University of St.Gallen
Institute for Mobility

The Evolution of Shared Autonomous Vehicles

Part 2: Bringing the SAV Economy to Life

A research study by the PwC Lab for Smart Mobility

The Evolution of Shared Autonomous Vehicles – Part 2: Bringing the SAV Economy to Life

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Founded in 1898, the University of St. Gallen (HSG) is one of Europe's top business schools. In 2025, its Strategy and International Management programme (SIM-HSG) was ranked as the number one global management master by the Financial Times - for the 14th time in 15 years. With its focus on international, integrative, and practice-oriented programmes in business administration, economics, law, social sciences, and international affairs, the HSG attracts a diverse student population from around 100 countries. In addition to its student programmes, the HSG is furthermore renowned for its wide variety of world-class executive education programmes, serving more than 6,000 participants annually.

PwC Lab for Smart Mobility

The mobility sector faces numerous future challenges: it needs to be highly connected, environmentally sustainable, and universally accessible at all times and in all places. At the same time, it should continue to be affordable – essentially, it should be "smart". Creating concepts and solutions that meet all these requirements demands a comprehensive understanding of the complexities involved.

To address this, the Institute for Mobility (IMO-HSG), one of 40 independently managed research institutes and centres at the University of St. Gallen, joined forces with PwC Germany to establish the PwC Lab for Smart Mobility. This newly formed think tank examines models of connected and sustainable future mobility and their impact on people's mobility behaviour. In addition, the Lab for Smart Mobility explores how the mobility industry evolves and which products and solutions it will be likely to offer.

The present study is part of a series of publications by the PwC Lab for Smart Mobility, where science meets practice.

The PwC Lab for Smart Mobility is led by:

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Introduction

The development of autonomous vehicle technologies is set to revolutionise the way people and goods move. With extensive and in some cases highly advanced pilot programmes already underway – particularly in the United States and China – we expect that the technology will be sufficiently mature for widespread deployment within the next five to ten years. Autonomous vehicles are expected to benefit societies and transportation systems by being safer and less accident-prone than human-driven vehicles. They promise more efficient, environmentally sustainable, and socially inclusive transportation. To unlock these benefits, autonomous vehicles must be meaningfully integrated into existing transport systems. Without this integration, there is a risk of increased traffic and reduced efficiency due to poor coordination with public transport or extensive private use. The technology promises to be most beneficial when implemented in shared mobility models. This requires that societies – particularly policymakers, public administrations, and mobility providers – take early steps to make autonomous vehicles available for shared use and foster a sharing culture from the outset. Furthermore, Europe faces fierce competition from market leaders in the US and China – not only in technological developments but also in creating business models that foster the rapid introduction and evolution of these technologies in a shared-use context.

Against this backdrop, the aim of this white paper is to identify key challenges and potential solutions for the introduction of shared autonomous vehicles (SAVs) – with a specific focus on Europe and Germany. While a previous publication of PwC and IMO-HSG focused primarily on the needs of users of SAVs and core target groups for their market entry (see white paper The Evolution of Shared Autonomous Vehicles, Part 1: Market potential, user acceptance and early adopter groups[1]), this paper places its focus on the development of the supply side.

We begin with a brief overview of the current global landscape in the race to implement shared autonomous mobility offerings. Subsequently, based on 30 expert interviews conducted across different regions (Europe, Asia, and North America) and stakeholder groups (including manufacturers and suppliers, transport operators and mobility providers, and legislative bodies and public authorities), we explore the central challenges to the deployment of shared autonomous services. We present an SAV ecosystem and discuss four potential configurations for the implementation of the ecosystem by various ecosystem players. Building on this foundation, we created a financial model for the deployment of SAVs. The final section of the paper covers a fundamental prerequisite for the successful introduction of shared autonomous vehicles (SAVs) in Germany, namely the financial requirements for their deployment and possible approaches to meeting those investment needs. Specifically, we analyse the economics of introducing SAVs in public transport and the introduction of robotaxis in Germany.

The global state of play on autonomous mobility

Several providers have launched commercial SAV services in designated areas worldwide, already demonstrating the capabilities and practical benefits of this technology. In the United States, Waymo operates fully commercial services in cities such as Phoenix, San Francisco, and Los Angeles, and can even charge fares for their 24/7 available service.[2] Motional, a joint venture between Hyundai and Aptiv, has deployed driverless robotaxis in Las Vegas, Los Angeles, Boston, Pittsburgh, and Singapore – but not yet commercially.[3, 4, 5] In China, Baidu's Apollo, Pony.ai and WeRide are leading the autonomous vehicle sector with deployments in Beijing, Chongqing, Guangzhou, Shanghai, Shenzhen and Wuhan. They provide a glimpse into the future of urban mobility with roughly 1,750 vehicles in service in those cities in October 2024.[6, 7, 8, 9] However, commercial SAV services are still very limited both in their operational design domains (ODDs), namely geographic coverage, and in their fleet size. Companies such as Waymo and Apollo Go have begun to operate in specific, pre-defined ODDs with the goal of expanding those ODDs to make the service available in entire cities and, in the future, perhaps even entire states.

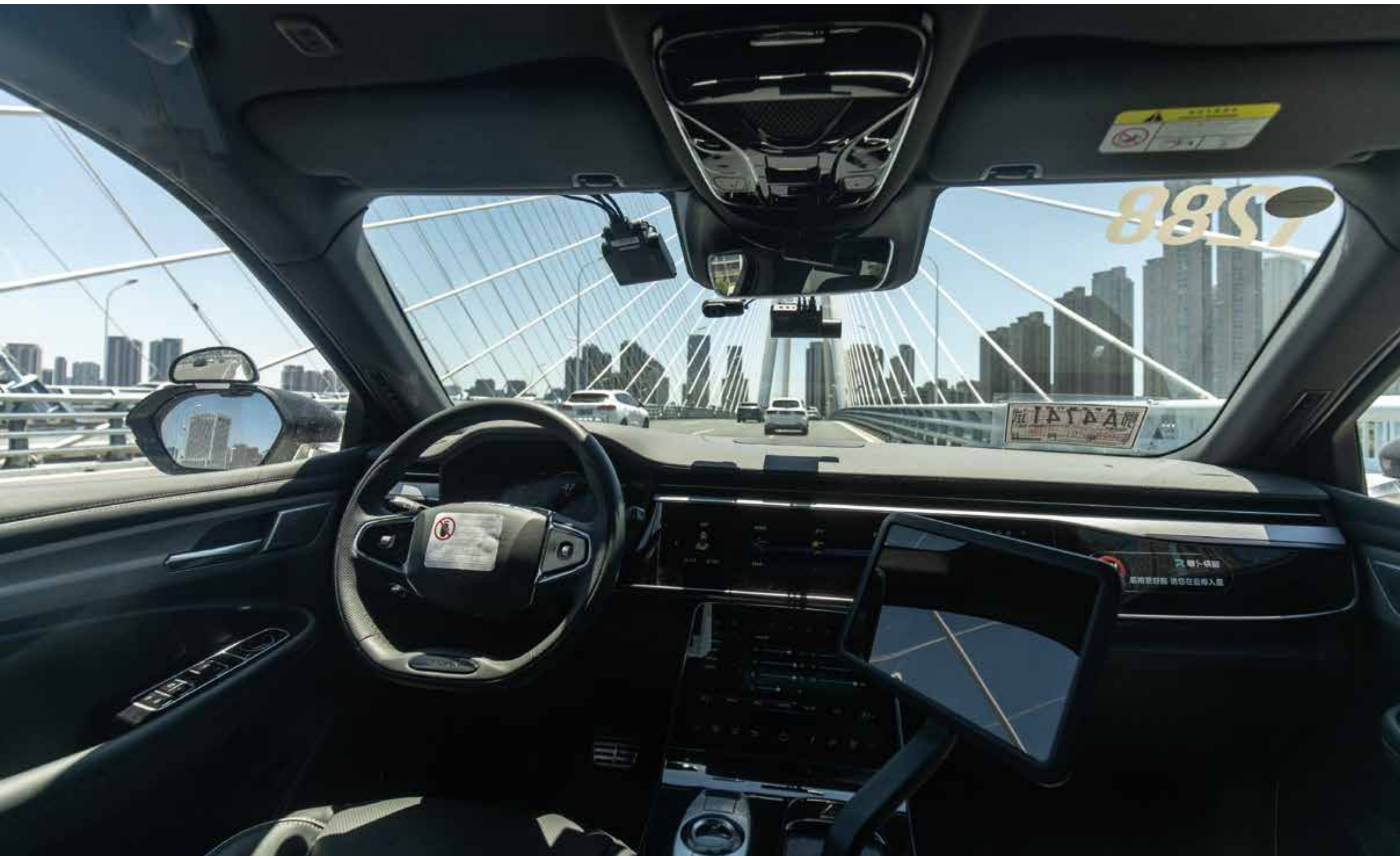
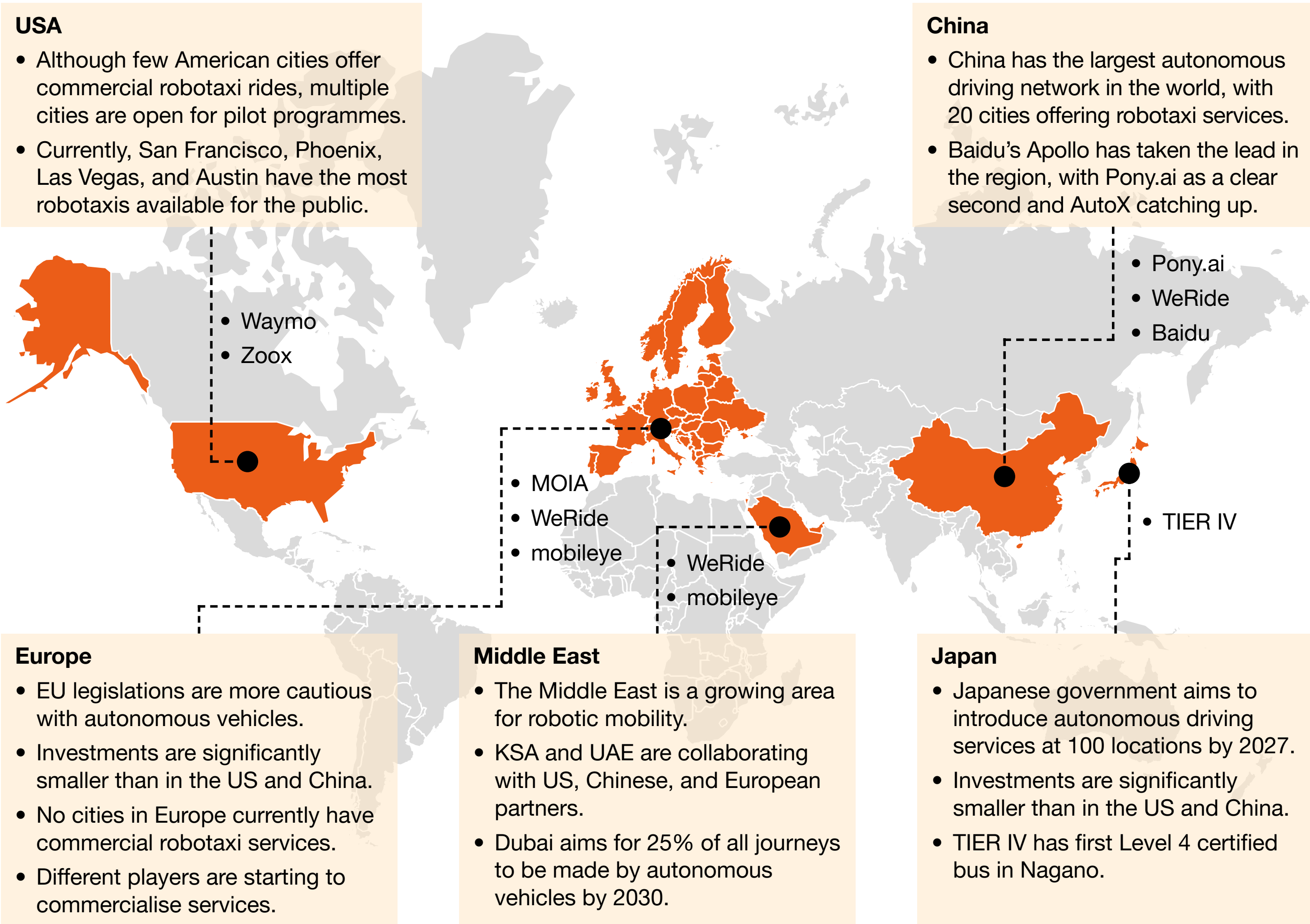


Fig. 1 Summary of some commercial fully driverless SAV services worldwide



Source: PwC and IMO-HSG analysis.

While we observe certain areas in which pilot projects with SAVs are maturing, even slowly shifting into fully commercial services (especially in the US and China), European countries – including Germany – are lagging behind in the development and deployment of autonomous mobility services. A patchwork of about 35 pilot projects exists, with very small fleets below 20 vehicles. Examples of this can be seen with the *ahoi* project in Hamburg and the KIRA project in Frankfurt. However, large-scale pilot initiatives aimed at substantially advancing the technology and generating early experience for integration into existing mobility systems are largely absent. An exception is the joint venture between Ruter, Mobileye, and Holo in Oslo – but with only 20 vehicles even this initiative falls short of the maturity seen in American and Chinese efforts.[10]

As outlined above, there is little doubt that autonomous vehicles will fundamentally transform the way we move in the future. However, unlocking the full potential of this technology requires its meaningful integration into existing transportation systems. The current mobility landscape in Europe differs fundamentally from that of the US and China: core transportation planning concepts, the range of mobility offerings, the organisational structures of public transport systems, settlement patterns, topography, and the design of urban environments all vary significantly from the regions where SAVs are currently being tested. Consequently, the types of vehicles being considered or used for autonomous deployment also differ. While the US and China are primarily focusing on robotaxis in ride-hailing usage, the debate in Germany also touches on the advantages and disadvantages of such smaller vehicles compared to mini- and roboshuttles designed for ride-sharing or on-demand services. Additionally, a fundamental question remains: should these novel services be developed and provided by private companies – as is currently the case in the US and China – or should they be integrated into future public transportation systems and thus be publicly operated? This reflects a more European, or specifically German, perspective. For the purpose of this white paper, we will initially cover a wide-range of options and approach the question of optimal implementation in Germany with an open and exploratory mindset.

Fig. 2 AV categories on land constituting the focus of our analysis

	Light vehicles		Public transport on roads			Public transport on tracks	
Mode	**Private owned cars**	**Ride-hailing**	**Ride-sharing line/on-demand service**			**Shared vehicles**	
Existing vehicles	Private car	Taxi	Mini-shuttles	Shuttles	Bus	Tram	Subway
New automated transportation	Private robocar	Robotaxi (4 pers.)	Mini-shuttles (4 pers.)	Robo-shuttles (16 pers.)	Robobus (60 pers.)	Robotram	Robo-subway
Product readiness	**Commercial** (L3 – MB and BMW)	**Commercial** (L4 – Waymo and Apollo)	**Pilots** (L4 – Iony)	**Pilots** (L4 – Holo, Mobileye, and VW)	**Pilots** (L4 – ADASTEC and Karsan)	**Pilots** (L4 – ADASTEC and Karsan)	**Commercial** (L4 – Siemens)

Focus

Source: PwC and HSG-IMO analysis.

