WHITE PAPER

State of the Industry: Automated Vehicle Control Systems

Key Advances in Vehicle Control and ADAS (2022–2026)

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1. Executive Summary:

In late 2022, a similar white paper to this paper, was produced to document the state of the industry and explaining many concepts that were being conflated, like artificial intelligence and machine learning. Since that time, we have had AI explode into our lives and impacting basically all areas. However, in 2022, AI was being used for car control, with training models using synthetic and real-world data, and inference models deployed to cars for testing, and then issues found and models retrained. Up to that point ADAS, or advanced driver safety systems were being added to many human controlled cars, like lane keeping, advanced cruise control and the like, making the cars feel autonomous, but they were not really.

In that intervening time, the automated vehicle and advanced driver assistance sector has advanced from predominantly experimental and tightly geofenced demonstrations to sustained commercial-scale robotaxi operations in multiple major cities. The most significant developments over the intervening four years include:

- Commercial robotaxi deployment at meaningful scale. Waymo has expanded driverless (Level 4) service to ten U.S. metropolitan areas, operating a fleet of approximately 2,500 vehicles and delivering more than 450,000 paid rides per week (December 2025), with cumulative autonomous kilometres exceeding 320 million. Zoox has commenced paid operations in Las Vegas, with purpose-built bidirectional vehicles and is scaling production toward 10,000 units annually.
- Demonstrated safety improvement. Waymo's published statistics (through late 2025) show 81–92 % reductions in injury and serious-injury crashes compared with human-driven benchmarks in the same operating domains, providing the strongest real-world evidence to date that commercial robotaxi services can materially improve road safety.
- Inside-out / vision-only architecture reaching broader viability. Tesla's Full Self-Driving (Supervised) system has accumulated more than 13 billion kilometres of real-world data, enabling frequent neural-network improvements via over-the-air updates. The system is now commercially available in the US market, and now for right-hand-drive markets (including Australia since September 2025)[1] and has begun supervised and limited unsupervised robotaxi operations (Austin, Texas). The Cybercab platform completed its first production units in mid-February 2026 at Giga Texas; independent drone footage from 3 March 2026 shows production ramping to higher test/validation volumes, with 25 or more Cybercabs observed on site as recent as 5 March 2025—the largest public grouping to date—confirming the transition ahead of scheduled low-volume production start in April.
- Significant programme terminations and strategic pivots. Several major Level 4 initiatives were discontinued or substantially scaled back: Argo AI (2022), GM Cruise independent robotaxi unit (2024), BMW Level 3 Personal Pilot (2026), Mercedes-Benz has paused their Level 3 Drive Pilot system (2026), Volkswagen CARIAD restructuring (2025), and Stellantis Level 3 AutoDrive suspension (2025). These outcomes highlighted the difficulty of scaling map-dependent (outside-in) architectures beyond geofenced domains and the high capital intensity required for commercial viability.

[1] Tesla's Full Self-Driving (Supervised) operates on public roads in the **U.S., Canada, China, Mexico, Puerto Rico, Australia, and New Zealand**

- Regulatory momentum toward harmonisation. The UNECE GRVA adopted a draft Global Technical Regulation on Automated Driving Systems in January 2026; final endorsement is anticipated at WP.29 in June 2026. In Australia, the National Transport Commission is aligning the forthcoming Automated Vehicle Safety Law (AVSL) with the UNECE safety-case framework, with conditional Level 3+ deployment enabled from 2027 in selected locations.
- Australian progress. Controlled public-transport trials (TfNSW Advanced Bus Technology Trial, 2026–2027), infrastructure-to-vehicle connectivity demonstrations (Transurban–Toyota C-ITS/V2X trial, 2025), and world-leading autonomous haulage fleets in the mining sector (1,024 trucks as of mid-2025, with Fortescue advancing battery-electric autonomous trucks) have laid practical foundations. Community testing and independent media coverage (The Driven) have increased visibility of inside-out system performance under local conditions.

Overall, the period between 2022 and 2026 has witnessed the transition from pilot-scale demonstrations to revenue-generating robotaxi operations, clear evidence of safety benefit in constrained domains, and growing recognition that map-independent, vision-first architectures offer the most plausible path to broad geographic scalability. At the same time, the high capital cost, problems with scaling training and inference models and extended timelines required for Level 4/5 autonomy have led several large players to exit or pivot, concentrating progress among a smaller number of well-resourced organisations while high-volume deployments accelerate in China.

