International Transport Forum

Making Automated Vehicles Work for Better Transport Services

Regulating for Impact

Case-Specific Policy Analysis

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The International Transport Forum

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Table of contents

Figures

Tables

Boxes

Abbreviations and acronyms

AI	artificial intelligence
AV	automated vehicle
ADAS	advanced driver assistance systems
ADS	automated driving systems
ADS-DV	Automated Driving Systems – Dedicated Vehicles
ASDE	authorized self-driving entity
C-ITS	cooperative intelligent transport systems
CPUC	California Public Utility Commission
DARPA	Defense Advanced Research Projects Agency
DDT	dynamic driving task
DMV	Department of Motor Vehicles
EM	emergency manoeuvre
FHWA	Federal Highway Administration
FMVSS	Federal Motor Vehicle Safety Standards
FTA	Federal Transit Administration
GHG	greenhouse gases
GPDR	General Data Protection Regulation (EU)
GPS	Global Positioning System
HD	high definition
ITF	International Transport Forum
ITS	Intelligent Transportation System
LDM	local dynamic map
LIDAR	light detection and ranging
MaaS	Mobility as a Service
MOLIT	Ministry of Land, Infrastructure and Transport
MRM	minimal-risk manoeuvre
NHTSA	National Highway Traffic Safety Administration
NUiC	No-User-in-Charge
OBU	onboard unit
ODD	operational design domain
OEM	original equipment manufacturer
PTO	public transport operator
R&D	research and development
RSU	roadside unit
SAE	Society of Automotive Engineers
TNC	transportation network company
UiC	User-in-Charge
UITP	International Association of Public Transport
UNECE	United Nations Economic Commission for Europe

USDOT	US Department of Transportation
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
V2X	vehicle-to-everything
VMT/VKT	vehicle miles travelled / vehicle kilometres travelled
VRE	vehicle recovery event
WAV	wheelchair-accessible vehicle

Executive summary

What we did

This report examines what regulatory changes, policy measures and institutional arrangements are needed to successfully introduce urban transport services based on automated vehicles (AVs). AVs can provide a variety of new transport services that could bring social benefits. To bring these about, more than technological advancement is needed. Under certain circumstances, negative consequences are also possible. A successful introduction of AV-based services will therefore require new regulatory approaches.

This report suggests where regulation should be adapted and outlines principles for forward-looking regulation. It offers six pragmatic recommendations for bringing about better transport for citizens. The study is based on two workshops with, and a survey of, experts, a review of the latest literature and several case studies from ITF member countries.

What we found

AV technology enables driverless, automated urban transport services. These can take various forms, such as the automated operation of scheduled bus services, on-demand public transport services, on-demand rides (robotaxis), and unmanned delivery vehicles. Such services have different operating characteristics and cost structures from existing offers. AV services could contribute to eliminating human errors in driving tasks, but new risks from employing artificial intelligence (AI) must also be considered.

If privately owned AVs become widespread before AV-based services, the latter will have difficulty competing with the former. As a result, the predominance of privately-owned AVs may worsen congestion and living conditions in cities. If, on the other hand, AV-based services are actively introduced to transform urban transport into a service-based system that does not primarily rely on privately-owned cars, various positive effects would ensue. Making this happen requires active government support through a well-designed regulatory framework for AV-based services.

AV-based services should be introduced and operated in ways that align with policy goals, for instance, increased safety, improved accessibility, enhanced equity, reduced environmental impact or accelerated economic development. AV-based services can have implications for various dimensions of mobility, ranging from the behaviour of passengers to the structure of urban spaces. The transition must be well-managed because these changes will likely occur at different speeds.

Depending on the readiness of the regulatory environment, the introduction of automated transport services is expected to take place in three phases: early, scale-up and maturity. In the early phase, AV-based services will be introduced as testing and pilot projects; thus, permit and license systems must be established to allow such pilots. In the scale-up phase, paid commercial services will be introduced, so it will be necessary to establish a system related to permitting paid commercial services and protecting users. Finally, in the maturity phase, AV-based services will be fully established as part of the urban transport system, and governments will need to focus on policies designed to maximise the positive effects of AV-based services.

The introduction of automated transport services will likely occur in three phases. The early phase will see tests and pilot projects requiring a system of testing permits or licenses. In the scale-up phase, introducing commercial services will necessitate a system to regulate paid services and protect users. In the maturity phase, AV-based services will be fully established as part of the urban transport system, and government policies will focus on maximising the benefits AV-based services can deliver.

What we recommend

Recognise new legal actors and responsibilities as part of the introduction of automated transport services

Automated vehicles will be developed by various companies and then operated by different service providers. Governments should distinguish AV developers and service providers operating AVs in regulation and clearly define their respective responsibilities, including those of remote operators.

Extend the Safe System approach to automated vehicles

It is important to have a consensus on acceptable safety levels to establish automated transport services. The Safe System approach focuses on designing the whole system in a way that accounts for human error and avoids the death or serious injury of people, even when a crash occurs. This approach should be applied to AV-based services so that the whole transport system is designed to eliminate deaths and serious injuries even when AV vehicles do not function as planned or expected.

Invest in supporting infrastructure for AV-based transport services

Developers of AVs construct them for existing infrastructure. However, infrastructure taking into account the functioning of AVs can help the safer operation of AVs, just as good infrastructure can enhance the safety of human drivers. Good connectivity that allows interventions of remote operators is particularly important. A range of other physical and digital infrastructure improvements could be worth considering, depending on the driving environment and maturity of AV-based services.

Plan a long-term pathway for the transition towards AV-based transport services

AV-based transport services would have long-term impacts on many domains, including employment, public finance and accessibility. There will be fewer driver jobs, but new jobs, such as remote operators, will be created. Revenue from parking will be diminished, but the re-allocation of that reclaimed urban space could open up new revenue sources. New ways to assist passengers with special needs, who today rely on support from drivers, need to be devised. Government should assess the long-term impact of AV-based services and plan ahead to respond to these changes. Part of this will also be to update the regulations for human-driven services where they are incompatible with AV-based services.

Co-ordinate the roles of each level of government in regulating AV-based transport services

The role of each level of government in regulating AV-based transport services must be clearly defined. Vehicle safety and service regulations should be governed by different authorities with expertise in their respective fields. For example, although responsibility for vehicle safety could remain with the national government, responsibilities for service provisions closer to local passengers could be addressed by lower levels of government.

Share data to ensure integrated transport services but protect passenger data against misuse

AV-based transport services generate data related to users and the driving environment. This data must be well protected against any misuse. At the same time, the data must be managed in ways that enable interoperability and data portability to allow the integration of AV-based services with other transport services.

Introduction

Automated vehicle (AV) technology has made great strides since a few AVs from university laboratories completed a closed circuit on an airport base at the DARPA Urban Challenge in 2007. The technology has now reached a level at which some companies are confident enough to pursue deployments of driverless AV fleets in urban environments for commercial on-demand service (Bellan, 2022; Hope, 2022).

This suggests that AVs may be approaching larger-scale deployment in certain settings, which in turn raises questions regarding the readiness of urban transport regulations to accommodate the new technology. Decision-makers at various levels of government around the world must anticipate this potential development. In particular, they should assess whether and how they should adapt transport service regulations to ensure AV technology delivers appropriate societal benefits.

The development of AV technology is not limited to passenger vehicles. It has enabled many new use cases employing new types of vehicles and new ways of operation. Driverless shuttles and unmanned delivery vehicles are being developed in multiple countries as a new mode of transport and logistics. Considering usages in non-transport sectors – such as the military, agriculture, and ports/logistics facilities – the scope of development is very broad. Among these various application cases, this report focuses on using AVs for mobility services in urban environments.

AV-based services present new layers of regulatory concerns. For individually owned AVs, the primary concerns will be driving performance and safety, which are governed mainly by vehicle safety standards. However, AV-based services using AV fleets for transport services would require more policy and regulatory interventions to ensure public safety and other key outcomes, such as sustainability and accessibility. Existing regulations for conventional public transport services may be able to cover some features of AV-based services. However, the distinct characteristics of automated vehicles will require new sets of regulations or adaptation of existing regulations.

This report provides recommendations for public authorities, especially at the national level, to develop a comprehensive and balanced regulatory framework for AV-based services deployment. It also suggests regulatory transition pathways over different phases of AV-based services development – from the early stage at which AVs are introduced to the mature stage when AVs are fully integrated into the urban mobility system.

The report is informed by lessons drawn from wider ITF work on AVs and related topics. In addition, the AV strategies and regulations of selected ITF member countries were closely examined: the ITF conducted two workshops with experts from both public and private sectors to learn from their perspectives on the key issues related to the deployment of AV-based services and their impacts on transport. The ITF also conducted an expert survey regarding the impacts of AV-based services (see Box 1).

The report is structured as follows. The next section discusses why there should be specific regulations for AV-based services in addition to regulations on AVs themselves. The following section examines key safety regulations that enable AV-based services. The final section focuses on managing transitions towards a transport system fully integrating AV-based services and provides recommendations on regulatory interventions to manage the impacts of AV-based services across diverse policy areas.

Box 1. Inputs from the workshops and the survey

The International Transport Forum conducted two expert workshops and an expert survey as part of the project. The first workshop took place on 22 February 2022 and the second on 5 July 2022, both as virtual meetings. The workshops were attended by 36 and 40 persons, respectively. During the workshops, scholars, researchers, national government officials developing national-level regulatory frameworks, representatives of private enterprises operating AV fleets, and representatives of private consultancies specialised in AVs shared their experiences and views.

An expert survey on the foreseeable impacts of AV-based services was conducted from 24 May to 15 August 2022. The survey included questions on the definitions used in the study as well as questions on impact domains that had been identified during the literature review: passenger behaviours, travel patterns, infrastructure, accessibility, employment, environment, public finance, health and safety, and urban space. Participants were asked to scale the degree of impacts on different areas at different stages of AV implementation (2 to 3 questions per impact domain). Open-ended questions invited respondents to provide more insights on the regulatory components and goals the policy and regulatory framework were to pursue. For each section, participants could provide any comments they deemed fit for additional insights, and many indeed provided additional thoughts. Among the replies, 34% were from private industry, 28% from academia, 19% from governments, 16% from international organisations, and the remaining were from public institutions, consulting and city-level government. The survey obtained 32 responses, which did not allow for sufficient coverage across different regions. Thus, the survey was mainly used for indicative purposes.

AV-based services and regulatory challenges

Automated vehicles are not limited to passenger vehicles. Automation can be applied to all kinds of vehicles ranging from small sidewalk delivery pods delivering coffees to heavy construction equipment. This means it is possible to produce purpose-built automated vehicles for mobility services or retrofit existing vehicles into automated ones. It is expected that the services provided by these automated vehicles will have different impacts from those of conventional services in terms of cost-efficiency, safety, accessibility, and other factors. Whatever the impact, regulation will need to keep pace and adapt accordingly.

Automated vehicles can be used to provide urban transport services

AV-based services are transport services provided by AVs, such as automated shuttles, passenger cars, buses and delivery vehicles. Even though it is required to have in-vehicle operators at the pilot stage in most countries, those services are expected to be provided without in-vehicle drivers eventually. Removing the driver from vehicles creates new opportunities for vehicle design and operation. Automated buses could gradually replace conventional buses providing scheduled services. On-demand public transport and on-demand ride services could be added as new feeders or standalone transport modes. Unmanned truck- and van-like vehicles can facilitate goods delivery and logistics, especially for last-kilometre distribution. Alongside these road vehicles, last-metre delivery pods and drones could also be part of AV-based logistics services. All these new developments, if realised, will open up new possibilities to businesses, public agencies and citizens.

This chapter presents the issues of AV-based urban passenger and logistics services using public road systems where vehicles need to share the space with pedestrians, cyclists and other users, as encircled in red boxes in Figure 1. The focus is on preparing regulations to maximise positive and minimise negative impacts resulting from these new services.

AV-based services have different costs and capabilities that will have second-order effects on transport

The characteristics of AV-based services differ from those of conventional services, and this has repercussions for urban transport. The uptake of AVs will change the cost structure of transport services. Even though the vehicles themselves may cost more due to the additional sensors and computing systems, removing the driver will lead to savings in operation costs. Nonetheless, additional workers may be needed for fleet management, vehicle maintenance, and for certain new tasks such as remote operation and intervention.

Other factors related to specific business models, such as fleet size and operation hours, will also affect costs. The balance of these costs is not yet clear, nor is the possibility of achieving cost parity with conventional services. The cost per kilometre of shared automated vehicles is predicted to range from USD 0.11/km to USD 1.03/km (Narayanan, Chaniotakis and Antoniou, 2020) based on different assumptions on overhead and other cost factors. In any case, AV services will have different cost structures than conventional services.

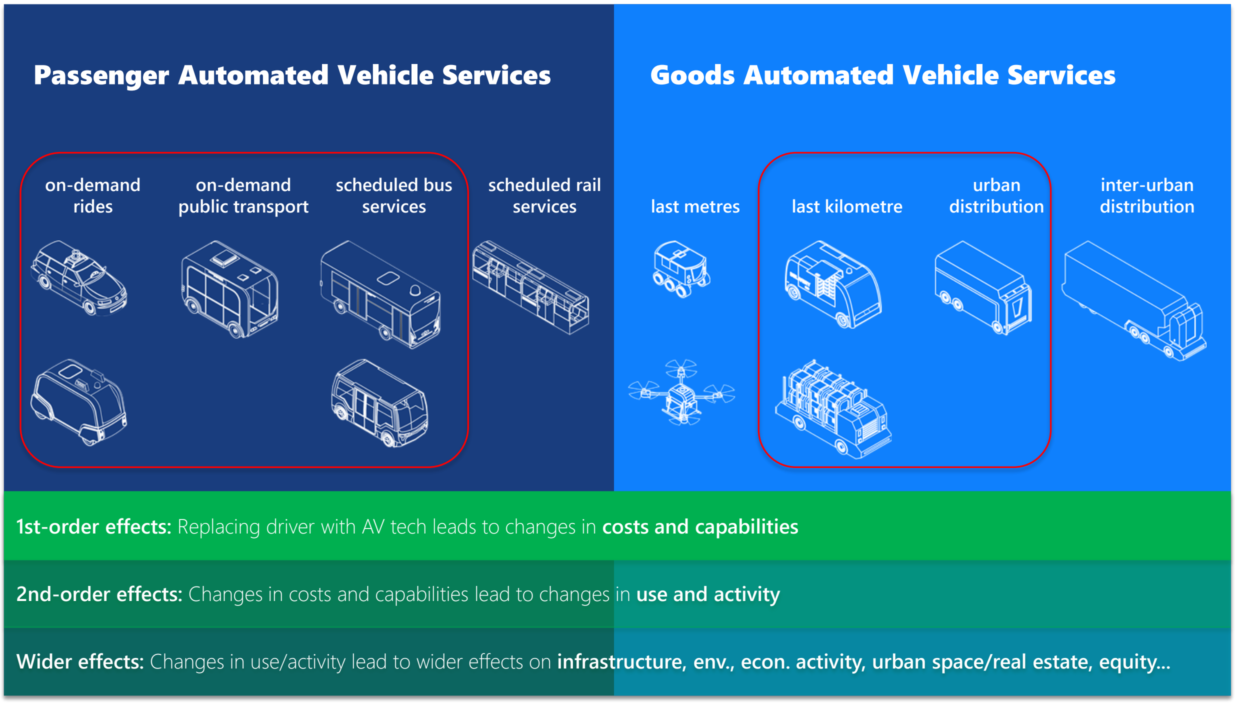
The other direct effects of AV-based services are linked to the characteristics of the vehicles, notably their capabilities and safety performance. AVs' passenger capacity (load capacity for logistics), speed, and driving distance per charge/fuelling determine the service capability of the AVs. Their safety performance will also affect boundaries to their operation area and conditions. AV-based services could reduce crashes by eliminating driver errors (Singh 2015; Gov.UK 2022a; 2022b).

However, even though AVs would eliminate human errors, they may still operate in unforeseen and potentially dangerous ways as they respond to diverse real-world situations. Their sensing and computing capabilities may be better than human drivers in some instances, but they do not have the same cognitive skills to comprehend situations heuristically. While they may be more able to visually recognise traffic cones or hand signals from further away than most humans, they may nonetheless experience more difficulties interpreting the significance of what they see. Machine-learning-based artificial intelligence (AI) systems used for AVs may operate in unpredictable and possibly unsafe ways in certain cases. These can emerge at the extreme limit of the system's design parameters (its operation design domain) – i.e., "edge" cases. They may also emerge when operating outside of normal operating parameters, including when multiple unique situations present themselves simultaneously – i.e., "corner" cases (ITF, 2018). At the early stage of AV services, there could be crashes from different driving patterns between human-driven vehicles and AVs. A 2022 National Highway Traffic Safety Administration summary report (NHTSA, 2022b) and data from Waymo (Schwall, 2020) indicated that rear-end crashes (i.e., those damaging the AVs' own rear ends) are the most common crashes. These potential vulnerabilities of AVs should be addressed or compensated for to ensure an acceptable level of safety.

AV-based services will have second-order effects that could go far beyond their immediate impacts on transport service provision. The cost and capability of AV-based services will determine the use cases and the relative costs of trips by AV services versus other means. If the costs of trips by AV services are lower than those of other options – or if the amenity of those trips is valued more highly than the amenity of other services – then people will not only shift their travel to AV services but will likely make new trips as well (i.e. "induced demand"). Changes in AV capabilities and relative costs will have second-order effects relating to shifting activities and associated travel patterns. Driverless services could provide access to transport in off-peak hours or in previously less accessible neighbourhoods.

Ultimately, these changes will have broader effects on the lives of both users and non-users by changing how urban space is used and how urban transport is organised (Crute et al., 2018; Stead and Vaddadi, 2019). For example, the need for parking spaces could be diminished or relocated if AV-based services replace trips made by private passenger cars (Soteropoulos, Berger and Ciari, 2019). AV service deployment could have energy and environmental implications if shared mobility services can replace trips made by personally owned vehicles (Salazar et al., 2019; Jones and Leibowicz, 2019; Silva et al., 2022). It would have equity implications in transport provision if AV-based services could provide mobility to people who have difficulties using conventional services alone, such as minors, the elderly and people with disabilities (Riggs and Pande, 2022). Figure 1 summarises the types of services and their immediate and second-order effects.

