PROJECT BRIEF

HOW TO PLACE PUBLIC TRANSPORT AT THE CENTRE OF THE AUTOMATED VEHICLE REVOLUTION

SEPTEMBER | 2021

INTRODUCTION

Public transport enables social inclusion by connecting people, and supports a future with lower carbon emissions. But public transport is not enough to deter people from their private vehicles. It is therefore key for public transport authorities to enhance their vision of shared mobility with the advantages of technologies such as automated vehicles (AVs), by supporting autonomous technological development with the goal of serving citizens and communities.

The Shared Personalised Automated Connected vEhicles (SPACE) project's goal was to investigate how to place public transport at the centre of the Automated Vehicles (AV) revolution and help build a combined transport ecosystem. The research project followed the belief that for automated vehicles to contribute to better mobility, they should be introduced in fleets of shared vehicles and integrated with public transport services, helping cities and regions to reach the goals they set for the future.

This Project Brief gives an overview of the methodology, findings, and key takeaways from the SPACE project.

PROJECT OBJECTIVES

SPACE had the following objectives:

- Define use cases for AVs deployment depending on the local environment.
- Develop a roadmap for the best use of AVs in passenger services.
- Advocate for a harmonised framework to allow the safe operation of AVs in real mobility scenarios.
- Evaluate scenarios for automated and connected road transport systems.

To reach these ambitious objectives, a consortium was built with 50 stakeholders from the global AV ecosystem: Public transport authorities and operators, original equipment manufacturers (OEMs), technology suppliers and services providers, as well as research and academic institutes. The entire list of members can be found on the SPACE website: space.uitp.org.

EXAMPLES OF AV DEPLOYMENT

AVs provide many opportunities for better urban mobility services, but how AVs can best be integrated depends on the environment of the area. The SPACE project partners defined a list of different use cases to offer guidance on how to deploy AVs in environments with different densities, ranging from an urban setting, a suburban setting and small cities, to rural areas. Below, 13 use cases have been identified as operational concepts of how AVs can be used and integrated within the different environments[1].

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Table 1: The SPACE Use Cases

USE CASES	DESCRIPTION OF THE SERVICE
1. First/last mile feeder to public transport station	Feeder service, fixed route, operational times in parallel to high-capacity public transport, on-demand or fixed stops (e.g. during rush hour) and shared use. **Integration:** Fully integrated in public transport offer: Ticket, fare, app, dispatching, control room. **Vehicle needs:** Mixed traffic, low-floor, ramp, space for pram/luggage/wheelchair. **Target:** Users in areas not covered by public transport core network.
2. Area-based service and feeder to public transport station	Proximity service, area–based, dynamic routing, on-demand stops and shared use. **Integration:** Fully integrated in public transport offer: Ticket, fare, app, dispatching, control room. **Vehicle needs:** Mixed traffic, low-floor, ramp, space for pram/luggage/wheelchair. **Target:** Users in areas not covered by public transport core network.
3. Premium shared point-to-point service	On-demand point-to-point service with dynamic routing, shared use and extended operational times. **Integration:** Fully integrated in public transport offer: Ticket, app, dispatching, control room and higher fare. **Vehicle needs:** Mixed traffic, comfortable vehicles, no standing, accompanying person onboard, low-floor, ramp, space for pram/luggage/wheelchair, special equipment according to target user. **Target:** Workers, adults with children.
4. Shared point-to-point service	On-demand point-to-point service where/when demand is low: Dynamic routing, shared use and extended operational times. **Integration:** Fully integrated in public transport offer: Ticket, fare, app, dispatching and control room. **Vehicle needs:** Accompanying person onboard, low-floor, ramp, space for pram/luggage/wheelchair. **Target:** All users.
5. Local bus service	Replacement of local public transport in small cities, on-demand shared fleet-based service, dynamic routing, 24h operation. **Integration:** Ticketing, app, dispatching, control room and maintenance. **Vehicle needs:** Mixed traffic, low-floor, ramp, space for pram/luggage/wheelchair. **Target:** All users.

1 The list is not exhaustive and given the ongoing changes and technological developments, it needs to be updated over time.

