In collaboration with
Boston Consulting Group

WORLD ECONOMIC FORUM

Autonomous Vehicles:
Timeline and Roadmap Ahead

WHITE PAPER

APRIL 2025

Images: Getty Images

Contents

Foreword

Jeremy Jurgens
Managing Director,
World Economic Forum

Nikolaus Lang
Managing Director
and Senior Partner,
Boston Consulting Group

Over thousands of years transport has always connected people and expanded their access to opportunities, consistently growing economies and advancing societies. Within that ongoing evolution, autonomous vehicles (AVs) represent one of transport's most anticipated developments, offering the potential to improve road safety, enhance logistics and enable new mobility services. There are, however, significant technological, regulatory and operational challenges to realizing those benefits. AVs must also be carefully integrated into existing transport ecosystems as mixed traffic conditions will create complexities for years to come.

It is crucial that the sector's stakeholders can base informed decisions on realistic expectations, yet predictions about the deployment timeline for autonomous vehicles have tended to be overly optimistic. While vehicle automation technology has advanced considerably, its large-scale integration will take longer than most have anticipated. This white paper aims to provide a more grounded perspective on the adoption timeline, addressing three key use cases of vehicle autonomy between 2025 and 2035: personal vehicles, robotaxis and autonomous trucks. It strives to answer some of the key questions of policymakers, business leaders and the public about these evolving technologies.

The timeline for adopting these innovations has wide societal implications beyond transport planning, and addressing these challenges at an early stage is essential to a successful rollout. For example, many workers may struggle to adapt to changing job requirements. An accurate timeline can help decision-makers better prepare workforce reskilling programmes. Data privacy and cybersecurity must also be prioritized; autonomous vehicles gather vast amounts of real-time and, to some extent, sensitive data, about what is happening in the vehicle and its surroundings. Equitable access to vehicle automation technology is critical, too: AV development must enable more holistic and inclusive mobility systems instead of exacerbating existing transport inequalities.

Widespread adoption of autonomous vehicles will remain slow, but the decisions made today will shape how this technology integrates into society tomorrow. Governments, industry leaders and civil society need to collaborate to ensure that societal needs are met and that autonomous vehicles contribute to a more efficient, sustainable and inclusive mobility landscape.

Executive summary

Autonomous vehicles: Scaling for impact while addressing remaining challenges.

Early deployments of autonomous vehicles are already on the roads. However, it is becoming apparent that large-scale rollout will be slower than once anticipated. While previous and even some current forecasts state that autonomous vehicles will be widely adopted during the 2020s, the analyses of this white paper suggest mainstream deployment will be slower than that given the many challenges and inherent technological, regulatory and economic complexities.

Despite this, the rationale for AV adoption remains compelling, driven by substantial potential benefits including enhanced safety, improved efficiency and lower costs. This white paper provides a refined forecast for deployment and identifies key remaining gaps and actions for accelerating that deployment safely. It explores three main use cases: personal vehicles, robotaxis and autonomous trucks. The key insights on each of these are as follows:

- While personal vehicles will progressively transition toward higher levels of automation, L2 and L2+ systems will dominate this use case for the next decade due to their cost-effectiveness and regulatory readiness. L3 adoption will remain limited due to safety risks, liability concerns and high costs, and L4 deployment will be niche during this timeframe: only around 4% of new personal cars sold by 2035 are expected to feature L4 capabilities. China is forecast to adopt L2+ and L3/L4 vehicles most quickly, driven by strong consumer demand, a regulatory push and an ecosystem that encourages innovation. (See Box 1 for an explanation of the levels of automation.)

- Robotaxis have already demonstrated technological feasibility, with large-scale deployments running in selected US and Chinese cities. However, the high costs of software development, infrastructure set-up and scaling continue to slow deployment. By 2035, robotaxis are likely to be present in large numbers across 40 to 80 cities globally, mostly in China and the United States. Until at least 2030, Europe is expected to remain cautious about the rollout of robotaxis. Europe is likely to prioritize small, controlled pilots and focus on integrating roboshuttles with public transport systems instead. Large-scale robotaxi (and roboshuttle) deployments will lead to modal shifts, affecting not only taxi and traditional ride-hailing but also personal car and public transport use.

- Autonomous trucking presents a strong case for autonomy. Compared to traditional trucking, it introduces a new value proposition that goes beyond advantages in efficiency and total cost of ownership. Several companies have started commercial operations, and 2025 is expected to be an important year for autonomous trucking deployments. Among the different use-cases, hub-to-hub trucking has the most promise for automation. The United States is expected to lead adoption for this use case: it is projected that autonomous trucks will account for up to 30% of new truck sales in the US by 2035. In Europe, international borders pose challenges for long-haul applications, and China's weaker cost benefits may limit deployment unless policy interventions accelerate progress.

The forecasts in this white paper aim to account for expected developments. However, technological breakthroughs, such as the successful deployment of map-free and vision-only L3/L4 systems, or massive additional funding injections could significantly accelerate adoption beyond these projections.

To further speed up the deployment of vehicle autonomy, the industry needs to keep working on five different fronts. First, bring the public on board by communicating consistent messages and building consumer trust. Second, continue leveraging advances in technology, including AI and cybersecurity breakthroughs, to tackle the current shortcoming surrounding safety, usability and scalability. Third, develop sustainable business models that foster long-term viability. Fourth, co-create regulations to help policymakers better understand the progress and readiness of vehicle automation technology. And, finally, collaborate within and across industries to better facilitate large-scale deployments.

Introduction

Autonomous vehicles move beyond initial hype and disillusionment towards real-world deployment.

This white paper aims to shed light on the evolving vehicle autonomy timeline between now and 2035.

Until very recently, forecasts stated that autonomous vehicles would be everywhere in the 2020s. However, it is now evident that technological, regulatory and economic challenges mean adoption will happen more gradually.

Despite the difficulties, the rationale for AVs remains strong, driven by potential safety and efficiency benefits, among others. Road safety remains one of the most pressing concerns in global transport, and advanced driver assistance and autonomous driving (ADAS/AD) could help reduce the 1.2 million road fatalities that occur each year.[1] The many efficiency gains include achieving higher vehicle utilization rates through reduced idle time and maximized vehicle loads. These advantages apply to both passenger transport, through ride pooling, and goods transport, through optimized freight movement. Better transport options may also spur a shift away from personal vehicle dependence, leading to a more sustainable mobility system.

This white paper aims to shed light on the evolving vehicle autonomy timeline between now and 2035 across three key use cases: personal vehicles, robotaxis and autonomous trucks (see Figure 1). Special-purpose vehicles operating in enclosed facilities, such as those for mining or agriculture, are also highly suited for automation but fall outside of the scope of this white paper.

The forecasts developed here are based on analysis grounded in five key dimensions:

1. Consumer trust and interest
2. Projected ADAS/AD prices and consumers' willingness to pay
3. Technological obstacles and the timeframe for overcoming them
4. Current regulatory status and anticipated regulatory developments
5. Ecosystem developments to support scaling

While the first two dimensions help determine the potential demand, the last three concern the potential supply. These dimensions also form the basis of the actions outlined in this paper to safely scale vehicle autonomy.

The forecasts in this white paper aim to account for expected progress. However, technological breakthroughs, such as the successful deployment of map-free and vision-only L3/L4 systems, or massive additional funding injections could significantly accelerate adoption beyond these projections.