Figure 1. The types and effects of automated vehicles services



Note: this report focuses on automated vehicle services for urban transport encircled in the red boxes.

Why AV-based services need regulatory interventions

The adoption of AV-based services will require governments to take an active role. Although many private entities are developing automated vehicles, this will not necessarily result in better traffic outcomes in the urban environment. Multiple future outcomes are possible, from one in which automated privately-owned cars dominate to one in which AV-based services assume a major role in urban transport. Governments need to work proactively to ensure the future they want.

Two different AV development strategies

There are two pillars for describing AV technology. The first pillar is the levels of driving automation that reflect how well automated driving systems (ADS) can carry out dynamic driving tasks (DDTs) without human engagement. The most widely recognised criteria for the level of driving automation are those developed by the Society of Automotive Engineers (SAE International, 2021), which categorises levels of automation from 0 to 5. Vehicles equipped with level 3 and above ADS are regarded as automated vehicles. Level 3 vehicles can handle most driving in pre-defined operational conditions but require humans to take control when the ADS cannot carry out DDT; it is thus impossible to remove human drivers in level 3 vehicles. By contrast, levels 4 and 5 do not require human engagement when the ADS drives the vehicle in pre-defined operational conditions; thus, people in the vehicle are solely passengers, like when using public transport.

The second, lesser-known pillar is the operational design domain (ODD). The ODD defines in which area and under which conditions the vehicle may drive. A wider ODD means the vehicle can drive itself in a more diverse environment. Depending on their ODDs, the same level-4 vehicles have widely different capabilities.

The development of AV technology means increasing the level of driving automation and expanding the operational design domain (ODD) of automated driving systems (ADS). While numerous combinations of the levels and the ODD are possible, most development strategies can be categorised into two groups that the ITF (2015) has described as "something everywhere" and "everything somewhere" strategies.

The "something everywhere" (ITF, 2015) strategy involves progressively adding automated features such as advanced driver assistance systems (ADASs) to commercially available passenger vehicles deemed to have unrestricted ODD on public roads. This approach is pursued by many global original-equipment manufacturers (OEMs) with broader consumer bases for their conventional models. Several OEMs have been equipping level 2 functions to their mass-market vehicles (McKinsey & Company, 2023), and new models with level 3 features are being released (Hawkins, 2023).

This strategy does not focus on removing drivers but on providing car owners with a more comfortable driving experience. A vehicle development pathway based on this strategy would be an incremental improvement on commercially available models, as the functionality and safety of every new automated driving feature need to be tested and verified in a very broad ODD. Also, vehicles must comply with vehicle safety standards to be commercially available to the general public. The World Forum for Harmonization of Vehicle Regulations (WP.29[1]), which develops international vehicle regulations, has developed regulations on automated driving features that are designed to be taken up in national regulations.

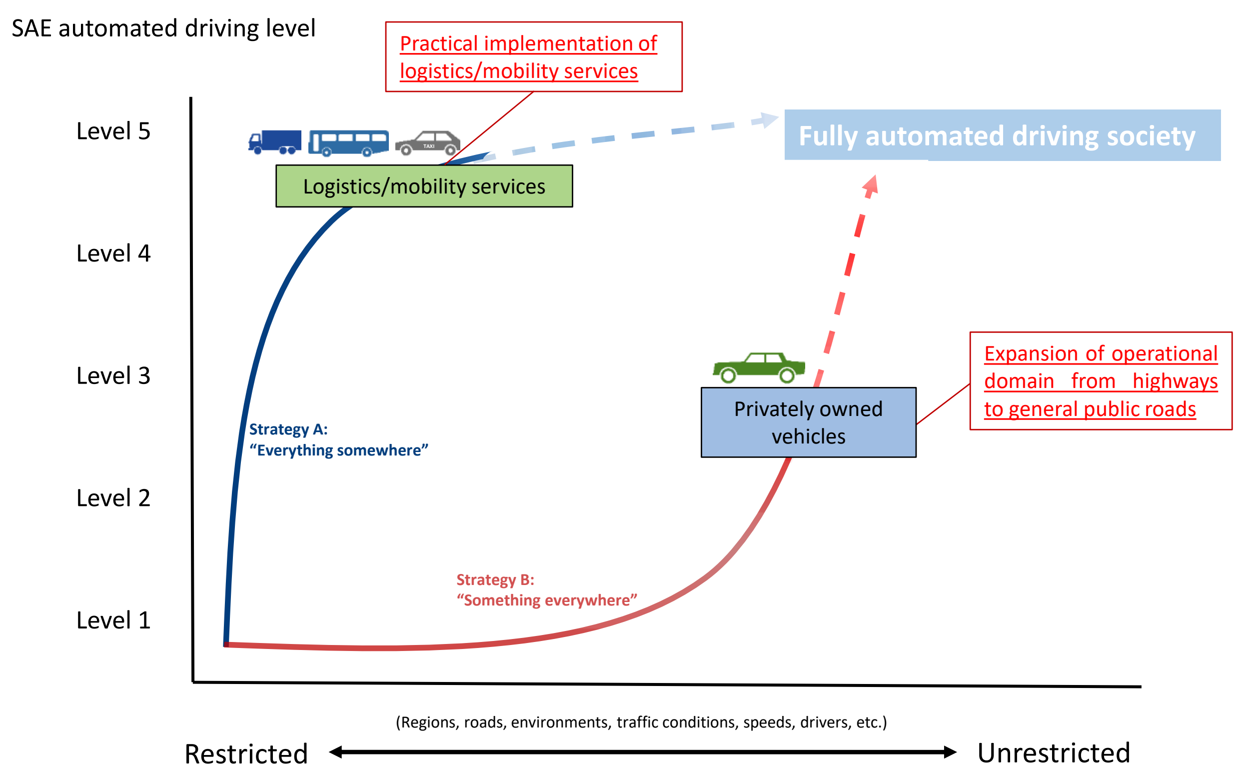
This process will likely be more complicated and slower than rulemaking for other safety features due to the special nature of automated driving features. Automated driving features are, in essence, “cyber-physical systems”, combining both physical features and information-processing components such as AI algorithms. Unlike mechanical specifications for other safety features, which can be completely tested before being released in a consumer market, automated driving features employ machine-learning techniques that are difficult to verify fully in advance (Koopman and Wagner, 2017). WP.29 has set out international regulation on level 3 automated lane-keeping features in the ODD limited to roads with prohibited pedestrians and cyclists access (UNECE, 2022a). However, it remains to be seen when international regulations on higher-level automated driving features will be released.

On the other hand, the "everything somewhere" (ITF, 2015) approach is a strategy to expand the ODD of level 4 AVs that can drive without human intervention in their ODDs. A notable example of this is Automated Driving Systems – Dedicated Vehicles (ADS-DV), which are designed without consideration for in-vehicle human drivers. These include low-speed shuttles without driver’s seats or steering wheels and “robotaxis” using ADS-installed conventional vehicles within certain urban boundaries. This approach requires flexible and supportive regulations allowing the deployment of vehicles designed in an unconventional way and thus not fully proven for their safety performances. This approach is better suited for transport services with bounded operation routes or areas.

The International Association of Public Transport (UITP) and the Japanese government have also acknowledged these two approaches. UITP (2017) refers to the “something everywhere” strategy, more directly, as the “Car Industry Path” and to the “everything somewhere” strategy as the “Public Transport Path.” Japan's cross-ministerial Strategic Innovation Programme on Automated Driving for Universal Services (SIP-adus) presented these two approaches originally developed in 2019 public-private ITS initiative/roadmap (Strategic Conference for the Advancement of Utilizing Public and Private Sector Data and Strategic Headquarters for the Advanced Information and Telecommunications Network Society, 2019; SIP-adus, 2022), as described in Figure 2. The ultimate goal is to achieve a fully automated driving society where fully automated vehicles can meet all needs in unrestricted ODDs.

Two distinct pathways are presented to reach this goal. SIP-adus makes clear that pursuing an "everything somewhere" strategy by providing logistics and mobility services would be a way to resolve societal challenges. This path can make use of automated technology to provide mobility and logistics services in specific settings, even before the adoption of international vehicle-safety regulations required for the commercialization of AVs. While the roadmap indicates that both paths will eventually lead to a fully automated driving society, the ultimate state of the transport system may differ depending on whether personally owned passenger AVs or AV-based services predominate.

Figure 2. Two pathways toward a fully automated driving society



Source: SIP-adus (2022).

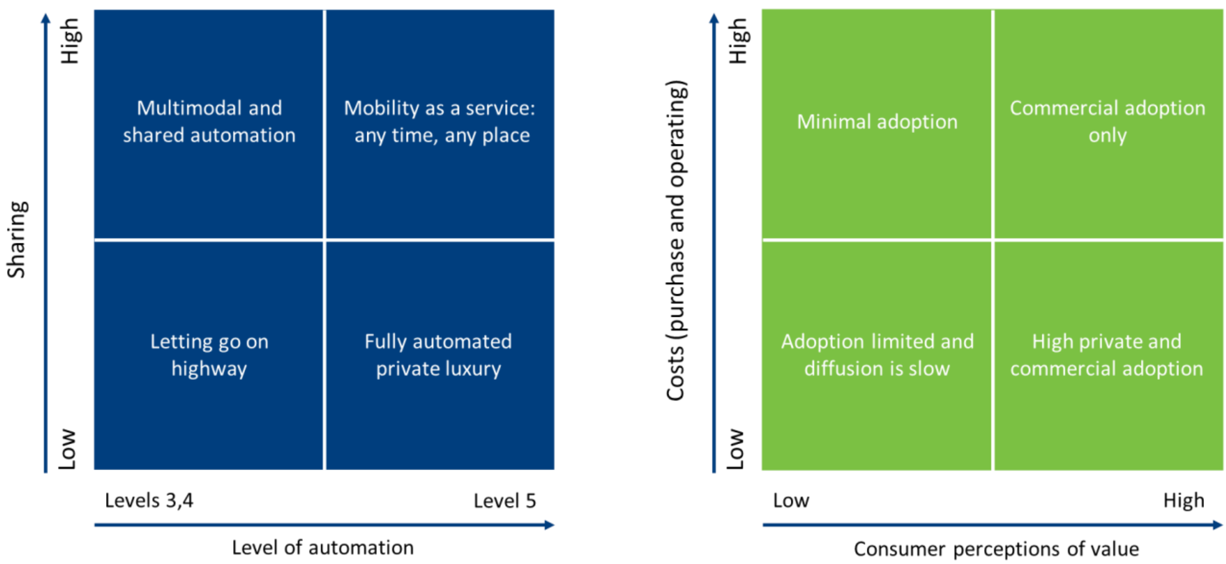
Multiple scenarios and the role of regulations

Both strategies aim for automated vehicles capable of driving themselves in any driving environment. However, different transition paths towards this enhanced functionality could lead to different outcomes and thus have far-reaching impacts on urban transport systems. The Netherlands Institute for Transport Policy Analysis (KiM, 2015) and the National Transport Commission of Australia (NTC, 2019) presented interesting scenarios based on different influencing factors and underlying assumptions.

The Netherlands Institute for Transport Policy Analysis (KiM, 2015) suggested four scenarios based on two elements: levels of both automation and degree of carsharing (Figure 3, left). It showed that different futures with different societal consequences would depend on the degree of sharing and the level of AV technology. For example, if the automation stays at level 3 and there are limited sharing options, it could increase highway traffic because the vehicles can drive themselves on the highway. As the perceived cost of driving on highways falls, it could exacerbate urban sprawl. In contrast, with a higher level of automation that does not require drivers and a higher level of shared mobility, shared automated mobility service could be the dominant way of travelling, which could lead to a decrease in the number of private cars in urban areas.

The National Transport Commission (2019) of Australia suggested four different AV uptake scenarios based on costs and consumers' perceived values of AVs. If consumers do not consider AVs useful, the uptake will remain low regardless of cost. If consumers find AVs valuable, but the costs remain high, the AVs will be used for commercial services rather than privately owned (Figure 3, right).

Figure 3. Multiple scenarios on AV development



Source: adapted from KiM (2015) (left) and NTC (2019) (right).

These scenario analyses depict the final states but not the paths to getting there from the current situation. If development paths in AV technologies are considered, dynamic scenario analysis is possible. The ITF suggests two different dynamic scenarios based on different assumptions about changes in the capability and cost of AVs, as shown by the blue and red lines in Figure 4 (NTC, 2019).

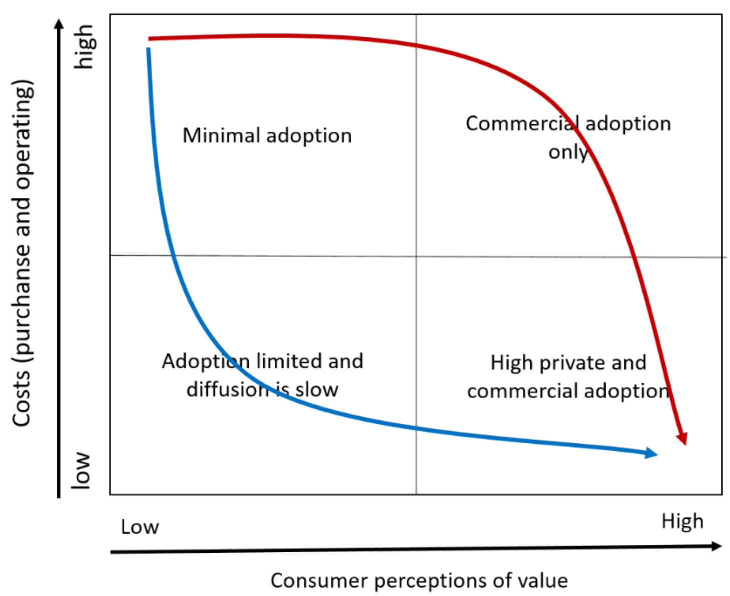
High adoption of private-use AVs scenario (blue line)

In this scenario, several large OEMs gradually set out new automated vehicle models with incrementally increased AV functions in a price range accessible to general consumers, beginning with level 3 highway support. Meanwhile, service-oriented, driverless level 4 vehicles struggle to find a market and expand to multiple locations due to a lack of policy support and co-ordination. Private-use-oriented automated vehicles will slowly earn consumers' trust and rapidly gain market share after a certain tipping point. Ultimately, roads flood with privately owned AVs before AV-based services take hold. Conventional public transport and AV-based services suffer from diminishing demand, making it harder to maintain service and maintenance quality.

High AV-service modal share scenario (red line)

While AV technology for passenger cars is still expensive and needs to earn public trust, governments actively work to test and deploy AV-based transport services. Governments provide more confidence in AV-based services through transparent information sharing and a learning-by-doing approach that safeguards road safety. Governments encourage AV-based public transport and shared services by employing regulations that curb the use of privately owned vehicles in urban areas and providing policy support to make them financially sustainable. Governments also work to provide the best mix of new AV-based services (e.g. robotaxis, shared shuttles) and existing public transport to provide for better societal outcomes. AV-based services will be firmly established as a part of urban life before private AVs capable of level 4 automation in urban areas become widely available.

Figure 4. Two dynamic scenarios of AV development



Note: The **blue line** denotes the high adoption of privately-use automated vehicles scenario. The **red line** denotes the high automated-vehicle-service modal share scenario.
Source: Adapted from NTC (2019).

Both scenarios are within the realm of possibility. One of the key factors in determining which of the two scenarios the future holds is government policies. Without policy support and proactive rule-setting, there is a chance that the ultimate equilibrium will be "fully automated private luxury" (i.e. high private AV uptake), which could result in more traffic congestion and overall societal disbenefits. However, governments may facilitate better societal outcomes if they work proactively during the early phases of AV deployment.

AV impacts domains, policy goals and deployment phases

AV-based services will have diverse impacts on multiple domains. Governments need to anticipate those impacts and work to amplify positive and minimise negative impacts. The deployment of AV-based services and, thus, the impacts from the AV-based services may not happen in a linear way. Rather, it will go through certain phases closely linked to the regulations that will be put in place.

AV-based services are expected to serve policy goals over diverse impact domains

AV-based services may have far-reaching impacts on people's lives. Governments, non-governmental organisations, research institutions and industry have sought to assess the scope and scale of these potential impacts. Some have explicitly noted that the development of AV-based services should seek to achieve positive impacts in specific policy domains. For example, the US NHTSA identifies the potential role of AVs in achieving benefits to do with safety, economic and social, efficiency and convenience, and mobility (National Science and Technology Council and United States Department of Transportation, 2020). The European Commission has pointed out that AVs could positively impact safety, accessibility, sustainability, land use, efficiency and innovation (European Commission, 2018). The State of California (2022), reflecting regional priorities, has set out guiding principles to maximize public benefits in mobility, safety, job quality, equity, health, environment, land use and quality of life. Urbanism Next (2020), focusing more on the impacts on cities, has highlighted five areas – land use, urban design, building design, transportation and real estate – as multi-level impacts of AV deployment and other mobility technology development. Narayanan, Chaniotakis and Antoniou (2020) reviewed the literature on shared automated vehicles and noted the following impact domains: travel behaviour, traffic and safety, transport supply, land use, economy, environment, and governance.

For the purposes of this report, the ITF has identified and categorised five policy goals and nine impact domains based on (a) a literature review of academic articles; (b) the AV strategy plans of member economies, including the United States (National Science and Technology Council and United States Department of Transportation, 2020), EU (European Parliament, 2018), Germany (BMVI, 2015), France (National Strategy for the Development of autonomous vehicles, 2018; Ecologie, 2019 and 2021), UK (Law Commission of England and Wales and the Scottish Law Commission, 2022a), Japan (SIP-adus, 2022) and South Korea (MOLIT, 2021b); and (c) policy reports from NACTO (2016), POLIS (2018), Levitate (Elvik et al., 2019), etc.

