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# D3.4 Brief Ad hoc Innovation radar report (b)

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DISSEMINATION LEVEL

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Acronyms and definitions

| | |
|---|---|
| ADS | Automated Driving System |
| AI | Artificial Intelligence |
| ASDE | Authorised Self-Driving Entity |
| AV | Autonomous Vehicle |
| CAD | Connected Automated Driving |
| CCAM | Connected, Cooperative and Automated Mobility |
| CCAM-ERAS | Connected, Cooperative and Automated Mobility for Employment Realisation through Acquisition of Skills |
| CHORUS | Coordination of Heterogeneous Actors in Mixed Traffic within CCAM (EU project) |
| CityMobil | Towards advanced road transport for the urban environment (EU project) |
| CityMobil2 | Cities demonstrating cybernetic mobility (EU project) |
| DCAS | Dynamic Control Assistance Systems |
| EV | Electric Vehicle |
| GRVA | Working Party on Automated/Autonomous and Connected Vehicles |
| GTR | Global Technical Regulation |
| IN2CCAM | Enhancing Integration and Interoperability of CCAM eco-system (EU project) |
| KIRA | AI-based regular operation of autonomous on-demand transport (project) |
| L4 | Level 4 Automation (SAE classification – high automation without driver intervention in defined conditions) |
| LivingLAPT | Future Apt Living Lab for Autonomous Public Transport (EU project) |
| MODI | A leap towards SAE L4 automated driving features (EU project) |
| NIMFEA | Navettes Innovantes Modulaires du Futur Expérimentales et Autonomes (project) |
| ODD | Operational Design Domain |
| OEM | Original Equipment Manufacturer |
| SAE | Society of Automotive Engineers |
| SAMS | Sunderland Advanced Mobility Shuttle (project) |
| SHOW | Shared automation Operating models for Worldwide adoption (EU project) |
| UiC | User-in-Charge |

| | |
|---|---|
| ULTIMO | Advancing Sustainable User-centric Mobility with Automated Vehicles (EU project) |
| UNECE | United Nations Economic Commission for Europe |
| UNR | United Nation Regulation |
| URBANE | Upscaling innovative green urban logistics solutions (EU project) |
| V2I | Vehicle-to-Infrastructure communication |
| V2X | Vehicle-to-Everything communication |
| WIPO | World Intellectual Property Organization |

# Executive summary

The CCAM-ERAS project aims to support society in understanding and preparing for the labour market impacts associated with Connected, Cooperative and Automated Mobility (CCAM). This report presents the Innovation Radar, a tool designed to identify, structure and assess key technological innovations in the CCAM ecosystem and evaluate their potential implications for employment, skills, and the broader mobility system.

The document builds on both quantitative assessments and qualitative desk research to develop a set of innovation profiles across five key domains: robotaxis, self-driving shuttles, city logistics, freight transport, and remote operation. Each profile assesses the maturity of the technology, current deployment status, market readiness, and expected societal impacts, providing a comprehensive snapshot of the state-of-the-art.

- **Robotaxi** services are being deployed globally, and early scaling efforts are also emerging in Europe. While commercial services are operating in several international markets, European deployment remains in a transition phase, moving from pilots to limited real-world services. Robotaxis have strong potential to reshape urban mobility systems by reducing private car dependency and enabling on-demand, shared transport, but their large-scale adoption depends on regulatory progress, public acceptance, and integration with public transport networks.
- **Self-driving shuttles** are progressing from pilot projects toward early commercial services, particularly in controlled or semi-controlled environments such as campuses, business parks, and urban districts. These services are increasingly integrated into public transport systems to provide first- and last-mile connectivity. Although the technology is maturing, scaling remains constrained by operational complexity, infrastructure requirements, and the need for reliable remote supervision, with further work needed to ensure economic viability and seamless integration into multimodal mobility systems.
- **City logistics** automation is emerging as a solution to improve efficiency in last-mile delivery, which is traditionally a labour-intensive and costly segment of transport. Real-world deployments of autonomous delivery vehicles and small electric cargo solutions are taking place in urban environments, supported by remote operation and AI-based routing systems. While these innovations offer potential benefits in reducing congestion, emissions, and operational costs, the large-scale impact remains uncertain due to fragmented regulations, complex urban environments, and the continued reliance on hybrid human-autonomous delivery models.
- **Freight transport** is seeing emergence of autonomous trucks in real-world commercial services, particularly in hub-to-hub and middle-mile logistics. These deployments demonstrate productivity benefits, including 24/7 operations and increased efficiency, while also addressing structural driver shortages. However, scaling beyond controlled corridors requires further progress in cross-border regulation, infrastructure readiness, and interoperability, particularly in the European context where harmonisation is still evolving.
- **Remote operations** play a critical enabling role across CCAM applications, acting as a bridge between fully autonomous driving and human control. It is already deployed in real-world operations across freight, shuttles, and shared mobility services, allowing operators to intervene or supervise vehicles remotely in complex or unexpected

situations. This hybrid model enhances safety and scalability but introduces new technical, regulatory, and human-factor challenges, particularly concerning communication reliability, operator workload, and legal responsibility.

The document also provides an overview on the regulatory environment for CCAM which can be a key enabler and constraint for large-scale deployment. Globally, regulatory maturity is advancing unevenly, with a limited number of countries enabling commercial Level-4 deployments and a larger group permitting testing, reflecting a gradual but ongoing transition from experimental pilots to early deployment frameworks. In the UK the regulatory environment is well advanced with the Automated Vehicles Act (2024) establishing a legal framework for authorisation, liability, and safety oversight to enable commercial scale deployment from this year onwards. Across Europe, the regulatory progress is advancing but remains fragmented with recent developments at UNECE level and EU initiatives supporting higher levels of automation, while cross-border harmonisation and operational consistency continue to be key challenges.

Contents

# 1 Introduction

## 1.1 Project overview

CCAM-ERAS aims to prepare society to manage labour market impacts arising from the deployment of connected, cooperative, and automated mobility (CCAM) services in the transport sector. As CCAM technologies advance, understanding their impact on employment, skills, and the mobility ecosystem becomes essential. A key objective of this project is to gain detailed insights into technological progress and innovations in CCAM and their implications for the workforce.

CCAM-ERAS has developed and implemented an Innovation Radar. The radar is a strategic tool for identifying and structuring innovations that might affect the future labour market and required skills. It focuses on high-potential innovations and key innovators in CCAM deployment. The radar identifies CCAM innovations, which are then further evaluated based on their maturity and relevance to the project and the stakeholder community. This report aims to enhance understanding of CCAM developments and the future transformation of the workforce. This report builds on Deliverable D3.2[1], "*Brief Ad hoc Innovation radar report (a)*", documenting the methodology and the first iteration of using the radar and its results.

## 1.2 Purpose of the document

This report builds on the work carried out by the Innovation Radar and uses its findings to develop a set of selected Innovation Profiles related to CCAM. Using a combination of quantitative data analysis and qualitative desk research, this report presents the current state of development of key CCAM use cases, including robotaxis, self-driving shuttles, city logistics, freight transport and remote operation. These profiles describe the technology's readiness, its areas of application, the innovation's relevance to the market and society, and the potential impacts of these developments.

The report is structured as follows: Chapter 2 describes the innovation capacity, which serves as the basis for the Innovation Radar. Chapter 3 presents the quantitative assessment, covering technological readiness, market and key innovators. Chapter 4 outlines the innovation profiles. Chapter 5 outlines the regulatory landscape for CCAM in the EU and worldwide. Finally, Chapter 6 offers reflections and concluding remarks.

# 2 Innovation capacity

The innovation Radar is revealing the *innovation capacity*, which, in a CCAM-ERAS context, is defined as the ability to realise innovation in real-life systems and services, with the potential to affect the future labour market and required skills.

Innovation capacity depends on the technical (in this context, CCAM) and market potential, as illustrated in Figure 1.

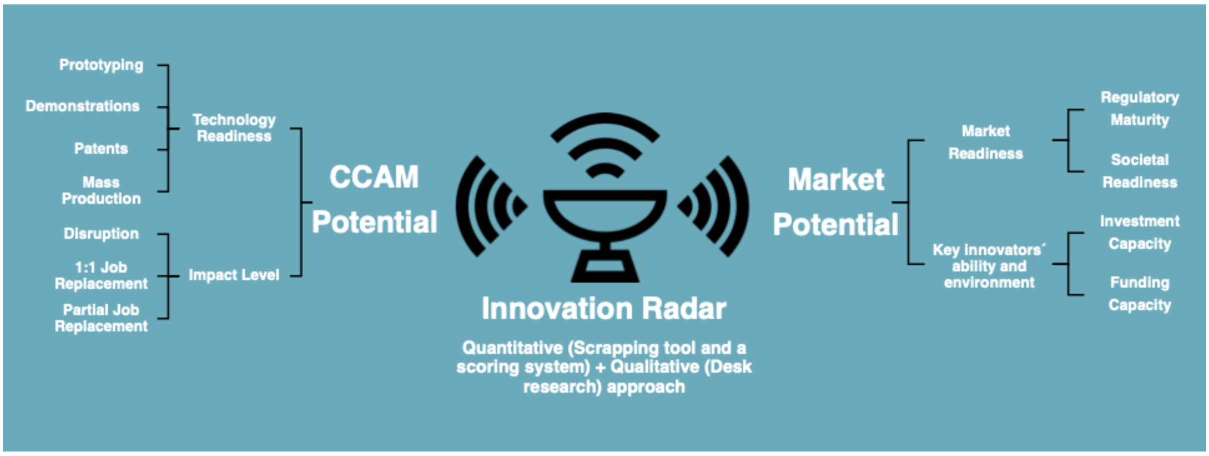


*Figure 1: Innovation Radar concept*

CCAM potential comprises two dimensions:

- **Technology readiness** indicates the maturity of a technology, measured by relevant prototypes, demonstrations, patents, and mass production. Hence, the technology readiness dimension measures the technical feasibility of realising an innovation.
- The **impact level** indicates whether the innovation in question has the potential to impact the labour market and required skills (relevance). This is measured by market disruption, full or partial job replacement.