For the reasons outlined above, it is essential to develop European flagship projects with urgency and determination. However, in many relevant institutions, there is still a lack of sufficient knowledge regarding the specific challenges and prerequisites for the development of large-scale pilot programmes. Additionally, there is limited clarity around the financial resources required for the rollout of such services. These aspects will be addressed in the subsequent sections of this paper.

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Implementation challenges for shared autonomous vehicles

The path to realising the full potential of SAVs is marked by multiple challenges. Drawing on insights from 30 in-depth interviews with experts – including manufacturers, suppliers, transport operators, mobility providers, legislative bodies, and public authorities – across Europe, Asia, and North America we identified four core dimensions of implementation challenges, namely technical, regulatory, economic, as well as structural and organisational. While we will give an overview of all four dimensions and possible solution paths in this next section, we will particularly focus on structural/organisational and economic implementation challenges in the further course of this paper, as these are the fields that we perceive as most relevant to action in the current implementation phase of SAVs in Europe and Germany.

Fig. 3 Overview of the four key implementation challenges for deploying SAVs

Implementation Challenges

Technical	Regulatory	Economical	Structural/organisational
• Software-related technology (“digital driver”) not mature enough • Industry is still preparing safety and security measures • No existance of generally approved Level 4 vehicles for individual sale and use in regular road traffic • Need for physical infrastructure mostly driven by regulatory requirements and standards • Certain level of digital infrastructure required (e.g. connectivity)	• Heterogenous local to hyper-local approvals/ regulations and lack of political will • Complex and undefined processes (e.g. vehicle homologation) • Fragmented national and local regulations • Lack of standardisation and unified industry guidelines • Unsolved liability and legal frameworks	• Lack of investment capital, financial security, and commitment (incl. market guarantee) • Chicken-egg problem: lack of stakeholder commitment inhibits scalability • High CapEx and OpEx and low to no profitability due to lack of scalability and long-term perspective • Challenging coexistence or rivalry of different business cases/models	• Failure or unwillingness to partner and collaborate can be a major drawback • Vendors following the “doing it all” approach face many hurdles and will start to disappear • Role of operator and orchestrator not clear yet • Underestimating the complexity of reliable services, operations, and orchestration

Detailed examination in this whitepaper

Source: PwC and IMO-HSG analysis.

Technical challenges

Some of the most significant challenges for the adoption of SAVs relate to their technical maturity. This applies in particular to AV software, also referred to as the digital driver. The challenge is not only to achieve a very high level of reliability, but also to ensure that the AV software can consistently and safely handle all complex and unpredictable situations on public roads. Simply put, AV software needs to outperform human driving performance. This has been achieved by, for example, Waymo in certain areas and conditions.[11, 12] They can draw on data from over 96 million driven miles and show, for example, that they caused 92% fewer crashes with injuries to pedestrians, as well as 80% fewer injury-causing crashes compared to humans driving the same distances in the same cities.[13] However, acceptance and trust in the digital driver in the broader public are still lacking behind, resulting in risk averse decision-making for AV deployment.[14, 15]

Safety and security are paramount, and the industry is still in the process of establishing safety and (cyber-)security measures for the validation and technical verification of autonomous vehicles. Stringent safety expectations, particularly in Europe, require a high level of technical validation and reliability. Not only do the vehicles themselves need to be tested and verified to be safe on the road, but they also need to be secure in their communications with control centres and the interior (e.g. surveillance cameras), where cybersecurity also plays an important role. In the US and China, we see a more “flexible” approach, which is certainly one of the reasons why robotaxis are already commercially available in restricted areas. Hardware, sensors, and vehicles are actually available, but the software solutions for individual markets have not yet been finalised and must be specifically tested and approved. This has fundamental consequences for European operators and mobility providers wishing to put SAVs on the roads. The availability of pilot-vehicles is still very limited and they are not yet marketed in a professionalised setup. Moreover, competition among pilot projects to acquire the most mature vehicles is fierce, with access usually restricted to particularly ambitious projects. In addition, the sensor setups for the vehicles currently available are very expensive because many sensors have triple redundancy for safety reasons. Ultimately, the sensor setups in the next generation of vehicles for L4 will also change and be reduced to the necessary minimum. This emphasises another crucial challenge: depending on the particular sensory- and software-related solutions utilised, vehicles depend on different types of infrastructural requirements (such as GPS, wireless data coverage, and street design). The provision of these, however, goes in hand with substantial investments on the one hand, while being very prone to the volatility and insecurity of future technological developments on the other. Investments in these fields are consequently very insecure and risky. In addition, operators or technical supervisors must ensure the seamless upgrade of constantly evolving technology to ensure smooth operation.

Recommendations:

- **Focus on advancing software and hardware:** Developers and manufacturers must still prioritise innovations in software (e.g. autonomous driving algorithms and digital driver) and hardware (e.g. microprocessors and redundant systems) to achieve the technological maturity required for L4 autonomy.
- **Pursue a frugal infrastructure approach:** While infrastructure changes are capital-intensive, it is essential to leverage and upgrade existing infrastructure to support safe SAV operation. This underscores the importance of software and hardware solutions that are as independent and parsimonious as possible in their reliance on infrastructure.

Regulatory challenges

The regulatory landscape for SAVs has not kept pace with technological advances, creating significant challenges for their deployment. The lack of standardised industry guidelines and the diversity of regulatory requirements across jurisdictions complicate the commercialisation of SAV services.

Although Germany accelerated AV legislation with its autonomous driving law back in 2021, heterogeneous local to hyper-local approval processes and regulations represent a significant barrier to entry and further limit the scalability of SAV services.[16, 17] In addition, the expectation in society and among some stakeholders that autonomous vehicles must achieve a “zero failure tolerance” is perceived as overly stringent, as this is not technologically feasible. The political will and risk appetite of stakeholders to support such advances is insufficient, impeding faster progress. Furthermore, the industry lacks L4 type-approved vehicles and platforms. Each vehicle requires a separate homologation process for a given area, making scalability difficult. The test must be repeated if the territory is extended or if the area of application is new. Thus, the homologation process for SAVs is complex and challenging due to a lack of common definitions and procedures, even though, for example, the European Union originally tried to address some of these points in Regulation (EU) 2019/2144 and then adapted its approach in Regulation (EU) 2022/1426.[18] Approval processes are still very complex and undefined, slowing down deployment speed. The fragmentation between national and local approvals, licenses, and authorities has resulted in further regulatory uncertainty, discouraging manufacturers and mobility providers from committing to large-scale deployments.

Furthermore, the industry suffers from a lack of standardised guidelines. Each manufacturer, supplier, and tech player operates under different internally set conventions and definitions, with no “level playing field”. Indeed, standardisation is absent across various processes, such as technical specifications, remote control, and tenders. This absence of uniformity complicates the regulatory landscape further.

Lastly, liability issues remain unresolved and there is no harmonised legal framework. Legal frameworks in the US and Asia appear to be more relaxed on liability issues than in Europe, where legislative and political will play a significant role. This disparity hinders the global harmonisation of regulations necessary for the widespread deployment of SAVs and also reveals preferred deployment areas with lower barriers to entry in the US and China (e.g. California, Nevada, and Beijing).

Recommendations:

- **Establish harmonised regulations and approvals** at national and, in the best case, international (e.g. European) levels.
- **Develop thorough but simplified processes for L4 type approvals** (and homologation processes) to enable standardised industry guidelines and scalability.
- **Develop realistic and applicable safety requirements** for SAVs that ensure that utilisation is as safe as possible and particularly that deployment is safer compared to the status-quo (i.e. human-driven vehicles).

Economic challenges

The economic feasibility of the introduction of SAVs depends on overcoming substantial investment barriers and providing the market with guarantees while offering financial security. The feedback from experts highlights a “chicken-egg” problem, where a lack of stakeholder commitment (e.g. where there is no financial security or commitment for purchasing volumes) hinders scalability and further investments, thereby impeding hardware and software costs from falling. Achieving profitability with SAV services remains elusive for many stakeholders, with high initial capital expenditures for the vehicles, the development of AV software technology, and operational expenditures not yet offset by sufficient revenue streams.

The discussion extends to the need for public sector subsidies and financial support, particularly in the EU, to kick-start the commercial deployment of SAV services, underscoring the critical role of government investment and financial incentives in catalysing the SAV market. In the US and China, on the other hand, experts believe that business cases are already viable today and that sustainable profitability could be achieved sooner. The primary player in the USA, the Google-owned robotaxi company Waymo, is handling over 250,000 trips per week across five cities and was able to report 10 million trips in total in May 2025, doubling its trips in just five months.[19, 20] Waymo raised $2.25 billion in a first external funding round in 2020, followed by another $2.5 billion in 2021. In October 2024, Waymo was able to secure an additional $5.6 billion, showcasing the enormous investment necessary to develop AV software and robotaxi services. Simultaneously, it shows the enormous potential and trust the market has in this technology, with Waymo now valued at $45 billion.[21, 22] Still, Waymo has not yet achieved profitability and does not currently disclose any revenue numbers. Similarly, Apollo Go, the robotaxi unit of Baidu, expects that its commercial robotaxi service in Wuhan will become profitable by 2025.[23] From its launch to mid-2025, Apollo Go carried out around 11 million rides nationwide.

This shows that although business models and companies for the most part still have a long way to go before they are profitable, the first players appear to be closer to reaching profitability in specific cities or areas.[24, 25] Interestingly, WeRide (Apollo Go's competitor in China) actually disclosed a profit in its Q1 financial results with a gross profit margin of 35.0% across their various activities. They also disclosed that their robotaxi revenue reached $2.2 million, i.e. 22.3% of total revenue – a 10.4 percentage point increase year-on-year.[26]

The choice of initial business cases and models are critical decisions that affect the viability of SAV deployment, as well as its impact on urban mobility systems. The emergence of different business models, such as private providers of robotaxi services as in the case of Apollo and Waymo, or public roboshuttle services in the hands of public transport operators (PTOs), will be challenging to orchestrate. It is still unclear which player will be the main driver of the business and whether different business models will coexist or compete and potentially cannibalise each other. In the following chapters we will delve further into questions regarding the organisation and financing of SAV services.

Structural and organisational challenges

The structural and organisational challenges which deploying SAV fleets commercially presents are manifold. Due to high development costs and the large number of tasks related to commercially deploying, operating, and orchestrating entire fleets of SAVs, a collaborative industry push is needed to speed up scalability. Effective collaboration among hardware, software, and vehicle manufacturers, suppliers, transportation operators, and public authorities is essential for progress toward mass production and widespread deployment. However, there is a notable lack of collaboration among cities, PTOs, public transport authorities (PTAs), and relevant private stakeholders, which is decelerating the development of a cohesive SAV ecosystem. In the eyes of the interviewed experts, many PTOs and PTAs are strongly occupied with the management of current mobility challenges with, in many instances, little capacity for the development of future transport strategies, which are crucial for the introduction of radically new technologies such as SAVs.

In addition, markets naturally tend to fragment as they mature, which presents another layer of challenges. While some players consciously focus on their core business and develop products from their core competencies, such as Schaeffler with their rolling chassis platform, other players initially seem to try to solve all (too many) problems on their own, which has in some cases proved to be too difficult. As a result, it appears that companies that try to tackle all aspects of SAV deployment instead of focusing on their core strengths often face insurmountable hurdles and risk disappearing from the market. Although Waymo, for example, shows that this approach can work, when scaling they also outsource many tasks and focus more on their core business strengths.

Day-to-day operations and orchestration of SAV services present further significant challenges. The role of the operator and orchestrator remains unclear, as there is no common understanding of or standard for which roles and responsibilities are carried out by which stakeholders, leading to potential further conflicts between private business objectives and public or societal benefits. The next chapters provide more insight into the details of which tasks and responsibilities need to be performed in a complete SAV ecosystem and which stakeholders may take control of the operation or orchestration. Ensuring the high reliability of SAV services is paramount, as they must operate dependably under all environmental conditions. A full range of services and their reliability is hard to maintain when limited to specific ODDs, complicating customer retention and revenue generation. The "fail fast and fix" approach more commonly being used in the US seems less applicable in Europe, where regional challenges necessitate a more cautious and durable approach, especially in the roboshuttle business, which is often associated with PTOs and thus public transportation services.

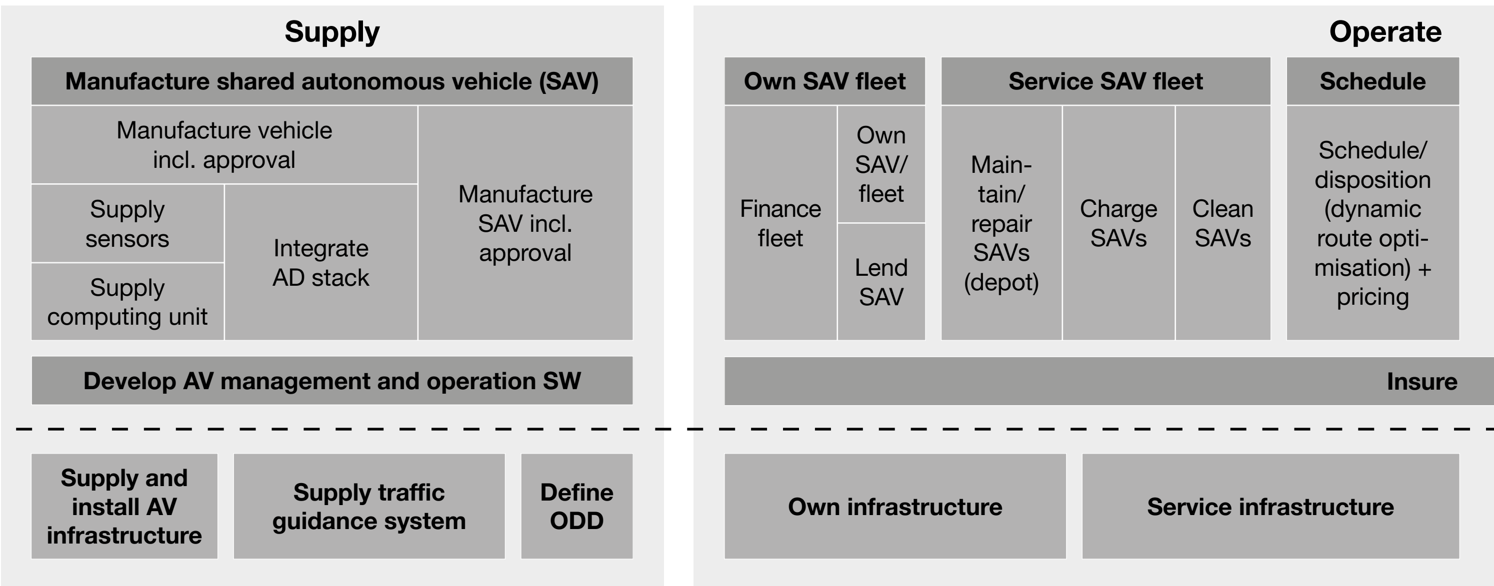
The complexity of deploying SAVs is therefore often underestimated, since that complexity encompasses not only technical aspects, but also service, operations, and orchestration challenges. Intricate urban structures and infrastructure, combined with regulatory and economic hurdles add to this complexity, making it difficult to deploy commercial SAV services seamlessly and scalably.

While acknowledging the multifaceted nature of the four above outlined fields of challenges, this paper limits its focus to economic and structural challenges in order to lay the groundwork for a comprehensive exploration of the SAV ecosystem and strategies for addressing the identified challenges. Most of the technical challenges are very likely to be solved by technology companies, OEMs, and suppliers, and the regulatory challenges will require collaborative work led by strong political will and power from legislators and authorities. However, the task of overcoming the economic and structural/organisational challenges and breaking barriers does not yet seem to be directly linked to a specific stakeholder group. The analyses provided in the following chapters intent to illuminate these barriers and provide valuable insights for stakeholders navigating the complex landscape of SAV deployment.