The five policy goals are increased safety, improved accessibility, enhanced equity, reduced environmental impact, and economic development (see Table 1). Among these goals, the most important one is safety. Promoting AV-based services could be interpreted as sacrificing safety for other values' sake if safety is not ensured. Naturally, most of the current discussions on regulations revolve around how to ensure safety with the intrinsic uncertainty of AVs. The other goals are commonly mentioned as potential positive impacts of AVs. However, they are not guaranteed, and active roles of governments are required.

Table 1. Exemplary policy goals of AV-based services

Policy goals	AV services should …
Increased safety	help make traffic safer for the passengers using the services and for all road users interacting with the AV-based services.
Improved accessibility	provide efficient and attractive mobility services complementing public transport so that people do not have to rely on private modes.
Enhanced equity	help make urban transport more affordable, inclusive and accessible. They should provide accessibility for vulnerable users such as older people, people with disabilities, and people in underserved regions.
Reduced environmental impact	help reduce overall GHG emissions and air pollution. AV-based services should contribute to a better, more liveable urban environment.
Economic development	help to create better and more jobs than the jobs replaced or removed by them, stimulate more innovation and provide industrial competitiveness.

These goals can be translated into nine impact domains, as depicted in Table 2. AV-based services will directly affect passenger behaviours, traffic patterns and accessibility. As AV-based services become widely available, impacts on employment, health and safety, and the environment will also become evident. AV-based services will influence infrastructure and urban space (Crute et al., 2018; Riggs et al., 2019). They will also have implications for public revenues and expenditures (Adler et al., 2019; Blas et al., 2022; Fisher, 2020). According to the ITF's expert survey, AV-based services are expected to positively impact some domains, such as accessibility and safety, and to negatively impact employment by eliminating driver jobs; the expectation for new job creation is mixed.

However, it is worth noting that some countries are experiencing driver shortages, and AV-based services could be a way to address the issue (Okamoto, 2019; European Commission, 2023). Opinions on whether AV-based services will positively or negatively impact public finance were mixed and could depend on policy measures. More active government transition management would be needed for those domains where a negative outcome is expected, or expectations are mixed.

Table 2. Domains that AV-based services could have positive and negative impacts on

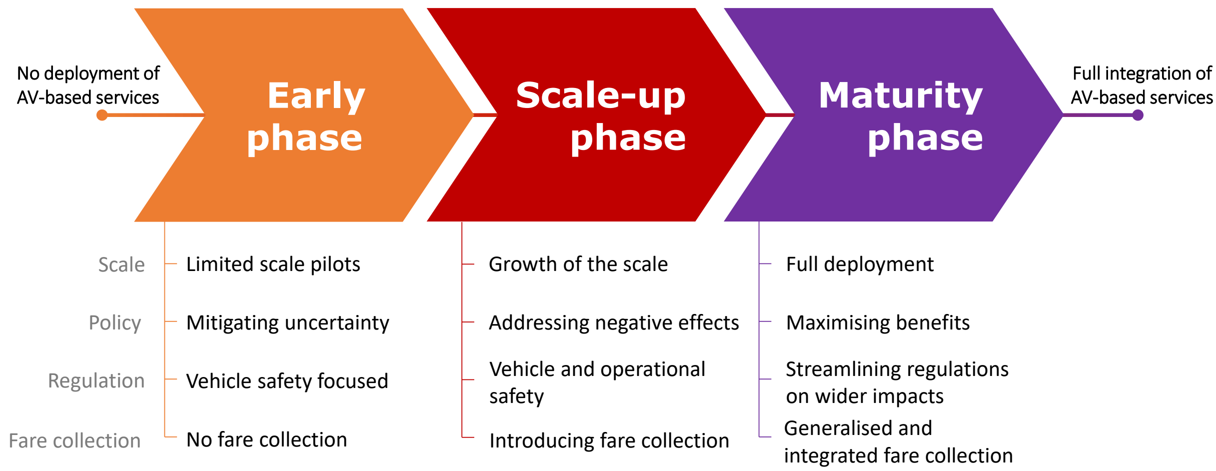
Impact domains	Descriptions
Passenger behaviours	Changes in individual passenger behaviours, such as how frequently and how far people travel, are expected to change, which could be captured by metrics like the distance passengers travel (VMT/VKT).
Traffic patterns	Changes in urban transport patterns in terms of shared mobility rates (e.g. percentage of shared trips, including public transport) or vehicle utilisation rates (e.g. hours of operation as a percentage of total available time).
Infrastructure	AV-friendly infrastructure (e.g. intelligent traffic lights) will likely promote the advent of AV-based services and vice versa. The need for digital infrastructure will likely be increased to manage AV-based services.
Accessibility	The shift towards autonomous mobility services can significantly transform transport systems and influence spatial accessibility (e.g. the number of opportunities accessible for the same amount of time) and physical accessibility (the difference in travel time between vulnerable user groups and other groups).
Employment	The advent of AV-based services will likely affect a broader range of employment in the transport sector and beyond, beginning with drivers' jobs.
Environment	AV-based services could affect the environment by fostering improvements in terms of unit energy consumption and average unit GHG emissions.
Public finance	AV-based services could affect the public budget balance by inducing changes in both public revenues (parking tickets, fuel taxes, etc.) and public expenses (traffic regulation enforcement, road maintenance level, etc.).
Safety and health	AV-based services could raise safety considerations for passengers and street users. These safety and health considerations could be expressed in terms of crashes (e.g. number and severity).
Urban space	AV-based services could affect how urban space is used and allocated, including changes in parking space, road space (e.g. road, curb) and urban sprawl.

Note: GHG = greenhouse gases; VMT/VKT = vehicle miles travelled/vehicle kilometres travelled.

This is not an exhaustive list of all the goals and impact domains mentioned. However, it indicates those most frequently emphasised by multiple sources as key factors and thus worthy of consideration while designing regulatory interventions.

The extent and strength of each impact in the nine domains will grow alongside the uptake of AV-based services. The deployment of these services, however, is not likely to be linear. On the contrary, deployment is likely to be phased by regulatory developments and the focus of government interventions. For example, before AVs can be deployed on public roads, public authorities must establish test permits in their regulations. Similarly, establishing or adapting regulations enabling public or private AV-based service operators to accept fares is a necessary pre-condition for deploying AV-based passenger transport services. If such regulations are not prepared, the deployment of AV-based services could be delayed, and it might not be able to proceed to the next phase. Broadly speaking, the deployment of AV-based services could be characterised by three phases (see Figure 5).

Figure 5. Deployment phases of AV-based services



Early phase. The early phase covers test and pilot operations. This initial phase requires that public authorities provide criteria and procedures that allow AVs to be deployed on certain public roads. This usually requires specific technical assessment procedures to verify the functionality of ADS and the overall safety of the deployment scheme. Because the AVs may not fully comply with existing vehicle safety standards, public authorities may need to implement additional measures such as technical assessments or outlining specific operating conditions. At this stage, most deployments are conducted to develop ADS technology and accumulate operation experience. Fare collection may not be considered or, if conducted, more likely to be done so on a trial basis.

Scale-up phase. The second phase encompasses the early commercial deployment of AV-based services. As AV service operators gain experience and confidence, governments will face increasing calls to provide a clear regulatory framework for the commercial operation of AV-based services and expanded operational zones. Many business models will be tested in this phase. Companies will gain experience from learning by doing and will be able to make their services more reliable and improve their commercial viability over time. The impacts of AV-based services will be more clearly pronounced as services grow. There will be responses from diverse stakeholders, including other road users and existing transport service providers. Governments will be asked to address negative impacts on competing business operators and any inconvenience caused to other road users resulting from scaled-up deployment of AV-based services.

Maturity phase. In the long run, new, comprehensive AV safety standards will be developed, and level 4 AVs will be available on the consumer market. Special regulations dedicated to accompanying the early deployment of AVs, such as testing permits, will become obsolete. AV-based services will potentially be fully integrated into the urban transport system. Operational zones will be expanded more broadly. At this stage, the focus will move from enabling AV-based services to utilising AV-based services to achieve better policy outcomes across diverse impact domains.

These three phases are interconnected in that the outcome of the earlier phases will affect the dynamics in the following phases. The final picture will depend on how public authorities set up regulatory frameworks over the whole process. If, for example, AV-based services are successfully integrated with public transport early on and provide competitive alternatives to owning a private AV, the final equilibrium would likely favour more sustainable, efficient and liveable cities. Therefore, having a sound, future-proof and outcome-oriented regulatory framework is crucial to ensure better outcomes.

Currently, most ITF member countries are in the early phase, and only a few are transitioning to the second phase in certain locations. Many member countries have established procedures to allow testing and pilot projects for AVs on public roads. Some countries or sub-national governments such as California (USA), China, France, Germany and Korea are starting to authorise driverless AV deployment in specific contexts. Countries such as the United Kingdom and South Korea have developed laws dedicated to the commercial deployment of AV-based services. Deployment requirements and conditions vary, however, and are not harmonised.

Regulations to ensure the introduction of safe automated-vehicle-based services

The most important issue with the deployment of AV-based services is safety. Governments need to provide a process to verify and ensure the safety of AVs in order to initiate AV deployment programs and make them commercially available. However, even though it is believed that AVs will be safer than human-driven vehicles, the technology is still in a developing stage, and test procedures for safety validation are not yet fully established. Under such circumstances, it is important to have a regulatory framework reflecting a holistic approach in which all the influencing elements share the responsibility to achieve zero road-crash casualties (ITF, 2016). In this section, the "Safe System" approach is revisited to apply its principles to AVs, followed by more specific measures.

The Safe System approach for automated vehicles

The Safe System approach has been endorsed and emphasised as an effective approach for reducing road crash casualties (ITF, 2008; ITF, 2016; ITF, 2018; ITF,2022b; World Health Organization and World Bank, 2004). First adopted by Sweden as the "Vision Zero" approach (Swedish Parliament, 1997), this approach innovated the view on how crashes can be prevented. According to the traditional approach, individuals who made mistakes were regarded as responsible for the crashes; thus, the policy focus was on improving human behaviour to prevent crashes.

By contrast, the Safe System approach accepts that humans make mistakes and acknowledges that the overall system – including users, vehicles, roads and post-incident response systems – interacts as a whole entity. The policy focus is not on eliminating human error but rather on designing the whole system such that even when humans make mistakes and contribute to a crash, the crash does not lead to deaths or serious injuries. The four guiding principles below are central to a Safe System (ITF, 2016, p. 26):

1. People make mistakes that can lead to crashes. The transport system needs to accommodate human error and unpredictability.

2. The human body has a known, limited physical ability to tolerate crash forces before harm occurs. The impact forces resulting from a collision must therefore be limited to prevent fatal or serious injury.

3. Individuals have a responsibility to act with care and within traffic laws. A shared responsibility exists with those who design, build, manage and use roads and vehicles to prevent crashes resulting in serious injury or death and to provide effective post-crash care.

4. All parts of the system must be strengthened in combination to multiply their effects and to ensure that road users are still protected if one part of the system fails.

Governments can pursue the Safe System approach with AVs while acknowledging the intrinsic risks and uncertainties of the driving performances of ADS. AV-based services will be provided entirely by ADS in their normal operations. Therefore, they will be free of direct human mistakes that could lead to crashes. However, ADS are not infallible and have a certain degree of unpredictability intrinsic to a machine-learning-based system (Koopman and Wagner, 2017; Bolte et al., 2019). Furthermore, human coding errors in the underlying algorithms may lead to unexpected and potentially dangerous AV operation. These intrinsic risks may not be eliminated even if the verification and validation processes are fully established.

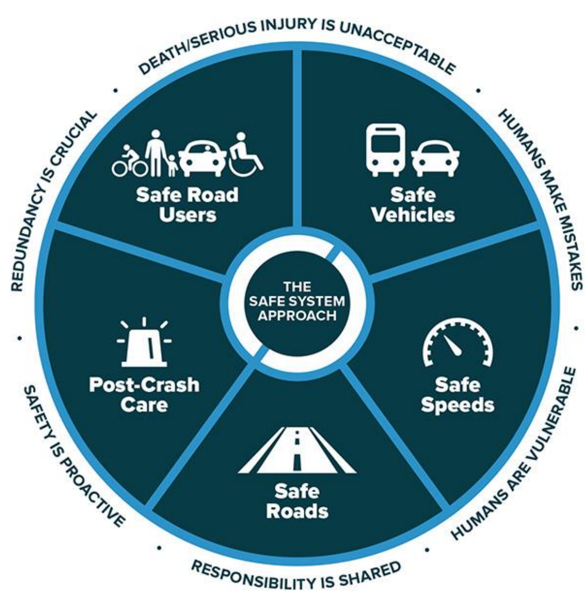
Therefore, just as human drivers with proper driver licenses are expected to occasionally make mistakes, the possibility of ADS making undesirable driving manoeuvres should be recognised as a given condition. This does not mean that all unexpected and dangerous AV operation should be accepted; AVs should be able to handle driving tasks with skills equivalent to those of competent and careful drivers (GOV.UK, 2022b). Rather, it means that it is not possible to eliminate the possibility of the AV behaving in an unpredictable way under rare or unusual situations. This uncertainty is more pronounced with the deployment of AV-based services because deployment is needed before internationally agreed test and validation processes for level 4 ADS features, which are expected to take many more years to be developed.

Therefore, like the Safe System approach for human driving conditions, a Safe System approach for AVs should focus on preventing death and serious injuries from crashes involving AVs rather than preventing any crashes involving AVs. In that sense, the first principle of the Safe System approach could be adapted for ADS as follows:

> ADS are not perfect and could perform unexpected and unusual manoeuvres that can lead to crashes. The transport system must accommodate ADS's imperfection and ensure minimally acceptable levels of safety – e.g. no death or serious injury -- even in edge and corner cases.

The Safe System approach emphasises the shared responsibility of those who design, build, manage and use roads and vehicles. This is the same with AVs. Not only AVs but surrounding infrastructure, other road users, passengers and service providers, and post-crash response systems need to be strengthened to ensure the safety of AV-based services. Figure 6 shows the Safe System approach principles and elements as illustrated by the FHWA (2022). The same principles should be applied to the operation of AV-based services, with additional elements of ADS.

Figure 6. The Safe System approach: principles and elements



Source: FHWA (2022).

New legal actors and new responsibilities in AV-based services

There are two key differences between AV-based services and conventional services. The first is that the AV technology is still being developed and needs to be used without a fully developed validation methodology. The second is that there is no in-vehicle human driver to take responsibility for driving tasks. Consequently, AV-based services require an additional layer of regulatory interventions.

New legal entities need to be defined to address these differences. The first issue when using AV technology is that it requires an alternative validation process. It also makes it necessary for government authorities to interact closely with the entities developing the technology to address any new technical issues. The government needs cooperation between these entities to evaluate and update validation procedures, analyse any crashes or unexpected incidents and provide clear and transparent communication with the general public.

For these new responsibilities, the Law Commission of England and Wales and the Scottish Law Commission (2022b; 2022c) recommended introducing a new legal actor, an "Authorized Self-Driving Entity" (ASDE), as described in Figure 7, along with two other legal actors: a "User-in-Charge" and "No-User-in-Charge (NUiC) operator". The concept of ASDE is not new in most countries permitting AV deployment on public roads, but it is not always explicitly defined as a standalone legal actor distinct from vehicle manufacturers or ADS developers. Defining ASDE will clarify who should be responsible when multiple actors are involved in a certain AV deployment scheme. For instance, there could be a case that a certain AV has an ADS developed by company A, which is installed on a vehicle manufactured by company B and submitted for a permit by another organisation C that wants to operate it. However, no one may want to take post-crash responsibility. Providing appropriate, clear legal terms would help assign responsibilities in a clearer and more straightforward manner.

Figure 7. Exemplary responsibilities and conditions of an Authorized Self-Driving Entity

ASDE (Authorized Self-Driving Entity)
• Needed for all on-road AVs • Puts the AV forward for authorisation as having self-driving features • Legally responsible for the performance of the AV • Responsible for the safety case • Must be of good repute • Have appropriate financial standing

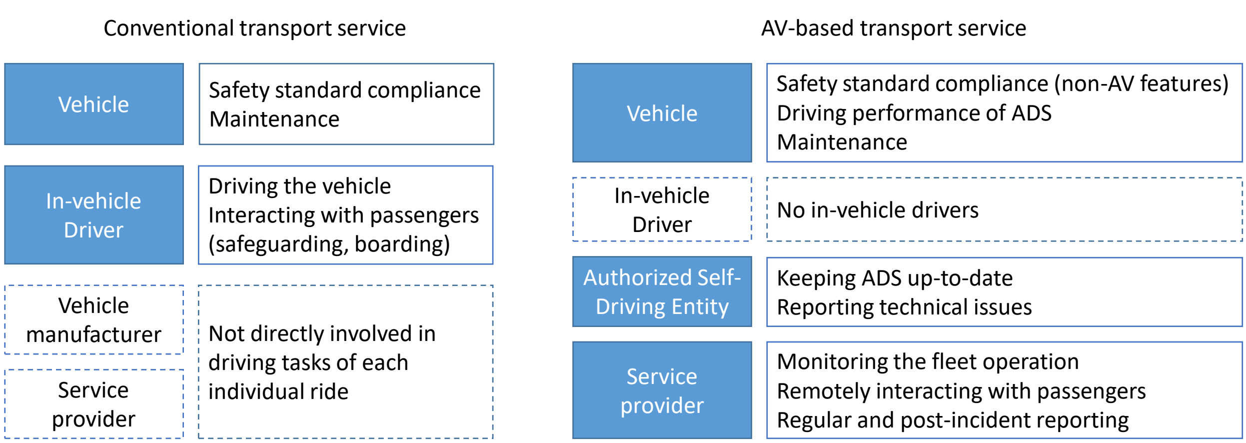
Note: AV = automated vehicle.
Source: Adapted from Law Commission of England and Wales and Scottish Law Commission (2022b).

