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Abbreviations

Abbreviation	Definition
4G	Fourth-generation mobile telecommunications – A mobile communication standard (LTE) that enables broadband connectivity for vehicles and transport systems, supporting early connected mobility services.
5G	Fifth-generation mobile telecommunications – An advanced mobile communication standard offering high data rates, low latency, and high reliability, considered a key enabler for advanced CCAM services.
6G	Sixth-generation mobile telecommunications – A future, emerging communication standard expected to support ultra-low latency, high data throughput, and advanced sensing capabilities for next-generation mobility systems.
ADAS	Advanced Driver Assistance Systems – In-vehicle systems that provide safety and convenience functions (e.g. lane-keeping, adaptive cruise control) to assist the driver.
ADS	Automated Driving System – The hardware and software that enable a vehicle to drive itself autonomously (often referring to the self-driving technology stack).
AFIR	Alternative Fuels Infrastructure Regulation — the EU regulation on the deployment of alternative fuels infrastructure, formally Regulation (EU) 2023/1804.
AI	Artificial Intelligence – Computer systems or algorithms able to perform tasks that typically require human intelligence, such as perception, decision-making, and learning.
AMRs	Autonomous Mobile Robots – Self-navigating robots used in logistics, warehousing, and industrial environments to transport goods without fixed infrastructure.
AR	Augmented Reality — Technology that overlays digital information (images, data, etc.) onto the real-world environment, often through devices like smart glasses or mobile screens.
AS/RS	Automated Storage and Retrieval System(s) – Computer-controlled systems used in warehouses and distribution centres to automatically place and retrieve loads from defined storage locations.
AV	Autonomous Vehicle – A self-driving vehicle capable of operating without a human driver by using sensors, cameras, and AI to navigate. (In this report,

Abbreviation	Definition
	often referring to vehicles with high automation, such as SAE Level 4 vehicles.)
CAV	Connected and Automated Vehicle(s) – Vehicles that combine automated driving functions with connectivity to other vehicles, infrastructure, and digital services through communication technologies.
CCAM	Connected, Cooperative, and Automated Mobility – An umbrella term for next-generation transport systems where vehicles are connected (able to communicate with each other and infrastructure), cooperate with traffic management, and have automated driving capabilities.
CCAM-ERAS	*CCAM – Employment Realisation through the Acquisition of Skills* – The name of the European project under Horizon Europe focusing on the workforce and skills aspects of CCAM deployment (this project produces Deliverable D5.1).
CEDEFOP	European Centre for the Development of Vocational Training – An EU agency that supports the development of VET policies through research, skills intelligence, and analysis of labour market and training trends.
ENISA	European Union Agency for Cybersecurity
EU	European Union – A political and economic union of 27 member states in Europe, which funds and regulates many transport and research initiatives relevant to this report.
EV	Electric Vehicle. In EU usage, this generally refers to a vehicle powered wholly or partly by electricity, including battery-electric and plug-in hybrid vehicles
ICT	Information and Communication Technology – A broad category covering digital technologies such as software, networks, data systems, and telecommunications that enable connectivity, data exchange, and system control in CCAM.
ITF	International Transport Forum
ITS	Intelligent Transport Systems
GDPR	General Data Protection Regulation – The EU's strict data privacy and protection law, which governs how personal data (including data from connected vehicles and sensors) must be handled and protected.
HEI	Higher Education Institution(s) – Universities and similar institutions providing advanced education and research, including engineering, ICT, and interdisciplinary skills relevant to CCAM development and governance.

Abbreviation	Definition
LaaS	Logistics as a Service – A service-based logistics model in which transport, warehousing, and fleet operations are provided through integrated digital platforms rather than owned assets.
LiDAR	Light Detection and Ranging – A sensor technology that uses laser light to measure distances and create precise 3D maps of the environment; commonly used by autonomous vehicles for detecting obstacles and surroundings.
M2M	Machine-to-machine communication – Automated data exchange between devices or systems without human intervention, supporting real-time coordination between vehicles, infrastructure, and digital services.
MaaS	Mobility as a Service – An integrated transport model where users can plan, book, and pay for multiple types of mobility services (public transit, ride-sharing, bike rental, etc.) through a single digital platform.
NACE	Statistical Classification of Economic Activities in the European Union.
ODD	Operational Design Domain – The specific conditions under which an automated driving system is designed to function. The ODD defines the environment and scenarios (such as types of roads, weather, speed range) where the vehicle can operate in autonomous mode.
OEM	Original Equipment Manufacturer – A company that designs and produces vehicles or vehicle components, and is responsible for system integration, compliance with safety and regulatory requirements, and lifecycle management.
OTA	Over-the-air – The remote delivery of software and firmware updates to vehicles and systems via wireless communication, enabling continuous improvement, security patching, and compliance updates.
PESTLE	Political, Economic, Social, Technological, Legal, and Environmental – An analytical framework used to examine the external factors affecting a project or industry. (In this context, a PESTLE analysis was conducted to understand the broader context for CCAM.)
R&D	Research and Design
SAE	Society of Automotive Engineers – Refers here to the **SAE International** standard J3016, which defines levels of driving automation from 0 (no automation) to 5 (full automation). For example, *SAE Level 4* indicates a high level of vehicle autonomy within set conditions.
SAVs	Shared Automated Vehicle(s) – Automated vehicles designed for shared use (e.g. robotaxis or automated shuttles), often operated as part of mobility-as-a-service systems.

Abbreviation	Definition
SME	Small and Medium-sized Enterprises
UITP	Union Internationale des Tranports Publics / International Association of Public Transport
V2X	Vehicle-to-Everything – A broad term for vehicle communication with any relevant entity, including other vehicles (V2V), infrastructure (V2I), pedestrians or networks. V2X connectivity supports cooperative driving and informed decision-making by automated vehicles.
VET	Vocational Education and Training – Education and training programmes focused on practical skills and occupational competence, playing a key role in preparing technicians and operators for CCAM-related roles.
VR	Virtual Reality – An immersive technology that simulates a complete digital environment, often experienced through VR headsets. (Used in training or visualisation, e.g. to simulate driving scenarios for operator training.)
WP	Work Package – A component of a research or innovation project that groups related tasks and deliverables. (For example, *WP5* in CCAM-ERAS refers to the project phase dealing with skills development and workforce adaptation.)

Executive summary

Connected, Cooperative and Automated Mobility (CCAM) is expected to alter how transport systems are designed, operated, maintained and governed in Europe. These changes extend beyond vehicles and infrastructure. They affect the organisation of work, the allocation of tasks between humans and automated systems, and the skills required across the full CCAM value chain. Anticipating how skills demand may evolve is therefore essential for ensuring that CCAM deployment is both operationally viable and socially sustainable.

This report, CCAM-ERAS (Connected, Cooperative and Automated Mobility – Employment Realisation through the Acquisition of Skills) Deliverable D4.5, provides a forward-looking analysis of CCAM-related skills needs across sectors and enabling functions. It forms part of Work Package 4 (WP4) of the CCAM-ERAS project and contributes the skills foresight perspective within WP4. The analysis does not aim to predict precise employment levels or future job numbers. Instead, it identifies credible directions of change in skills demand, potential bottlenecks and mismatches, and the conditions under which these may emerge.

Analytical approach and scope

The analysis is based on a synthesis of desk research, sectoral analysis, stakeholder interviews, survey evidence and structured skills foresight consultations conducted within the CCAM-ERAS project. An open online survey generated 19 responses from stakeholders across industry and education and training providers. In addition, 20 semi-structured interviews were conducted with representatives from industry, higher education institutions (HEIs), vocational education and training (VET) providers, representative organisations and road transport operators.

The foresight component was further informed by five structured consultation moments: the CCAM-ERAS Stakeholder Workshop (Brussels, 26 November 2024), the International Transport Forum (ITF) Roundtable (Paris, 6–7 February 2025), the Intelligent Transport Systems (ITS) European Congress (Seville, 19–21 May 2025), the International Association of Public Transport (UITP) Conference (Hamburg, 16–18 June 2025), and the CCAM-ERAS WP4 Validation Workshop (Brussels, 19 November 2025). These consultations provided expert validation and cross-sectoral reflection on emerging skills trends.

These sources were combined to identify recurring patterns across sectors rather than isolated signals. Skills needs are highlighted where they appear consistently across multiple sources or contexts and treated more cautiously where evidence is limited or divergent.

The report covers the CCAM value chain and key enabling functions. This includes vehicle and system development and manufacturing; passenger transport and shared mobility; freight transport and logistics; maintenance, repair and service activities; information and communication technologies; and enabling sectors such as civil engineering, energy and charging infrastructure, insurance and risk-related services, professional and technical services, education and training provision, and public administration and regulatory authorities. The analysis considers both technical skills and broader competences related to safety, supervision, service delivery and governance.

To support comparison across sectors, the report uses three indicative time horizons: short term (0–5 years), medium term (5–10 years) and long term (10+ years). These horizons are analytical reference points rather than uniform deployment forecasts. CCAM uptake remains uneven across use cases, regions and regulatory contexts, and skills demand is therefore expected to emerge at different speeds and in different forms across the value chain.

Policy and governance as drivers of skills demand

A central finding of the analysis is that CCAM-related skills demand is shaped as much by policy and governance as by technological capability. Regulation affects not only when CCAM applications can be deployed, but also which actors carry responsibility for safety, compliance and oversight. This has direct implications for skills demand across industry and public authorities.

Safety regulation and type approval increasingly treat automated driving as a system-level capability rather than a collection of discrete components. This places growing emphasis on skills related to system validation, safety assurance, documentation, simulation assessment and in-service monitoring. Data protection, data access rules and emerging obligations under European Union (EU) digital legislation further increase demand for skills related to data governance, cybersecurity and compliance. Artificial Intelligence (AI) governance and evolving liability frameworks introduce additional requirements for legal-technical understanding and cross-functional coordination.

Policy timelines also shape the sequencing of skills demand. Near-term regulatory requirements tend to concentrate skills needs in organisations involved in pilots and early deployments, as well as in public authorities responsible for approvals and oversight. Over time, as compliance baselines broaden, skills demand is expected to spread more widely across the value chain. The analysis therefore treats policy as a key timing and distribution mechanism for skills demand, rather than as an external constraint.

Sectoral patterns of skills change

Across manufacturing, CCAM is associated with a continued shift towards software-defined vehicles and systems. Skills demand increasingly combines mechanical, electronic and digital competences, with growing importance of software engineering, systems integration, sensor technologies, data analysis and cybersecurity. While many traditional manufacturing tasks remain, their relative importance declines as automation, electrification and digitalisation advance. The analysis suggests that long-term skills demand in manufacturing will concentrate in specialised roles combining deep technical expertise with assurance, compliance and governance competences.

In the sale, maintenance and repair of motor vehicles, CCAM contributes to a gradual reconfiguration of tasks rather than abrupt job loss. Manual inspection and routine mechanical work decline in relative importance, while skills related to diagnostics, data-enabled maintenance, software updates and system integration grow. Medium-term risks of skills mismatch appear particularly pronounced in this sector, as existing training pathways may struggle to supply hybrid technical-digital profiles at sufficient scale. Long-term demand points towards higher educational attainment and stronger digital foundations within the workforce.

Freight transport and logistics show a pattern of task reallocation rather than full automation of roles. CCAM applications in hubs, terminals and controlled environments tend to advance faster than in complex open-road operations. Skills demand shifts towards supervision of automated processes, exception handling, coordination across actors and data-driven planning. The analysis highlights growing demand for skills that combine operational understanding with digital systems literacy, particularly in roles linked to fleet management and logistics coordination.

In passenger transport and shared mobility, CCAM is expected to alter front-line roles through partial automation and remote support rather than through complete removal of human involvement. Skills related to customer interaction, safety assurance and service management remain important, but increasingly combine with digital monitoring, system oversight and coordination tasks. Public transport operators face near-term needs for training in hybrid operational environments and longer-term needs for system-level supervision and integration.

The Information & Communication Technology (ICT) sector plays a cross-cutting enabling role across all CCAM applications. Skills demand remains strong in software development, data engineering, cybersecurity and systems reliability. Over time, the analysis suggests a shift from development-focused roles towards continuous monitoring, resilience engineering and assurance of large-scale deployed systems. Competition for digital talent across sectors may exacerbate skills shortages, particularly for public authorities and smaller operators.

Enabling sectors show distinct but connected patterns. Civil engineering skills increasingly relate to systems integration rather than large-scale physical redesign of infrastructure. Energy and charging infrastructure demand combines electrical engineering with digital energy management and integration with fleet operations. Insurance and risk-related services face a shift from driver-centred risk models to system-level, data-driven assessment, increasing demand for analytical, legal and technical hybrid skills. Professional and technical services show growing importance of interdisciplinary competence supporting assessment, certification and compliance.

Public administration and regulatory authorities emerge as a critical skills bottleneck. The analysis indicates growing near-term demand for technical literacy related to automated systems, data governance and cybersecurity, combined with legal and policy expertise. Over the longer term, public authorities face a structural shift from regulating static products to overseeing dynamic, software-driven systems. This places sustained demands on institutional learning, systems thinking and cross-jurisdiction coordination.

Education and training services are themselves affected by CCAM-related skills dynamics, although in a highly specific rather than system-wide way. The main pressures fall on the subset of higher education, vocational education and training, adult learning, and professional training provision that is most directly linked to automated driving, software-enabled vehicle systems, diagnostics, remote supervision, safety assurance, data governance, and mobility-system integration. The pace of technological change challenges traditional curriculum cycles and increases the importance of modular learning, micro-credentials, short courses, and work-based training. However, much early CCAM-related upskilling is likely to take place outside formal HE and VET, through vendor-led provision, in-company learning, and other non-formal training routes. Train-the-trainer capacity therefore emerges as a recurring constraint not only in formal education, but also across the wider training ecosystem, particularly where educators, trainers, and workplace mentors lack access to up-to-date systems, specialised equipment, or meaningful industry exposure.

Cross-sectoral skills clusters and bottlenecks

Synthesising sectoral findings reveals a small number of recurring skill clusters across the CCAM value chain. These include digital and systems literacy; data, analytics and AI-adjacent skills; cybersecurity and digital risk awareness; remote supervision and exception handling; coordination and systems integration; and transversal, human-centred competences such as communication and good judgement.

The analysis identifies several shared bottlenecks. A persistent pace mismatch exists between rapid technological change and slower training and certification cycles. Role ambiguity remains high in emerging functions such as remote supervision and system monitoring, complicating recruitment and qualification design. Train-the-trainer constraints limit the ability of education and training systems to scale relevant provision. Small and Medium-sized Enterprises (SME) capacity constraints amplify these challenges, contributing to uneven adoption and regional divergence.

Importantly, skills demand does not emerge uniformly over time. Some skills, particularly those linked to safety validation, cybersecurity and regulatory understanding, are already in demand in the short term. Others, such as advanced system-level oversight and governance, become more salient as deployment scales. The medium term appears to carry the highest risk of skills mismatch, as task change accelerates while institutional adaptation lags.

Implications for skills anticipation and policy

Taken together, the findings suggest that CCAM-related skills demand will be characterised less by wholesale job replacement than by task reconfiguration and hybridisation across existing roles. Skills development therefore requires coordinated action across sectors, education and training systems, and public authorities. Policy and governance play a central role in shaping both the timing and content of skills demand, and institutional readiness emerges as a key condition for scalable deployment.

The report's findings provide an evidence base for the development of targeted upskilling and reskilling strategies, alignment of qualification frameworks, and strengthening of institutional capacity. They also underline the importance of treating skills anticipation as an ongoing process rather than a one-off exercise, given the evolving nature of CCAM technologies and regulatory frameworks.

Deliverable D4.5 thus contributes to the broader objective of the CCAM-ERAS project: supporting a transition to connected, cooperative and automated mobility that is technologically sound, economically viable and socially robust.

Contents

1 Introduction

Connected, Cooperative and Automated Mobility (CCAM) is expected to reshape parts of the European transport system through the progressive deployment of automation, connectivity, and data-driven operations across passenger and freight mobility. These developments affect not only vehicles and infrastructure, but also how work is organised, how tasks are distributed between humans and automated systems, and which competences are required to design, operate, maintain, supervise, and regulate mobility services. The availability of appropriate skills across the full CCAM value chain is therefore a critical condition for safe, scalable, and socially sustainable deployment.

This report provides a forward-looking analysis of CCAM-related skills needs across sectors and enabling functions. It forms part of Work Package (WP) 4 of the CCAM-ERAS (Connected, Cooperative and Automated Mobility - Employment Realisation through the Acquisition of Skills) project, which examines the employment, skills, and social impacts of CCAM deployment. WP4 combines complementary analytical perspectives: WP4A focuses on employment effects and modelling, WP4B examines how CCAM is likely to reshape tasks, competence requirements, and skills demand over time, and WP4C concerns the socio-economic factors of CCAM deployment. This report synthesises the work done within the context of WP4B.

1.1 Purpose and objectives

The primary objective of this report is to anticipate future CCAM-related skills needs across the full value chain, rather than to predict exact employment outcomes or future job numbers. The analysis focuses on how CCAM may change tasks within existing roles, which new combinations of skills are emerging, and where existing education systems, training pathways, and institutional frameworks may need time to adapt. Attention is given to skills that recur across sectors, because these are most likely to become shared constraints as CCAM deployment expands.

The report aims to support policymakers, education and training providers, industry actors, social partners, and public authorities in preparing timely and proportionate responses to emerging skills needs and potential mismatches. The findings are intended to inform subsequent project activities on education and training instruments (WP5) and on roadmap and policy recommendations (WP6).

1.2 Methodological approach and evidence base

The skills foresight analysis presented in this report is based on mixed qualitative evidence base and a synthesis-oriented analytical approach. It draws on desk research and literature review, sectoral analysis, stakeholder interviews, survey evidence, and structured skills foresight consultations conducted within the CCAM-ERAS project.

Primary data sources include an open online survey (19 responses) covering stakeholders from industry and education and training providers, as well as 20 semi-structured interviews conducted with representatives from industry, higher education institutions (HEIs), vocational education and training (VET) providers, representative organisations, and road transport operators.

The foresight component was further informed by five structured consultation moments: the CCAM-ERAS Stakeholder Workshop (Brussels, 26 November 2024), the International Transport Forum (ITF) Roundtable (Paris, 6–7 February 2025), the Intelligent Transport Systems (ITS) European Congress (Seville, 19–21 May 2025), the International Association of Public Transport (UITP) Conference (Hamburg, 16–18 June 2025), and the CCAM-ERAS WP4 Validation Workshop (Brussels, 19 November 2025). These consultations provided expert validation and cross-sectoral reflection on emerging skills trends.

These sources are used in combination to identify recurring patterns and credible directions of change rather than to generate precise forecasts. Emphasis is placed on triangulation: skills needs and potential bottlenecks are highlighted where they are consistently indicated across multiple sources or sectors and treated more cautiously where evidence is limited or divergent. The analysis focuses on changes in tasks and competence requirements rather than on the emergence of entirely new occupations, reflecting the expectation that CCAM will primarily reconfigure existing roles before giving rise to fully distinct job categories at scale.

The report acknowledges that CCAM deployment remains uncertain and uneven. Regulatory developments, business models, organisational capacity, and policy choices will continue to shape both the pace and the form of skills demand. The findings should therefore be read as evidence-informed guidance for anticipation and planning, rather than as deterministic predictions.

1.3 Scope and time horizons

The scope of the report covers the CCAM value chain and key enabling functions. This includes vehicle and system development and manufacturing; transport operations in passenger mobility and freight logistics; maintenance, repair, and service activities; information and communication technologies; and enabling sectors such as civil engineering, energy and charging infrastructure, insurance and risk-related services, professional and technical services, education and training provision, and public administration and regulatory authorities. Both technical skills and broader competences related to safety, supervision, service delivery, and governance are considered.

To support comparison across sectors, the analysis uses three indicative time horizons:

- Short term (0–5 years): characterised by pilots, early deployments, incremental automation and connectivity, and the immediate need to build foundational competence in organisations involved in CCAM design, operation, maintenance, and oversight.
- Medium term (5–10 years): a period in which some CCAM applications may move from pilots to more routine operation, and where risks of skills mismatches are expected to be most pronounced as task change accelerates.
- Long term (10+ years): associated with more mature automation in defined operational domains, stronger system integration, and growing demand for system-level oversight, assurance, and continuous learning.

These horizons are analytical reference points rather than uniform deployment forecasts. CCAM uptake is expected to vary significantly by use case, geography, and regulatory context, and skills demand is therefore likely to emerge unevenly across the value chain.

1.4 Structure of the report

The report is structured to move from the conditions shaping skills demand to sector-specific evidence, cross-sector synthesis, and recommendations.

Chapter 2 examines the policy and governance context shaping CCAM-related skills needs. It explains how regulation, liability frameworks, data governance, cybersecurity requirements, infrastructure policies, and EU skills policy instruments influence not only which skills are required, but also when and where they are likely to emerge.

Chapter 3 presents sectoral foresight analyses across core CCAM-affected sectors and enabling functions. Each sector section follows a common structure, covering sector relevance, technical and organisational trends, employment and task change, and skills needs across the three time horizons.

Chapter 4 synthesises the sector findings into a cross-sectoral perspective. It identifies common skill clusters, shared bottlenecks and emerging mismatches, and divergent timelines of skills demand across sectors and functions. It also provides a gap analysis and skills mapping.

Chapter 5 translates the analysis into recommendations for skills development, education, and transition governance. Recommendations are structured by time horizon, are directed at EU, and national policymakers, education and training providers, industry actors, and public authorities.

2 Policy and governance context shaping CCAM-related skills

Policy and regulation shape CCAM skills demand more directly than in many other transport technology transitions. CCAM systems combine software-intensive vehicle functions, connectivity, data sharing, and operational oversight.[1] These features place CCAM within safety regulation, digital regulation, and public sector governance. Policy therefore affects not only when CCAM deploys, but also which actors carry responsibility for assurance and compliance.[2]

Skills foresight benefits from treating policy as a timing and distribution mechanism. Regulatory approvals, phased application dates, and national implementation choices influence where skills shortages emerge first. Policy also affects which tasks stay internal to firms, and which move to specialised service providers. These dynamics may affect the demand for skills in safety engineering, cybersecurity, data governance, operations supervision, and public administration.

The three analytical time horizons defined in Section 1.3 are applied here to assess how policy and governance influence skills demand over time. Policy effects are not confined to a single segment of the value chain; across all horizons, they shape developments from design and manufacturing to operation, maintenance, and regulatory oversight.

2.1 Safety regulation and type approval

EU vehicle safety regulation increasingly treats automated driving as a system-level capability rather than a set of discrete components. A key element is the framework for type approval of automated driving systems for fully automated vehicles. Commission Implementing Regulation (EU) 2022/1426 sets out procedures and technical specifications for type approval of the automated driving system of fully automated vehicles under the General Safety Regulation framework.

This approach has direct implications for skills needs in the short term. Manufacturers and their suppliers require staff who can build safety arguments, document system behaviour within an operational design domain, and demonstrate compliance through test evidence. These tasks depend on skills in scenario-based testing, simulation and tool qualification, safety case development, and requirements traceability. They also require staff who can work across software, vehicle engineering, and human factors.[3]

Public authorities and technical services face parallel skill needs. Type approval and market surveillance require staff who can assess evidence submitted by developers and identify gaps. This shifts skills demand from component inspection towards system assurance and audit

[1] European Commission (2021), 'Sustainable & Smart Mobility Strategy: Putting European transport on track for the future', available at: https://transport.ec.europa.eu/document/download/be22d311-4a07-4c29-8b72-d6d255846069_en?filename=2021-mobility-strategy-and-action-plan.pdf

[2] Ciuffo, B., Dona, R., Galassi, M., Giannotti, W., Sollima, C., Terzuoli, F., Vass, S. (2024), 'Interpretation of EU Regulation 2022/1426 on the Type Approval of Automated Driving Systems', available at: https://www.ecologie.gouv.fr/sites/default/files/documents/JRC136417_01_0.pdf

[3] European Parliamentary Research Service (2021), 'Artificial Intelligence in road transport: Annex to Cost of non- Europe report', available at: https://www.europarl.europa.eu/RegData/etudes/STUD/2021/654212/EPRS_STU(2021)654212(ANN1)_EN.pdf

capability. It also increases demand for specialist expertise in validation methods, safety engineering standards, and software lifecycle assurance.

2.2 Data protection, privacy, and data access rules

CCAM generates and processes large volumes of data, including data that may relate to identified or identifiable persons. EU rules therefore affect CCAM through both privacy requirements and data access rules. The ePrivacy Directive regulates, among other topics, access to information stored in terminal equipment.[4] The European Data Protection Board has issued guidance for connected vehicles and mobility-related applications.[5] It notes that ePrivacy rules may apply alongside the General Data Policy Regulation (GDPR) in relevant circumstances.

These rules influence skills needs in engineering and compliance functions. In the short term, organisations need staff who can translate legal requirements into technical controls, including privacy by design, data minimisation, retention, and access management. They also need staff who can manage consent and transparency interfaces in services that involve drivers, passengers, and bystanders.[6] This work often spans multiple organisations, which raises demand for skills in contractual governance and shared accountability models.

The Data Act introduces additional implications for CCAM data practices.[7] The Commission notes that the Data Act entered into force on 11 January 2024 and applies from 12 September 2025. It provides users with rights to access data generated by connected products such as cars, and includes measures related to switching between data processing services and contractual fairness.

From a skills perspective, the Data Act strengthens demand for capabilities that sit between engineering and governance. Organisations may need to design secure data interfaces, manage data access requests, and implement data sharing arrangements with third parties.[8] This is relevant for vehicle manufacturers, fleet operators, mobility service providers, and aftermarket service providers. It also raises demand for skills in API security, identity and access management, and data quality and interoperability.

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[4] Directive 2002/58/EC of the European Parliament and of the Council of 12 July 2002 concerning the processing of personal data and the protection of privacy in the electronic communications sector (Directive on privacy and electronic communications).

[5] European Data Protection Board (2021), 'Guidelines 01/2020 on processing personal data in the context of connected vehicles and mobility related applications', available at: https://www.edpb.europa.eu/system/files/2021-03/edpb_guidelines_202001_connected_vehicles_v2.0_adopted_en.pdf

[6] Council of the European Union, 'The general data protection regulation', available at: https://www.consilium.europa.eu/en/policies/data-protection/data-protection-regulation/#gdpr; Sara Landini and Kyriaki Noussia (2022), 'Big Data, Privacy, and Protection of the User of Autonomous Vehicles: Ethical Issues, Insurance Aspects, and Human Rights', available at: https://link.springer.com/chapter/10.1007/978-3-030-82704-5_6.

[7] European Commission (2025), 'Data Act', available at: https://digital-strategy.ec.europa.eu/en/policies/data-act

[8] RSM (undated), 'The Impact of Recent EU Regulations on the Evolution of Automotive Technologies with Autonomous Features', available at: https://www.rsm.global/netherlands/en/insights/impact-recent-eu-regulations-evolution-automotive-technologies-autonomous-features

Policy also aims to reduce fragmentation in mobility data sharing. The Commission's work on a common European mobility data space positions data sharing as an enabler of multimodal services and system optimisation.[9] The Commission adopted a Communication on the European mobility data space in November 2023 and describes it as a framework that interlinks heterogeneous transport data ecosystems rather than a single database.

This direction reinforces medium-term skills needs in data stewardship, interoperability engineering, metadata management, and governance of federated data ecosystems. These skills matter for transport authorities and infrastructure operators as well as for private operators.

2.3 Cybersecurity and digital resilience requirements

CCAM expands the attack surface of vehicles and mobility services. Policy responses address cybersecurity both as a product issue and as an operational resilience issue. The NIS2 Directive establishes EU-wide requirements for cybersecurity risk management and incident reporting across critical sectors.[10] It highlights requirements related to risk management and reporting, and notes that Member States must establish lists of essential and important entities by 17 April 2025.

NIS2 affects skills demand mainly in organisations that operate critical services and depend on connected systems. This includes parts of transport operations and digital infrastructure providers. The skills implications include incident reporting capability, risk analysis, business continuity planning, supply chain security, and operational cybersecurity practices. These capabilities are relevant in fleet operations, traffic management systems, and mobility service platforms.

The Cyber Resilience Act adds requirements focused on products with digital elements.[11] The Commission's digital policy page states that the Cyber Resilience Act entered into force on 10 December 2024, with reporting obligations applying from 11 September 2026 and main obligations applying from 11 December 2027. This policy timeline is relevant for medium-term skills planning. It implies increasing demand for product security engineering, vulnerability handling processes, and conformity documentation. In the CCAM value chain, these skills extend beyond vehicle manufacturers. They also affect suppliers of software, sensors, connectivity modules, and fleet management platforms.

The European Union Agency for Cybersecurity (ENISA) has analysed cybersecurity in the connected and automated mobility ecosystem and framed it as an ecosystem challenge involving many actors and infrastructures. ENISA's work also links cybersecurity expectations to the transposition and implementation of relevant international vehicle cybersecurity approaches.

A practical implication for skills is the growth of roles that bridge engineering and governance. Examples include product security managers, cybersecurity assurance specialists, and staff

[9] European Commission (2021), 'Sustainable & Smart Mobility Strategy: Putting European transport on track for the future', available at: https://transport.ec.europa.eu/document/download/be22d311-4a07-4c29-8b72-d6d255846069_en?filename=2021-mobility-strategy-and-action-plan.pdf
[10] European Commission (2022), 'Directive on measures for a high common level of cybersecurity across the Union (NIS2 Directive)', available at: https://digital-strategy.ec.europa.eu/en/policies/nis2-directive
[11] European Commission (2025), 'EU Cyber Resilience Act', available at: https://digital-strategy.ec.europa.eu/en/policies/cyber-resilience-act

who maintain cybersecurity management systems. This also increases demand for cybersecurity skills among test engineers and service technicians, since software updates and connected diagnostics become routine.

2.4 AI governance and liability frameworks

CCAM deployment increasingly depends on AI-enabled perception, prediction, and decision support. EU AI regulation therefore shapes compliance expectations and workforce needs. The AI Act sets application dates and includes earlier applicability for some chapters. The Regulation applies from 2 August 2026, with specific parts applying earlier.[12]

The AI Act influences skills needs through risk management, documentation, transparency, and oversight requirements that may apply to relevant AI systems. For CCAM actors, this tends to increase demand for staff who can combine AI engineering competence with compliance practice. This includes data governance for training and testing datasets, documentation of model behaviour, and monitoring of performance and drift.

Liability policy also shapes skills needs, particularly in risk and assurance functions. The Product Liability Directive (EU) 2024/2853 states that software is included within the concept of a product and that the Directive applies to products placed on the market or put into service after 9 December 2026.[13]

This strengthens medium-term skills needs in evidence management, incident investigation, and traceability across the supply chain. It also increases demand for legal and compliance roles that understand software-based products and post-market obligations. Insurers and claims specialists may also require deeper technical literacy to interpret incident evidence and system logs.

2.5 Infrastructure and interoperability policies

CCAM deployment depends on supportive digital and physical infrastructure. EU policy in intelligent transport systems emphasises interoperability and phased deployment of cooperative services. The EU C-ITS strategy distinguishes between Day 1 and Day 1.5 services and highlights cross-sector collaboration and the need for security and certification approaches.[14]

This type of policy direction shapes skills needs in road operators, cities, and technology providers. In the short term, it raises demand for skills in ITS deployment, roadside and back-office system integration, certificate and trust management, and operational monitoring. These needs sit at the interface of civil engineering, ICT operations, and transport systems management.

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[12] European Commission (2024) 'AI Act' https://digital-strategy.ec.europa.eu/en/policies/regulatory-framework-ai

[13] Council Directive 85/374/EEC of 25 July 1985 on the approximation of the laws, regulations and administrative provisions of the Member States concerning liability for defective products

[14] European Commission (2016), 'An EU strategy on cooperative, connected and automated mobility', available at: https://ec.europa.eu/commission/presscorner/detail/en/memo_16_3933; European Commission (2016), Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility.