This White Paper was created as a collaboration between Exner Group and RSA with the team at RSA providing peer review and feedback to the content and information.

RSA has been undertaking road safety audits, risk assessments, legal expert witness, safe system assessments and DDA assessments across Australia since 1994. Our team have expertise in roads, rail, logistics, mining, and car parks. We assess safety issues affecting drivers, workers, pedestrians and cyclists.

Exner Group are established engineers and project managers in the infrastructure space providing expertise to clients in commercial, technical, contractual and delivery requirements.

The collaboration of these two organisations in this area of autonomous vehicle control is a natural convergence of the expertise from both companies to a sector that is rapidly changing.

2. Introduction

As of March 2026, the automated vehicle industry has reached a significant inflection point. Commercial robotaxi services now operate at scale in multiple U.S. cities, purpose-built autonomous vehicles are entering low-volume production, and over-the-air software updates continue to advance supervised systems in consumer vehicles.

Despite these advances, unsupervised autonomy (SAE Levels 4–5) for personal vehicles on unrestricted public roads remains constrained by regulatory approval, unresolved edge cases, and the need to establish broad public trust. This report presents a comprehensive overview of the current state, contrasting successful deployments with notable programme terminations, and highlights developments of particular relevance to Australia.

Approach and Core Objectives

Development efforts continue to optimise three interdependent criteria: safety, passenger comfort, and reasonable travel speed. These remain the fundamental benchmarks for evaluating system performance and user acceptance.

Artificial Intelligence in Automated Driving

All current automated driving systems are classified as narrow artificial intelligence (ANI). Most have moved from heuristic hard coded programming that many started with for their inference models that sit in the cars local computer to drive the car. They are moving to neural networks with little or no hard coding with training of the model occurring in supercomputers and that produces the inference neural network that then is loaded on the cars local computer that then drives the car. These training and inference models rely on multi-layered machine-learning models and deep neural networks trained on billions of real-world and simulated kilometres. Tesla's Full Self-Driving (Supervised) system has accumulated more than 13 billion kilometres, enabling rapid model iteration through proprietary supercomputing infrastructure. Other providers combine simulation with on-road data to accelerate learning. No system approaches artificial general intelligence[2]; all remain task-specific and operate within clearly defined operational design domains (ODDs). The problem of this conflation is something we have to live with, as while computers and AI do things that might look intelligent, is just a cute expression of machine learning.

Advanced Driver Assistance Systems (ADAS)

Advanced Driver Assistance Systems (ADAS) are electronic technologies that support the driver by enhancing safety and situational awareness. Operating at SAE Levels 0–2, ADAS provide warnings, temporary intervention, or limited automation, but the driver retains full responsibility and must remain attentive and ready to take control at all times.

ANCAP evaluates ADAS under its Safety Assist category, assessing both feature presence and real-world effectiveness through rigorous testing protocols. Points awarded contribute directly to a vehicle's overall star rating. Key categories include:

- Autonomous Emergency Braking (AEB) – car-to-car, vulnerable road user (pedestrian/cyclist), junction turning, and back over variants
- Lane Support Systems – Lane Keep Assist (LKA), Lane Departure Warning (LDW), Emergency Lane Keeping (ELK)

[2] The car is not aware that it is a car, or even what a car is. While it can think, it isn't aware

- Speed Assistance Systems – Intelligent Speed Assistance (ISA) and speed-limit recognition
- Driver Monitoring Systems – detection of distraction, drowsiness, or inattention
- Supporting features – blind-spot monitoring, rear cross-traffic alert, seat-belt reminders

From 2026, ANCAP will introduce separate Assisted Driving assessments for SAE Level 2 and Level 3 systems, evaluating driver engagement, assistance competence, and safety fallback performance. These assessments will influence the overall star rating and emphasise real-world robustness and alignment with Australian conditions.

In essence, ADAS are driver-support tools that reduce crash risk through assistance, whereas full vehicle control systems (covered below) aim to sustain or completely assume the driving task (SAE Levels 3–5) within defined or unrestricted domains.