The other key difference of not having an in-vehicle driver requires AVs to be connected to the service providers. The service providers need to be able to respond to unexpected situations remotely and, if needed, dispatch personnel on-site. The current UNECE regulations (E/ECE/TRANS/505/Rev.3/Add.156 UNR 157) for the level 3 Automated Lane Keeping Systems (ALKS) feature define the "emergency manoeuvre (EM)" and the "minimum risk manoeuvre (MRM)" to address risks of immediate collision and severe vehicle failure of level 3 AVs. In addition, many new vehicles, whether automated or not, are equipped with "eCall", a system that automatically alerts emergency services and has been mandatory in the EU since 2018 (ETSI, 2015).

These measures would be sufficient for private AVs. However, for AV-based services, a service provider must actively respond to these incidents to assist the affected customers and participate with authorities in post-incident investigations. The service provider providing transport services with level 4 AVs may also need to monitor fleets to optimize the dispatch of vehicles. Connectivity is also needed for interacting with passengers to provide interactions that were previously provided by drivers, such as safeguarding passengers from in-vehicle harassment, interacting with police, etc. (Law Commission of England and Wales and Scottish Law Commission, 2022b)[2]. Therefore, service providers of AV-based services should take a more significant and active role than their counterparts in conventional services. These legal responsibilities should be reflected in the authorisation and licence system for AV service providers.

There are many cases where these two legal actors, the ASDE and the service provider, are the same entity. This is the case when an AV-developing company also operates fleets, like Waymo and Cruise (Bellan, 2022). However, there are cases where these two are different. For example, the Norwegian bus and ferry company Kolumbus operates a fleet of large buses manufactured by a Turkish company and equipped with an ADS developed by another Turkish company (Schreiber, 2022). As the AV service market gradually matures, more instances of one ASDE providing vehicles to multiple service providers and one service provider operating multiple fleets of vehicles from different ASDEs will arise. ASDEs would need to update the ADS of all the vehicles operated by multiple service providers. Service providers may need to manage AVs from multiple ASDEs. Given all these possibilities, it is necessary to consider the ASDEs and the service providers as two separate legal actors. Figure 8 shows the differences between the relevant regulatory intervention points.

Figure 8. Different regulatory intervention points of conventional and automated-vehicle-based services



Note: ADS = automated driving systems, AV = automated vehicle.
Legend: blue boxes= regulatory intervention points, dotted Box = no direct regulatory interventions are needed.

To respond remotely to any needs in the service vehicles, human remote operators should always be on call. The European Commission recently defined the new role of a “remote intervention operator” who would carry out intervention tasks (European Commission, 2022a). SAE International has also added new definitions for “remote driving” and “remote assistance” in the 2021 version of its J3016 standard (SAE International, 2021). The exact ranges of tasks may differ by country, but this “remote operator” role should be defined to provide driverless AV-based services. When the ASDE and the service provider are the same, remote operators would be employees of the entity. However, when the ASDE and the service provider are not the same, diverse forms of employment would emerge. Considering the possibility of cases where an ASDE is an overseas company not located in the country in which the service is provided, remote intervention operators are likely to be under the supervision of service providers.

Regulations for deployment and operation

Automated vehicles bring fundamental changes in legal responsibilities. For conventional vehicles, it has been very clear that the driving tasks are conducted by human drivers, while vehicles are passively performing the tasks instructed by human drivers through input devices. Thus, two separate sets of regulations have been developed to regulate: first, the human driver's capability to drive safely, and second, the vehicle's capability to protect people from an accident. In most countries, road traffic law addresses how drivers should drive, and vehicle safety standards prescribe detailed conditions that vehicles need to comply with. Drivers' quality is ensured primarily through driver training and licencing and by traffic law enforcement afterwards. Vehicle quality is regulated by the vehicle safety standards and by vehicle inspection when in use.

AVs present challenges to this conventional system. Especially for driverless AV-based services, there would be no in-vehicle human drivers, and the ADS would drive the vehicle while in service. Because ADS is a part of the vehicle, the functionality of ADS needs to be validated by vehicle safety standards via the homologation process. If homologation regulations are established, additional processes would not be needed to verify the safety of the ADS' driving ability. The vehicles complying with the regulations will be freely available on the market. The German government has made it clear that their law on automated driving is "an interim solution until internationally harmonised provisions enter into force" (DMVI, 2021).

However, the distinct characteristics of ADS make it difficult to design safety standards for these systems. Other vehicle parts, such as a steering wheel or a brake, perform a limited number of well-defined actions. Therefore, creating an exhaustive list of criteria and test procedures was possible to verify whether the parts satisfy the criteria. By contrast, unlike these conventional parts and features, an ADS needs to perceive the surrounding environment in real time and make decisions on driving tasks. This is a dynamic task whose outcome is affected by diverse, complex and often unpredictable driving situations. Validation procedures are unlikely to test ADS' decisions in all potential critical scenarios. Therefore, vehicle safety regulations for ADS will require approaches that differ from the existing certification process for vehicle safety standards used for other functions, and it will likely take an extended amount of time to develop internationally harmonised rules.

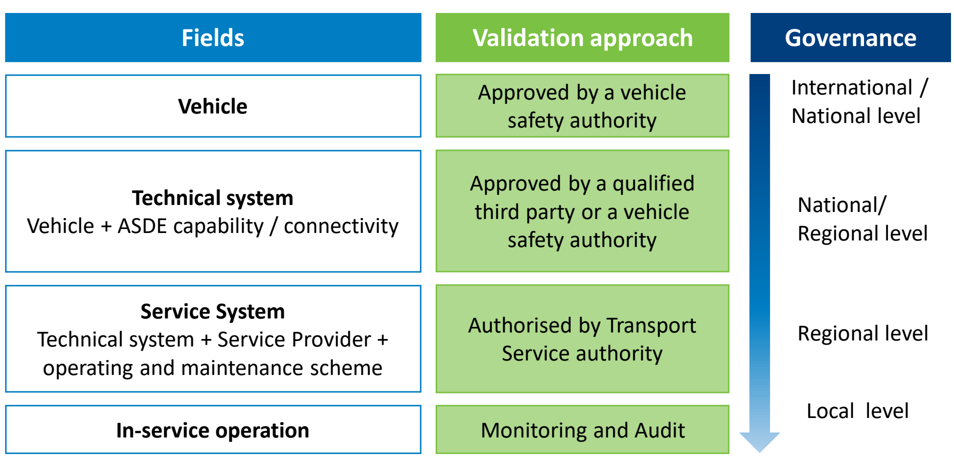
This difficulty will require governments to develop a new legal approach that allows the limited operation of AVs while existing regulations may not fully cover uncertainties and risks pertinent to safety. How to address these uncertainties and risks to a socially acceptable level is key to these new approaches. The Safe System approach of shared responsibility and strengthening all parts of the system (ITF, 2018) needs to be applied here. A multi-dimensional approach involving the vehicle and the ASDE, operation conditions and the monitoring strategy will be more appropriate for ensuring the safety of AVs and AV-based services.

Figure 9 shows a suggested validation structure for AV-based services. This architecture has four points ("fields") of regulatory intervention: the **vehicle**; the **technical system**, including ASDE; the **service system**, including service provider and service plan; and **in-service operation**. Each of these points is discussed later in this section. Overall, it needs to be proven that 1) the vehicle is as roadworthy as other vehicles and 2) its ADS can perform driving tasks reliably enough to allow the AV on public roads.

In addition, the overall technical system, including the ASDE's capability and connectivity, needs to be assessed to ensure that ASDEs can manage their fleets safely. Approving the technical system would be enough for test deployments without services open to the general public. However, operation and maintenance plans with passenger protection elements must be assessed if the service is provided to the general public. For commercial services collecting fares, assessments from the transit services perspective need to be added. In this case, the transport service regulation authority would need to engage and review the service providers' capability and operation plans.

The governance for each assessment and approval process spans from the international to the local level. For vehicle safety standards, internationally coordinated efforts are put forward via international governing bodies. The UNECE sets out regulations on level 3 vehicles and develops regulations related to AVs, such as cyber security, data recording and validation methods for automated driving (UNECE, 2022b). In the EU, where the type-approval approach is employed for vehicle homologation, a new ADS regulation has been established (European Commission, 2022). National vehicle safety authorities governing the homologation process could adopt these rules and make up for any additional needs with their own requirements. National governments may need to develop national-level regulations to validate the technical system, which provides clear guidance on ASDEs' responsibilities. However, for service authorisation and in-service operation, the involvement of regional and local governments responsible for transport service licencing and local regulations on service-related issues (such as placing stops for routed service and parking spaces for taxi services) will be necessary.

Figure 9. Example of validation architecture for AV-based services



Source: Adapted from Delache (2022) and further developed.
Note: AV = automated vehicle.

[Vehicle] Vehicles need to satisfy existing vehicle safety regulations as far as possible

For all the non-automated driving features, automated vehicles need to satisfy existing vehicle safety regulations to ensure their safety. However, some of the features may not fit into existing regulations due to the AVs' characteristics. For example, unmanned delivery vehicles may not need to have safety features intended for human passengers. By contrast, driverless automated service vehicles should be connected to the control centre so that remote operators can respond to emergencies. Governments need to provide clear guidance on which regulations can be exempted and what kind of additional features should be put in place.

The guidance also needs to take into account different AV types and operation types (see Figure 10). AVs have different features depending on whether they have a driver seat and whether they are intended to have in-vehicle occupants or not. In addition, whether they will be operated by an in-vehicle operator or not also affects their response to critical situations. The guidance may have additional requirements for the speed limit and designated operation area to limit the level of safety risks. However, these additional requirements can also impede the ASDE technology's development in a more diverse and challenging environment. During the ITF's expert workshops, private AV developing companies unanimously expressed concerns about setting prescriptive requirements prematurely. Thus, governments need to set out regulations that strike an appropriate balance between ensuring safety and encouraging technology and service development.

Figure 10. Different types of automated service vehicles

AV type	Driver seat with input devices	In-vehicle occupants	Driver / Operator
Conventional vehicles 	✓	✓	Both an in-vehicle driver and a remote operator can engage
Driverless passenger vehicles 	X	✓	Both an in-vehicle operator and a remote operator can engage
Unmanned goods vehicles 	X	X	Only a remote operator can engage

[Technical system] The ASDE's active role is requested

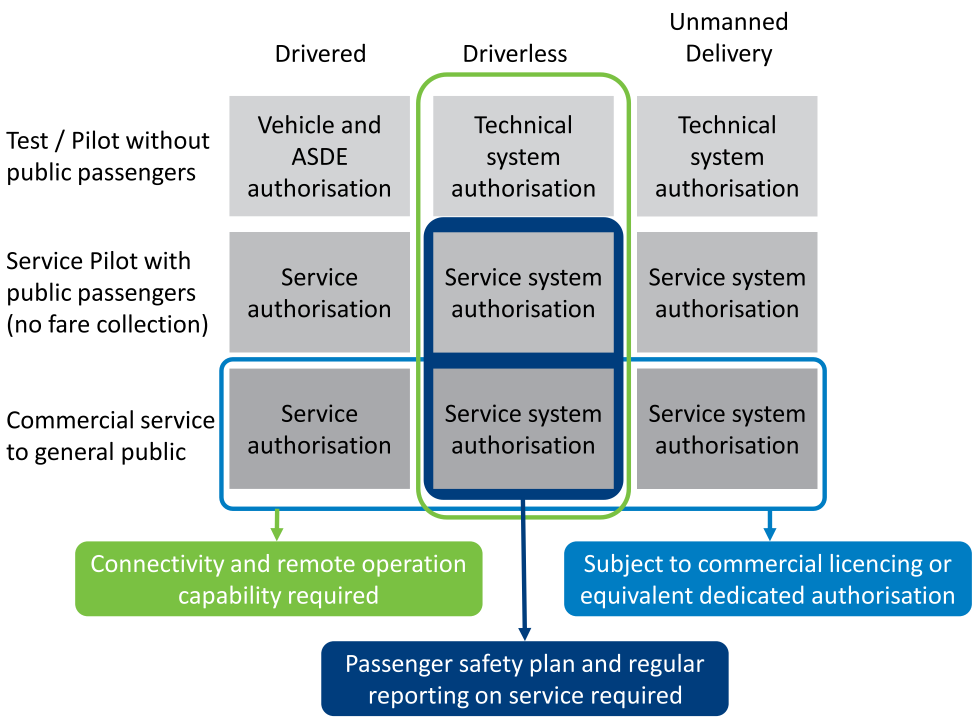
In terms of balancing safety and technology development, the key principle is to avoid exposing passengers and other road users to unreasonable safety risks. This is reflected in both the EU's new ADS implementing regulation (European Commission, 2022) and the NHTSA's enforcement guideline (NHTSA, 2016). Considering that regulations may not cover all the risks of AVs, ASDEs' active role is important. ASDEs should provide governments with documents explaining that their ADS is free from unreasonable risks in the ODD they have defined. Also, ASDEs should monitor and analyse the movement of fleets and share safety-related data with the government; and governments need to establish a process for assessing and validating ASDEs' ability to monitor and report this safety-related information. ASDEs also need to manage the fleet in a way that they are always up to date with their functionality.

[Service system] A participatory process for the service commission is needed

Service providers enter the regulatory framework from the time the AV fleets are opened to the general public. The transport service authority needs to review the service providers' plans and authorise them. The transport service authority may set regulations and impose certain responsibilities on the service providers to encourage positive impacts for their regions. (This aspect is discussed in more detail in the Transition Management section. Regarding safety, the local environment is taken into account at this stage, and the transport service authority may designate certain restrictions on the service scheme (such as vehicle speed, service area and service time) to them.

The review process should be participatory, including stakeholder consultations to obtain inputs from diverse stakeholders affected by the service, including the impacts on existing transport services. Local law enforcement authorities need to be included in the process. If the service is provided with fare collection, the service needs to be regarded as a commercial service, similar to that offered by other services of the public transport system and by transportation network companies (TNCs). Thus, AV-based services would be subject to existing transport service licencing systems applied to similar types of services provided with conventional vehicles. The whole structure is shown in Figure 11. The regulatory requirements for driverless logistics services (unmanned delivery) would be simpler than driverless passenger services as they do not need to take the safety of in-vehicle occupants into consideration.

Figure 11. Authorisation structure based on the vehicle and deployment types



Source: adapted from CPUC (2021) and further developed.

Some reporting duties would be added to the service providers on top of the mandatory reporting from ASDEs. While both entities would need to keep monitoring the fleets, service providers have the primary role in dispatching vehicles and responding to any interaction with other road users, passengers and law enforcement. Thus, the service provider would be the entity that would report such cases, and if the issue is believed to be a technical one, both the service provider and ASDE need to cooperate with the authorities for follow-up processes. In the early phase, when the service is provided on a pilot basis without fare collection, it is more likely that the ASDEs would take the role of service providers. During the ITF's expert workshops, private ASDEs expressed concerns that reporting burdens are excessive and the levels of technical expertise are incongruent across different authorities. Reporting burdens can be reduced through coordination between government agencies in charge of vehicle safety and transport services. However, the importance of setting a separate role for the service provider will be more evident over time in the scale-up phase, where multiple ASDEs engage with multiple service providers.

[In-service operation] Regular reporting and post-incident responses

During in-service operation, the focus is on operational safety. The service provider needs to monitor the fleets and identify any potential risks. The relevant authorities would need to request regular reporting and case-specific reporting on crashes, disengagement, and potentially risky incidents that will need to be reflected as possible scenarios. Vehicle safety authorities would focus more on disengagement and collision cases, while the transport service authority would focus on service quality and in-vehicle safety (harassment, assaults). In California, the California Public Utility Commission (CPUC), which authorises services, requests quarterly reports from AV service development programmes that include collision and harassment cases (CPUC, 2022). The California Department of Motor Vehicles (DMV) requests an annual report on disengagement and collisions while also asking for more immediate reporting on collision cases (DMV.CA 2022a and 2022b). There might be a potential overlap with regard to collisions, which is important for both authorities. Although the authorities need to work to reduce the reporting burden from the private side, having two reports from ASDEs and service providers would provide a more comprehensive understanding that will help both governments and private companies to upgrade the overall AV-based services structure.

Of all the items requiring reporting, the most important ones requiring authorities' immediate involvement are crashes and near-crash events. These incidents require not only reporting but also appropriate measures, including sanctions. Governments need to provide clear paths, processes and indications to the ASDEs and service providers regarding post-incident measures to take as well as the potential sanctions they risk for non-compliance; sanctions need to be proportional to the severity of the cases. This includes a technical assessment of the cause of the incidents. If the incident is related to technical vulnerabilities, the authorities need to verify whether the ASDE has provided enough measures to mitigate the vulnerabilities. Sanctions need to be balanced so as not to impede technical development or competitiveness of services while also encouraging ASDEs and service providers to make all due efforts to minimise collisions.

Physical and digital infrastructure for a safer driving environment

AVs are expected to be driven on existing road systems. However, this does not mean governments do not have to invest in providing a safer environment for AVs. AVs may perceive their driving environment differently from humans, and some road features not causing problems for human drivers could confuse AVs. Roads without lane markings could add additional difficulty for AVs to detect road lanes and localise their position in the designated lane (Ambrosius, 2018). ITF (2018) highlights many ways machine-learning algorithms can be spoofed with targeted scene-alteration techniques, including placing "trigger" elements, placing additional shapes or deploying visual noise perturbation techniques. Each resulted in misclassifying stop signs or red lights as speed limit signs or green lights. Left turning at unsignalized intersections may not be a very difficult task for humans. However, it could be much more difficult for AVs that have difficulties interpreting the intention of other vehicles (Shu et al., 2020). Better **physical and digital infrastructure** could help reduce such issues that potentially affect the safe driving of AVs in negative ways, expanding the ODDs of AVs while also being helpful for non-automated vehicles.