6. Special service (campus, business park, hospital)	Feeder to public transport stations and additional service on private grounds, shared use, scheduled service during morning and afternoon peak – otherwise on-demand. Possibility of hybrid vehicle use carrying correspondence and small parcels. **Integration:** Information integration. **Vehicle needs:** Pedestrian areas and mixed traffic, low-floor, ramp, space for pram/luggage/wheelchair. Lockers if used for parcel delivery. **Target users:** Workers, students, visitors and patients.
7. Bus Rapid Transport (BRT)	High frequency fixed route, fixed stops, separated lane, shared use. **Integration:** Fully integrated in public transport offer: Ticket, fare, app, dispatching and control room. **Vehicle needs:** High-capacity buses, ramp **Target:** All users.
8. School bus	Point-to-point service, fixed route with fixed operational time. **Integration:** No integration unless part of contract. **Vehicle needs:** Mixed traffic, larger capacity, access for people with reduced mobility **Target:** Students
9. Premium - Robo-taxis	Point-to-point on demand premium service; for private use and sequential sharing. **Integration:** Fully integrated in public transport offer: Access, app, dispatching, control room **Vehicle needs:** Vehicle designed for high comfort, equipped with premium facilities like WiFi. Geofenced covering a defined area, **Target:** Families, private groups, workers.
10. Car-sharing	On-demand sequentially shared private service, reserved for a period of time, dynamic routing, extended operational times. **Integration:** Fully integrated in public transport offer : Access, app, dispatching and control room. **Vehicle needs:** High comfort, level 4 if limited to a certain area, outside need to drive manually or need level 5 automation. **Target:** Families, private groups, workers.
11. Depot	Automated and optimised fleet management in the bus depot (parking and charging management).
12. Intercity travel	Long distance fixed route connection between urban areas on highways. **Integration:** Fully integrated in public transport offer: Ticket, app, dispatching and control room. **Vehicle needs:** High-capacity buses and ramp. **Target:** All users.
13. Pop-up shuttle transport	Temporary service with fixed route, operational only for period of time during events. **Integration:** Fully integrated in public transport offer: Ticket, fare, app, dispatching and control room. **Vehicle needs:** Depends on the event. **Target:** Event attendees.

It is important to note that not every use case necessarily requires a different type of vehicle and a fleet of AVs can be used for different environments. For instance, alongside transporting passengers, another important functionality of AVs is urban freight distribution. The service can be converted to urban cargo distribution at night or at planned timeslots, which would require special vehicle equipment, for example lockers for parcel delivery.

Overall, the speed and size of AVs should always be based on the demand, local needs and context, rather than technological developments. In the future, all services should aim to operate based on demand and with minimum SAE level 4 automation[2]. This is so they can operate without a driver, but with accompanying staff on board when needed. Where smaller AVs are used, they can be deployed as modular, or through platooning (i.e. a train of vehicles driving close to each other aiming at increasing the capacity of roads) whenever larger capacity is required. Over time, the expected decrease in private car use will lead to larger vehicles serving in automated fleets.

2 SAE has provided a taxonomy with detailed definitions for six levels of driving automation, ranging from no driving automation (Level 0) to full driving automation (Level 5), in the context of motor vehicles and their operation on roadways. More information under: https://www.sae.org/standards/content/j3016_202104