Approaches to Vehicle Control

Two principal philosophies continue to shape the industry:

- **Outside-In**: Relies on high-definition (HD) maps, pre-surveyed environments, and multi-sensor suites (LiDAR, radar, cameras, ultrasonics). Effective within tightly geofenced areas, but scalability is limited by the cost and effort required to maintain up-to-date maps. Temporary changes—roadworks, lane closures, signage alterations—introduce latency as real-time perception must reconcile with outdated map data.
- **Inside-Out**: Constructs real-time occupancy networks and environmental models primarily from vision sensors and neural networks (including neural radiance fields). Requires no pre-loaded HD maps[3], operates effectively on any road network (with or without lane markings), and adapts immediately to temporary traffic management. This approach offers clear advantages for broad geographic scalability.

SAE Levels 0–5 remain the global reference framework. Most consumer systems operate at Level 2 (supervised), while leading robotaxi deployments achieve Level 4 within defined ODDs.

[3] All systems need street level maps to enable navigation, with context overlays of restrictions of use like one way, no left turn, tollways etc, and these maps are strategic, and not used to drive the car.

3. Global Industry Progress

Outside-In Systems

Geofenced, map-dependent platforms have achieved the largest commercial scale to date. Waymo (Alphabet) operates commercial driverless service across its ten U.S. cities with a fleet of approximately 2,500 vehicles. Weekly paid rides exceeded 450,000 by December 2025 and continue to grow toward a 1-million-ride weekly target by year-end 2026. Cumulative autonomous kilometres on public roads exceed 320 million.

Zoox (Amazon) has commenced paid robotaxi service in Las Vegas (early 2026) with San Francisco Bay Area rollout planned later in the year. The current operational fleet stands at approximately 50 purpose-built bidirectional vehicles, supported by a new serial-production facility targeting 10,000 units annually. Autonomous kilometres have surpassed 1.6 million.

Legacy Level 2+ highway systems (Ford BlueCruise, GM Super Cruise, Mercedes Drive Pilot) continue on pre-mapped corridors with mandatory driver monitoring.

Inside-Out Systems

Tesla's Full Self-Driving (Supervised)—classified as SAE Level 2—is commercially available in Australia, the United States, and other markets, with Netherlands approval anticipated around 20 March 2026. The Cybercab (steering-wheel-less, vision-only robotaxi) rolled the first production unit off the line in mid-February 2026 at Giga Texas. Independent drone footage from 3 March 2026 documents a clear ramp to higher test/validation volumes, with 25 or more Cybercabs observed on 5 March 2026 across factory exit, crash testing, and end-of-line areas—the largest public grouping seen to date. This activity, supported by new infrastructure (test track preparation, supplier readiness, and hiring), confirms the transition ahead of scheduled low-volume production start in April 2026. The inside-out architecture enables seamless operation across any road network, directly addressing the mapping and latency limitations of outside-in competitors.

Chinese Robotaxi Leadership

China now leads the world in robotaxi deployment volume and commercial maturity. Baidu's Apollo Go operates fully driverless services across 26 cities, delivering more than 20 million cumulative rides by February 2026 (including 3.4 million in Q4 2025 alone, with weekly peaks exceeding 300,000). Pony.ai and WeRide each operate fleets above 1,000 vehicles and have achieved city-wide unit-economics breakeven in flagship markets such as Guangzhou; both companies target fleets exceeding 3,000 vehicles by the end of 2026, supported by rapid cost reductions (Gen-7 platforms approximately 70 % cheaper than prior generations) and international pilots in Dubai, Abu Dhabi, and South Korea. These high-volume, inside-out deployments demonstrate that dense urban environments, policy support, and aggressive scaling can achieve profitability far faster than many Western programmes. Independent observers such as FutureAzA, on his third China visit in early 2026, continue to highlight the intensely competitive EV and autonomy landscape.

Hogback Driver Assistance Challenge

The Hogback Driver Assistance Challenge offers one of the most rigorous public, head-to-head comparisons of ADAS and emerging autonomous capabilities. Conducted on a demanding 19 km mountain circuit in Colorado, the route includes steep grades, tight switchbacks, narrow lanes, variable weather, construction zones, wildlife crossings, and dynamic obstacles—conditions that expose limitations not visible on controlled test tracks.