The Sustainable and Smart Mobility Strategy frames connected and automated mobility and data-driven innovation as part of a broader shift towards smart mobility.[15] The Commission summary refers to actions supporting connected and automated multimodal mobility and the development of a European common mobility data space.

Decarbonisation policy interacts with CCAM, especially in fleet renewal and infrastructure investment cycles. The Alternative Fuels Infrastructure Regulation creates binding planning and deployment requirements for recharging and refuelling infrastructure across the TEN-T network.[16]

While AFIR does not regulate CCAM directly, it affects the operational environment for connected fleets. It may increase demand for combined skills in electric fleet operations, digital energy management, and infrastructure maintenance. These needs are likely to become more visible in the medium term as electric and connected fleet deployments scale.

2.6 EU skills policy instruments relevant to CCAM

EU skills policy provides horizontal instruments that influence CCAM workforce development. The Digital Decade Policy Programme sets targets for digital skills and ICT specialists.[17] The Commission's digital skills page reports that only 55.6% of the EU population has at least basic digital skills, and that at the current pace ICT specialists would reach 12 million by 2030, compared with the target of 20 million.[18]

These figures matter for CCAM because CCAM skills demand relies on digital competences across many occupations. CCAM does not only require advanced AI engineering. It also requires widespread baseline competence in digital systems, cybersecurity hygiene, and data literacy among technicians, operators, and supervisors.

The European Skills Agenda provides a framework for cooperation on upskilling and reskilling and for improving the use of skills.[19] In practice, many CCAM-relevant responses are implemented through partnerships and sector initiatives. The Pact for Skills Annual Report 2023 reports that Pact members' upskilling and reskilling activities reached nearly 1.5 million individuals in 2023.[20]

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[15] European Commission (2021), 'Sustainable & Smart Mobility Strategy: Putting European transport on track for the future', available at: https://transport.ec.europa.eu/document/download/be22d311-4a07-4c29-8b72-d6d255846069_en?filename=2021-mobility-strategy-and-action-plan.pdf

[16] European Commission (undated), 'Alternative Fuels Infrastructure' available at: https://transport.ec.europa.eu/transport-themes/clean-transport/alternative-fuels-sustainable-mobility-europe/alternative-fuels-infrastructure_en

[17] European Commission (2025), 'Europe's Digital Decade', available at: https://digital-strategy.ec.europa.eu/en/policies/europes-digital-decade#tab_1

[18] European Commission (2024), 'Communication from the Commission to the European Parliament, The Council, the European Economic and Social Committee and the Committee of the Regions: State of Digital Decade 2024', available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2024:260:FIN

[19] European Commission (undated), 'European Skills Agenda', available at: https://ec.europa.eu/social/main.jsp?catId=1223&langId=en

[20] European Commission (2023), 'Pact for Skills Annual Report 2023: Progress on upskilling and reskilling the European workforce', available at: https://pact-for-skills.ec.europa.eu/document/download/612aca7a-0798-4187-bf27-fc14a3d86857_en?filename=Pact%20for%20Skills%20Annual%20Report%202023%20FINAL.pdf&prefLang=sv

These initiatives can support CCAM skill development, but they are not CCAM-specific by design. Skills foresight therefore benefits from identifying which CCAM roles are likely to remain undersupplied without targeted programmes. These often include safety assurance specialists, cybersecurity compliance staff, and public sector regulators with technical literacy.

Education policy also supports digital skills development. The Digital Education Action Plan 2021–2027 sets out a common vision for digital education and includes two strategic priorities and a set of actions.[21] The Council Recommendation on a European approach to micro-credentials supports modular learning and common approaches to design and use micro-credentials.[22]

For CCAM, micro-credentials and modular learning formats may be relevant for roles that require rapid updating of competences, such as remote operations staff, fleet supervisors, and technicians working with software updates and diagnostic tooling. They may also support cross-disciplinary upskilling in areas such as cybersecurity for engineers and safety assurance for software developers.

2.7 National policy initiatives addressing CCAM-related skills

National CCAM/Autonomous Vehicle (AV) strategies that explicitly embed skills measures can advance "readiness" by shifting when and where demand peaks for assurance, oversight, and operational roles, while countries without such measures may risk skills bottlenecks as EU compliance obligations mature (e.g., AI Act and Data Act timelines).

Luxembourg's "Automatiséiert Fueren 2028" (published 2025) is a strong illustrative case because "Skills and Talent" is treated as a core strategic lever, not an externality. The strategy frames automated driving skills around three complementary profiles: Technology Experts, Field Operatives, and Facilitators, explicitly connecting design, deployment/operations, and governance functions. It proposes concrete measures that would affect both supply and diffusion of skills, including: strengthening scientific competencies (e.g., support for interdisciplinary research, and doctoral/postdoctoral pathways); continuous education modules for operational roles; a certified skills label; and the use of simulation platforms to train on real-world use cases with local authorities. It also envisages integrating specialised modules into university curricula and continuing education, plus interdisciplinary programs and collaboration with professional bodies—targeting the cross-disciplinary assurance roles that CCAM creates. Notably, the strategy links skills to institutional capacity. It discusses a "single point of contact" for automated driving and flags training needs for police and emergency services as part of the enabling framework.[23]

Czechia's "Autonomous Mobility Plan until 2025 with a Prospect to 2030" (approved 10 April 2024) includes an explicit education measure on updating driver training and examinations to reflect automated driving functions, including practical testing of system understanding and (where appropriate) simulator-supported learning. This illustrates a different national emphasis

[21] European Commission (2025), 'Digital Education Action Plan (2021-2027) ', available at: https://education.ec.europa.eu/focus-topics/digital-education/action-plan
[22] Council Recommendation of 16 June 2022 on a European approach to micro-credentials for lifelong learning and employability 2022/C 243/02.
[23] Luxembourg Ministry of the Economy (2025), 'Automatiséiert Fueren 2028', available at: https://meco.gouvernement.lu/en/publications/strategie/strategie-automatiseiert-fueren2028.html .

than that of Luxembourg: accelerating user/operator competence in the transition phase where Level 2–3 features diffuse and safe human–system interaction remains critical.[24]

In the Netherlands, national policy on self-driving vehicle testing explicitly links "learning by doing" to future-proofing legislation, infrastructure, and mandatory driving skills, and notes that testing conditions may require trained drivers; it also anticipates tests where no driver is physically present, but a human can take command remotely. This approach tends to concentrate early skills demand in regulators, technical services, and remote-operations capabilities, potentially advancing national deployment timelines relative to countries that rely mainly on horizontal digital-skills policies.[25]

Switzerland offers a useful additional European example, although through regulation more than through a dedicated skills strategy. Following adoption by the Federal Council in December 2024, its automated driving ordinance entered into force on 1 March 2025 and embeds training and competence requirements directly into the operational framework for automated driving. The ordinance requires operators supervising driverless vehicles, and persons who may manually intervene, to complete certified training and further education provided by the manufacturer or importer. Federal pilot-test guidance also requires applicants to submit a training concept for safety and operating personnel and proof of completed training and refresher training. In parallel, Switzerland updated elements of driving theory and practical testing to reflect driver-assistance and automation systems. This makes Switzerland a valuable non-EU comparator because it shows how binding regulatory requirements can create structured early demand for training, competence validation, and operational readiness in emerging CCAM roles.

2.8 Implications for short-, medium-, and long-term skills needs across the value chain

In the short term, policy-driven skills demand concentrates where regulatory readiness is most immediate. This includes safety validation and type approval preparation, cybersecurity management system development, and privacy and data protection compliance in connected services. Skills needs are likely to be most acute in organisations that run pilots and early services, and in their direct suppliers. Public authorities also face near-term needs for technical capability to evaluate trials, exemptions, and approvals.

In the medium term, the policy calendar tightens and broadens the compliance baseline. The Data Act applies from September 2025. The AI Act applies from August 2026, with some provisions applying earlier. The Cyber Resilience Act introduces reporting obligations from September 2026 and main obligations from December 2027. The Product Liability Directive applies to products placed on the market after December 2026.

This sequencing suggests that medium-term skills needs will extend beyond Research and Design (R&D) and testing. Demand is likely to grow for operational compliance roles, product security engineering, vulnerability handling, incident reporting, and structured post-market monitoring. Skills demand may also rise in aftermarket service providers as data access

[24] Czech Ministry of Transport (2025), 'Autonomous Mobility Plan 2025 with a view to 2030', available at: https://md.gov.cz/Uzitecne-odkazy/Autonomni-mobilita/asdasd.
[25] Government of the Netherlands (Undated), 'Self-driving vehicles', available at: https://www.government.nl/topics/mobility-public-transport-and-road-safety/self-driving-vehicles.

expectations and software-enabled maintenance expand. The same period may increase demand in insurance, legal services, and certification bodies for staff who can interpret technical evidence.

In the long term, policy goals related to interoperability, data sharing, and system integration may become more influential. The mobility data space direction implies increasing reliance on federated data ecosystems and cross-actor coordination. This would shift skills demand towards system-of-systems engineering, governance of shared digital infrastructures, and workforce capability in maintaining safety and cybersecurity over long operational lifecycles.

Across all horizons, the policy context points to a recurring skills challenge. Many CCAM-related competencies sit at interfaces between disciplines and organisations. This includes safety engineering linked to software evidence, cybersecurity linked to supply chain governance, and data sharing linked to interoperability and legal constraints. Workforce strategies therefore need to support hybrid competence profiles, and support coordination between industry, authorities, and education providers.

3 Sectoral foresight analyses

This chapter presents the sectoral foresight analyses across the core CCAM-affected sectors and enabling functions covered by this report. It examines how CCAM is likely to reshape work, tasks, and skills needs across manufacturing; the sale, maintenance and repair of motor vehicles; freight transport and logistics; passenger transport and shared mobility; information and communication; and other relevant enabling sectors, including civil engineering, education and training services, energy and charging infrastructure, insurance and risk-related services, professional and technical activities, and public administration and regulatory authorities.

Each sector section follows a common structure. It begins with a sector overview and CCAM relevance, outlining why the sector matters for CCAM deployment and which activities are most exposed to change. It then examines technical and organisational trends, highlighting the main technological, business-model, and operational developments shaping demand for new competences. This is followed by employment and occupational change, which considers how tasks and roles are likely to be reconfigured as automation, connectivity, and digitalisation progress. Each section closes with a skills foresight subsection, which assesses likely skills needs across the short, medium, and long term, using the common analytical time horizons set out earlier in the report.

Taken together, these sector analyses provide the evidence base for the cross-sectoral synthesis in Chapter 4 and the recommendations in Chapter 5. They are intended to show not only where sector-specific skills pressures are emerging, but also where common patterns of task change, hybridisation, and institutional adaptation can already be identified across the wider CCAM value chain.

3.1 Manufacturing

3.1.1 Sector overview and CCAM relevance

The manufacturing sector plays both a central and evolving role in the deployment and functionality of CCAM. It is responsible for supplying the components, systems, and production capabilities necessary for automated and connected (electric) vehicles.

The most relevant manufacturing activities for CCAM fall under the following NACE activities: C26 Manufacture of computer, electronic and optical products (e.g. sensors, cameras and embedded systems); C27 Manufacture of electrical equipment (including vehicle electronics and related electrical systems); C29 Manufacture of motor vehicles, trailers and semi-trailers; and C33 Repair and maintenance of machinery and equipment; which supports the servicing and upkeep of increasingly complex automated production systems and components. These activities together provide essential CCAM-related technologies such as sensors (cameras, radar, LiDAR), power electronics, battery systems, communication units, and vehicle platforms.[26]

The deployment of CCAM technologies requires substantial innovation in vehicle design and systems integration, with demands increasing sharply as automation levels rise.[27] While existing manufacturing and engineering capabilities are generally sufficient enough to support Society of Automotive Engineers (SAE) Level 2 automation, SAE Levels 4 and 5 represent assistance.[28]These higher levels demand the complex integration of sophisticated ICT components (where software is anticipated to become more critical than hardware), alongside native drive-by-wire systems, multi-sensor configurations, secure Vehicle-to-everything (V2X) communication, and advanced robotics.[29]

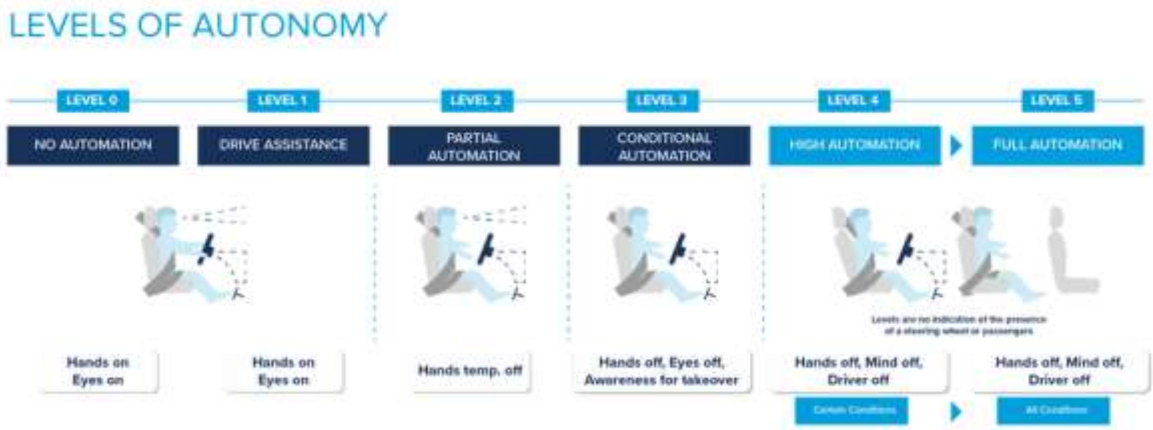

Figure 1: SAE Levels of automation.
Source: Mobileye.

[26] Eurostat (2024) '*Statistical Classification of Economic Activities in the European Community, Rev. 2.1 (NACE Rev. 2.1)* – Section C: Manufacturing' available at: https://showvoc.op.europa.eu/#/datasets/ESTAT_Statistical_Classification_of_Economic_Activities_in_the_European_Community_Rev._2.1._%28NACE_2.1%29/data?resId=http:%2F%2Fdata.europa.eu%2Fux2%2Fnace2.1%2FC, accessed 24 November 2025.
[27] European Trade Union Institute (2019) 'Towards a just transition: coal, cars and the world of work – Chapter 6', available at: https://www.etui.org/publications/books/towards-a-just-transition-coal-cars-and-the-world-of-work , accessed 16 September 2024.
[28] SAE International (2021), 'Taxonomy and Definitions for terms related to Driving Automation Systems for On-Road Motor Vehicles' available at: https://www.sae.org/standards/j3016_202104-taxonomy-definitions-terms-related-driving-automation-systems-road-motor-vehicles.
[29] Alonso et al. (2018) 'An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe - Effects of automated driving on the economy, employment and skills', available at: https://op.europa.eu/en/publication-detail/-/publication/60258b54-597c-11e8-ab41-01aa75ed71a1/language-en.

In terms of workforce size, manufacturing employed approximately 31.7 million people in the EU in 2024,[30] of whom approximately 2.4 million were directly employed in motor vehicle manufacturing, accounting for roughly 8% of the EU's total manufacturing employment.[31] Countries with strong vehicle manufacturing bases, such as Czechia (14% of total manufacturing employment), Germany (11%), Hungary (13%) Slovakia (16%), Romania (15%) and Sweden (14%) may therefore experience more pronounced employment transformation as CCAM-related technologies mature and diffuse across production processes. In these contexts, the challenge is less one of net employment decline than of occupational restructuring, as demand gradually shifts from mechanical assembly and routine production tasks towards software-intensive, systems integration and quality assurance roles (See Section 3.1.3).[32]

Figure 2 below illustrates the share of automotive employment as a proportion of total manufacturing employment across EU Member States. It highlights substantial cross-country variation, with several Central and Eastern European economies (such as Slovakia, Romania, Czechia and Hungary) as well as Germany and Sweden, exhibiting particularly high levels of sectoral concentration. In these countries, changes in vehicle design, production processes and skill requirements associated with CCAM are likely to have more systemic labour market implications, affecting not only vehicle manufacturers but also regional supplier networks and associated training systems. By contrast, Member States with lower automotive employment shares may experience CCAM-related impacts in a more contained or specialised manner.

[30] Eurostat (LFS 2024), available at: https://ec.europa.eu/eurostat/databrowser/view/lfsa_eisn2__custom_19099057/default/table?lang=en.
[31] European Commission (2021), 'Automotive Industry', available at: https://single-market-economy.ec.europa.eu/sectors/automotive-industry_en, accessed 13 September 2024.
[32] European Automobile Manufacturers' Association (ACEA) (2021), 'Share of direct automotive employment in the EU by country', available at: https://www.acea.auto/figure/share-of-direct-automotive-employment-in-the-eu-by-country/; Stakeholder consultations.

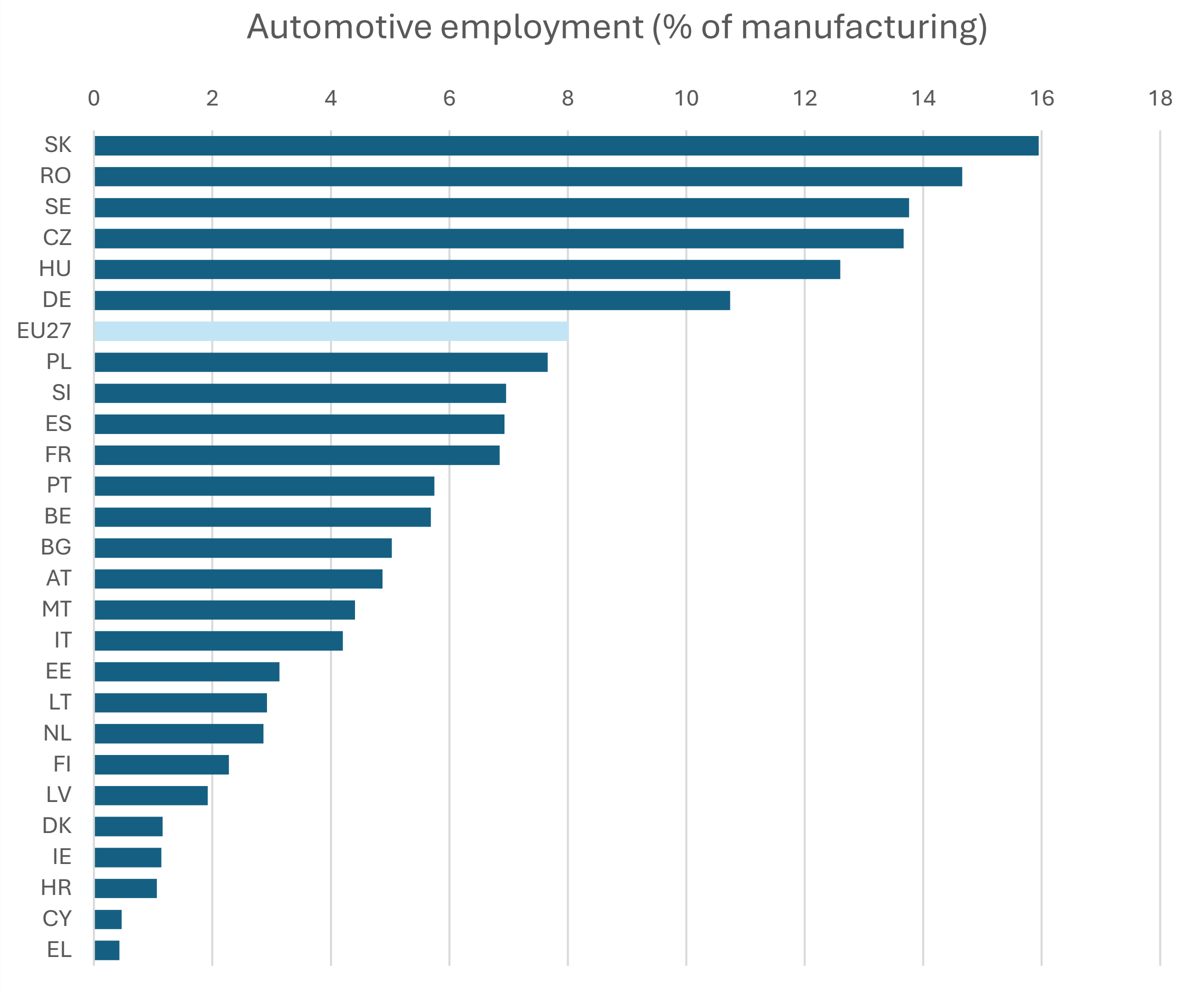

Figure 2: Automotive employment's percentual share of total manufacturing across EU-27, 2024
Source: CCAM-ERAS, based on available Eurostat data 2024.
Note: No data available for LU,

3.1.2 Technical and organisational trends

CCAM-relevant parts of the manufacturing sector are undergoing a technological and organisational shift as automated and connected mobility requires the integration of advanced digital, electronic and software-driven systems into vehicle and component production. This shift is most visible in manufacturing activities linked to vehicle systems, electronics, sensors, control units and software-enabled platforms, rather than across manufacturing as a whole.[33] As automation levels increase, vehicle architectures are becoming more complex, incorporating integrated sensor suites (including cameras, radar and LiDAR), advanced control systems and continuous connectivity. A critical technical prerequisite for higher levels of automation is the widespread adoption of drive-by-wire systems, which enable software to assume direct control over vehicle functions and fundamentally alter how vehicles are designed, tested and produced.

[33] Groshen et al. (2019) 'Preparing US Workers and Employers for an Autonomous Vehicle Future', available at: https://research.upjohn.org/cgi/viewcontent.cgi?article=1039&context=up_technicalreports, accessed 16 September 2024.

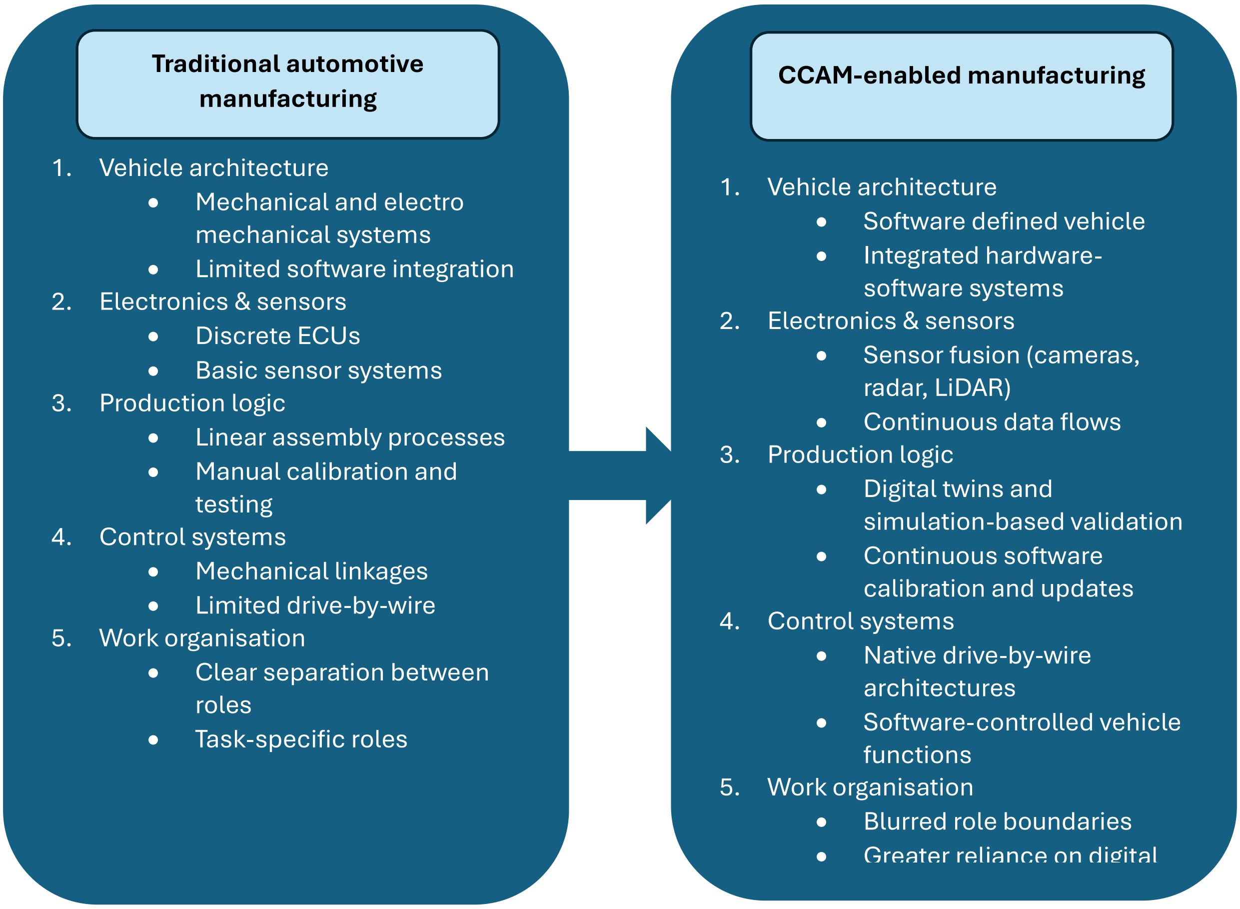

Figure 3: Conceptual shift from traditional automotive manufacturing towards CCAM-enabled, software-centric production systems. Higher levels of automation require deeper integration of software, sensors and digital validation processes, alongside changes in work organisation and firm-level structures.
Source: CCAM-ERAS

These developments are accelerating the digitalisation of relevant manufacturing and engineering processes and reinforcing a shift towards software-centric production. In practice, this means greater reliance on digital design environments, simulation, software validation, systems integration, and lifecycle management processes that connect vehicle development more closely with production and post-production updating. According to one estimate, the software share of a vehicle's value is projected to rise from 10% in 2018 to 40% by 2030,[34] prompting manufacturers to redefine themselves as software developers and prioritising the development and maintenance of complex AV software,[35] as reflected in recent strategic shifts among major European automotive groups. Volkswagen, for instance, has established a group-wide software division to develop a proprietary vehicle operating system and automated driving

[34] Alonso et al. (2018) 'An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe - Effects of automated driving on the economy, employment and skills', available at: https://op.europa.eu/en/publication-detail/-/publication/60258b54-597c-11e8-ab41-01aa75ed71a1/language-en.
[35] Asselin-Miller et al. (2017) 'GEAR 2030 Strategy 2015- 2017 - Comparative analysis of the competitive position of the EU automotive industry and the impact of the introduction of autonomous vehicles', available at: https://op.europa.eu/en/publication-detail/-/publication/24c9ad0e-da38-11e7-a506-01aa75ed71a1/language-en, accessed 16 October 2024.

software,[36] while Stellantis has announced large-scale investments in in-house software platforms and the recruitment of thousands of software engineers to support autonomous driving development.[37] Similar strategies are evident at Mercedes-Benz, which is developing its own operating system (MB.OS) alongside a significant expansion of its global software workforce,[38] and at Renault, which has created Ampere as a dedicated EV-and-software-focused entity explicitly structured around software-defined vehicles.[39]

Organisationally, these technological shifts are changing traditional occupational boundaries within manufacturing. Tasks once clearly separated between technicians and engineers may increasingly overlap, with technicians expected to perform analytical and diagnostic activities, and engineers engaging more directly with production processes.[40] As vehicles become software-defined products, Original Equipment Manufacturers (OEMs) may have to redefine their organisational identities, positioning themselves as software developers alongside their traditional manufacturing role.[41] This often involves acquiring new digital capabilities, retraining existing staff and relying more heavily on external suppliers for specialised hardware components such as sensors and communication units.

3.1.3 Employment and occupational change

A central employment effect of CCAM in manufacturing is the gradual shift away from traditional mechanical skill profiles centred on analogue vehicle systems, engines and transmissions, and towards digital, battery-related and software-oriented engineering and technical roles. In other words, the deployment of CCAM is not only changing how vehicles are produced; it is changing the knowledge base on which automotive manufacturing work

[36] Volkswagen Group (2019) ‘Volkswagen strengthens new software organisation‘ available at: https://www.volkswagen-group.com/en/press-releases/volkswagen-strengthens-new-software-organization-17007; Volkswagen Group (2021) ‘Volkswagen is accelerating transformation into software-driven mobility provider‘ available at: https://www.volkswagen-newsroom.com/en/press-releases/volkswagen-is-accelerating-transformation-into-software-driven-mobility-provider-6878.
[37] Piovaccari & Carey (2021) ‘Stellantis looks to revenue-generating software for its cars’ available at: https://www.reuters.com/business/autos-transportation/stellantis-targets-20-bln-euros-additional-revenues-software-by-2030-2021-12-07/; Stellantis Press Release (2021) ‘Stellantis Targets ~€20 Billion in Incremental Annual Revenues by 2030 Driven by Software-Enabled Vehicles’ available at: https://www.stellantis.com/en/news/press-releases/2021/december/stellantis-targets-20-billion-in-incremental-annual-revenues-by-2030-driven-by-software-enabled-vehicles.
[38] Andrea Hoffmann-Topp (2025) ‘Software-defined vehicles are transforming value creation, customer models, and strategies across the automotive industry, from BMW to Stellantis and NXP’ available at: https://www.automotivemanufacturingsolutions.com/smart-factory/software-defined-vehicles-are-transforming-value-creation-customer-models-and-strategies-across-the-automotive-industry-from-bmw-to-stellantis-and-nxp/539033; Mercedes-Benz Group (2020) ‘Mercedes-Benz and NVIDIA to Build Software-Defined Computing Architecture for Automated Driving Across Future Fleet’ available at: https://media.mbusa.com/releases/mercedes-benz-and-nvidia-to-build-software-defined-computing-architecture-for-automated-driving-across-future-fleet.
[39] Renault Group Press Release (2022) ‘Renaulution, now Revolution’ available at: https://media.renaultgroup.com/renaulution-now-revolution/.
[40] Crane et al. (2020) ‘Understanding the Middle Skill Workforce in the Connected and Automated Vehicle Sector’, available at: https://www.dot.state.mn.us/automated/docs/cav-middle-skill-workforce-report-june-2020.pdf, accessed 16 September 2024.
[41] Horl et al. (2016) ‘Recent perspectives on the impact of autonomous vehicles’ available at: https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/121359/ab1216.pdf, accessed 16 September 2024.

depends. The transition therefore requires movement away from manual and mechanical tasks towards digital, software-centric and cross-functional expertise. Traditional automotive job roles that rely heavily on manual labour, such as assembly line workers, data entry clerks, and accounting clerks,[42] are becoming less prevalent as these activities are increasingly displaced or augmented by machinery.[43] Furthermore, the industry-wide transition away from combustion engines and towards digital, electric, and software-defined vehicles means that traditional mechanical engineering roles, particularly those linked to combustion engine design, are expected to phase out.[44] Industry representatives note that vehicle electrification removes many traditional components, reducing the need for combustion-engine expertise while increasing the importance of digital and battery-related engineering skills.[45] As a result, parts of the current workforce, especially those focused on manual and mechanical roles, may need to develop additional technical and digital competences.