THE ROAD TO SHARED INTEGRATED AVS

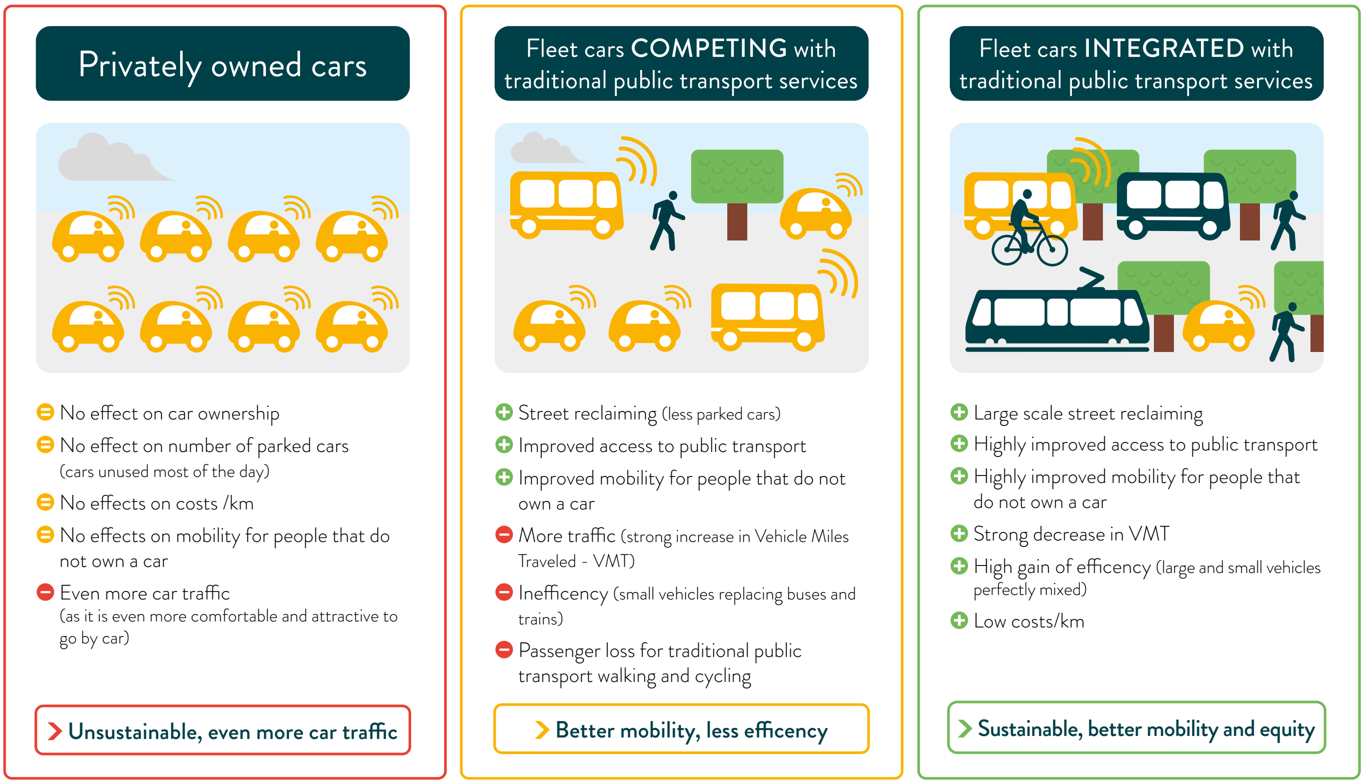
A roadmap for future mobility and more specifically autonomous vehicles has been developed by the SPACE project. The background for the roadmap is the UITP Policy brief "Autonomous vehicles: a potential game changer for urban mobility"[3], which explores ways of using autonomous vehicles and points specifically to three different scenarios for using technology (Figure 1). The scenarios imply different impacts depending on how the AVs are deployed.

SPACE has embraced the green scenario as the way to deploy autonomous vehicles for better and clean mobility, more equity in a way that is sustainable.

A roadmap was built as a tool to generate discussions and better visualise the elements that are needed to transition towards the green scenario. The roadmap is **a tool to engage with relevant stakeholders and build a specific vision of AVs to guide actions,** while acknowledging that every urban and regional area has different local contexts with specific challenges and resources. The methodology and an example of roadmap can be found in Annex 1.

These three key steps largely summarise the example of the roadmap built in Oslo, Norway, to achieve liveable cities with better accessibility, vibrant public spaces and a better environment.