FIGURE 1 **Comparative overview of the four main vehicle autonomy segments**

	Focus of this whitepaper			
	Personal vehicles	**Robotaxis and roboshuttles**	**Autonomous trucks**	**Special purpose autonomous vehicles**
Expected benefits	– Increase road safety by reducing human error – Enhance convenience during travel	– Enhance the flexibility of public transport – Reduce operational costs and improve accessibility	– Address critical driver shortages – Increase efficiency and flexibility with 24/7 uptime	– Improve safety in hazardous environments – Enhance efficiency for specialized tasks
Ownership	Privately owned or leased	Fleet providers own and operate	Fleet providers own and operate	Specialist firms own and operate
Tech level*	Gradual development from ADAS (L0-L2+) to AD (L3/L4)	Autonomy-first system development (L4)	Autonomy-first system development (L4)	Autonomy-first system development (L4)
Domain	Highway, suburban and urban	Suburban and urban	Highway and suburban	Special environments

*See Box 1 for more information on technology levels.

BOX 1 | **Definition of ADAS/AD levels**

Vehicle automation is classified into different levels that differentiate the extent of automation, the driver's involvement and where the respective system can be used – the so-called operational design domain (ODD). This classification reflects the technological progress and helps ensure clarity about the technology's capabilities and liability.

To make the technological differences even clearer, the levels are further subdivided according to the driver's required activities, namely whether it is required to hold the steering wheel in their hands, keep their eyes on the road or focus their mind on the driving environment (e.g., whether sleeping is allowed).

Level 4 is the first level considered autonomous. That is, where the driver has no driving tasks in the operating design domain specified. For L4 in private vehicles, this white paper differentiates between L4 Highway and L4 Urban, since, due to the greater complexities of urban areas, AD capabilities are expected to become commonplace sooner in highway settings.

Six levels of ADAS/AD systems

		Explanation	Sample features	Hands-on	Eyes-on	Mind-on
Assisted	L0 Manual	– Safety warnings or temporary assistance – Driver retains all driving tasks	– Automatic emergency braking – Lane departure warning			
	L1 Assisted driving	– Steering OR speed control by the system – Driver remains hands-on and eyes-on	– Adaptive cruise control (ACC) – Lane-keeping assist system (LKAS)			
	L2 Partially automated driving	– Steering AND speed control by the system – Driver remains hands-on and eyes-on	– Coupled ACC & LKAS			
	L2+/++ Advanced partially automated driving	– Steering AND speed control by the system – Driver remains eyes-on	– Navigate on Autopilot (NOA) **Driver must be able to immediately take full control whenever requested**			
Automated	L3 Automated driving under conditions	– System drives under pre-defined conditions – Driver needs to step in within ~10 seconds upon system request	– Traffic jam pilot – Valet parking **Critical change: liability switches from the driver to the system**			
Autonomous	L4 Autonomous driving under conditions	– System drives under pre-defined conditions – No take-over by the driver is required (within the ODD)	– Autonomous driving in approved ODDs **Can differentiate between L4 Highway and L4 Urban, due to their different complexities**			
	L5 Autonomous driving in all conditions	– System drives in all conditions – No take-over by the driver is required	– Ubiquitous autonomous driving			

Driver System

Source: Authors, adapted from the six levels of vehicle automation defined in SAE J3016.[2]

1 Assisted, automated and autonomous personal vehicles

Private ADAS/AD adoption is an evolution, with partially automated vehicles, not autonomous vehicles, dominating the next decade.

4%

Only 4% of new personal vehicles sold in 2035 are expected to feature L4 capabilities.

Personal vehicles represent the largest AV market segment by volume. This means that automation advances in this area are crucial for improving road safety and enhancing travel convenience. However, vehicle automation in personal vehicles is an incremental evolution rather than a disruptive revolution. While many projections have long stated driverless vehicles are imminent, this white paper finds that, over the next decade, personal vehicles will benefit primarily from advanced assistance features rather than autonomy. Detailed expectations for the uptake of each level between 2023 and 2035 are shown in Figure 2. As well as personal cars, Figure 2 also shows the share of L4 robotaxis (more on robotaxis in the next chapter).

Forecasts for the uptake of each automation level

Assisted driving technologies, particularly at L2 and L2+ levels, are expected to be the most dominant technologies in new cars sold in 2030 and beyond. This is due to broad market availability, low regulatory hurdles and lower system costs than for L3/L4. As a result, drivers of most new cars will still be required to keep their hands on the steering wheel and their eyes on the road long after 2035. The transition from L2 to L2+ will also be gradual, with L2 systems staying more popular during the upcoming decade. This is primarily due to cost constraints: while L2 systems are currently available for less than $700, L2+ systems can cost up to $3,000.

L3 vehicles – where liability moves from the driver to the system, yet the driver still needs to be able to regain control in a short timeframe if required – will remain a transitional offering rather than a long-term solution (aside from specific use cases such as valet parking or traffic jams). There are four key constraints limiting the widespread adoption of L3 vehicles that are also beyond the timeline considered in this whitepaper:

1. Safety risks: at L3, drivers are required to retake control within around 10 seconds, creating potential safety concerns in real-world conditions.

2. Liability concerns: the shift from driver responsibility to OEM liability, with the related issue of determining who was driving, makes manufacturers hesitant to scale L3 in public environments.

3. High costs: L3 requires a similar tech stack to L4, leading to nearly identical system costs that typically range from $7,000 to $10,000.

4. Limited value: consumers might expect full autonomy, but they are not allowed to fully disengage as they may be required to take over quickly.

For these reasons, many OEMs continue to prioritize L2/L2+ advancements over L3, meaning that by 2035 and potentially beyond, L3 vehicles will still constitute only a small fraction of sales.

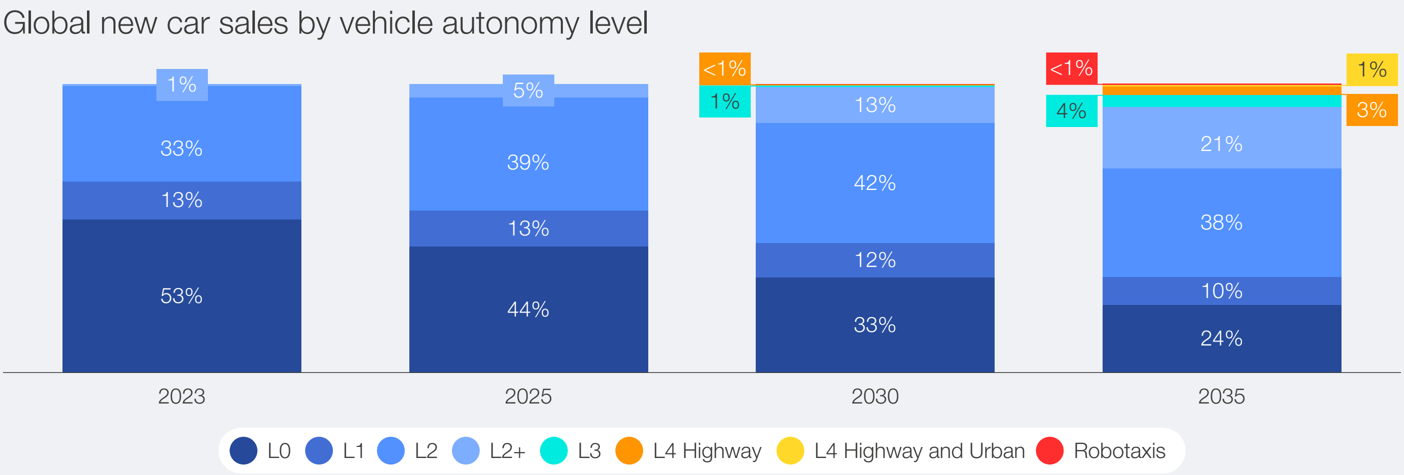
For personal vehicles, L4 autonomy remains significantly constrained by both technical and regulatory barriers. At L4, if the vehicle operates within its defined ODD, the driver is entirely uninvolved, and the vehicle can bring itself to a safe stop if required. Only 4% of vehicles sold in 2035 are expected to feature L4 capabilities, reflecting the slow and selective deployment of true autonomous technology in this arena. In addition, given the additional operational challenges in urban settings, some of these capabilities will only be available for highway environments. Furthermore, in urban settings, fleet-based models, such as robotaxi services, may prevail over private ownership in the longer term.