Both physical and digital infrastructure could contribute to providing a safer driving environment. Physical infrastructure comprises the physical road, traffic control infrastructure (such as road signs and traffic signals), traffic operation infrastructure (such as sensors on roadsides), traffic control centres that process sensor inputs and manage traffic information and lastly, maintenance and operation (ITF, 2023a). The digital infrastructure includes mobile networks supporting remote monitoring of service operation, high definition (HD) maps supporting localisation of AVs, traffic management information, cooperative intelligent transport systems (C-ITS), low-latency "vehicle-to-everything" (V2X) safety communication, and cybersecurity.

In terms of physical infrastructure, a basic but important measure that could be taken is providing and maintaining better-quality infrastructure. In particular, good and consistent lane marking and signalling are expected to be necessary and would benefit both AVs and non-AVs, as shown in Table 3 (Lawson, 2018). One potential regulatory intervention could be enhanced road assessment in the service area of AV-based services. Criteria and tools developed by the International Road Assessment Programme (iRAP) could be used as a reference for such an assessment (Lawson, 2018). The other potential intervention is equipping the service area with sufficient traffic operation infrastructure to provide traffic data, including unexpected infrastructure changes from construction works. Providing traffic information would help service providers better manage their fleets and avoid potential safety risks.

Table 3. Crash configuration influencers and infrastructure attributes

Crash partners	Potential changes in risk	Examples of infrastructure needed
AV vs conventional vehicle	Measures may lower the likelihood of severe crashes due to speed control and speed-limit compliance but may increase the frequency of conventional vehicles striking automated vehicles.	Signing and lining Median barriers Intersection choice (priority intersections or roundabouts or signals)
AV vs AV	Similar to above but with risk reduced due to AV increased control and connectivity – e.g. shunt* crashes eliminated.	Signing and lining Connectivity with roadside infrastructure and vehicles
AV vs Infrastructure	AV – better lane-keeping, speed adjustment on a curve, barriers required but less often (speed reduction, reduced threat from roadside hazards), vehicle-to-infrastructure (V2I) connectivity with roadside and traffic information.	Signing and lining Verge measures such as a revision of roadside crash restraint policy (i.e. provision of barriers) Connectivity
AV vs motorcycle	Similar to AVs versus conventional vehicles but also dependent on the ability of AV to detect the motorcycle and of the rider to interpret manoeuvres of the car and vice versa.	Signing and lining Median barriers Intersection choice (priority intersections or roundabouts or signals) Motorcycle recognition by other vehicles and infrastructure
AV vs bicycle	Similar to AV versus conventional vehicles but also dependent on the ability of AV to detect bicycles and of the rider to interpret manoeuvres of the car and vice versa.	Signing and lining Median barriers, nearside segregation Intersection choice (priority intersections or roundabouts or signals) Bicycle recognition as above
AV vs pedestrian	The ability of AV to detect pedestrians and the pedestrian to interpret manoeuvres of cars and vice versa.	Pedestrian recognition as above Nearside segregation Crossing designs and priority

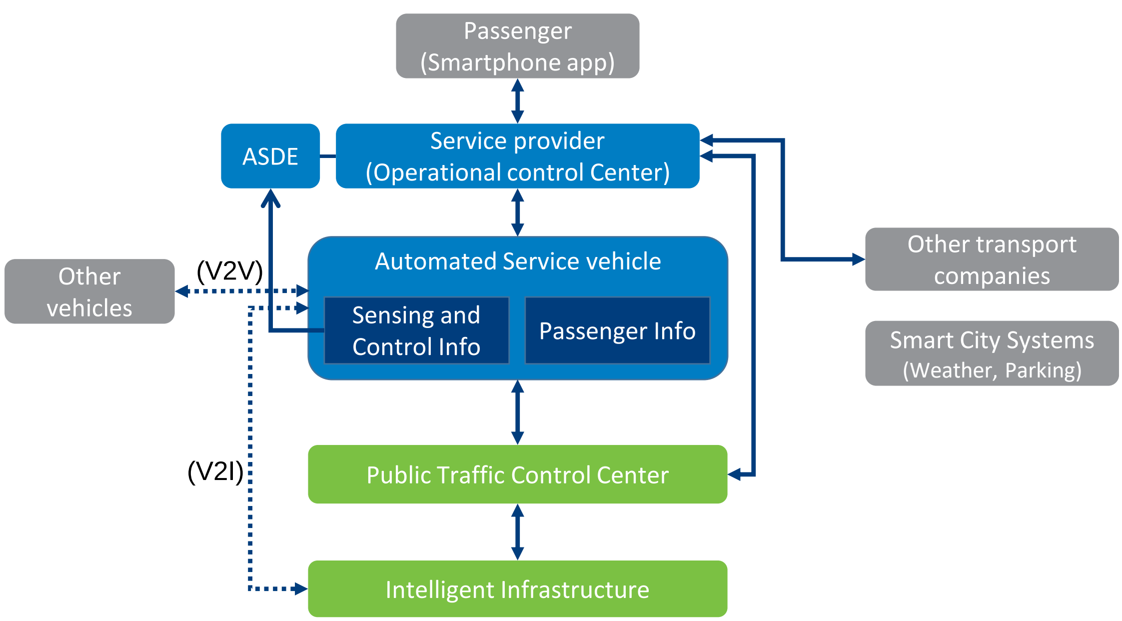
Source: Lawson (2018).
* A *shunt* is a car accident in which one vehicle drives into the back of another.

Regarding digital infrastructure, one of the most critical infrastructure features would be **mobile connectivity** that enables remote monitoring and intervention. This will enable the service providers to engage remotely with the vehicles when necessary and the ASDEs to acquire vehicle data in real time. Therefore, the AVs used for transport services would be automated and connected vehicles. While mobile networks are almost ubiquitous in most urban areas, AV-based services would benefit from a seamless connection throughout the driving environment, including tunnels and underpasses. Governments could use mobile network infrastructures to provide information useful to automated driving (traffic signals, lane closures due to construction, etc.) to AV-based services. Considering these potential needs, governments may need to develop strategies to ensure communication infrastructure meets AV-based services' connectivity requirements.

If mobile connectivity is one of the basic conditions for data transmission, then the **information-exchange systems** between different actors are the core of the digital infrastructure for AV-based services. UITP (2021) proposes a reference design for an "Intelligent Transportation System for Autonomous Vehicles (ITSxAV)" centred on the fleet orchestration platform. Szigeti, Csiszár, and Földes (2017) suggest similar architecture but with more emphasis on the role of smart stops.

Figure 12 depicts one of several possible information systems for AV-based services, with the service vehicle in the centre. This could be expanded, including financial transactions and charging infrastructure (Szigeti, Csiszár, and Földes, 2017). Vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) information can be provided using direct communication. Both public and private sectors would need to work together to provide a sophisticated information system required for AV service operation.

Figure 12. Sample information-exchange system for AV-based services



Source: Adapted from (Szigeti, Csiszár, and Földes, 2017), (UITP, 2021)

In addition to the existing mobile network, a **cooperative intelligent transport system (C-ITS)** can provide enhanced safety via direct vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. A C-ITS can employ both existing cellular networks and short-range direct communication using dedicated bandwidth (C-Roads, 2021). C-ITS infrastructures are being deployed in many ITF member economies, including the C-ROADS programmes in the EU, Japan and South Korea. Information transmitted via C-ITS would be an important data source for traffic management. Unlike mobile networks, where information needs to pass through centralised network systems via routers, short-range direct communication between terminals enables low-latency communication among multiple agents in the vicinity. This characteristic is useful for time-sensitive information, such as providing emergency vehicle warnings for approaching vehicles and providing signal phase information at an intersection to multiple vehicles simultaneously.

The short-range C-ITS communication requires the installation of roadside units (RSU) and onboard units (OBU) for vehicles, which could add additional cost to vehicles. AV developers generally aim for a level that allows vehicles with ADS to drive safely in their designated ODD without additional external support. However, governments may consider having a C-ITS system and requiring transport service vehicles to be equipped with OBUs via regulation and financial support for an additional layer of safety – especially at the scale-up and maturity phases, where communication between automated service vehicles would increase. If the governments provide C-ITS infrastructure, key principles of interoperability and backward compatibility should be seriously considered (ITF, 2023a). *Interoperability* guarantees the seamless provision of C-ITS service using different communication methods. *Backward compatibility* guarantees seamless C-ITS services for different generations of communication technology by ensuring new equipment supports previously existing communication methods.

The **digital map** is another driving environment that governments can invest in to support safe and efficient AV service operations. A digital map is the digital representation of geolocated data. The data the map provides to AVs can be divided into three broad categories:

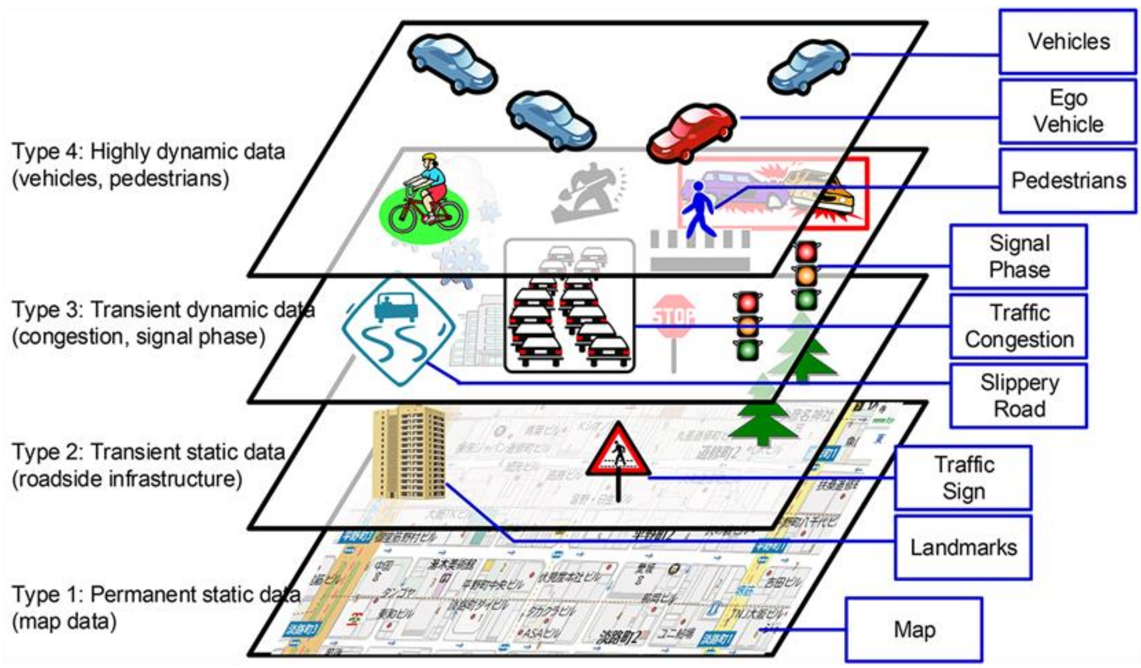
- Data that allow the vehicle to situate itself in space and with respect to other things occupying that space (static and dynamic). This is the “where” data and relates to positioning.
- Data that communicate to the ADS how to legally operate wherever it is. This is the “what is permissible” data. It relates to rights and obligations and can be a form of machine-readable regulation.
- Ancillary data relating to local services and features (restaurants, schools, petrol stations, etc.).

The first two are areas of policy relevance for public authorities tasked with governing the operation of AVs. The third is an additional area of relevance for authorities tasked with governing AV services (especially as these relate to critical facilities and services like schools, hospitals or public transport stations). Governments need to provide regulations to ensure accurate and timely updates of these map data.

AVs combine map data with sensor data to create a local dynamic map (LDM) with which the ADS can make a judgement on driving tasks. The data reflecting the real world in LDM can be categorised into four different types (ETSI, 2011), as shown in Figure 13. Of the four types, the permanent static data (type 1) is the base map with highly accurate coordinates. The transient static data (type 2) also could be provided as publicly available information. Transient dynamic data (type 3), such as signal phases or construction works, could be provided by the traffic control centre via connectivity. The highly dynamic data (type 4) are mostly acquired by the sensors on the vehicle.

The government could take a more active role in providing digital map data. In the case of South Korea, the government has already created high-definition (HD) maps of the entire motorway and national highway networks (MOLIT, 2020). Since 2021, the MOLIT set up a new regulation that any road works bringing changes in road features need to submit updated HD maps as a part of the final deliverable so that the information can be timely updated (MOLIT, 2021a). This kind of policy would enable type 1 and type 2 data to be provided as public information and thus reduce the map updating cost from the private sector. Some governments may prefer more private sector-driven approaches that let each ASDE develop these data by themselves or in collaboration with mapping companies. Even in that case, governments could facilitate data sharing and exchange by providing standardised data structure and data quality standards.

Figure 13. The four types of data in a local dynamic map (LDM)



Source: Shimada et al. (2015).
Note: Ego vehicle = connected and/or automated vehicle, the behaviour of which is of primary interest in testing, trialling or operational scenarios.

Infrastructure can not only provide supportive data, but it can also guide AVs in certain specific cases. For instance, some busy transit centres where several scheduled automated buses gather at the same stop may need to manage the flow of AVs. For instance, if automated buses need to stop in a crowded transit centre such as the bus transit centre in Seoul station (Figure 14) – where more than 700 buses from over 80 different routes stop per hour (Seoul Metropolitan Government, 2016) – the exact stopping spot may need to be designated from a control centre to efficiently and safely process traffic. This issue would be relevant only in the later phases, but authorities may consider this possibility in advance.

Figure 14. Busy transit centres, a potentially challenging situation for AV-based services

Source: image provided by Seoul Metropolitan Government.

Table 4 presents a classification scheme for infrastructure support for automated driving (ISAD) designed by the Inframix project (Carreras et al., 2018). This table comprises all the LDM types and active guidance concepts:

- Level E is the level that no digital information is provided
- Level D corresponds with type 1 and type 2 data of the LDM layers that could be provided by HD maps.
- Level C is the level where type 3 data are provided via telecommunication. An ITS system is the prerequisite for collecting, processing and disseminating data.
- Level B is the level where type 4 data are provided; thus, real-time V2I communication is required.
- Level A is the level where guidance mentioned in the previous paragraph is provided.

Not all roads need to be equipped with higher ISAD levels to support AVs. Most AVs are being developed with a view to driving on existing road infrastructure. However, providing infrastructure support in a certain area or route for AV-based services would make traffic more efficient and enhance the safety of AV-based services. Governments may need to assess how much digital infrastructure they need to provide on the basis of their potential benefits and costs. Even improving marking and signs would be more than enough in less-complicated areas, while the higher level of support might be worthy of investment in certain urban areas.

Table 4. Infrastructure Support Levels for Automated Driving

	Level	Name	Description	Digital information provided to AVs			
				Digital map with static road	VMS*, warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Digital infrastructure	A	Cooperative Driving	Based on real-time information on vehicle movements, the infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimise the overall traffic flow.	V	V	V	V
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations and providing these data to AVs in real time.	V	V	V	
	C	Dynamic digital information	All dynamic and static infrastructure information is available in digital form and can be provided to AVs.	V	V		
Conventional infrastructure	D	Static digital information / Map support	Digital map data are available with static road signs. Map data could be complemented by physical reference points (landmark signs). Traffic lights, short-term road works, and variable message signs (VMS) need to be recognised by the AVs.	V			
	E	Conventional infrastructure / no AV support	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs.				

Note: VMS = variable message signs.
Source: Carreras et al., (2018).

Transition management

Recent examples illustrate how technological breakthroughs and related innovations (e.g. ride-sourcing services) can significantly impact transport services. Like any other innovation-driven transformation, AVs will also impact cities and societies (Winston & Karpilow, 2020). Innovation describes the translation of an idea into a new method, technology, business model, service, etc. Unlike an invention, innovation implies a – sometimes – fluid process that goes from the implementation phase to the adoption stage and then the diffusion of the innovation (ITF, 2019). In this context, transition management will be central to managing automated driving and the service's continuously evolving technical and regulatory landscape. This observation emphasises how important policymaking is in ensuring positive impacts while mitigating negative ones. Adapted rules regarding AV-based services will enable public authorities to reach their policy objectives. However, this supposes identifying the impacted domains (e.g. safety, environment, employment, public finance, etc.), the outcomes of AV's impact on this domain (e.g. positive, mixed, negative), and identifying adapted policy actions to mitigate these issues.

The following sections will discuss the broader impacts of deploying services based on AVs. It will provide policy recommendations to public authorities to better manage the transition toward AV-based services maturity (Fagan et al., 2021). The impacts discussed in this section are by no means comprehensive. Still, they illustrate how policymaking can contribute to enabling AV-based services' positive outcomes for public authorities in various domains (e.g. labour, public revenues, public service obligations, and institutional co-ordination). The examples in this section highlight policy actions and their effects on managing automation consequences in various cities and industries.

Labour force issues

Any discussion of the future of automated vehicles will necessarily involve labour issues. In this section, we will explore the following topics:

- The historical relationship between automation and labour
- Sectors at risk of automation
- Potential consequences for transport services labour
- Mitigating the impact of AV-based services on labour: upskill, reskill, train

Technology, automation and transport

There is a historical relationship between technological developments and labour. This is because technological progress is often used to replace human work (e.g. workforce) with another type of labour (e.g. engine, machine, computer). Technology affects three dimensions of labour: employment (e.g. the number and distribution of jobs), workers' wages, and working conditions.

Automation is a continuation of this broader process of technological development. And like other technological progress, it raises concerns about its labour impacts. Automation enables the substitution of human labour with machine work. Routine tasks are more likely to be automated due to their repetitive dimension. From an economic perspective, it increases the quantity and quality of outputs (e.g. goods or services) at a reduced cost. For example, recent progress in computer technology (e.g. artificial intelligence and machine learning) has led to a lower computer capital price (Winston & Karpilow, 2020).

What is and is not at risk of automation?

Within the transport sector, workers are not equally exposed to the risk of automation (OECD, 2018; World Maritime University, 2019). The risk of automation expresses a technical potential regarding the probability that an occupation will be automated. However, one should note that the effective automation of transport services operations may depend on non-technical factors (e.g. acceptability, safety).