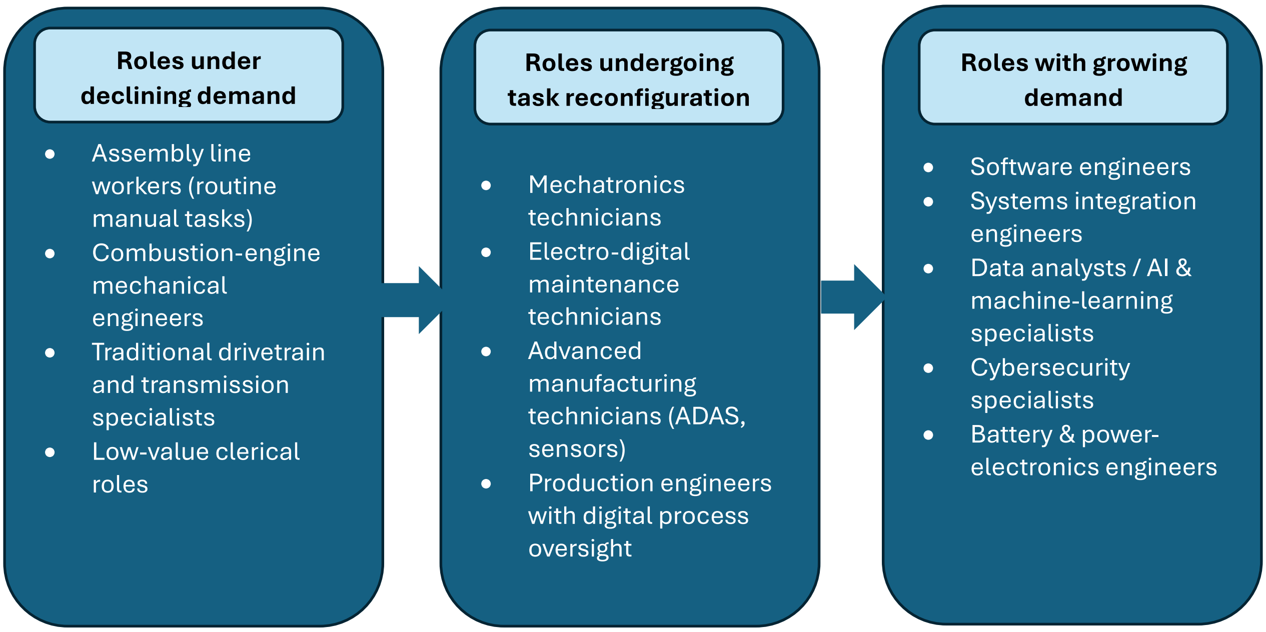

Figure 4. Occupational shift in automotive manufacturing under CCAM
Source: CCAM-ERAS

Further evidence from CCAM-ERAS stakeholder consultations supports the expectation of substantial task change rather than a uniform “replacement” narrative. Among those working with CCAM-related technologies in roles closely linked to manufacturing and engineering activity, most anticipate that automation will affect jobs to a moderate extent, with a smaller share expecting significant transformation. This pattern is consistent with a shift away from

[42] Lucia Novakowa (2020) ‘The impact of technology development on the future of the labour market in the Slovak Republic’, available at: https://www.sciencedirect.com/science/article/abs/pii/S0160791X2030035X accessed 16 September 2024.
[43] Kearney et al. (2020) ‘How automakers can survive the self-driving era’, available at: https://www.kearney.com/industry/automotive/article/-/insights/how-automakers-can-survive-the-self-driving-era accessed 16 September 2024.
[44] Russo et al. (2023) ‘Automation in the automotive sector: Romania. Spain and Germany’, available at: https://mpra.ub.uni-muenchen.de/121707/1/MPRA_paper_121585.pdf accessed 16 September 2024.
[45] Stakeholder interview (Bram Hendrix); Stakeholder interview (Miles Garner, Aurrigo).

routine manual tasks towards more knowledge-intensive work related to the integration, testing, monitoring and troubleshooting of software-enabled systems.

Simultaneously, the transition is giving rise to new roles in ICT and AI, where specialists are needed to oversee, maintain, and optimise complex digital and software-based mobility systems. This general trend is reflected in the fact that AI-related skills in manufacturing accounted for 13% of all job postings between 2019 and 2022.[46] As previously noted, manufacturing companies are shifting their strategic focus towards software development, necessitating new roles such as machine learning specialists, driving algorithm developers and deep learning experts.[47] In fact, nearly nine out of ten automotive companies now consider software for Advanced Driver Assistance Systems (ADAS) and autonomous driving “essential” to their future success. Similarly, around 80% of automakers report establishing dedicated software units or platforms to accelerate digital features, signalling that this shift applies to most mainstream manufacturers rather than only a select few. As a result, companies are adapting to these changes by investing in expanding their software engineering workforce and creating new internal units focused on AV algorithms, machine learning, and data. For example, Volkswagen created CARIAD, a dedicated software subsidiary, to unify and expand the company’s in-house software development, with around 300 CARIAD experts focusing on cloud services and automated driving algorithms, and used the CES tech event to recruit additional AV tech talent.[48]

Earlier projections suggested that by 2025, approximately 12% of OEM jobs would be filled by data and mobility IT specialists.[49] This anticipated shift aligns with evidence from the European Centre for the Development of Vocational Training (CEDEFOP), which notes that the EU automotive industry has set an objective to double the number of ICT professionals in its workforce by 2030.[50] Accordingly, CCAM deployment is expected to reflect a growing demand in roles such as software engineers, systems engineers, design engineers, cybersecurity specialists, and data analysts, due to the need to develop and integrate advanced CCAM technologies. CCAM-ERAS interview findings consistently confirm this trajectory, highlighting rapidly growing demand for high-skilled workers in data science, cybersecurity, software development, system integration, and remote fleet supervision as CCAM technologies scale.[51] Experts further emphasise that future technicians and engineers must acquire advanced skills in big data analytics, sensor technologies, and cybersecurity - skills currently in shortage across the sector.[52] This is further supported by the European Commission, which reports that over

[46] OECD (2023) ‘OECD Skills Outlook 2023: Skills for a Resilient Green and Digital Transition’, available at: https://www.oecd.org/en/publications/2023/11/oecd-skills-outlook-2023_df859811.html, accessed 17 November 2024.

[47] Moayad Shammut (2020) ‘Driverless Car Implications: A Literature Review’ Massey University, available at: https://www.transportationgroup.nz/wp-content/uploads/Driverless-Cars-Implications-Moayad-Shammut-2020.pdf, accessed 16 October 2024.

[48] CARIAD (undated), https://cariad.technology/de/en/company.html

[49] European Trade Union Institute (2019) ‘Towards a just transition: coal, cars and the world of work – Chapter 6’, available at https://www.etui.org/publications/books/towards-a-just-transition-coal-cars-and-the-world-of-work accessed 16 September 2024.

[50] European Centre for the Development of Vocational Training (CEDEFOP) ‘Going digital means skilling for digital - Using big data to track emerging digital skill needs’ available at: https://www.cedefop.europa.eu/files/9188_en.pdf.

[51] Stakeholder interview (Claudio Roncoli, KU Leuven); Stakeholder interview (Guus Arts & Joost Haverman); Stakeholder interview (DAF trucks); Stakeholder interview (Bram Hendrix).

[52] Stakeholder interview (Claudio Roncoli, KU Leuven); Stakeholder interview (Bram Hendrix).

70% of businesses identify a lack of staff with adequate digital skills as an obstacle to investment.[53]

Despite this growing demand, CCAM-ERAS survey results indicate that skills gaps remain material across manufacturing-related CCAM activities. Most respondents assessed the gap between current workforce skills and those required for CCAM adoption as minor to moderate, yet training needs were commonly described as moderately urgent, with a smaller but notable share reporting very high urgency. This suggests that even organisations with existing digital capabilities face continuous pressure to update skills as CCAM technologies evolve.

Further evidence from CEDEFOP highlights that companies urgently require specialists in data analytics, AI, and automation, yet such profiles remain difficult to recruit. Industrial surveys report "critical shortages of candidates with the required skills" in areas such as data analysis and AI, aligning with broader digital skills shortage trends. Around 21% of manufacturing companies in one survey indicated that improving cybersecurity (awareness, incident response skills) is a major skills priority. Overall, the shortage of engineers, especially those with hybrid digital skills, is an increasing concern. Industry groups warn that it could undermine competitiveness if left unaddressed. For example, the CECIMO 2024 survey of manufacturing firms showed nearly 90% had taken action in the past year to address skills shortages, such as in-house upskilling, due to the lack of available talent on the market.[54]

CCAM-ERAS survey data provide additional specificity on where shortages concentrate when they occur. Among respondents who reported CCAM-related skills shortages (and who selected the top shortage areas), the most frequently selected shortage area was data analysis / AI and machine learning. Cybersecurity, system integration, and embedded systems / sensor fusion were also commonly selected, suggesting that the tightest bottlenecks are concentrated in software-intensive and cross-domain engineering profiles rather than traditional mechanical specialisations.

In addition, many existing roles are beginning to transform. Traditional mechanical positions are shifting towards mechatronic and electro-digital profiles,[55] requiring workers to combine mechanical knowledge with expertise in software, electronics, and data systems.[56] This shift is also reflected in CCAM-ERAS interview insights, where one manufacturer confirmed that "the person who makes a vehicle now and who now deals with hardware will be more involved in software in the future… the vehicle will become software-defined", requiring entirely new engineering profiles with strong digital and software competences.[57] For example, auto assembly workers are being reassigned to other departments, such as painting and packaging,

[53] European Commission (2021) '2030 Digital Compass: the European way for the Digital Decade' available at: https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52021DC0118.
[54] CECIMO (2025), 'Insights beyond the skills gap 2025', available at: https://www.cecimo.eu/wp-content/uploads/2025/02/Insights-Beyond-the-Skills-Gap-2025-3.pdf.
[55] Eurofound (2025) 'Crisis in the EU automotive industry: Can the sector remain competitive in the context of the twin transitions?' available at: https://www.eurofound.europa.eu/en/publications/all/crisis-in-the-eu-automotive-industry-can-the-sector-remain-competitive-in-the-context-of-the-twin-transitions.
[56] Beyond 4.0 (2022) 'Frontrunner companies and the digital transformation: strategies to deliver inclusive economic growth' pg. 72, available at: https://addi.ehu.eus/bitstream/handle/10810/75822/oeij-2022-frontrunner.pdf.
[57] Stakeholder interview (Bram Hendrix).

or continuing their work with significantly more technological assistance.[58] Interviewees stressed that although mechanical skills remain relevant, they will decline in importance as next-generation vehicles require technicians who can diagnose and repair interconnected digital systems. This includes strong numeracy, electronics, and ICT-based diagnostic capabilities, which are currently lacking in parts of the current workforce.[59]

As CCAM advances from SAE Levels 2 to 5, manufacturing workforce structures will likely be affected by a gradual reduction in manual roles alongside rising demand for specialised, high-skilled positions. Jobs requiring manual labour, particularly low value-added positions such as assembly line workers, are becoming less prevalent, while demand grows for engineers and software specialists supporting digital and software-based functions.[60] CCAM-ERAS interview findings confirm this trajectory, noting that jobs involving repetitive manual driving or low-value mechanical tasks shall be among the first to decline, while automation places increasing pressure on traditional driving and logistics support roles.[61] The increasing adoption of Mobility-as-a-service models may amplify these effects in the longer term by reducing overall vehicle production volumes, potentially reinforcing employment pressures in manufacturing.[62] This contributes to a sector-wide skills imbalance and vacancy pressures, illustrated by the manufacturing branch of the automotive sector already facing 4.3 vacancies per 100 employees, 43% above the EU average.[63]

Economically, the high costs associated with infrastructure development and technological integration create considerable hesitation, especially among SMEs. While large logistics companies express more optimism about automation, SMEs often struggle with these cost barriers, risking monopolisation by large firms unless targeted public support is implemented.[64] In terms of employment exposure, the deployment of automation poses a differential risk across specific regions, depending largely on the concentration of existing manufacturing activity. Countries with a strong automotive manufacturing base, such as Slovakia, face a significant employment threat, with up to 33% of automotive jobs projected to be at risk of automation as of 2020, contrasted with only 6% in countries such as Norway.[65]

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[58] Russo et al. (2023) 'Automation in the automative sector: Romania. Spain and Germany', available at: https://mpra.ub.uni-muenchen.de/121707/1/MPRA_paper_121585.pdf accessed 16 September 2024.
[59] Stakeholder interview (HE and VET institutions); Stakeholder interview (Claudio Roncoli, KU Leuven); Stakeholder interview (CCAM ERAS – WP4C – Stakeholders' interview – Object 2)
[60] Russo et al. (2023) 'Automation in the automative sector: Romania. Spain and Germany', available at: https://mpra.ub.uni-muenchen.de/121707/1/MPRA_paper_121585.pdf accessed 16 September 2024.
[61] Stakeholder interview (Guus Arts and Joost Haverman, DAF Trucks); Stakeholder interview (CCAM ERAS – WP4C – Stakeholders' interview – Object 2); Stakeholder interview (CCAM ERAS – WP4C – Stakeholders' interview – Object 3); Stakeholder interview (Jeroen Corbeek, Van der Wal).
[62] European Trade Union Institute (2019) 'Towards a just transition: coal, cars and the world of work – Chapter 6', available at https://www.etui.org/publications/books/towards-a-just-transition-coal-cars-and-the-world-of-work accessed 16 September 2024.
[63] CXC Team (2024) 'Recruitment and retention challenges for the automotive industry', available at: https://www.cxcglobal.com/blog/employer-of-record-eor/automotive-industry-recruitment-retention-talent-shift/ , accessed on 25 November 2024.
[64] CCAM-ERAS D3.1 PESTLE Analysis.
[65] Lucia Novakowa (2020) 'The impact of technology development on the future of the labour market in the Slovak Republic', available at: https://www.sciencedirect.com/science/article/abs/pii/S0160791X2030035X accessed 16 September 2024; OECD (2018) 'Automation, skills use and training' available at: https://www.oecd.org/content/dam/oecd/en/publications/reports/2018/03/automation-skills-use-and-training_b611ef08/2e2f4eea-en.pdf.

Finally, the speed and scope of occupational change are geographically uneven. Countries and regions with more advanced technical infrastructure and stronger training systems are generally better positioned to manage workforce transition, while parts of Southern and Eastern Europe face more pronounced skills mismatches and slower adaptation due to more limited access to digital training and education.[66] Employment exposure therefore remains closely linked to the concentration of automotive manufacturing activity, with some countries facing substantially higher shares of jobs at risk of automation than others. Overall, manufacturing employment is shifting toward a smaller, more specialised, and more digitally oriented workforce, with substantial implications for training and skill development across Europe.

3.1.4 Skills foresight: short, medium and long term

As vehicles become more software-centric, sensor-dependent, electrified, and automation-ready, workers need to acquire new combinations of technical, digital, and transversal skills to support the transition to SAE Levels 2 through 5.[67] This shift structurally favours skilled labour over unskilled labour, as automation and digitalisation increase demand for workers with hybrid technical–digital skill profiles.[68] Skills related to the integration of advanced technologies, connected systems, and autonomous functions will therefore become central. These include coding literacy, the ability to run and test programs, and systems-based competencies such as cybersecurity.[69]

In manufacturing, hybrid expertise combining mechanical, electronic, control-engineering, and mechatronics skills will be particularly important for integrating hardware and software within ADAS and autonomous platforms. CCAM-ERAS interviewees consistently note the growing importance of cross-disciplinary competence, particularly the ability to integrate physical vehicle components with digital ecosystems, where technicians must understand both vehicle electronics and the communication protocols used by CCAM technologies.[70]

The CCAM-ERAS stakeholder survey strongly reinforces this assessment. Across respondents active in manufacturing-related CCAM roles, a clear majority rated system integration and automation, cybersecurity and data privacy, embedded systems and sensor fusion, and data analysis / AI as “very important” future skills. This confirms that the dominant skills trajectory in manufacturing is toward software-defined, security-critical, and systems-oriented competence rather than incremental extensions of traditional mechanical expertise.

CCAM deployment also requires manufacturers to adapt to a wider set of enabling technologies. Familiarity with advanced sensing technologies (including ultrasonic, infrared and

[66] International Labour Organisation (ILO) (2021) ‘Changing demand for skills in digital economies and societies’, available at: https://www.ilo.org/media/378741/download, accessed on 27 November 2024.
[67] Groshen et al. (2019) ‘Preparing US Workers and Employers for an Autonomous Vehicle Future’, available at: https://research.upjohn.org/cgi/viewcontent.cgi?article=1039&context=up_technicalreports, accessed 16 September 2024.
[68] OECD (2023) ‘Skills for a Resilient Green and Digital Transition’ available at: https://www.oecd.org/en/publications/2023/11/oecd-skills-outlook-2023_df859811.html.
[69] Crane et al. (2020) ‘Understanding the Middle Skill Workforce in the Connected and Automated Vehicle Sector’, available at: https://www.dot.state.mn.us/automated/docs/cav-middle-skill-workforce-report-june-2020.pdf, accessed 16 September 2024.
[70] Stakeholder interview (Bram Hendrix); Stakeholder interview (Claudio Roncoli, KU Leuven); Stakeholder interview (Guus Arts and Joost Haverman, DAF Trucks).

radar systems), cellular connectivity (4G/5G, and, in the longer term, 6G), and satellite positioning systems is becoming integral to Connected Autonomous Vehicle (CAV) engineering. As autonomous fleets expand, manufacturers are expected to rely more heavily on remote diagnostics, fleet supervision, and software-based troubleshooting, raising demand for professionals skilled in maintaining complex, networked systems.[71] Stakeholders further note that future manufacturing teams will make greater use of digital learning platforms and real-time instructional tools, signalling a structural reorganisation in how skills are updated and delivered within the sector.[72]

CCAM-ERAS survey responses indicate that this reorganisation of skills is expected to be broad-based. Around half of respondents reported that digital literacy will be required across most job roles, not only specialist engineering positions, while the majority highlighted a shift away from manual tasks toward more knowledge-intensive and analytical work. This suggests that skills upgrading in manufacturing will need to extend beyond a narrow group of high-skilled specialists to encompass a wider share of the workforce.

While this transition is underway, CCAM and electrification will render some traditional skills obsolete. Mechanical skills focused on combustion engines, transmissions, and analogue vehicle systems are declining in relevance as electrification and automation advance. This is illustrated by a Volkswagen case study in Germany, which indicates that combustion-engine design skills are expected to disappear by 2030, with production ending by 2035.[73] As diagnostic and maintenances processes become more software-driven, basic mechanical troubleshooting alone will no longer be sufficient. CCAM-ERAS interviews additionally highlight that education and training pathways, especially those centred on traditional driver behaviour and legacy mechanical systems, will lose relevance as CCAM removes human intervention from many operational tasks. Survey findings are consistent with this trend, as respondents rarely prioritised purely mechanical or analogue skills when asked about future CCAM skill needs. Instead, skills related to digital diagnostics, software-supported maintenance, and systems oversight were consistently ranked higher, suggesting a clear perception that legacy mechanical skill sets will become insufficient without digital augmentation.

In line with standard foresight practice, SAE automation levels are used below as indicative markers of technological maturity and associated skills requirements, rather than as precise deployment forecasts. For the purposes of this analysis, the short term refers to a 0–5 year horizon, the medium term to a 5–10 year horizon, and the long term to a period beyond 10 years.

Time horizon	SAE Level	Core skill focus	Skills declining in relevance	Typical roles affected
Short-term (0-5 years)	SAE Levels 0–2 / early Level 3; pilot deployments	Foundational digital literacy; systems integration; basic AI and data handling; sensor installation	Routine manual assembly tasks without digital augmentation;	Technicians, safety drivers, integration engineers, test and validation staff

[71] Crane et al. (2020) 'Understanding the Middle Skill Workforce in the Connected and Automated Vehicle Sector', available at: https://www.dot.state.mn.us/automated/docs/cav-middle-skill-workforce-report-june-2020.pdf, accessed 16 September 2024.
[72] Stakeholder interview (Miles Garner, Aurrigo); Stakeholder interview (HE and VET institutions).
[73] Russo et al. (2023) 'Automation in the automative sector: Romania. Spain and Germany', available at: https://mpra.ub.uni-muenchen.de/121707/1/MPRA_paper_121585.pdf accessed 16 September 2024.

	and partial automation	and calibration; software-supported diagnostics	Basic mechanical diagnostics not supported by software tools; Low-complexity quality inspection based solely on visual/manual checks	
Medium-term (5-10 years)	Domain-specific SAE Levels 3–4; scaling of automated and connected systems	Advanced AI and data analytics; cybersecurity; systems and design engineering; electrification and battery systems; remote monitoring and fleet supervision	Combustion-engine–specific mechanical engineering (engine design, transmission optimisation); Mechanical-only maintenance and calibration skills; Routine production tasks not integrated with automation or robotics	Systems engineers, design engineers, cybersecurity specialists, remote operations staff
Long term (10+ years)	Mature highly automated systems in defined domains; wider Level 4-type deployment, with Level 5 as an upper-bound reference	Advanced software engineering; sensor fusion and high-performance computing; cloud and embedded systems; regulatory compliance; ethical oversight and complex problem-solving	Analogue vehicle-system design without software integration; Manual production roles without systems oversight; Quality control functions not supported by data, AI or sensor-based monitoring	System architects, safety and compliance specialists, autonomous system supervisors

Table 1. Evolution of manufacturing skills needs under CCAM by time horizon
Source: CCAM-ERAS

Short-term skills needs

In the early stages of CCAM deployment, marked by connected vehicles, advanced driver-assistance systems, and limited automation, human oversight remains central. This phase prioritises skills that enable the integration and production of CCAM-enabling hardware and software, such as software development, network infrastructure and data analysis. New and evolving skills such as systems integration and early-stage digital competencies will be critical in this phase. Additionally, digital skills such as expertise in software and AI development are critical for enabling vehicles to interpret sensor data and make real-time decisions. Professionals must be skilled in AI sub-processes like learning, reasoning, and behavioural modelling.[74]

The integration of cellular connectivity and V2X communication requires professionals who can install sensors, analyse data, and manage these interconnected transport systems. From a technical perspective, the sector requires technicians capable of combining mechanical expertise with digital systems, reinforcing the importance of cross-functional and hybrid skill profiles. CCAM-ERAS interview findings support this view, with employers anticipating that safety drivers, vehicle operators, and technical staff will require specialised CCAM training

[74] Giannakos et al. (2023) 'Understanding the Gap of CCAM solutions deployment', s 2.2.1.

frameworks, including certification modules on AV operation and early-stage monitoring, to bridge the skills gap during pilot and pre-deployment phases.[75]

CCAM-ERAS survey evidence aligns closely with this short-term outlook. Most respondents expect an increase in demand for CCAM-related roles within the next five years and emphasise the immediate importance of foundational digital skills. Training needs during this period are typically described as slightly to moderately urgent, indicating a need for rapid but incremental upskilling rather than large-scale workforce replacement.

Medium-term skills needs

In the medium term, as more advanced and domain-specific automated-driving functions begin to scale, particularly in the transition towards SAE Levels 3–4, skills demand shifts towards more specialised engineering and systems-management roles. Consequently, cybersecurity, data science, AI, and machine-learning expertise will become central, as manufacturers seek multidisciplinary professionals capable of designing and safeguarding automated systems.[76] Engineers will require deeper training in robotics, electrical engineering, and software engineering to support the development of advanced vehicle architectures and communication networks.

Systems engineering and design engineering gain particular importance in this phase, as sensor alignment and calibration skills become critical for autonomous functions.[77] The continued shift away from combustion engines necessitates a demand for skills related to electrification, including battery systems, renewable energy integration, and supporting sustainable mobility.[78] CCAM-ERAS interview findings suggest that this period will create entirely new occupational profiles, such as autonomous fleet supervisors, remote intervention specialists, and systems-monitoring operators, reflecting the gradual transition from human-in-the-vehicle roles to remote operational command structures.[79]

Survey responses strongly reinforce this medium-term projection. A clear majority of respondents anticipate growing demand for CCAM-related roles over the next 5–10 years and identify AI, advanced data analytics, cybersecurity, and system integration as priority skill areas during this period. At the same time, respondents report that skills gaps are likely to widen if training provision and recruitment pipelines do not adapt, indicating a heightened risk of skills mismatches during this period.

Long-term skills needs

[75] Stakeholder interview (Filip Pavic & Lovro Nobilo, Verne); Stakeholder interview (Guus Arts and Joost Haverman, DAF trucks).
[76] European Commission Joint Research Centre (2018) 'An Analysis of Possible Socio-Economic Effects of CCAM in Europe' available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC111477.
[77] Shammut (2020) 'Driverless Cars Implications: A Literature Review' available at: http://www.transportationgroup.nz/wp-content/uploads/Driverless-Cars-Implications-Moayad-Shammut-2020.pdf.
[78] Yankelevich et al. (2018) 'Preparing the Workforce for Automated Vehicles', available at: https://comartsci.msu.edu/sites/default/files/documents/MSU-TTI-Preparing-Workforce-for-AVs-and-Truck-Platooning-Reports%20.pdf accessed on 7 October 2024.
[79] Stakeholder interview (Claudio Roncoli, KU Leuven); Stakeholder interview (Guus Arts and Joost Haverman, DAF Trucks); Stakeholder interview (CCAM ERAS – WP4C – Stakeholders' interview – Object 2).

In the longer term, as highly automated systems become more mature and more widely deployed in defined operational domains, manufacturing skill needs are expected to intensify further. The most relevant reference point here is not universal SAE Level 5 automation, which remains uncertain, but the wider deployment of highly automated Level 4-type systems and the broader shift towards software-defined, sensor-intensive, and continuously updated vehicle architectures. These developments are expected to increase demand for highly specialised digital and theoretical expertise, including advanced software engineering, intelligent navigation, and large-scale data analytics.[80] Technicians will be required to combine electrical, mechanical, electronic, data-analytic, and software-maintenance capabilities to manage autonomous systems end-to-end, with particular emphasis on cloud services, embedded systems, and AI-based diagnostics.[81]

Alongside technical expertise, transversal skills will gain importance as human roles focus more on oversight than direct operation. Ethical decision-making, regulatory compliance, complex problem-solving and adaptability may become essential, as workers assume responsibility for oversight of fully autonomous ecosystems.[82] CCAM-ERAS interviews also point to a growing need for communication and public-facing skills, as professionals will be expected not only to operate CCAM technologies but also to explain them to users and ensure safe, inclusive adoption.[83] Over time, substantial curriculum changes are anticipated, with the introduction of new CCAM-focused disciplines and research fields (including fleet management, sensor technologies, and cybersecurity) to align long-term education pathways with future labour market demands.[84]

CCAM-ERAS survey respondents echo this long-term shift, frequently highlighting ethical decision-making, regulatory knowledge, and advanced problem-solving as increasingly important competences as automation matures. This suggests that, already in the short to medium term and increasingly in the long term, manufacturing roles will combine deep technical expertise with governance, safety, and societal-facing responsibilities linked to trust in autonomous systems. As skills become more digitalised, workers will not only need to deepen their technical capabilities but also develop parallel competences in regulatory awareness, safety assurance, communication, and responsible system oversight.

3.2 Sale, maintenance and repair of motor vehicles

3.2.1 Sector overview and CCAM relevance

The sale, maintenance and repair of motor vehicles sector covers the retail and sale of new and used motor vehicles, the wholesale and retail of motor-vehicle parts and accessories, as well as

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[80] Clarke *et al.* (2025), Can AI Fill the Automotive Industry Skills Gap? A Needs Assessment of the UK Automotive Industry, available at: https://www.researchgate.net/publication/396529283_Can_AI_Fill_the_Automotive_Industry_Skills_Gap_A_Needs_Assessment_of_the_UK_Automotive_Industry.

[81] European Commission (2021) 'Study on the social dimension of the transition to automation and digitalisation in transport, focusing on the labour force' available at: https://op.europa.eu/en/publication-detail/-/publication/476d738a-404c-11ec-89db-01aa75ed71a1.

[82] European Commission (2019) 'Ethics Guidelines for Trustworthy AI' available at: https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai.

[83] Stakeholder interview (CCAM ERAS – WP4C – Stakeholders' interview – Object 2); Stakeholder interview (HE and VET institutions).

[84] Stakeholder interview (Claudio Roncoli, KU Leuven); Stakeholder interview (HE and VET institutions).

the maintenance and repair of vehicles across mechanical, electrical and electronic systems.[85] The most relevant sectoral activities for CCAM fall under the following NACE activities: G45.1 Sale of motor vehicles, G45.2 Maintenance and repair of motor vehicles, and G45.3 Sale of motor vehicle parts and accessories. Together, these activities encompass the full customer journey from point-of-sale (dealerships or independent resellers) to after-sales services, regular servicing, mechanical and electronic repairs, diagnostics, and the replacement of vehicle parts.

As vehicles become increasingly digital, autonomous, and electric, traditional car sales, servicing, and repair are required to evolve. Dealerships and sales outlets will no longer focus solely on internal combustion engine vehicles but may increasingly handle electric and automated models.[86] Maintenance and repair workshops will need to adapt to more complex after-sales tasks, such as calibrating sensors (e.g., LiDAR, radar, cameras), updating and maintaining embedded software and firmware, servicing electric drivetrains and battery systems, and ensuring the continued functionality of safety-critical systems.[87] In this context, the sale and after-sales segment becomes a key gatekeeper for the long-term reliability, safety, and user acceptance of CCAM vehicles.[88]

In terms of scale, according to the latest EU Labour Force Survey data in 2024, the sector accounts for approximately 3.6 million jobs across the EU, corresponding to around 1.6% of total EU employment[89]. Countries with a strong % of total employment include Romania (2.7%), Poland (2.1%), Portugal (2.3%), Bulgaria (2.1%), Lithuania (2.2%), Latvia (2.3%), and Cyprus (2.2%). Moreover, data shows that the sector carries a strong presence of SMEs, such as small local dealers or independent repair shops rather than large multinational dealership networks.[90] This structure could present significant structural challenges in the context of CCAM deployment, as smaller firms may lack the capital, technical infrastructure, or skilled labour to service advanced electric or autonomous vehicles. Given the prevalence of SMEs, CCAM-related change is likely to not only alter the nature of services provided, but also to affect the sector's overall structure, potentially concentrating activity among firms that are able to adapt while others face increasing pressure or exit.

[85] Eurostat (2008) 'NACE Rev. 2: Statistical classification of economic activities in the European Community', p. 217, available at: https://ksh.hu/docs/osztalyozasok/teaor/teaor_exp_notes.pdf.
[86] Raposo et al. (2018) '*An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe. Effects of automated driving on the economy, employment and skills'* available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC111477/kjna29226enn.pdf.
[87] Autodepot (2024) 'Autonomous bus depot' available at: https://www.saam.swiss/wp-content/uploads/AutoDepot-report_vfin_eng.pdf; Stakeholder interview (Claudio Roncoli, KU Leuven); Stakeholder interview (Miles Garner, Aurrigo); Stakeholder interview (Guus Arts and Joost Haverman, DAF Trucks); Stakeholder interview (HE and VET institutions).
[88] CCAM Partnership (2022) 'CCAM Strategic Research and Innovation Agenda (SRIA), Version 1.4' available at: https://www.ccam.eu/wp-content/uploads/2021/12/CCAM-Partnership-SRIA-v1.4_FINAL_VER_-ELECTRONIC-17032022.pdf; CCAM Partnership (2025) 'Future of the CCAM Partnership under FP10 – Position Paper' available at: https://www.ccam.eu/wp-content/uploads/2025/02/Future-of-the-CCAM-Partnership-under-FP10.pdf.
[89] Leončika et al. (Eurofound) (2024) 'Employment in the EU's automotive sector' available at: https://assets.eurofound.europa.eu/f/279033/513b319511/ef25036en_en.pdf.
[90] Eurostat (2025) '*Businesses in distributive trade sector'* available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Businesses_in_distributive_trade_sector, accessed March 7, 2025.

The impact of CCAM technologies on this sector increases markedly from SAE Level 3 onwards. At partial automation levels (SAE Levels 2-3), impacts are likely to remain limited to occasional software updates and the early maintenance of electronic systems. However, as automation progresses toward SAE Levels 3-4, workshops are expected to face growing demand for sensor calibration, electronic diagnostics, software maintenance, and battery or electric-drivetrain servicing. Under full automation (SAE Level 5), the sales and repair sector would be required to support high-complexity maintenance activities, including the management of redundant safety systems, continuous software updates, remote diagnostics, and possibly even lifecycle management for autonomous fleets. Thus, CCAM technologies start affecting this sector meaningfully at SAE 3-4 and would transform it more fundamentally under higher levels of automation.