Evaluated systems typically include Tesla Full Self-Driving (Supervised), Ford BlueCruise, GM Super Cruise, Mercedes Drive Pilot/Distronic, Comma.ai Openpilot, and select Chinese-market systems (XPENG, Li Auto) when comparable configurations are available.

Consistent findings include:

- Tesla's vision-only, inside-out approach completes the circuit with the fewest disengagements, demonstrating robust handling of temporary lane markings, construction zones, narrow shoulders, and sudden geometry changes.
- Map-dependent Level 2+ systems frequently disengage or require intervention when real-world conditions diverge from pre-mapped data (seasonal roadwork, faded markings, recent resurfacing).
- LiDAR + HD-map systems perform reliably within mapped ODDs but exhibit hesitation or overly conservative behaviour outside those boundaries.
- Aftermarket solutions such as Comma.ai Openpilot often outperform factory Level 2 suites relative to cost, though they remain supervised and lack OEM-scale compute resources.

While not a formal regulatory test, the Hogback series has become a widely referenced public benchmark highlighting the advantages of map-independent, neural-network-driven systems in unstructured environments.

Halted or Scaled-Back Programmes

Several high-profile programmes have been terminated or significantly scaled back, illustrating the technical, financial, and timeline challenges of achieving scalable autonomy. These outcomes contrast sharply with the programmes that are currently advancing:

- Argo AI (Ford & Volkswagen-backed) — shut down October 2022 after US$3.6 billion investment
- GM Cruise independent robotaxi unit — scaled back December 2024, folded into supervised ADAS development
- BMW Level 3 "Personal Pilot" — withdrawn from 7 Series April 2026
- Mercedes-Benz, as of 2026, has paused or temporarily scaled back its Level 3 "Drive Pilot" system, rather than abandoning autonomous development entirely.
- Volkswagen CARIAD — major restructuring 2025; China-market autonomy now licensed from XPENG (XNGP)
- Stellantis Level 3 AutoDrive — suspended August 2025

Common factors include reliance on external providers, maintaining hard coded heuristic programming rather than moving to neural networks, training on synthetic driving models instead of libraries of real world video imaging, unable to train models on super computers to create the inference models, using outside-in architectures difficult to scale beyond geofenced areas, unsustainable capital burn, and unrealistic profitability timelines.

Safety Improvements from Commercial Deployments

Commercial robotaxi operations are delivering measurable safety benefits. Waymo data (through late 2025) shows 90 % fewer serious-injury-or-worse crashes, 82 % fewer airbag-deployment crashes, 81 % fewer injury-causing crashes, 92 % fewer pedestrian injury crashes, and 83 % fewer cyclist injury crashes compared with human-driven benchmarks in the same cities. Results are based on more than 200 million autonomous kilometres (127 million rider-only) and are statistically significant. Zoox reports similar early trends in reduced human-error incidents within its operational domains.

By eliminating distracted, fatigued, or impaired human drivers—the leading cause of most crashes—robotaxis are demonstrably improving safety for all road users, including vulnerable pedestrians and cyclists.

Vehicle Control Systems: Complexity and Availability

Public-road automation remains the most complex domain due to high cost to implement, high degrees of freedom and unpredictable human behaviour. Highway scenarios are comparatively tractable. Current consumer offerings include mandatory car-to-car Autonomous Emergency Braking in Australia (effective March 2025) and near-standard Level 2 suites across most new models. Aftermarket solutions (e.g., Comma.ai) and frequent over-the-air updates (particularly Tesla) continue to raise baseline capability. Tests by local road operators like Transurban have proved that cleaning and clear signs and clear line marking are the key to allow autonomous vehicles to traverse the road network safely.

Consumer Adoption and OEM Strategies

Fleet turnover inertia (typically 8–12 years) and preference for proven reliability continue to slow personal-vehicle uptake. Robotaxi exposure is gradually shifting perceptions. Corporate fleets and long-haul operators remain the strongest early adopters of highway-focused automation. In Australia, community testing by advocates such as Electric Chris (Chris Vanderstock) has provided valuable real-world demonstrations of Full Self-Driving under local conditions (hook turns, roundabouts, variable weather).