The SAV ecosystem requires orchestration of wide-ranging tasks

As outlined in the previous section, the structural and organisational challenges of deploying SAVs are manifold, and relevant players currently lack an overarching and comprehensive SAV ecosystem in which to operate SAV fleets. Building on the interviews conducted and the observation of current pilot endeavours, we modelled an SAV ecosystem consisting of three main sections: a triad of supply-centric, operation-centric, and demand-centric tasks, with a further distinction between infrastructure-related tasks (see lower part of Figure 4) and SAV product/service-related tasks (see upper part of Figure 4). Each section includes various subparts, detailing the specific activities necessary for the successful deployment and operation of SAVs. The model only refers to additional infrastructure or services required for the deployment of SAVs, so roads, parking, traffic lights, etc. are explicitly excluded from the model but their possible adaptations or extensions are included.

Fig. 4 The SAV ecosystem – supply-centric, operation-centric and demand-centric tasks



Roads, parking lots, traffic lights, etc. are not included in the model

Source: PwC and IMO-HSG analysis.

Operate SAVs

- Deploy
- Driving/ parking
- Monitor fleet/ monitor cabin
- Vehicle assistance (control center)
- Assist manually in field (field team)

Operate infrastructure

Demand

Book and pay

- Pay
- Book and set price

Offer mobility services

- Plan mobility paths
- Offer mobility platform (incl. aggregation)

Marketing

- Marketing/ CRM

Ensure mobility services

Supply section

The supply section lays the foundation for the entire SAV ecosystem by establishing the necessary technologies, products, and infrastructure. This begins with the manufacturing of vehicles and ensuring they adhere to regulatory standards, which includes obtaining the necessary approvals and fulfilling the homologation process to make them L4 roadworthy. The manufacturing process also includes the supply of advanced sensors, which are integral to SAVs and allow them to identify obstacles, define the driving path, and ensure safety by providing real-time data about the vehicle's status and surroundings. Computing units process the data collected by the sensors, thus supporting the complex computations required for autonomous driving. The AD stack comprises both the software and hardware necessary for autonomous operations, enabling the vehicles to make decisions and drive themselves.

At the same time, setting up AV infrastructure is another key area within the supply section. This involves the installation of physical and digital infrastructure, such as communication networks or smart traffic lights, which may become essential for the reliable operation of SAVs. Further, an effective traffic guidance system must be supplied, which is necessary for managing and guiding SAVs on the road. This system will ensure that SAVs navigate efficiently through traffic by providing real-time traffic data and navigation paths. Lastly, the ODDs on which an SAV is authorised to drive also constitute an integral part of the supply section, especially in the short- to mid-term of the SAV scale-up and adoption process. Designating these involves analysing and classifying the specific conditions and environments in which SAVs can operate, such as geographic areas and types and conditions of roads. This classification will assist in determining the operational limits and capabilities of the SAVs for a specific area, ensuring they operate safely and effectively within their defined parameters.

Operate section

The operation of SAVs involves a comprehensive list of tasks from owning and managing fleets to scheduling and maintaining infrastructure with the ultimate aim of ensuring smooth services. Owning an SAV fleet requires either the financing of the vehicles/entire fleet or lending the SAV fleets, e.g. through rental or leasing agreements. The vehicles will also need to be serviced, which includes several tasks such as regular maintenance and repairs to keep the vehicles in a reliable and safe condition, managing the charging processes of the fleet, and regular cleaning to maintain hygiene and user satisfaction. Today, it seems that the complexity and necessary reliability of those operational tasks and responsibilities are underestimated by many, as the projects executed so far have mostly been small pilot projects. In addition, vehicle scheduling and disposition is an operational task that involves reacting dynamically to additional requirements and ensuring sufficient mobility coverage at all times. This task aims to maximise fleet efficiency and ensure that SAVs are deployed where they are most needed. Operating SAVs also involves strategically repositioning vehicles in high-demand locations, managing their driving and parking, and continuously monitoring the fleet. Remote control capabilities can be provided for critical situations, allowing operators to take control if necessary. Field teams provide manual support for SAVs and handle situations that require human intervention, ensuring seamless operation even in challenging scenarios.

The infrastructure that supports SAV operations must also be regularly serviced and maintained to ensure ongoing upkeep. This includes street conditions, street markings, and more. Infrastructure operations further include providing traffic movement data to manage traffic flow. This data is used to develop paths and traffic management systems that guide the SAVs and ensure they navigate efficiently. Monitoring the day-to-day operation of the infrastructure supporting (S)AVs, ensuring that all systems function reliably, is also part of this segment.

Demand section

The demand section focuses on ensuring that the public can effectively utilise the mobility services offered by SAVs and therefore fulfil a certain demand level. This begins with managing booking and payment systems for users by providing an easy booking and seamless transaction process. These tasks ensure that users can easily access, book, and pay for SAV services. However, such mobility services require providers to plan mobility paths and offer a platform for users to access those services. This platform could potentially integrate multiple transportation modes to provide a comprehensive mobility solution. In addition, marketing and customer relationship management (CRM) are essential for promoting SAV services and ensuring customer satisfaction. Effective marketing strategies help attract users, while CRM ensures that their needs and concerns are addressed promptly and ultimately leads to customer retention.

Looking at the public sector, mobility services are controlled and monitored by cities, municipalities, legislators, and authorities. Continuous monitoring of mobility services and availability will help to maintain high service standards and identify areas for improvement. Strategic planning is necessary for municipalities and cities to meet the evolving demand for mobility, where among many solutions, one solution may be SAV services (in addition to trains, metros, etc.). Subsidising SAV services in the short term or subsidising less profitable routes will ensure comprehensive coverage, making SAV services accessible to a wider public. This financial support will ensure that routes with lower demand are also served, providing a more inclusive service.

In summary, the SAV ecosystem is a complex network of interdependent tasks and responsibilities. Each section and its elements illustrate the comprehensive approach required for developing a scalable and commercial SAV service that involves multiple stakeholders working together. By addressing challenges and ensuring the functioning of these multifaceted components, the SAV ecosystem has the chance to change our mobility significantly.

Identifying the most promising ecosystem configurations

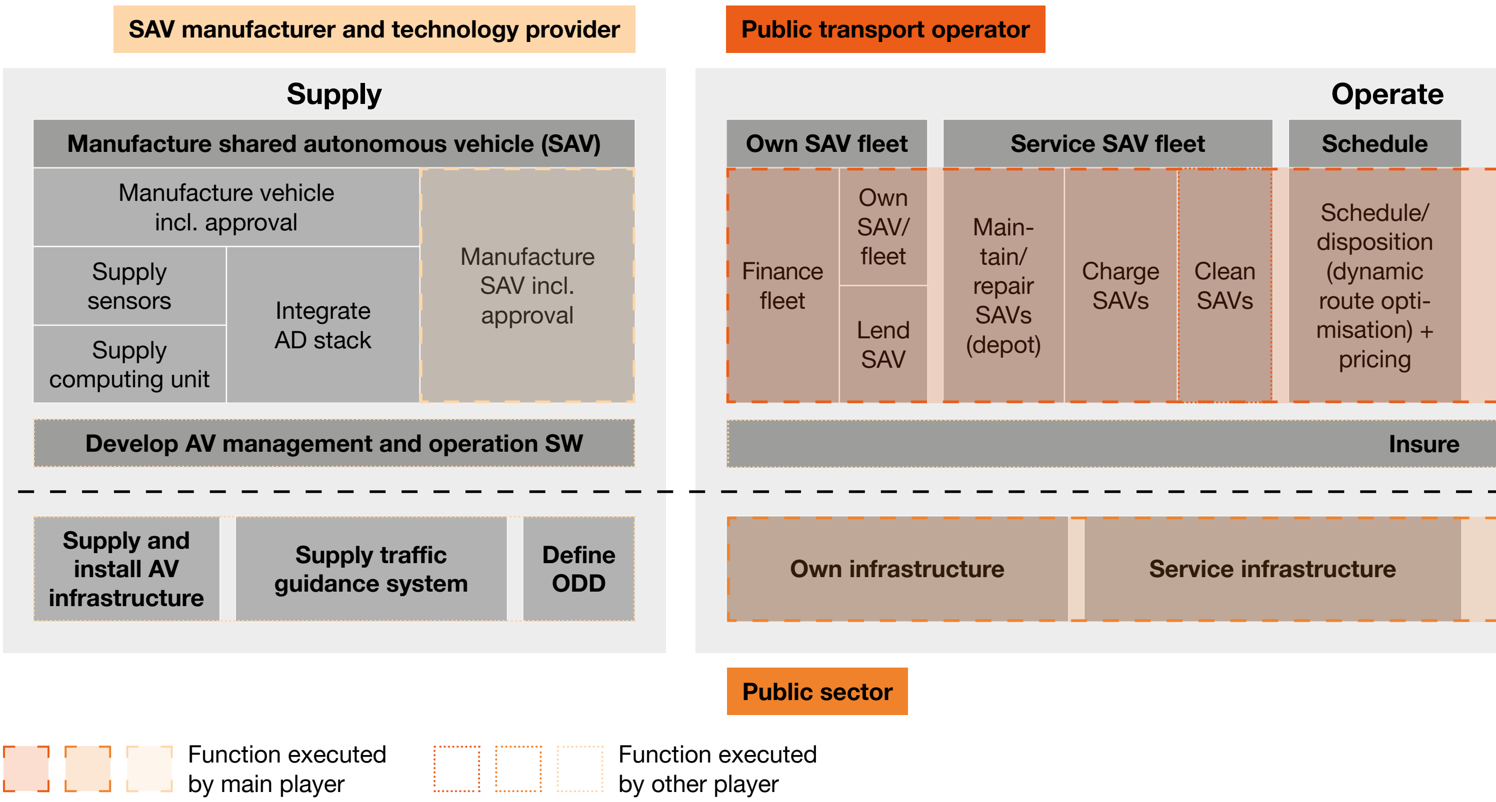
Given the complexity and interconnected nature of the SAV ecosystem, it is crucial to identify the configurations that are most likely to be deployed in the coming years. Different players and stakeholders will need or want to fulfil certain tasks based on their unique roles, expertise, and resources. Strategic allocation of responsibilities can ensure that all tasks and components of the SAV ecosystem are optimised for efficiency, safety, and user satisfaction. We explored different configurations of the SAV ecosystem, looking at which tasks are most likely to be performed by different market players and who will end up operating and orchestrating SAV fleets and be the face to the end customer. By understanding these configurations, we can subsequently address the economic, structural, and organisational challenges associated with deploying commercially viable SAV fleets and ensure the seamless integration of SAVs into urban and suburban areas.

Configuration 1 – PT-centric

This first configuration focuses on the public transport (PT) sector. Since it is mostly public transport operators (PTOs) that manage and operate their fleets today, with some private companies also active, this configuration assumes that the same will apply for SAV fleets in the future. In this scenario, it is therefore PTOs who are responsible for the service and operation of SAVs, including scheduling and owning or lending the fleet. When servicing SAVs, PTOs carry out most of the maintenance, repairs, charging, and cleaning themselves. In addition, they take on the daily deployment and driving of the vehicles, the monitoring of the entire fleet, remote control, and providing manual field assistance. PTOs also manage the financing and leasing or rental of the vehicles, depending on the desired approach. Meeting the demand through marketing, CRM, and providing mobility services will also be part of PTO's role. Furthermore, they will control bookings and provide mobility services to users, although these tasks may be only partly carried out by the PTO itself, with the bulk provided by third parties. Tasks related to payment systems are also more likely to be handled by third parties.

The production and installation of the AV infrastructure and its operation and maintenance are handled separately, with the public sector and public authorities being responsible. The production of SAVs is also handled separately, with OEMs and technology providers being responsible for providing homologated and licensed ready-to-use vehicles.

Fig. 5 Configuration 1 – PT-centric



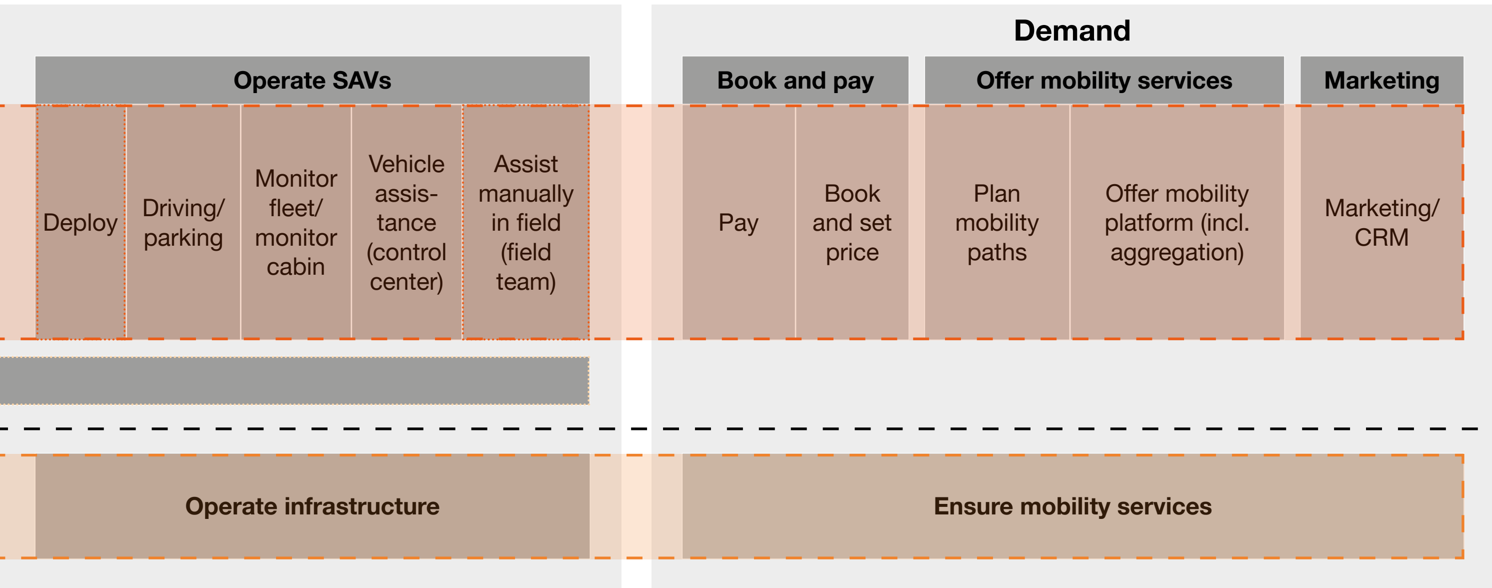
Roads, parking lots, traffic lights, etc. are not included in the model

Source: PwC and IMO-HSG analysis.

The PT-centric configuration thus offers several advantages. Unified control under PTOs can ensure integrated public transport solutions, leveraging their existing expertise today in public transport operations and services. However, it also presents challenges, such as placing a high level of responsibility on PTOs for both SAV fleet management and new related tasks such as remote driving, monitoring, and daily deployment of SAVs, which require significant additional expertise in AV technology and operations.

Potential variations to this configuration:

- Demand-side tasks might be provided by third parties.
- Individual SAV service and operation tasks, such as vehicle repair by OEMs or remote driving by other specialised companies, might be provided by specialised third parties.
- The financing of the fleet could be provided by a finance company that lends or leases the vehicles.