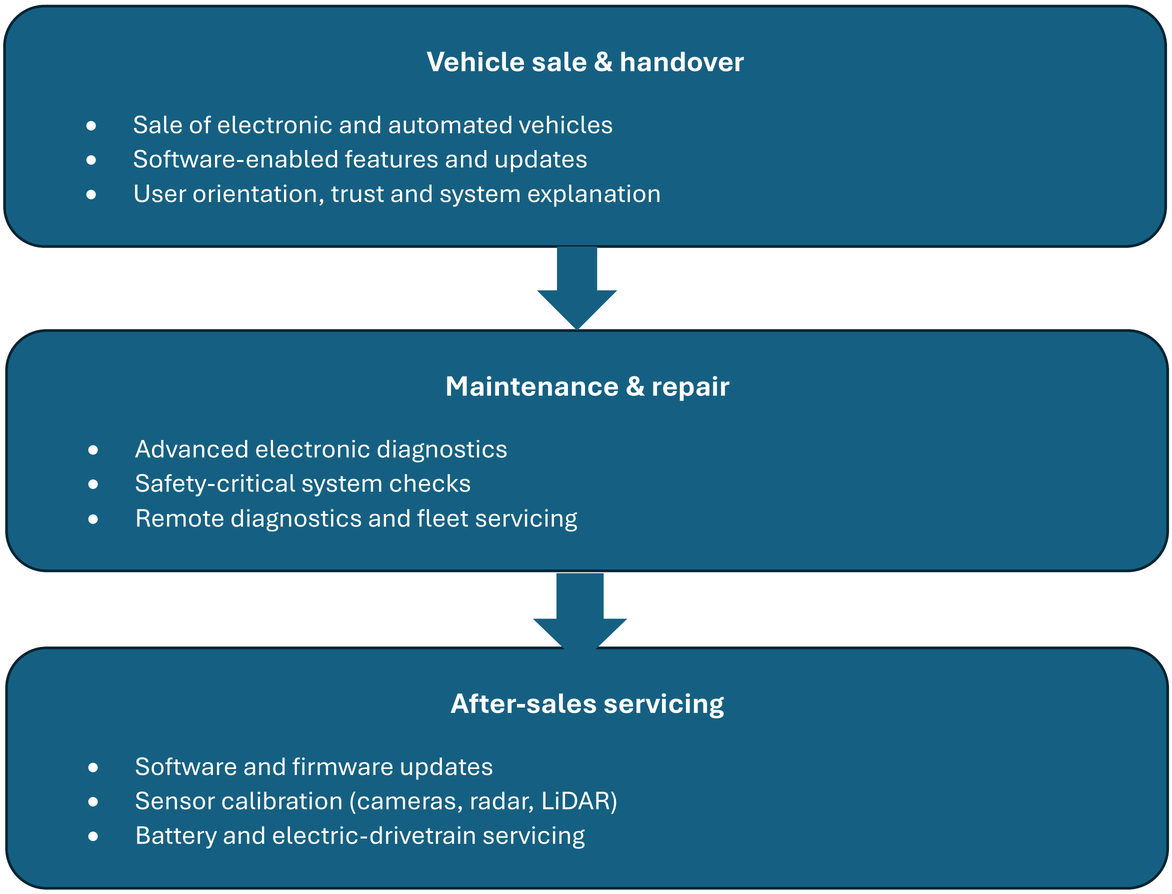

Figure 5. How CCAM technologies affect the sale, maintenance and repair of motor vehicles

3.2.2 Technical and organisational trends

The sale, maintenance and repair sector is expected to undergo considerable transformation as CCAM technologies reshape the nature of diagnostics and servicing. In vehicle sales, traditional dealership models are increasingly complemented, and in some cases replaced, by online and virtual sales platforms.[91] While this trend is primarily driven by broader digitalisation in retail, the

[91] European Trade Union Institute (2019) 'Towards a just transition: coal, cars and the world of work – Chapter 6', available at https://www.etui.org/publications/books/towards-a-just-transition-coal-cars-and-the-world-of-work accessed 16 September 2024.

growing complexity of electric and automated vehicles may alter the nature of customer-facing roles, placing greater emphasis on explaining vehicle functionalities and supporting customers in the use of software-enabled features throughout the ownership cycle.

In maintenance and repair, digitalisation is more directly reshaping core operational processes. Modern vehicles, particularly automated and connected models, continuously generate large volumes of sensor and operational data that enable real-time monitoring of vehicle and component performance. This supports a shift toward condition-based and predictive maintenance, where physical inspections are replaced by data-driven diagnostics to optimise repair timing and reduce downtime.[92]

Software management has also become a central element of maintenance and repair activities. Automated and highly connected vehicles depend on complex software architectures that require frequent updates, calibration, and troubleshooting.[93] Over-the-air (OTA) update capabilities enable manufacturers to deploy software patches remotely, meaning that maintenance work will increasingly involve managing digital networks, identifying software-related faults, and ensuring system stability, rather than only focusing solely on mechanical repairs.[94]

Moreover, automated vehicles rely on tightly coordinated perception hardware (cameras, radar, LiDAR, and other sensor arrays) that must be precisely aligned to ensure safe functioning.[95] As a result, calibration and recalibration have become routine yet highly specialised tasks, while collision repairs have grown more complex due to the risk of damaging sensor-embedded components.[96] Taken together, these developments imply an organisational shift within the sector. Generalist mechanical roles will progressively give way to profiles centred on managing high-tech, networked vehicle systems, including remote diagnostics and troubleshooting. Workshops and service providers must therefore adapt their internal processes, equipment and workflows to accommodate software-driven maintenance, advanced diagnostics and closer integration with manufacturers' digital systems.[97]

[92] World Maritime University (2019) 'Transport 2040: Automation, Technology, Employment - the Future of Work', available at: https://commons.wmu.se/cgi/viewcontent.cgi?article=1071&context=lib_reports accessed 30 September 2024.
[93] Groshen et al. (2019) 'Preparing US Workers and Employers for an Autonomous Vehicle Future', available at: https://research.upjohn.org/cgi/viewcontent.cgi?article=1039&context=up_technicalreports, accessed 16 September 2024.
[94] Crane et al. (2020) 'Understanding the Middle Skill Workforce in the Connected and Automated Vehicle Sector', available at: https://www.dot.state.mn.us/automated/docs/cav-middle-skill-workforce-report-june-2020.pdf, accessed 16 September 2024.
[95] Grosso et al. (2021) 'How will vehicle automation and electrification affect the automotive maintenance, repair sector?', available at: https://www.researchgate.net/publication/356566290_How_will_vehicle_automation_and_electrification_affect_the_automotive_maintenance_repair_sector, accessed 12 November 2024.
[96] Nikoo Razavi & Grzegorz Sierpinski (2024) 'An attempt to determine the impact of the implementation of autonomous vehicles on a larger scale on the planning of city transport systems', available at: https://jsdtl.sciview.net/index.php/jsdtl/article/view/217/162, accessed 12 November 2024.
[97] Crane et al. (2020) 'Understanding the Middle Skill Workforce in the Connected and Automated Vehicle Sector', available at: https://www.dot.state.mn.us/automated/docs/cav-middle-skill-workforce-report-june-2020.pdf, accessed 16 September 2024.

3.2.3 Employment and occupational change

The shift toward CCAM is accelerating the decline of several traditional roles while simultaneously creating new technical positions and transforming existing ones within the sector. Conventional mechanics specialising in engine repairs, oil changes and routine mechanical servicing face declining demand, as automated and electric vehicles require fewer mechanical interventions and less frequent component replacement.[98] CCAM-ERAS interview findings support this trend, indicating that many routine diagnostic and inspection activities will be absorbed by automated systems and AI-driven tools, reducing the need for purely manual troubleshooting.[99] In addition, the potential gradual decline in crash-related repairs may further reduce demand for low-skilled repair work. Declines are also evident in roles involving routine operational tasks, manual inspection and physical troubleshooting, which are increasingly replaced by predictive diagnostics, automated inspection tools, and remote monitoring technologies.[100]

Declining roles and tasks	Transforming roles	Emerging CCAM-related roles
Routine mechanical repair (e.g., engine servicing, oil changes)	Mechatronics-oriented technicians combining mechanical and digital competences	Automated vehicle technicians
Manual diagnostics and visual inspection	Digitally assisted mechanics using software-based diagnostic tools	Software-diagnostics technicians
Low-skilled inspection and troubleshooting tasks	Hybrid mechanical–ICT profiles supporting electronic and software systems	Predictive-maintenance specialists
Crash-repair intensive roles without sensor expertise	Sensor-aware repair technicians responsible for calibration and validation	Fleet maintenance coordinators and remote maintenance specialists
Isolated workshop-based repair roles	Technicians integrated into digitally connected service networks	CAV maintenance technicians supporting automated and shared fleets

Table 2. Occupational change in the sale, maintenance and repair of motor vehicles under CCAM
Source: CCAM-ERAS

CCAM-ERAS survey evidence strongly supports this transformation of task profiles. Among respondents active in vehicle maintenance, repair, fleet servicing, and related CCAM activities, most expect automation to affect existing jobs at least to a moderate extent, with a smaller share anticipating significant transformation. This pattern suggests that while widespread job

[98] Combe et al. (OECD) (2023) 'Adapting to automation: Transport Workforce in Transition', available at: https://www.oecd-ilibrary.org/transport/adapting-to-automation_905fdc2c-en, accessed 30 September 2024.
[99] Raposo et al. (2018) '*An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe. Effects of automated driving on the economy, employment and skills'* available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC111477/kjna29226enn.pdf.
[100] European Trade Union Institute (2019) 'Towards a just transition: coal, cars and the world of work – Chapter 6', available at https://www.etui.org/publications/books/towards-a-just-transition-coal-cars-and-the-world-of-work accessed 16 September 2024.

loss is not expected in the short term, the content of maintenance and repair work is already shifting from routine manual tasks toward digitally mediated diagnostics and system oversight.

Alongside these declines, CCAM deployment is generating a range of new occupations linked to the growing digital and electronic complexity of modern vehicles. The emergence of electric and automated systems has introduced new technical profiles such as EV technicians, electronics specialists and software-diagnostics technicians responsible for interpreting data logs, managing OTA updates and ensuring the integrity of automated functions.[101] Additional roles are emerging around the maintenance of shared and autonomous fleets, including fleet-maintenance coordinators, predictive-maintenance specialists and CAV maintenance technicians engaged in remote troubleshooting and sensor calibration.[102] CCAM-ERAS survey responses reflect this expansion, with respondents most frequently identifying automated vehicle technicians and electrification and battery specialists as relevant CCAM-related roles, indicating a broadening of the sector's occupational structure beyond workshop-based mechanical repair.

As CCAM deployment extends beyond the vehicle itself, new roles are also emerging in the upkeep of supporting infrastructure, including municipal technicians tasked with maintaining roadside communication units, fibre-optic links, V2X systems and automated inspection technologies.[103] Within vehicle sales, digital-sales advisors and online mobility consultants are emerging to support customers in selecting, configuring and updating increasingly digital, connected vehicles. CCAM-ERAS interview findings illustrate a growing demand for specialists capable of working across both physical components and the software systems governing autonomous vehicles, reinforcing the need for dual competences in electronics diagnostics and software-based system maintenance. In parallel, the emergence of roles focused on communication with customers and the public has also been noted, as staff must be able to explain complex automated functionalities and reassure users about safety and reliability.

CCAM-ERAS survey responses reinforce this need for hybrid technical–communication roles. Around half of respondents highlighted an increased need for digital literacy across a wide range of job roles, including customer-facing positions, while many also emphasised communication, adaptability, and problem-solving as critical transversal skills for staff interacting with users of automated and connected vehicles.

In many cases, existing roles are not disappearing but undergoing substantial transformation. A prominent example of this is the evolution of conventional mechanics into mechatronics-oriented technicians who must combine mechanical knowledge with competencies in

[101] Groshen et al. (2019) 'Preparing US Workers and Employers for an Autonomous Vehicle Future', available at: https://research.upjohn.org/cgi/viewcontent.cgi?article=1039&context=up_technicalreports, accessed 16 September 2024.
[102] Yankelevich et al (2018) 'Preparing the Workforce for Automated Vehicles', available at: https://comartsci.msu.edu/sites/default/files/documents/MSU-TTI-Preparing-Workforce-for-AVs-and-Truck-Platooning-Reports%20.pdf, accessed 1 October 2024.
[103] Raposo et al. (2018) '*An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe. Effects of automated driving on the economy, employment and skills'* available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC111477/kjna29226enn.pdf.

electronics, ICT systems and software interpretation.[104] Maintenance activities are moving away from manual disassembly and visual inspection toward data-driven diagnostics, software troubleshooting, sensor calibration and battery-management tasks.[105] Stakeholder findings indicate that foundational electronics knowledge is already insufficient among many vocational level mechanics, creating a pronounced skills gap that limits the sector's readiness for CCAM maintenance demands.[106] Diagnostics specialists, in particular, are expected to require stronger mathematical and ICT problem-solving skills to interpret complex data streams generated by autonomous and semi-autonomous vehicles.[107]

The CCAM-ERAS survey provides further confirmation of these skills gap. Most respondents assess the gap between existing workforce skills and those required for CCAM-related maintenance and repair as minor to moderate, while a notable minority reported a large gap. Importantly, training needs were most often described as moderately to very urgent, indicating that skills shortfalls are already constraining organisations' ability to adapt to CCAM technologies.

These occupational shifts intensify as automation progresses from SAE Level 2 towards higher levels. At lower automation levels, the impact is modest and remains focused on the growing need to service electronic systems and conduct software updates.[108] However, from SAE Level 3 onward, vehicles rely heavily on sensor suites, redundancy systems and continuous software management, significantly increasing the technical intensity of maintenance activities.[109] Mechanical tasks continue to decline, while demand for electronic diagnostics, system checks, and software-related maintenance expands. At SAE Levels 4 and 5, workforce structures become predominantly oriented toward ICT-rich competencies, with technicians required to manage autonomous-system diagnostics, ensure the reliability of safety-critical components and support remote supervision functions for automated fleets.[110] This shift alters both the skill composition of the workforce and the internal organisation of repair shops, which must restructure workflows to accommodate software-based maintenance tasks. These findings are confirmed by CCAM-ERAS stakeholders' interviews which indicate that as automation increases, new remote operational roles will integrate directly into maintenance structures,

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[104] Raposo et al. (2018) '*An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe. Effects of automated driving on the economy, employment and skills'* available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC111477/kjna29226enn.pdf.
[105] Yankelevich et al (2018) 'Preparing the Workforce for Automated Vehicles', available at: https://comartsci.msu.edu/sites/default/files/documents/MSU-TTI-Preparing-Workforce-for-AVs-and-Truck-Platooning-Reports%20.pdf, accessed 1 October 2024.
[106] Stakeholder interview (HE and VET institutions).
[107] Stakeholder interview (Claudio Roncoli, KU Leuven); Stakeholder interview (HE and VET institutions).
[108] Groshen et al. (2019) 'Preparing US Workers and Employers for an Autonomous Vehicle Future', available at: https://research.upjohn.org/cgi/viewcontent.cgi?article=1039&context=up_technicalreports, accessed 16 September 2024.
[109] Grosso et al. (2021) 'How will vehicle automation and electrification affect the automotive maintenance, repair sector?', available at: https://www.researchgate.net/publication/356566290_How_will_vehicle_automation_and_electrification_affect_the_automotive_maintenance_repair_sector, accessed 12 November 2024.
[110] Crane et al. (2020) 'Understanding the Middle Skill Workforce in the Connected and Automated Vehicle Sector', available at: https://www.dot.state.mn.us/automated/docs/cav-middle-skill-workforce-report-june-2020.pdf, accessed 16 September 2024.

marking a shift from hands-on mechanical repair to system oversight and remote control.[111] CCAM-ERAS survey respondents' time-horizon expectations align with this trajectory: while near-term impacts are generally seen as manageable, a clear majority anticipate a growing increase in demand for CCAM-related roles over the next 5–10 years, coinciding with higher automation levels and reinforcing expectations of deeper occupational restructuring in the medium term.

The sector's strong reliance on SMEs significantly influences its adaptation capacity. While large dealership networks are generally better positioned to invest more readily in advanced diagnostic tools, staff training and digital sales infrastructure, smaller workshops frequently face higher barriers in acquiring the equipment and competences needed to service automated and electric vehicles.[112] Many SMEs rely on generalist mechanics whose skill profiles are increasingly misaligned for the demands of CCAM technologies, requiring substantial reskilling, capital investment and organisational changes to remain viable. In contrast, large dealerships often have formal training partnerships with manufacturers, giving them a structural advantage as vehicle technologies become more complex. CCAM-ERAS interviewees highlight that these disparities will widen unless national-level training standards and unified certification systems are implemented, as inconsistent requirements across countries currently hinder workforce mobility and create fragmentation in skills supply.[113] CCAM-ERAS survey results echo these structural constraints, with respondents frequently identifying lack of qualified candidates, high costs of training and equipment, and difficulty reskilling existing employees as key challenges. These barriers are particularly pronounced for smaller organisations, reinforcing concerns that SMEs may struggle disproportionately to adapt without coordinated support and accessible training pathways.

Finally, European skills-forecasting evidence points to a declining demand for low-skilled mechanical occupations alongside growing demand for high-skill technical and ICT-related roles within automotive services.[114] CEDEFOP identifies an increasing need for digital problem-solving, system-monitoring, and technology-rich operational roles, aligning closely with the new requirements introduced by CCAM technologies.[115] This reinforces the view that the sector is transitioning towards a labour structure characterised by hybrid technical-digital skillsets supported by strong analytical and transversal competencies. Stakeholders anticipate a long-term shift toward higher educational attainment within the maintenance workforce, with new career pathways attracting individuals with backgrounds in data, ICT and automation, groups not traditionally associated with automotive repair.[116] CCAM-ERAS survey findings support this

[111] Stakeholder interview (Claudio Roncoli, KU Leuven); Stakeholder interview (Guus Arts and Joost Haverman, DAF Trucks); Stakeholder interview (CCAM ERAS – WP4C – Stakeholders' interview – Object 2).
[112] Institute of the Motor Industry (2023) 'Supporting the future of EV repairs in the independent sector' available at: https://tide.theimi.org.uk/industry-latest/motorpro/supporting-future-ev-repairs-independent-sector.
[113] Stakeholder interview (HE and VET institutions); Stakeholder interview (CCAM ERAS – WP4C – Stakeholders' interview – Object 2).
[114] CEDEFOP (2021) 'Sectors in transition – the automotive industry' available at: https://www.cedefop.europa.eu/en/news/sectors-transition-automotive-industry.
[115] CEDEFOP (2024) 'Drivers and vehicle operators: skills opportunities and challenges (2023 update)' available at: https://www.cedefop.europa.eu/en/data-insights/drivers-and-vehicle-operators-skills-opportunities-and-challenges-2023-update.
[116] Stakeholder interview (HE and VET institutions); Stakeholder interview (Claudio Roncoli, KU Leuven).

outlook, as respondents most frequently prioritised data analysis and AI, cybersecurity, system integration and digital diagnostics when identifying future training priorities.

3.2.4 Skills foresight: short, medium and long term

Skills requirements in the sale, maintenance and repair sector are expected to evolve progressively as CCAM technologies mature and diffuse across vehicle fleets. Across all time horizons, this transformation is characterised less by the disappearance of work than by a reconfiguration of tasks and professional profiles, as manual, inspection-based and low-complexity activities decline in relative importance while hybrid technical–digital and advisory roles become more prominent. Rather than a single, uniform shift, skills demand changes across time horizons in line with the growing digitalisation, electrification, connectivity, and automation of vehicles, as well as the gradual restructuring of maintenance, repair, and sales activities. SAE automation levels are used here only as indicative markers of technological maturity and associated skills requirements, rather than as precise deployment forecasts. The short term is characterised by incremental upskilling to support increasingly connected and partially automated vehicles; the medium term presents the greatest risk of skills mismatches as automation and electrification scale; and the long term reflects an upper-bound skills profile associated with highly automated vehicle and service systems.

Time horizon	SAE Level	Core skill focus	Skills declining in relevance	Typical roles affected
Short-term (0-5 years)	SAE Levels 2–3; early deployment of automated and connected functions	Foundational digital literacy; OEM diagnostics; basic ADAS calibration; EV safety and battery systems; customer-facing communication	Routine mechanical servicing; manual inspection tasks; low-complexity sales interactions	Vehicle technicians, workshop mechanics, service advisors, dealership staff
Medium-term (5-10 years)	SAE Levels 3–early 4; scaling of automated and connected vehicles	Predictive maintenance; data-enabled diagnostics; telematics integration; multi-system fault analysis; mechatronics	Mechanical-only repair profiles; reactive maintenance; isolated workshop-based roles	Mechatronics technicians, predictive-maintenance specialists, CAV fleet maintenance technicians
Long term (10+ years)	Mature highly automated vehicle and service systems; wider Level 4-type deployment, with Level 5 as an upper-bound reference	Advanced system integration; software diagnostics; sensor fusion calibration; cybersecurity; regulatory and safety assurance; remote operations	Manual precision tasks; collision repair linked to human driving errors; low-complexity transactional sales roles	Systems-oriented technicians, remote operations specialists, safety and compliance staff

Table 3. Evolution of skills requirements in sale, maintenance and repair of motor vehicles under CCAM. Source: CCAM-ERAS.

Short-term skills needs

In the short term, workshops will need technicians who can operate OEM diagnostic platforms, process fault codes, handle software updates and perform basic calibration of advanced driver-assistance systems such as lane-keeping assistance or automatic emergency braking. Increasing penetration of electric vehicles requires familiarity with high-voltage safety, battery management systems and power electronics, alongside traditional mechanical knowledge.[117] Whereas staff in dealerships must be able to explain digital features, connectivity services and driver-assistance functions, which raises the importance of basic digital literacy and the ability to communicate technology-rich information clearly to non-expert users.[118] This is confirmed by CCAM-ERAS interview findings, which emphasise how frontline staff will increasingly require communication and public-engagement skills to help customers trust and properly use early automated functions, skills not historically associated with workshop or dealership personnel.[119] Among CCAM-ERAS survey respondents active in maintenance, repair, fleet servicing and related CCAM activities, most identified digital literacy, vehicle diagnostics, and basic ADAS-related competences as immediate priorities. Training needs in this phase were most often described as moderately urgent, indicating that while skills gaps are manageable in the short term, rapid upskilling is required to ensure workshops and dealerships can safely service and explain increasingly digital vehicles.

Medium-term skills needs

Over the medium term, as higher levels of automation and more sophisticated EV platforms become widespread, the skill mix shifts towards electronic diagnostics and data-driven maintenance. Workshops are expected to rely on remote failure-detection systems, predictive maintenance tools and real-time data streams from connected vehicles, requiring technicians to interpret diagnostic data, configure telematics devices and integrate information from multiple subsystems when planning repairs.[120] Traditional mechanics increasingly evolve into mechatronics-oriented specialists who combine mechanical, electrical and IT skills, while new roles such as predictive-maintenance specialist, CAV fleet maintenance technician and infrastructure-support technician emerge to service shared, automated fleets and their communication units.

On the commercial side, sales staff move towards more advisory roles, supporting customers in configuring software packages, connectivity subscriptions and mobility services rather than simply selling a physical vehicle.[121] Furthermore, CCAM-ERAS interview findings indicate that

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[117] Economic Growth Institute (2020), 'Understanding the Middle-skill Workforce in the Connected and Automated Vehicle Sector', available at: https://economicgrowth.umich.edu/publications/understanding-the-middle-skill-workforce-in-the-connected-automated-vehicle-sector/ accessed on 8 October 2024.

[118] Raposo et al. (2018) '*An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe. Effects of automated driving on the economy, employment and skills'* available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC111477/kjna29226enn.pdf.

[119] Stakeholder interview (HE and VET institutions); Stakeholder interview (CCAM ERAS – WP4C – Stakeholders' interview – Object 2).

[120] Groshen et al. (2019) 'Preparing US Workers and Employers for an Autonomous Vehicle Future', available at: https://research.upjohn.org/cgi/viewcontent.cgi?article=1039&context=up_technicalreports, accessed 16 September 2024.

[121] Kearney et al. (2020) 'How automakers can survive the self-driving era', available at: https://www.kearney.com/industry/automotive/article/-/insights/how-automakers-can-survive-the-self-driving-era accessed 16 September 2024.

medium-term skill needs will particularly focus on multi-system fault analysis and interconnected diagnostics as AV-related malfunctions often span across communication networks, sensors and vehicle-level subsystems, requiring technicians to diagnose errors beyond the vehicle itself.[122]

Additionally, it is highlighted that digital learning platforms and Augmented Reality (AR)-based remote guidance will become standard for technician upskilling, replacing traditional apprenticeship-based training models.[123] The CCAM-ERAS stakeholder survey provides strong confirmation of this medium-term shift. A clear majority of respondents anticipate an increase in demand for CCAM-related roles over the next 5–10 years and prioritise predictive maintenance, data-enabled diagnostics, system integration, and telematics-related skills. At the same time, respondents frequently reported moderate to large skills gaps in these areas, signalling a heightened risk of skills mismatches if training provision does not evolve in parallel with technological deployment.

Long-term skills needs

In the longer term, as highly automated and increasingly software-defined vehicles become more common, and as connected fleet and Mobility-as-a-Service (MaaS)-type service models expand, the sector's skills profile is expected to become increasingly dominated by hybrid technical-digital competences. Maintenance and repair operations will depend heavily on advanced IT and systems-related skills, including software diagnostics, system integration, secure over-the-air updates, sensor fusion calibration, and the use of augmented-reality tools to support complex maintenance procedures.[124] Technicians are increasingly required to work across vehicle and infrastructure boundaries, maintaining not only vehicles but also smart-road equipment, roadside communication units, and V2X interfaces that support automated mobility systems.

CEDEFOP's sectoral analysis of the automotive industry indicates that the vast majority of forecasted job growth up to 2030 is concentrated in engineering and ICT occupations, reinforcing the long-term shift toward high-skill, technology-intensive roles in automotive services.[125] Stakeholder findings support this trajectory, noting that CCAM deployment is expected to make remote operations a regular component of workshop structures, with technicians gradually coordinating with automated inspection systems and remote command teams responsible for fleet oversight.[126] CCAM-ERAS survey respondents echo this long-term outlook, frequently identifying advanced system integration, cybersecurity, and ethical and regulatory awareness as critical competences as automation matures.

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[122] Stakeholder interview (Claudio Roncoli, KU Leuven); Stakeholder interview (Guus Arts and Joost Haverman, DAF Trucks).
[123] Stakeholder interview (Miles Garner, Aurrigo); Stakeholder interview (HE and VET institutions);
[124] Raposo et al. (2018) '*An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe. Effects of automated driving on the economy, employment and skills'* available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC111477/kjna29226enn.pdf.
[125] CEDEFOP (2021) 'Sectors in transition – the automotive industry' available at: https://www.cedefop.europa.eu/en/news/sectors-transition-automotive-industry.
[126] Stakeholder interview (Claudio Roncoli, KU Leuven); Stakeholder interview (Guus Arts and Joost Haverman, DAF Trucks); Stakeholder interview (CCAM ERAS – WP4C – Stakeholders' interview – Object 2).

Taken together, these findings suggest that future maintenance and repair roles will progressively combine deep technical expertise with responsibilities linked to safety assurance, data governance, and regulatory compliance. Academic experts further anticipate that long-term skills formation will require substantial adaptation of vocational and higher-education curricula, including the integration of new CCAM-focused disciplines related to system integration, cybersecurity and automated fleet management.[127]

Across all time horizons

Across the skills foresight horizon, certain task-specific competences decline in relative importance. Work that relies primarily on manual control precision, near vision for visual inspection or repetitive operations becomes less central as diagnostics, inspection and maintenance are increasingly automated through advanced diagnostic tools, automated inspection systems and predictive health-monitoring technologies.[128] Collision repair associated with human driving errors is also expected to diminish as safety systems and automation reduce accident frequency, particularly in contexts with high penetration of advanced driver-assistance systems.[129] Similarly, low-complexity sales roles based on basic product knowledge and transactional interactions are progressively displaced by digital sales channels and self-service configurators.[130] CCAM-ERAS survey findings are consistent with these trends, as respondents rarely prioritised purely manual or low-complexity mechanical tasks when identifying future skills needs, instead assigning greater importance to software-supported diagnostics, remote supervision and system-level oversight.

Simultaneously, core occupational profiles within the sector undergo substantial transformation. Vehicle mechanics increasingly evolve into systems-oriented or mechatronic technicians who work simultaneously with mechanical assemblies, high-voltage systems, sensors and software, using digital interfaces and augmented-reality tools as standard elements of their work. [131] Maintenance technicians extend their remit beyond on-site manual intervention toward remote supervision, condition monitoring and coordination with automated inspection technologies, including robots and drones, particularly for complex or hard-to-reach components.[132] In a similar way, service advisors in dealerships expand into digital mobility

[127] European Training Foundation (2021) 'The Future of Skills – A case study of the automotive sector in Turkey' available at: https://www.etf.europa.eu/en/publications-and-resources/publications/future-skills-case-study-automotive-sector-turkey.
[128] Yankelevich et al. (2018) 'Preparing the Workforce for Automated Vehicles', available at: https://comartsci.msu.edu/sites/default/files/documents/MSU-TTI-Preparing-Workforce-for-AVs-and-Truck-Platooning-Reports%20.pdf accessed on 7 October 2024.
[129] Raposo et al. (2018) '*An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe. Effects of automated driving on the economy, employment and skills'* available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC111477/kjna29226enn.pdf.
[130] Crane et al. (2020) 'Understanding the Middle Skill Workforce in the Connected and Automated Vehicle Sector', available at: https://www.dot.state.mn.us/automated/docs/cav-middle-skill-workforce-report-june-2020.pdf, accessed 16 September 2024.
[131] Raposo et al. (2018) '*An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe. Effects of automated driving on the economy, employment and skills'* available at: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC111477/kjna29226enn.pdf.
[132] Crane et al. (2020) 'Understanding the Middle Skill Workforce in the Connected and Automated Vehicle Sector', available at: https://www.dot.state.mn.us/automated/docs/cav-middle-skill-workforce-report-june-2020.pdf, accessed 16 September 2024.

consultants, advising customers on software features, safety settings, data-privacy options and the interaction between vehicles and digital infrastructure such as home chargers, fleet platforms and mobility applications.

These shifts require not only new technical competences but also stronger transversal skills. The ability to explain complex systems, address customer concerns related to automation and safety, and coordinate effectively with ICT specialists becomes increasingly important across roles. CCAM-ERAS survey responses underline the growing relevance of these transversal competences, with communication, adaptability and problem-solving among the most frequently prioritised skills, reflecting the expanding role of maintenance and sales staff as intermediaries between complex CCAM technologies and end users.

3.3 Freight transport & logistics

3.3.1 Sector overview and CCAM relevance

The freight transport & logistics sector's relevance to CCAM adoption is twofold: it is among the earliest domains of adoption in specific, controlled operational contexts, and it acts as a key driver of operational and economic experimentation with automation. This sector is not only a recipient of CCAM technology but is a key driver for its development and integration, particularly because automation promises economic and operational benefits.

The most relevant sectoral activities for CCAM fall under the following NACE activities: H49.41 Freight transport by road, H52.10 Warehousing and storage, H52.21 Service activities incidental to land transportation, H52.22 Service activities incidental to water transportation (particularly relevant for port-based CCAM developments), H52.24 Cargo handling, and H53.20 Other postal and courier activities, which includes parcel delivery, express delivery and last-mile services. Together, these activities cover the core operational environments in which freight-related CCAM applications are most likely to emerge, including long-haul and hub-to-hub road freight, depots and warehouses, terminals and ports, and parcel and last-mile delivery networks.

In employment terms, freight transport and logistics activities are distributed across several closely related segments of the EU economy. According to Eurostat, road freight transport and removal services (H49.4) employed approximately 3.4 million people in the EU-27 in 2023, representing the largest single employment block within the sector. Warehousing and storage activities (H52.1), which are central to logistics hubs and depot-based operations, accounted for a further 383,000 jobs. In addition to these core activities, several supporting service categories are highly relevant for CCAM deployment, particularly in relation to port and terminal operations, cargo handling, logistics coordination and last-mile delivery. Support activities for transportation (H52.2), which include terminal operations, cargo handling and other services incidental to land and water transport, employed approximately 2.1 million people across the EU-27 in 2023. Postal and courier activities (H53.2), which underpin parcel delivery, express services and last-mile logistics, accounted for a further 918,000 jobs.[133]

While these employment figures should not be aggregated due to differences in activity scope and potential overlap, taken together they illustrate the substantial workforce engaged in freight transport, logistics hubs, terminals and last-mile delivery services. These segments align

[133] Eurostat (2023), 'Enterprises by detailed NACE Rev. 2 activity and special aggregates,' available at: https://doi.org/10.2908/SBS_OVW_ACT.

closely with the use cases examined in CCAM-ERAS, including ground-based freight transport, depot and hub operations, port and terminal environments, and last-mile delivery services (See CCAM-ERAS Deliverable 3.3).