Automation is about substituting a labour force with a machine that accomplishes the same task. A job may comprise several types of tasks (See Table 5). Operating a transport service involves routine and manual tasks (e.g. driving the vehicle, detecting and responding to objects and events) as well as non-routine interactive tasks (e.g. selling the service). However, a routine task is not necessarily without complexity regarding the operation of a transport service. For example, operating automated transport services in a closed environment (e.g. warehouse, metro lines with platform screen doors) is far less complex than in open environments (e.g. non-fenced roads, cities).

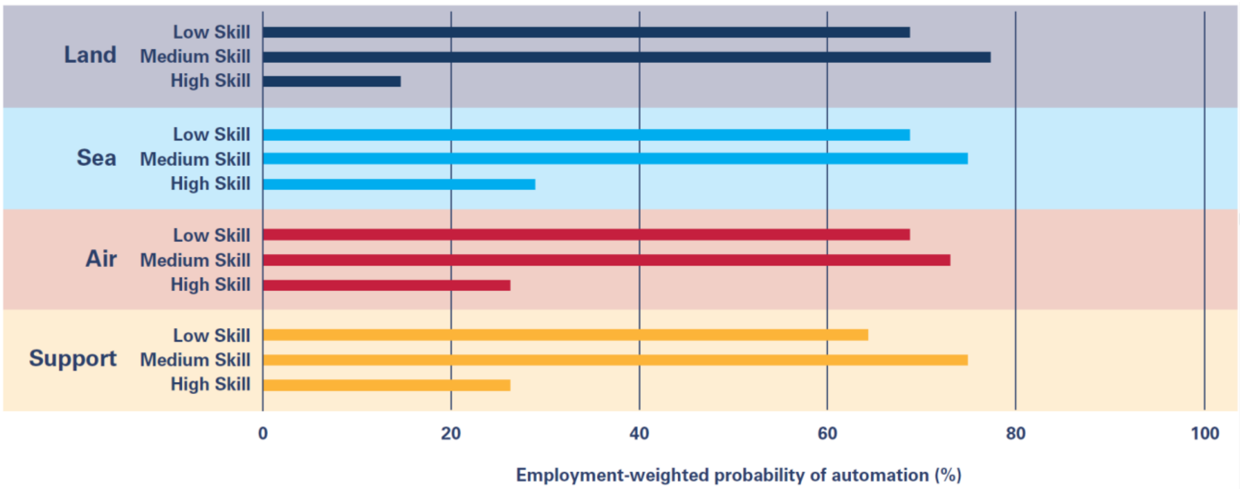
Table 5. Classification of tasks depending on their type and category

Type of task	Category	Tasks
Non-routine	Analytic	Designing, gathering information, documenting, developing, researching
	Interactive	Advising, training, teaching, planning, promoting, marketing, public relations, buying, selling, supervising
	Manual	Repairing, patching, serving
Routine	Cognitive	Measuring, checking, controlling
	Manual	Driving, transporting, controlling machines, stocking, posting, producing goods

Source: Adapted from (Antonczyk et al., 2009).

Studies indicate that the risk of automation depends on skill type rather than on transport mode (see Figure 15) (World Maritime University, 2019). Middle-skilled jobs face a higher risk (77%) than low-skilled jobs. Within land transport, driving-related jobs (e.g. bus driver, taxi driver, freight transport) are likely to be impacted by automation due to the large share of routine tasks they comprise.

Figure 15. Automation risk, by transport mode



Source: World Maritime University (2019).

The ITF surveyed experts on AV-based services' impacts on various domains (See Box 1 in the first section). Respondents indicated that AV-based services would have a more pronounced negative impact on driver jobs (69%) than other jobs in the transport sector (38%) and that AV-based services' impact on employment would be more pronounced in the maturity stage. However, more than a quarter of respondents (26%) indicated that these AV-based services would affect jobs in the scale-up phase. This finding suggests the need to consider emerging impacts during the scale-up phase.

Crucially, existing trends point to a generalised drop-off in service drivers entering the workforce, including for public transport and freight (ITF, 2017a) – and, in some contexts, for taxi-driving. The job-replacement impact of AV services must be considered against this backdrop. The chronic shortage of drivers could lead to more important disruptions within the transport sector and have a consequent impact on the wider economy. The current challenges are that greater demand for driving positions meets fewer people. In Paris, only 700 persons have been recruited for 1 500 job vacancies (47%) by the RATP, which operates Paris' transport network (RFI, 2022). Recruitment issues usually result in operational challenges. Île-de-France Mobilités, Paris region's public transport authority, had to cut its public transport services by 7-8% due to recruitment problems (RFI, 2022). Similarly, in the UK, rail operating companies had to remove nine of their 40 daily services due to driver shortages (FT, 2022).

Potential consequences for transport services labour

Survey results and literature show that automation could reduce the number of driver jobs. However, the number of other jobs related to the operation, remote intervention, and maintenance of AV-based services might increase. For example, participants noted that the transport sector would require research-and-development (R&D) engineers and AV specialists during the early and scale-up phases. Some participants emphasised how shared transport services could generate new occupations:

> "Personal cars get a lot of maintenance and cleaning hours done "for free" by owners. Fleet maintenance is only done by paid labour. Therefore, any personal vehicles that are shed in favour of shared vehicles will come with an increased need for paid maintenance employment (washing, maintaining, charging, repairing)." - ITF survey respondent.

In addition, all displaced workers will not stay unemployed. Some may leave the labour market (e.g. retirement, people not actively seeking work), while some may decide to transfer (e.g. re-employment). However, this situation could still lead to substantial inequalities between employed and non-employed people.

Because AV-based services will mainly impact middle-skilled jobs (e.g. drivers), they will contribute to employment-market “polarisation”, a term that describes the simultaneous growth at the bottom and the top of the income distribution curve (Acemoglu & Autor, 2011; Fonseca et al., 2018). Autor et al. (2003) link job polarisation to technological progress in automating routine tasks. Within the transport labour market, this implies a decrease in drivers. At the same time, the deployment of AV-based services may imply a growing demand for non-routine, low-skilled (e.g. maintenance, repairing) and high-skilled occupations (e.g. those involving problem-solving and creativity).

Job polarisation might have an impact on wages in the transport sector. Within the transport sector, the erosion of middle-skilled jobs could worsen wage inequalities. Data from the United States since the end of the 1980s show that job polarisation was associated with a stagnation of real wage for the middle percentile, while those low and high percentiles increased. Other phenomena may contribute to wage polarisation; as experienced in other industries, the decline of unions in the transport sector may lead to a sharp decline in middle-skilled workers' wages, thus aggravating inequalities between low- and high-percentile workers (Firpo et al., 2011).

Mitigating the impact of AV-based services on labour: Upskill, reskill, train

Public authorities should take proactive measures to mitigate the negative impacts of the introduction of AV-based services on employment. Profound changes in required skills highlight the rising importance of education in the future job market. Education policies should promote the development of non-routine skills as they are more challenging to automate. From an employment perspective, these skills give workers a comparative advantage in the future.

Upskilling (e.g. people's willingness to adopt new skills for their *current* job) or reskilling (e.g. people's willingness to learn new skills for a *different* job) constitute two ways to achieve this.

Workplace training may favour upskilling within organisations. In addition, public organisations and companies can encourage their employees to participate in third-party training programmes. Upskilling has wider benefits and can substantially impact economic growth (World Economic Forum, 2020, 2021). It is also expected to generate additional gains in innovation and contribute to developing new types of jobs and services.

Companies and public organisations with displaced jobs should also seek to implement reskilling (or retraining) programmes. Reskilling improves the employability of displaced individuals and can address skill shortages. As automation will mainly replace routinised jobs, reskilling programmes should promote non-routine skills (e.g. problem-solving, creativity, ability to experiment, system thinking, collaboration). In addition, as automation will change the nature of transport-related work, this constitutes an opportunity to address the gender imbalance in the transport workforce (World Economic Forum, 2020).

Public authorities should be mindful of upskilling and reskilling duration. The effect of the establishment of education and retraining policies may be delayed. To that end, if most of the impacts of AV-based services on employment are expected to happen during the maturity stage, long-term (e.g. education policies) and mid-term policies (e.g. reskill, upskill) should be implemented respectively during the early and scale-up phases.

Fiscal issues

The progressive deployment of AV-based services constitutes a paradigm change for public authorities. The transformations induced in terms of vehicle use, travel behaviour and land use could significantly impact governments' budgets at different levels (e.g. national, federal, regional and local). In most political systems, the government's budget covers revenues (e.g. taxes, administrative revenues, commercial revenues) and expenditures (e.g. revenue expenditure, capital expenditure).

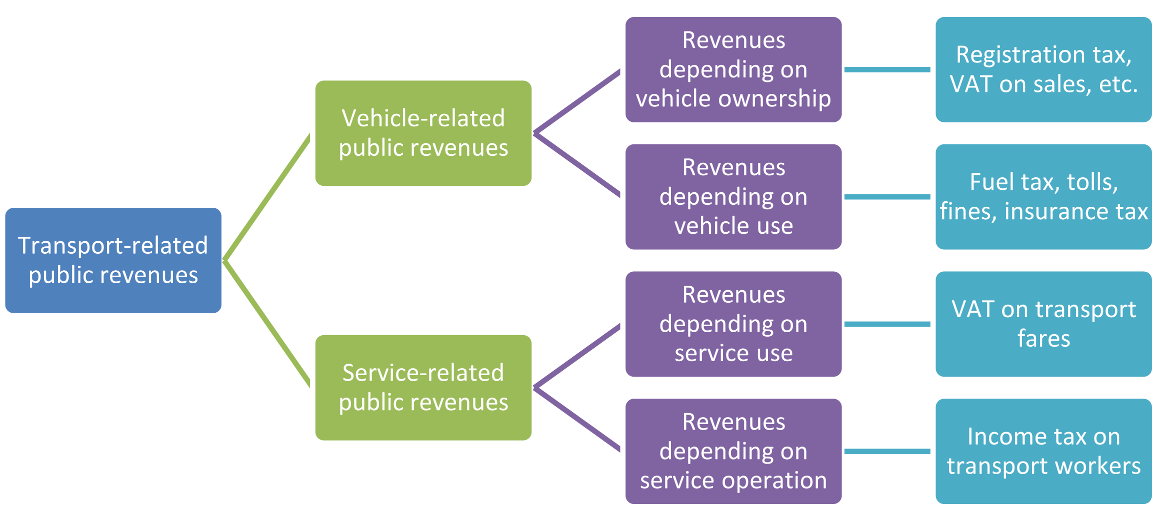
Transport-related taxes contribute to an extensive share of public revenues at the national and local levels. At the same time, infrastructure construction, maintenance, and public transport services operation heavily rely on public revenues. Therefore, tax policies are essential to funding public functions and particularly transport.

Moreover, tax and fiscal policies have additional functions. Taxation can be targeted to steer particular behaviour or encourage the consumption of certain goods or services. Governments can also establish fiscal policies to reduce inequalities by improving redistribution (e.g. social fares). Public revenues are thus essential to address various transport sector challenges.

A taxonomy of transport-related fiscal revenues

Transport services substantially contribute to public revenues through different fiscal levies. This section will present a taxonomy of government transport-related revenues, including vehicle- and services-related revenues.

Figure 16. Taxonomy of transport-related public revenues



There are substantial differences between transport taxation systems across countries. Countries' taxation structure may vary depending on the available tax instruments, their intended goals, or the level of governance collecting the taxes. However, most OECD countries have common tax base mechanisms that make up a substantial part of transport-related tax revenues. They include fuel taxes (e.g. gasoline taxes, diesel tax, VAT on fuels, sales tax), registration taxes, and circulation tax (Adler et al., 2019; European Commission, 2012).

Vehicle-related taxes make up a large share of public revenues in OECD countries. Adler et al. (2019) estimate that these revenues generally contribute to approximately 5% of total collected taxes. In specific cases, it can reach 10% of overall fiscal revenues (e.g. Portugal). According to ACEA (2022), the average annual tax revenue per motor vehicle was EUR 1,938 in January 2022, with substantial differences among countries (e.g. EUR 2,892 in Belgium, EUR 1,148 in Spain). Vehicle-related revenues can be divided between:

- revenues that depend on vehicle ownership (e.g. VAT on vehicle sales, registration tax); and
- revenues that depend on vehicle use (e.g. fuel taxes, parking revenues, insurance taxes, tolls, fines, customs duties, etc.).

These revenues can often be earmarked to fund transport infrastructure or services at various levels. At the national/federal level, the United States Highway Trust Fund, which finances the majority of federal government spending on mass transit and highways, is funded primarily (84%) by transport-related excise taxes (e.g. fuel tax) (TPC, 2020). At the local level, Amsterdam earmarks its parking revenues surplus to the Amsterdam Mobility Fund, which mainly supports alternatives to car use. Between 2012 and 2016, the Amsterdam Mobility Fund allocated around 30% of its EUR 29.1 million budget to support bicycle projects (e.g. the construction of a tunnel under the central station and bike parking spots), 17% to public transport projects (e.g. contribution to the construction of rapid bus services and bus stations) and 13% on road safety programs (Tub AB Trafikutredningsbyrån, 2014).

Additionally, transport services contribute to public revenues. Some countries charge VAT on transport services. The Netherlands use a 9% VAT rate on all public transport prices (e.g. bus, train, metro and tram) and taxi services.

Transition and impacts

The large-scale deployment of AV-based transport services could have both *first-order* and *second-order* impacts on transport-related revenue sources. Fiscal challenges may arise because service automation will directly impact variables that serve as a budgetary basis (e.g. car ownership, type of energy, fines, parking, etc.); these are first-order impacts. AV-based services will profoundly transform cities and travel behaviour, leading to broader fiscal impacts; these are second-order impacts. The impacts will vary depending on the deployment stage and how AV-based services are deployed (e.g. shared fleet or not, electrified fleets or not). The remainder of this section will discuss the two types of impact.

First-order direct and indirect fiscal impacts of AV-based services

Automating transport services will directly affect revenues that depend on the presence of a driver. From a business model perspective, the absence of a driver is most likely to contribute to a reduction in transport services costs. Numerous works (Bösch et al., 2018; Lim & Tawfik, 2018; Litman, 2022) suggest a decrease in the operating costs of modes and services in urban areas with the progressive deployment and availability of AV technologies. In Buenos Aires, Blas et al. (2018) estimate a 61% to 72% cost reduction of automated taxis or ride-hailing services compared to manned ones. From an economic perspective, operation cost reduction should lead to a decrease in user fares and, thus, an additional erosion of public revenues based on VAT on transport services. During the early and scale-up phases, the net reduction of the number of drivers will also lead to a decrease in income tax revenues. However, as with other profound disruptions, new occupations will likely appear in the maturity stage, thus mitigating the overall loss of income tax. Similarly, an increase in vehicle kilometres travelled (VKT) associated with modifications of travel behaviour (e.g. second-order impacts) could lead to an increase in variable revenues based on fuel and electricity taxes or road charges, thus mitigating this first-order overall loss.

At the same time, the automation of transport services is expected to generate benefits in terms of safety and traffic enforcement in the maturity stage. Nowadays, traffic-enforcement-related revenues represent a non-negligible share of public revenue. In 2021-22, parking fines provided the City of Los Angeles (2022) with USD 112 million, which represented about 1.5% of the City's total budget. Consequently, local authorities may witness a progressive decrease in their revenues based on traffic control and enforcement (e.g. parking fares, parking fines, traffic fines).

Ongoing techno-economic transformations associated with automation (e.g. electrification, digitalisation, shared ownership) are likely to further impact public revenues (Adler et al., 2019). The combination of these technologies is expected to bring profound disruption to the mobility sector and public finances (e.g. first-order effects). However, these evolutions are not directly linked to AV-based services but rather to specific dimensions of these services (e.g. type of energy used, individual vehicles or shared fleet).

Notably, the electrification of vehicles will make taxes based on fuels (e.g. excise tax on fuel, fuel tax, VAT on fuel sales) obsolete. Fox (2020) notes that the wide availability of electric AVs will decrease fuel consumption. However, current dynamics towards the adoption of new tax bases by countries (e.g. distance charge, electricity or energy taxes) will likely replace fuel taxes in the mid-to-long term (ITF, 2023b; ITF, forthcoming; Povich, 2022). Policy makers should implement anticipatory and adaptive fiscal policies to cope with ongoing tax transitions.

Deploying AV-based services may also be associated with cost savings for public authorities. Alonso Raposo et al. (2018) suggest that AV-based services would likely reduce road safety expenses by public authorities. Safety improvements will reduce the need for traffic police control (e.g. parking and circulation). This includes costs for wages, controlling infrastructure (e.g. radar), intervention vehicles, fuel and land. However, NTC (2019) emphasises how regulation of AV in-use costs could vary between different regulatory options. It estimates it could vary between USD 25 million annually for a national regulator and USD 50 million annually in a state-based regulation system. The cost of the lower option is explained by the greater economies of scale of having a unique national regulator and the avoidance of potential duplications between states.

Second-order fiscal impacts of AV-based services

The large-scale development of AV-based services is expected to profoundly impact cities, land use, the environment, and infrastructure, thus potentially impacting other public revenue sources – i.e. generating *second*-order effects. Bertolini (2012) argues that business practices and lifestyles are increasingly dependent on mobility.

Automation may radically change how transport services are supplied in urban areas. Soteropoulos, Berger and Ciari (2018) note that AV-based services may complement or replace existing transport services depending on the context. This change is likely to have broader impacts on societies. In the early and scale-up phases, the progressive deployment of AV-based services will introduce new mobility options for city dwellers. During the maturity phase, as AV-based services become more common, they are expected to affect location choices for companies and households. As a result, AV-based services could indirectly impact land-use prices and related public revenues, such as land-value tax.