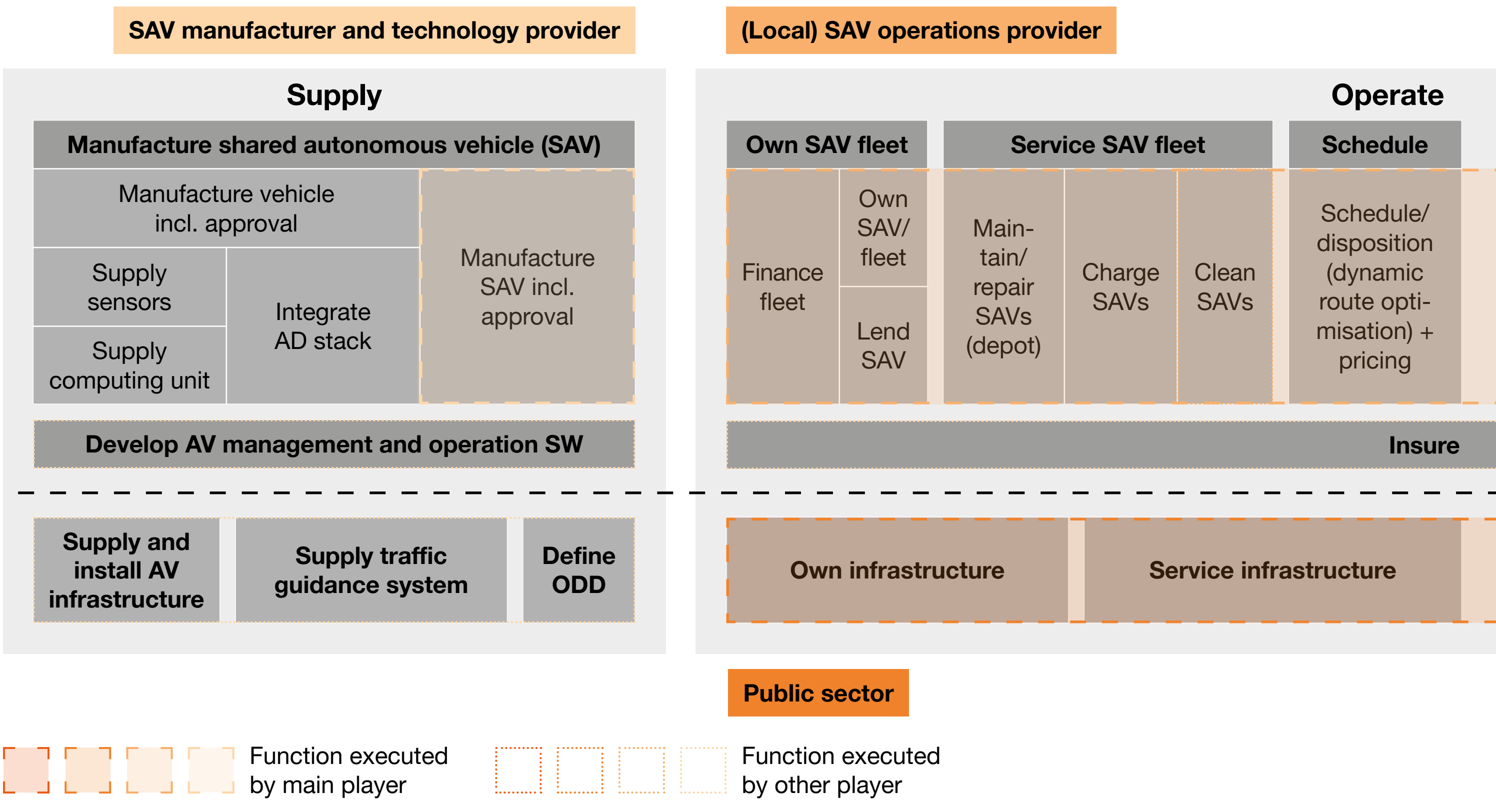


Configuration 2 – Integrated SAV mobility solution

The second configuration integrates (local) SAV operations providers with public transport (e.g. PTOs). The local or national/international SAV operations provider handles most of the service and operations, while the PTOs handle the demand side. Thus, in this configuration, the PTOs have fewer tasks and most likely purchase a "near-turnkey mobility solution" from the SAV operations provider that can easily be integrated into the transport network of the PTO's area of operation.

The service and operation will be mainly performed by the (local) SAV operations provider, including the management of the SAV fleet operations, maintenance, repair, charging, route scheduling, and all tasks related to SAV operations (daily deployment, driving, fleet monitoring, remote driving, and the manual assistance field team). However, cleaning may be a task that the (local) SAV operations provider outsources to a third party, or the PTO may continue to clean the vehicles as it does today. The PTOs carry out booking, payment, and customer relationship management on the demand side, while the actual provision of the mobility, booking, and payment services will most likely be outsourced.

Fig. 6 Configuration 2 – Integrated SAV mobility solution



Roads, parking lots, traffic lights, etc. are not included in the model

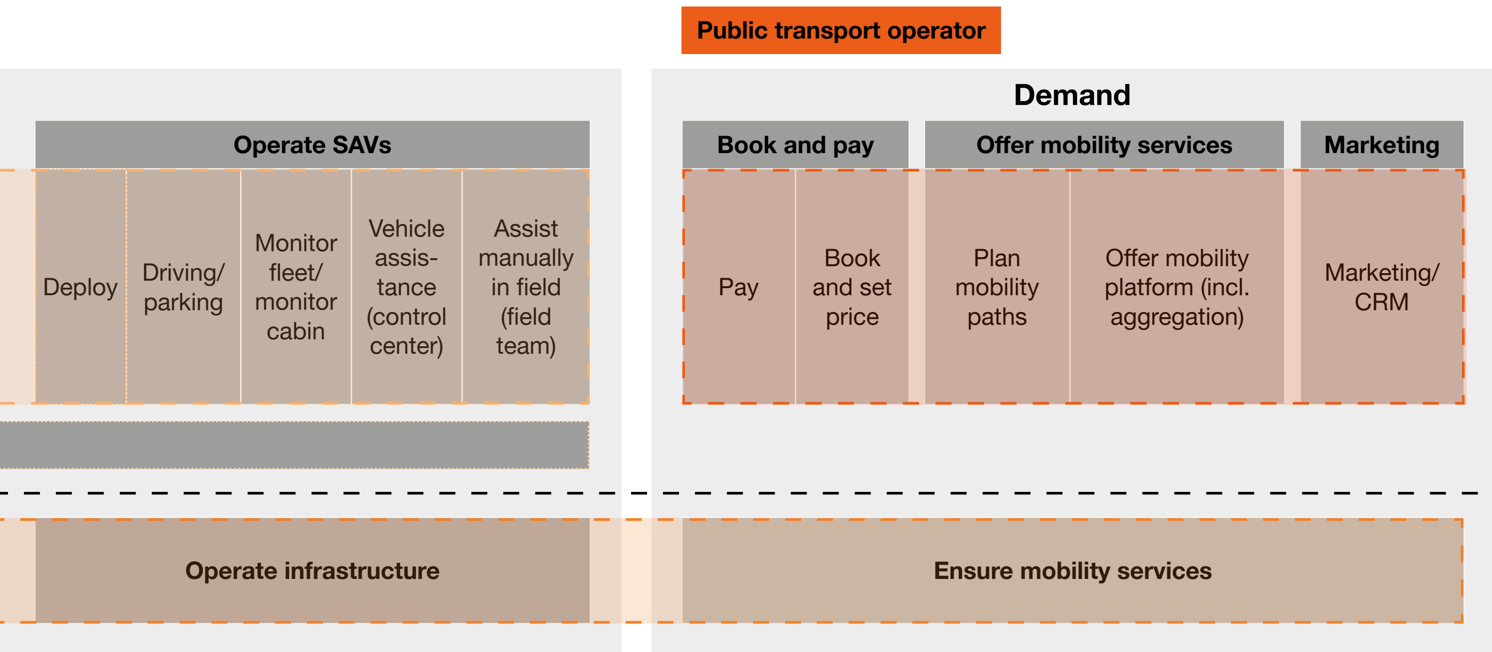
Source: PwC and IMO-HSG analysis.

As in the first configuration, responsibility for the production of SAVs lies with the OEMs and technology providers, while responsibility for the production and installation of the AV infrastructure, and for the operation and maintenance of the AV infrastructure, lies with the public sector and public authorities.

As a result, the integrated SAV mobility solution offers benefits such as shared responsibilities between the PTO and the SAV operations provider, leading to more specialised and efficient operations while leveraging expertise from both the public and private sectors. However, partnerships between PTOs and local providers can pose challenges, and there is the potential for a fragmented user experience if the system is not well coordinated.

Potential variations to this configuration:

- Demand-side tasks might be provided by third parties.
- Individual SAV service and operation tasks, such as cleaning, charging, or the manual assistance field team, might be provided by specialised third parties or the PTO itself.
- The financing of the fleet could be provided by a finance company that lends or leases the vehicles.



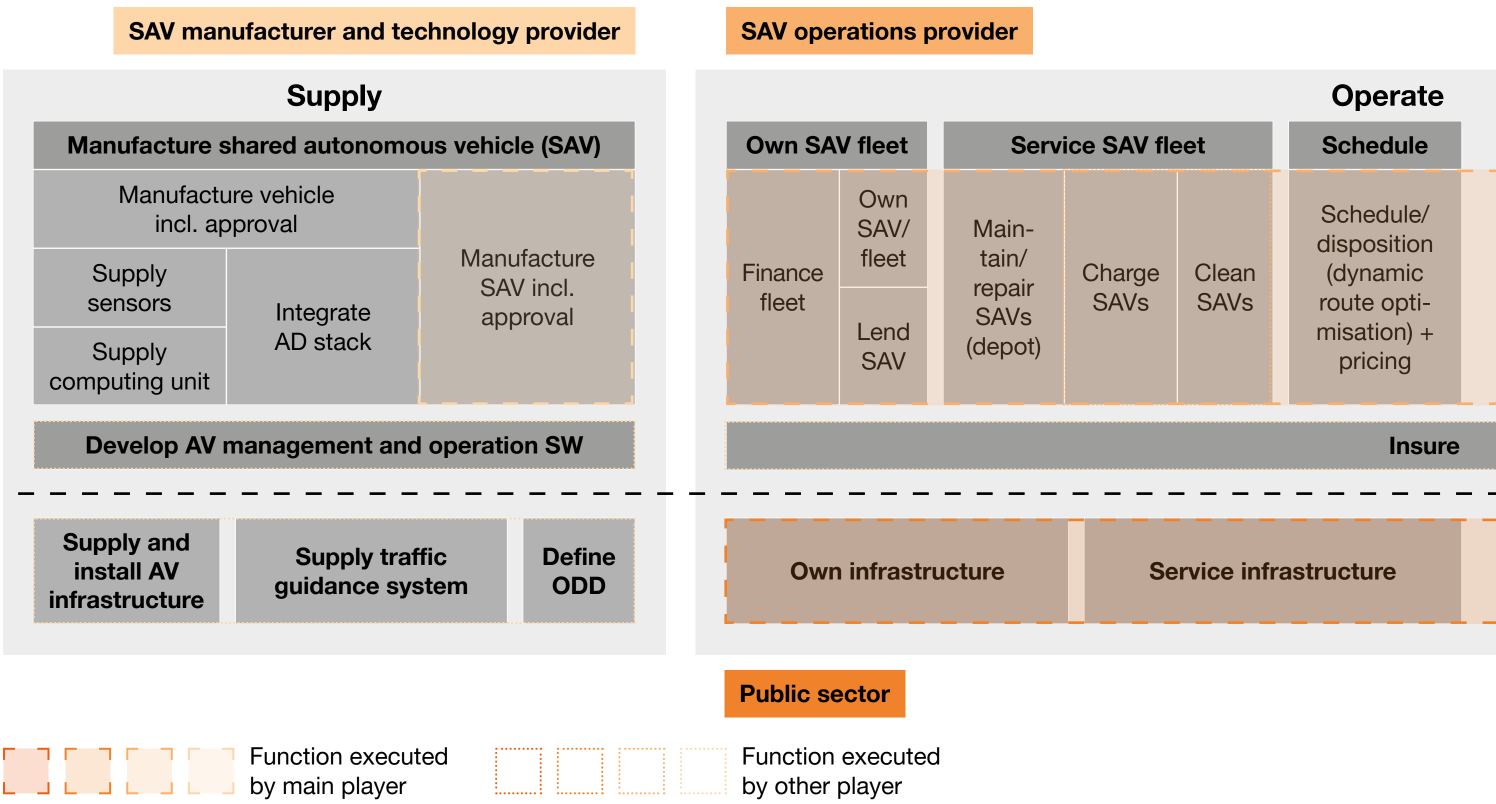
Configuration 3 – Lean PT

In the third configuration, named "lean PT", the SAV operation providers take on an even greater share of the tasks and responsibilities, while the PT company (or potentially a further private player) will only be responsible for marketing, CRM, and overall commissioning and supervision. All remaining demand-side tasks (offering mobility services, booking, and payment systems), as well as all service and operation-related tasks, will be taken on by the SAV operations provider.

On the operational side, the SAV operations provider can manage fleets, including the management of financing or leasing the fleets, and service and maintain the SAVs. While CRM and marketing will continue to be managed by the PTOs, the SAV operation provider will also manage the mobility service offering, booking, and payment. As in the previous configuration, the SAV operation provider will be responsible for all service and operation-related tasks, including maintenance/repair, charging, cleaning, scheduling, daily deployment, driving, monitoring, remote driving, and assistance by manual field teams.

As in the previous configurations, manufacturing of the vehicles, AD stacks, and their integration will be handled by OEMs and technology providers. The production and installation of the AV infrastructure, as well as the operation and maintenance of the AV infrastructure, will be provided by the public sector and public authorities.

Fig. 7 Configuration 3 – Lean PT



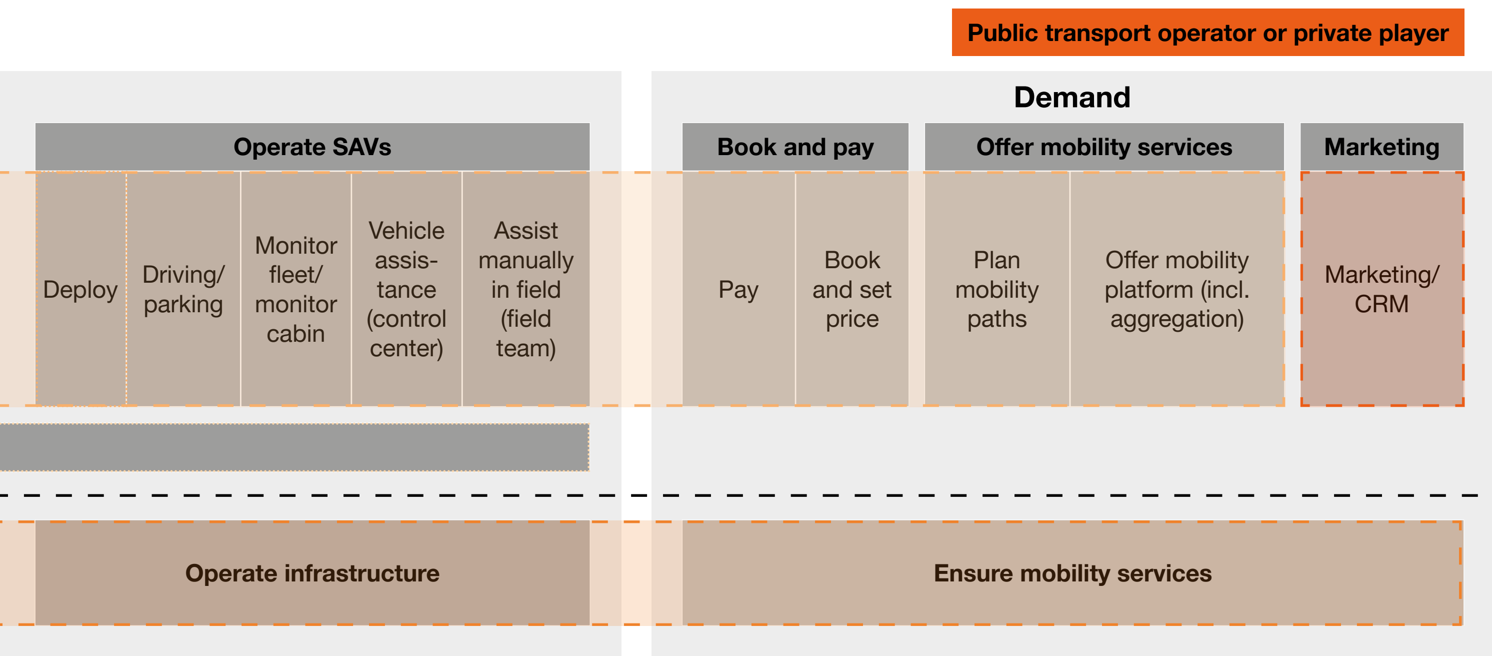
Roads, parking lots, traffic lights, etc. are not included in the model

Source: PwC and IMO-HSG analysis.