Alongside manufacturing and passenger transport, freight transport and logistics is therefore one of the three sectors most closely associated with CCAM development.[134] The sector exhibits a strong orientation toward automation, as a large share of logistics processes are, in principle, amenable to automation. CCAM technologies are already being piloted to streamline logistics operations through applications such as truck platooning,[135] which is typically associated with SAE Level 3 automation and may extend toward Level 4 in more structured operating environments.[136] More broadly, the sector is expected to become one of the early adopters of CCAM technologies because automation can diminish operating costs and allow more efficient logistics.[137]

Early CCAM deployment is most feasible in controlled environments such as ports, warehouses, logistics terminals and depots, where autonomous vehicles and automated handling equipment can operate within confined and predictable settings.[138] In these contexts, higher levels of automation (SAE Level 4 and above) are particularly relevant, including for long-haul freight corridors and terminal-based operations. While full SAE Level 5 automation is not expected before 2030, industry stakeholders anticipate gradual deployment in freight applications from 2040 onwards, especially in environments where operational conditions can be tightly managed. High levels of automation are also a strategic objective for last-mile freight and parcel delivery services using light-duty vehicles.[139]

Skills forecasting workshops carried out in the context of CCAM-ERAS consistently confirmed freight and logistics as a leading testing ground for CCAM, particularly in ports, warehouses, logistics hubs, and designated freight corridors. However, participants stressed that large-scale deployment on Europe's open and heterogeneous road network faces significant infrastructural, regulatory, and organisational constraints. These constraints are expected to limit the pace of system-wide automation and reinforce the importance of hybrid operational models combining automated systems with human supervision.

Freight use case/ operating context	Typical activities	CCAM maturity and relevance

[134] Lucía Mejía Dorantes and Heather Allen (2024), 'A review of the future transport labour market: An EU approach,' available at: https://doi.org/10.1016/j.ets.2024.100007.
[135] Safer research (2022) 'ENSEMBLE Project' https://www.saferresearch.com/projects/ensemble
[136] Geert Smit, Ecorys (2020) (2020), 'Study on exploring the possible employment implications of connected and automated driving,' available at: https://www.Ecorys (2020).com/app/uploads/files/2021-03/CAD_Employment_Impacts_Annexes.pdf.
[137] Alonso Raposo M., et al., Publications Office of the European Union (2018), 'An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe - Effects of automated driving on the economy, employment and skills,' available at: https://doi.org/10.2760/777.
[138] Matteo Brunetti, Martijn Mes and Eduardo Lalla-Ruiz (2024), 'Smart logistics nodes: concept and classification,' available at: https://doi.org/10.1080/13675567.2024.2327394.
[139] Ecorys (2020) (2020), 'Possible employment implications,' available at: https://www.Ecorys (2020).com/app/uploads/files/2021-03/CAD_Employment_Impacts_Annexes.pdf.

Open-road freight transport	Long-haul and regional road freight; platooning; line-haul operations	Medium – CCAM pilots underway (e.g. platooning, assisted driving), but large-scale deployment constrained by mixed traffic, infrastructure and regulation
Logistics hubs and depots	Internal vehicle movements; loading/unloading; yard management; fleet coordination	High – controlled environments enable early deployment of SAE Level 4 automation and automated handling systems
Ports and terminals	Container transport; cargo handling; terminal operations; yard logistics	Very high – advanced automation already in use; strong alignment with CCAM deployment in confined, predictable environments
Mid- and last-mile delivery (light-duty vehicles)	Parcel delivery; urban distribution; courier services	Medium to high – strong interest in automation and electrification, but deployment shaped by urban complexity and regulatory constraints

Table 4: CCAM maturity and relevance across freight transport and logistics operating contexts. Source: CCAM-ERAS.

3.3.2 Technical and organisational trends

The freight transport and logistics sector is characterised by trends towards digitalisation and the electrification of vehicles, in line with broader CCAM developments. These developments are closely linked to efforts to improve operational efficiency, address persistent labour shortages and adapt logistics business models to more data-driven and automated forms of operation. Technological change in the sector centres on the deployment of increasingly automated vehicles, the expansion of digital infrastructure and the intensified use of operational data. CCAM-ERAS skills forecasting workshops consistently highlighted that data availability, quality and governance represent binding constraints for more advanced automation in freight logistics. While predictive maintenance and route optimisation are already widely deployed, higher-level CCAM applications depend on access to large, standardised and interoperable datasets, which remain uneven across regions and operators, particularly among SMEs.

Technologies in the logistics sector trend towards several specific developments. Firstly, vehicle platooning represents an early and incremental step towards automation in open-road freight transport, allowing vehicles to travel in close coordination and communicate with each other and with infrastructure systems. These applications are primarily associated with SAE Level 3 automation and, in more structured operating contexts, may extend towards Level 4. Platooning is intended to reduce fuel consumption and optimise logistics operations, while also enabling gradual shifts towards remote supervision rather than continuous manual driving.[140] However, workshop participants emphasised that widespread deployment on Europe's heterogeneous road network remains constrained by infrastructure readiness and regulatory fragmentation.

[140] Alonso Raposo M. (2018) 'Effects of automated driving,' available at: https://doi.org/10.2760/777.

More advanced automation is already being implemented in controlled environments such as logistics hubs, depots, ports and warehouses. In these contexts, autonomous trucks, automated guided vehicles and automated stacking cranes are increasingly used to reduce reliance on manual labour for repetitive tasks, including container handling, yard movements and internal transport. These environments are particularly well suited to higher levels of automation due to their confined, predictable operating conditions and the possibility of integrating vehicles, equipment and infrastructure within closed systems.

Across all freight contexts, digitalisation plays a central enabling role. Logistics operations increasingly depend on connectivity between in-vehicle systems, infrastructure and logistics platforms to manage data flows and coordinate activities. Digital systems support automated documentation, scheduling optimisation and real-time operational decision-making. Technologies such as digital twins are used for simulation and predictive analysis, while AI-driven transport platforms enable real-time dispatching and dynamic route planning. Within this context, cybersecurity has emerged as a critical concern.[141] In CCAM-ERAS skills forecasting workshops, cybersecurity was consistently framed not only as a technical requirement but also as a workforce capability gap. Participants highlighted that vulnerabilities in connected logistics systems often stem from human and organisational factors, including insufficient training, fragmented responsibilities across subcontractors and limited cybersecurity awareness among operational staff.[142]

Organisationally, the transition towards CCAM is closely linked to evolving logistics business models.[143] In particular, the emergence of Logistics-as-a-Service (LaaS) models reflects a shift towards outsourcing logistics functions to specialised providers that rely on automated mobility and digital platforms to manage supply chains. LaaS is often discussed in connection with the Physical Internet concept, which aims to integrate digital and physical logistics flows through interconnected, standardised systems based on the Internet of Things.[144] Together, these models promise efficiency gains and greater flexibility but also introduce new organisational challenges. Workshop discussions cautioned that increased reliance on automated and platform-based logistics services may further fragment accountability across actors, increasing the importance of skills related to coordination, oversight and responsibility allocation within complex, automated logistics ecosystems.

3.3.3 Employment and occupational change

The implementation of CCAM and increasing automation in the freight transport and logistics sector are leading to a gradual reduction in demand for some job roles centred on manual labour, vehicle operation, and routine administrative tasks, alongside substantial task reconfiguration and role transformation. This trend is exacerbated by the sector's shift toward digital platforms and electric vehicle technology.

[141] UNECE (2024), 'Handbook on Digitalization and Automation in Intermodal Freight Transport,' available at: https://unece.org/sites/default/files/2025-01/Handbook%20on%20Digitalization%20and%20Automation%20in%20Intermodal%20Freight%20Transport%20EN.pdf.
[142] CCAM-ERAS Stakeholder workshops.
[143] CCAM, 'Innovation Agenda,' available at: https://www.ccam.eu/wp-content/uploads/2023/11/CCAM-SRIA-Update-2023.pdf.
[144] Matteo Brunetti (2024), 'Smart logistics,' available at: https://doi.org/10.1080/13675567.2024.2327394.

Road freight transport is often identified as particularly exposed to automation, as driving constitutes a core component of the occupation.[145] While automation does not imply the immediate elimination of drivers, it may reduce overall demand as fewer drivers are required to oversee coordinated vehicle fleets. Estimates from the European Commission's Joint Research Centre suggest a potential decline in truck-driving jobs in the EU from around 3.2 million in 2021 to between 2.3 million and 0.5 million by 2040.[146] However, stakeholders consistently cautioned against interpreting these figures as a linear displacement trajectory. CCAM-ERAS interviewees emphasised that Europe's road network, characterised by dense traffic, mixed-use roads and cross-border regulatory fragmentation, is not designed for full vehicle automation. Combined with existing driver shortages in several Member States, including Spain and Germany, this suggests that drivers are likely to remain integral to freight operations for the foreseeable future.

CCAM-ERAS survey evidence supports this more nuanced interpretation. Among respondents active in freight transport, fleet operations, and logistics-related CCAM activities, most expect automation to affect driving and operational roles at least to a moderate extent, while only a small share anticipate full displacement of drivers in the short term. Instead, respondents frequently point to task redistribution, with drivers increasingly shifting toward supervisory, coordination, and exception-handling roles rather than being removed from the system entirely. CCAM-ERAS skills forecasting workshops reinforced this view, highlighting that full automation of road freight in Europe remains considerably more complex than in more standardised highway contexts, and that hybrid operational models combining automation with human oversight are likely to persist well into the medium term.

In warehousing, terminals and logistics hubs, the effects of automation are more immediate. Routine tasks such as inventory sorting, order picking and packaging are increasingly automated through the deployment of autonomous mobile robots and automated storage and retrieval systems.[147] As a result, the demand for physically demanding manual work declines, while new requirements emerge for monitoring, maintaining and coordinating automated systems. Survey respondents active in warehousing and logistics services confirm that this transition is already underway, with around half identifying a shift from manual tasks towards knowledge-based and system-monitoring work as a key workforce impact of CCAM. Workshop participants warned that automation in warehouses and logistics hubs may polarise the workforce, as demand grows for high-skilled system supervisors alongside lower-skilled support roles, while mid-level routine positions decline. Without targeted reskilling strategies, this dynamic risks exacerbating inequalities within logistics workforces.

Declining roles and tasks	Transforming roles	Emerging and hybrid roles

[145] Aleksandr Yankelevich, R.V. Rikard, Travis Kadylak, Michael J. Hall, Elizabeth A. Mack, John P. Verboncoeur, Shelia R. Cotton (2018), 'Preparing the Workforce for Automated Vehicles', available at: https://comartsci.msu.edu/sites/default/files/documents/MSU-TTI-Preparing-Workforce-for-AVs-and-Truck-Platooning-Reports%20.pdf.
[146] JRC (2019), 'The future of road transport: Implication of automated, connected, low-carbon and shared mobility', available at: https://visitors-centre.jrc.ec.europa.eu/en/media/publications/future-road-transport.
[147] Amandeep Dhaliwal (2020), 'The Rise of Automation and Robotics in Warehouse Management,' available at: https://www.researchgate.net/publication/346769930_The_Rise_of_Automation_and_Robotics_in_Warehouse_Management.

Routine long-haul driving without automation support	Drivers shifting to supervisory and exception-handling roles	Remote fleet supervisors and control-room operators
Manual warehouse handling and picking	System-assisted warehouse operators overseeing Autonomous Mobile Robots (AMRs) and Automated Storage and Retrieval System(s) (AS/RS)	Automated systems technicians
Routine logistics administration	Data-supported logistics coordinators	Logistics data analysts and dispatch optimisation specialists
On-site vehicle-only operation	Hybrid vehicle–office roles combining monitoring and coordination	"Vehicle–office fusion" mobility operators

Table 5. Occupational change in freight transport and logistics under CCAM. Source: CCAM-ERAS.

At an aggregate level, some projections suggest that automation in logistics could be associated with net employment growth, reflecting increased demand for IT-intensive, coordination and data-related roles. Estimates cited in the literature indicate potential employment growth of around 8.4% in the sector in the early 2020s, alongside the creation of up to 750,000 IT-related vacancies linked to CCAM deployment over the longer term.[148] However, CCAM-ERAS workshop discussions emphasised that such aggregate figures may mask significant distributional effects across regions, firm sizes and occupational groups. New jobs are expected to be concentrated in larger firms and technologically advanced hubs, while smaller operators and peripheral regions may face greater adjustment challenges.

Macroeconomic modelling results from the CCAM-ERAS project, based on the E3ME model, are consistent with this interpretation (See CCAM-ERAS Deliverable 4.4). For road freight transport, the model does not project abrupt economy-wide employment contraction as CCAM diffuses. Instead, by 2050 it indicates relatively modest net employment losses at EU level of around 89,000 in a high CCAM uptake scenario and 65,000 in a medium uptake scenario, equivalent to declines of 0.046% and 0.034% relative to baseline, respectively. These losses are concentrated primarily in the land transport sector, where employment falls by around 90,000 in the high uptake scenario and 69,000 in the medium uptake scenario, while indirect and induced effects in most other sectors remain limited. At occupational level, the strongest effects are observed among drivers and mobile plant operators, whose employment is projected to decline by around 34,000 under high uptake and 27,000 under medium uptake by 2050. The model therefore reinforces the expectation that CCAM deployment in freight transport is more likely to reshape occupational structures within the sector than to generate uniform or abrupt job losses across the wider economy. These effects are also uneven across adopter groups, with earlier-adopting Member States generally experiencing larger and earlier employment adjustments.

[148] Directorate-General for Mobility and Transport (European Commission), ECORYS (2020), Hellenic Institute of Transport (2021), 'Study on the social dimension of the transition to automation and digitalisation in transport, focusing on the labour force,' available at: https://op.europa.eu/en/publication-detail/-/publication/476d738a-404c-11ec-89db-01aa75ed71a1; Ecorys (2020), 'Possible employment implications,' available at: https://www.Ecorys (2020).com/app/uploads/files/2021-03/CAD_Employment_Impacts_Annexes.pdf.

In practice, occupational change in freight and logistics is expected to take the form of role transformation rather than wholesale replacement. In this context, a number of hybrid and data-oriented roles are expected to grow. Positions such as delivery dispatchers, logistics operators and data analysts are likely to become more prominent as supply chains become increasingly data-driven and optimised for efficiency.[149] Literature, CCAM-ERAS interview and workshop evidence also point to the emergence of hybrid profiles, sometimes described as "vehicle–office fusion" roles, which combine remote monitoring of automated vehicles with administrative coordination and logistics support tasks that were traditionally performed in office-based functions.[150] Experienced drivers are increasingly expected to transition into roles such as remote supervisors or control-room operators, overseeing automated vehicle fleets in real time and intervening in exceptional situations. In controlled logistics environments, workers are shifting from manual handling and equipment operation towards supervising autonomous equipment and managing system performance. CCAM-ERAS survey respondents consistently emphasised that reskilling existing staff, rather than recruiting entirely new profiles, will be critical over the next 5–10 years. Competences related to remote supervision, exception management and system monitoring were repeatedly highlighted as essential for redeploying experienced drivers and warehouse workers into CCAM-enabled roles.

Finally, the sector's strong reliance on SMEs significantly shapes its capacity to adapt to CCAM-related change. Around 80% of transport companies in the EU are SMEs, many of which face constraints related to limited financial resources, restricted access to advanced technologies and reduced in-house training capacity. CCAM-ERAS survey respondents echo these concerns, frequently citing high investment costs, lack of in-house training capacity, and difficulty reskilling existing employees as key barriers to adaptation. CCAM-ERAS skills forecasting workshops repeatedly identified SMEs as a critical vulnerability point in the CCAM transition, highlighting limited access to finance, training infrastructure, and in-house expertise as barriers that could slow adoption and intensify workforce displacement risks without targeted public support.

3.3.4 Skills foresight: short, medium and long term

The ongoing transition toward CCAM, combined with the parallel digitalisation of freight infrastructure and logistics operations, is redefining the skills requirements across the sector. Across all time horizons, the dominant pattern is not the disappearance of work but a reconfiguration of tasks and roles. Skills demand is shifting away from manual, routine and physically intensive activities towards hybrid profiles that combine digital literacy, system supervision and specialised technical expertise. These changes unfold unevenly over time, reflecting both the staged deployment of automation across SAE levels and the gradual transformation of logistics operations.

As in other sectors analysed in this report, SAE automation levels are used as indicative reference points for technological maturity and associated skills requirements rather than as precise deployment forecasts. In freight transport and logistics, however, the relationship between

[149] Kayle Giroud, et al. (2022), 'Needs, wants and behaviour of Drivers and automated vehicles users today and into the future', available at: https://www.drive2thefuture.eu/wp-content/uploads/2023/01/D4.3-AV-Training-certification-requirements-acceptance-creation-measures-and-impact-to-employment.pdf.
[150] Ecorys (2020), 'Possible employment implications,' available at: https://www.Ecorys (2020).com/app/uploads/files/2021-03/CAD_Employment_Impacts_Annexes.pdf.

automation levels and time horizons is particularly use-case dependent. For the purposes of this analysis, the short term (0–5 years) is associated primarily with connected and partially automated operations; the medium term (5–10 years) with the scaling of more advanced automation, especially in controlled environments such as logistics hubs, ports, and designated freight corridors; and the long term (10+ years) with upper-bound skills requirements linked to more mature highly automated systems in selected logistics contexts.

Time horizon	SAE Level (indicative)	Core skill focus	Skills declining in relevance	Typical roles affected
Short-term (0-5 years)	Connected and partially automated operations; broadly corresponding to SAE Levels 1–3	Foundational digital literacy; system monitoring; V2X awareness; basic data handling; cybersecurity awareness; safe interaction with driver-assistance systems	Fully manual driving without system support; paper-based coordination; purely physical warehouse tasks	Drivers, warehouse operators, dispatch staff, fleet technicians
Medium-term (5-10 years)	More advanced automation in controlled corridors, hubs, and fleet operations; broadly corresponding to domain-specific Levels 3–4	Remote supervision; system integration; data analysis; exception handling; cybersecurity; coordination across vehicles and infrastructure	Routine long-haul driving tasks; manual exception handling; stand-alone vehicle operation	Remote fleet supervisors, logistics coordinators, telematics and predictive-maintenance specialists
Long term (10+ years)	Mature highly automated logistics systems in defined and semi-controlled contexts; upper-bound skills associated with Levels 4–5	Advanced software and systems engineering; AI-supported operations; robotics and automation management; secure remote command; regulatory and safety oversight	Manual driving skills; repetitive physical logistics work; routine operational decision-making	Control-room operators, system supervisors, automation engineers, safety and compliance specialists

Table 6. Skills evolution in freight transport and logistics under CCAM.
Source: CCAM-ERAS.
Note: SAE levels are used as indicative reference points for skills analysis rather than deployment forecasts. Skills demand varies by use case and operational context.

Short-term skills needs

In the short term, corresponding to the adoption of connectivity technologies such as V2X and lower levels of vehicle automation, skills demand centres on foundational digital competences and safety-monitoring capabilities. Drivers and operational staff continue to play an active role in vehicle control, but increasingly interact with automated assistance systems. This requires strong capabilities in selective attention, information ordering, and system monitoring, alongside familiarity with digital interfaces and coordination platforms.

Professionals involved in vehicle operations and infrastructure connectivity must also develop basic competences in data handling and sensor interpretation, supported by an understanding of cellular connectivity for V2X communication. Cybersecurity awareness becomes increasingly relevant at this stage, particularly in relation to protecting connected systems from external interference, even if advanced cybersecurity specialisation remains limited.[151] CCAM-ERAS workshops consistently characterised this phase as a high-risk transition period, in which insufficient training for semi-automated systems could undermine safety and worker confidence.

CCAM-ERAS survey responses closely align with this short-term outlook. Most respondents expect CCAM-related skills demand to increase already within the next 0–5 years and prioritise digital literacy, basic data handling, system-monitoring skills, and cybersecurity awareness as immediate training needs. Training urgency in this phase is typically described as moderate, suggesting a need for rapid upskilling rather than wholesale occupational replacement. CCAM-ERAS workshops consistently framed this phase as a "high-risk transition period", in which insufficient training for semi-automated systems could undermine safety and worker confidence, even if full automation remains limited.

Medium-term skills needs

In the medium term, automation technology becomes more advanced, as manual control will lower in necessity. As higher levels of automation (SAE Levels 3–4) become more common, particularly in controlled logistics corridors and fleet operations, skill demands shift toward advanced integration, data analysis, and remote oversight. In the medium-term skills needs, the IT sector is expected to advance the incorporation of ADAS, which refers to suite of technologies designed to increase vehicle safety as well as assist drivers.[152] The more drivers are able to relegate movement tasks to the vehicle, the more remote operation skills will become sought after. Freight fleets, warehouse logistics mobility and various CCAM vehicles will fall under the supervision of remote operators which intervene in the case of operational exceptions. This transition implies a broader scope of responsibilities for former drivers, requiring skills in data management, cybersecurity, and emergency handling as they ensure smooth operations in a more technology-driven environment.[153]

CCAM-ERAS survey evidence strongly reinforces this medium-term transition. A clear majority of respondents anticipate growing demand for CCAM-related roles over the next 5–10 years and identify remote supervision, data analysis, system integration, and exception handling as priority skills. Additionally, respondents frequently report moderate to large skills gaps in these areas, indicating that skills mismatches are likely to intensify unless reskilling pathways for drivers and logistics workers are scaled up. Workshop participants also highlighted the absence of harmonised certification and professional standards for remote operators and fleet supervisors as a growing bottleneck, stressing that skills development must be accompanied by regulatory clarity to ensure safe and scalable deployment.

[151] Lazaros Giannakos, Anna Antonakopoulou, Alexandros Liazos (2023), 'Understanding the Gap of CCAM solutions deployment,' available at: https://sinfonica.eu/wp-content/uploads/2023/07/D1.3-Understanding-the-Gap-of-CCAM-solutions-deployment_v1.0.pdf.
[152] European Commission (2024), 'Status of progress on Connected, Cooperative and Automated Mobility in Europe', available at: 1720a5ef-01bf-498e-85f5-c61bb3a7bc31_en (europa.eu).
[153] Kayle Giroud, 'Needs, wants,' available at: https://www.drive2thefuture.eu/wp-content/uploads/2023/01/D4.3-AV-Training-certification-requirements-acceptance-creation-measures-and-impact-to-employment.pdf.

Long-term skills needs

In the long term, under conditions of more mature and widespread deployment of highly automated systems (SAE Levels 4–5), the sector's workforce will require advanced specialised knowledge for maintenance, software management, and remote command. Skills related to digitalisation, AI, robotics, advanced communication systems, software engineering, navigation systems, and data analytics will be necessary for back-end and coordination roles.

While manual driving skills are expected to decline in operational relevance, evidence suggests that prior experience with manual driving remains valuable for understanding system behaviour and identifying failures in automated environments.[154] Current data shows that individuals with previous experience in manual driving systems perform much better when dealing with automated systems, compared to those who only experienced automatic control systems.[155] As a result, long-term skill profiles are less about the complete abandonment of operational knowledge and more about its integration into higher-level system supervision and control functions. CCAM-ERAS survey respondents echo this long-term perspective, frequently highlighting advanced system integration, cybersecurity, and complex problem-solving as critical future competences. In addition, transversal skills such as adaptability, communication, and collaboration, were consistently prioritised, reflecting the expectation that human roles will focus increasingly on oversight, coordination, and trust-building in automated logistics systems.

Across all time horizons

Across the skills foresight horizon, certain competences decline in relative importance. Skills tied primarily to manual operation, repetitive physical effort and routine driving tasks face the highest risk of obsolescence as automation and digitalisation progressively replace these activities.[156] This includes manoeuvring tasks, routine interaction with traffic environments, and physically demanding logistics work that can be automated through advanced driver-assistance systems, autonomous vehicles and robotic handling technologies.

At the same time, core occupational profiles undergo substantial transformation rather than disappearance. Drivers evolve into system supervisors and exception handlers; warehouse workers transition from manual handling towards overseeing automated equipment; and logistics staff increasingly operate as coordinators within digitally integrated supply chains. CCAM-ERAS survey findings are consistent with this pattern, as respondents rarely prioritised manual driving or routine operational skills when identifying future training needs, instead emphasising technology oversight, data management and system-monitoring capabilities.

[154] Darina Havlickova, Petr Zamecnik, Eva Adamovska, Adam Gregorovic, Vaclav Linkow and Ales Zaoral (2020),'Model of Driving Skills Decrease in the Context of Autonomous Vehicles', available at: https://doi.org/10.1007/978-3-030-20503-4_16

[155] Kessel, C.J., Wickens, C.D. (1982), 'The transfer of failure detection skills between monitoring and controlling dynamic systems,' available at: https://doi.org/10.1177/001872088202400106.

[156] Konsta Rautakorpi (2021), 'Automation, job market and future skills', available at: https://www.theseus.fi/bitstream/handle/10024/500003/Rautakorpi_Konsta_Thesis_Final.pdf?sequence=2&isAllowed=y.

3.4 Passenger transport & shared mobility

3.4.1 Sector overview and CCAM relevance

Passenger transport and shared mobility play a central role in the CCAM ecosystem, both because of their scale in employment terms and because they constitute the most visible interface between automated systems and the general public. The most relevant sectoral activities for CCAM fall under the following NACE activities: H49.31 Urban and suburban passenger land transport and H49.32 Taxi operation. These activities capture much of the operational space in which CCAM-enabled passenger services are expected to emerge, including public transport, on-demand mobility, and shared urban transport services.

In the European Union, passenger transport sector directly employs between 1.3[157] and 2 million people,[158] when considering the changes in systematic definitions. According to Eurostat, in 2023 around 534,000 people were employed in urban and suburban passenger road transport and a further 662,000 in taxi operations, both of which are highly relevant to CCAM deployment.[159]

Beyond employment scale, passenger transport and shared mobility are critical to CCAM adoption because they shape everyday user experience, public trust, and social acceptance of automated mobility. The shared mobility segment, in particular, plays a complex role in the CCAM value chain by driving early deployment of shared automated vehicles, supporting urban sustainability objectives, and accelerating the reskilling and familiarisation of the workforce and wider population with automated mobility options.[160]

Private shared mobility services hold significant commercial importance within the CCAM ecosystem and act as a testing ground for scalable business models, technology adoption and new revenue structures in urban mobility. Shared Automated Vehicles (SAVs) are often identified as a high-potential market segment due to expected efficiencies in fleet operation and high potential ridership.[161] SAE Level 3 automation represents a key transitional stage in this context, as it enables the Automated Driving System to perform the driving task under defined conditions while still requiring human intervention when necessary. Over the longer term, private shared mobility strategies increasingly rely on higher levels of automation to enable driverless fleet operations, tighter integration with mass transit, and the development of new service models. These trends align closely with the recent emergence of MaaS, which integrates multiple transport modes and services into unified digital platforms.

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[157] Foteini Orfanou, Eleni Vlahogianni, George Yann (2020), 'A Taxonomy of Skills and Knowledge for Efficient Autonomous Vehicle Operation', available at: https://link.springer.com/chapter/10.1007/978-3-030-61075-3_30.

[158] European Union Agency for the Space Programme (2023), "Report on Public Transport: User Needs and Requirements," available at: https://www.euspa.europa.eu/sites/default/files/documents/Report%20on%20Public%20Transport%20User%20Needs%20and%20Requirements.pdf.

[159] Eurostat (sbs_ovw_act), 'Enterprises by detailed NACE Rev. 2 activity and special aggregates,' available at: https://doi.org/10.2908/SBS_OVW_ACT.

[160] Christos Karolemeas, Stefanos Tsigdinos, Evi Moschou, and Konstantinos Kepaptsoglou (2024), 'Shared autonomous vehicles and agent based models: a review of methods and impacts,' available at: https://doi.org/10.1186/s12544-024-00644-2.

[161] Andres Fielbaum, Baiba Pudane (2024), 'Are shared automated vehicles good for public- or private-transport-oriented cities (or neither)?,' available at: https://doi.org/10.1016/j.trd.2024.104373.

Public and shared passenger transport services also include use cases targeting specific user groups, such as on-demand shuttles or assisted services designed for older passengers, people with disabilities, or users with reduced mobility. Evidence from CCAM pilot projects indicates that such services are often among the earliest applications of automated vehicles in urban environments, as they operate on defined routes or within constrained service areas. In these contexts, automation is typically combined with human supervision or on-board assistance, highlighting the continued importance of hybrid operational models rather than full automation.[162]

Public passenger transport	Private (shared) mobility	Targeted shared services
• Buses (mixed traffic) • Rail, metro, light rail • Automated shuttles (pilots) • **CCAM relevance:** gradual, hybrid, human presence central	• Taxis, ride-hailing • Shared Automated Vehicles (SAVs) • Robo-taxis (pilots) • **CCAM relevance:** early deployment, business-model experimentation, MaaS	• On-demand shuttles • Services for older passengers • Accessible mobility for people with disabilities • **CCAM relevance:** early pilots, defined routes, assisted automation

Tab;e 7. Passenger transport and shared mobility use cases relevant to CCAM
Source: CCAM-ERAS.

In operational terms, early deployment of higher levels of automation in passenger transport has so far been most feasible in rail-based and segregated systems, including metro and light rail, where fixed infrastructure and long-standing automation experience reduce safety-related risks and organisational complexity. By contrast, large-scale automation of buses operating in mixed traffic remains technically, economically and organisationally more challenging, particularly in dense urban environments. CCAM-ERAS skills forecasting workshop participants consistently highlighted that, while automated shuttles and pilot bus services are expanding, widespread deployment of fully automated buses is unlikely in the short to medium term. Human presence and hybrid operational models are therefore expected to remain central to bus-based public transport for an extended period.

Across all passenger transport and shared mobility use cases, stakeholder consultations carried our within the context of CCAM-ERAS consistently emphasised the sector will be among the first to shape public trust most visibly in CCAM, precisely because it combines automated technologies with direct, everyday interaction between systems and passengers. As a result, workforce adaptation in these sectors is seen as critical not only for operational performance, but also for social acceptance of automated mobility more broadly.