Market potential comprises two dimensions:

- **Market readiness** indicates the maturity of the market and comprises both regulatory maturity and societal readiness. This dimension assesses whether the innovation can be introduced legally (e.g., supported by regulation) and whether the market is ready to adopt.
- **Key innovators' abilities and environment** indicate whether the innovation can be realised financially. This dimension is measured by the investment capacity and the funding capacity.

# 3 Quantitative assessments

## 3.1 Technology Readiness

To assess the readiness of CCAM technology for deployment, the project sought data on the number of AV deployments, active services, and service types (e.g., still in the pilot stage or already established commercial services) for both passenger and freight transport.

Since much news and results are published on this topic, and it is difficult to create a comprehensive overview with accuracy, a single source was selected for monitoring of these indicators: the CCAM Knowledge Base[1], which includes a list and map of CCAM test sites, pilots, trials and operations in Europe.

Furthermore, the recently launched Global CCAM Observatory[2] provides a list of all AV services worldwide, including their status, year of launch, service function, and other relevant information.

As shown in Figure 2 below, the number of active AV services for both freight and passenger transport has steadily increased over the last decade.

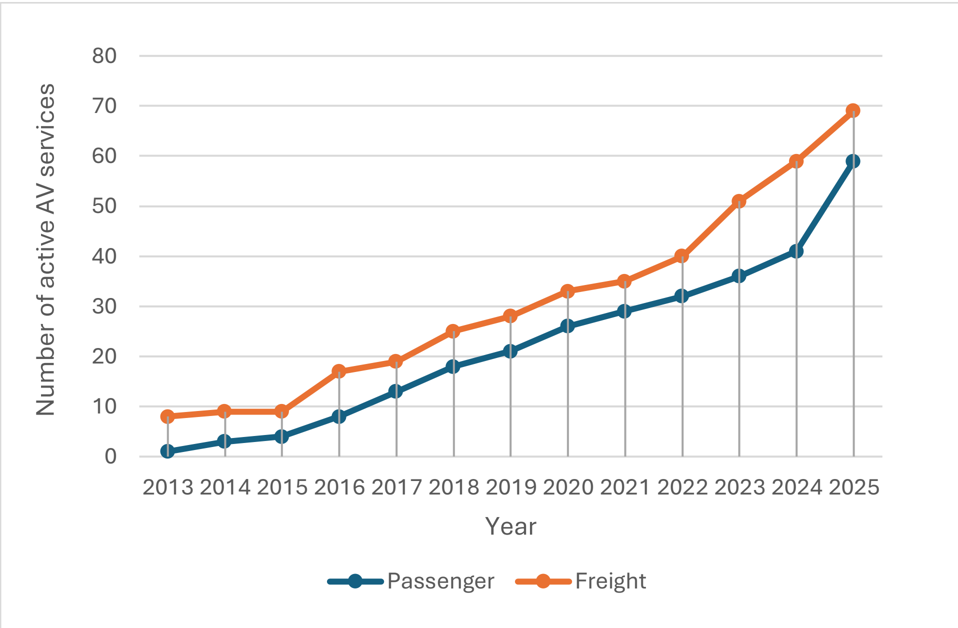


*Figure 2: Cumulative number of AV services (2013-2025)*
*Source: Graph developed based on data from CCAM Global Observatory*

Freight transport, often recognised as a key use case to lead CCAM deployment, has seen a rapid increase in CCAM services since 2022, while passenger transport is recently catching up, with a record number of 19 newly deployed services in 2025 (see Figure 3)

[1] https://www.connectedautomateddriving.eu/
[2] https://www.connectedautomateddriving.eu/observatory/

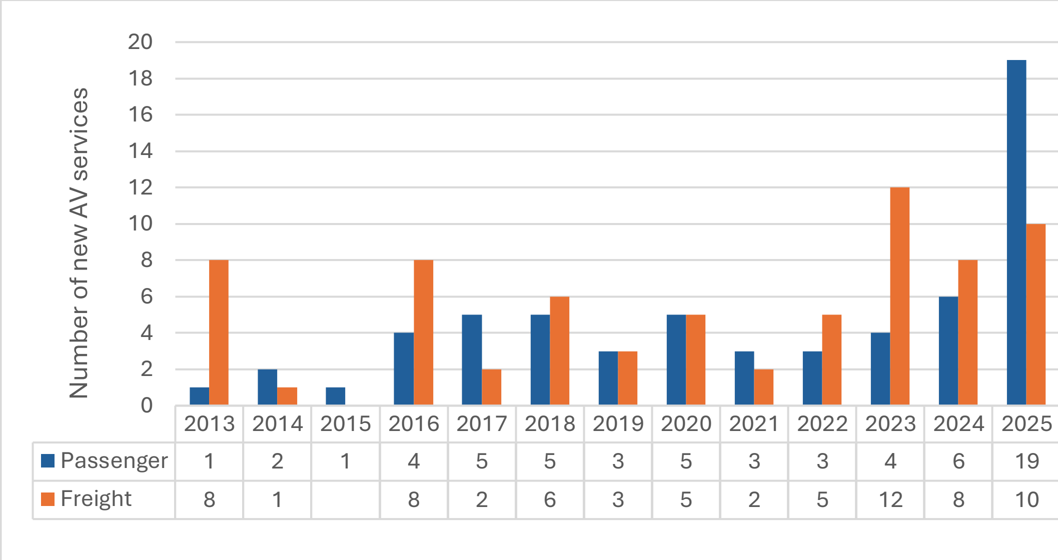


*Figure 3: Newly launched AV services per year (2013-2025)*
*Source: Graph developed based on data from CCAM Global Observatory*

For passenger mobility, a significant **47%** of the identified services have reached the **commercial operation** stage. Of the remaining **53%**, which are in **last-stage pilot** phases, a large portion (42%) was launched in 2025.

The Freight Transport services are similarly distributed by status: 42% are at the last-stage pilot level, while 52% have reached the commercial operation stage.

Moreover, the types of functions deployed for passenger and freight transport services were also evaluated from the Global CCAM Observatory list. The results are shown in Figure 4 and Figure 5 below.

For Passenger Transport, Shuttles comprise the majority of active services at 59%, while 42% of them are Robotaxis. Only 2% are private car cases.

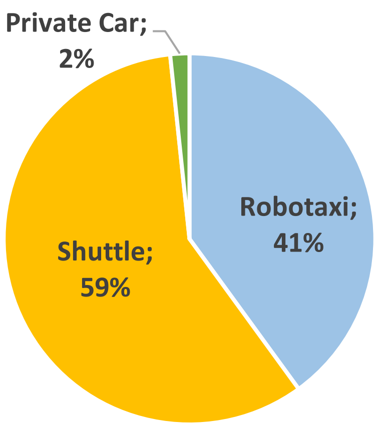


*Figure 4: Passenger Transport Service Types*
*Source: Graph developed based on data from CCAM Global Observatory*

For Freight Transport, Autonomous Trucks represent the larger portion of the service functions with 58%, and the remaining 42% are Delivery Bots.

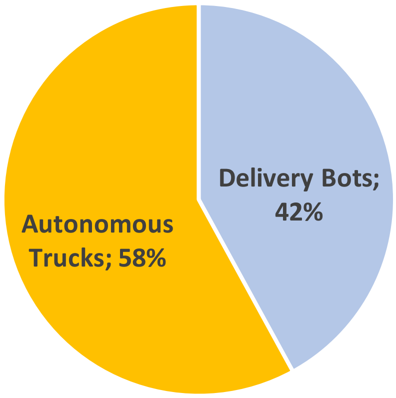


*Figure 5: Freight Transport Service Types*
*Source: Graph developed based on data from CCAM Global Observatory*

Furthermore, the technology readiness and innovation capacity analysis included monitoring the number of registered patents in relation to CCAM. This was achieved through the PatentScope search platform of the World Intellectual Property Organization (WIPO). With the search term ‘Automated Driving’, the results show that the number of registered patents globally had peaks in 2018 and 2022 and has decreased in recent years.

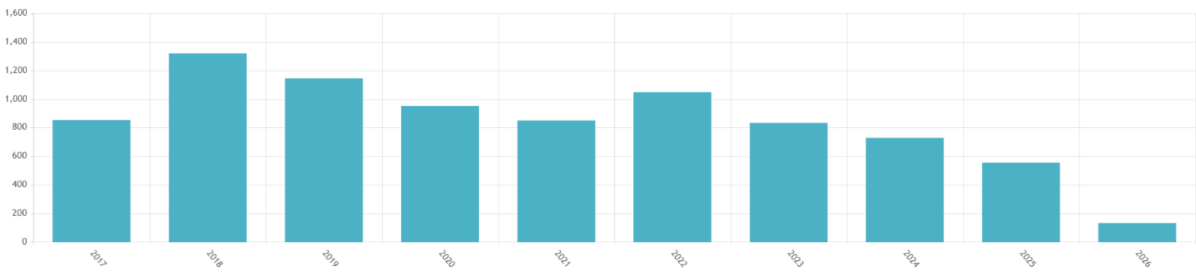


*Figure 6: Registered patents globally related to ‘Automated Driving’ (2017-2026)*

However, this is not the case if we only consider patents registered with the European Patent Office: Europe has significantly increased the number of registered patents over the last 4 years. Before 2022, fewer registrations took place each year.