Infrastructure Owners and Connectivity

Inside-out systems require only existing road markings and signage. Outside-in and hybrid systems benefit from intelligent infrastructure. In Australia, Transurban's trials on Melbourne motorways have demonstrated infrastructure-to-vehicle (I2V) connectivity enhancing automated truck performance in live traffic. The 2025 Toyota C-ITS/V2X trial at a high-risk merge point further validated connectivity for immediate safety and future scalability.

Australian Developments

Australia advances connected and automated vehicle (CAV) capabilities through targeted trials, national coordination, and policy alignment focused on practical deployment, public acceptance, and regulatory readiness.

Transport for NSW's Advanced Bus Technology Trial (February 2026–2027) at the Cudal Future Mobility Testing and Research Centre evaluates SAE Levels 2–4 on full-size electric buses (up to 66 passengers). Features under assessment include automated emergency braking, blind-spot detection, lane-keeping, and fully automated depot functions (self-parking, charging). The programme aims to accelerate safer, zero-emission public transport, support workforce transition, optimise depot operations, and provide evidence for future regulatory updates.

Transurban's Melbourne motorway trials (CityLink, Monash Freeway) have demonstrated I2V connectivity supporting automated freight. The 2025 Toyota C-ITS/V2X trial at a high-risk merge point confirmed immediate safety and flow benefits while laying groundwork for future automation.

The Centre for Connected and Automated Transport (CCAT) which brings government and industry together to facilitate planning for connected and automated transport technologies. CCAT's 2025 National Future Transport Summit produced Australia's first industry-led recommendations on planning for these technologies. A March 2026 stakeholder event focused on public attitudes and social licence. These efforts aim to support the government's planning for CAVs and other emerging technologies.

CCAT's parent organisation, the National Transport Research Organisation (NTRO) is Australia and New Zealand's leading independent transport research and technology centre. NTRO works with all levels of government, industry and communities in the provision of expert consulting, standards development, and innovative transport solutions, including CAVs. With the goal of accelerating the development and deployment of CAVs, NTRO is bringing automated solutions to Australia through global partnerships and projects.

Mining and Off-Highway Autonomy

Australia's Pilbara iron-ore operations host one of the world's most mature autonomous fleets. As of July 2025, 1,024 autonomous haul trucks operated in Australia (second globally to China). Major operators include BHP, Rio Tinto (187–200 trucks), and Fortescue (193 diesel autonomous trucks). These fleets have hauled billions of tonnes with gains in safety, productivity (increased by 20–30 %), tyre life (gain of 20–30 %), and reduction in maintenance costs.

Fortescue is integrating autonomy with zero-emission technology via its Liebherr partnership (360 trucks have been ordered), developing the world's first fully integrated Autonomous Haulage Solution for battery-electric 240-tonne trucks. Validation is underway, with initial deployments targeted for early 2026 and phased scaling to 300–400 trucks (Liebherr and XCMG supply). Scania's autonomous in-pit rigid trucks are also launching in the Pilbara in late 2025. These controlled-environment successes provide transferable learnings for public-road CAV development.

NVIDIA vehicle control system

NVIDIA has established itself as a major enabler in automated vehicle control with its high-performance DRIVE AGX Thor computing platform and DRIVE AV software. Through its Omniverse and Cosmos systems, the company has significantly advanced synthetic data generation, allowing developers to simulate billions of driving scenarios and accelerate training. Nevertheless, this technology constitutes only part of the overall solution. Experience across the industry demonstrates that, even with sophisticated synthetic data, very large quantities of real-world driving data are still required to fully train robust vehicle control systems, as the real world presents far greater messiness, unpredictability, and edge-case complexity than simulated environments can yet replicate.

Uber

Uber has signalled strong commitment to the sector with its February 2026 launch of Uber Autonomous Solutions, a suite of services designed to support the commercial scaling of robotaxis through ride-hailing integration, fleet operations, regulatory expertise, and financing. Backed by partnerships including Lucid and Nuro for purpose-built vehicles as well as collaborations with Stellantis and other OEMs, the company aims to become a leading platform for autonomous mobility. In reality, however, Uber provides the operational and demand-side infrastructure rather than the core technology. The company continues to depend on original equipment manufacturers and specialist autonomous technology providers to develop and supply the actual self-driving vehicles.