Figure 1: Potential scenarios for AVs deployment (Source: UITP/Martin Röhrleef)



3 UITP, 2017. *Autonomous vechicles: A potential game changer for urban mobility*. Policy Brief

1 Deploy a large fleet of shared vehicles integrated with public transport

- High capacity
- Accessible for all users
- Seamless integration with public transport; experienced as one system
- Capable of meeting all needs at all times
- Competing with less attractive and less convenient private cars

2 Mobility is bought as a service and car ownership is low

- Fixed costs are included in costs, VMT as incentive
- People are comfortable with ride-sharing

3 Strong decrease in Vehicles Miles Travelled (VMT)

- Fewer motorised transport
- High average occupancy per motorised vehicle
- Goods and people transport are coordinated

= Better accessibility, vibrant public spaces and better environment

- LIVEABLE CITIES

Following these steps will enhance liveability in cities and ensure that AVs are deployed in the most effective and sustainable way

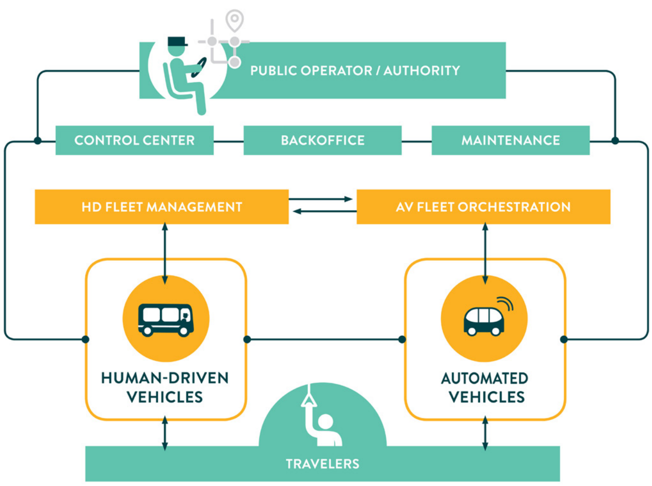
HARMONISED FRAMEWORK FOR SAFE AV OPERATION

When public transport operators and authorities plan to integrate fleets of Shared Personalised Automated Connected vEhicles (SPACE) into public transport, what does it mean from a technical point of view, besides buying the vehicles? Which key components are required to develop and deploy the scenarios we identified in the previous section?

This section presents a high level reference architecture to ensure proper integration of AV fleets into public transport systems, as well as performance, efficiency, safety and security. The objective is not to be prescriptive, but to determine the main functions and elements necessary to operate AVs in passenger service, while identifying the relationship between them.

The below diagram shows the interactions between the actors and the main software and hardware components involved in a typical Intelligent Transportation System for Automated Vehicles architecture.

Figure 3 : Typical value chain for Intelligent Transportation System for Automated Vehicles architecture (Source: SPACE)



SPACE has developed a **high-level reference architecture** that aims to ensure a comprehensive and seamless integration of driverless vehicles with other IT systems in the mobility ecosystem using a **fleet orchestration platform.**

The main goal of this reference architecture is to help operators and cities make the best technical decisions from the start, hence speed up the development and deployments of driverless mobility services. It also allows for **cross-site, cross-vehicle type/brand and cross-operators real-life operations.**

Finally, the reference architecture should enable mixed fleet operation using both manually-driven and automated vehicles using the same fleet orchestration software.