Finally, there are still expected to be a significant number of new vehicles with L0 and L1 technologies by 2035. The features of these technologies are also becoming increasingly commoditized, with many countries mandating basic safety features, such as lane-keeping assistance and automatic emergency braking. L1 systems, however, struggle to deliver a compelling value proposition: they are a similar cost to L2 systems but offer significantly less functionality. As such, much of the L0 market share is projected to shift directly to L2 over time, bypassing L1 systems altogether.

Supplementing the data represented in Figure 2, Figure 3 summarizes the sensitivity analysis carried out across the five key dimensions underlying the forecast. Technological progress, driven by possible breakthroughs in AI (see Box 2), sensors and computing power, offers the strongest potential for accelerating the rollout of AVs. Yet even if this technology leap was fully realized, L4 technologies would still only be present in a modest 7.5% of new car sales by 2035. In terms of the limits to uptake, the risk of unfavourable regulation is likely to be the biggest barrier. Such regulations could be enacted if major, negative incidents involving L4 technologies occurred, thereby underlining the importance of industry collaboration to ensure the safety of these technologies.

> **Data, together with breakthroughs in E2E AI and scalable software, are integral factors to fast-track vehicle autonomy and enable global deployment.**
>
> Bernd Schmaul, Chief Digital Officer, Bosch Mobility

FIGURE 2 **Passenger car ADAS/AD forecast**



Note: Some of the totals do not sum to 100% due to rounding.

FIGURE 3 **Sensitivity analysis of the passenger car forecast**

	Dimension	Major factors that could influence L4 car sales by 2035	Percentage point change of L4 new car sales by 2035 from the base scenario of 4% (see Figure 2)
Demand	Consumer trust and interest	**Easy-to-use deployments** with positive media coverage increase demand	+1.0
		High-profile accidents negatively impact public trust	-2.0
	Pricing and willingness to pay	**Intense competition** (incl. price wars) drives availability of cost-efficient solutions	+0.5
		Prices remain high due to component shortages and non-scalable solutions	-1.0
Supply	Technological maturity	**Technological breakthroughs** enable earlier, more scalable L4 deployments	+3.5
		Key **ODDs remain unresolved,** and scalability continues to be limited	-3.0
	Regulatory developments	**Governments support** AVs for technological leadership, safety and efficiency	+1.5
		Regulators limit deployment due to major incidents	-3.5
	Ecosystem readiness	**AV solutions scale globally** across automakers, standardizing tech	+2.0
		Poor coordination and weak business cases hinder progress	-2.0

BOX 2 What do advances in AI mean for vehicle automation?

AI and generative AI (GenAI) are becoming integral to vehicle automation technology. They are transforming decision-making, model training and human-machine collaboration, particularly across three key areas:[3]

1. End-to-end (E2E) AI models are replacing traditional rule-based systems that struggle to handle real-world driving complexity. By combining perception, prediction and planning into a single neural network, E2E AI enables faster learning and better responses across a variety of environments. While historically criticized for a lack of transparency, recent innovation is making these E2E AI models more interpretable and verifiable, resolving safety concerns and increasing industry adoption.

2. By creating synthetic data, GenAI plays a key role in training autonomous systems. Real-world data collection is costly and inexhaustive, whereas simulations using GenAI create more diverse, scalable datasets that can expose models to unusual driving scenarios. This allows autonomous systems to learn from millions of simulated miles, improving their ability to handle edge cases, such as sudden obstacles or extreme weather. However, real-world validation remains essential to ensure robustness and safety.

3. AI is strengthening human-machine collaboration through enhanced driver monitoring systems (DMS) and human-machine interfaces (HMI). DMS use AI to track driver attention, fatigue and stress, triggering alerts or intervening to prevent accidents. GenAI helps improve vehicle interfaces, enabling more intuitive voice commands and adaptive controls that minimize distractions. Moreover, by leveraging GenAI, systems become more capable of explaining their decisions, improving the user's understanding.

Regional adoption differences

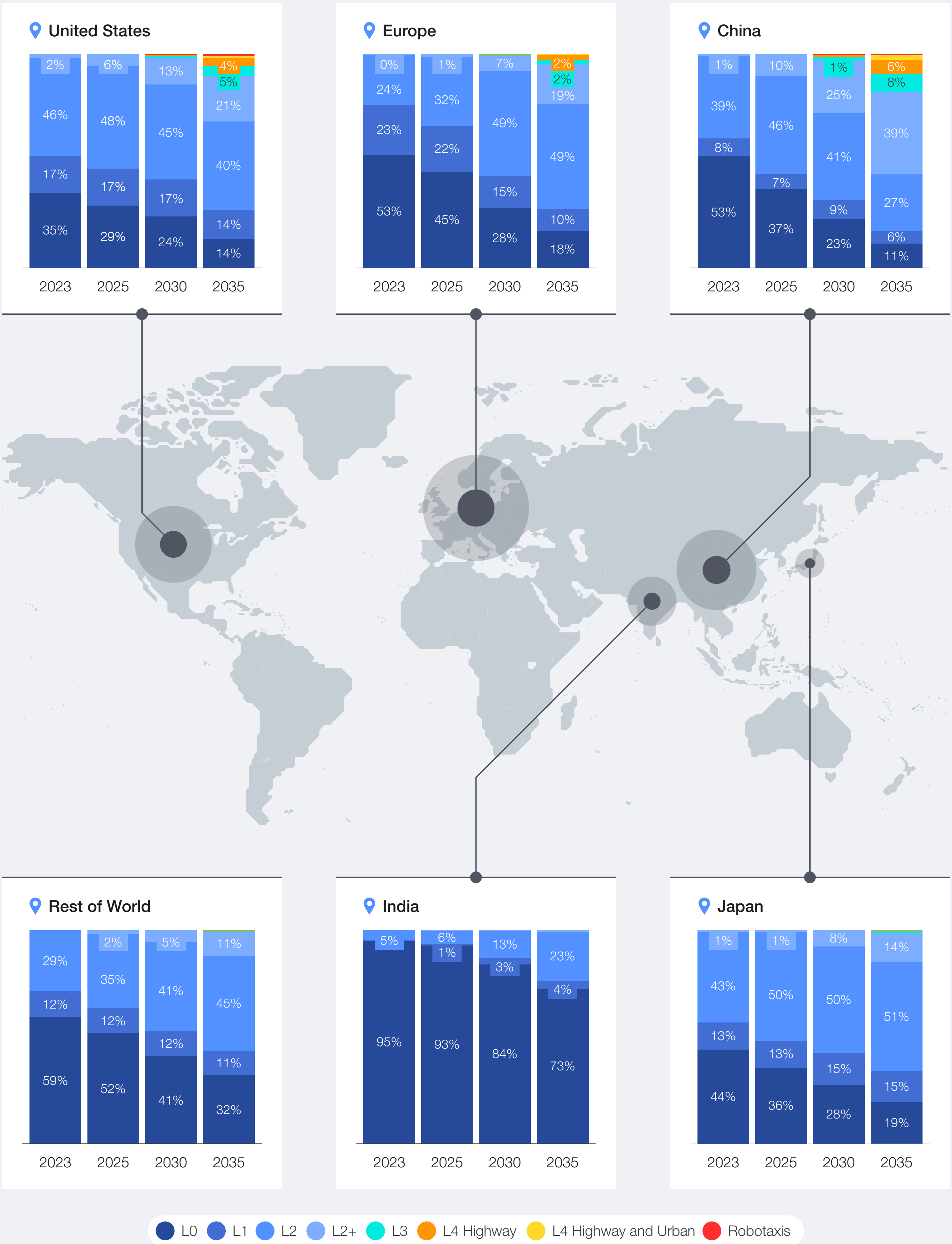
As Figure 4 demonstrates, personal vehicle automation will be adopted at different rates around the world. The shift is expected to be led by China followed by the United States, with Europe and Japan likely to follow a similar yet slower trajectory over the coming decade. In terms of L2+ adoption, the share of new car sales in 2035 is expected to be significantly greater in China than any other major territory. This is caused, in part, by the willingness of Chinese customers to embrace automation and domestic OEMs and suppliers' rapid advances in automation. China is also expected to have slightly higher shares of L3 and L4 vehicles than other geographies in 2035 – the US and Europe being the only other two markets where these technologies will start to appear in privately owned passenger cars by 2035.