The lean PT configuration thus has the advantage of leveraging the technical expertise of specialised mobility service providers, but the actual offering of the SAV mobility service is still commissioned overall by the PTO. However, the even higher level of coordination required between PT companies and the service providers, suppliers, and third parties compared to the second configuration will make a seamless user experience and operation even more challenging.

Potential variations to this configuration:

- Demand-side tasks of the SAV service provider may be provided by third parties.
- Individual SAV service and operation tasks, such as cleaning, charging, scheduling, and a manual assistance field team, could be provided by specialised third parties or by the PTO itself.
- The financing of the fleet could be provided by a finance company that lends or leases the vehicles.

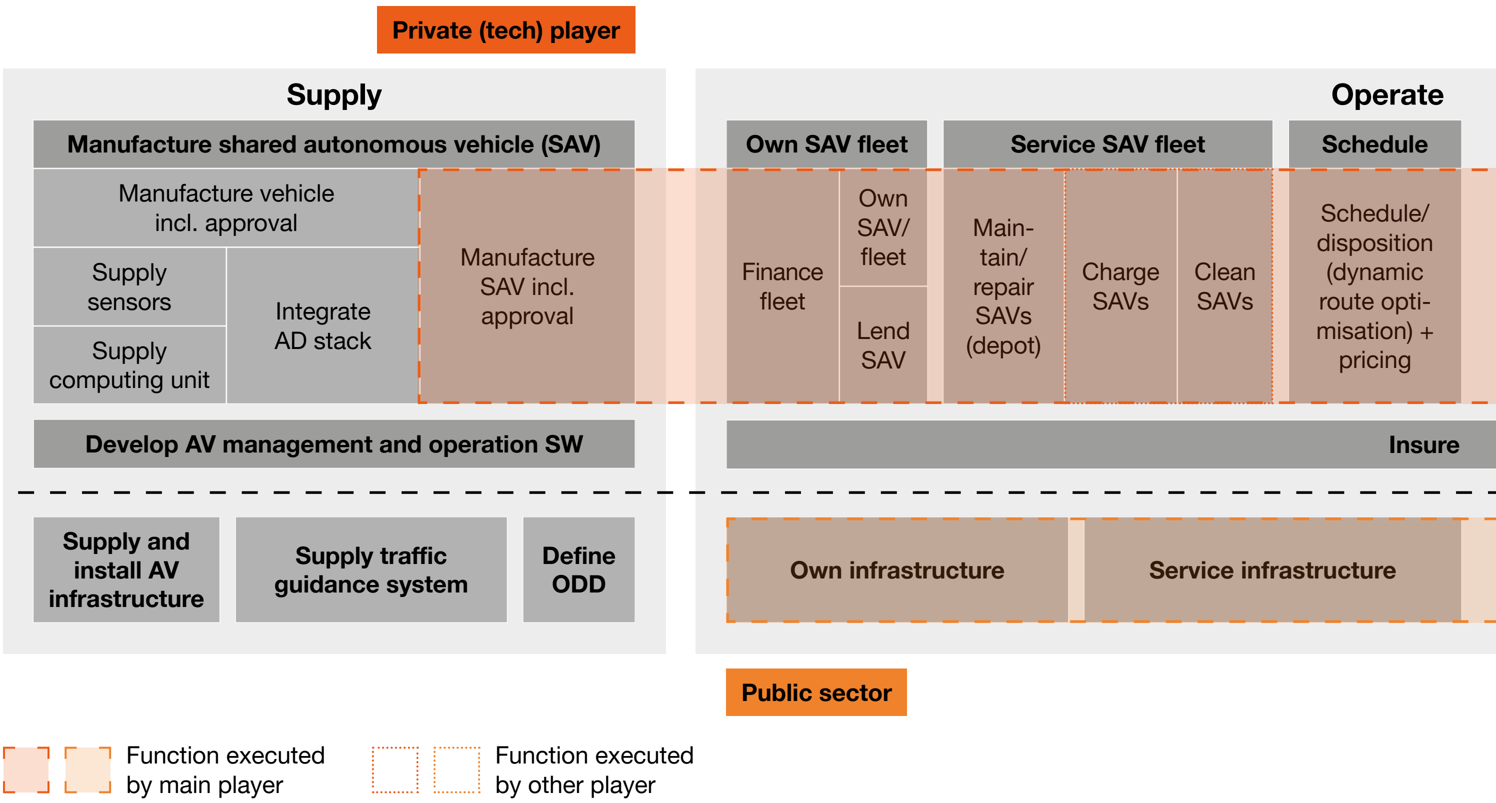


Configuration 4 – Private (tech) player

Finally, the fourth configuration represents an approach where, for example, a private (tech) player such as Waymo, WeRide, or Pony.ai acts as both technology provider and service/operation provider. Waymo, for example, owns and manages the SAV fleet, while also managing the integration of its proprietary AD stack in the vehicles, which are likely to come from OEMs (except in the case of Zoox, where the tech player also manufactures the vehicle itself).

On the service and operations side, the tech player, such as Waymo today, manages all aspects of SAV operations but is likely aiming to outsource as much as possible in the future, as this is not the core business of such companies. On the demand side, Waymo offers the mobility service directly to customers, managing marketing, booking, payment systems, and customer service through a self-developed app. Typically, such companies are open to demand-side tasks and can easily link up their software backend to customer front ends and apps.

Fig. 8 Configuration 4 – Private (tech) player



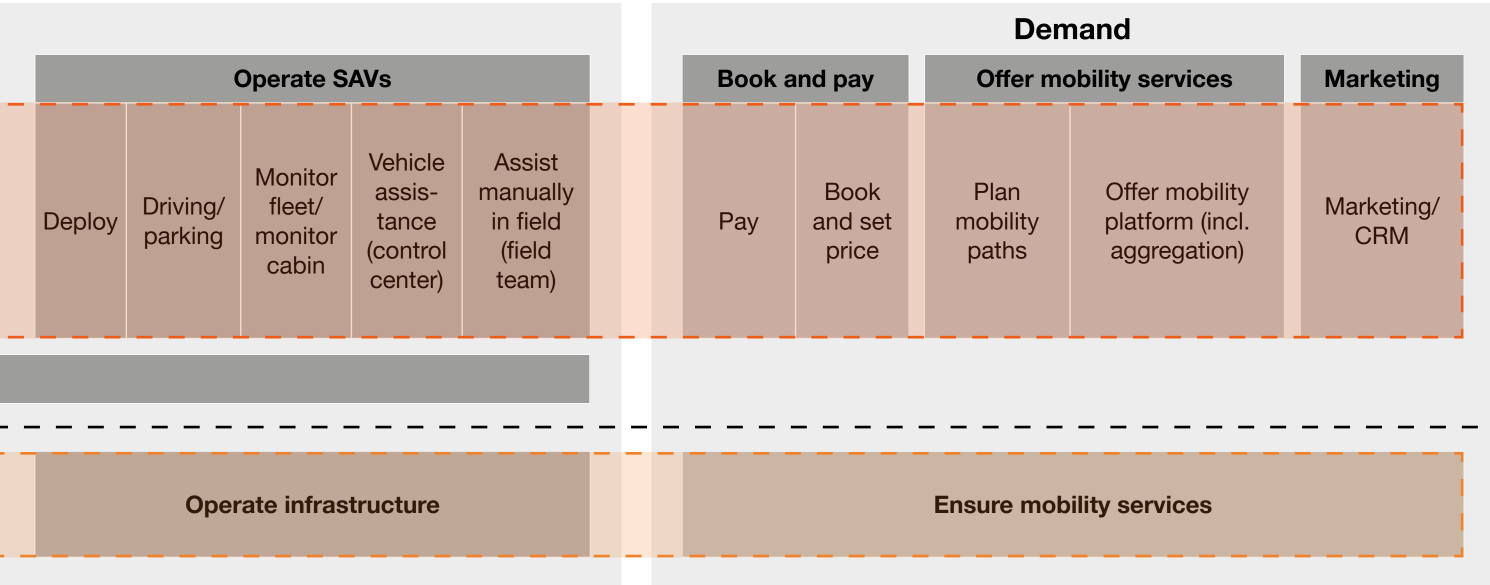
Roads, parking lots, traffic lights, etc. are not included in the model

Source: PwC and IMO-HSG analysis.

Overall, the “private (tech) player” configuration offers full control of the entire SAV ecosystem to the tech player/mobility company, allowing for streamlined operations and faster innovation. Direct interaction with customers followed by direct implementation of adjustments can improve service quality. However, this approach requires significant investment and expertise in both technology and service operations and places a high risk on a single entity owing to the extensive responsibilities involved.

Potential variations to this configuration:

- The tech player/mobility company might outsource some or several of the service, operation, or demand-related tasks.



The configuration question

Each of these configurations presents unique advantages and challenges. The ideal configuration will not only depend on various factors, including the specific market, country and local contexts, regulatory environment, and the readiness of the stakeholders involved, but also on the vehicles type, namely robotaxis, roboshuttles, or robobuses, and their operation mode (e.g. on-demand or fixed route). Integrating the strengths of different participants while ensuring smooth coordination and efficient service delivery is crucial for the success of these SAV ecosystem configurations.

Since the tasks, responsibilities, and the orchestration and operation roles vary in these configurations (see Figure 9), it could be the case that not one but potentially even two or more of the presented SAV ecosystem configurations, or adaptations thereof, could be applied and co-exist in a single city. For example, while a city such as Hamburg might use a PT-centric configuration to offer roboshuttle and robobus services orchestrated and operated by the PTO, in the future there might also be some private robotaxi players in Hamburg which offer their fully autonomous robotaxi services orchestrated and operated by themselves.

Fig. 9 The four most promising SAV ecosystem configurations in comparison

	1 PT-centric	2 Integrated SAV mobility solution	3 Lean PT	4 Tech player
Face to customer	PTO	PTO	PTO/Mobility provider	Mobility provider/ tech company
Orchestrator	PTO	PTO	PTO	Mobility provider/ tech company
Mobility service operator	PTO	Mobility provider	Mobility provider	Mobility provider
Infrastructure operator	Municipalities, districts, states, …	Municipalities, districts, states, …	Municipalities, districts, states, …	Municipalities, districts, states, …
Tasks & responsibilities PTO				
Tasks & responsibilities SAV mobility provider				

Source: PwC and IMO-HSG analysis


Vehicle type: car
Direction: passing
Vehicle type: car
Direction: passing

Flexible business case modelling

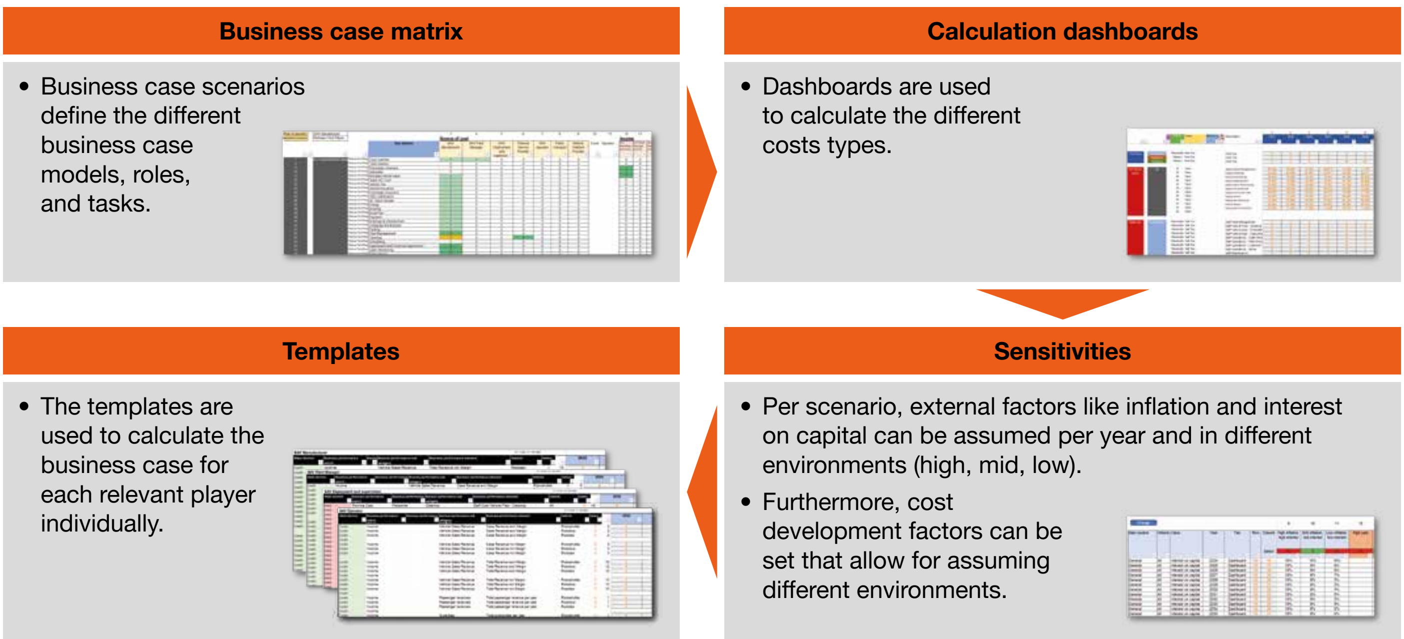
In order to examine and quantify the economic challenges in deploying SAVs, we have developed a flexible business case modelling tool (see Figure 10). Based on our ecosystem representation (see Figure 4), the tool allows different business cases to be configured and calculated for each of the ecosystem configurations:

- Configuration 1 – PT-centric
- Configuration 2 – Integrated SAV mobility solution
- Configuration 3 – Lean PT
- Configuration 4 – Private (tech) player

Various players and potential external subcontractors can be defined and integrated in the modelling process. Furthermore, it is possible to calculate and analyse business cases with different sensitivities for different countries and ramp-up scenarios.

Overall, the tool considers both the vehicle ramp-up and economies of scale, as well as cost reductions in technology achieved over time through better integration, and a reduction in service costs through higher reliability of vehicles and technologies.