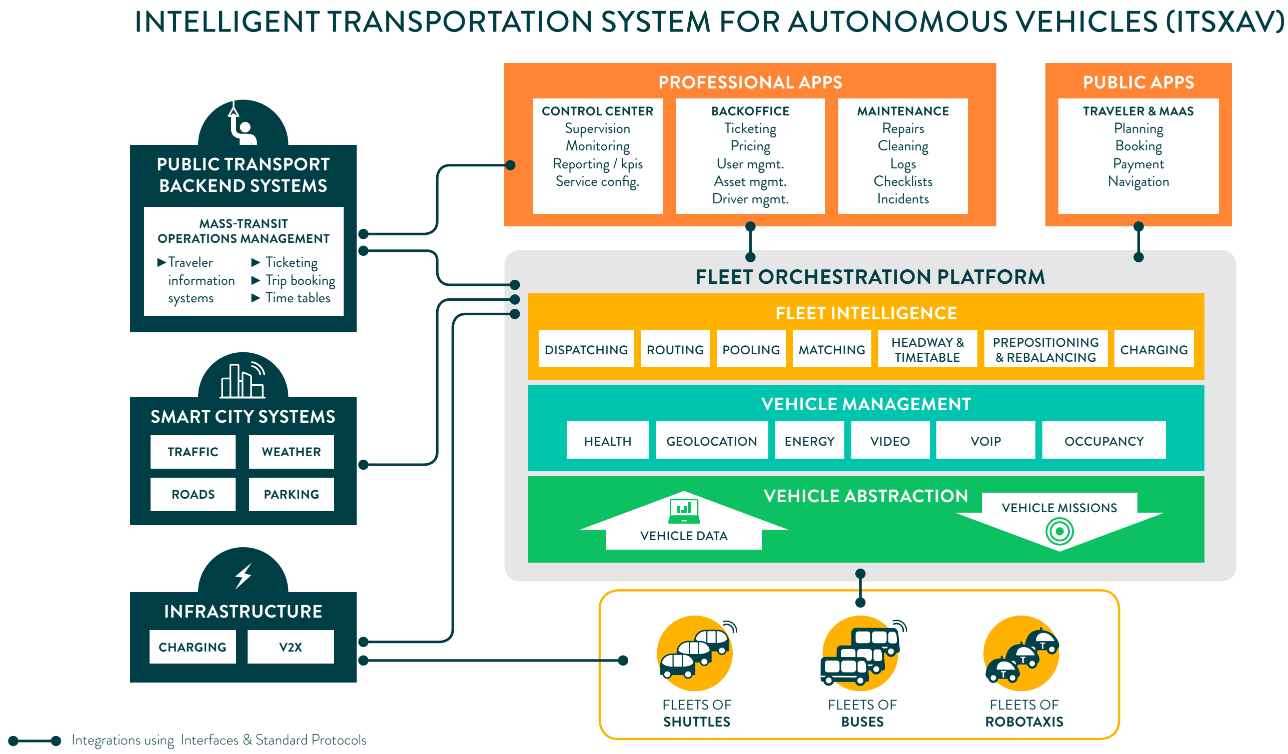
To efficiently orchestrate the fleet, in other words, send the right vehicle to the right place at the right time, the platform is interconnected with the existing public transport back-end systems, the digital road infrastructure and the smart city data sources (e.g. Traffic Management Centres, smart parking, IoT platforms). The Intelligent Transportation System for Autonomous Vehicles (ITSxAV) reference architecture is a tool for any operator or authority in the process of developing autonomous mobility solutions.

Furthermore, the reference architecture takes into account **all necessary pieces of a real-life mobility service.** It includes the surrounding public transport systems but also the smart city infrastructures and the many integration points in between. The architecture also aims at guiding the industry towards **more standardisation and more openness** to provide operators with enough software, hardware and integration options.

As mentioned, the platform ensures a brand- and type-agnostic integration with the driverless vehicles and provides rich and open Application Program Interface (APIs) to develop professional and end-users' applications.

The reference architecture (Figure 4) is designed according to the use cases defined in Chapter 2.

Figure 4 : SPACE Reference Architecture (Source: SPACE)



All the building blocks of the reference architecture are essential functionalities to ensure the integration of new fleets of AVs into the public transport systems. Especially, within the fleet orchestration platform, following functionalities have been identified as essential for managing the fleet intelligence:

- **Dispatching:** Fleet orchestration by scheduling trips with respect to vehicle availability, exposing vehicle plans to mission management, adjusting vehicle plans based on mission execution progress and on traffic as well as optimising delay propagation and reduction.
- **Routing:** Finding and dynamically updating the fastest routes between locations with respect to current or predicted traffic conditions, based on desired departure or arrival times as well as vehicle-specific operational design domains.
- **Pooling:** Group travellers to maximise vehicle utilisation and fleet efficiency while managing vehicle capacity, load and occupancy.
- **Matching:** Assigning and scheduling rides optimally under various time constraints while managing vehicle capacities and occupancy and to rematch rides automatically in case of delays and incidents.
- **Headway and Timetable Management:** Generates conflict-free vehicle movement plans, control headways for optimal coverage of target frequencies, find optimal timetables with respect to demand and predict energy consumption as well as plan charging intervals into the vehicle plans.
- **Prepositioning and Rebalancing:** Determines optimal prepositioning locations and catchment areas and to assign idle vehicles to prepositioning locations.
- **Charging:** Predicting energy consumption of vehicles and planning optimal charging schedules and locations.