Land-value premiums induced by AV-based services may vary depending on the context. Brookfield (2020) notes that the shift in real estate value will largely depend on population densities and the public transport network structure. This shift will likely result in additional land-use-related revenues for public authorities. Due to spatial constraints and the existence of viable transport options, impacts on land-use values in cities with an advanced public transport system (e.g. a sophisticated underground network) will be less pronounced. Conversely, effects should be more pronounced in less-densely populated urban areas with fewer public transport options. However, depending on their operation costs, AV services may require public subsidies as lower-density areas do not enable transport services to support their cost recovery (Riggs et al., 2019).

The extent to which AV-based services' fleets are shared (or not) will impact parking infrastructure. AVs can reduce the need for parking demand. Simulations conducted by ITF (2015, 2017b, 2017c, 2018, 2020) showed the potential of shared mobility services to reduce parking requirements in several cities (I.e. Auckland, Dublin, Helsinki, Lisbon, and Lyon). In Lisbon, the most favourable scenario – with a 100% shared self-driving fleet paired with high-capacity public transport – showed a significant reduction in parking requirements (5.6% of baseline scenario) (Table 6). This finding is consistent with Zhang et al. (2015), which indicates that 90% of parking demand can be reduced by implementing shared AVs.

Table 6. Maximum number of parked vehicles for different vehicle automation scenarios in Lisbon

			Max. Parking requirements	% of baseline
		Baseline	160 000	
100% shared self-driving fleet	Ridesharing (TaxiBot)	No high-capacity public transport	11 563	7.2
		With high-capacity public transport	8 901	5.6
	Carsharing	No high-capacity public transport	25 621	16.
		With high-capacity public transport	17 110	10.7
50% private car use for motorised trip	Ridesharing (TaxiBot)	No high-capacity public transport	5 928 + 153 122*	99.4
		With high-capacity public transport	4 622 + 116 689*	75.8
	Carsharing	No high-capacity public transport	12 705 + 153 330*	103.8
		With high-capacity public transport	9 561 + 116 467*	78.8

* = shared + private cars.
Source: ITF (2015).

However, recent simulations conducted by Larco et al. (2023) in San Francisco suggest that parking demand reduction may not be immediate. In the near term, parking supply could continue to rise until the developers are certain that vehicle ownership is decreasing. Meanwhile, an ITF simulation in Lisbon showed that in a hybrid system – where AV ride-sharing services replace high-capacity public transport and operate in parallel with private vehicles – parking requirements could be higher than today (103.8% of baseline) (ITF, 2015).

Policymakers should thus promote the deployment of shared AV services with high-capacity public transport in order to reduce the need for parking requirements and reallocate parking space for other uses. This reallocation can result in various outcomes. Cities can use this space to promote active modes (e.g. walkability, bicycle lanes), introduce vegetation to mitigate heat-island effects or reclaim space for other purposes (e.g. terraces, shops) (ITF, 2022a). The reallocation of space will result in land-use price transformations.

The evolution of fiscal policies to fit with technological changes induced by AVs will likely shift power towards local and urban authorities. Policy makers should be aware of shifts in the fiscal power of the different levels of governance. Adler et al. (2019) note that:

> “a future with high penetration rates of [AVs] may thus entail higher vehicle-related tax revenues for local level of governance (in particular cities), and lower vehicle-related tax revenues for higher governance levels (in particular, the federal state)”.

Electrical and shared AV-based services will affect large-base public revenues (e.g. fuel tax, income tax). These revenues will likely erode. At the same time, local authorities and cities may try to assign a price to negative externalities related to AV-based services (e.g. congestion, air pollution, noise). National and local governments should seek not to hinder AV-based services deployment when implementing tax policies.

Public service obligations

Emerging technologies (e.g. ITC, artificial intelligence) have an important impact on the transport sector and societies. They enable the creation of new products and services for users (e.g. ride-hailing, micromobility devices) and new business models (e.g. the gig economy). At the same time, innovation can also disrupt markets and potentially cause harmful impacts on societies (Korinek, 2022). As discussed earlier, deploying AV-based services will likely result in profound changes in transport services and affect societies.

The sections below summarise the current transport services regulatory landscape and then discuss how a new approach could be implemented as AV-based services are deployed.

A new approach to transport service regulation

Public authorities should understand that the deployment of automated vehicles will affect transport services and the regulations that apply to them. It will constitute a paradigm shift in the way transport services are regulated. Automation will lead to changes in service operation, the shape and capabilities of the vehicle, and the presence of a driver (i.e. service oversight). All these changes should be reflected in the requirements imposed on mobility services. These regulations differ from vehicle-related regulations that target automated driving systems (ADS) or the dynamic driving task (DDT).

Current regulations are based on the operation of conventional transport services. They include requirements regarding the offer (e.g. fixed line or on-demand, shared or private service, general interest or commercial service), the vehicle's characteristics (e.g. accessibility), and the transport service personnel (e.g. driver, onboard attendant).

These requirements may not be adapted to the introduction of automated services. In the UK, the Law Commission of England and Wales and the Scottish Law Commission (2022c) note that the layers of regulation that apply to passenger services could easily be used in an AV passenger service context *when a safety driver is present*. However, regulating *unmanned* passenger services will be challenging. Passenger services without a driver will require a new regulatory approach. In the context of AV-based services without a safety driver, the applicability of existing regulations is uncertain. Law Commission of England and Wales and Scottish Law Commission (2022c) notes that “without some changes to the existing law, passenger services may either be banned or entirely unregulated. Where there is no ‘driver’, it could be argued that the service does not require licensing at all”. In such a context, unmanned passenger services could skew competition as they would be unregulated market participants.

According to the Law Commission of England and Wales and Scottish Law Commission (2022c), this could lead to two risks: "operators might exploit legal gaps to run an entirely unlicensed service; [and] some operators may be deterred from running passenger services, fearing that these require licences they cannot obtain". Mitigating these risks requires a new approach to redesigning transport services regulation to make it automation-proof. Experience from pilot programs and early commercial deployments will inform subsequent efforts to choose the most suitable policy, depending on the local context.

Managing the transition: Assess, update, adapt, inform

There are two main ways to redesign transport services regulations. Public authorities could either update existing rules that apply to conventional transport services (e.g. taxi, public transport, private hire) or design a specific transport licensing scheme for automated vehicles (Law Commission of England and Wales and Scottish Law Commission, 2022b). These approaches may not be mutually exclusive. Conventional and automated services share common features beyond their fundamental differences. From a service provision perspective, an automated taxi service will perform the same service as one operated by a conventional taxi: move someone from point A to point B. Public authorities should take these similarities into account when developing their regulatory framework.

The regulatory framework should align requirements for aspects common to automated and conventional services. Automation should not be used as a rationale to over-regulate transport services. For instance, AV and manned vehicles will have different requirements between 2030 and 2035 in California, USA. AV taxi services will have to be electric, while manned taxis can remain fuel-powered. This situation could hamper the conversion of fuel-powered conventional vehicles into automated ones (Bonifacic, 2021; CARB, 2022; IEA, 2019; Executive Order N-79-20, 2020). At the same time, public authorities should develop or adapt AV-specific regulations for the features that are fundamentally different between conventional services and automated ones (e.g. features related to the driver, the service liability, cybersecurity risks etc.).

For public authorities, the process of designing a suitable regulatory framework will include four steps:

- Assess: Identify regulations that could apply to AV-based services.
- Update: Modernise existing requirements for AV-based services.
- Adapt: Implement new requirements for features introduced by AV-based services.
- Inform: Tell transport operators, passengers, and the general public about how the regulatory framework is evolving.

Assess: identifying existing regulations that could apply to AV-based services

In the context of AV regulations, modernising the regulatory framework implies identifying, analysing and auditing existing regulations that could apply to AV-based services operation. Modernisation presupposes the transformation of an already existing element into something that conforms to current needs. To that end, modernisation requires both (a) an extensive knowledge of what exists and (b) an understanding of future needs and constraints.

Assessing AV-based services' legal and regulatory status is the first step to understanding how current legislation and regulations could apply to future AV-based services. The audits should list existing regulatory tools, the type of actors responsible for them, and all relevant regulations (e.g. transport, insurance, cybersecurity regulations) that may apply to AV transport services (Smith, 2017). As AV-based services will operate locally, local governments should actively participate in auditing.

Update: Paving the way for AV-based services regulation

Suppose the audit shows that the regulatory framework is ambiguous or fails to enable AV-based services. In that case, public authorities should then update their regulatory and legislative framework to allow the circulation of Avs. For example, in 2021, France updated its regulatory framework to enable the deployment of AV-based services. First, the “Loi d’orientation des Mobilités” (LOM), enacted in 2019, opened the possibility of updating the existing regulatory framework to allow the circulation of AVs on public roads (Ministry of Ecological Transition, 2022). Two subsequent decrees, published in April and June 2021, set the legal conditions to allow automated vehicles to circulate on roads and specify the liability regimes that would apply in case of a traffic infraction or a crash (French Government, 2021). A decree published in July 2022 transposed the Vienna International Convention on Road Traffic amendment adopted in January 2022, which allows a vehicle to circulate without a driver. Finally, three additional decrees, published in August 2022, prepared the entry into force of the updated legislative and regulatory framework.

Regulations applying to transport services and vehicle safety standards should also be updated. Current regulations provide guidelines for conventional manned transport vehicles (e.g. buses, taxis, vans). They also require vehicles to comply with safety and accessibility standards (e.g. ramps, boarding, bridge plate). In the United States, the Federal Transit Administration (FTA 2019) stated that public entities and private companies under contract with the public must acquire wheelchair-accessible vehicles for fixed-route services. For on-demand services, the FTA stated that non-accessible vehicles for transit services might be acquired “as long as the service, in its entirety, provides equivalent service to persons with disabilities”. In this case, the Americans With Disabilities Act (ADA) would apply to automated services. Also, according to the U.S. Access Board (2021), “accessible solutions are often contingent upon the geometry of the vehicle”. Automation will likely transform the shape and geometry of vehicles. For example, batteries in the floor of an AV could constrain its access as they increase the height of the vehicle floor; and the possibility of removing the driver’s seat will transform the vehicle’s interior geometry. Thus, public authorities should update their accessibility regulation and passive safety standards to ensure that AVs will be usable by people with disabilities when required by law.

Updating the regulatory framework may also imply eliminating or modifying requirements that pose barriers to the deployment of AVs (Brown et al., 2018). Current safety standards were designed with conventional vehicles in mind and thus assume the presence of a human driver. From a safety perspective, failure to update these standards could pose significant challenges to the deployment of AVs and, thus, to services based on them. Kim et al. (2016) found that “33 of 73 of U.S. Federal Motor Vehicle Safety Standards (FMVSS) may present certification challenges for certain types of automated vehicles because they contain references to a driver.” NHTSA (2022a) updated FMVSS to “update the standards in a manner that clarifies existing terminology while avoiding unnecessary terminology, and, in doing so, resolves ambiguities in applying the standards to ADS-equipped vehicles without traditional manual controls.“ A similar update at the international level was made by an amendment to the Vienna Convention on Road Traffic, which defines an automated driving system as an alternative controller to the human driver of a vehicle (UNECE, 2020).

Adapt: Addressing AV-based risks specific to services

Public authorities should adapt the requirements they impose on transport services to mitigate the new risks introduced by AVs. This may imply introducing new requirements, especially those governing the safety and accessibility of the service. These requirements should specifically target AV-based services and thus not apply to conventional ones.

Because cybersecurity risks may arise with the deployment of AV-based services, public authorities should set specific requirements and establish an adapted cybersecurity framework (ITF, 2018a). These strategies rely on several pillars: assessing the potential risks, protecting against these risks, monitoring potential risks, responding to threats, and developing recovery strategies (NIST, 2018). Public authorities should empower staff to manage cybersecurity risks arising. This approach relies on raising staff awareness regarding cybersecurity risks and adapting training for staff responsible for IT assets. Risk-mitigation strategies should also include procedures for responding to and recovering from cybersecurity threats. Furthermore, public authorities should build ad-hoc and up-to-date cyber protection mechanisms (i.e. technology to prevent and mitigate cyber threats for software and hardware assets).

Inform: Disseminating knowledge to operators and passengers

Public authorities should provide technical assistance and guidelines showing how requirements apply to services using AVs. The shift from a regulatory framework based on conventional services to a new one integrating automated services will likely raise many questions from transport stakeholders.

In the United States, the FTA (2019) listed frequently asked questions (FAQs) regarding requirements for public authorities looking to deploy automated vehicles in their fleets. The FAQs highlighted several regulations that applied to AV-based services, including provisions related to the type of vehicle used, the degree of accessibility, and the role of the service operator. These guidelines also provide a regulatory map indicating how the provisions apply to automated services.

Public authorities and services providers using AVs should also inform passengers regarding changes in regulations, especially regarding safety. Law Commission of England and Wales and Scottish Law Commission (2022b) suggest that, as in other high-risk industries (e.g. petroleum, rail transport), regulators should establish “safety cases” to determine the level of safety that AV must reach. Safety cases could be adapted to AV-based services. They should be designed by organisations responsible for the AV deployment (e.g. service providers, car manufacturers) to ensure that they comply with safety standards set by the regulator.

Passengers should be aware of what the automation of the service changes in terms of responsibilities and in-use liability of the service. As the number of passengers grows with the increase in AV-based service deployments, public authorities cannot precisely predict how passengers will adapt to AVs. Raising public awareness regarding risks can take many forms (See Box 2). It should also target street operators (e.g. police, fire departments and first responders) who may have to interact with automated vehicles.

Box 2. The FTA's recommended actions to reinforce public awareness regarding risks

The U.S. FTA's *Security and Emergency Preparedness Actions Items for Transit Agencies* report features recommended actions to strengthen public awareness regarding risks, including the following:

a. Develop and implement a public security and emergency awareness program.
b. Prominently display security awareness and emergency preparedness information materials throughout the system (e.g., channel cards, posters and fliers).
c. Incorporate general security awareness and emergency preparedness into public announcement messages (e.g., security messages and evacuation procedures) in stations (e.g., electronic message boards, voice) and onboard vehicles.
d. Post security awareness and emergency preparedness information on the transit agency website.
e. Ensure security awareness materials and announcements emphasize the importance of vigilance and provide clear direction to the public on reporting suspicious activities.
f. Vary the content and appearance of messages to retain public interest.
g. Increase the frequency of security/emergency awareness activities (e.g., public address announcements) as the threat situation changes.
h. Issue public service announcements in local media (e.g., newspaper, radio and/or television).
i. Provide volunteer training to the public for system evacuations and emergency response.

Source: extracted from FTA (2014).

Institutional and intergovernmental co-ordination

Public authorities have played a central role in road safety for decades. By establishing objectives and setting measures, they ensure that vehicles – and their drivers – can meet public goals in terms of safety. This role started after the introduction of the automobile with the establishment of safety standards for vehicles, infrastructure, and driver license requirements (NHTSA, 2016). Governments should pursue this role as vehicles become automated for two main reasons: to unlock AVs' positive potential and mitigate risks while addressing safety and liability issues.

Specifying the role of each actor

Rather than creating regulatory frameworks *ex-nihilo* (from scratch), public authorities often build regulatory frameworks for AV-based services on existing ones. Movements toward regulating AV-based services are happening on several fronts (Brown et al., 2018). They have often resulted in a multi-scalar regulatory framework where responsibilities are shared – and sometimes duplicated – by different levels of governance and agencies and authorities (e.g. transport, economy, justice, traffic) that all have a stake in regulating AV-based services, but from different perspectives. In the United States, Brown et al. (2018) note that several policies have been implemented not only at the national level (e.g. NHTSA, House of Representatives, U.S. Senate) but also at the state level (e.g. enacted legislation and/or executive orders) and at the city level (e.g. the AV policy framework in Boston and the Smart Autonomous Vehicle Initiative in Portland).

Although national strategies are meant to facilitate AV adoption, they often fail to provide a robust and coherent governance structure. This can result in an unclear division of responsibilities. Brown et al. (2018) describe the risk associated with the emergence of a "patchwork of regulations governing AV operation and infrastructure across governance boundaries". Establishing an appropriate governance structure to accommodate the progressive deployment of AVs is necessary. Ill-adapted frameworks could hamper the positive impacts of AV-based services, and inefficiencies in the way AVs are regulated could worsen transport issues.

Understanding how conventional passenger services are regulated is crucial to facilitate the transition to AV-based services. As emphasised by the Law Commission of England and Wales and the Scottish Law Commission (2022b), the existing service regulation layer may – to some extent – be fit for purpose for the deployment of early AV-based services that include a safety driver. In this context, the existing regulatory bodies will continue to fulfil their mandates.

However, the transition to driverless AV-based services will require extensive changes in the regulation and imply establishing new regulatory bodies and improving co-ordination between existing institutions. For instance, currently, public authorities enforce non-compliance with traffic rules through a system of fines and penalties imposed on the driver, with traffic offences potentially leading to the withdrawal of the driving licence. This type of regulation within the AV context will become obsolete, and a new approach to enforcing traffic rules will be required.

In the UK, as recommended by the Law Commission of England and Wales and the Scottish Law Commission (2022b), this role would be assigned to an “in-use regulator” whose function would be to (a) assess AVs’ safety compared to that of conventional vehicles and (b) to apply regulatory sanctions (e.g. penalties, improvement notices). While the report does not specify who should assume the in-use regulator's functions, the Law Commission of England and Wales and the Scottish Law Commission (2022b) underlines how this new regulatory authority should co-ordinate with existing ones (e.g. police and local authorities).

Separating service regulation from vehicle certification

Regulating AV-based services is a cross-cutting issue. From an institutional perspective, it will require both vertical (i.e. between different levels of government) and horizontal co-ordination (i.e. among agencies at the same level) of the various institutions that have a responsibility and a role to play over AV-based services (NHTSA, 2017).