4. Regulatory Landscape

International – UNECE Global Technical Regulation

The UNECE GRVA adopted the draft Global Technical Regulation (GTR) on Automated Driving Systems in January 2026. The performance-based “safety-case” framework requires manufacturers to present evidence-based arguments demonstrating sufficient safety within the intended ODD. The draft will be considered by WP.29 in June 2026; endorsement would enable incorporation into national law and reduce regulatory fragmentation.

Australia – NTC Alignment and Latest Status

The National Transport Commission is developing the Automated Vehicle Safety Law (AVSL), a national in-service safety regime assigning primary responsibility to Automated Driving System Entities (ADSEs). The AVSL explicitly adopts the UNECE GTR’s safety-case approach for validation and ongoing assurance.

Transport Ministers agreed in November 2025 to enable conditional deployment (SAE Levels 3+) from 2027 in selected locations, with full readiness to follow. The NTC is incorporating the forthcoming GTR into policy and model legislation. Australian Design Rules will be amended to align with the GTR once endorsed. Current regulations mandate car-to-car AEB (March 2025) and permit controlled trials; unrestricted commercial Level 4/5 operations await the AVSL framework.

Insurers and Liability

Usage-based insurance programmes continue to expand. Liability transfer for Level 3+ systems remains under active discussion in Australia (NTC horizon accelerated) and internationally.

Outlook and Key Enablers

Robotaxi services (Waymo, Zoox, and leading Chinese operators) are scaling in constrained domains and delivering proven safety gains. Personal-vehicle Level 4/5 autonomy awaits regulatory clarity and edge-case resolution. Inside-out architectures offer the clearest path to open-road scalability, with Tesla’s Cybercab production ramp providing a real-time illustration of the sector’s daily pace. Targeted infrastructure connectivity, continuous data flywheels, and evidence-based policy—supported in Australia by CCAT, mining-sector leadership, and independent analysis—will determine adoption pace. Global competition between high-volume Chinese deployments and technology-leading U.S. programmes will accelerate innovation and cost reduction.

The next 12–18 months will be decisive as U.S. and European regulatory milestones converge with expanding commercial fleets and Australia’s unique opportunity to transfer mining-autonomy expertise to public roads. Key remaining challenges include adverse-weather robustness, cybersecurity assurance, and workforce transition.

Use of driver assistance on public roads

Under Australian road rules, which are based on the harmonised Australian Road Rules and administered by each state and territory, the driver of a motor vehicle must at all times maintain proper control of the vehicle. This longstanding obligation—typically expressed in provisions equivalent to Road Rule 297 or state-specific equivalents—requires the driver to be seated in the normal driving position, capable of exercising full directional and speed control, and ready to respond immediately to any road condition or hazard. It does not impose a rigid statutory mandate that one or both hands must remain continuously on the steering wheel at all times; rather, "proper control" is interpreted in light of the vehicle's technology and the driver's ability to intervene effectively.

For supervised Full Self-Driving (FSD), classified as SAE Level 2 partial driving automation and commercially available in Australia since September 2025, this requirement is satisfied when the driver keeps their eyes on the road and remains fully attentive and prepared to resume manual control at any moment. Tesla's in-cabin driver-monitoring camera confirms attentiveness, enabling the system to perform sustained lateral and longitudinal control (steering, acceleration, and braking) without requiring the driver's hands on the wheel. State transport authorities and the National Transport Commission have accepted this operation for approved Level 2 systems, see below, provided the driver retains ultimate legal responsibility and supervision. Consequently, hands-off use of FSD (Supervised) would appear to meet current Road Rules, subject only to the driver's ongoing visual attention and readiness to intervene.

This is not legal advice, and the responsibility is always with the driver of their vehicle, and their investigations and knowledge of the Road Rules, and this is only provided as one interpretation.

For a deep dive into what the NTC has interpreted "proper control" in the context of driver assistance please review their guidelines: https://www.ntc.gov.au/sites/default/files/assets/files/AV_enforcement_guidelines.pdf.