One key objective for the Reference Architecture is to **secure interoperability.** This means to define an architecture that includes any type of systems and any type of transport modes (AV and conventional) though **standard and modular interfaces.** Interoperability is key in public transport operations, which involves multi-operators of vehicle fleets, multi-suppliers of IT systems and multi-providers of vehicles. With the introduction of new modes of transport like AVs, this interoperability goal is even more strategic as it introduces newcomers in the ecosystem. **Consequently, standardisation of interfaces is a must to secure an efficient and sustainable architecture.**

STAKEHOLDER EVALUATION OF AV SCENARIOS

The successful implementation of fleets of shared vehicles in the transport system will require the engagement of all stakeholders in the sector. Keeping in mind that these fleets will need to be integrated in public transport and operate seamlessly to offer efficient transport, it is important that the views of the stakeholders are accounted for the planning of future deployment and investment.

This section presents the approach for a structured evaluation of autonomous vehicle scenarios that integrate fleets of autonomous vehicles in the existing public transport system.

Figure 5 reflects the overall results of different stakeholders evaluating autonomous mobility alternatives. This figure is based on stakeholder consultations using the MAMCA approach during workshops within the SPACE and Drive2theFuture[4] projects. The detailed methodology for the stakeholders' evaluation of SPACE is described in Annex 2.

The stakeholder groups are depicted on the left axis. The scenarios are outlined on the right axis. The lines that connect the two reflect the overall assessment of a scenario by a stakeholder group, taking into account the weight of stakeholder objectives and the impact or performance of the scenario in terms of the evaluation criteria. For the stakeholder groups, the width of the vertical bar is the sum of each overall assessment of all the scenarios. For the scenarios, the width of the vertical bar is the sum of their overall assessment from every stakeholder group. It must be noted that the manufacturers were underrepresented during these workshops.

This visualisation indicates that stakeholder groups expect that the automated scenarios will be an improvement compared to business as usual. Business as usual reflects the current transport system with non-automated passenger cars and non-automated public transport services. Depending on the problem or project at hand, the business-as-usual scenario can be used as a reference for evaluating the impacts of a future alternative in terms of specific criteria (e.g. traffic safety).

For instance, looking at the authorities, the tick lines flowing towards the scenarios "mass rapid transit", "first/last mile feeder" and "ride sharing" indicate the summed preference towards these scenarios compared to "business as usual", "car sharing" and "personal autonomous vehicles (AV)". This preference trend is visible for the other stakeholder groups as well.

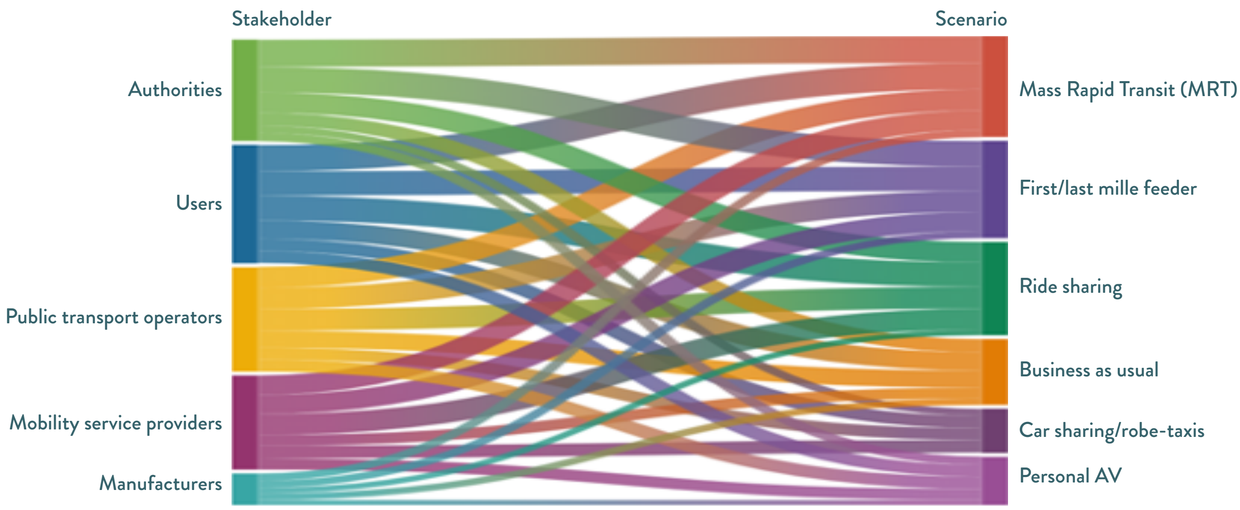
The stakeholder groups across different workshops agree that the **automated shared services will have higher positive impacts on mobility** compared to the privately-owned and sequentially shared automated vehicles. Notably, for most stakeholder groups, these scenarios are not believed to improve mobility.