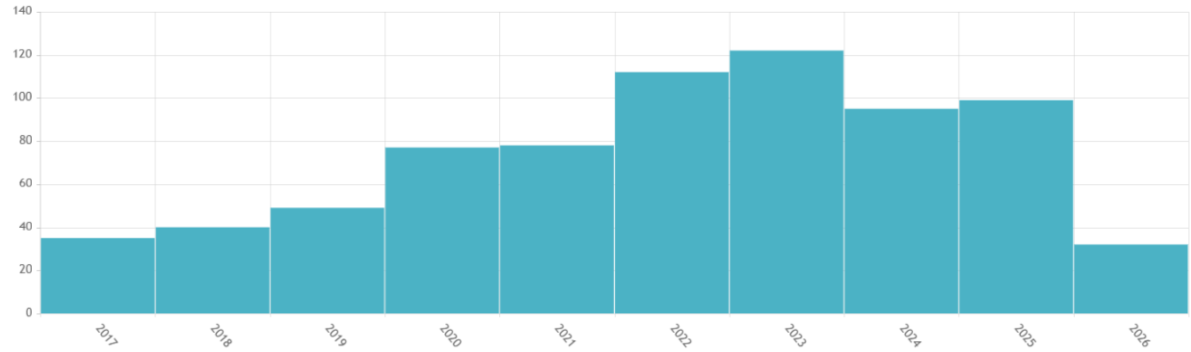


*Figure 7: Registered patents at European Patent Office related to 'Automated Driving' (2017-2026)*

Looking at the number of patents registered per country/region between 2017 and 2026, China leads by a significant margin, with over 4,000 registrations related to automated driving. The USA follows, with approximately 2500 patents.

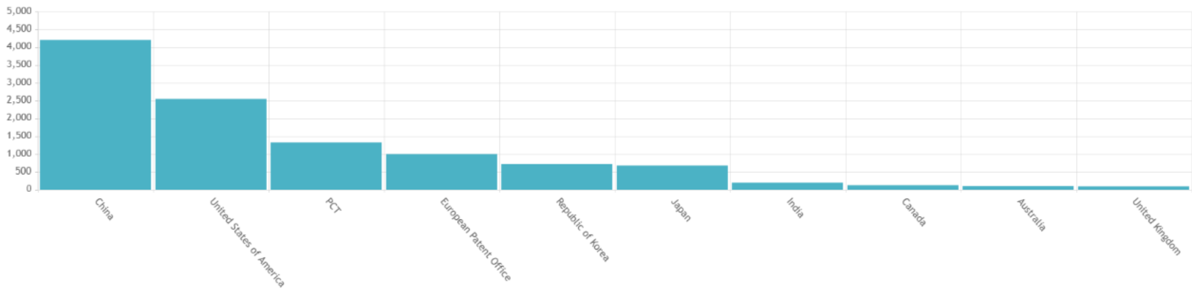


*Figure 8: Registered patents by country related to 'Automated Driving' (2017-2026)*

## 3.2 Market and key innovators

Based on the list of AV Industry Actors from the Global CCAM Observatory, the innovation and market capacity of the EU were compared with those of other parts of the world.

As shown in Figure 9, 22% of the identified AV Industry Actors are based in the EU. This represents a strong position for Europe as a region to drive CCAM innovation and deployment. The USA and China follow with 17% share each, while other relevant players are South Korea (11%) and Japan (9%).

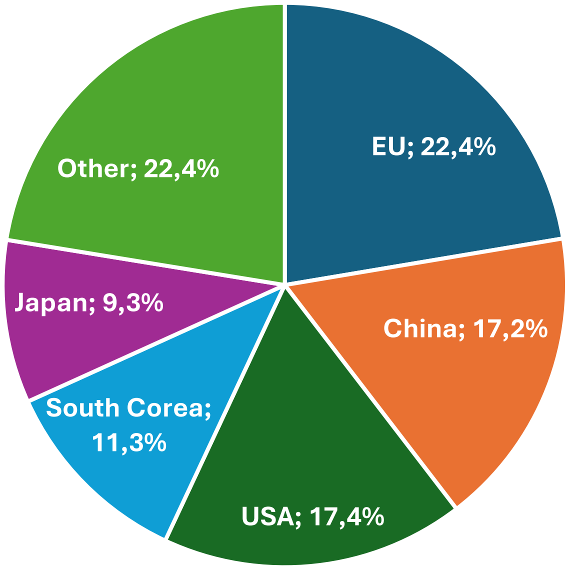


*Figure 9: AV Industry Actors per country*
*Source: Graph developed based on data from CCAM Global Observatory*

# 4 Innovation profiles

This chapter presents a set of innovation profiles related to CCAM services. It is a qualitative description in contradiction to Chapter 3, which focused on aggregated numbers.

The innovation profiles exemplify a broader shift in which innovation is increasingly driven by rapid technological advancement rather than traditional demand-pull dynamics. A key enabler is the accelerating development of digital technologies, particularly artificial intelligence (AI), sensing systems, and advanced computing. AI, in particular, is expected to play a disruptive role by enabling higher levels of autonomy. As these technologies evolve, they continuously redefine what is technically and commercially feasible within the transport sector.

At the same time, automated transport innovations are fundamentally data-intensive. The performance, safety, and scalability of these services depend on access to large volumes of high-quality data, collected from vehicles, infrastructure, and users. This reliance introduces cross-cutting considerations common to all profiles presented in this chapter. These include challenges related to data quality and validation, data sharing and interoperability, and the governance frameworks required to ensure secure and responsible data use.

Regulatory and safety considerations further shape the deployment landscape. European and national regulations for Level 4 driverless operations are still evolving, and uncertainties around liability, certification, cybersecurity and data governance can slow progress. In parallel, robust safety validation frameworks are required to provide assurance not only for automated driving functions but also for remote intervention capabilities, passenger experience and emergency procedures. These frameworks must mature alongside technology to avoid creating bottlenecks for large-scale rollouts.

The innovation profiles presented in this chapter should therefore be understood within this broader technological and systemic context. While each profile highlights specific service concepts and implementation pathways, they all share common dependencies and challenges related to technology development, data, safety, and regulation.

The profiles describe emerging CCAM-based services. Given the rapid pace of development, the innovation profiles should be considered examples and "snapshots" of the situation at the time the background information was collected (2025-2026). Therefore, they should not be interpreted as a definitive answer on the concrete and complete status here and now.

The profiles are structured as follows:

1) Introduction explaining the service and the related context
2) Examples of real-world deployments
3) Evidence of economic, social and environmental benefits. It is worth mentioning that these are largely expected effects, as there is little data to support them.
4) Challenges and research questions
5) Summary

## 4.1 Methodology

The innovation profiles are derived from a multistep approach, as illustrated in Figure 10.

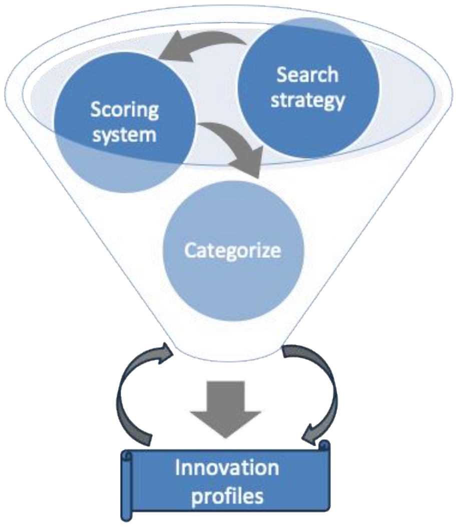


*Figure 10: AV Industry Actors per country*

**Step 1**: The innovation capacity is defined and broken down into sub-groups representing CCAM and market potential, as described in Chapter 2.

**Step 2:** The targeted results from the data mining procedures are identified, and keywords are selected.

**Step 3:** The data mining search strategy is defined and applied, using the selected keywords. Adjustments are made based on experience with search outcomes, e.g., hit rate for autonomous vs automated.

**Step 4:** A flexible scoring system is defined and applied. The scoring system filters the data to be considered for further analysis to create innovation profiles.

**Step 5:** The remaining data is analysed, categorized and transformed into a set of innovation profiles.

**Step 6:** The results from steps 3 and 4 were collected at an early stage of the project, and in general, at least 1 year old. Therefore, targeted manual search for updates on the respective innovation profiles was applied. The profile descriptions were updated accordingly in an iterative process.

Steps 1-4 are described in detail in the project Deliverable D3.2 "*Brief Ad hoc Innovation radar report (a)*[2]".

## 4.2 Self-driving shuttle

Self-driving shuttles are small autonomous vehicles typically carrying 1 to 30 passengers, designed for short-distance mobility in urban districts, campuses, business parks, airports, and rural communities. These shuttles are usually electric, operate at Level 4 autonomy, and function as part of public transport, providing first-/last-mile connectivity, on-demand mobility, or fixed-route circulators.