Beyond these four key markets, the rest of the world follows a mixed trajectory, with some regions steadily adopting L2 and L2+ systems while others face economic, technological and regulatory hurdles that will slow the transition to higher ADAS/AD levels. Figure 4 also highlights the example of India, which follows a somewhat different trajectory to the other highlighted markets. In India, L0 systems are forecasted to still dominate in 2035 due to lower purchasing power and more complex road environments. India is also expected to leapfrog L1 and move more directly to L2 as this technology matures.

> **Autonomous driving transforms cars into living spaces. ADAS/AD systems must be accessible across all regions and segments, enhancing safety and user-centric in-vehicle experiences for everyone.**
>
> Gürcan Karakas, CEO, TOGG

FIGURE 4 | **Passenger car ADAS/AD forecast by region**

New car sales by vehicle autonomy level



2 Robotaxis and roboshuttles

Deployments in the United States and China are ongoing, but scaling will take time, both here and elsewhere.

Taking into account the array of potential outcomes and adoption speeds, fleets of robotaxis are expected to operate at large scale in 40 to 80 cities by 2035.

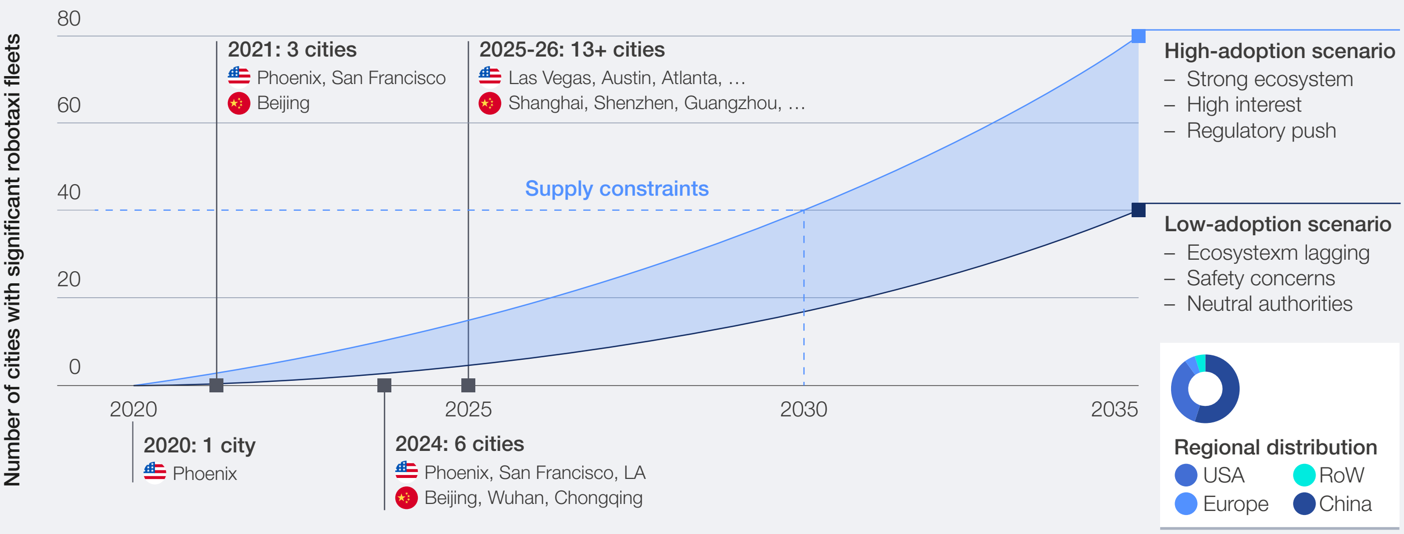
Robotaxis and roboshuttles have the potential to revolutionize urban mobility. The ongoing large-scale deployments of autonomous taxis have proved self-driving fleets to be technologically feasible: in the United States, robotaxi firms have completed millions of paid rides without safety drivers, and Chinese firms have deployed hundreds of robotaxis in cities such as Wuhan. However, scaling these operations remains a significant challenge due to city-specific regulatory approvals, variations in driving environments and other operational complexities. In addition, the investment and operations required are fundamentally different from personal vehicle ADAS/AD, prompting several leading OEMs to exit the space and refocus on ADAS/AD exclusively. While both robotaxis and roboshuttles share many of the previously discussed benefits and challenges, the forecasts in this white paper focus solely on robotaxis as they are expected to be more widely deployed over the coming decade.

Taking into account the array of potential outcomes and adoption speeds, fleets of robotaxis are expected to operate at large scale in 40 to 80 cities by 2035 (see Figure 5). Entering and expanding a city market requires such substantial time and investment that it will constrain supply until at least 2030.

The high cost of technology is another major barrier. Developing the right AI algorithms demands billions in R&D, while mapping and adapting software for each city's unique driving environment adds complexity. Ensuring safety and reliability through the use of expensive systems such as lidar (light detection and ranging) sensors ratchets up the costs even further. Scaling fleets also demands extensive physical infrastructure, including depots, maintenance hubs and high-speed connectivity. Operators must establish systems to clean, maintain and charge hundreds or thousands of vehicles daily, all of which build out the expenditure and slow down the speed to market.

Expansion is expected to vary considerably across regions. Based on current trajectories, it is no surprise that China and the United States are forecasted to dominate the deployment of robotaxis in cities. Europe is expected to be the next biggest market, but these deployments are likely to have a stronger focus on roboshuttles that complement public transport networks. The Middle East is also emerging as an early adopter, but the number of cities suitable for mass deployment remains limited at present.

FIGURE 5 **Robotaxi forecast showing number of cities with large-scale operations**



Source: Boston Consulting Group.

Without proactive regulatory frameworks, the widespread deployment of robotaxis could lead to increased congestion and inefficient fleet utilization.