The match between the highly ranked scenarios evaluated by both public and private actors indicates that the **shared automated mobility services of the future are most likely to receive broad support.**

The common **preference towards automated shared services** across stakeholders represents hope for the future of shared fleets of automated vehicles. Nonetheless, as each stakeholder has a specific role and different objectives now and for the future, there is a need for continuous effort to involve them in the assessment of new mobility scenarios. Understanding the objectives and evaluation criteria of stakeholders in the assessment of automated mobility services will help operators and authorities in the design of services, development of business models and prioritisation of infrastructural investments.

Equally important is the definition of specific and concrete mobility alternatives that present a potential solution for the transport system at hand. This will help stakeholders in evaluating the performance or impact of a scenario in terms of the criteria and also provide insight into to trade-offs between stakeholders.

Figure 5: Stakeholder evaluation trends



4 For more information: www.drive2thefuture.eu

CONCLUSION

The SPACE project successfully achieved its goals of unveiling the necessary steps towards a meaningful deployment of automated vehicles. Together, during the three years of the project, the 50 stakeholders worked together on defining potential Use Cases for AV deployment depending on the local environment. Since their publication, these Use Cases have been considered by other projects, such as the SHOW project, which emphasises their relevance.

During the definition of the roadmap towards the most sustainable scenario for AV deployment, it was made clear how crucial discussions among the variety of stakeholders are to find solutions that accommodate most of the parties, while still advancing towards liveable cities. The roadmap itself can be use as recommendation for cities to deploy shared AV fleets into their public transport system.

SPACE also contributed to pave the way towards more harmonisation for orchestrating fleets of shared AVs in a secure, safe and efficient manner. Other projects working on defining open modular system architecture for shared AV fleets can make use of the reference architecture as a starting point to get familiar with its building blocks and understand interdependencies between them. As a next step, a gap analysis on standardisation should be at the centre of discussions for reaching efficient interoperability.

The stakeholders' consultation that took place during the project, to evaluate different scenarios for AV deployment, validated the initial hypothesis that public transport needs to be placed at the centre of the Automated Vehicles revolution.

As leader of the project, UITP will make sure that the SPACE consortium outlives the project in order to continue discussing and developing best solutions for a meaningful deployment of automated vehicles for liveable cities.

THANK YOU TO OUR EDITORS AND AUTHORS!

Editors:

- Guido Di Pasquale, UITP
- Henriette Cornet, UITP

Authors:

- Emmanuel de Verdalle, ITxPT
- Lieselot Vanhaverbeke, VUB
- Endre Angelvik, Ruter
- Luc Texier, Bestmile
- Evy Rombaut, VUB
- Manon Feys, VUB
- Josep Mension, TMB
- Mihai Chirca, Transdev
- Lidia Signor, UITP

SEPTEMBER | 2021

UITP ADVANCING PUBLIC TRANSPORT

Rue Sainte-Marie 6, B-1080 Brussels, Belgium | Tel +32 (0)2 673 61 00 | info@uitp.org | **www.uitp.org**