5. Glossary

- SAE Levels: Level 0 (no automation) to Level 5 (full automation under all conditions).
- ADS: Automated Driving System.
- C-ITS / V2X: Cooperative Intelligent Transport Systems / Vehicle-to-Everything.
- I2V: Infrastructure-to-Vehicle.
- ODD: Operational Design Domain.

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7. SAE Levels of Driving Automation

The **SAE Levels of Driving Automation** (defined in SAE J3016, the standard taxonomy published by SAE International) classify the degree of automation in on-road motor vehicles from Level 0 to Level 5. These levels describe who performs the **dynamic driving task** (DDT)—including steering, acceleration/deceleration, monitoring the environment, object/event detection and response, fallback, and manoeuvre planning—and under what conditions.

Detailed (complicated) version — official SAE definitions (based on the latest refinements as of 2021 and consistent through 2026):

- **Level 0: No Driving Automation** The human driver performs the entire DDT at all times. The vehicle may provide momentary warnings (e.g., forward collision alert) or emergency interventions (e.g., automatic emergency braking), but these do not constitute sustained automation. The driver is fully responsible for vehicle operation and environment monitoring.
- **Level 1: Driver Assistance** The vehicle provides sustained, ODD-specific execution of **either** the lateral (steering) **or** longitudinal (acceleration/deceleration) subtask of the DDT, but not both simultaneously. The human driver performs the remainder of the DDT, including all object/event detection and response (OEDR), and remains fully responsible.
- **Level 2: Partial Driving Automation** The vehicle provides sustained, ODD-specific execution of **both** lateral and longitudinal subtasks of the DDT simultaneously. The human driver must complete the OEDR subtask, supervise the system continuously, and remain ready to intervene at any time. The driver retains full responsibility for safe operation.
- **Level 3: Conditional Driving Automation** The automated driving system (ADS) performs the entire DDT sustained and ODD-specific. The human driver is expected to respond appropriately to a request to intervene issued by the system (with sufficient transition time provided). The driver may disengage from DDT execution and OEDR but must remain available as fallback-ready user. This is the first level where the system assumes responsibility within its ODD, but the human must still be capable of taking over.
- **Level 4: High Driving Automation** The ADS performs the entire DDT and fallback within a specific, limited ODD (e.g., geofenced areas, highways, or urban robotaxi zones). No human driver is required to be present or ready to intervene within that ODD. Outside the ODD, the system may request human intervention or achieve a minimal risk condition independently.
- **Level 5: Full Driving Automation** The ADS performs the entire DDT and fallback under **all** roadway and environmental conditions that a human driver could manage (unrestricted ODD). No human driver is required at any time; the vehicle can operate without controls designed for human use (e.g., no steering wheel or pedals in some designs).

Simple version

Using the analogy of hands-off, eyes-off, mind-off analogies (a widely used, driver-centric simplification that aligns closely with SAE levels while focusing on human involvement):

- **All on** → Levels 0 and 1 The driver must keep hands on the wheel, eyes on the road, and full mental attention on driving. Automation provides only basic assistance (e.g., cruise control or lane-centring separately).
- **Hands-off** → Level 2 The driver can remove hands from the wheel (e.g., highway systems like Tesla Autopilot or GM Super Cruise in certain modes), but must keep eyes on the road and mind fully engaged to supervise and intervene immediately if needed.
- **Eyes-off** → Level 3 The driver can take hands off the wheel and eyes off the road (e.g., read or watch a screen), but the mind must remain available—ready to take back control quickly when the system requests intervention. This is sometimes called "mind-on but relaxed."
- **Mind-off** → Level 4 The driver (or passenger) can fully disengage—hands off, eyes off, mind off—within the system's defined domain (e.g., robotaxi in a city). No supervision is required, but the vehicle may be restricted to certain areas or conditions.
- **All off** → Level 5 Complete disengagement is possible under all conditions—no human driver needed at all, ever. The vehicle handles everything autonomously in any drivable environment.

These analogies help clarify the shift in responsibility: Levels 0–2 keep the human fully in the loop (driver support), Level 3 introduces conditional system responsibility with human fallback, and Levels 4–5 transfer full responsibility to the vehicle (true automated driving).