Introducing robotaxis to urban areas may significantly impact citizens' choice of transportation. Modal shifts are likely to go beyond changes in the use of traditional taxi and ride-hailing services to also impact public transport and private car use. This may have a knock-on effect for private vehicle ownership. Robotaxis' overall impact on transportation capacity will depend heavily on whether they are used for shared or private rides. If they primarily serve single riders, empty miles will increase, lowering vehicle utilization and contributing to congestion. In turn, this would reduce overall transportation efficiency. If robotaxis are not properly integrated with existing public transport, the effect will deepen as they will begin to 'cannibalize' the public network – a previous World Economic Forum publication already showed this by modelling the potential impact for the US city of Boston.[4]

Currently, most robotaxi operators do not incorporate shared rides into their business models. This underscores the need for thoughtful policy measures that align autonomous mobility with cities' transportation and sustainability goals. Without proactive regulatory frameworks, the widespread deployment of robotaxis could lead to increased congestion and inefficient fleet utilization, undermining some of the major benefits autonomous mobility aims to deliver.

Ecosystem readiness

Scaling robotaxis requires more than simply manufacturing greater numbers of autonomous vehicles. Success depends on a complex ecosystem of stakeholders, spanning production, operations and usage. The main tasks – some of which remain as-yet substantially unfulfilled – for the various stakeholders are outlined in Table 1.

The first set of stakeholders identified are the OEMs and autonomous driving tech companies producing autonomous robotaxis. OEMs must provide vehicles tailored for robotaxi use, and this requires transforming software-defined vehicles with new electrical/electronic (E/E) architectures. Meanwhile, AD tech companies must ensure reliable safety across ODDs and regions while also making their technology both scalable and affordable.

For the enabling stakeholders, the successful deployment of robotaxis requires strong availability of funding for R&D, regulatory alignment across geographies, and insurance models. Insurance companies play a crucial role here, and they will need to redefine their risk assessment models and liability frameworks – a highly complex task hindered by scarce data and the potential for many unknown risks.

A number of stakeholders must collaborate closely for robotaxi operations to be implemented smoothly. Cities and utilities can contribute by providing dedicated charging stations, pick-up/drop-off zones and easily accessible maintenance depots. These efforts should be coordinated with fleet management firms, many of which are still in the early stages of development. The role of fleet control becomes increasingly important for a safe operating environment. Fleet operators must establish advanced control centres to monitor and optimize vehicle uptime, safety and performance. Many of the tasks for fleet management and control are still being defined, creating opportunities for ambitious new players to enter the ecosystem.

Finally, the role of the end user as a key stakeholder cannot be underplayed. The long-term success of robotaxis hinges on user adoption and, ideally, integration into public transit networks for more efficient and sustainable usage. Large-scale education campaigns on the capabilities and limitations of robotaxis are crucial for building public trust and increasing road safety.

TABLE 1 | **Robotaxi ecosystem stakeholder mapping and remaining gaps**

Limited gaps Major gaps

	Role/Stakeholders	Tasks	At current trajectory, what is missing for scaling by 2030?
Production	**Vehicles** Original equipment manufacturers (OEMs)	Develop and produce vehicles tailored for robotaxi usage	– Successful transformation to software-defined vehicles (SDVs) including new electrical/electronic (E/E) architecture
	AD tech Hardware and software suppliers	Develop AD software and hardware customized to local needs	– Reliable safety performance across ODDs and regions – Easily scalable and affordable software
Enablers	**Funding** Venture capitalists, strategic investors, public-private partnerships	Provide funding for R&D and scaling	– Secured funding for improving tech and scaling operations
	Regulation Governments, authorities	Set regulation and homologation standards, provide licences, set zones	– Harmonized regulation across cities and countries
	Insurance Insurance, risk analytics, reinsurance	Develop risk assessment models and policies	– Large-scale data availability for robust risk models and policies
Operations	**Infrastructure** Utilities, cities	Provide charging, vehicle-to everything (V2X) communication, pick-up zones; integrate in-traffic control	– Dedicated inner-city robotaxi infrastructure (lanes, kerb spaces) – Integration in traffic management systems
	Fleet management OEMs, suppliers, ride-hailing, fleet management	Handle fleets and maintenance, determine service areas	– Defined task distribution among OEMs, platforms, fleet management – Scalable fleet management frameworks
	Fleet control OEMs, suppliers, ride-hailing, fleet management	Manage safety backup drivers, monitor fleet performance	– Defined task distribution among OEMs, platforms, fleet management – Dedicated fleet control centres with specialized staff
	Platform Ride-hailing and Mobility as a Service (MaaS) platforms	Integrate robotaxis into platforms, ensure smooth interactions and support	– Defined customer journey and smooth processes – Integration with fleet management and control providers
Usage	**Education** Public groups, media, universities	Educate on safety and benefits, advocate for equitable access	– Large-scale education on capabilities and limitations – Analysis of societal benefit of large-scale fleets
	Customer B2B and B2C end users	Use robotaxis, engage in feedback loops	– Trust to share streets with robotaxis as well as use them

3 Autonomous trucks

There is a clear business case for autonomous trucking.

The development of autonomous trucks is at a pivotal point, with extensive testing and early commercial deployments underway in the United States and China. These vehicles promise to transform logistics. The economic case for them is strong, driven by efficiency gains from 24/7 operations, lower total cost of ownership and their ability to resolve driver shortage problems. However, challenges remain before they can be widely adopted. These include ensuring the technology is reliable in all road conditions, securing funding to scale operations, navigating complex regulations and integrating the trucks into existing supply chains.

Autonomous truck deployments on public roads can be categorized according to five distinct use cases, each at different stages of technological, regulatory and infrastructural readiness:

1. Long-haul hub-to-hub

2. Mid-distance hub-to-hub

3. Mid-distance point-to-point

4. Intra-city distribution

5. Operations in closed environments

These use cases and their suitability for vehicle autonomy are described in Figure 6.

For operations on public roads, the fixed routes of hub-to-hub operations are strong candidates for autonomous truck deployments. At the other end of the spectrum, intra-city distribution remains a far bigger challenge as the driver needs to take care of many related tasks, such as loading and unloading, that cannot be easily automated. The key difference between long-haul and mid-distance hub-to-hub use cases is the greater need for additional infrastructure, such as charging stations, in the former. If autonomous trucks continue using internal combustion engines, long-haul deployment could outpace mid-distance in the coming years.

Closed-environment operations, such as those in construction sites, mines, farms or ports, are best suited to autonomous truck deployments because of their controlled conditions and repetitive tasks They are also less impacted by regulatory and ecosystem constraints. However, this white paper focuses on use cases on public roads, so this scenario is not considered further here.

As shown by Figure 7, the US is expected to lead the adoption of autonomous vehicle deployments on public roads, particularly with regard to long-haul and mid-distance hub-to-hub routes. This leadership is driven by strong total cost of ownership (TCO) benefits and a pressing need to address driver shortages. These routes will experience the highest growth, with autonomous trucks expected to make up nearly 30% of new truck sales for mid-distance hub-to-hub routes by 2035, driven by fixed highway routes that enable autonomous driving.

> **Autonomous trucking is more than an evolution - it creates a new value proposition, redefining how goods are transported across supply chains.**
>
> Nils Jäger, President, Autonomous Solutions, Volvo Group

Europe will also reap strong TCO benefits from long-haul and mid-distance hub-to-hub use cases. However, estimates suggest slower adoption in Europe due to cross-border regulatory hurdles and more complex operational environments. A pan-European approach is key if the continent is to rapidly scale these long-haul operations. However, mid-distance hub-to-hub autonomous trucks could make up around 26% of new truck sales by 2035.