*Figure 11: Self-driving shuttle (Source:* Travel and Tour World, AI -generated)

### 4.2.1 Real-world shuttle deployments

Across Europe and worldwide, shuttles are transitioning from research pilots toward commercial deployment, supported by improvements in autonomous driving stacks, remote supervision, vehicle-to-infrastructure (V2I) communications, and integrated digital public transport systems. European initiatives such as CCAM, SHOW, ULTIMO and LivingLAPT are accelerating the scale-up of autonomous shuttle mobility, demonstrating an expanding ecosystem of operators, OEMs, and technology suppliers. [CCAM[3]] [SHOW[4]] [ULTIMO[5]] [LivingLAPT[6]]

The European piloting and deployment of self-driving shuttles has a longer history than many other CCAM deployments. Early piloting dates back to 2006-2011 and the EU-funded CityMobil project, which demonstrated self-driving shuttles in countries such as France, Italy, and the UK, followed by the CityMobil2 project in 2012-2016. [Cordis[7]] [CordisII[8]]. A first generation of trials using Navya and EasyMile vehicles established proof of concept across campuses, hospital sites and controlled urban routes in many European countries. Among these, five Norwegian pilots demonstrated the operational feasibility, integration with public transport daily operations and the legislation for testing automated vehicles on public roads between 2018 and 2019, followed by a number of Norwegian pilots from 2020 onward. [AET[9]] [Vy[10]] The EU-funded SHOW project ran demonstrations across 20 cities between 2021 and 2024 and provided substantial evidence based on the performance of technologies, user acceptance, and operational models in mixed urban environments. [EU Urban Mobility Observatory[11]] [Cordis[12]] The NIMFEA project in rural France demonstrated a 12-kilometre round trip in a sparsely populated area, showing the potential for filling mobility gaps in communities with limited public transport. [Future Transport News[13]] These earlier deployments were largely experimental in character, typically operating at low speeds with safety drivers on board, and did not translate into permanent services. They did, however, generate the operational data and regulatory experience that the current generation of programmes is now building on.

The ongoing EU-funded ULTIMO project deploys 45 driverless electric minibuses across Oslo, Norway; Herford, Germany; and Geneva, Switzerland. ULTIMO is explicitly designed to test a commercially viable on-demand public transport model, with services running 24 hours a day. Trials began in Oslo in February 2024, Herford followed in March 2025 with vehicles from manufacturer eVersum using ZF autonomous driving technology, and Geneva is planned for 2026. [Urban Transport Magazine[14]] [ULTIMO[15]]

The German KIRA project has been running Level 4 shuttles integrated with on-demand public transport in the RhineMain region since 2025, expanding into parts of Darmstadt in the second half of 2025, making it one of the first examples of autonomous shuttles operating as a genuine component of a regional public transport network. [KIRA[16]] [FutureTransport[17]] [ADAS & aut. vehicle[18]] [EU Urban Mobility Observatory[19]] Berlin's public transport operator BVG began the NoWeL4 project in October 2025 with five Level 4 VW ID.Buzz AD minibuses covering a 55-kilometre network across 80 stops, with passenger operations due in the first half of 2026. [EU Urban Mobility Observatory[20]] Hamburg's ALIKE project has MOIA testing up to 20 autonomous vehicles across a 37-square-kilometre urban area from mid-2025, bookable via an app, with a long-term ambition to deploy 10,000 vehicles across the city by 2030. [Hamburg Business[21]]

Renault Group and WeRide conducted their first European open-road trial in Paris during the Roland-Garros tournament in May 2024, covering 1,000 km and carrying nearly 700 passengers, and have since run further trials in Barcelona and at Zurich Airport for staff transport, with a commercial Level 4 service connecting a railway station to a business park in Valence, France targeted from July 2025. [Future Transport News[22]] [Renault Group[23]]

PostBus is launching its AmiGo service in Eastern Switzerland, offering bookable on-demand electric autonomous vehicles across four cantons, with test runs beginning in December 2025 and a fully driverless regular service planned from 2027. [PostBus[24]] [Connected Automated Driving[25]] The EU-funded LivingLAPT project is running Aurrigo Auto-Shuttles in Prague, Brno and Milton Keynes with an explicit roadmap toward remote supervision replacing onboard safety drivers. [ADAS & aut. vehicle[26]] [EIT Urban Mobility[27]] In the UK, the SAMS project in Sunderland demonstrated a public-road autonomous shuttle service in 2024 linking the city interchange, university and hospital, with a particular focus on remote supervision protocols. [ADAS & aut. vehicle[28]] [TTI[29]]

At the other end of the operational spectrum, a Level 4 shuttle service at the FM Logistic site in Escrennes, France has been transporting employees since 2024 with no onboard operator, illustrating how private logistics sites can provide a more controlled environment for early driverless operation. [CCAM KB[30]] EasyMile and Keolis also deployed two fully driverless remotely supervised shuttles at France's National Sports Shooting Centre ahead of the 2024 Paris Olympics, carrying spectators and athletes along a 1.5-kilometre route, and demonstrated that a single remote supervisor can manage multiple vehicles simultaneously. [Future Transport News[31]]

### 4.2.2 Evidence of economic, social and environmental benefits

Economic benefits are expected to arise from reduced operating costs, enabled by reduced reliance on human drivers and more efficient remote supervision. The shift toward automated operations also supports more flexible and scalable transport services, in which vehicles can be dynamically allocated based on demand rather than fixed staffing patterns. The shift towards replacing larger buses with low-capacity vehicles improves fleet utilisation and optimising operational efficiency across an entire mobility ecosystem. Furthermore, the sector is also beginning to generate new industrial value: the development of autonomous shuttle production facilities, such as those established by Benteler/HOLON, signals the emergence of new manufacturing capabilities and cross-regional innovation supply chains. [BENTELER[32]] [Future Transport News[33]]

The social benefits of autonomous shuttles are becoming increasingly visible through a range of real-world pilots. Early deployments in both rural and urban areas, university campuses, etc. have demonstrate improved mobility for all users, including those who traditionally face access barriers, including students, older adults, and those without access to private vehicles. By offering reliable first- and last-mile services, autonomous shuttles help fill gaps in existing service, particularly during off-peak hours when conventional public transport options may be limited. As these services are tested in real-world settings, large-scale European demonstration programmes such as SHOW have reported growing public familiarity and acceptance of autonomous transport. This progress is underpinned by structured user engagement, comprehensive safety validation exercises, and demonstration events that allow passengers to interact directly with the technology. [FutureTransport[34]] [ADAS & aut. vehicle] [ADAS & aut. vehicle II] [TTI] [SHOW[35]] [CCAM[36]]

Environmental benefits relate to the zero-emission vehicles. Beyond emissions, the operational design of shuttle services can help ease congestion: ride-pooling systems and integrated planning framework aim to shift shorter urban journeys away from private cars. Smaller vehicles with lower energy consumption and reduced spatial footprint offer further environmental gains, making autonomous shuttles particularly well suited to dense urban areas, compact campuses and airports where conventional vehicles can be inefficient or disruptive.

Most evidence, however, is derived from pilots and simulations rather than large-scale longitudinal data.

### 4.2.3 Challenges and research questions

From a technical standpoint, achieving robust Level 4 performance in complex urban environments remains a critical hurdle. Weather-related issues highlighted in ongoing weatherproofing work still limit reliability, particularly in regions with heavy rain, snow or fog. Additional complexity arises when shuttles navigate mixed traffic scenarios, where the behaviours of pedestrians, cyclists and manual operated vehicles can be unpredictable. Remote supervision and teleoperation introduce another layer of technical and organisational complexity: pilots show that scalable models are feasible, but questions remain around the optimal balance between automation and human oversight. Similarly, integration with city infrastructure especially traffic signals and broader V2X systems remains technically challenging.

Operational challenges relate to the real-world integration of autonomous shuttles into public transport systems. Pilots emphasises that public transport operators are central to deployment success, since they control key elements such as scheduling, ticketing, customer service standards and regulatory compliance. Meaningful integration requires that data flows, operational procedures and safety protocols align seamlessly between shuttle providers and established public transport authorities.

Business model sustainability is another open issue. Uncertainty of long-term cost structures and market opportunity, combined with existing long-term procurement contracts and processes, is hindering the willingness to invest. Ensuring a viable model for maintenance, charging infrastructure, vehicle replacements, staffing of remote-supervision centres, and insurance obligations will be critical to widespread adoption.

These challenges give rise to several key research questions that continue to drive innovation in the sector. A major focus is on understanding how autonomous shuttles can scale economically to citywide fleets. Closely linked is the question of optimal remote supervision ratios, how many vehicles a single operator can safely oversee, and how that number changes across different operational contexts. Research is also needed to determine how autonomous shuttle services can most effectively integrate with established public transport networks to maximise ridership, accessibility and social equity. Environmental research must quantify long-term climate benefits, accounting for mode shift, electrification, and system-level impacts on congestion and energy use. Finally, governance and liability frameworks must evolve to support hybrid mobility systems in which human-driven and autonomous vehicles operate together, ensuring clarity, safety and public trust as autonomous mobility becomes more widespread.

*Table 1: Self-driving shuttle summary*

| | |
|---|---|
| **Self-driving shuttle services** | - Short-distance mobility<br>- Urban districts, campuses, business parks, airports, rural communities, etc.<br>- Feeding into mobility hubs<br>- L4 minibuses/minivans, 1-30 pax |
| **Expected business benefit** | - Reduced operating costs<br>- More flexible and scalable transport services<br>- Increased fleet utilization |
| **Expected societal benefit** | - Improved mobility for all users, including those with access barriers like students and older adults<br>- Easier access to high-capacity public transport<br>- Fills the gap in existing services, especially in non-peak hours |
| **Expected environmental benefit** | - Zero emission<br>- Modal shift from private cars<br>- Reduced congestion |

## 4.3 Robotaxi

Robotaxi is an on-demand ride-hailing service by use of self-driving vehicles operating at Level 4 autonomy. Robotaxi vehicles are usually passenger-car-sized, seating 4-5 passengers. The service can be individual or shared. Robotaxi should not be interpreted as referring only to a conventional taxi service with automated vehicles. In the context of this report, robotaxis may also function as a supplement to public transport service, carrying multiple passengers with similar travel needs.