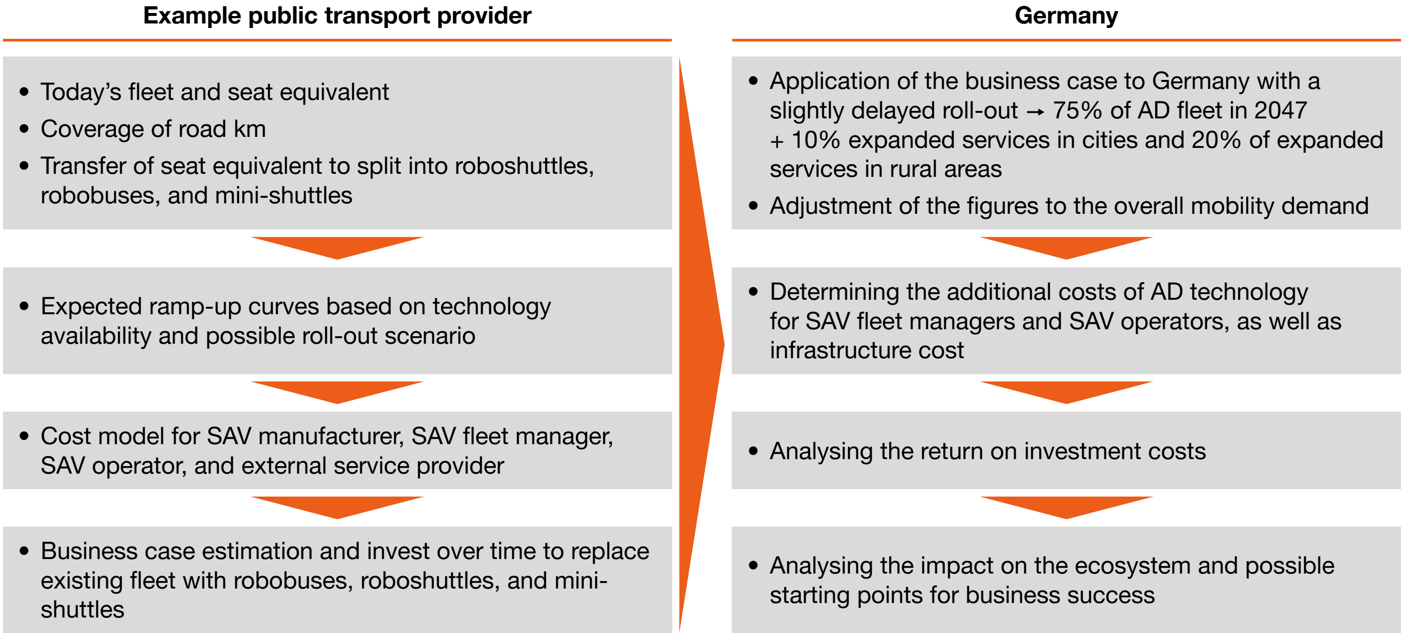
Fig. 10 Flexible business case modelling tool



Source: PwC.

The initial configuration and specifications of the model and its underlying data set were derived from the case of an existing German public transport operator in a given German city (see Figure 11). Starting from today's fleet and seat equivalent and the city's road network, the model considers expected ramp-up curves and costs (including cost development forecasts) for vehicles, fleet management, SAV operations, and external services. It calculates estimates for the business case and investment requirements. The second step is an extrapolation to the entire public transport system in Germany under the assumption of a slightly delayed roll-out. The model helps to analyse the impact on the ecosystem and possible starting points for business success.

Fig. 11 Deriving the parameters for the investment calculation for the Germany case study



Source: PwC and IMO-HSG analysis.

The cost items that go into the model cover the entire ecosystem across the sections below:

- Vehicle provision (e.g. depreciation, financing, and insurance)
- Maintenance and repair (e.g. MRO costs)
- Vehicle preparation (e.g. fleet management, vehicle deployment, and cleaning)
- Energy (e.g. electricity)
- Infrastructure (e.g. depots, parking areas, and charging infrastructure)
- Background systems (e.g. monitoring, software, and ticketing)
- Overhead costs (e.g. implementation, ramp-up, staff, and marketing)

While our model can be applied to any of the above outlined ecosystem configurations, we will focus on two selected configurations in the following chapters:

- Configuration 1: SAV rollout in public transport (see Chapter 7)
- Configuration 4: Rollout of robotaxis in Germany (see Chapter 8)

SAV rollout in public transport

Public transport today

Local public transport is an important pillar of mobility today and will continue to be in the future. Around 100,000 bus drivers are currently employed in public transport throughout Germany. In order to increase and improve public transport offerings to attract more passengers, the number of drivers must be increased by around 21% by 2030. At the same time, 4,000 to 6,000 skilled workers will retire every year, and there is already a shortage of 20,000 professional drivers, forcing PTOs to reduce routes and services.[27]

Furthermore, costs in public transport are set to rise significantly in the coming years. As an example, based on our experience from various projects, weexpect an approximate increase of 40% of operation costs for electric buses (with drivers) between 2025 and 2040 due to inflation and higher wages.

Can shared autonomous vehicles (SAVs) in public transport help solve these problems? Will SAVs make public transportation cheaper? How high are the upfront investments? How high are the running costs for monitoring, etc.? Can public transportation subsidies be reduced? In order to answer these questions, we applied the business case modelling tool to a given German city.

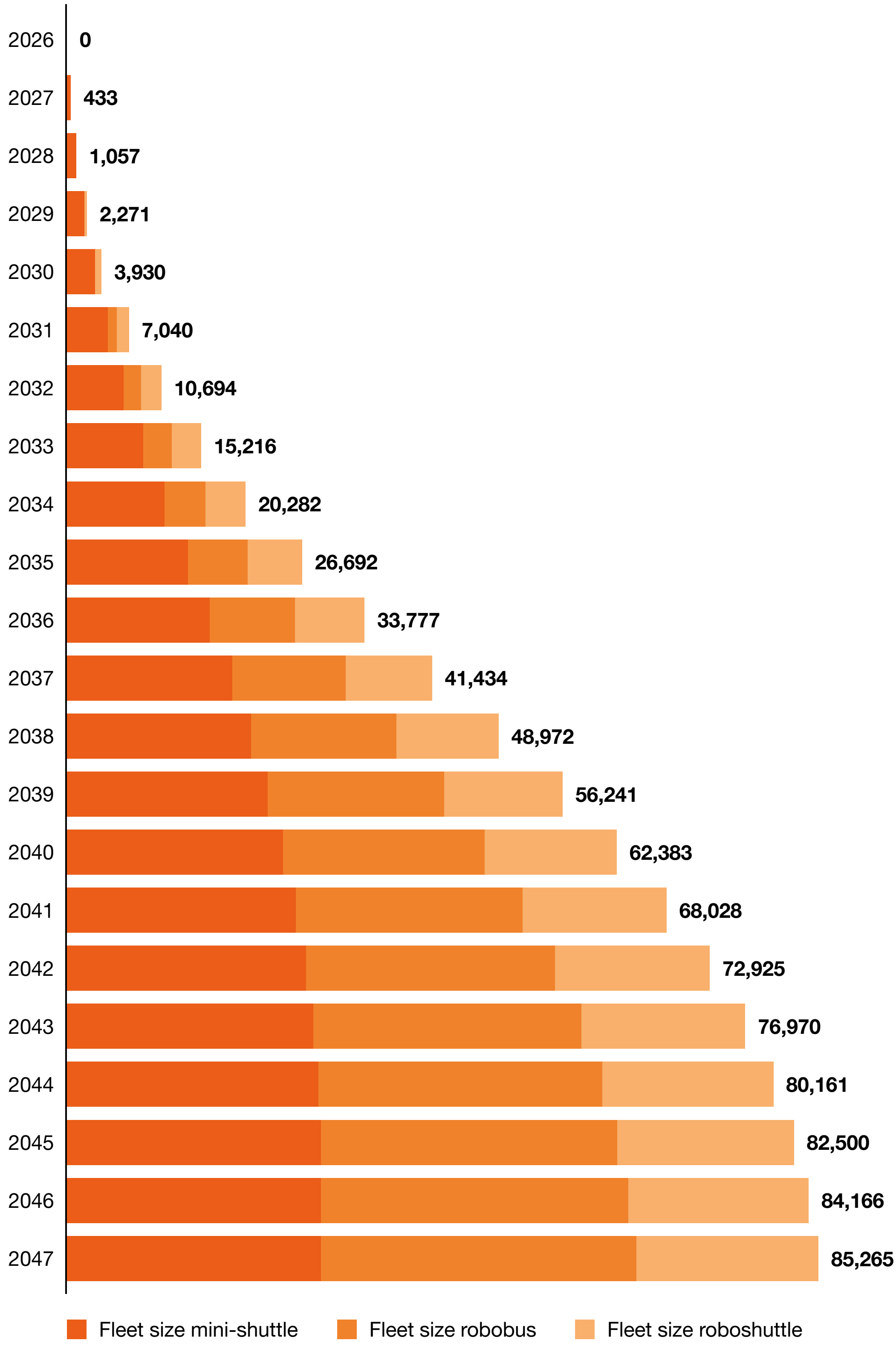
Assumptions

The scenarios examined are based on the current demand structures of Germany with 15.02 billion passenger kilometres in cities and 30.42 billion passenger kilometres in regional transport (PwC analysis). In addition, we anticipated a 10% expansion of services in cities and a 20% expansion in rural areas, in line with the overall goal of improving service levels. We have made the following assumptions for modelling the Germany case study:

- Ramp-up of various types of autonomous vehicles between 2027 and 2031 to reach 75% of demand volumes between 2045 and 2047.
- Use of different vehicle sizes:
  - Robobus with 60 passengers
  - Roboshuttle with a maximum of 16 passengers
  - Mini-shuttle (similar to a robotaxi) for up to four passengers for peripheral districts and less frequented, as feeder or on-demand service. During off-peak hours, mini-shuttles can also be used as robotaxis.
- Average mileage of each vehicle type including empty drives, determined according to Figure 11:
  - Robobus: approximately 64,000 km/year at 992,000 passenger km/year
  - Roboshuttle: approximately 60,000 km/year at 262,000 passenger km/year
  - Mini-shuttle: 85,500 km/year at 51,000 passenger km/year

Based on the goal to cover 75% of today's demand with buses and 10% improved services in cities and 20% in rural areas, we assume that at least 20,687 roboshuttles, 35,755 robobuses and 28,823 mini-shuttles will be deployed in German cities by 2047 (see Figure 12).

Fig. 12 Vehicle fleet ramp-up (replacements of SAVs due to age or mileage are not shown in the graph)



Source: PwC analysis.

When calculating the business cases for the various players, we also considered the fact that economies of scale will lead to considerable savings on components and vehicles in the long term. Inflation factors and interest rates were also considered in the model. The model therefore represents a greenfield approach based on input parameters underlying possible scenarios. On this basis we determined the investment requirements for all players and for permanent capacity expansion.

AD/SAV-specific investments

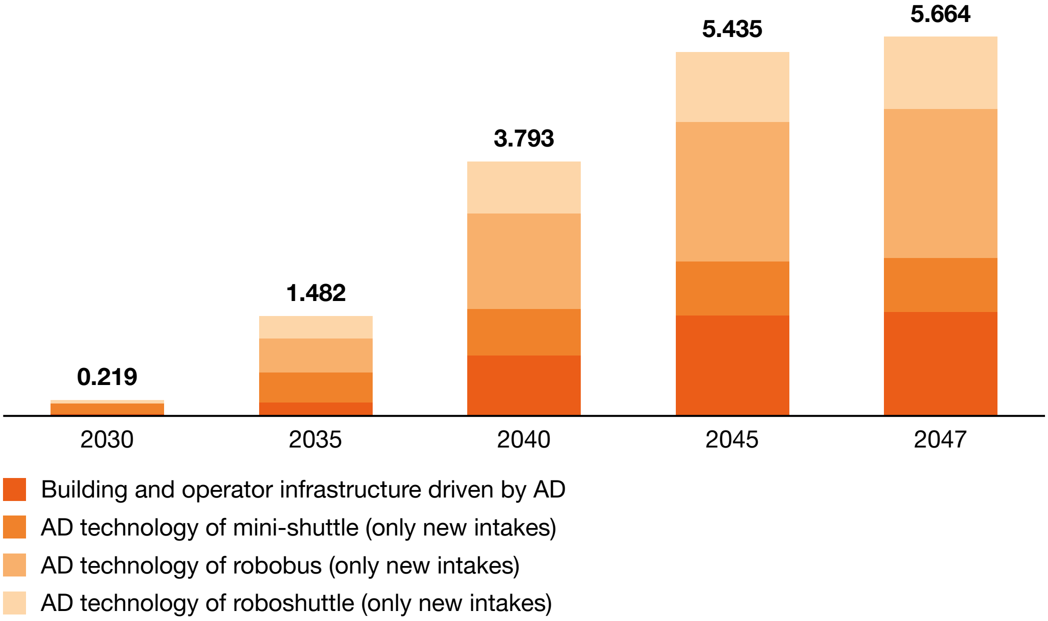
The following investments were considered for the calculation of cumulated AD-driven investments for Germany:

- Vehicle technology: AD tech stack for SAVs (AD sensors, AD main computing unit, and AD software)
- Building and operator infrastructure: additional space required in the depots due to more vehicles (robobuses with 60 passengers versus articulated bus with a maximum capacity of 170 passengers), additional roboshuttles and mini-shuttles, space required for new functions to control the SAV fleet, and additional software needed for monitoring and management of the SAV fleet

The share of the AD investments in the total investment required to run the public transport vehicle fleet autonomously is approximately 15% for a city bus (60 passengers). In our model, only these additional investments were taken into account. Any investments for the vehicles as such and general urban infrastructure (roads, telecoms, etc.) are excluded from our analysis.

A projection of investments for Germany results in a total investment of approximately €5.66 billion by 2047 for 75% of the bus fleet (see Figure 13).

Fig. 13 Cumulated AD-driven investments for Germany (PT-centric case) in € billion



Source: PwC analysis.

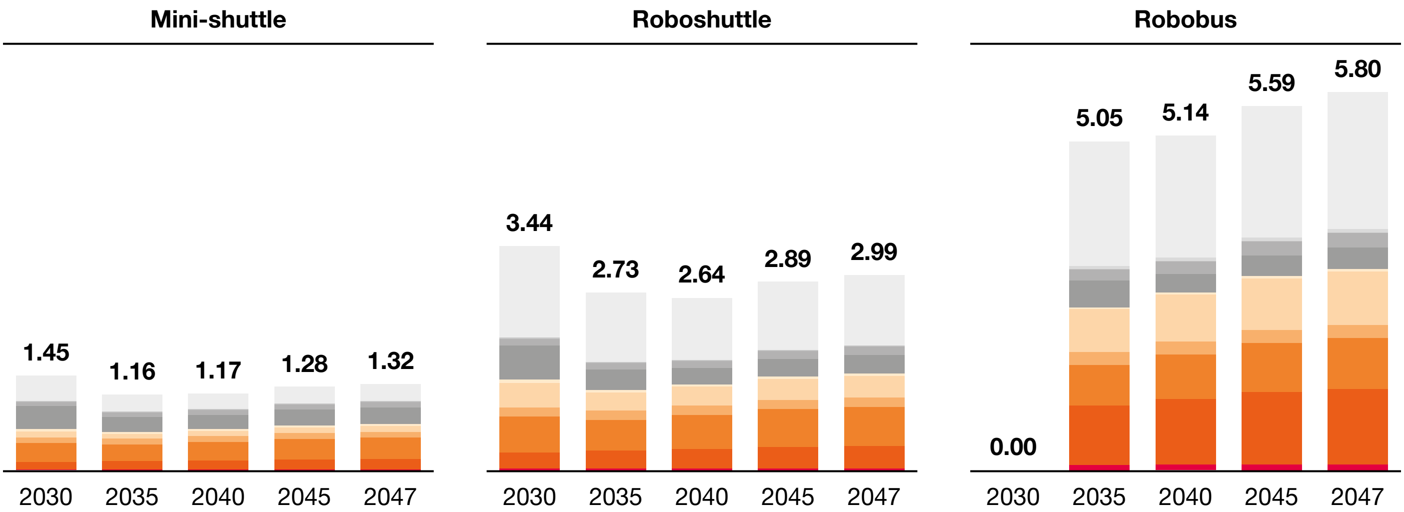
In the light of these high investments, the question arises as to which players will enter the leasing and operator businesses. In addition to the established providers like public transport operators, tech companies or even automotive OEMs might enter the market to bring their vehicles to market with economies of scale.