China is projected to follow a slower adoption pathway, mainly due to lower TCO benefits and higher upfront investment compared to conventional options. Government support could speed up the Chinese trajectory, enabling deployment to match or even outpace Western growth rates.

FIGURE 6

Autonomous trucking use cases

Anticipated readiness by 2035

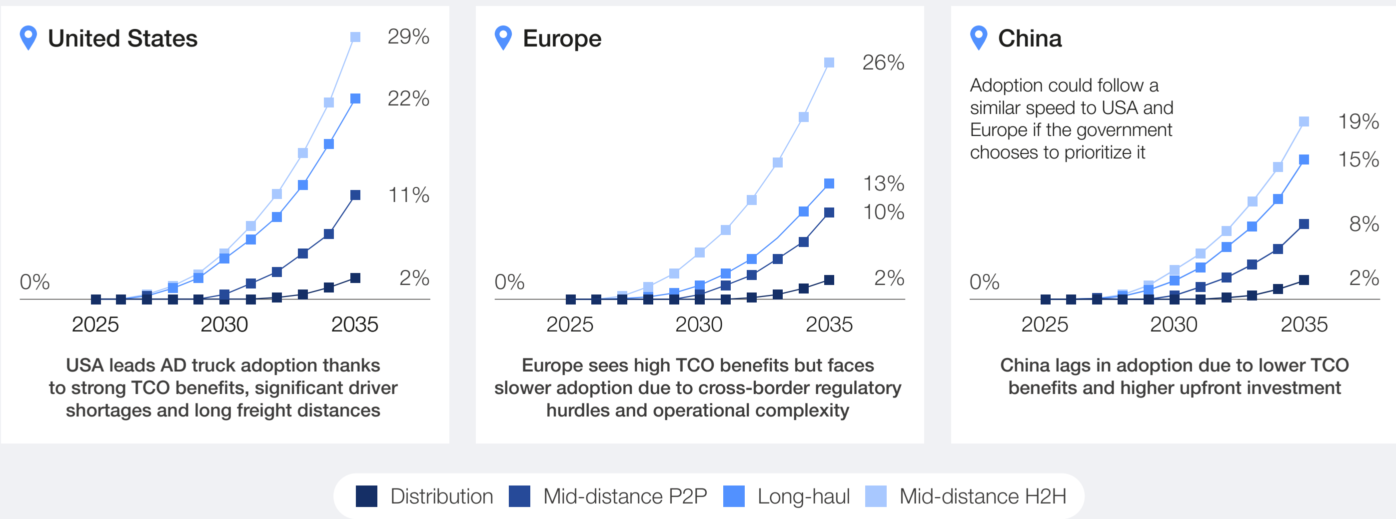
Use cases	Technology	Regulation	Infrastructure	Rationale
Long-haul hub-to-hub				– Fixed routes along highways align with L4 strengths – Regulation is focused on main highway routes – High-volume corridors need to be upgraded to enable AV operations
Mid-distance hub-to-hub				– Less infrastructure needed than for long-haul (when transitioning away from internal combustion engines in line with sustainability objectives) – Shorter routes are easier to regulate and equip for AD
Mid-distance point-to-point				– Route variability strongly increases technological complexity – Similar regulatory needs as for mid-distance hub-to-hub use case – Infrastructure upgrades are more demanding than for hub-to-hub
Intra-city distribution				– Tech readiness is largely dependent on progress of light vehicles – Likelihood of risk of failure causing human harm will slow regulation – Complex environments with many road users challenge developments
Closed environment				– Autonomy is best suited to controlled environments and repetitive tasks – Limited potential for human harm reduces the demand for regulation – The operating area is restricted, widely mapped and monitored

Deployable without limitations · Partially deployable · Deployment not possible

FIGURE 7

Autonomous trucking deployment forecast for the four use cases operating on public roads

Expected share of autonomous trucks in new sales for 2025-2035 by region and use case



Source: Boston Consulting Group.

> From a customer perspective, the transition to autonomous freight transport presents clear TCO advantages and eliminates many operational inefficiencies.

Ecosystem readiness

As with robotaxis, the entire ecosystem – not only OEMs and AD tech companies – must prepare for large-scale autonomous truck deployments. Table 2 presents the main roles and tasks that are required to enable this by 2030.

There are clear parallels between the production and enabling roles for both autonomous trucking and robotaxis. However, trucking benefits from lower operational complexity (especially in hub-to-hub use cases) and a clearer return on investment. Mass deployment still relies on OEMs and tech providers developing dedicated E/E architectures, ensuring reliable safety across ODDs and providing scalable, cost-effective software, but strong investor commitment, harmonized regulations and robust insurance models are essential, too.

Operationally, autonomous trucking will introduce new stakeholders and redefine traditional roles, requiring coordinated efforts across the value chain to ensure adoption is seamless and efficient. For example, fleet management firms need to set up remote monitoring and emergency response mechanisms as existing legal requirements, such as placing a warning triangle behind a broken-down truck, pose challenges for fully autonomous operations. Transport operators will also need to upgrade warehouse yards and upskill their workforces to integrate autonomous trucks effectively.

Digital platforms will also need to evolve as multiple stakeholders enter the market. These platforms must provide unified solutions that support multi-OEM fleets and define roles clearly. Additionally, infrastructure investment will play a part in scaling autonomous trucks even though these vehicles are not strictly dependent on dedicated infrastructure.

From a customer perspective, the transition to autonomous freight transport presents clear TCO advantages and eliminates many operational inefficiencies. Strong demand is expected as soon as the technical and regulatory frameworks are established.

TABLE 2 | **Autonomous trucks ecosystem stakeholder mapping and remaining gaps**

Ready to scale / Limited gaps / Major gaps

	Role/Stakeholders	Tasks	At current trajectory, what is missing for scaling by 2030?
Production	**Vehicles** OEMs	Develop and produce vehicles tailored for autonomous usage	– Autonomous trucks with respective E/E architecture
Production	**AD tech** Hardware and software suppliers	Develop AD software and hardware customized to local needs	– Reliable safety performance across ODDs and regions – Easily scalable and affordable software
Enablers	**Funding** Venture capitalists, strategic investors	Provide funding for R&D	– Strong commitment across investors to investment case
Enablers	**Regulation** Governments, authorities	Set regulation and homologation standards, provide licences, set zones	– Harmonized regulation across cities and countries
Enablers	**Insurance** Insurance, risk analytics, reinsurance	Develop risk assessment models and policies	– Large-scale data availability for robust risk models and policies
Operations	**Infrastructure** Utilities, cities	Charging, V2X, integration in traffic control	– Dedicated infrastructure for charging and V2X communication – Integration in traffic management systems
Operations	**Asset ownership** OEMs, leasing firms, 3PLs*, fleet operators, cargo owners	Own trucks, leasing to operators or self-operate	– Defined role and sales model (price/km, price/kg, etc.) – Ensured 24/7 uptime to leverage TCO benefits
Operations	**Fleet management** OEMs, AD suppliers, fleet operators, 3PLs	Control tower, (remote) maintenance, repairs	– Establish control tower (alerts, remote driving, etc.) processes – Facilities and staff along routes for emergency response
Operations	**Transport operator** Fleet operators, 3PLs, cargo owners	Warehouse network, unloading/loading, load pre-check	– Widely upgraded warehouse yards and loading docks – Upskilled workforce and processes for handling autonomous trucks
Operations	**Digital platform** Freight platforms, AD suppliers, TMS firms**	Load matching, route optimization, fleet management, TMS integration	– Clear task distribution as multiple stakeholders strive for this role – Unified platform supporting multi-OEM fleets
Usage	**Customer** Cargo owners	Book trucking services	– n/a – TCO benefits lead to high interest in autonomous trucks

*3PL = 3rd party logistics (e.g., DHL, Schenker, FedEx). **TMS = transport management system.