3.4.2 Technical and organisational trends

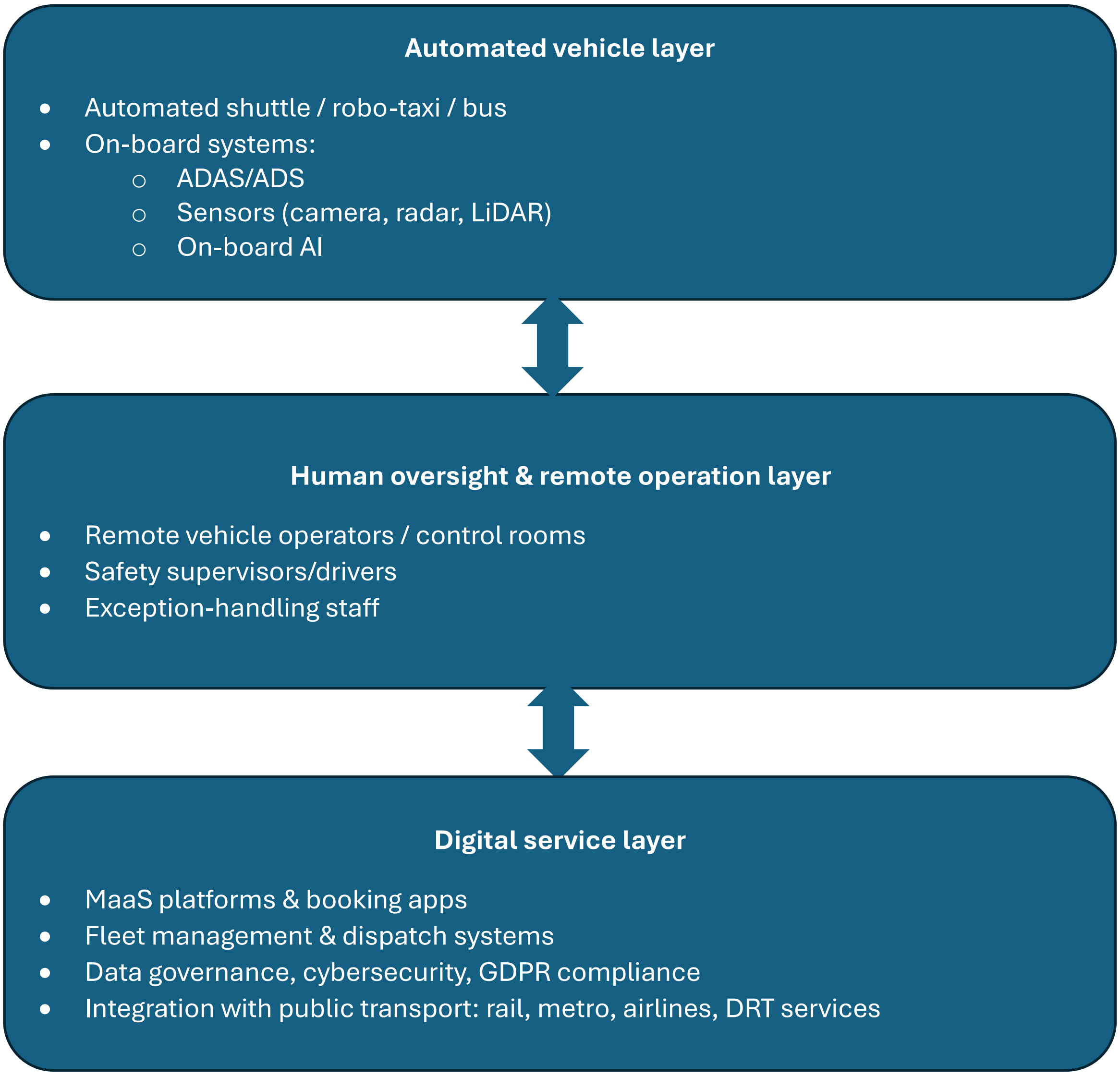
The development of CCAM in passenger transport depends on the integration of multiple technological advances that enable vehicles to operate autonomously in populated and operationally complex environments. As in other transport domains, technological progress is primarily driven by digitalisation and electrification. Current deployments span a range of automation levels depending on operating context. Many pilot projects cluster around SAE Levels 3–4, while higher levels of automation are more feasible in constrained environments. This uneven deployment has direct organisational implications, particularly the continued need

[162] See for example: https://ultimo-he.eu/; https://www.letsholo.com/grorud-valley; https://blees.co/en/

for human oversight and remote operation capabilities in the event of system limitations or failures.

Passenger transport CCAM applications include self-driving passenger vehicles such as automated shuttles, robo-taxis and, to a more limited extent, automated buses. These rely on combinations of ADAS and Automated Driving Systems (ADS). ADAS refers to technologies that support the driver in specific tasks, such as lane keeping or adaptive cruise control, while ADS are designed to perform the dynamic driving task under defined conditions.[163] In practice, many current passenger transport deployments combine elements of both, resulting in hybrid operational models rather than fully autonomous services.

CCAM-ERAS skills forecasting workshops repeatedly underlined that while SAE Level 3–4 technologies are advancing, large-scale deployment in passenger transport remains uneven across cities and regions. Participants described the current phase as one of "foundation-setting and experimentation", in which pilot projects coexist with legacy systems and require significant organisational adaptation rather than full operational replacement.



[163] European Commission (2024), 'Status of progress on Connected, Cooperative and Automated Mobility in Europe,' available at: 1720a5ef-01bf-498e-85f5-c61bb3a7bc31_en (europa.eu).

Figure 6. Hybrid operational model in CCAM-enabled passenger transport.
Source: CCAM-ERAS.
Note: Illustration of the interaction between automated vehicles, human oversight functions and digital coordination platforms in current and near-term passenger transport deployments. The figure highlights the persistence of hybrid operational models combining automation with human supervision and system-level coordination.

Supporting technologies play a critical enabling role. Artificial intelligence and machine learning are fundamental for processing sensor data, enabling real-time decision-making and supporting predictive functions within automated systems. Cybersecurity is equally central, as CCAM applications depend on continuous connectivity between vehicles and infrastructure. CCAM systems require stringent protocols, advanced encryption, and continuous monitoring to ensure system safety and data protection. In shared mobility services, data protection is particularly sensitive due to the handling of personal and location data, making compliance with data protection frameworks such as the GDPR a core operational concern. However, there is a sentiment that regulations are not yet up to date with technological innovations,[164] and CCAM-ERAS workshop participants note that regulatory frameworks are still evolving and do not yet fully reflect the complexity of emerging CCAM-enabled services.

The MaaS model of functioning introduces new organisational and workforce challenges. Digital coordination systems raise additional cybersecurity and data governance risks, while algorithmic management tools used in ride-hailing and shared mobility services have been criticised for limited transparency and potential impacts on working conditions.[165] CCAM-ERAS workshop participants also stressed that remote operation and digital coordination roles can be more cognitively demanding than traditional driving. Managing multiple vehicles, maintaining situational awareness, and intervening in rare but safety-critical events require sustained attention and carry significant responsibility. These dynamics introduce new occupational safety considerations, particularly in public transport contexts where operators remain accountable for passenger safety and service continuity.

3.4.3 Employment and occupational change

The CCAM transition in passenger transport and shared mobility is already leading to a task reconfiguration in traditional driving roles, the predicted gradual displacement of some manual driving functions in the longer term, the emergence of new technical and oversight positions, and the transformation of existing jobs into hybrid service-oriented roles. This transformation is expected to widen inequality between low-skilled and high-skilled workers, with most of the benefits being reaped by highly skilled individuals.[166] Low-skilled employees would be incentivised to diversify their skillset to participate in the market shift more easily under a CCAM transition. Across survey respondents active in passenger transport, shared mobility, and CCAM-enabled service operations, most expect CCAM to primarily transform jobs rather than eliminate them outright, but with a clear shift toward higher-skilled, digitally enabled roles.

[164] Paolo Balboni, Kate Francis, Anastasia Bots, and Martim Taborda Barata (2020), 'Designing Connected and Automated Vehicles around Legal and Ethical Concerns: Data Protection as a Corporate Social Responsibility', available at: https://cris.maastrichtuniversity.nl/en/publications/designing-connected-and-automated-vehicles-around-legal-and-ethic.
[165] Camille Combe, Changgi Lee, Jagoda Egeland, Elisabeth Windisch, Marguerita Lane, Anna Milanez, Stijn Broecke (2023), 'Adapting to automation: Transport Workforce in Transition', available at: https://www.oecd-ilibrary.org/transport/adapting-to-automation_905fdc2c-en.
[166] Alonso Raposo M., 'Effects of automated driving,' available at: https://doi.org/10.2760/777.

Respondents consistently highlighted the risk that workers in low-skilled, routine driving roles may be disproportionately affected unless supported by targeted reskilling pathways.

Driving roles centred primarily on manual vehicle operation are generally considered the most exposed to displacement in the long term, particularly with the integration of higher levels of automation (SAE Levels 4–5). Roles such as drivers of public transportation services or traditional dispatchers are at risk as CCAM technologies gradually assume tasks related to vehicle operation and routing. It is estimated that 89% of taxi driver tasks can be automated, making these roles highly exposed to displacement.[167] As an example, by 2050, human-driven taxis in the Netherlands are expected to almost disappear, dropping from around 30,000 drivers in the mid-2030s to just 3,300 by 2050.[168] Multiple stakeholders support the possibility of passenger drivers becoming obsolete due to widespread automation.[169] However, both CCAM-ERAS interview and workshop evidence caution against interpreting these projections as uniform or inevitable outcomes. CCAM deployment is expected to vary significantly depending on local infrastructure, operating environments and regulatory readiness. In complex urban settings with dense traffic and mixed road use, full automation remains technically and organisationally challenging, and traditional driving roles may persist for longer periods. While a clear majority of survey respondents expect automation to significantly affect passenger-driving roles in the long term, only a small share anticipates full displacement in the short term. This assessment was strongly echoed in CCAM-ERAS skills forecasting workshops, where participants emphasised that buses and on-demand shuttles are technically and economically more challenging to automate than rail-based systems, and that human presence is likely to remain necessary for safety, passenger assistance, and trust-building well into the medium term.

The dominant pattern of change therefore involves existing personnel transitioning into hybrid roles that require new competencies, especially in managing automated systems and interacting with digital technology. Taxi and bus drivers could feasibly transition into such roles, especially in the earlier stages of automation technology, when remote supervision would be needed. As such, former taxi and bus drivers may transition from manual control to roles requiring supervision, selective intervention skills, and customer service. These workers require basic driving skills combined with awareness of automated systems' behaviour. They are expected to transition out of the vehicle and into roles such as remote operators as remote supervision becomes standard, although such transitions could happen in the later stages of automation. Most survey respondents anticipate growing demand for remote supervision, system monitoring, and exception-handling roles over the next 5–10 years, and many emphasised that redeploying experienced drivers into such positions will be critical for managing the transition in a socially sustainable way. CCAM-ERAS workshop participants cautioned, however, that remote supervision should not be framed as a simple or low-intensity alternative to driving. Managing multiple vehicles, handling rare safety-critical events, and maintaining situational awareness in low-stimulation environments were described as

[167] Kayle Giroud, et al., 'Needs, wants,' available at: https://www.drive2thefuture.eu/wp-content/uploads/2023/01/D4.3-AV-Training-certification-requirements-acceptance-creation-measures-and-impact-to-employment.pdf.
[168] Ecorys (2020), 'Possible employment implications,' available at: https://www.Ecorys (2020).com/app/uploads/files/2021-03/CAD_Employment_Impacts_Annexes.pdf.
[169] Stakeholder interviews (Henk van Gelderen, Sociaal Fonds Mobiliteit).

demanding tasks that require careful job design, adequate staffing levels, and continuous training.

Current roles (pre-CCAM/low automation)	Transitional roles (hybrid operation)	Emerging roles (higher automation contexts)
Bus drivers and taxi drivers focused on manual vehicle operation	Assisted drivers combining vehicle oversight with passenger interaction	Remote vehicle supervisors overseeing multiple automated vehicles
On-board staff primarily responsible for driving and fare collection	On-board stewards supporting passengers during automated operation	Passenger support agents assisting passengers with additional support needs in automated services
Route-based dispatchers managing fixed schedules	Fleet coordinators managing semi-automated vehicles and exceptions	MaaS operations managers coordinating automated fleets via digital platforms
Customer service staff handling ticketing and basic enquiries	Mobility service agents supporting app-based booking and service use	Mobility experience managers overseeing end-to-end passenger journeys
Control-room operators focused on traffic or timetable monitoring	Hybrid control operators supervising automated systems and intervening when required	Remote operations specialists responsible for safety-critical intervention and system oversight

Table 7 . Occupational transitions in passenger transport and shared mobility under CCAM. Source: CCAM-ERAS.

Technical roles within passenger transport operations are also evolving, particularly on the operator and fleet-management side. As vehicles become more electric, connected and automated, passenger transport organisations require staff capable of interfacing with complex vehicle systems, diagnostic platforms and digital fleet-management tools. Rather than focusing on mechanical repair, these roles increasingly involve system monitoring, software-based diagnostics, coordination with manufacturers or maintenance providers, and oversight of sensor-dependent vehicle functions.

In parallel, dispatchers are moving from managing fixed routes toward coordinating dynamic fleets via MaaS platforms, requiring greater fluency in data analytics and digital fleet-management systems to optimise vehicle allocation, routing and service reliability in real time. Survey respondents most frequently identified data analysis, system integration and digital fleet-management competences as priority skills for passenger transport services, alongside communication and adaptability. This reinforces the view that future roles in the sector increasingly sit at the intersection of technical oversight and service delivery rather than in isolated operational functions.

Beyond technical transformation, CCAM is also expected to reshape employment through the creation and expansion of human-centred service roles that automation cannot easily replicate. Stakeholders consistently distinguish between two broad, overlapping categories of emerging jobs: ICT-intensive maintenance and coordination roles on the one hand, and customer-facing support and mediation roles on the other. In shared mobility and public transport services, automation reduces the need for continuous manual driving but increases the importance of assisting passengers, managing exceptions and maintaining trust in automated systems.[170] Taxi and shuttle services targeting specific user groups, such as older passengers or people with disabilities, illustrate this shift particularly clearly. Instead of focusing solely on driving, drivers will be expected to assist passengers with special needs, such as those requiring physical support or social interaction, thus tasks that AVs cannot perform.[171] This shift could lead to a structural split in the industry, where independent passengers rely on a self-service model while those requiring more personalised help are served by human drivers. Survey respondents consistently highlighted the growing importance of customer-facing and trust-related functions. Communication, empathy, and problem-solving were among the most frequently prioritised transversal skills, reflecting expectations that human roles in passenger transport will increasingly focus on supporting users, managing exceptions, and maintaining public trust in automated services. In CCAM-ERAS workshops, participants from public transport authorities also stressed the importance of preserving meaningful roles for workers with lower formal qualifications, noting that fully automating customer-facing functions risks excluding groups who rely on part-time, flexible, or locally embedded transport jobs.

Concrete examples of emerging roles include field support agents responding to on-the-ground incidents, passenger support agents providing assistance to vulnerable users, and mobility experience managers overseeing service quality across booking, boarding and travel stages. On the technical side, new roles include AV system technicians, data analysts and app interface developers responsible for maintaining MaaS platforms, managing software updates and ensuring system reliability. Additional profiles such as urban integration planners or community mobility coordinators are also emerging, focusing on integrating CCAM services into local transport systems with attention to accessibility and inclusivity. Survey evidence supports this bifurcation of employment trajectories, with respondents frequently describing future passenger transport work as split between ICT-intensive system maintenance and coordination roles and human-centred service and mediation roles, with successful profiles combining elements of both.

From a macroeconomic perspective, these dynamics are broadly consistent with CCAM-ERAS projections for road passenger transport (See Deliverable 4.4). The E3ME results suggest that employment effects depend strongly on the pace of CCAM uptake rather than following a single displacement trajectory. Under the high uptake scenario, EU employment is projected to be around 165,000 above the baseline by 2050 (+0.085%), whereas under the medium uptake scenario employment remains close to baseline and is projected to be around 9,000 lower. This indicates that, in passenger transport, higher levels of automation do not necessarily translate into net employment loss, because the negative effects on some operational roles may be offset by increased demand for passenger transport and related investment effects.

The model also shows that these outcomes are uneven across adopter groups. In the high uptake scenario, employment gains reach around 42,000 in early-adopter Member States, 51,000 in mid adopters, and 72,000 in late adopters by 2050. At occupational level, the picture

[170] Aleksandr Yankelevich, ‘Preparing the Workforce,’ available at: https://comartsci.msu.edu/sites/default/files/documents/MSU-TTI-Preparing-Workforce-for-AVs-and-Truck-Platooning-Reports%20.pdf.
[171] Christina Pakusch, Alexander Boden, Marting Stein and Gunnar Stevens (2021), ‘The Automation of the Taxi Industry – Taxi Drivers’ Expectations and Attitudes Towards the Future of their Work’, available at: https://www.researchgate.net/publication/354429617_The_Automation_of_the_Taxi_Industry_-_Taxi_Drivers%27_Expectations_and_Attitudes_Towards_the_Future_of_their_Work.

is similarly differentiated. In the high uptake scenario, the five main land-transport occupation groups show a net positive difference of around 80,000 by 2050, including around 45,000 additional drivers and mobile plant operators, while in the medium uptake scenario drivers and mobile plant operators are projected to decline by around 4,000 relative to baseline. Taken together, these results reinforce the interpretation that in passenger transport and shared mobility, the main labour-market effect of CCAM is not uniform job destruction, but scenario-dependent restructuring shaped by uptake rates, service demand, and national deployment conditions.

3.4.4 Skills foresight: short, medium and long term

As in other sectors analysed in this report, the CCAM transition is characterised less by the disappearance of work than by a progressive reconfiguration of tasks and competences. Manual and routine driving activities gradually decline in relative importance, while hybrid profiles combining technical, digital, and transversal skills become increasingly central.

Skills demand evolves unevenly over time, reflecting the diversity of passenger transport use cases, operating environments, and service models, as well as the gradual scaling of more advanced automation. For the purposes of this analysis, the short term is associated primarily with assisted and semi-automated operation, where automation supports but does not replace human operation; the medium term corresponds to the scaling of more advanced automation in defined operational contexts; and the long term reflects upper-bound skills requirements linked to more mature deployment of highly automated passenger transport systems. Across all horizons, survey evidence points to a growing importance of transversal and social-facing competences alongside technical skills, particularly as automation reduces the need for continuous manual vehicle operation. International evidence supports this trajectory. Analysis by the International Transport Forum indicates that, under automation, the future passenger transport workforce increasingly values social-facing and non-routine skills, while highly automatable physical and control-based skills lose relative importance.[172]

Time horizon	SAE Level (indicative)	Core skill focus	Skills declining in relevance	Typical roles affected
Short-term (0-5 years)	Assisted and semi-automated operation; broadly corresponding to SAE Levels 1–3	Digital literacy; system monitoring; first-line diagnostics; ADAS interaction; basic cybersecurity awareness	Manual control precision; routine visual inspection; repetitive driving tasks	Drivers, conductors, frontline service staff, early remote operators
Medium-term (5-10 years)	More advanced automation in defined contexts such as shared mobility,	Remote supervision; system management; fleet coordination; data analysis; customer	Continuous manual driving; fixed-route dispatching; routine vehicle operation	Remote supervisors, fleet coordinators, service advisors, mobility operators

[172] Calculations are based on the OECD Expert Survey on Skills and Abilities Automatability and O*NET. The measure has a scale between 1 and 5 (low indicating low automation risk and vice versa). Original sources used by the ITF: Lassébie and Quintini (2022) and OECD Skills for Jobs database; https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/09/adapting-to-automation_fd689cc9/905fdc2c-en.pdf

	shuttles, and buses; broadly corresponding to Levels 3–4	interaction and exception handling		
Long term (10+ years)	Mature highly automated passenger transport systems in defined contexts; Levels 4–5 as an upper-bound reference	Advanced system integration; cybersecurity; data governance; ethical oversight; complex problem-solving; trust-building	Manual driving skills as primary competence; routine operational control	System supervisors, safety stewards, mobility service managers

Table 8. Skills evolution in passenger transport under CCAM.
Source: CCAM-ERAS.
Note: SAE levels are used as indicative reference points for skills analysis rather than deployment forecasts. Skills demand varies by use case and operational context.

Short-term skills needs

In the short term, skill transitions are shaped by the integration of connectivity technologies and semi-automated vehicle functions (SAE Levels 1–3). Current estimates suggest that around 18.5% of skills used in transport occupations are highly automatable, while only 3.7% constitute bottleneck skills that are difficult to replace through automation.[173] Physical abilities such as control precision, near vision and selective attention are among those most exposed to automation. However, complete job obsolescence remains unlikely in the short term due to the breadth of skill sets required in passenger transport.

Short-term adaptation therefore centres on augmenting existing roles with digital and system-oriented competences. Staff may gradually require the ability to monitor vehicle sensors, identify system malfunctions and perform first-line troubleshooting of ADAS and early ADS functions. Survey responses strongly support this focus, with respondents most frequently identifying basic digital literacy, system monitoring and first-line diagnostic skills as immediate priorities. Training needs are most often described as moderately urgent, indicating that the primary challenge in this phase is rapid upskilling of existing staff rather than radical occupational restructuring. CCAM-ERAS skills forecasting workshops reinforced this assessment, consistently warning that underestimating this transitional phase could generate safety risks and undermine public trust, even where full automation remains limited.

Medium-term skills needs

In the medium term, as connectivity becomes more robust and higher levels of automation (SAE Levels 3–4) are deployed more widely, particularly in shared mobility and defined urban or suburban contexts, skills demand shifts toward system management, remote supervision and service-oriented functions. Drivers in semi-automated systems are required to maintain situational awareness and intervene when necessary, which demands a deeper understanding

[173] Camille Combe, 'Adapting to automation,' available at: https://www.oecd-ilibrary.org/transport/adapting-to-automation_905fdc2c-en.

of automated system behaviour and the ability to transition between automated and manual control.[174]

In parallel, the role of passenger-facing staff evolves. As driving tasks diminish in intensity, greater emphasis is placed on customer interaction, exception handling and service quality. Social and communication skills, including emotional intelligence and problem-solving, become increasingly important, particularly in shared mobility services and use cases targeting passengers requiring additional support.

Digital competences also expand in scope. Medium-term roles will increasingly require proficiency in data analysis, fleet coordination and system integration, including the use of MaaS platforms to optimise routing, vehicle allocation and service reliability. Survey evidence strongly reinforces this transition. A clear majority of respondents anticipate growing demand for remote supervision, fleet coordination and service-quality management roles over the next 5–10 years, while many report moderate to large skills gaps in data analysis, system integration and customer-facing competences.

CCAM-ERAS workshops further highlighted the absence of harmonised certification and professional standards for roles such as remote operators, safety stewards and system supervisors, identifying regulatory clarity as a key enabling condition for effective skills development in this phase.

Long-term skills needs

In the longer term, as highly automated passenger transport systems become more mature in selected operational contexts, demand is expected to increase for advanced technical expertise in areas such as system integration, software oversight, cybersecurity, data governance, and remote command of automated fleets. During this phase, non-routine cognitive and social skills are also likely to grow in importance, including complex problem-solving, critical thinking, and adaptability in managing rare or high-impact system failures.

While manual driving skills decline in operational relevance, evidence suggests that prior experience with conventional driving remains valuable for understanding system behaviour and identifying failures in automated environments. Long-term skill profiles therefore reflect not the complete abandonment of operational knowledge, but its integration into higher-level supervision, oversight and control functions.

Survey respondents consistently highlight advanced system integration, cybersecurity and ethical awareness as critical long-term competences. Transversal skills such as communication, collaboration and adaptability are also prioritised, reflecting expectations that human roles will increasingly focus on oversight, exception handling and trust-building rather than routine operation. CCAM-ERAS workshop participants repeatedly stressed that even in highly automated scenarios, human judgement and the ability to question algorithmic outputs remain essential safeguards in complex passenger transport systems.

Across all time horizons

[174] Christina Pakusch, 'The Automation of the Taxi Industry,' available at: https://www.researchgate.net/publication/354429617_The_Automation_of_the_Taxi_Industry_-_Taxi_Drivers%27_Expectations_and_Attitudes_Towards_the_Future_of_their_Work.

Across the skills foresight horizon, certain competences decline steadily in relative importance. Skills tied primarily to manual vehicle control, repetitive physical effort and routine driving tasks face the highest risk of obsolescence as automation and digitalisation progress. Survey findings are consistent with this pattern, as respondents rarely prioritised such skills when identifying future training needs.

At the same time, core occupational profiles undergo substantial transformation rather than disappearance. Passenger transport work increasingly combines technical oversight, digital coordination and human-centred service functions. The evolution of skills therefore reflects a shift from task execution toward supervision, mediation and responsibility for system performance and user experience.

3.5 Information and communication

3.5.1 Sector overview and CCAM relevance

Information and communication technologies are vital to connected and automated systems, as they enable V2X communication, handle mobility datasets, support AI-based perception and decision-making, strengthen cybersecurity and system integrity, and link vehicle sensors with cloud computing and digital infrastructure. The most relevant sectoral activities for CCAM fall under the following NACE activities: J61 Telecommunications, J62 Computer programming, consultancy and related activities, and J63 Information service activities. Together, these activities provide the digital backbone on which CCAM systems depend, from connectivity and software development to data processing and platform services.

In telecommunications, automation increases the need for high-capacity, low-latency connectivity, driving demand in 5G networks and vehicle-to-infrastructure communication. Computer programming will play a central role in developing the AI, big data analytics, and machine-to-machine (M2M) systems that support automated driving functions. Information service activities are likewise affected, with a growing need for professionals capable of managing large mobility data flows, developing digital platforms, and ensuring adequate cybersecurity frameworks.

The importance of ICT intensifies at higher levels of automation. SAE Levels 4 and 5 depend most heavily on this sector, as they require continuous connectivity and advanced AI-driven decision-making. Data sovereignty and secure data access are therefore critical conditions for automated-driving development, since a reliable, open data infrastructure is a prerequisite for effective CCAM deployment. AI techniques are used to enhance object recognition and improve scene interpretation, including predictions of pedestrian behaviour.[175] At these levels of automation, the connectivity dimension must not be underestimated as this is the enabling factor of successful interactions between vehicles and infrastructure.

In employment terms, the ICT sector already exhibits a high concentration of specialised skills relevant to CCAM. In 2024, ICT specialists accounted for almost 61% of total employment in the sector, the highest share among all sectors.[176] Over the past decade, employment of ICT

[175] European Road Transport Research Advisory Council (ERTRAC) (2022), 'ERTRAC Connected, Cooperative and Automated Mobility (CCAM) Roadmap', available at: https://www.ertrac.org/wp-content/uploads/2022/07/ERTRAC-CCAM-Roadmap-V10.pdf

[176] Eurostat (2025), 'ICT specialists in employment', available at: https://ec.europa.eu/eurostat/statistics-explained/SEPDF/cache/47162.pdf

specialists grew at an average annual rate of 5.0 %. In 2023, across the EU, approximately 1 million people were employed in telecommunications, 4.7 million in computer programming, consultancy and related activities, and just under 500,000 in information service activities (ages 15–64).[177] These figures illustrate both the scale of the ICT workforce and its central relevance for the development, deployment and operation of CCAM systems.

3.5.2 Technical and organisational trends

Technological progress is a core enabling factor for CCAM, with several ICT-centred technologies underpinning system development and deployment. Interoperable digital systems are required to support continuous communication between vehicles, infrastructure, and mobility platforms. In this context, the rollout of 5G- and, in the longer term, 6G- networks is vital for achieving the low-latency, high-reliability connectivity required for real-time data transmission. Developments in Multi-Access Edge Computing (MEC) further support this shift by enabling rapid data processing and interaction between vehicles and nearby infrastructure.

Artificial intelligence has become a core component of automated driving systems, relying on large-scale data, modelling techniques such as data fusion and hybrid AI, and extensive physical and virtual testing environments.[178] Cybersecurity constitutes another foundational element, as connected and automated transport systems depend on secure communication channels and robust protection against interference or malicious attacks. In parallel, digital twins and simulation tools are increasingly used to test, validate, and refine CCAM technologies before wider deployment, reducing risks associated with real-world operation.

In telecommunications, the expansion of machine-to-machine communication and high data throughput increases demand for professionals capable of managing complex network architectures and analysing data flows across connected systems. In computer programming and related activities, shared data environments intensify the need for expertise in machine learning, data analysis, and AI-based testing, as autonomous vehicles rely on models trained on extensive sensor and operational datasets. Within information services, CCAM places particular focus on the importance of data management and cross-functional IT skills, including working with cloud systems, modelling tools, and algorithms used for mobility applications.[179]

Overall, the most significant organisational and skills-related shifts stem from the growing importance of AI, machine learning, data analysis, and cybersecurity, combined with cross-functional competences that link advanced ICT expertise with an understanding of transport systems. These developments increase demand for profiles capable not only of developing and operating digital technologies, but also of working effectively across disciplinary boundaries and within safety-critical, system-oriented environments.

[177] Eurostat [NACE Rev. 2 two-digit level], 2023.
[178] European Climate, Infrastructure and Environment Executive Agency (CINEA) (2023), 'European Partnership on Connected, Cooperative and Automated Mobility (CCAM) – Horizon Europe brochure', available at: https://www.ccam.eu/wp-content/uploads/2023/05/HE-CCAM-2023_brochure-web-FIN.pdf
[179] Alonso Raposo M., Grosso, M., Després, J., Fernández Macías, E., Galassi, C., Krasenbrink, A., Krause, J., Levati, L., Mourtzouchou, A., Saveyn, B., Thiel, C. and Ciuffo, B. (JRC), 'An analysis of possible socio-economic effects of a Cooperative, Connected, and Automated Mobility (CCAM) in Europe', available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC111477

3.5.3 Employment and occupational change

The demand for AI developers, including AV machine-learning specialists and deep-learning experts, is increasing, along with software developers who design and oversee the digital systems essential for automated vehicles to rely on.[180] Network-focused roles are also expanding, with telecommunications engineers, technicians, and telematics specialists needed to install, maintain, and optimise 5G and V2X systems. Additionally, the integration of automotive and communication technologies is giving rise to specialised profiles that bridge vehicle systems and advanced communication networks.[181]

As frequently mentioned elsewhere in this report, the continued development of connected vehicles is also generating sustained demand for cybersecurity specialists. Cybersecurity analysts and IT security managers are increasingly required to safeguard connected and automated vehicle infrastructures, often within dedicated Network Operations Centres that support continuous monitoring and incident response. Moreover, the large volumes of data generated by connected and automated vehicles are driving demand for mobility data scientists and data service providers capable of collecting, analysing, and, in some cases, monetising transport data.[182] Across survey respondents active in CCAM-related software, data, and system-integration activities, a clear majority identified AI, data analysis, cybersecurity, and system integration as critical skills underpinning CCAM deployment. These skills were consistently prioritised across multiple sectors, confirming ICT roles as a structural bottleneck for CCAM rather than a niche specialisation.

Direction of change	Occupational profiles	Nature of change	Skills implications
Growing demand	AI developers; machine-learning and deep-learning specialists; software developers for automated systems; telecommunications engineers; V2X and telematics specialists; cybersecurity analysts; mobility data scientists	Expansion driven by automation, connectivity, data intensity and safety-critical requirements of CCAM	Advanced AI and data analytics; cybersecurity; system integration; software reliability and validation; understanding of mobility systems
Role transformation	Systems administrators; general software	Shift from local infrastructure and routine management toward cloud-based,	Cloud integration; real-time data handling; secure system operation;

180 European Centre for the Development of Vocational Training, 'Digital skills ambitions in action: Cedefop's Skills forecast digitalization scenario', available at: https://www.cedefop.europa.eu/files/4218_en_0.pdf
181 Alonso Raposo M., Grosso, M., Després, J., Fernández Macías, E., Galassi, C., Krasenbrink, A., Krause, J., Levati, L., Mourtzouchou, A., Saveyn, B., Thiel, C. and Ciuffo, B. (JRC), 'An analysis of possible socio-economic effects of a Cooperative, Connected, and Automated Mobility (CCAM) in Europe', available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC111477
182 Shah Khalid Khan, Nirajan Shiwakoti, Peter Stasinopoulos, Matthew Warren, ' Cybersecurity regulatory challenges for connected and automated vehicles – State-of-the-art and future directions, available at: https://www.sciencedirect.com/science/article/pii/S0967070X23002330

	developers; network engineers	safety-critical and distributed system oversight	formal verification and compliance with safety standards
Hybrid and cross-domain roles	Automotive–telecom integration specialists; cloud-integration engineers; ICT professionals with transport-domain expertise	Emergence of cross-functional profiles combining ICT expertise with mobility, traffic management and regulatory knowledge	Cross-domain system thinking; mobility modelling; regulatory and safety awareness; collaboration across engineering domains
Declining relative importance	Server technicians; data-centre staff; help-desk and routine infrastructure support roles	Partial displacement through cloud automation and outsourcing rather than full job elimination	Reduced demand for routine infrastructure skills; need for reskilling toward advanced cloud, security and integration roles
System-level constraint	ICT workforce as a whole	Persistent shortages limit pace of CCAM deployment across sectors	Urgent need for training, certification and retention of advanced ICT skills

Table 9. Direction of occupational change in ICT-related roles under CCAM
Source: CCAM-ERAS.

