, always during weekdays. Over twelve months, the AV fleet performed successfully without incidents, driven by twelve (12) safety drivers.. The autonomous bus depot management use case has focused on process automation to achieve more efficient resource management within the bus depots, with numerous bus driver hours considered as non-productive yet with a high potential for increased efficiency. The bus depot – bus dominant traffic - included a mix of cars (service cars) and trucks, as well as pedestrians (employees and visitors, walking around by foot) interacting under different traffic conditions, as the traffic density varies across the area and across the day, considering depot rush hours very early in the morning and evenings.

- The 5-stops service consisted of an 800m long round trip (circular), giving public transport service to EMT employees, as well as depot external visitors, to Carabanchel's points of interest. The first Tecnobus minibus (Gulliver_1) and one 12m IRIZAR bus (i2eBus) have operated this service inside the depot, where the speed is limited to 10 km/h, dropping to 5 km/h in the bus cleaning area, and 20 km/h on the bus testing circuit.
- The auto-parking has been operated by the 12m i2eBus IRIZAR bus, meant primarily to manage the depot and auto park the e-bus during the day, once the 5 stops service is completed (sometimes in the afternoon). Platoon use case was validated and operative not for the full 12 months due to the fact Madrid local partners prioritised the 5 stops service to be ready for Villaverde scenario. It happened at the beginning of the demo period and was used to move the parked i2eBus to a designated charger, for being charged.
- Teleoperation has been tested with the second Gulliver minibus (Gulliver_2), including both supervision and actuation on the vehicle.

As for the two (2) Renault Twizy provided by TECNALIA, they have been devoted during development phase (in WP7), to transfer AV algorithms verified (in WP11.1) and technically validated (WP11.2) to the minibuses (Gulliver) and the 12m bus (i2eBus). The Twizy does not have the capacity to transport passengers

Subjective data has been collected, via specific questionnaires, to collect the particular view of the safety drivers, the passengers, the PTO and OEMs and have been analysed in the context of *D13.5: SHOW impact assessment on user experience, awareness and acceptance* and *D1.3: Stakeholder & travellers needs evolution through Pilots*. As for Madrid KPIs, this is visualised in SHOW's dashboard (https://show-project.eu/show-dashboard/).

The main objective was to evaluate the technical feasibility of automating operations that are currently carried out manually, to improve the efficiency and to optimize the functioning of the bus depot in many ways, such as reducing the space used for parking, reducing the number of non-productive hours of bus drivers driving inside the bus depot upon arrival at the end of its service, and improving road safety.

In the context of SHOW, a preliminary and brief cost analysis has considered both costs and savings assuming the automation of the bus fleet at a generic bus depot such as the Carabanchel one, exclusively considering the autonomous operations within the bus depot. Despite the evident savings in personnel costs (up to 1 million € per year per bus depot), it is not possible to conclude with a proper cost analysis of costs and savings. The high upfront cost of purchasing the equipment and retrofitting conventional buses, shows a low cost/benefit ratio for adapting existing non autonomous buses (around 26% of the initial cost of an e-bus plus the cost of the e-bus itself), and the uncertainty about some aspects, including depreciation, makes extremely complex to provide concluding figures.

As from the OEM's point of view, Carabanchel's large scale pilots showed that there are potential new business lines, where the effort is focused on industrialization and deployment; whereas PTO's perspective is: (1) that there are potential savings in non-productive hours at bus depots, (2) the importance of training, (3) and that autonomous mobility solutions are mature enough to be deployed in semi-controlled environments (such as bus depots); however, there are still uncertainties about open traffic situations, where further technology development and permissions are needed.

Linked to this, it can be said that SHOW has contributed to the concern towards autonomous transport services, at local level. As a matter of fact, the reborn political support received, at the last stages of the project, thanks to which the two big public events have been used to provide the SHOW service (BACSI 2023 and EMW 2024), have also motivated that EMT Madrid is assessing the possibility of providing autonomous public transport services within *"Casa de Campo"* park, something that could happen, potentially by late 2025.

Hence, SHOW has been extremely useful to open de debate, in Madrid, on which are the needs and requisites of autonomous transport services to be both tested and deployed. The main outcome of this fact is the approval last October 3rd, of Madrid mobility Sandbox[18], ordinance project which will regulate the use of the city as a controlled environment for testing innovative products, services, and projects.

[18] https://x.com/MADRID/status/1841806664678170635

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