4 An overarching industry agenda

Five key industry actions to ensure safety and drive innovation.

Consistent messaging is particularly important for partially automated driving (L2+/L3), where both driver and machine play active roles.

To overcome the main roadblocks and ramp up adoption of autonomous vehicles, the industry must focus on both ensuring safer roads and fostering the continuous innovation that will increase commercial value for stakeholders.

This chapter details five key industry actions that can deliver on these requirements. They address each of the five dimensions that form the basis of this white paper: consumer trust and interest, projected ADAS/AD system prices and consumers' willingness to pay, remaining technological obstacles and timeframe to overcome them, current regulatory status and anticipated regulatory developments, and ecosystem developments to support scaling.

Communicate consistent messaging and build consumer trust

Consistent messaging is particularly important for partially automated driving (L2+/L3), where both driver and machine play active roles. It is imperative that drivers understand the system's capabilities and their own role at all times, especially during transitions between automation levels, such as regaining control in L3 systems. Clear communication requires driving schools, manufacturers, dealerships and regulators, among others, to collaborate, ensuring transparent advertising and structured onboarding processes for the system.

Consumer trust hinges on transparency and demonstrable performance. Through openly shared safety data and key performance indicators, buyers can validate the reliability of driverless systems and overcome their scepticism. Public education campaigns, third-party validation and visible, real-world deployments make autonomous technology more tangible, boosting understanding and trust.

Leverage technology to increase safety, usability and scalability

Continued progress that leverages technology is key to surmounting several of the sector's remaining challenges. There are four main dimensions across which the industry can make the most of technology to improve safety, usability and scalability:

1. **Enhance understanding about the capabilities and limitations of vehicle automation technologies and discouraging incorrect and improper use.** This means improving HMI and DMS. A seamless and intuitive HMI also makes it easier and more attractive for dealers to integrate ADAS/AD education into the vehicle purchasing journey.

2. **Ensure reliable performance.** Standardized validation metrics and safety testing protocols help reinforce trust and increase comparability across different automated and autonomous systems. Useful metrics could include activation time, hard braking events, disengagement rates and broader performance benchmarks.

3. **Keep autonomous systems secure.** Autonomous systems require robust protection against cyber threats to prevent unauthorized access, system manipulation and potential safety breaches. Strong cybersecurity frameworks and compliance measures will need to evolve alongside the technology to ensure system integrity.

4. **Develop scalability.** A central challenge for autonomous driving, scalability requires continuous progress in AI and system architecture. End-to-end AI-driven tech stacks can help improve reasoning capabilities, enhance perception and decision-making and enable vehicles to adapt better to complex environments.

To scale autonomous driving safely and reliably, the industry must prioritize the development of clear validation metrics and cybersecurity.

Steve Basra, Head of Global Automotive, Google

Optimize business models for economic viability

Sustainable business models are vital for encouraging the long-term success of autonomous vehicles. For personal vehicles, the strategies for achieving this will depend on the level of automation. L0 to L2 capabilities are becoming increasingly commoditized, requiring automakers to integrate these costs into standard vehicle pricing. L2+ is expected to provide the highest potential for differentiation over the coming years. For the levels beyond this, high costs and other limiting factors will restrict the market to the premium segment only until at least 2035.

In commercial applications, autonomous trucks and robotaxis are expected to provide strong long-term returns on investment, but substantial initial capital expenditure remains a barrier. Moreover, the companies developing the technology are not necessarily the ones reaping the rewards, making investment decisions more complex. Investors must be prepared to take a long-term perspective, recognizing that their returns will depend on selecting the right business models and establishing efficient operations.

> **Scalable, OEM-agnostic solutions will be a cornerstone to speed up autonomous mobility developments.**
>
> Anup Sable, Chief Technology Officer, KPIT

Co-create regulation to enable deployments

Regulatory alignment is essential for ensuring safety and reliability while accelerating the deployment of autonomous vehicles. Active collaboration between regulators and industry is essential, especially given the fast pace and technological complexity of the sector's innovation.

Autonomous vehicle deployments will also benefit from comprehensive policy packages. Important industrial policies might incorporate factors such as incentives or encouragement for urban planning integration.

Table 3 summarizes current policy and regulatory efforts in China, the US and the EU across seven different domains. While progress is being made across all areas, the rate of change varies.

TABLE 3 **Policy and regulatory efforts to advance vehicle autonomy (regional examples are not comprehensive)**

Advanced progress/support · Moderate progress/support · Development areas

	What's needed	United States	Europe	China
Test frameworks	Align on predictive and unified test frameworks across regions	Individual states provide test grounds, but no federal alignment is currently available	Small individual test programmes (e.g., HEAT project with one vehicle in Hamburg), no cross-Europe alignment	Centralized AV pilot programme with 20 cities, 32,000 km of assigned roads and 16,000 issued vehicle licences
Homologation criteria	Define clear technical standards for AV performance and safety	Manufacturers self-certify compliance; guidelines by NHTSA but federal homologation criteria are pending	Technical standards developed by bodies such as the European Commission, implementation still country driven	A unified technical framework for performance and safety standards is under development
Incentives	Provide incentives, such as tax breaks and pilot project funding	Limited incentives for pilot schemes by, for example, California Mobility Center and USDOT ($60 million in 2018)	Various small funds to incentivize AV programmes, such as €290 million distributed among 70 projects in Germany	Federal subsidies for pilot schemes in, for example, Shenzhen and Guangzhou to support AV fleet deployment
Industrial policies	Foster ecosystem with domestic manufacturing and infrastructure	CHIPS Act allocates $52.7 billion to boost domestic semiconductor industry, yet few dedicated federal AV investments	Through Horizon Europe, European Commission invests €500 million in R&D initiatives for connected, automated mobility	Heavy investment in V2X infrastructure, HD mapping of cities and domestic manufacturing
Data regulations	Foster purposeful data sharing and enforce cybersecurity	Transparent incident reporting in California, voluntarily reporting to NHTSA; data privacy and cybersecurity fragmented	Data privacy and cybersecurity core to regulations (e.g., UK AV Act, GDPR), but no transparent incident reporting	Mandatory reporting of incidents to MIIT but low transparency; strict data collection and storage laws (PIPL law)
Liability frameworks	Define responsibility for system failures and during takeovers	Product liability framework covers AVs, yet legal debate about product versus operator liability ongoing	Liability governed by existing frameworks, such as product liability or Motor Insurance Directive	Liability is primarily assigned to operator; in case of a technical defect to the manufacturer
Urban planning integration	Designate AV lanes and pick-up zones, and include AVs in ITS systems	Limited dedicated infrastructure for AVs, few localized efforts to integrate AVs in transportation systems	Some dedicated infrastructure, such as pick-up zones; EU push for integrating AVs in cooperative intelligent transport systems	Testing AV lanes, pick-up zones and extensive V2X-enabled smart transportation systems

Source: Authors, based on public information from Chinese Ministry of Public Security, California Public Utilities Commission, United States White House, EU Commission, UK Government, German BMDV and press research.

Engage partners and related industries to scale up operations

A robust and collaborative ecosystem is crucial for scaling autonomous vehicle deployments beyond pilot projects. As depicted in Tables 1 and 2, collaboration with related industries is crucial for success. This includes not only cooperation across the tech stack to streamline development and avoid duplication but also partnerships with industries, such as insurance and urban planning.