Alongside potential employment growth, CCAM is also contributing to a qualitative transformation of existing ICT roles. AI is automating routine system management tasks, shifting priorities toward cloud integration, cybersecurity and the management of distributed services. Systems administrators are therefore increasingly evolving into cloud-integration engineers who oversee cloud platforms, support real-time data streams, and maintain remote digital infrastructures rather than local hardware. In parallel, the growing safety-critical nature of CCAM software is raising expectations for data reliability and validation. This may push software developers toward more specialised roles focused on designing open platforms, APIs, and advanced algorithms while adhering to formal safety and verification standards.[183]

Meanwhile, some ICT roles are expected to decline in relative importance. Research on cloud-hosting and automation trends indicates that roles centred on traditional infrastructure and support functions (such as server, network, help-desk, and data-centre technicians) are particularly exposed, as these activities evolve to be handled by automated cloud systems or outsourced services.[184] Survey respondents rarely prioritised such roles when identifying future CCAM skill needs. Instead, they consistently emphasised advanced cloud, cybersecurity, and system-integration capabilities, suggesting a redistribution of employment within ICT rather than a uniform expansion across all occupations.

Stakeholders across multiple CCAM-ERAS consultation exercises (interviews, workshops, surveys) also highlighted that CCAM is driving a shift from generic IT work toward safety-critical

[183] AI-Enabled ICT Workforce Consortium (2024), The Transformational Opportunity of AI on ICT Jobs, available at: https://www.cisco.com/c/dam/m/ai-enabled-ict-workforce-consortium/report.pdf
[184] George et al. (2023), 'The Impact of Cloud Hosting Solutions on IT Jobs: Winners and Losers in the Cloud Era', available at: https://doi.org/10.5281/zenodo.8329790

mobility software, with important implications for training and certification. The safe operation of automated transport systems depends on specialised knowledge in areas such as AI system assessment, cybersecurity, sensor technologies, and remote fleet supervision. Educational institutions are therefore redesigning curricula to incorporate sensors, AI, and advanced diagnostics, while industry experts highlighted the need for new national and European standards to ensure consistent competence across safety-critical mobility roles. Former checklist-based IT tasks are increasingly replaced by responsibilities that require workers to evaluate open standards, complex system behaviour, and interactions across vehicle, cloud, and infrastructure layers. CCAM-ERAS survey respondents assessed ICT-related CCAM skills gaps as moderate to large, with training needs frequently described as moderately to very urgent, indicating that shortages concern not only workforce numbers but also the depth and formalisation of required skills.

In addition, CCAM is contributing to the emergence of hybrid ICT profiles that combine advanced digital competences with domain knowledge in transport and mobility systems. Stakeholders anticipate growing demand for professionals who can integrate software engineering with understanding of traffic management, mobility processes, modelling techniques, and regulatory or safety frameworks. New entrants to the CCAM market, including specialised ICT firms, are expected to seek engineers with cross-functional capabilities spanning mathematics, physics, machine learning, robotics, data science, and software development.[185] CCAM-ERAS survey respondents frequently described future ICT roles as cross-domain profiles rather than standalone “pure IT” positions.

These trends unfold against a backdrop of persistent ICT skills shortages in the EU. CEDEFOP reported in 2019 that 24 EU Member States were already experiencing shortages of ICT professionals. By 2023, two-thirds of EU based companies have reported that they are experiencing difficulties in filling ICT vacancies. Skills such as software engineering, Python programming, AI, and machine learning are in particularly short supply, which leaves critical roles in cybersecurity and software development unfilled. The European Commission estimates that the EU could encounter a shortage of an estimated 8 million ICT specialists by 2030. International comparisons also suggest that the EU lags behind other regions in key advanced skills and technologies, particularly in cloud computing, big data, and micro-electronics.[186] CCAM-ERAS survey findings and various stakeholder consultations reinforce that CCAM will further intensify these shortages. Stakeholders consistently highlighted competition for ICT talent across sectors as a major constraint, suggesting that CCAM deployment risks being slowed not by technological readiness alone, but by persistent shortages in advanced ICT skills.

3.5.4 Skills foresight: short, medium and long term

Skills requirements in the information and communication sector evolve progressively as CCAM technologies mature and scale across vehicle, infrastructure and platform layers. Across all time horizons, the impact of CCAM is less about the disappearance of ICT work than about a sustained reorientation of tasks towards safety-critical, data-intensive and cross-domain

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[185] Ecorys (2020), ‘Study on exploring the possible employment implications of connected and automated driving’, available at: https://www.Ecorys (2020).com/app/uploads/files/2021-03/CAD_Employment_Impacts_Annexes.pdf

[186] Foundation for European Progressive Studies (FEPS) (2022), ‘Europe Needs High-Tech Talent: A Skills and Jobs Strategy for the Digital Decade’, available at: https://feps-europe.eu/wp-content/uploads/2022/07/Final_6.7.22_Europe-needs-high-tech-talent.pdf

activities. Routine and standardised digital tasks decline in relative importance, while demand grows for advanced software, data, cybersecurity and system-integration competences that support automated and connected mobility.

As in other sectors analysed in this report, skills foresight is structured primarily by time horizon and by the increasing technical and organisational complexity of CCAM systems. SAE automation levels are used only as broad reference points for technological maturity, rather than as precise deployment timelines. In the short term (0–5 years), skills demand focuses on foundational software, connectivity, and cybersecurity capabilities that support early CCAM deployment. The medium term (5–10 years) presents the highest risk of skills mismatches as system complexity, data volumes, and safety-critical requirements increase. The long term (10+ years) reflects upper-bound skills requirements associated with more mature highly automated systems, characterised by advanced AI, system oversight, regulatory compliance, and interdisciplinary coordination.

Time horizon	SAE Level	Core skill focus	Skills declining in relevance	Typical roles affected
Short-term (0-5 years)	Early CCAM deployment; assisted and partially automated systems, broadly corresponding to Levels 1–3	Foundational software development; data handling and interpretation; network and connectivity skills (5G, V2X); basic AI processes (learning, reasoning, behavioural modelling); cybersecurity awareness; system integration across vehicle and cloud	Routine data processing; standardised digital analysis; basic IT support tasks; repetitive rule-based system monitoring	Software developers; network engineers; ICT technicians; junior data analysts; cybersecurity support staff
Medium-term (5-10 years)	Scaling of connected and safety-critical automation, broadly corresponding to domain-specific Levels 3–4	Advanced software engineering; AI and machine learning; cloud and edge computing; embedded systems; cybersecurity engineering; large-scale data management and analytics; system integration across vehicle, infrastructure and platforms	Generic IT administration; non-specialised programming; routine system supervision; mid-level infrastructure support roles	Cloud and platform engineers; AV system engineers; data scientists; cybersecurity specialists; hybrid ICT–mobility roles
Long term (10+ years)	Mature highly automated and safety-critical digital mobility systems; Levels	Safety-critical software design and validation; advanced AI and robotics;	Traditional infrastructure maintenance; routine IT operations; isolated	AI architects; system safety engineers; cybersecurity architects;

	4–5 as an upper-bound reference	cybersecurity architecture; data governance and regulatory compliance; large-scale system oversight; interdisciplinary coordination across digital and mobility systems	"pure IT" roles without domain knowledge	mobility systems integrators; ICT roles combining technical, regulatory and mobility expertise

Table 10. Skills foresight in the information and communication sector by time horizon. Source: CCAM-ERAS.

Short-term skills needs

Early CCAM deployment, primarily associated with SAE Levels 1-3, will require skills in software development, network infrastructure, and data analysis, as vehicles rely on AI-enabled systems capable of interpreting sensor data and real-time decision making. Professionals working in this phase will need competencies in AI-related processes such as learning, reasoning, and behavioural modelling, alongside the ability to manage and interpret diverse road, traffic, and environmental data.

Cybersecurity and data privacy expertise will also be essential at this stage, including familiarity with measures that support system integrity in connected environments. As a result, immediate skill needs centre on AI development, cybersecurity awareness, 5G connectivity and basic system integration.[187] Alongside technical capabilities, transversal skills such as problem-solving, communication, adaptability, and teamwork will be equally important for working effectively in fast-changing CCAM environments.[188]

Whilst this increase of specific skills increases, skills linked to routine or repetitive digital tasks begin to decline in relative importance. Automation now streamlines activities such as basic data processing, routine analysis and standard problem-solving, reducing the need for workers who rely heavily on these tasks. As AI reshapes traditional job functions, skills that do not involve advanced technical capability, adaptability or higher-level reasoning may decline in importance, raising concerns about whether the existing workforce is prepared to meet the evolving skill demands.[189]

Medium- term skills needs

In the medium term, as CCAM technologies mature, the demand for specialised ICT and engineering skills is expected to intensify. This phase broadly corresponds to the wider deployment of domain-specific SAE Levels 3–4, where automated driving functions operate under defined conditions but remain embedded in connected, safety-critical digital ecosystems. The integration of advanced driver-assistance systems will require professionals

[187] Lazaros Giannakos, Anna Antonakopoulou, Alexandros Liazos, 'Understanding the Gap of CCAM solutions deployment' 2023, s 2.2.1

[188] A.T. Kearney: Michael Römer, Steffen Gaenzle, and Christian Weiss, 'How automakers can survive the self-driving era', available at: https://www.kearney.com/industry/automotive/article/-/insights/how-automakers-can-survive-the-self-driving-era

[189] AI-Enabled ICT Workforce Consortium (2024), 'The Transformational Opportunity of AI on ICT Jobs', available at: https://www.cisco.com/c/dam/m/ai-enabled-ict-workforce-consortium/report.pdf

with strong expertise in software engineering, robotics and electrical engineering, supported by comprehensive training in safety-critical automotive systems. AV Lab Managers and AV Platform System Engineers will require proficiency in cloud services, messaging protocols and embedded systems.[190] As CAVs generate large volumes of data, skills in data management and mobility-system operations, such as advanced traveller information systems and integrated network flow optimisation, will be essential.[191]

Additionally, clustering methods, regression models and algorithm development for perception and path planning will require higher proficiency in ICT skills.[192] Software developers and ICT specialists will need programming expertise tailored to autonomous-vehicle applications, particularly in languages such as Python and JavaScript, which support sensor data processing and machine learning.[193] Hybrid IT roles that combine digital skills with knowledge of traffic management, mobility processes and modelling techniques will also be created.[194] Cybersecurity will remain a rapidly growing field, with high demand for experts in information security, computer science and electric-vehicle system architecture.[195]

As manufacturers modernise production systems and increasingly rely on data to optimise operations, supply chains, and predictive maintenance, new employment opportunities are expected to arise for data analysts and data scientists. Advancing autonomous-vehicle development will also increase demand for civil-engineering professionals capable of integrating digital tools into transport infrastructure and vehicle–infrastructure systems.

Long-term skills needs

In the long term, under conditions of more widespread deployment of highly automated systems approaching SAE Levels 4–5, the ICT sector's skills profile shifts further toward advanced, safety-critical and system-level competences. At these levels of automation, vehicles and mobility services rely on continuous connectivity, complex AI-driven decision-

[190] Shammut, M., 'Driverless Car Implications: A Literature Review' Massey University, available at: https://www.transportationgroup.nz/wp-content/uploads/Driverless-Cars-Implications-Moayad-Shammut-2020.pdf

[191] Chris Hendrickson, Allen Biehler, Yeganeh Mashayekh - Pensylvania department of Transportation, 'Connected and Autonomous Vehicles 2040 Vision', available at: https://www.cmu.edu/metro21/resources1/images/joint-statewide-connected-and-autonomous-vehicles-2040-vision-final-report-smaller.pdf; Darsh Parekh, Nishi Poddar, Aakash Rajpurkar, Manisha Chahal, Neeraj Kumar, Gyanendra Prasad Joshi, Woong Cho, 'A Review on Autonomous Vehicles: Progress, Methods and Challenges', available at: https://www.mdpi.com/2079-9292/11/14/2162

[192] Shammut, M., 'Driverless Car Implications: A Literature Review' Massey University, available at: https://www.transportationgroup.nz/wp-content/uploads/Driverless-Cars-Implications-Moayad-Shammut-2020.pdf

[193] Gourav Bathla, Kishor Bhadane, Rahul Kumar Singh, Rajneesh Kumar, Rajanikanth Aluvalu, Rajalakshmi Krishnamurthi, Adarsh Kumar, R. N Thakur, Shakila Basheer, 'Autonomous Vehicles and Intelligent Automation: Applications, Challenges, and Opportunities', available at: https://www.researchgate.net/publication/361136562_Autonomous_Vehicles_and_Intelligent_Automation_Applications_Challenges_and_Opportunities

[194] Eftihia G. Nathanail, Giannis Adams and Ioannis Karakies, 'Advances in Mobility as a Service Systems', available at: https://link.springer.com/book/10.1007/978-3-030-61075-3

[195] Dorlecontrols, 'Cybersecurity for Autonomous Vehicles', available at: https://medium.com/@dorlecontrols/cyber-security-for-autonomous-vehicles-8747dbdabfb5

making and secure interaction between vehicles, infrastructure and digital platforms, placing ICT at the core of system performance and safety assurance.

As autonomous vehicle technologies continue to evolve and scale, the labour market will increasingly require specialists in AI, robotics, cybersecurity and advanced communication systems. Demand for expertise in software engineering, intelligent navigation and large-scale data analysis is expected to grow, alongside rising expectations related to ethical decision-making and regulatory compliance. Education and training therefore play a critical role, with future programmes needing to combine strong theoretical foundations with practical experience in safety-critical and data-intensive environments.

To keep pace with these developments, both graduates and the existing workforce are likely to require ongoing professional and vocational training.[196] ICT professionals will increasingly require skills related to innovation, advanced digital literacy and mathematical competence, with specialised software, databases and programming languages such as SQL, JavaScript, PHP and Python remaining prominent in job requirements. Evidence also indicates that a growing share of professional vacancies already explicitly mention AI-related skills, underscoring the structural nature of this shift.[197]

Long-term ICT roles are characterised by a growing need for interdisciplinary collaboration. Professionals may be expected to combine deep technical expertise with interpersonal and transversal competences, including problem-solving, communication, adaptability, teamwork and continuous learning. [198]Technical depth remains essential, particularly in areas such as robotics, electrical engineering and modelling, but is increasingly complemented by knowledge of traffic management, mobility systems and the operational contexts in which automated technologies are deployed.[199]

Findings from stakeholders during CCAM-ERAS consultation exercises reinforce this outlook. Interviewees note the rising demand for AI, machine learning, big data analytics, cybersecurity, and sensor-technology expertise as CCAM systems expand. Several emphasised that future roles will focus on software integration, remote fleet supervision, data-driven traffic management, and advanced diagnostics, confirming a shift towards highly technical and digitally enhanced positions. Experts also observed the emergence of hybrid roles that combine

[196] M. Pomoni, A. Loiou, C. Plati, G. Yannis, M. Loukea and E. Bekiaris, 'Future trends in transport workforce based on demographic, behavioural, cultural and socioeconomic factors', available at: https://www.sciencedirect.com/science/article/pii/S2352146520306566?ref=pdf_download&fr=RR-2&rr=9aeee5daea91f6ad

[197] European Centre for the Development of Vocational Training (Cedefop) (2023), 'ICT professionals: skills, opportunities and challenges – 2023 update', available at: https://www.cedefop.europa.eu/en/data-insights/ict-professionals-skills-opportunities-and-challenges-2023-update

[198] A.T. Kearney: Michael Römer, Steffen Gaenzle, and Christian Weiss, 'How automakers can survive the self-driving era', available at: https://www.kearney.com/industry/automotive/article/-/insights/how-automakers-can-survive-the-self-driving-era

[199] Alonso Raposo M., Grosso, M., Després, J., Fernández Macías, E., Galassi, C., Krasenbrink, A., Krause, J., Levati, L., Mourtzouchou, A., Saveyn, B., Thiel, C. and Ciuffo, B. (JRC), 'An analysis of possible socio-economic effects of a Cooperative, Connected, and Automated Mobility (CCAM) in Europe', available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC111477

ICT skills with mobility knowledge, including traffic modelling, system integration, and infrastructure–vehicle communication.[200]

3.6 Other relevant sectors

While much of the employment and skills impact of CCAM is concentrated in the core sectors discussed above, a range of additional sectors also play important enabling and support roles in the wider CCAM ecosystem. In these sectors, CCAM is generally less likely to trigger direct, sector-wide restructuring of employment levels than in vehicle manufacturing, transport operations, or maintenance and repair. Its influence is more often indirect, operating through changing task profiles, new coordination requirements, and rising knowledge demands. The following sub-sections therefore examine how CCAM affects these sectors primarily through task evolution, upskilling needs, and organisational adaptation. The table below provides a comparative overview of the role of these sectors in the CCAM ecosystem, and the nature of the employment and skills changes they face.

Sector	Role in the CCAM ecosystem	Intensity of employment impact	Dominant type of change	Key skill implications
Civil engineering	Provision and adaptation of physical infrastructure supporting CCAM deployment	Low	Task evolution within existing roles	Digital literacy; BIM and digital twin tools; data interpretation; coordination with ICT and mobility actors
Education and training services	Skills supply, upskilling and reskilling across the CCAM value chain	Medium (indirect)	Expansion and reorientation of tasks	Curriculum redesign; educator upskilling; modular and lifelong learning formats; industry–education cooperation
Energy and charging infrastructure	Enabling electrified and automated fleet operations	Medium	Task expansion and emergence of hybrid roles	Smart charging and grid integration; digital operations; data handling; cybersecurity awareness
Insurance and risk-related services	Risk allocation, liability management and market enablement	Medium	Task transformation within existing roles	Data analytics; cyber-risk assessment; system- and fleet-level

[200] Stakeholder interviews.

				liability analysis; regulatory expertise
Professional, scientific and technical activities	Research, testing, validation and technical consultancy	Medium	Increasing specialisation	AI and data analytics; simulation and digital twins; systems engineering; safety assurance and certification
Public authorities, mobility planners and transport governance actors	Governance, approval, supervision, mobility planning, multimodal integration, procurement and policy coordination	Medium (systemic)	Knowledge and capability upgrading	Understanding of CCAM systems and Operational Design Domain (ODDs); interpretation of technical and operational data; multimodal planning; procurement and permitting; cybersecurity awareness; cross-sector coordination

Table 10. Nature and intensity of CCAM impacts in selected enabling and supporting sectors.
Source: CCAM-ERAS.
Note: "Intensity of employment impact" refers to the extent of direct employment restructuring attributable to CCAM, not to the strategic importance of the sector for CCAM deployment.

3.6.1 Civil engineering

Civil engineering encompasses the planning, construction, and maintenance of transport infrastructure such as roads, bridges, tunnels, ports, depots, and related public works. In the context of CCAM, the sector plays a supporting and enabling role, rather than being a primary site of automation-driven employment transformation.[201] This is consistent with EU research such as the INFRAMIX project, which shows that automated vehicles are designed to operate primarily on existing infrastructure, with infrastructure providing incremental and voluntary support rather than determining automation capability.[202] While fully autonomous operation at higher automation levels may benefit from supportive infrastructure elements, the general consensus among stakeholders indicates that CCAM systems are largely expected to operate within existing road environments, with targeted upgrades rather than large-scale infrastructure redesign.

[201] Stakeholder interviews.
[202] INFRAMIX Consortium (2019). D5.4 – Infrastructure Classification Scheme. Horizon 2020 Project INFRAMIX – Road INFRAstructure ready for MIXed vehicle traffic flows.

The most relevant developments for civil engineering relate to the integration of digital tools that support CCAM-enabled mobility systems. These include the deployment of roadside units for cooperative ITS (C-ITS), improved lane markings and signage consistency, sensor-based traffic and weather monitoring, and interfaces with digital traffic management platforms. These physical components are increasingly underpinned by digital systems such as Building Information Modelling (BIM) and digital twins, which enable lifecycle monitoring, maintenance planning, and coordination with mobility operators and public authorities.

CCAM does not generate large-scale employment shifts in civil engineering. Instead, it contributes to task evolution within existing professional roles. Roles such as site engineers, infrastructure planners, and maintenance technicians may gradually evolve towards more data-enabled and system-oriented profiles, while entirely new occupations remain limited. Employment impacts are therefore characterised primarily by upskilling needs rather than job displacement or employment growth.

In the short to medium term, skills demand in civil engineering related to CCAM may focus on

- Digital literacy and data interpretation
- Familiarity with BIM and digital asset management tools
- Basic understanding of ITS, connectivity, and sensor-based monitoring
- Coordination skills for working across infrastructure, mobility, and ICT domains

In the longer term, the importance of systems thinking, lifecycle management, and sustainability-related skills is expected to grow, alongside knowledge of regulatory requirements and safety considerations linked to connected and automated mobility.

3.6.2 Education and training services

Education and training services play a critical enabling role in supporting workforce transitions associated with CCAM, but their relevance is highly specific rather than system-wide. CCAM does not transform all of higher education, vocational education and training, or adult learning provision equally. Instead, it creates pressure in a relatively small but strategically important segment of provision linked to automated driving, software-enabled vehicle systems, diagnostics, remote supervision, safety assurance, data governance, and mobility-system integration. Within this segment, education and training providers are expected to support both initial skills formation and the adaptation of incumbent workers as CCAM-related roles begin to emerge across the value chain. This is consistent with CCAM-ERAS wider finding that skills demand is concentrated in hybrid and cross-domain profiles rather than in wholesale occupational replacement.

A central issue is that much of the early upskilling and reskilling linked to CCAM is unlikely to happen through formal HE and VET alone. In practice, many immediate skills needs arise during pilot and early deployment phases before stable occupational standards or full public training pathways are in place. As a result, organisations often rely on short courses, informal workplace learning, vendor- or OEM-led instruction, simulator-based training, professional training programmes, and in-company training delivered by operators, manufacturers, or specialised providers. Some AV- and CCAM-specific provision exists in precisely these forms, but remains fragmented, unevenly distributed, and insufficiently standardised for wider deployment. Education and training services should therefore be understood broadly here, encompassing not only HE and VET institutions but also non-formal and informal learning channels, private training providers, and structured in-company learning.

Within formal provision, the most visible effects concern the content and organisation of programmes that are directly relevant to CCAM. Higher education institutions are progressively integrating CCAM-related topics into engineering, computer science, data, transport, and mobility programmes, often through interdisciplinary modules that combine technical, regulatory, and societal perspectives. In VET, the challenge is particularly pronounced where provision has traditionally focused on mechanical systems and must now incorporate electronics, software diagnostics, connected subsystems, cybersecurity awareness, and digital tools relevant to advanced driver assistance and early automation functions. However, CCAM-ERAS stakeholder consultation evidence suggests that such adaptation is uneven across Member States and institutions, and often lags behind technological developments and operational practice.

At the same time, training by industry is likely to remain especially important in the short term. For several CCAM-relevant role clusters, several suitable responses to addressing skills needs include OEM tool-based training, vendor modules, work-based learning, short accredited courses, and in-company applied projects. This reflects the fact that firms involved in pilots and early deployments often have the most direct access to current systems, equipment, and use cases. Some pilots currently provide training almost entirely in-house, especially where no shared public standards yet exist. The implication is not that industry training should replace formal HE/VET, but that CCAM skills formation will depend on stronger complementarity between formal provision, private and vendor-led provision, and workplace-based learning.

CCAM also affects the tasks and roles of educators and trainers. Like with any other technological change, teaching staff are increasingly required to update course material, develop new training formats, and engage with industry partners to ensure relevance. Some institutions report constraints related to staff capacity, access to specialised equipment, and the availability of educators with up-to-date technical expertise, particularly in smaller VET providers and regional institutions. Skills forecasting consultations repeatedly raised the question of “who teaches the teachers” in a context of evolving AI and automation technologies. Stakeholders noted that educators themselves often lack access to systematic upskilling opportunities, creating a risk that knowledge gaps among trainers become a structural bottleneck for wider workforce adaptation.

This area is also important from an equity perspective. Education and training systems are not only channels for supplying technical skills; they are also intervention points for shaping who participates in the emerging CCAM workforce. Project evidence indicates that inclusive training and job design could help diversify the transport sector by attracting more women, older workers, and people from backgrounds not traditionally associated with automotive or transport occupations, particularly into new remote, support, coordination, and user-facing roles. At the same time, there is a risk that exclusion patterns are reproduced if gender, accessibility, disability, and digital-readiness issues are not systematically included in programme design, outreach, and recruitment. Flexible, modular and work-compatible formats may therefore be especially important, both for incumbent workers and for groups that have historically been underrepresented in transport and mobility occupations.

In the short to medium term, CCAM-related skill needs within education and training services are therefore likely to focus on:

- targeted curriculum updates in the subset of HE, VET, and professional training provision most relevant to CCAM;

- educator, trainer, and in-company mentor upskilling in software-enabled systems, AI fundamentals, diagnostics, safety concepts, and digital tools;
- modular, flexible, and rapidly updateable learning formats, including micro-credentials, simulation-based learning, short professional courses, and work-based learning;
- stronger cooperation between education providers, employers, manufacturers, operators, and public authorities;
- clearer bridging pathways between formal education, vendor/OEM provision, and workplace learning;
- integration of inclusion, accessibility, and diversity objectives into CCAM-related recruitment and training design.

In the longer term, the importance of institutional adaptability, interdisciplinary teaching capacity, and sustained investment in educator skills is expected to grow. As CCAM technologies evolve through continuous software updates and system integration, education and training systems will need to respond more rapidly than traditional curriculum cycles allow. The responsiveness of the education and training ecosystem will depend on sustained investment in trainer capability, stronger public-private coordination, and better mechanisms for updating provision as new CCAM role profiles mature. Without this, uneven institutional capacity may widen differences across regions and organisational types, turning skills formation into a structural bottleneck for deployment rather than a facilitator of it.

3.6.3 Energy and charging infrastructure

The energy sector (including electricity networks and charging services) is progressively more relevant to CCAM because automation and connectivity are developing alongside vehicle electrification, especially in fleet-based and shared mobility use cases. Skills foresight consultations have explicitly highlighted the convergence of automation, digitalisation and electrification as a core technology trend shaping vehicle models and supporting services. In practice, several CCAM demonstrations already combine higher automation with battery-electric vehicles and automated/robotic charging in controlled environments (e.g., terminals and depots), indicating that energy infrastructure is not just an enabling condition for decarbonisation, but also part of how automated fleets are operationalised.

At EU level, the policy driver is primarily the electrification pathway of the Green Deal and “Fit for 55”, including the binding framework for rollout of publicly accessible recharging infrastructure under the Alternative Fuels Infrastructure Regulation (AFIR). While AFIR is not specific to CCAM, its targets and interoperability requirements shape the conditions under which electric (and potentially automated) fleets can scale on the TEN-T network and in urban contexts.

The most relevant developments for the energy/charging domain relate to the shift from “static” charging provision to digitally managed charging operations. As electric automated fleets expand, charging becomes increasingly embedded in operational planning (e.g., depot optimisation, charging scheduling, and integration with fleet management platforms), and this trend is visible in CCAM-ERAS use cases where charging is treated as part of automated logistics or depot workflows rather than a standalone service. This also amplifies dependencies on grid capacity, smart charging capabilities, data exchange, and cybersecurity, particularly were charging systems interface with connected vehicles and remote operations.

Employment impacts in the sector are less about displacement and more about task expansion and new hybrid roles. Stakeholders already anticipate growing demand for profiles such as energy management engineers focused on managing charging networks, integrating storage, and improving energy efficiency, reflecting electrification pressures that intersect with automated mobility deployment. Operational roles in charging networks require digital monitoring, incident response, interoperability management, and coordination with mobility operators, local authorities, and (where relevant) depot/terminal managers.

In the short to medium term, CCAM-related skills demand in energy and charging infrastructure may focus on:

- Charging network deployment and operations, including interoperability and compliance with EU requirements (e.g., AFIR)
- Digital operations and data handling (monitoring, load management, basic analytics for utilisation and reliability)
- Grid/charging integration skills, including smart charging, basic storage integration, and coordination with fleet operators
- Cybersecurity awareness for connected charging infrastructure and interfaces with fleet/traffic systems

In the longer term, the importance of systems integration is expected to grow: the sector increasingly needs professionals who can link charging infrastructure with fleet management, automated depot/terminal operations, and potentially vehicle-to-infrastructure data ecosystems, alongside resilience and risk management for critical infrastructure. Evidence from CCAM demonstrations combining electric automated vehicles with automated charging also suggests a growing need for skills in automated charging systems, remote diagnostics, and lifecycle management of digitally controlled energy assets.

3.6.4 Insurance and risk-related services

Insurance and risk-related services are directly affected by the deployment of CCAM, as automation and data-intensive vehicle operation fundamentally alter how transport-related risks are generated and assessed. Unlike some other enabling sectors, insurance is not only indirectly influenced by CCAM adoption but is actively reshaped by changes in liability, safety responsibility, and data availability. This is reflected in stakeholder evidence, which emphasise the central role of insurance in enabling market uptake while managing uncertainty during the transition to automated mobility.[203] Industry discussions further underline that insurance is not merely a downstream financial service but a prerequisite for scaling CCAM beyond pilot phases, as vehicles cannot operate legally without coverage and unresolved risk allocation can delay or prevent wider deployment.[204]

In the European context, the transition is characterised by gradual adaptation under regulatory uncertainty, rather than abrupt disruption. Stakeholders broadly anticipate that conventional motor insurance will continue to coexist with new forms of coverage for an extended period, as legal frameworks for automated driving, product liability, and artificial intelligence continue to evolve. Rather than eliminating insurance demand, CCAM reshapes insurance markets by shifting emphasis towards fleet-based, product- and software-related, and cyber-risk coverage, particularly in shared and automated mobility services. Recent industry exchanges also point to increasing experimentation with hybrid and integrated insurance models tailored to automated

[203] Stakeholder interviews.
[204] SAAM (2025), Reimagining Risk: How Autonomous Vehicles Are Reshaping the Future of Insurance, available at: https://www.saam.swiss/autonomous-vehicle-insurance-future/

mobility ecosystems, although these remain at an exploratory stage and are not yet reflected in harmonised EU practice.

The most significant developments for insurance relate to the reconfiguration of risk assessment and liability models. As automated driving functions begin to replace human control, responsibility for incidents is expected to move partially from individual drivers towards manufacturers, software providers, fleet operators, and mobility service providers. From an insurance perspective, this implies a shift away from driver-centred risk assessment towards system- and ecosystem-based approaches, where risk is increasingly understood as contextual and dependent on operational conditions rather than universal vehicle characteristics. Increased vehicle connectivity introduces new categories of risk, notably cybersecurity, data protection, and system-level failures. These developments require insurers to move beyond traditional actuarial models based primarily on historical claims data and instead incorporate real-time vehicle data, system performance information, and legal-technical assessments into underwriting and claims management processes.[26]

CCAM also affects how insurance-related work is organised. Automation and data analytics are increasingly used in claims handling, fraud detection, and risk evaluation, reducing reliance on manual processing and standardised procedures. However, CCAM-ERAS stakeholder interviews and EU research indicate that this does not lead to large-scale employment reductions in the sector. Instead, it contributes to substantial task transformation within existing roles, with growing demand for analytical judgement, technical understanding of automated systems, and regulatory expertise. In line with broader CCAM development practices, insurers are also beginning to explore simulation-based and synthetic-data approaches to complement historical loss data, particularly where real-world claims data remain limited. New responsibilities emerge around software and product liability, fleet-level risk management, and cyber-risk assessment, particularly in business-to-business insurance markets linked to automated transport services.[127]

In the short to medium term, CCAM-related skills demand in insurance and risk-related services may focus on:

- Data analytics and interpretation of vehicle and telematics data
- Cybersecurity and digital risk assessment
- Legal and regulatory expertise related to product liability and automated systems
- Risk management for fleets and mobility service providers
- Interpretation of scenario-based and simulation outputs for risk evaluation and underwriting

In the longer term, the importance of systems-level understanding and regulatory competence is expected to grow, particularly as continuous software updates and in-service monitoring, become more prevalent in automated mobility systems. Traditional skills centred on manual claims handling, paper-based processes, and purely retrospective risk modelling are expected to decline in relevance, while analytical, legal–technical, and cross-sector coordination skills become increasingly central. Industry perspectives suggest that this evolution may support a gradual shift from reactive to more predictive and preventive insurance practices, although such approaches depend on continued regulatory clarity, data governance arrangements, and cross-sector cooperation.