*Figure 12: Robotaxi (Source: AI-generated)*

### 4.3.1 Real-world robotaxi deployments

Robotaxi services are expected to grow rapidly across Europe as major players race to test them. Across Europe, ride-hailing provider Bolt will begin deploying Level 4 robotaxis with Pony.ai in 2026, starting with real-world testing in selected EU and non-EU cities before expanding to fully driverless operations; timelines and fleet sizes remain unspecified, but the partnership is positioned for continent-wide scaling. [Euronews[37]] [Bolt[38]]

Volkswagen plans to introduce autonomous taxis in Los Angeles later in 2026, partnering with Uber to commercialise the service. [TechCrunch[39]] [Uber[40]] Their Robotaxi unit, MOIA, already operates around 100 test vehicles across Europe and the USA, including 30 in Hamburg, and is now negotiating with additional European cities for a rollout planned from 2027 onward. Looking further ahead, Volkswagen aims for rapid scale-up: the company's long-term target is a fleet of 100,000 autonomous vehicles by 2033. [Financial times[41]]

Pony.ai has started testing in Luxembourg in partnership with Emile Weber. Luxembourg has developed a national strategy to deploy autonomous vehicles nationwide by 2028, supported by updated regulations. [RTL today[42]]

Baidu's Apollo Go robotaxi unit plans to put the first vehicles on the road in Switzerland from 2026, targeting commercial development across rural and peripheral regions. PostBus introduces a new mobility service, "AmiGo", by use of electric autonomous vehicles from Apollo Go. [Bluwin[43]] [le News[44]] [PostAuto[45]] Switzerland has granted authorisation for self-driving cars in the Furttal valley since 2025. [SWI[46]] Meanwhile, Waymo plans to enter the European market by launching driverless taxi services in London in 2026, pending regulatory changes. [BBC[47]] [TTI[48]]

In Norway, Ruter has been testing autonomous vehicles in Oslo since 2019, and public shared robotaxi services were launched in early 2025 as part of the ULTIMO project. Partnering with MOIA and Holo, Ruter is planning to further integrate shared autonomous mobility into the region´s public-transport network with a targeted fleet of 100-500 vehicles, starting in 2027. [TU[49]] [Ruter[50]] [Ruter II[51]]

NVIDIA and Uber are planning to scale-up to 28 cities with driverless operations across North America, Europe, Australia, and Asia by 2028. [Uber[52]]

The international robotaxi market is significantly more mature than the European. Baidu's robotaxi service, Apollo Go, is operating in 22 cities worldwide, with the majority in China. [le News[53]] [Bluwin[54]] Waymo is operating commercially in cities like Phoenix, Los Angeles, San Francisco, and Miami in the USA. [Assembly[55]] [ADAS & Aut. vehicle[56]] [ADAS & aut. vehicle II[57]] [FutureTransport[58]] Zoox expands AV testing to Austin and Miami using retrofitted Toyota Highlanders. [ADAS & Aut. Vehicle[59]] Meanwhile, Uber and WeRide are launching a jointly operated robotaxi service in Abu Dhabi and soon, Dubai, integrating WeRide's autonomous vehicles directly into the Uber app and marking Uber's first AV deployment outside North America and China. Uber and WeRide plan to expand their AV deployment to 15 additional cities worldwide over five years (outside USA and China) [WeRide[60]] [ADAS & Aut. vehicle[61]]

### 4.3.2 Evidence of economic, social and environmental benefits

Economic benefits are emerging from reduced labour needs, increased capacity utilisation, and lower operating costs. The initial technology investment is substantial and will shift the cost savings until the market matures and economies of scale are obtained. However, the rapid progress in deployment indicates high expectations for a profitable future market. From an individual perspective, the costs of car ownership will be replaced by mobility services at presumably lower cost.

Social benefits include increased mobility, as shared on-demand robotaxis offer flexible, tailored mobility services that supplement the rigid, high-capacity public transport and reduce the reliance on privately owned cars. The safety level is expected to increase significantly, as it eliminates human error and has a high capacity to analyse and resolve complex, conflicting traffic situations in real-time driving.

Environmental benefits are emerging from reduced emissions, as all AV vehicles are battery-electric. Automated driving is presumed to result in lower energy consumption. Furthermore, robotaxis are expected to reduce private car ownership and traffic, opening up for alternative land-use urban developments.

Most evidence, however, is derived from pilots and simulations rather than large-scale longitudinal data.

### 4.3.3 Challenges and research questions

Automated vehicle deployment is held back by technical, commercial, and regulatory challenges. The EU regulatory framework for automated driving is built on harmonized technical requirements. Industry reports, however, highlight the lack of scalable, purpose-built AV platforms and argue that public co-investment, early regulation, and industry risk-taking are needed to break the current stagnation. In the UK, this tension is clear: although Uber says its robotaxi technology is ready, national rules prevent deployment before 2027, despite earlier plans for 2026. [TTI[62]]

Priority research questions include scaling and operational challenges; economic viability and business models; regulatory and policy frameworks; integration in public transport; and safety, reliability, and public trust.

*Table 2: Robotaxi summary*

| | |
|---|---|
| **Robotaxi services** | - On-demand rail-hailing<br>- Individual or shared<br>- Passenger-car-sized vehicles, 4-5 pax |
| **Expected business benefit** | - Reduced operating costs<br>- Increased capacity utilisation<br>- Profitable future markets<br>- Private costs of car ownership replaced by mobility services at presumably lower cost |
| **Expected societal benefit** | - Increased flexible and tailored mobility<br>- Increased traffic safety<br>- Fills the gap in existing services |
| **Expected environmental benefit** | - Zero emission<br>- Lower energy consumption<br>- Modal shift from private cars<br>- Reduced congestion |

## 4.4 City logistics

Last-mile delivery represents the most complex, costly and labour-intensive segment of the logistics chain, where goods move through dense cities to reach homes, businesses or micro-depots. AVs are increasingly tested as a means to reduce congestion, lower emissions, and enhance operational efficiency in urban logistics ecosystems.

*Figure 13: City logistics (Source: AI-generated)*

### 4.4.1 Real-world city logistics deployments

Faction is trialling self-driving light EVs in Houston to perform curbside deliveries using its DriveLink autonomy system and TeleAssist remote support, with Verizon's centimetre-level location accuracy improving operational reliability. These vehicles deliver to real customers while collecting routing data to refine navigation algorithms. [ADAS & aut. vehicle[63]]

Clevon has expanded into the US market, deploying the Clevon 1 electric autonomous courier capable of navigating public roads to deliver groceries and appliances; its modular chassis adapts to multiple cargo types Kodiak Robotics and Martin Brower operate autonomous refrigerated freight runs between Dallas and Oklahoma City, completing more than 600 autonomous deliveries using a shuttle-lane model that blends long-haul autonomy with human-led last-mile distribution. [Assembly[64]]

Abu Dhabi has launched a major pilot of autonomous delivery vehicles developed by AutoGo, integrating them into noon's logistics network to service mini-fulfilment centres, aiming to lower congestion and emissions while advancing the city's 2040 smart mobility goals. [TTI[65]] The region has also approved fully commercial Level-4 robotaxi services (WeRide, AutoGo-K2), providing evidence that urban ODDs, digital oversight platforms and safety assurance frameworks can scale across real city environments. [ADmobility[66]]

European research initiatives like CHORUS and IN2CCAM explore integrated CCAM frameworks for multimodal mobility, including last-mile logistics pilots in cities such as Zürich, Trikala and Bari. Bari's Living Lab is testing route-planning tools, micro-hub-based delivery and AI-powered traffic optimisation. [CHORUS Project[67]] [In2CCAM[68]]

In addition, in Europe, autonomous delivery robots are also being tested for delivering food, groceries, and supplies. Wolt is delivering food in Finland [Coco Robotics[69]], REWE is delivering groceries in Germany [Retail Optimiser[70]] and URBANE (an EU funded project) is also testing them to deliver construction materials around worksites. [Urbane[71]]

### 4.4.2 Evidence of economic, social and environmental benefits

Economic benefits are emerging from reduced labour needs, optimised routing and more reliable fulfilment. Faction's trial demonstrates efficient curbside delivery with supervised autonomy, while Clevon reports potential reductions of up to 90% in labour costs for its autonomous courier deployments.

Social benefits include increased safety: Kodiak's autonomous trucking operations highlight improved reliability on long-haul routes, while IN2CCAM demonstrations emphasise inclusive mobility and safer multimodal transport design. Abu Dhabi's regulated deployments also enhance public trust through rigorous safety frameworks.

Environmental benefits stem from electrified autonomous fleets reducing tailpipe emissions. Clevon's lightweight EV platform supports energy-efficient freight, and Abu Dhabi's AutoGo deployment aims to lower congestion and emissions by modernising e-commerce fulfilment.

Most evidence, however, is derived from pilots and simulations rather than large-scale longitudinal data. European CCAM projects rely heavily on modelling to forecast impacts on congestion, inclusivity and network efficiency.

### 4.4.3 Challenges and research questions

Key challenges include scaling ODDs from controlled routes to diverse city environments, regulatory fragmentation across regions, ensuring safe kerbside operations, and balancing autonomous and human-led tasks in hybrid fleets. Urban AV logistics require harmonised data sharing, liability frameworks and interoperable infrastructure.