The advantage for tech companies is that they can easily transfer their acquired know-how to other public transportation systems with similar structures and processes, and at very low implementation costs. Furthermore, not every public transport company will want to operate the business, and supra-regional standardisation driven by a global tech player will bring additional potential in the long term.

Results of the analysis

Our analysis shows that operating costs will develop differently over time for the three vehicle types. The total cost of the vehicles will decrease with the second and third generations, as we expect a reduced sensor setup over time and competition among AD stack providers will also drive down running costs. In addition to vehicle costs, the costs for the digital driver and vehicle monitoring are the main drivers in the use of the vehicles.

Fig. 14 Expected cost per productive kilometre (in €/km)



Payment and booking
Energy costs
Digital driver
Vehicle tax/insurance
Maintenance/repair
Administration and marketing
Deployment and vehicle supervision
Vehicle preparation
Fleet management
Infrastructure/building
Vehicle cost

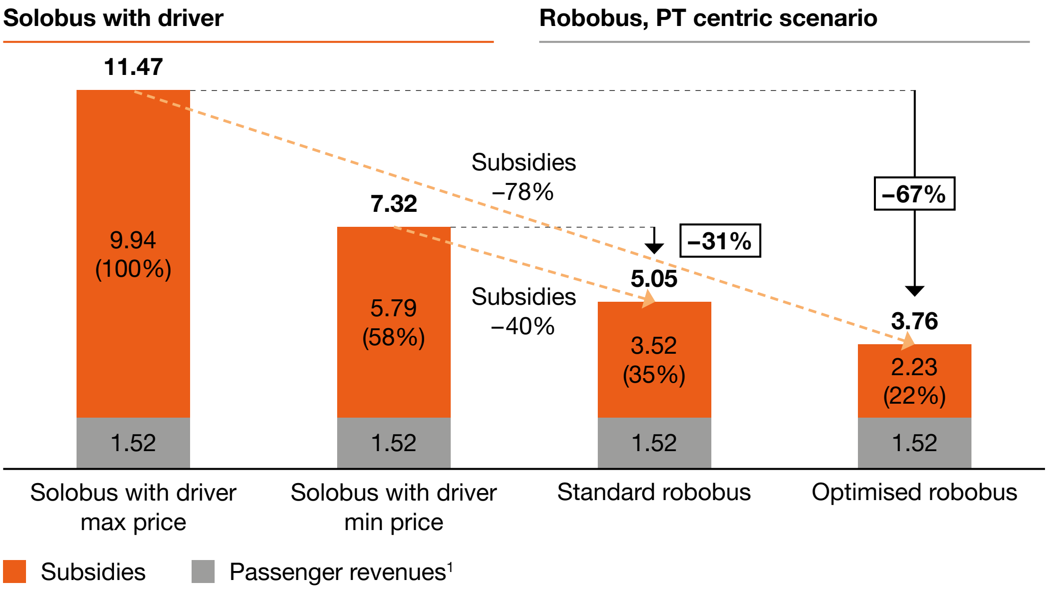
Source: PwC analysis.

Based on the numbers in Figure 14, we expect further optimization of the vehicles to result in significant additional cost reductions, which will be reflected in the commercial vehicle kilometre costs. The main lever here is the elimination of the driver's workplace, including the display, pedals, mirrors, and steering wheel. This also simplifies the overall design of the vehicle and reduces costs.

Are these cost structures attractive for public transport operators or private players? Public transport is currently financed by revenues from ticket sales, which are usually insufficient, and subsidies to cover the remainder of the costs. With an average ticket revenue of €0.11 per passenger kilometre (PwC evaluation), an average vehicle utilisation rate of 22.7%, and 10% empty trips, the revenue per passenger kilometre for solo buses is around €1.52 in 2035. Consequently, the subsidies are often many times higher than the actual ticket price. In fact, less than 50% of the cost of a bus kilometre is currently covered by ticket revenues owing to the implementation of the flat-rate "Deutschland-Ticket", among other reasons.

With autonomous vehicles, higher capacity utilisation, and optimised standard vehicles, subsidies could be reduced to less than 60% of ticket revenue. This would at least ease the burden on the public purse to cover the cost for public transport. Ancillary revenues could possibly also be achieved with additional on-demand services, which may lead to a further reduction in subsidies.

Fig. 15 Cost comparison and subsidies required to equalise the cost for the solobus with driver and robobus by 2035 (in €/km)



[1] Passenger revenue: average price per km 0.11 €/passenger km, average allocation of vehicle 28.7%, empty drives 10%.

Source: PwC analysis.

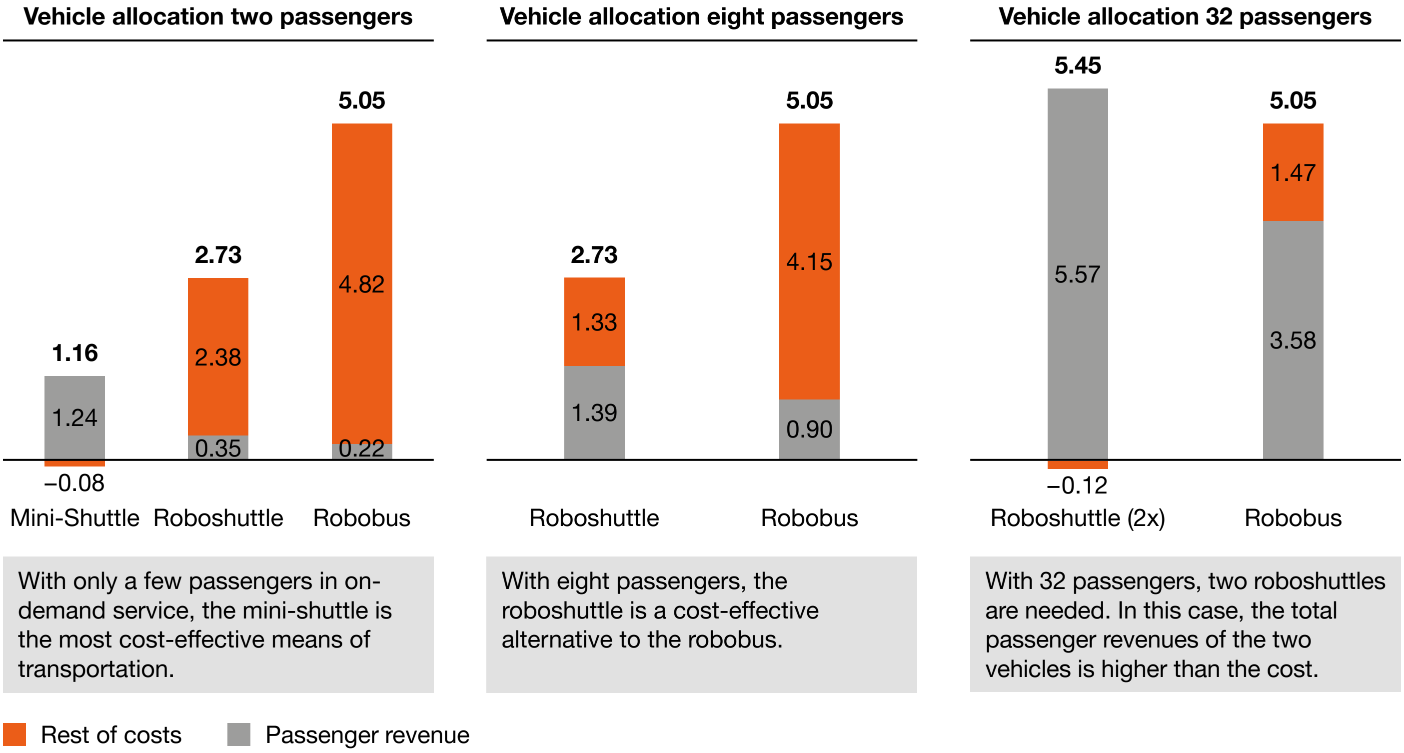
Annual ticket revenue will amount to approximately €6.2 billion in 2050 for mid-level utilisation and 75% of vehicles will be replaced by SAVs with 10% (city) to 20% (regional) improved mobility services.

In vehicle operations, further potential can be tapped by improving utilisation and optimising the dynamic deployment of different vehicle types. However, this will also increase the costs for "large" vehicles that are not used as intensively.

By choosing the right vehicle type and different pricing for the services, an on-demand service with a mini shuttle for two passengers can be used to cover costs, for example, instead of maintaining a regular service with a roboshuttle or robobus. For eight passengers, for example, a shuttle service to the city limits can be provided more cheaply with a roboshuttle. In this example, however, it was assumed that a small surcharge would be charged for these services. With 32 passengers, the choice of the best vehicle type depends on the fares. With higher fares, it may be possible to cover costs with two roboshuttles running at half the frequency instead of using a robobus.

In conclusion, the choice of the best means of transport depends on the fare and the vehicle's capacity utilisation on the route.

Fig. 16 Vehicle costs per kilometre in 2035 depending on the number of passengers for different vehicles using the PT-centric configuration (in €/km)



Assumptions 2035: Passenger revenue mini-shuttle 0.62 €/km / roboshuttle 0.17 €/km / robobus 0.11 €/km

Source: PwC analysis.

Capabilities of incumbents and new entrants

For today's public transport, a future scenario with SAVs is imperative. It will help solve the driver shortage problem, reduce subsidies, and ease congestion on roads in German cities.

Public transport operators will continue to play a key role. Whether a contractor in the form of a private (tech) player, an integrated SAV mobility solution, a lean PT operator, or a global PT-centric player itself gets involved will largely depend on their capabilities and whether the mobility mandate can be adequately met with an external partner and what dependencies and control options arise for the municipality as a result.

Fig. 17 Capabilities of various SAV ecosystem players

Aspect	PT-centric	Private (tech) player	SAV manufactureras integrated SAV mobility solution	Global public transport provider (PT-centric)
Invest in vehicles	– –	+	+	++
Scaling effects AD stack	–	++	+	o
Rollout/implementation cost	–	+	o	+
Funding	–	+	o	+
Scaling effects in operation	o	+	–	++
Customer services	++	o	o	+
Collaboration with municipality	++	–	o	+

Evaluation:
++ very good + good o sufficient – not sufficient – – not acceptable

Source: PwC analysis.

From a qualitative perspective, the private (tech) player and the global PT-centric player – a merger of several transport associations – have a high right-to-win. The individual public transport operator may lack the economies of scale to offer mobility services at appropriate prices. This means that transport associations, since they are not in competition with each other, may join forces and adopt common standards and jointly purchase vehicles and infrastructure, but manage operations locally themselves. The tech player will probably have little interest in the business, as the public sector would certainly not want to pay more subsidies than necessary that will result in lower margins.

Conclusions

We see the following conclusions from the model and the analysis of the figures:

- In the long term, the use of SAVs will definitely cost less than transport services with a driver today. In 2035, we expect costs to be 31% to 67% lower for a robobus compared to an electric solobus with driver.
- SAVs can reduce public transport subsidies to a certain extent, but not eliminate them completely. Robobuses, for example, can bring subsidies down by 40% to 78% by 2035.
- Cost effects over time due to a higher integration of the technology will ensure greater savings in the long term compared to the current operating costs of the vehicles.
- Through the dynamic use of different vehicle sizes, new services can be offered as a supplement, such as on-demand services to transport people from the outskirts to inner-city areas, or to offer cost-effective coverage of passenger transport during off-peak times.
- However, operating only small vehicles with a higher frequency in order to improve the service will make no sense as smaller vehicle types generate higher costs per kilometre.
- Instead of drivers, new personnel will be needed for the management and monitoring of the SAV system. While approximately one to two employees (drivers) can be saved per vehicle, it is estimated that half an employee per vehicle will be needed across all functions of the SAV ecosystem in 2035. Still, SAVs will be economically advantageous compared to conventional buses in the long run.
- In the medium term, we expect an increase in mobility convenience and thus an expansion of local public transport as a result of:
  - increasing the frequency of public transport,
  - demand-oriented services for e.g. outlying districts and off-peak times, and
  - seamless integration into mobility services and ultimately Mobility-as-a-Service.

Shared autonomous mobility should not be a city-by-city play. If the operation of SAVs comes from a single source across many cities, a high degree of standardisation in technology, implementation, and operation – and thus cost savings – can be achieved. Transport associations may consider collaborating to implement a standardised mass-produced SAV, a standardised procedure for the rollout, and uniform systems for the operation of SAVs.

Rollout of robotaxis in Germany

Robotaxis today

Taxis are an important means of transportation for individual mobility, especially in places where public transport does or does not run at a particular time. In Germany, there are around 55,000 taxis[28] in operation. There is also an increasing shortage of drivers in the taxi industry,[29] which is mainly due to their age structure. An ageing pool of taxi drivers and a lack of interest from younger generations in becoming taxi drivers has accelerated the decline. The industry simply cannot keep up with the number of drivers retiring or seeking new careers. On top of the driver shortage, the traditional taxi business faces soaring operating costs and competition from new entrants like Uber, rental car companies – and robotaxis.

Robotaxis could indeed be a game-changer. They have not arrived in German cities yet but we know from promising pilot projects in other parts of the world that robotaxis can be operated safely, with no need for drivers, at lower costs, and for longer operating times.

Fig. 18 Different ways to play in the robotaxi ecosystem

	Supply		Operate		Fulfil demand	
	Manufacture SAV		Own SAV fleet / Service SAV fleet	Schedule / Operate SAVs	Book and pay / Offer mobility services	Marketing
	Vehicle	AD-stack/SAV				
Waymo San Francisco	Jaguar Land Rover	Waymo	Waymo		Waymo	
Uber Austin/TX	Jaguar Land Rover	Waymo	Waymo		Uber	
AVRide Dallas/TX	Common vehicle development: Hyndai	AVRide	No commercial operation		No commercial operation	
ZOOX	ZOOX	ZOOX, NVIDIA	No commercial operation		No commercial operation	
Robotaxi Plan	Tesla	Tesla	Commercial operation via Tesla		Commercial operation via Tesla	
WeRide Switzerland	Nissan	WeRide	Swiss Transit Lab	WeRide	Ioki	Swiss Transit Lab
WeRide Suadi-Arabia	GAC Motor	WeRide	WeRide		Uber	Abu Dhabi Mobility
Pony.ai China	Toyota Lexus	Pony.ai NVIDIA	Pony.ai		Pony.ai	
VW CV/ Moia ADMT	VW CV; Apex.ai	Mobileye; Apex.ai	MOIA		MOIA	

Source: Strategy& analysis.