In the early phases of deployment, authorities in charge of vehicle authorisation will play a crucial role: ensuring that vehicles are safe to operate before operation. Similarly to the necessary distinction between vehicle certification and the safety assessment of vehicles on the road presented above (Law Commission of England and Wales and Scottish Law Commission, 2022b), service regulation should be strictly separated from vehicle regulation. The rationale behind the establishment of two separate regulatory bodies is that the functions are fundamentally different tasks. In California, the state government implemented a two-tier regulation that applies to AV-based services. Whereas the Department of Motor Vehicles (DMV) focuses on rules governing impacts related to the deployment of automated vehicles, the California Public Utility Commission (CPUC) regulates the deployment of AV-service pilots and programs, issuing issues rules and guidance that apply to AV service providers (e.g. safety, physical accessibility of the service, equity, and environmental impact).

Empowering local authorities over service regulation

Local authorities should continue to play a role in local transport provision. In many countries, responsibilities over AV regulations tend to be concentrated in the hands of the national government. In countries where the regulation of transport services is the responsibility of local authorities, especially in decentralised countries, this concentration of regulatory power at the national level may hinder local authorities' leadership in transport services regulation. Regulations regarding AVs should not undermine local authorities' competencies in transport planning and operation.

Local authorities’ empowerment is crucial to ensure a smooth and efficient integration of automated transport services within the current transport system. For example, the priorities of the French National Strategy for 2022-2025 aim to assist local authorities in charge of transport with the deployment of AV-based services (French Government, 2023). During the consultation process, local authorities indicated their need for information and feedback on AV services deployment. Therefore, the French Government plans to establish a resource centre to disseminate relevant knowledge to local authorities with power over the licensing and commissioning of AV services.

Similarly, in the UK, the Scottish and Welsh Parliaments have regulatory power over taxi and bus regulation. Law Commission of England and Wales and Scottish Law Commission (2022b) recommend that these authorities should have power over permitting transport service providers to allow initial AV-based services to be provided (e.g. "interim passenger permits") while noting that this permitting duty should not replace local authorities’ licensing power over local transport services. They recommend that local authorities keep their licensing power. Local licensing authorities should ultimately authorise the deployment of AV-based services for AV-based services resembling existing transport services (e.g. taxi, public transport, private hire).

Enabling the safe and efficient use of AV service data

For decades, conventional vehicles’ trajectories on the road were controlled by drivers without external interference (EDPB, 2020). Drivers have had to control their environments and take appropriate decisions themselves in order for the car to perform the expected actions (turning, braking, etc.).

The expansion of vehicle connectivity and automated driving technologies has introduced a progressive shift from this initial reality. As they become connected, vehicles perform additional roles linked to data acquisition, data process, and data sharing. According to France’s National Commission on Informatics and Freedoms, connected vehicles are "vehicles that communicate with the outside world" (CNIL, 2017). Vehicle connectivity is not specific to AV. However, while not all conventional vehicles are connected (e.g. low-end vehicles), AVs, especially all AVs for transport services, are connected by definition. To that end, existing guidelines and regulations for connected vehicles may apply to AV-based services.

Protecting and empowering AV-based services users

Connected vehicles and AVs produce significant amounts of data. AV operation relies on a complex system of sensors and cameras that generate information from the vehicle's direct environment (i.e., vehicle-generated data). Additionally, AVs collect location data through navigation services and data related to the passenger and/or user (i.e., customer-provided data). AV-based services add another layer of data which also relates to the user, including personal settings (e.g. trip preferences) and identification information (e.g. addresses, name, fingerprints, photo).

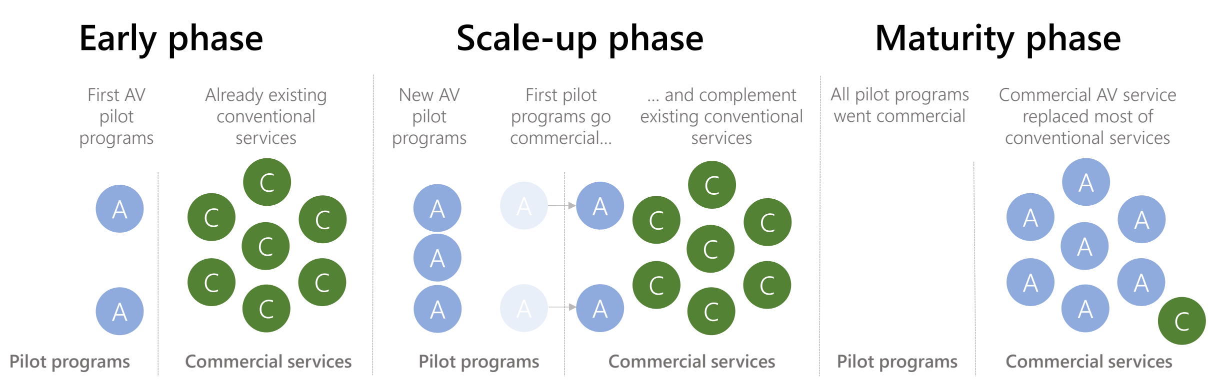
AV-based services users' data fall under personal data protection regulations (e.g. the EU General Data Protection Regulation, or GDPR). In many jurisdictions, AV data are considered personal data as they directly relate to passengers (EDPB, 2020). According to the European Commission (2016), data shared from connected vehicles should be considered personal inasmuch as they relate *"to identified or identifiable natural persons*". This definition includes anonymised data that could be re-identified (i.e. processes that enable linking de-identified data to its subject). Therefore, AVs must comply with applicable data protection frameworks. FIA (2017) emphasised that the data subject (i.e. the AV user) should consent to the processing of personal data.

Data sharing, interoperability and portability to enable other services

AV-based services take many forms. Transport services based on automated shuttles are already used to complement public transport services in cities (e.g. Lyon, Singapore, Sion) or certain areas (e.g. campuses, stadiums). Additionally, companies have launched commercial AV taxi services in several countries (e.g. United States, China). As of October 2022, the California Public Utility Commission (CPUC) granted three companies with permits for the commercial deployment of AV-based services.

Most AV-based services are in the early stages of deployment and function as pilot programs. While tests on public roads are multiplying, most operate in total isolation from existing transport services. In the longer term, public authorities should integrate AV-based services with other transport services, conventional or not. In the early phase, pilot programs provide a proof of concept for service providers and public transport authorities. The rationale behind pilot programs is to test how the service will work and how passengers will interact with it and to assess the potential consequences of AVs on society (e.g. land use, travel behaviour, travel patterns). In the scale-up phase, more advanced AV service providers will start operating commercial services in addition to conventional ones. Finally, in the maturity phase, the experience in the previous stages will facilitate the commercial deployment of AV-based services. At this stage, AV-based services may progressively replace conventional ones (See Figure 17).

Figure 17. Potential integration of AV-based services within the mobility landscape



Note: A = automated vehicle; C = conventional.

AV-based services should not be considered as a standalone transport service. Applying a siloed approach to AV-based services will hamper their integration into the transport services ecosystem. Conventional services have traditionally not been designed to be integrated with other transport services (ITF, 2021b). However, in mobility as a service (MaaS), mobility services are distributed using shared data and a digital interface. Such a distribution model efficiently sources and manages the provision of transport services into a seamless offer for the customer (ITF, 2021a). It requires transport services operators to share their data, which must be digitally interoperable to overcome traditional silos.

Data-sharing requirements applying to conventional services should apply to AV-based services based on their role (e.g. taxis, public transport, transporting people with disabilities). Therefore, AV service providers should use existing interoperable data standards to facilitate their integration into the mobility ecosystem. AV-based services may progressively replace conventional transport services, allowing a smooth transition from the early stages of deployment to the maturity stage without disrupting current service integration efforts (e.g. MaaS, combined offers).

Public authorities should ensure that AV service providers share interoperable data. The European Data Protection Supervisor (2022) defines data interoperability as "*the functionality of information systems to exchange data and to enable sharing of information*". This characteristic facilitates data access and exchange between market actors. Some countries already require the integration of conventional transport services within the transport sector. These requirements could be extended to personal transport services. European Commission (2022b) recommended that conventional private-hire and taxis should support MaaS, thus requiring them to share relevant data to enable taxi integration into MaaS. The rationale behind this recommendation is that taxis and private hire should not be a substitute for other transport services (e.g. public transport, micromobility).

Sharing interoperable data enables the creation of added-value services for users and fosters competition between market actors (see Box 3). Data-sharing requirements enable the creation of a secondary market for services. Automatic communication of vehicle data can allow connected vehicles and, by extension, AV-based service users to ask for additional services.

Box 3. France's compliance package for connected vehicles

In France, the National Commission on Informatics and Freedoms (CNIL), an independent regulatory body responsible for data protection, published guidelines presenting the CNIL's interpretation of how the French data rules apply to connected vehicles (described as "vehicles that communicate with the outside world"), including automated vehicles. The guidelines note that one of the purposes for processing vehicle data is the commercial use of the data. Three scenarios imply data processing and the creation of added-value services for the user:

- the "*In>In scenario*" – the vehicle's data are processed by the vehicle but are not transmitted to the service provider (e.g. parking assist, eco-driving advice)
- the "*In>Out scenario*" – the vehicle's data are transmitted to the service provider, but this does not imply an automatic action in the vehicle (e.g. eCall, customized insurance)
- the "*In>Out>In scenario*" – the vehicle's data are transmitted to the service provider, which uses them to trigger an automatic action in the vehicle remotely (e.g. remote maintenance, dynamic information).

The "In>Out" and "In>Out>In" scenarios imply data sharing with external entities. In these scenarios, the data subject using a connected vehicle can obtain added-value services from external service providers – including services linked to driving (e.g. dynamic information), assistance (e.g. emergency call), and/or customised services (e.g. insurance, pay-as-you-go services).

CNIL indicates the rules that apply if data (e.g. anonymous or personal) are shared with a commercial partner. On this, CNIL emphasises that location data should be regarded as personal and, accordingly, "the service provider shall be particularly vigilant not to collect location data except if doing so is absolutely necessary for the purpose of processing".

Source: CNIL (2017).

Public authorities should require service providers to comply with applicable data protection policies, and service operators deploying AV-based services should consider these requirements when designing their data protection policies. Public authorities should also enforce data portability requirements to allow service users to change service providers depending on their needs. Article 20 of the GDPR defines data portability as "the right to receive the personal data concerning him or her, which he or she has provided to a controller, in a structured, commonly used and machine-readable format" and provide that users should "have the right to transmit those data to another controller without hindrance from the controller to which the personal data have been provided" (European Commission, 2016).

Data portability is a prerequisite to allowing the integration of AV-based services in transport services platforms such as MaaS. The use of portable data allows users to switch from one service to another easily or to use multiple services. Data portability reduces the barrier to accessing a new service by transmitting personal data directly to other service operators. Because service providers and transport operators have no incentive to set data portability rules, public authorities should establish minimum data portability requirements for service operators (ITF, 2021c) (ITF, 2021b). Service providers' compliance with these requirements should condition service licensure.

Reporting AV-based services data to unlock public policy outcomes

Public authorities can draw many benefits from service providers' data. Gaining access to, and then processing, these data can allow public authorities to fulfil their public mandates more effectively by enabling them to monitor the impacts of their decisions and to enforce rules (ITF, 2021b).

Since conventional and AV-based services share similarities from a service provision perspective, data reporting requirements should be aligned between them. As they become mainstream, AV-based services will have an increasingly large impact on the transport sector and society. Public authorities have a role in ensuring that services based on AVs deliver desired outcomes for societies and mitigate negative impacts. Public authorities may require additional data during the pre-deployment and pilot program phases to assess the impacts of AV-based services. However, as soon as AV-based services are commercially deployed, public authorities should apply existing data reporting requirements.

Public authorities can access market stakeholders' data in very different ways. They may select specific acquisition pathways depending on various factors (e.g. costs, objectives). Data reporting's levels of constraint vary. Public authorities could make data reporting compulsory (an example of a "high" constraint for market stakeholders) in order for a service provider to obtain a license. Alternatively, data could be reported through the use of voluntarily crowdsourced data, or public authorities could decide to purchase data from aggregators and processors (an example of a "low" constraint for market stakeholders) (ITF, 2021b). Public authorities have already made several conventional services' licenses conditional to data reporting requirements. In London, Transport for London (TfL, 2022) requires licensed private-hire vehicle service providers to report data related to their drivers and vehicles every week.

Data reporting requirements should be made compulsory or conditioned to licensure for services where access to service data is crucial for the public authority. Public authorities should describe specific actions if service operators are not meeting these reporting requirements. In London, if private-hire vehicle service providers fail to meet data reporting requirements, TfL indicates that it can take action over service providers' licenses, including their revocation (TfL, 2022).

Data reporting requirements should be purposive. The purpose should be clearly specified and motivated by the public authority (ITF, 2021a) (see Box 4). Public authorities should require the minimal amount of data necessary to fulfil their public mandates. They should provide AV service providers with the required data list, including the purpose for which the data is necessary. Additionally, public authorities should specify how data should be reported (e.g. aggregation, anonymisation) and to whom (e.g. which agencies, which level of government). In California, the Public Utilities Commission (CPUC) requires AV service providers involved in pilot programs to share specific data (see Box 5) (CPUC, 2022). The list of required data, reporting period, and the report submission date are publicly available on the CPUC's website, and CPUC enables the download of data reports from its website.

Box 4. How is reported data used?

ITF (2021a) identifies three general uses of data-reporting mandates by public authorities: planning, operations and enforcement.

- Data required for **planning** purposes refers to information that enables public authorities to improve their understanding of how cities function. It requires aggregated insight into vehicle movements. This data is crucial to allow public authorities to deliver policies and infrastructure where it is needed. The reporting can be periodic and should not comprise personal data unless public authorities provide an express reason for an exception to this rule.
- Data required for **operations** purposes are used to help public authorities carry out their functions. They may include data to facilitate traffic control, manage public space and parking, or ensure safety. Unlike planning data, operations data require temporal and spatial precision to allow public authorities to intervene in real-time. Consequently, public authorities can require more frequent (e.g. real-time) data reports. The data should still be de-identified.
- Data required for **enforcement** actions (e.g. traffic, in-service infraction). As they generally relate to vehicles or individuals, enforcement data should be processed with specific protocols that allow high and adequate protection. Enforcement-related data should be destroyed once the enforcement action is completed.

Source: ITF (2021a).

Agencies and public authorities should seek to align data reporting requirements. Depending on their public mandates and responsibilities, authorities and agencies may have different needs. An agency in charge of safety that is assessing the effectiveness of a safety policy will not need the same data as a local government that wants to plan for future investments or a government seeking to enforce traffic rules. When applicable, agencies and authorities under the same jurisdiction (e.g. national, state, city) could gather data reporting requests. Cohen d’Agostino et al. (2021) note that in California, the state can draw insights from the AV service data that is already reported to the CPUC and the Department of Motor Vehicles (DMV), two agencies under the state's jurisdiction.

From a service provider perspective, reporting data to multiple agencies and authorities with different needs and using various reporting formats will require significant financial and human resources. Unaligned data reporting requirements place a higher burden on smaller market actors that may lack resources. Aligning data collection pathways and/or data reporting formats can ease the data-reporting burden on market players.

Box 5. Data reporting requirements on AV service providers in California

Following the deployment of automated services pilot programs in California, the California Public Utilities Commission (CPUC) required that entities participating in its AV Passenger Service Pilot programs (e.g. an AV passenger service with a safety driver and a driverless AV passenger service) report specific data every three months, including data relating to the following:

- Total quarterly vehicle miles travelled during passenger service by all vehicles in the entity's list of AV equipment, provided for each vehicle.
- Total quarterly vehicle miles travelled during passenger service that is served by electric vehicles or other vehicles not using an internal combustion engine, provided for each vehicle.
- Total quarterly vehicle miles travelled during passenger service, from the vehicle's starting location when it first accepted a trip request to the pickup point for each requested trip, expressed in miles and provided for each vehicle.
- The amount of time each vehicle waits between ending one passenger trip and initiating the next passenger trip (*idling* or *dwell* time), expressed as both a daily average and a monthly total in hours or fraction of hours for each vehicle.
- Vehicle occupancy (total number of passengers) in each vehicle for each trip.
- Total number of wheelchair-accessible vehicle (WAV) rides requested.
- Total number of WAV rides requested but unfulfilled because no WAV was available.
- Total number of WAV rides requested but unfulfilled because the vehicle operator denied the request.
- Total number of WAV rides accepted and fulfilled.

The CPUC notes that these data should be disaggregated and anonymized. The CPUC's data reporting system is designed to gather data regarding how each AV service provider operates. The CPUC provides operators with a reporting template that facilitates the reporting process. On the service provider side, these data reporting requirements have raised concerns, and providers have claimed confidentiality over some portions of the reports.

Source: extracted from CPUC (2022).

Data-reporting requirements for AV-based services should relate to service data that serves clearly specified purposes and thus may not necessarily include vehicle-related data (e.g. data on the vehicle environment or vehicle hardware). Public authorities should expressly justify any exception to this rule by demonstrating why the service data alone are unsuitable. Access to vehicle data already raises real concerns, particularly among industry actors. In 2019 the European Commission launched an open public consultation to prepare the future policy agenda on Connected and Automated Mobility, which highlighted the industry actors' slight preference (34%) not to share the data generated by the vehicle with public authorities. Only 30% were willing to report this data to public authorities, and 33% would condition their reporting to the purpose (European Commission, 2019).

Notes

1 WP.29 is a permanent working party (WP) in the institutional framework of the United Nations with a specific mandate and rules of procedure. It works as a global forum allowing open discussions on motor vehicle regulations.

2 The Law Commission of England and Wales and Scottish Law Commission (2022c) recommended assigning this role to NUIC operators. In case of AV-based services, service providers would assume the role of the NUIC operator. It is up to each member country whether to develop an NUIC operator licence and require service providers to acquire it, or to revise service-operator licenses to have those roles as new requirements for AV-based service providers.

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Making Automated Vehicles Work for Better Transport Services
Regulating for Impact

This report explores how mobility services using automated vehicles might change the transport landscape. How can automated transport services enable positive outcomes for societies? How will they ensure passenger safety? What rules should apply to such new services that overlap with other, heavily regulated services like taxis and public transport? The report assesses where regulation should adapt and outlines principles for forward-looking regulation. It offers pragmatic recommendations to bring in better transport for citizens.

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