Priority research questions include: How can AV fleets demonstrate verifiable cost savings at scale? What are the measurable emissions impacts of city-wide autonomous logistics? How can regulators ensure safety for vulnerable road users at kerbside and pedestrian interfaces? What governance structures best support mixed human-autonomous logistics ecosystems?

*Figure 14: City logistics summary*

| | |
|---|---|
| **City logistics services** | - Last-mile delivery<br>- Dense cities<br>- All-size vehicles |
| **Expected business benefit** | - Reduced labour needs and operating costs<br>- Optimised routing<br>- More reliable fulfilment |
| **Expected societal benefit** | - Inclusive mobility<br>- Increased traffic safety<br>- Safer multimodal transport design |
| **Expected environmental benefit** | - Zero emission<br>- Lower energy consumption<br>- Reduced congestion |

## 4.5 Freight transport

While warehouse automation remains important, more transformative developments are occurring on the road where Level-4 autonomous trucks are already delivering freight daily, expanding corridors, and replacing manual long-haul segments with automated operations. Automated freight transport services cover two segments:

- Short-term: Short distances (e.g., hub-to-hub, drayage terminal–warehouse)
- Long-term: longer distances


*Figure 15: Freight transport (Source: AI-generated)*

### 4.5.1 Real-world freight transport deployments

The long-haul and middle-mile segments of freight transport face a critical driver shortage and the need to decarbonise. Worldwide, autonomous freight transport is developing rapidly, and extensive testing is underway. The freight sector is a bit behind passenger and midsize vehicles, though, both in terms of vehicles and services.

Since 2022, the EU-funded MODI project has been assessing the readiness of both physical and digital infrastructure for automated freight transport while demonstrating SAE Level 4 freight operations in real-world logistics environments. Demonstrations have been conducted on public roads and within logistics hubs in Norway, Sweden, Germany, and the Netherlands, providing evidence of how automated freight transport can be integrated into cross-border logistics operations and support its large-scale deployment across Europe. [MODI[72]] [HorizonMagazine[73]]

Einride has launched commercial, unmanned, electric freight vehicles capable of operating autonomously on predefined short-haul roads in Sweden and the USA. Commercial operations have been run at companies such as GE Appliances and APOTEA. Significant milestones came when an Einride autonomous truck completed the world's first driverless, cabless border crossing between Sweden and Norway as part of the MODI-project in 2025, and when Einride demonstrated the first autonomous truck ride in Belgium. [ConnectedAutomatedDriving[74]] [ADAS & aut. vehicle[75]] [Einride[76]] [ALICE[77]] [PortAntwerpBruges[78]]

By early 2026, Aurora´s Autonomy program, launched in 2024, has evolved from a limited pilot into a multi-lane freight network across the U.S Sun belt, preparing for hundreds of trucks on the road by the end of 2026. Commercial services are delivered to partners such as Uber Freight, Werner, FedEx, and Schneider. Aurora reports that their driverless trucks can travel farther distances faster than human drivers, due to the avoidance of resting hours [TechCrunch[79]] [Transport data[80]]

Aurora, Continental, and NVIDIA have formed a long-term strategic partnership to scale the deployment of driverless trucks. Together, the three companies aim to deliver a safe, reliable, and commercially scalable autonomous-trucking ecosystem capable of supporting thousands of driverless trucks. Mass production of autonomous-driving hardware is planned to begin in 2027. [Aurora[81]]

The TRATON Group and PlusAI expanded their partnership in January 2026 to accelerate the development and large-scale deployment of on-highway autonomous trucking solutions across the U.S. and Europe. This is a successor of the earlier operational testing performed under in 2024-2025, in which TRATON brands (Scania, MAN, Navistar/International) and Plus were running public-road testing and pilot programs. Furthermore, Plus partnered with TIER IV and Traton to expand autonomous trucking in Japan on expressways. [Traton[82]] [ADAS and aut. vehicles[83]] [Forbes[84]]

A UK feasibility study, eFreight Autonomous, was funded to assess the deployment of autonomous freight vehicles from a fleet operations perspective. In parallel, Berkeley Coachworks plans to develop autonomous freight vehicles, targeting real-world UK road trials, marking early steps towards real-world implementation. Results are expected by the end of 2027. [TTI[85]]

Volvo unveiled its first production-ready autonomous truck, integrated with Aurora Driver and built for commercial deployment in the USA back in 2024, marking a major milestone in the industry´s transition from pilot projects to real-world deployment. Furthermore, Volvo has operated a commercial automated service at a limestone quarry in Norway since 2023. [ADAS & aut. vehicle[86]] [Volvo[87]]

Since 2017, Transurban has completed numerous trials of fully and partially automated vehicles on highways in Australia and North America. Their and Australia´s first trial on highly automated self-driving trucks took place on the CityLink and the Monash Freeway in 2022, in live traffic conditions on public motorways. In 2024, IVECO partnered with Transurban and Plus to advance automated trucks in Australia. On-road pilot testing activity was expected to commence in early 2024. [ADAS & aut. vehicle[88]] [IVECO[89]]

IVECO and PlusAI launched a new Level 4 Autonomous Driving programme in Spain in 2026. Working in cooperation with the Spanish logistics operator Sesé and the Government of Aragon, the ambition is to develop heavy-duty trucks with Level 4 driving capabilities, targeted to operate autonomously along a freight corridor of approximately 300 km. Testing will start in 2026. [IVECO[90]]

Hyundai debuted the first Level 4 autonomous hydrogen fuel-cell truck in the U.S. back in 2024. Their collaboration with PlusAI on Hyundai Motor and PlusAI was recognised in TIME´s "Best inventions 2025" for revolutionising long-haul freight. [ADAS & aut. vehicle[91]] [PR newswire[92]]

Dubai completed initial real-world trials of driverless electric cargo trucks operating alongside other road users in the Dubai South logistics district. The initiative forms part of Dubai's broader autonomous transportation strategy, which aims to have autonomous solutions account for 25% of all journeys across the emirate by 2030. [ADAS & aut. vehicle[93]]

Gatik deploys fully driverless trucks at commercial scale in the United States, delivering daily for Fortune 50 retailers across Texas, Arkansas, and Arizona. The vehicles operate nearly 24 hours a day on public highways and surface streets, supporting continuous, real-world logistics operations. Gatik now operates autonomous truck deployments in Texas, Arkansas, Arizona, Nebraska, and Ontario, with plans to rapidly expand into additional markets. This progress builds on the company's ongoing collaboration with Isuzu Motors Limited. [Gatik[94]]

### 4.5.2 Evidence of economic, social and environmental benefits

Economic benefits arise from automation's capacity to address the projected driver shortage in Europe and globally. Furthermore, automation can improve operational efficiency by enabling continuous 24/7 operations, as autonomous systems do not require mandated rest periods, potentially reducing overall operating costs and increasing productivity. The full economic benefit is not expected to be realised until automation is sufficiently mature to be integrated into the logistics solutions.

Social benefits included improved road and operational safety, as automated transport can reduce accidents caused by driver fatigue or distraction on long-haul routes.

Environmental benefits arise from more energy-efficient driving resulting from autonomous systems that optimise acceleration and braking. When paired with zero-emission autonomous trucks, carbon emissions for middle-mile routes can be eliminated entirely. Furthermore, introducing battery-electric or hydrogen fuel-cell trucks will result in significant noise reduction.

### 4.5.3 Challenges and research questions

Automated transport will not reach its full potential without being integrated into the overall logistics system. This comprises taking care of all the operations drivers are conducting today, in addition to the driving task itself. This comprises operations such as automated loading and unloading, charging, access control, customs procedures, and digital documentation.

Long-haul freight transport faces challenges regarding border crossing. Harmonising regulations and physical and digital infrastructure to allow automated trucks to cross seamlessly between countries is a major hurdle.

As for all Innovation Profiles, mixed traffic interaction will be a challenge in the foreseeable future. Automated freight vehicles must coexist with human drivers and other road users in traffic. Safe interactions with unpredictable human drivers on both high-speed motorways and short-distance low-speed environments must be given close attention when preparing for deployment.

Physical and digital infrastructure is critical for operating in an extended Operational Design Domain (ODD). This comprises challenges such as identifying and supporting requirements (e.g., infrastructure design, road markings, communication equipment, high-power charging hubs). One specific hindrance is the alignment of who should be the responsible actor for making the investments in supporting infrastructure.

Most evidence, however, is derived from pilots and simulations rather than large-scale longitudinal data.

*Table 3: Freight transport summary*

| | |
|---|---|
| **Freight transport services** | - Freight delivery<br>- Long-haul transport |
| **Expected business benefit** | - Reduced labour needs and operating costs<br>- Improved operational efficiency<br>- Increased productivity |
| **Expected societal benefit** | - Increased road safety<br>- Increased safety in logistics operations |
| **Expected environmental benefit** | - Zero emission<br>- Lower energy consumption<br>- Reduced noise |

## 4.6 Remote operation

Remote operation is an emerging method to vehicle control in which the vehicle is operated from a location outside the vehicle itself. Remote operation serves as a third mode of vehicle control, complementing human drivers and automated driving systems (ADS). Remote operation can be performed in two ways: (1) remote assistance, where a remote operator provides guidance or temporarily takes over control when the ADS encounters a difficult situation or reaches its operational limits, and (2) remote driving, where the vehicle is driven entirely remotely.