When it comes to robotaxis, there are already a variety of ecosystem configurations. Given the complex set of required capabilities (as discussed in Chapter 3), robotaxi fleets are often put on the road through strategic partnerships. Waymo is a provider of a robotaxi services, but it also offers its vehicles to Uber to market the service on their platform. Both solutions currently use conventional-style passenger cars. Zoox wants to offer a complete solution that includes both the vehicle and the AD stack. Hyundai is working with AVRide to achieve a similar integrated solution. Tesla also wants to offer everything from a single source at a sensationally low price, thereby triggering the mass market for autonomous driving. The recently announced strategic partnership of Volkswagen ADMT, MOIA, and Uber is another example of collaboration in the SAV ecosystem.[30]

In the long run, another business model may evolve in which private individuals offer their own autonomous vehicles as robotaxis during unused periods. Today, this would violate the existing regulation for awarding taxi licenses, but it could be an interesting model for optimising vehicle utilisation.

Assumptions

In the next section, we will analyse which business case scenarios make sense when rolling out robotaxis to cover 80% of the current taxi fleet, i.e. 44,000 vehicles by 2047 in Germany.

We examined the following three business case scenarios:

- Case 1 – robotaxi business case with solution provider: customer care provided by the taxi operator/taxi centre and operations subcontracted to a mobility service provider
- Case 2 – robotaxi business case with lean taxi provider: a taxi service operated by a purchased complete solution and customer care provided by the taxi operator/taxi centre
- Case 3 – robotaxi business case with tech player: taxi service from a single source provided by a private (tech) player

All cases were calculated with a taxi fleet of 1,000 vehicles to simulate a taxi service in a larger city. The ramp-up of the vehicles will take place by 2033.

We also assume that different taxi services will differ in their choice of vehicle, equipment, and comfort. We have illustrated the costs for a larger cab business using three different vehicle classes:

- Standard robotaxi in the range of €28,000 to €42,000 for the base vehicle
- Luxury robotaxi in the range of €40,000 to €56,000 for the base vehicle
- Low-cost robotaxi in the range of €18,000 to €26,000 for the base vehicle

The base price of the vehicle does not include the AD stack and other vehicle modifications, such as a drive-by-wire system. The cost reduction over time results from the omission of the steering wheel, pedals, controls, and cockpit, as well as better technology integration over time, which will also lead to a reduction in base costs. The integration of technology will be completed in the second or third generation of robotaxis. After that, we expect costs to increase again.

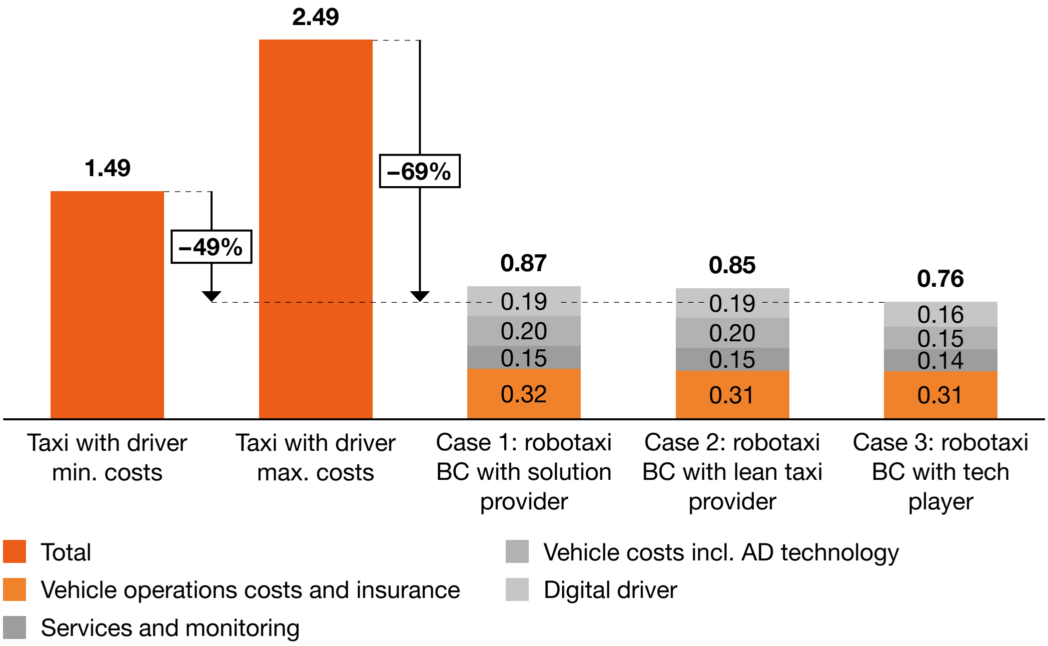
Results of the analysis

Our analysis shows that all three business cases offer clear cost advantages compared to a driver-operated taxi. Business case 3 (tech player) leads to a reduction of total costs between 49% and 69% (see figure 19).

Since technology companies consider the sale of the AD stack to be their main business, there will not only be Case 3. We are currently seeing several variants of Case 3 in the form of mergers between tech players and taxi service providers, such as UBER. The tech player controls everything related to technology and technical operations, while the taxi service provider knows the customers and their requirements better, resulting in a win-win situation.

Fig. 19 Minimum and maximum cost of a taxi with driver in 2035 in comparison with different robotaxi business case scenarios[1] (in €/km)

Robotaxi



BC = Business Case

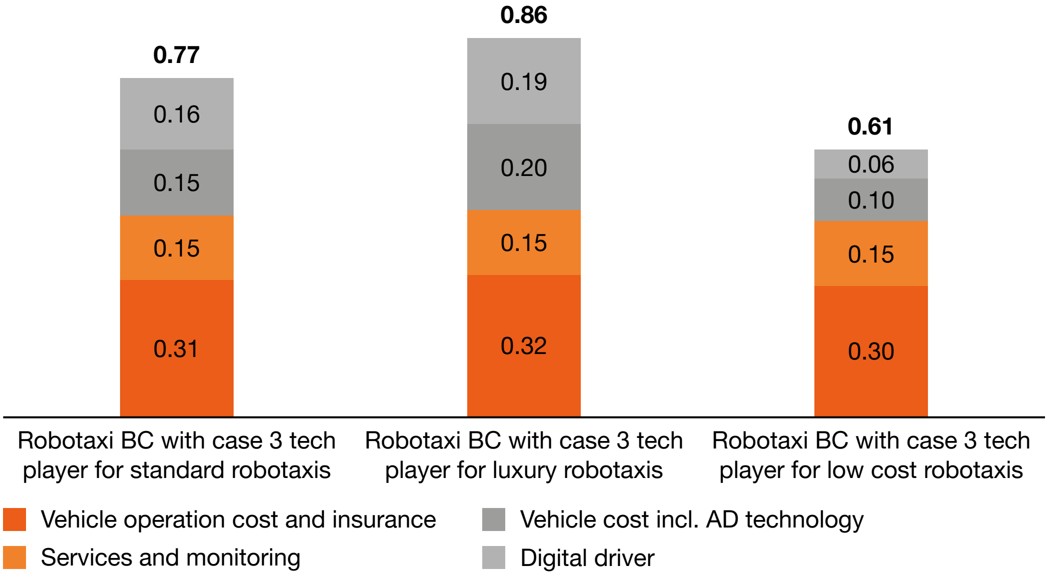
[1] Scenario with 1,000 standard robotaxis.

Source: PwC analysis.

By using different categories of vehicles, ranging from economy to luxury, we can meet customers' diverse needs. This also means costs will vary depending on the vehicle category and the vehicle's country of origin, as shown in Figure 20.

Fig. 20 Cost per kilometre in 2035 for different robotaxi types[1] for business case 3: robotaxi (tech) player (in €/km)

Robotaxi



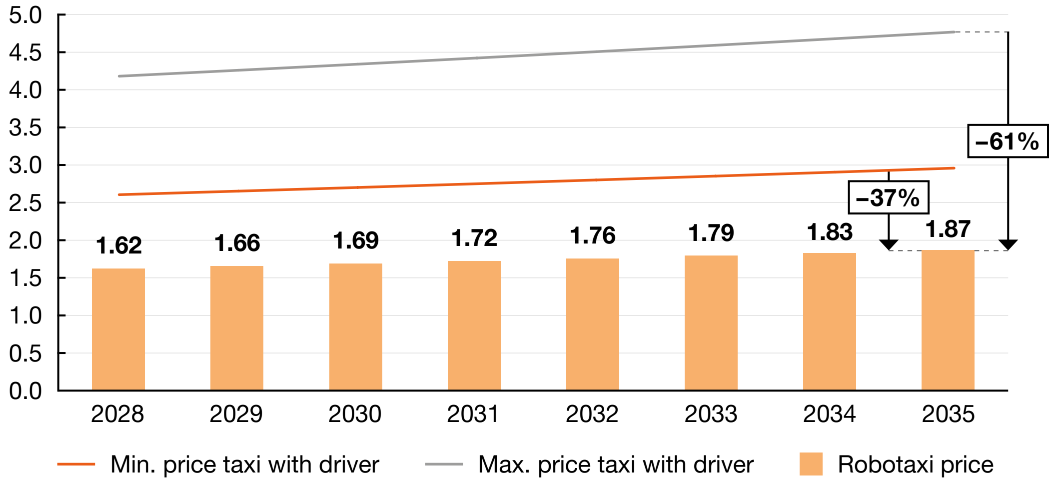
[1] Scenario with 1,000 standard robotaxis.

Source: PwC analysis.

The price per kilometre for robotaxis can be significantly lower than the minimum prices for taxis with drivers thanks to lower operating and maintenance costs. We expect prices to be approximately 37% to 61% lower than the projected prices for taxis with drivers in 2035 (see Figure 21). This price development also makes mobility attractive for individual trips.

The taxi prices were calculated based on the basic price + the kilometre costs on the basis of a 6 km route in German cities. Values were calculated as minimum and maximum values and projected with 2% inflation per year to the following years.

Fig. 21 Average price per taxi kilometre in Germany compared with robotaxi prices (in €/km)



Comments

- The passenger prices will increase according to inflation by 2% per year in the future
- This price advantage will make mobility affordable for many older people and make doctor's visits easier, for example.
- Due to the very low prices, the market must be regulated so that not too many people use the robotaxi as a means of transport instead of the robobus.

Source: PwC analysis.

Conclusions

Without a doubt, robotaxis will revolutionise the taxi business. They will help solve the driver shortage problem, offer maximum privacy for passengers, and can be operated 24/7. On top of these benefits, our analysis has shown that passengers can expect lower prices compared to a traditional taxi with driver.

Implementation in German cities will not be successful by itself but will depend on several factors:

- **Collaboration:** Due to the complex set of required capabilities, several players should be involved rather than one single operator.
- **Orchestration:** An orchestrator is needed to connect the many tasks and service providers with each other.
- **Economies of scale:** These can be generated through large robotaxi fleets.
- **Established providers:** Providers should be established in several cities and have the required infrastructure in place to ensure a rapid rollout.
- **Digitalisation:** Booking and payment processes should be fully digitized via MaaS apps for passengers. A taxi centre will only be used to handle irregularities and complaints.
- **Integration:** Robotaxis should be complementary to existing public transport offerings.

The latter of these success factors will require constructive cooperation between public transport authorities and private operators. This is because the cost advantage of robotaxis also carries a risk: affordable prices could make robotaxis accessible to broader segments of the population. While this is a positive aspect in terms of social participation, it could lead to an undesirable shift in mobility from public transport to robotaxis. This could result in buses, subways, and commuter trains running less full, coupled with even more congested roads.

Therefore, we expect the robotaxi market to be regulated via licenses awarded by district, municipal, or city administrations. They will have the power to strike a good balance between supply and demand and thereby direct people’s mobility behaviour.

Taking these considerations into account, two directions for operating a robotaxi business seem to emerge:

- The robotaxi services will require professional services for emergency assistance, vehicle monitoring, and ensuring technical safety. Professional services from a single source will result in the lowest costs while providing comprehensive service. Local support for vehicles could be provided by rental car companies, for example, which could offer vehicle charging, cleaning, and possibly minor maintenance work. A taxi centre will probably not be needed in this scenario due to fully digitised booking, payment, etc.
- Based on these results, there is a strong case for a small number of service providers offering a one-stop shop, perhaps even with a nationwide service. This argues very much in favour of large providers that can handle such vehicle volumes and services cost-effectively. Rental car companies, public transport operators, and even large taxi companies such as Uber are potential candidates for operating the robotaxi fleets.

The road ahead for autonomous mobility

Autonomous mobility will be a reality on European streets and roads. Our calculations prove the cost advantage of shared autonomous vehicles compared to driver-operated mobility services today.

Moreover, it can be assumed that technology developments and business optimisation will lead to further savings, especially through

- the assumption of monitoring tasks by artificial intelligence
- better or fully automated systems for vehicle scheduling and routing
- cooperation with external service providers who take on some of the operator's tasks, e.g. emergency management
- bundling of vehicle procurement with standardized vehicle types
- defining a common and uniform software platform for fleet management and monitoring of autonomous vehicles
- developing a concept for a uniform rollout from vehicle procurement to implementation of software systems

Beyond the economics, SAVs have the potential to solve the driver shortage problem and significantly enhance the service level of public and private mobility offerings. SAVs will make public transport more efficient, reliable, affordable, and sustainable in the long run.

Investments in new technologies are crucial to drive the transition to shared autonomous mobility forward, so that the ever-increasing shortage of drivers can be circumvented while continuing to expand local public transport

It is time to act now. All players in the mobility ecosystem must do their part to make shared autonomous mobility a reality. And so, we call upon

1.

… public transport operators:

- Actively shape the change – SAVs must become an integral part of the future public transport offering.
- No more federal nit-picking – there is a need for focused thinking and collaboration.
- Further expand public transport services, especially on-demand services in rural areas
- Establish partnerships with other public transport providers and tackle digitalisation together.

2.

… automotive OEMs:

- Don’t slow down now – market maturity is within reach.
- Define your strategy to become part of autonomous mobility and secure future business.
- Turn innovations into marketable products now.

3.

… political decision-makers:

- Consider SAVs as a lever for digitalisation, the mobility transformation, and climate protection.
- Create a clear perspective and vision for the future use of SAVs as an essential component of mobility systems.
- Consider launching a -European initiative for the development and deployment of SAVs. Following the example of Airbus, this would allow resources and capabilities to be pooled, international standards to be created, and economies of scale to be exploited in a pan-European market.
- Provide subsidies and funding from the public sector as the initial implementation costs for SAV services are high and the individual European markets are relatively small, compared to the US and China.
- Support innovation projects to accelerate implementation.

Ultimately, the future of autonomous mobility in Europe will depend on private and public sector players acting in concert. Through the establishment of public and private partnerships they can pool resources share the financial burden and reduce the financial risk for individual stakeholders while accelerating development and deployment. Care is needed when balancing interests of the public and the pursuit of profitability. However, speed is just as important to catch up with providers from other regions. The race is on.

Appendix

Abbreviations

AV	Autonomous vehicle
CapEx	Capital expenditures
CRM	Customer relationship management
GPS	Global Positioning System
HSG	University of St. Gallen
IMO-HSG	Institute for Mobility, University of St. Gallen
L4	Level 4 autonomous driving
MRO	Maintenance, repair and operations
ODD	Operational design domain
OEM	Original equipment manufacturer
OpEx	Operational expenditures
PPP	Public-private partnership
PT	Public transport
PTA	Public transport authority
PTO	Public transport operator
SAV	Shared autonomous vehicle

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