> **Scaling autonomy isn't just about technology – it is about building the right ecosystem. This includes integrating digital platforms, charging and fleet operations.**
>
> Noah Zych, Global GM, Autonomous Mobility & Delivery, Uber

Conclusion

Unlocking the potential of autonomous driving requires coordinated action across OEMs, suppliers, regulators and more.

Vehicle autonomy is already on our roads, and it is poised to transform mobility. Scaling this technology, however, will take time – much longer than many earlier forecasts have suggested. Assisted (and not autonomous) systems, in particular L2 and L2+, are still expected to be the main technologies in most new personal vehicles sold in 10 years' time.

When it comes to L4 vehicles on public roads, it is robotaxis and autonomous trucks that will lead the way. Indeed, these vehicles are already deployed today in specific locations. Increased robotaxi adoption will depend on maturing the ecosystem and overcoming the high upfront costs. By 2035, our estimates suggest that up to 80 cities will have large-scale robotaxi services in place, most of these cities being located either in the US or China. The US is expected to lead the deployment of autonomous trucks, with Europe and China following. In the short term, autonomous trucks present the most profitable autonomous use case, driven by strong total cost of ownership advantages and efficiency gains, particularly in hub-to-hub deployments.

The forecasts in this white paper provide industry, regulators and the public with a more realistic timeline for autonomous vehicle deployments. This insight supports informed decision-making on upcoming challenges, including developing infrastructure, reskilling workforces and encouraging public acceptance. Given the varying adoption timelines across regions, the white paper also highlights the leading geographies for each use case.

Advances in vehicle autonomy offer not only greater efficiency and convenience but, most critically, the potential to significantly reduce road accidents – a pressing global problem that claims 1.2 million lives annually. The entire industry plays a vital role in safely scaling vehicle autonomy – a scenario that can only be achieved through extensive collaboration among stakeholders.

This white paper outlines the broad ecosystem involved in this transition, detailing their roles and identifying key requirements that remain outstanding. Beyond OEMs and suppliers developing safe and reliable technology while transparently communicating its strengths and limitations, regulators must balance innovation with safety and promote harmonization across regions to avoid fragmentation. Additionally, related industries must establish fleet operations, insurance frameworks and charging networks. Autonomy is not a short-term race but a long-term transformation requiring sustained commitment and cross-sectoral cooperation.

Contributors

World Economic Forum

Maria Alonso
Lead, Autonomous Systems

Paul Jordan
Project Fellow, World Economic Forum; Consultant, Boston Consulting Group

Boston Consulting Group

Markus Hagenmaier
Partner & Associate Director

Alex Koster
Managing Director and Senior Partner

Nikolaus Lang
Managing Director and Senior Partner

Augustin Wegscheider
Managing Director and Partner

Acknowledgements

We extend our deepest gratitude to the members and guests of the *DRIVE-A: Vehicle Autonomy* initiative for their contributions to this white paper:

Kasim Alfalahi
Chief Executive Officer, Avanci

Katharina Amann
Chief Executive Officer VW Car Insurance, Allianz

Alwin Bakkenes
Head of SW Engineering, Volvo Cars

Junwei Bao
Co-Founder and Chief Executive Officer, Seyond

Steve Basra
Head of Global Automotive, Google

Michael C. T. Bond
GM Corporate Strategy, MTR

Francis Chow
VP & GM In-vehicle Operating System and Edge, Red Hat (IBM)

Ray Cornyn
VP & GM Vehicle Control and Networking Solutions, NXP Semiconductors

Paul Farrell
EVP and Chief Strategy Officer, BorgWarner

Christoph Hartung
President Cross-Domain Computing, Bosch

Andreas Hermann
Professor and Director Institute for Mobility, University of St. Gallen

Heiko Huettel
VP Software Products, Harman International (Samsung)

Parag Ashok Inamdar
VP & Head of Software Engineering, TVS Motor Company

Gerardo Interiano
SVP Government Relations & Public Affairs, Aurora

Nils Jäger
President Autonomous Solutions, Volvo Group

Akshay Jaising
VP Commercial & Strategy, Motional

Steven Jenkins
President Electronics, Magna

Anoop Kachhara
VP Group Strategy, Mahindra Group

Gürcan Karakaş
Chief Executive Officer, TOGG

Shinpei Kato
Chief Executive Officer & Founder, TIER IV

Andrea Ketzer
Director, Automotive Technology Strategy, Amazon Web Services

Andrea Kollmorgen
Chief Executive Officer, Simulytic (Siemens)

Erhan Köseoğlu
Executive Director of Growth and Smart Mobility, Ford Otosan

Michel Ladrak
Head of Land Mobility, NEOM

Dirk Linzmeier
Chief Executive Officer, TTTech Auto

Jörg Ohlsen
Chief Executive Officer, Cognizant Mobility

Kishor Patil
Managing Director, KPIT

Manaswini Rath
SVP ADAS & Autonomous Vehicles Business, KPIT

Gerd Rösel
Head of Innovation for Electrification, Vitesco / Schaeffler

Anup Sable
Chief Technology Officer, KPIT

Bernd Schmaul
Chief Digital Officer, Bosch Mobility

Christian Senger
Chief Executive Officer ADMT, Volkswagen Group

Gerhard Steiger
Chairman Europe, Momenta

Raquel Urtasun
Founder and Chief Executive Officer, Waabi

Huibert Verhoeven
SVP Digital Cockpit, Harman International (Samsung)

Jung Yeop Woo
SVP Global Policy Office, Hyundai Motor

Zhenghua Yu
Chief Executive Officer, Motovis

Noah Zych
Global GM, Autonomous Mobility & Delivery, Uber

We would also like to thank the following colleagues from the World Economic Forum and Boston Consulting Group for their support in preparing this white paper:

Sebastian Buckup
Head of Network and Partnerships and Member of the Executive Committee, World Economic Forum

Brian Collie
Managing Director and Senior Partner, Boston Consulting Group

Sebastian Sackmann
Project Leader, Boston Consulting Group

Arunima Sarkar
Head of Frontier Technologies, World Economic Forum

Sophie Xiaoran Tang
Community Engagement Specialist, Autonomous Systems, World Economic Forum

Alex Xie
Managing Director and Senior Partner, Boston Consulting Group

Production

Laurence Denmark
Creative Director, Studio Miko

Jay Kelly
Designer, Studio Miko

Chris Parsons
Editor, chrisparsonswrites.com

Endnotes

1. World Health Organization. (2023). *Road traffic injuries.* https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries.
2. SAE International. (2019). *SAE J3016 Levels of Driving Automation.* [Infographic] https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic.
3. Alonso, M., Koster, A. & Jordan, P. (2025). How GenAI is helping drive vehicle autonomy. *Agenda.* https://www.weforum.org/stories/2025/04/how-genai-is-helping-drive-vehicle-autonomy/.
4. World Economic Forum. (2018). *Reshaping Urban Mobility with Autonomous Vehicles – Lessons from the City of Boston.* https://www3.weforum.org/docs/WEF_Reshaping_Urban_Mobility_with_Autonomous_Vehicles_2018.pdf.

COMMITTED TO IMPROVING THE STATE OF THE WORLD

The World Economic Forum, committed to improving the state of the world, is the International Organization for Public-Private Cooperation.

The Forum engages the foremost political, business and other leaders of society to shape global, regional and industry agendas.

World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744
contact@weforum.org
www.weforum.org