*Figure 16: Remote operations (Source: AI-generated)*

### 4.6.1 Real-world remote operation deployments

The system relies on a complex IT infrastructure that integrates communication technology, sensors, actuators, control centres, and interfaces. Remote operations require reliable connectivity, dependable vehicle systems, and operators who can maintain situational awareness. However, in remote assistance, the vehicles are autonomous by default. In case of need for help, the vehicle stops safely and requests assistance from the remote operator. For example, Nissan's Seamless Autonomous Mobility (SAM) system combines in-vehicle AI with remote human support and cloud-based knowledge and data sharing across vehicles. [Nissan[95]]

Remote assistance introduces a control model that bridges conventional driving and fully autonomous operation. Rather than directly controlling the vehicle, remote operators provide guidance and support when automated systems encounter challenges. This requires dedicated control centres and specially trained personnel. Examples include Nissan's SAM mobility managers and Einride's remote operators, who monitor vehicles and assist in complex situations to ensure safe and efficient operation. [Einride[96]]

Real-world deployments exist in several domains, including passenger mobility, freight, shuttle and construction. They differ in the extent to which the remote human is involved.

Vay introduced remote driving services in Europe and the USA, where human drivers control the vehicles remotely. The core idea is that human drivers always stay in control, supported by technology that enhances their abilities rather than replacing them. The system emphasises a safety-by-design approach, integrating vehicle systems, remote driving stations, operational procedures, and thorough verification and validation processes. Vay employs numerous safety measures; for instance, if a connection fails, the vehicles automatically perform minimum risk manoeuvres, such as stopping safely with hazard lights. The company has received approval to operate remotely driven vehicles on public roads in Germany and has operated in Hamburg and Berlin. Vay claims tele-driving technology can boost vehicle redistribution efficiency by up to 200%. [Vay[97]] [Urban Mobility Observatory[98]]

Einride is an example of freight logistics. In Sweden, near Stockholm, an autonomous self-driving truck operated between two warehouses for pharmaceutical magazines. The truck drove fully autonomously within the warehouses' private areas. It travelled a short distance on the public road, which, due to legal regulations, requires a remote human operator. The operator was based 500 km away in Gothenburg. In challenging situations, the AI requested approval to proceed, as required by safety regulations. Einride states that these self-driving trucks are ideal for medium- to short-distance travel, repetitive tasks, high volume, and consistent operations. Einride demonstrates a model in which automated driving is the default, but human-report support is maintained for supervisory functions and to remain legally compliant. [DW[99]]

EasyMile uses remote supervision to support its automated shuttles and heavy-duty vehicles. In a tourist spot in Terhill, Belgium, five driverless shuttles operate as a real service after pilot testing, transporting 200 passengers per hour on private land. [Urban Transport Magazine[100]] Additionally, EasyMile runs a shuttle service at the Oncopole medical campus in Toulouse, France, without on-board supervisors, and driverless tractors in the Port of Helsingborg in Sweden. [GCR[101]] [ADAS and aut. vehicle[102]] Its vehicles are designed with sufficient safety and redundancy to allow a control centre to supervise multiple vehicles simultaneously, improving scalability. The DriveU.auto platform manages remote supervision of EasyMile's shuttles, with a "human in the loop" ready to intervene if needed—a requirement in some countries. Communication occurs via public cellular networks, which can be unreliable; thus, high-quality, low-latency video connectivity is essential for safe, effective supervision. EasyMile also reports expanding its remote operation capabilities.

In the United States, Teleo provides autonomous technology to address labour shortages. The technology allows Tomahawk's machine operator to remotely control three Teleo-equipped articulated dump trucks from a command centre 65 km away. Tomahawk has added autonomous features to its machines, meaning that when set to autonomous mode, they can carry out routine, repetitive tasks, such as transporting materials from one site to another, independently. For more complex tasks that the autonomous system cannot yet fully manage, the machine pauses until the operator takes over. The remote operator can switch between machines with a single button press. [ADAS & aut. vehicle[103]]

### 4.6.2 Evidence of economic, social and environmental benefits

The references below to [BASt], [ADAS & aut.vehicle] and [Urban Mobility Observatory] are the same URLs presented in sub-chapter 4.6.1. Therefore, these are not repeated in the list of references in Chapter 7.

The economic benefits of remote operation arise from reduced labour costs, increased operational efficiency, and higher productivity. Highly automated vehicles and machines can operate for extended periods, requiring human intervention only when necessary. As demonstrated by the Florida example, remote operations can also help address the driver shortage. [ADAS & aut.vehicle] Remote operation can further improve the efficiency of mobility services by streamlining vehicle maintenance, delivery, and collection. For instance, vehicles could be delivered directly to customers, eliminating the need for pick-up trips. [Urban Mobility Observatory]. Additionally, remote operation reduces reliance on the traditional one-driver-per-vehicle model. In automated driving, human involvement is typically limited to exceptional situations, allowing larger fleets to be managed with fewer staff and lowering labour costs. It can also increase fleet utilisation by enabling near-continuous operation, unconstrained by the working-time regulations that apply to conventional drivers.

Expected social benefits include increased road safety, improved traffic flow, and enhanced operational efficiency and transport system performance in complex traffic environments. [BASt] It may also help reduce congestion and offer a more sustainable alternative to conventional transport methods [Urban Mobility Observatory]. Remote operations can increase public trust in automated vehicles by maintaining a human oversight role and providing a fallback in case of system failure. Furthermore, remote operation reduces the need to expose skilled workers to hazardous environments. Despite these benefits, safety remains the key challenge, particularly ensuring a reliable and secure communication link between the remote operator and the vehicle.

Literature indicates remote operation may carry environmental benefits through being a basis for more sustainable ecological mobility alternatives in the transport sector. [BASt] Furthermore, remote operations being an absolute prerequisite for automated driving in general, it contributes to the environmental benefits outlined in the previous Innovation Profiles.

Most evidence, however, is derived from pilots and simulations rather than large-scale longitudinal data.

### 4.6.3 Challenges and research questions

Key challenges in remote vehicle operation concern safety communication reliability, human factors and legal responsibility.

Remote operation depends on communication networks, whose reliability can be affected by data transmission and video feed quality. Risks include connection loss or delayed data transfer, which are critical during driving and changing street conditions. Moreover, continuous remote driving using high-resolution video streams will place greater demands on latency, bandwidth, IT security, and connection stability. [BASt] It can also introduce new risks related to the reliability of data and video feeds and the potential for the remote operator to miss critical context in the driving environment. [Urban Mobility Observatory]

Remote operation presents human-related challenges. Remote operators may have lower situational awareness than drivers physically in the vehicle, as they depend on camera feeds, interfaces, and transmitted data, increasing the risk of missing important context. [BASt] There is also a risk of reckless driving by remote operators. Furthermore, an operator may become overworked and less focused when handling a high workload and managing numerous vehicles.

Challengers also concern legal responsibility. Remote operation raises questions about who is legally driving the vehicle and who will be liable if something goes wrong. Another aspect is the harmonisation of regulations opening for remote operations from another country. Additionally, it questions which technical standards should be mandatory and how quality can be ensured when a single operator is responsible for multiple vehicles. Moreover, there are labour concerns arising from remote assistance, such as how many vehicles can be assigned to a single remote operator and how to ensure service quality. [Science Direct[104]]

A recent public debate has arisen about Waymo. Waymo uses remote operation as an assistance tool for navigating difficult scenarios. There has been recent controversy, as the company employs remote operators based in the Philippines. The company states the personnel did not drive the vehicles, just provided advisory support in difficult situations when the automated system was triggered. However, the debate raised questions about the knowledge of local traffic regulations of the staff. [Reuters[105]]

Future research should focus on the safety of remote operations, particularly network connectivity, data transfer delays, and safety features for connection failures.

Research should also examine the legal aspects of remote operations, including who is legally driving the vehicles, who is liable if something goes wrong, what minimum standards should be mandatory, and how labour concerns related to overworking staff can be addressed.

| | |
|---|---|
| **Remote operation services** | - Remote assistance<br>- Remote driving |
| **Expected business benefit** | - Reduced operating costs<br>- Improved operational efficiency<br>- Increased productivity<br>- Increased fleet utilization |
| **Expected societal benefit** | - Increased road safety<br>- Improved traffic flow<br>- Enhanced system performance in complex traffic environment<br>- Increased public acceptance |
| **Expected environmental benefit** | - Reduced congestion<br>- Indirectly contributes to environmental benefits in other Innovation Profiles |

# 5 Regulatory Maturity

Regulation is both a prerequisite and an enabler for innovation and scaling of CCAM services.

The regulatory environment across Europe and globally is evolving very quickly. This report builds on previous analysis undertaken by the CCAMbassador project, which previously consolidated a regulatory picture across Europe in July 2025 [FAME[106]].

At that time, the primary focus was on regulatory frameworks for testing, data sharing from those tests, and small-scale deployments. Over the past ~12 months, rapid shifts have been underway, with a regulatory majority in the UK now forecasting scaled deployments by Waymo and Wayve in London by autumn 2026. At the same time, the United Nations Economic Commission for Europe (UNECE) Working Party on Automated/Autonomous and Connected Vehicles (GRVA) has adopted draft regulations, including UNR 171 DCAS Phase 3 (covering lower levels of autonomy and laying the groundwork for future higher levels) and the L3/4 ADS Regulation, which addresses more advanced levels of automation.

Below we provide a snapshot of a) the global picture, b) the UK picture, where regulation is very advanced and c) the European picture.

## 5.1 The global picture

The following desk research has been done via manual web research to cover the status of existing regulations allowing the test or in more mature regions the deployment of L4 automated vehicles on public roads. The scope was intentionally expanded to global research to allow for regulatory comparison within the European Union and worldwide.

The status has been summarised in a dynamic world map highlighting the countries that allow for L4 deployment (dark blue) and L4 testing (green).

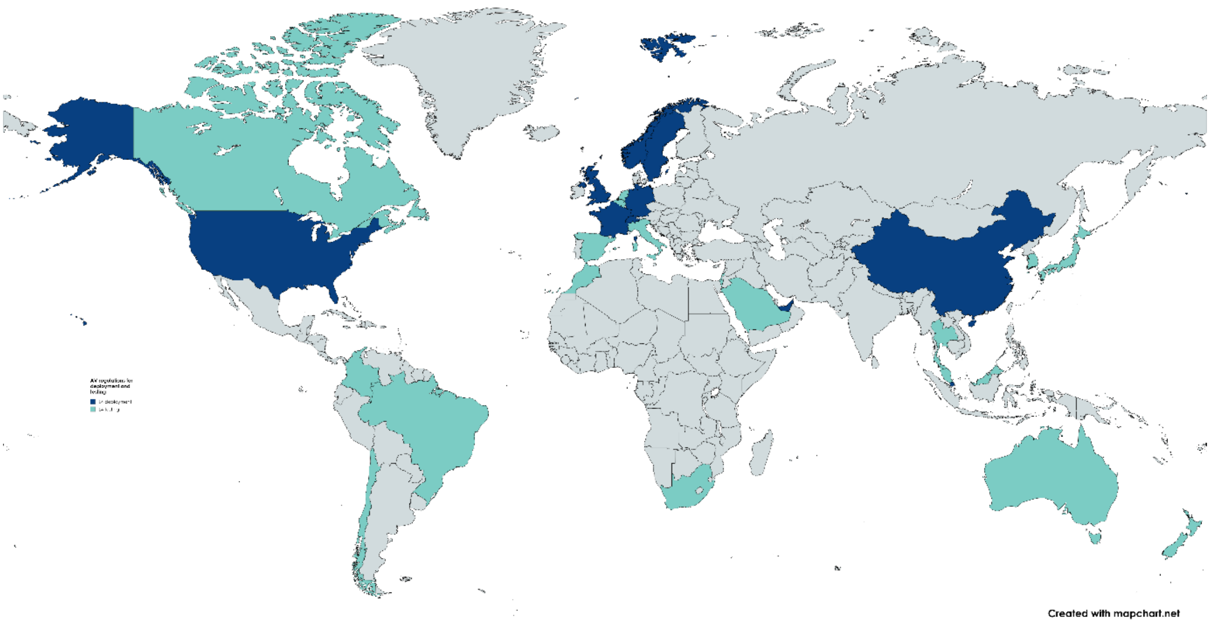


*Figure 17: AV regulations for deployment and testing*

By June 2026, 9 countries had enacted laws supporting the commercial deployment of L4 automated vehicles. In addition, 19 countries support testing of L4 automated vehicles either through laws or local permits. Going forward, countries like Canada and Japan, which are currently supporting L4 testing, are expected to pass laws for L4 deployment in the foreseeable future.

A more detailed narrative of this analysis and the data found through the research can be found in our Deliverable D3.1.

## 5.2 The UK is moving at pace

The UK has one of the most mature self-driving regulations globally and has provided a valuable reference point for regulatory shape and structure that the rest of Europe and beyond can turn to.

**Primary legislation**: The Automated Vehicles Act 2024 was passed by UK parliament in May 2024 and provides the core structural attributes of a legal framework, with key characteristics that include:

- Regulatory and Authorisation Framework: The Act establishes a formal authorisation regime requiring automated vehicles to pass a defined “self-driving test” and meet government safety principles before deployment. Regulators can approve, modify, suspend, or revoke permissions. This ensures only systems proven capable of safe autonomous operation are legally permitted on public roads.
- Legal Roles and Accountability Model: The Act introduces new legal actors, including the Authorised Self-Driving Entity (ASDE), User-in-Charge (UiC), and No-User-in-Charge operator. Responsibility for driving shifts from the human to the system provider when automation is active, clarifying liability and aligning legal responsibility with control of the vehicle.
- Enforcement, Sanctions and Oversight: Authorities are granted enforcement powers including issuing penalties, compliance notices, and investigating incidents. The Act creates offences for non-compliance and enables ongoing regulatory oversight. These mechanisms ensure operators maintain safety standards throughout a vehicle’s lifecycle, not just at initial approval.
- Consumer Protection and Marketing Rules: The Act restricts the use of terms like “self-driving” to vehicles that meet strict legal definitions. This prevents misleading marketing and protects consumers from confusing driver-assistance systems with full autonomy, fostering trust and ensuring transparency about what automated vehicles can safely do.

The UK has begun the implementation of secondary legalisation, a critical step to realising the regulatory potential enabled by the Act. Secondary legislation including ‘Protected Terms’ and ‘Advanced Passenger Services’ are expected to be implemented in 2026 to enable the first commercial scale deployments of self-driving services in Autum 2026. With other secondary legislation being worked on including ‘Statement of Safety Principles’ and ‘Licencing Frameworks’.

## 5.3 EU gathering momentum

A pivotal focus for EU regulation in self-driving is the recent United Nations European Commission for Europe (UNECE) Working Party on Automated/Autonomous and Connected Vehicles (GRVA) which in January 2026 formally adopted the 'draft ADS regulations' the group has been developing for a number of years. This addition covers a draft UN regulation for ADS (type approval countries) and a draft global technical regulation. The core principals of this regulation are safety first, evidenced based regulation, technology neutral, continuous compliance, and global harmonisations, and covers key technical attributes including:

- Safey case approach
- Safety management systems
- Validation and testing frameworks
- In service monitoring and data recording
- Operational Design Domain
- Performance requirements
- Type approval and regulatory approval
- Post deployment safety

Following draft adoption by GRVA, the regulation enters a formal multilateral approval process before it becomes operational law. The draft UN Regulation (under the 1958 Agreement) and the draft Global Technical Regulation (GTR under the 1998 Agreement) are first submitted to the UNECE World Forum for Harmonization of Vehicle Regulations (WP.29) for formal consideration and voting, typically at a subsequent plenary session. If adopted, the UN Regulation becomes binding for contracting parties that apply it, requiring national or regional transposition into domestic type-approval frameworks, while the GTR serves as a non-binding template requiring separate domestic rulemaking by each jurisdiction. Prior to and during this phase, further technical refinement may continue through guidance and interpretation documents and the completion of outstanding provisions, such as data recording or validation requirements. Once adopted, implementation is not immediate: regulators must establish administrative procedures, approval authority capabilities, and compliance infrastructure. In practice, this is followed by substantial secondary legislation and regulatory instruments at national or regional level, including detailed approval processes, enforcement mechanisms, and potentially complementary rules (e.g. cybersecurity, software updates, and operational restrictions). The framework therefore evolves iteratively, with the primary regulation providing high-level requirements, supplemented by subsequent technical standards, guidance, and amendments as operational experience with ADS deployment matures.

# 6 Conclusions and reflections

The implementation of the Innovation Radar within the CCAM-ERAS project represents a first step toward continuously identifying and assessing technological developments in the rapidly evolving CCAM domain. While this project confirms the methodology's foundational value, it also contains limitations and areas for further development.

## 6.1 Reflection on the methodology

The implementation of the Innovation Radar within the CCAM-ERAS project has followed a structured and effective methodology to regularly identify and assess technological developments in the rapidly evolving CCAM domain. The tool facilitates search capacity, providing a clear framework to process the large volumes of information that can be collected, and to derive trends and identify key innovations in the CCAM field.

Furthermore, the Innovation Radar framework presents a comprehensive approach to mapping the market potential and impact capacity of CCAM, covering technology readiness, impact, market readiness, and the innovator ecosystem, using both quantitative data and qualitative insights. This approach has proven to be a strong starting point for understanding the state of CCAM technologies and their potential societal effects.

The methodology's structure has worked well to organise and analyse the information. The mix of both technical and societal factors provides a balanced view of the innovation landscape.

The comprehensiveness and relevance of the results obtained heavily depends on the identification of suitable sources and up-to-date information. The analysis of the collected data mostly serves to inform trends, achievements and other qualitative results. The implementation of the methodology showed that quantitative analysis involving different source platforms, can lead to overcounting or uncertainty of the completeness of the obtained data. It was thus preferred to select a single, trusted and complete source for such cases.

The study of CCAM's market readiness, the state of industry and technology, trends, and key actors involved has gained interest and relevance as the technology matures, operational services are developed, and questions about strategies for technological sovereignty and global positioning are raised. In this context, the CCAM-ERAS innovation radar approach, with its mapping of CCAM impact, technology readiness, market potential and actor ecosystem, can support further analysis and studies. In conjunction with its data scraping methodology, it can help strengthen knowledge collection and management, including the CAD Knowledge Base and its CCAM Observatory.

# 7 References

List of URLs used in the search strategy – step 3, see Chapter 4.1.

| № | Source / URL | Search Terms / Key words |
|---|---|---|
| 1 | ADAS & Autonomous Vehicle International | Autonomous vehicle prototype test |
| 2 | Assembly | Topics » Autonomous & Electric Mobility » Autonomy |
| 3 | CCAM | News & events » CCAM News |
| 4 | Connected automated driving.eu | News |
| 5 | Future Transport News | Autonomous vehicle |
| 6 | SAE International | Filter by trends: Autonomous; Automated |
| 7 | Traffic Technology Today (TTI) | News » Autonomous Vehicles & ADAS |
| 8 | Zenzic | CAM Community » News, Blogs & Case Studies |

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