3.6.5 Professional, scientific and technical activities

Professional, scientific and technical activities encompass engineering and technical consultancy, technical testing and analysis, and scientific research and experimental development across disciplines relevant to connected and automated mobility. Similar to civil engineering, in the context of CCAM, the sector plays a supporting and enabling role, rather than being a primary site of automation-driven employment transformation. It concentrates many of the advanced digital, systems, and safety-critical capabilities that underpin Europe's capacity to innovate in automated mobility. This is particularly relevant in light of recent EU-level analyses, including the Draghi report on European competitiveness, which highlight structural challenges related to innovation scale-up, advanced digital skills shortages, and the translation of research into market-ready applications.[205]

The most relevant developments for professional, scientific and technical activities relate to the growing reliance on data-driven development, simulation, and scenario-based testing for CCAM systems. As automated driving depends on complex software, artificial intelligence, and large volumes of sensor data, traditional validation approaches based solely on physical testing are no longer sufficient. Instead, hybrid methods combining virtual testing, digital twins, and selected real-world testing will become central to system development, safety validation, and certification processes, particularly for higher levels of automation.

CCAM contributes to task evolution and increasing specialisation within existing professional roles, particularly among engineers, researchers, and testing and validation experts. While demand for advanced expertise in areas such as artificial intelligence, data analytics, systems integration, and safety assurance is increasing, the emergence of entirely new occupations remains limited. Employment impacts are therefore characterised primarily by rising skill requirements and upskilling needs, rather than by job displacement or employment growth.

In the short to medium term, skills demand in professional, scientific and technical activities related to CCAM may focus on:

- Advanced software engineering and software-defined system architectures
- Data analytics and management of large, heterogeneous datasets
- Artificial intelligence development, verification and validation
- Simulation, digital twins, and scenario-based testing methodologies
- Systems engineering and integration across vehicle, infrastructure, and traffic domains

In the longer term, the importance of systems thinking, lifecycle management, cybersecurity, and regulatory competence is expected to grow, particularly in relation to continuous safety assurance, certification, and in-service monitoring of automated systems. Routine analytical tasks and standardised testing activities are expected to decline in relevance, while advanced technical expertise, interdisciplinary collaboration, and adaptability may become more central. Strengthening skills in this sector is therefore closely linked to Europe's broader capacity to sustain innovation and competitiveness in CCAM, as highlighted in recent EU competitiveness assessments.

[205] Draghi, M. (2024). The Future of European Competitiveness. Report to the European Commission.

3.6.6 Public administration, mobility planning and regulatory authorities

Public administration, regulatory authorities, and related mobility-planning actors play a central enabling role in the deployment of CCAM, as they help define the legal, regulatory, organisational, and spatial conditions under which automated mobility systems can be introduced and operated. This includes EU and national ministries, vehicle approval and safety authorities, road and traffic administrations, data protection bodies, regional and municipal authorities, public transport authorities, and mobility or urban integration planners. In line with the wider pattern identified across this report, CCAM is not expected to fundamentally alter the overall size of employment in these functions, but it does create significant new knowledge demands, coordination requirements, and capability gaps across levels of governance.

This interpretation is consistent with the occupational perspective developed in CCAM-ERAS Deliverable D5.2, which identifies a range of public-domain and enabling roles that are increasingly important for CCAM deployment. These include policy and regulation officers, road infrastructure engineers, public infrastructure trainers, urban integration planners, programme managers in public transport authorities, and multimodal traffic management specialists. D5.2 also emphasises that many of these roles do not represent entirely new professions, but rather existing professional functions to which a distinct CCAM-related layer of competences must be added.

Across stakeholders active in CCAM operations, the capacity of public authorities and planning bodies to understand, assess, and govern complex automated systems was repeatedly identified as a decisive factor influencing the pace and scale of deployment. Skills foresight consultations similarly highlighted gaps in AI literacy, CCAM system understanding, and regulatory interpretation within public administrations as structural risks for deployment. Participants stressed that where authorities lack sufficient in-house understanding of automated systems, operational design domains, digital infrastructure requirements, or multimodal integration issues, they become more dependent on external expertise, which can weaken regulatory oversight, slow decision-making, and reduce public accountability.

Early CCAM pilots have highlighted gaps in existing governance frameworks, including unclear liability or safety rules for driverless operations, fragmented permitting pathways, and limited alignment between technical approvals and local deployment conditions. The effects of which are multi-level: some countries or cities are moving ahead with CCAM trials under ad-hoc exemptions, while others wait for harmonised EU standards, risking uneven deployment. CCAM-ERAS workshop discussions characterised the current situation as one of regulatory experimentation rather than harmonised rollout, with pilot projects advancing under exemptions while long-term regulatory clarity remains unresolved. This dynamic has led to greater cross-jurisdiction coordination and policy innovation. For example, two-thirds of EU countries now allow autonomous vehicle testing, but differences in national rules hinder cross-border pilots,[221] spurring initiatives like the European Forum for Automated Transport (EFAT) to align policies across regions.[222] CCAM-ERAS survey respondents frequently pointed to regulatory fragmentation and uncertainty as practical challenges for CCAM deployment, particularly for cross-border operations and scalable service models.

The most significant impacts concern the knowledge base required for regulatory, planning, supervisory, and coordination tasks. Authorities responsible for vehicle approval, road safety, public transport planning, and traffic regulation increasingly need to understand how automated driving systems function, how operational design domains are defined and updated, how safety is demonstrated, and how technical constraints interact with local road networks, infrastructure, and service models. Rather than relying primarily on physical inspections or static compliance checks, public authorities are increasingly expected to assess safety cases, software updates, data governance arrangements, cybersecurity measures, and operational performance data. This requires deeper engagement with technical documentation, system behaviour in rare or unexpected scenarios, and the distribution of responsibility across complex supply chains and mixed public-private delivery models.

At the same time, the organisation of public-sector work is becoming more cross-disciplinary and cross-institutional. CCAM-ERAS Deliverable 5.2 underlines that the main barriers to CCAM deployment are often institutional and organisational rather than purely technological, and stresses the growing importance of coordination between authorities, operators, infrastructure actors, and technology providers. This is particularly relevant at regional and municipal level, where local administrations and public transport authorities may need to assess CCAM deployments in terms of traffic integration, accessibility, inclusion, procurement, public communication, and alignment with broader urban mobility strategies. As a result, administrative and planning roles evolve towards greater emphasis on coordination, interpretation of technical and operational information, stakeholder facilitation, and policy learning rather than routine permit issuance alone.

In the short to medium term, CCAM-related knowledge and skill requirements in public administration and mobility governance are likely to focus on:

- understanding of automated driving systems, operational design domains, and safety concepts
- ability to interpret technical documentation, simulation results, dashboards, and performance data
- knowledge of EU and national legal frameworks related to automated driving, liability, procurement, and data protection
- basic cybersecurity and digital-risk awareness relevant to connected mobility systems
- multimodal planning and the ability to assess how CCAM services fit within wider transport systems
- coordination skills for working across policy domains, organisations, and levels of government
- ability to assess accountability and liability arrangements in systems involving automated decision-making and subcontracted service provision
- capacity to engage in informed procurement, contract design, and performance monitoring for CCAM-related systems and services

CCAM-ERAS survey findings are closely aligned with these priorities. Respondents frequently identified regulatory understanding, cybersecurity awareness, and system-level knowledge as critical transversal competences for public authorities, and noted that gaps in these areas can slow approval processes or increase uncertainty for CCAM actors. In skills foresight consultations, these gaps were not framed as abstract future concerns, but as immediate issues with implications for safety and public trust in early CCAM deployments.

In the longer term, the importance of systems thinking, risk-based regulation, and continuous learning is expected to grow. As automated systems evolve through software updates and data-driven optimisation, public authorities will need to oversee dynamic systems rather than static products. Stakeholders stressed that this shift towards dynamic oversight challenges traditional administrative cultures and requires new forms of continuous training, institutional memory, and knowledge-sharing across authorities, rather than one-off upskilling initiatives. This places sustained demands on institutional knowledge development, training, and retention, while traditional administrative practices based on fixed rules and infrequent updates become less sufficient. Strengthening the technical and analytical capacity of public authorities is therefore a key condition for safe and scalable CCAM deployment across Europe. CCAM-ERAS survey respondents consistently characterised these capacity-building needs as moderately to highly urgent, suggesting that without sustained investment in training and institutional learning, public authorities risk lagging behind technological development and becoming an unintended constraint on CCAM innovation.

4 Cross-sectoral synthesis of skills needs and implications

This chapter synthesises the sectoral analyses to identify cross-sector skills implications of CCAM. It focuses on recurring skills needs across the value chain and enabling functions, and on how these are likely to evolve over the short, medium and long term. It draws on the preceding sector chapters, combining desk research, stakeholder interviews, the stakeholder survey, and skills foresight consultations. The aim is to identify patterns that recur across sources, while recognising that deployment conditions vary across sectors and geographies. The chapter has four parts: common skill clusters, shared bottlenecks and mismatches, differing timelines of skills demand across sectors, and a gap analysis and skills mapping.

4.1 Common skill clusters emerging across the CCAM-value chain

This section groups recurring skills needs into a small set of cross-cutting clusters. Across sectors, CCAM tends to reshape tasks within existing roles more often than it creates entirely new occupations. Skills needs therefore emerge in recurring combinations across transport, industry, and enabling functions. The clusters below provide a common framework for describing these patterns across the value chain.

4.1.1 Digital and systems literacy

Across the CCAM value chain, many workers need to understand system states, operational limits, and handover conditions. This applies in passenger transport, freight logistics, maintenance, and fleet support, but also in public authorities assessing system behaviour and in education and training institutions updating curricula and teaching practice.

4.1.2 Data, analytics, and AI-adjacent skills

Dashboards, performance metrics, and data-driven decision support are becoming part of everyday work in fleet and service management, manufacturing, testing, and validation. In public administration, similar capabilities are needed to assess safety cases and system-performance evidence. In most cases, the demand is less for advanced coding than for interpretation, judgement, and the ability to question outputs critically.

4.1.3 Cybersecurity and digital risk awareness

As mobility systems become more connected, exposure to cyber threats, operational disruption, and data-governance risks increases. This affects operators and service providers, but also vehicle and system development, digital infrastructure, and maintenance. Public authorities and data protection bodies need enough expertise to assess cyber risk and governance arrangements, while education and training providers need to embed security concepts in technical and operational programmes.

4.1.4 Safety assurance, validation and evidence management

A distinct cross-sector skills cluster concerns the ability to generate, interpret, and manage evidence on the safe functioning of CCAM systems. This includes scenario-based testing, simulation assessment, documentation, traceability, safety-case preparation, and the interpretation of compliance evidence by manufacturers, technical services, operators, and approval authorities. These skills are especially important because CCAM regulation increasingly treats automated driving as a system-level capability requiring structured validation and ongoing assurance rather than one-off component checks.

4.1.5 Remote supervision and exception handling

A recurring cross-sector need concerns the competences required for remote supervision and structured exception handling. These include the ability to monitor automated processes through dashboards and live system feedback, detect anomalies, interpret alerts, apply escalation protocols, and intervene appropriately under conditions of uncertainty. These skills arise in passenger transport operations, logistics fleet supervision, and controlled environments such as hubs and terminals. They also rely on situational judgement, sustained attention, communication under pressure, and a clear understanding of system boundaries and operational design limits. In practice, this cluster combines technical interpretation skills with cognitive and organisational competences needed to manage rare but high-risk events safely.

4.1.6 Software update and lifecycle assurance

A further recurring skills cluster concerns the governance of software-enabled systems over time. As vehicles and mobility services increasingly depend on OTA updates, diagnostics, connected subsystems, and post-market software changes, organisations need skills in update governance, change control, configuration management, toolchains, and secure lifecycle maintenance. These needs arise not only in OEMs and suppliers, but also in maintenance ecosystems, fleet operations, and compliance functions.

4.1.7 Transversal and human-centred skills

Communication, problem-solving, and adaptability remain important even as tasks become more digital and system-mediated. In passenger transport, they support user assistance and trust in services. In logistics, they matter for customer interaction and coordination under time pressure. In public administration, they underpin cross-unit collaboration and clear communication of decisions. In education and training, they support new teaching formats and closer engagement with employers and learners.

4.1.8 Coordination and systems integration

CCAM depends on coordination across operators, suppliers, infrastructure managers, and regulators. In practice, that means working across organisational boundaries, managing accountability, and understanding the standards and interfaces that allow systems to function together. These needs are visible in transport operations, logistics supply chains, and public administration, where responsibilities often cut across transport, digital, legal, and data-protection functions.

4.2 Shared skills bottlenecks and emerging mismatches

Cross-sector evidence indicates that CCAM-related skills gaps are structural in nature. They do not arise solely from a lack of training content, but also from constraints in how training is funded, delivered, updated, and formally recognised. Several bottlenecks recur across sectors and are likely to intensify as deployment expands. These bottlenecks are also interdependent, meaning that gaps in one part of the system can reinforce shortages and mismatches elsewhere.

In this report, skills mismatches are understood in terms of both timing and fit. Timing concerns whether skills supply becomes available when deployment requires it. Fit concerns whether the skills available correspond to the tasks organisations actually need to perform. In the case of CCAM, both dimensions are often present at the same time. Many organisations report that suitable candidates exist in principle, yet still face difficulties in recruiting, retraining, or redeploying staff at the scale and speed required.

These mismatches are not only demand-side problems. They also reflect the characteristics of the available and potential labour supply. Across the CCAM-ERAS evidence base, emerging occupations are often filled from adjacent educational and occupational backgrounds rather than from dedicated CCAM pathways. This means that the pace and quality of transition depend not only on employer demand, but also on whether current workers, jobseekers and learners have the underlying foundations needed to build CCAM-related competences, and whether flexible learning pathways exist to support that transition. This is particularly important because different occupations draw on different mixtures of formal education, work experience, and non-formal learning.

4.2.1 Pace mismatch between technology change and training cycles

A recurring bottleneck concerns the pace at which training systems adapt to technological change. In CCAM-related work, tasks can change quickly through software updates, system integration, and new operational requirements, even where job titles remain unchanged. Training systems, by contrast, often operate on slower and more formalised cycles, requiring time to revise curricula, update teaching materials, and align qualifications and assessment.

This mismatch is most visible in operational settings where partial automation is already altering work. Drivers and logistics workers may need new competences in system monitoring and safe handover, while maintenance roles increasingly require software diagnostics and sensor calibration. These needs often emerge during pilot and early deployment phases before formal training pathways are fully available. Organisations therefore rely heavily on informal learning, short courses, or vendor-led training, which can leave gaps in consistency, depth, and shared practice.

The problem is particularly evident in VET and public administration, although for different reasons. VET providers often face constraints in equipment, instructor time, and access to current systems, while many programmes remain oriented towards conventional vehicle technologies. In public administration, recruitment, training, and professional development cycles tend to move more slowly, and capacity varies considerably across national, regional, and municipal levels. The result is uneven readiness to assess new systems, which can in turn delay approvals and increase uncertainty for operators.

Workplace learning can mitigate part of this mismatch, but it cannot fully resolve it. Incremental learning on the job can support adaptation to new tools and procedures, but it does not substitute for broader foundational training. Employers are often able to train staff in specific applications, yet less well placed to provide the underlying concepts needed for emerging roles. This applies not only to digital skills, safety concepts, and cyber-risk awareness, but also to higher-skill roles in which progression depends on deeper learning over time.

4.2.2 Polarisation risk and incomplete reskilling pathways

A second bottleneck concerns the risk of polarisation in skills demand. Many emerging CCAM tasks combine technical and digital competences with judgement, coordination, and service awareness, but they are not filled from a single, ready-made talent pool. CCAM-ERAS evidence shows that CCAM occupations draw on diverse backgrounds, including technical, legal, governance, customer-service, transport, and driving profiles. This diversity is valuable, but it also means that transitions into CCAM roles depend heavily on the foundations workers and learners already possess.

Polarisation does not necessarily imply immediate net job loss, but it does imply uneven adjustment across both the existing workforce and the future skills pipeline. Some workers and learners can move into new roles with targeted support, while others face barriers that training alone may not overcome. Prior educational attainment, confidence with digital tools, and access to appropriate learning formats all shape the feasibility of transition. In some cases, tacit operational knowledge built through work experience transfers well into supervision and exception handling. In others, the role requires stronger technical, mathematical, or regulatory foundations that are less easily developed through short-term upskilling. CCAM-ERAS Deliverable 5.2 similarly concludes that no single educational pathway is likely to be effective across all CCAM occupations, and that different target groups require different combinations of formal, non-formal, and workplace learning.

Reskilling pathways therefore remain incomplete. Many current approaches assume that workers affected by task change can move into technical roles, yet this is not always realistic. Some transitions require prior competences that are not in place, while access to longer training programmes remains uneven, particularly where participation requires time away from work or where employers operate with tight staffing and limited margins.

Labour-market competition further deepens these mismatches. Several sectors compete for the same digital and technical profiles, with transport and logistics often facing stronger competition from higher-paying industries. Public authorities are affected in similar ways. As a result, relevant skills may exist in the labour market but remain difficult to attract, retain, or deploy in the roles where they are most needed.

4.2.3 Train-the-trainer constraints

A further bottleneck concerns those responsible for delivering training and updating learning content, including educators in higher education and VET, as well as in-company trainers and supervisors. In many cases, the issue is not the absence of relevant content in principle, but limited capacity to teach it, assess it, and keep it aligned with current systems and practices. Trainer capacity therefore directly affects both the speed and the quality of skills adaptation.

This bottleneck is also visible in the professional development of public authorities and supervisors. Regulators and inspectors need sufficient understanding of system behaviour, safety cases, and cyber risks, while supervisors need to understand system limits, escalation protocols, and safe monitoring practice. Structured upskilling opportunities remain uneven. In some cases, staff rely on ad hoc learning; in others, they depend heavily on external experts. Over time, this can create dependency risks and weaken internal capability.

Cross-sector cooperation can help reduce this bottleneck. Partnerships between education providers, industry, and public authorities can support faster curriculum updates, shared learning resources, and more relevant forms of practical exposure. However, such arrangements remain uneven and depend on stable incentives and sustained coordination. Without them, train-the-trainer constraints are likely to persist even where skills needs are already well understood.

4.2.4 Certification gaps and role ambiguity

Several emerging CCAM roles remain weakly defined, particularly in areas such as remote supervision, system monitoring, and structured exception handling. These functions appear across passenger transport, logistics, and controlled environments such as hubs and terminals. In many cases, the tasks themselves are already visible, but the corresponding competence standards remain underdeveloped. This creates practical difficulties for skills development. Employers may struggle to specify requirements for recruitment and training, training providers to design qualifications, and workers to understand progression routes. The result can be slower deployment of new roles and greater inconsistency in practice across organisations and countries.

In many cases, ambiguity is linked to accountability. CCAM systems distribute responsibility across operators, manufacturers, and service providers, and where this division remains unclear, competence requirements are harder to formalise. This is especially relevant in safety-critical tasks, but also in areas such as cyber-risk management and incident handling, where regulators and employers may still operate with different assumptions about who should hold which competence.

A further tension arises between formal qualification requirements and practical competence needs. Some roles depend on cognitive and judgement-based skills that do not map neatly onto existing credentials, while safety-critical work often requires formal recognition. This can slow recruitment, exclude otherwise suitable candidates, and create mismatches between regulatory expectations and operational practice. The issue becomes more pronounced in cross-border settings, where the lack of harmonised standards limits the portability of skills across markets.

4.2.5 SME capacity constraints and uneven adoption capability

Skills bottlenecks are reinforced by differences in organisational capacity, particularly for SMEs. Many smaller firms operate with limited training budgets, limited scope to release staff for training, and tighter capital constraints. This can create a self-reinforcing cycle in which training is needed to adopt new systems, while adoption is needed to justify investment in training. The effect is visible in both operational and support roles.

SMEs also tend to have more limited access to specialist expertise. Many do not have dedicated training staff and rely instead on external providers, informal learning, or subcontracted support for digital and cybersecurity functions. This can fragment responsibility for competence development, weaken consistency, and make it harder to build internal capability over time.

Supply-chain structures can deepen the problem. CCAM-related logistics often depends on multiple firms and subcontractors, which can dilute accountability for training and competence assurance across the service chain. As a result, skills gaps may persist even where larger firms invest in training, because smaller partners lack the capacity to follow at the same pace.

These constraints also contribute to regional divergence. Larger firms and established hubs are generally better placed to adopt early and attract scarce talent, while smaller operators and peripheral regions may lag behind. Skills shortages therefore become both a cause and a consequence of uneven deployment. This matters for the interpretation of macro employment scenarios, since adoption pathways depend not only on technical readiness, but also on organisational capacity.

4.3 Divergent timelines of skills demand

Skills demand is unlikely to evolve at the same pace across the CCAM value chain. Deployment is most feasible first in operational contexts with controlled conditions, established infrastructure, or a long history of automation. In passenger transport, this has so far been most visible in rail-based and segregated systems such as metro and light rail, where operational complexity is lower and environments are more predictable than in mixed-traffic road settings. In freight and logistics, automation is already being implemented in logistics nodes, ports, and warehouses, where confined environments allow clearer operational design and more standardised processes.

Even where vehicle automation remains limited at scale, enabling functions and institutions may face early shifts in skills demand. Digital infrastructure and ICT roles are already evolving through growing requirements in cybersecurity, data integration, and cloud and edge computing. Public authorities face near-term needs in understanding automated systems, interpreting technical documentation, and developing basic cybersecurity awareness, because these capabilities shape approval processes, trial conditions, and local deployment decisions. Education and training services also face early pressure to adapt curricula and training formats in response to the growing importance of digital, data-related, and systems-based competences across CCAM-related roles.

4.3.1 Short term (0-5 years)

In the short term, augmentation rather than replacement is the dominant pattern. Most roles change through task expansion and new safety-critical interactions with semi-automated systems. In passenger transport, this mainly means adding digital competences to existing roles, including system monitoring, first-line diagnostics, and safe interaction with ADAS and early ADS functions. CCAM-ERAS survey responses point to rapid upskilling of existing staff as a more immediate challenge than radical occupational change. A similar pattern appears in freight and logistics, where early connectivity and lower levels of automation increase demand for foundational digital skills, safety monitoring, and cybersecurity awareness.

Short-term demand nevertheless varies by operational context and by the degree of system integration already in place. In passenger transport and shared mobility, workshops repeatedly highlighted the importance of the transition phase, warning that weak preparation for semi-automated operation could create safety risks and undermine public trust. This places early emphasis on safe human-machine interaction, monitoring discipline, and the ability to respond quickly to malfunctions. The same applies to remote-operation and digital-coordination roles, which can be cognitively demanding because they combine sustained attention, responsibility for multiple vehicles, and intervention in rare but high-risk events.

In freight and logistics, short-term demand is shaped by the coexistence of traditional work practices with increasingly digital workflows. This has been described as a high-risk transition period, in which insufficient preparation for semi-automated systems may weaken both safety and worker confidence, even where full automation remains limited. At the same time, logistics nodes and warehouses already face more immediate effects through the automation of repetitive tasks and growing reliance on platforms, routing tools, and digitally mediated coordination. In manufacturing, early demand is concentrated in foundational digital skills, basic AI and data handling, and systems-integration competences linked to pilot deployment and early operational phases.

In sale, maintenance and repair, the short term already requires technicians to use OEM diagnostic platforms, understand sensor calibration and software-based fault identification, and work with connected and electric vehicle subsystems. These shifts can emerge before higher levels of automation are widely deployed, because service and repair are already affected by the increasing software content of vehicles and the spread of sensors and assistance systems.

Enabling sectors also face early shifts because they underpin deployment readiness. In ICT, short-term demand includes cybersecurity awareness, V2X support, data integration, and cloud and edge computing, alongside early AI-assisted operational practices. In public administration, immediate needs include understanding automated-driving concepts and safety, interpreting technical documentation and performance information, and coordinating across policy domains. In education and training, short-term priorities include curriculum development in digital and automation-related areas, educator upskilling, and modular learning formats that support reskilling and lifelong learning.

4.3.2 Medium term (5-10 years)

In the medium term, the emphasis shifts from incremental upskilling to clearer reconfiguration of roles. Demand rises for supervisory, coordination, and hybrid functions that sit between technical oversight and service delivery. This is also the period in which mismatch risks are likely to intensify, as training systems, certification practices, and organisational readiness may not adapt at the same pace as deployment.

In passenger transport, medium-term demand moves towards more specialised systems management, remote supervision, and service-related competences. The sectoral analysis links this to higher automation levels and stronger connectivity, with growing importance attached to situational awareness, social skills, and customer-oriented problem solving. It also points to moderate to large skills gaps in data analysis, systems integration, and customer-facing competences if training provision does not keep pace. CCAM-ERAS survey responses indicate rising demand for remote supervision, fleet coordination, and service quality management, while workshop discussions underline the need for clearer certification pathways and greater regulatory clarity for remote operators and system supervisors. The medium-term challenge therefore concerns not only technical training, but also role definition, responsibility allocation, and assurance of safe operational practice.

In freight and logistics, the spread of higher automation in controlled corridors and fleet operations shifts demand towards advanced integration, data analysis, and remote oversight. The sectoral analysis points in particular to the growing relevance of remote operators who intervene in operational exceptions. CCAM-ERAS survey evidence reinforces demand for remote supervision, systems integration, and exception-handling skills, while workshops highlight the continued absence of harmonised certification and professional standards for remote operators and fleet supervisors.

Medium-term developments also bring upstream and downstream vehicle sectors closer together in their skills needs. In manufacturing, demand shifts towards more specialised engineering and systems-management roles, with stronger emphasis on cybersecurity, data science, AI, machine learning, robotics, electrical engineering, and software engineering. Emerging roles include autonomous fleet supervisors, remote intervention specialists, and systems-monitoring operators, reflecting a gradual move from in-vehicle tasks towards remote command structures. In sale, maintenance and repair, medium-term change includes deeper software diagnostics, sensor calibration, cybersecurity awareness, and more advanced interaction with digital platforms and connected vehicle systems.

In ICT, demand intensifies as systems scale. The medium term brings greater need for AI systems engineers, cybersecurity specialists, and more advanced V2X and communications roles. The sectoral analysis also links this period to increased demand for high-reliability software, real-time system oversight, and cross-disciplinary competences that combine engineering knowledge with operational understanding of mobility contexts. Medium-term ICT demand is therefore not only a question of technical depth, but also of systems integration across fleets, infrastructure, and service platforms.

Several enabling sectors face similar medium-term pressures as CCAM deployment becomes more system-wide. Civil engineering increasingly requires expertise in digital infrastructure, real-time data systems, sensor networks, and cybersecurity, with greater emphasis on integrated infrastructure readiness. Public administration needs stronger capacity to assess safety cases, software updates, data governance, and cybersecurity measures, and to coordinate across transport, digital, legal, and data-protection functions. Insurance and risk-related services face growing demand for analytics based on vehicle and telematics data, cyber-risk assessment, and legal expertise related to liability and automated systems. These shifts may arise well before full automation becomes widespread, because they are driven by changes in risk allocation, data availability, and the organisation of mobility services.

4.3.3 Long term (10+ years)

In the long term, the analysis assumes broader deployment of highly automated systems. Skills demand becomes narrower but more specialised, with human roles increasingly concentrated in oversight, exception handling, safety assurance, and governance-related functions. In passenger transport and shared mobility, this points to growing demand for specialised technical expertise alongside customer-facing and trust-related competences. The sectoral analysis highlights non-routine skills such as complex problem solving, critical thinking, and adaptability for managing exceptions and rare failures, alongside stronger emphasis on cybersecurity, data governance, and privacy requirements for vehicle and passenger data.

Long-term skills demand in passenger transport is also shaped by the limits of automation in complex environments. Human intuition, ethical judgement, and the ability to question algorithmic outputs remain important safeguards, particularly in rare but high-impact situations where automated systems may fail. Human roles are therefore more likely to persist in assurance, intervention, and trust-related functions than in continuous driving tasks.

In freight and logistics, the long term is associated with the maturity of highly automated and driverless systems. This increases demand for advanced knowledge in maintenance, software management, and remote command. Relevant skills include AI, robotics, advanced communication systems, software engineering, navigation systems, and data analytics. Manual driving skills are expected to decline in direct importance, although prior operational experience may still be valuable in identifying system errors and managing interventions. Long-term demand in freight therefore combines deep technical capability with sustained operational oversight and structured intervention protocols.

In manufacturing, the long term is associated with deeper integration of safety architectures, sensor fusion, and high-performance computing. Demand shifts towards highly specialised digital expertise, including software engineering, intelligent navigation, and advanced data analysis. At the same time, transversal competences such as ethical decision making, regulatory compliance, complex problem solving, and adaptability become more important, reflecting the growing weight of assurance and governance functions in highly automated production ecosystems.

In ICT, long-term demand is linked to large-scale deployment and system-wide reliability. The sectoral analysis points to continued growth in cybersecurity, resilience engineering, and high-reliability software, alongside deeper expertise in continuous monitoring and system assurance. Demand also extends to roles responsible for integrated data systems and cross-sector interoperability as connected mobility ecosystems expand. As in other sectors, long-term ICT demand is likely to concentrate in specialised roles with wider system responsibility.

Enabling sectors show distinct long-term patterns linked to deployment scale. In public administration, stronger systems thinking, risk-based regulation, and continuous learning become more important as automated systems evolve through software updates and data-driven optimisation. This reflects a broader shift from regulating static products to overseeing dynamic systems. Education and training services will need continued institutional adaptability and sustained updating of educator skills, while micro-credentials, short courses, and work-based learning are likely to complement formal qualifications more systematically.

In civil engineering, long-term skills demand is increasingly linked to systems integration across infrastructures, including charging infrastructure, fleet management, automated depot and terminal operations, and vehicle-to-infrastructure data ecosystems. Relevant competences include automated charging systems, remote diagnostics, and lifecycle management of digitally controlled energy assets. Insurance and risk-related services likewise shift towards systems-level understanding and regulatory competence, as continuous software updates and in-service monitoring reduce the relevance of manual claims handling and paper-based processes while increasing the importance of analytical and legal-technical skills. Professional, scientific and technical activities show a similar long-term shift towards interdisciplinary competence combining technical assessment, governance understanding, and cross-sector coordination in support of CCAM.

4.4 Gap analysis and skills mapping

Building on the sectoral analyses and the cross-sector synthesis, this section makes the gap-analysis dimension of the foresight more explicit. It (i) maps the principal skills anticipated across the CCAM value chain, (ii) identifies where the strongest gaps between expected demand and available skills are likely to emerge, and (iii) considers how far current education and training provision appears positioned to respond. The purpose is not to quantify exact shortages, but to clarify the skills areas, occupational profiles, and parts of the training system most likely to face pressure as CCAM deployment scales, particularly as governance and compliance requirements for digitalised mobility systems expand in parallel.

4.4.1 Mapping anticipated skills across the CCAM value chain

The mapping below groups skills into clusters that recur across manufacturing, service/maintenance, operations (passenger and freight), infrastructure/ICT enabling functions, and governance. A consistent finding across policy and strategy sources is that CCAM capabilities increasingly depend on cross-disciplinary combinations, not only deep engineering expertise, but also operational supervision, data governance, security, and compliance practice.

Several regulatory and policy frameworks illustrate why these clusters matter. EU type-approval rules for automated driving systems explicitly reference roles such as “on-board operator (if applicable)” and “remote intervention operator (if applicable)”, reinforcing that higher automation does not remove human responsibility but redistributes it into oversight and intervention functions.[206] International vehicle rules have also institutionalised cybersecurity and software-update expectations: UN Regulation No. 155 (cybersecurity and cybersecurity management systems) entered into force in January 2021 and introduced audit-related provisions and ongoing risk assessment expectations for manufacturers and suppliers, while UN Regulation No. 156 formalises software update management.

These frameworks, while limited in applicability,[207] translate directly into demand for safety assurance skills, software lifecycle assurance, vulnerability handling, audit capability, and evidence management. This is especially the case for organisations responsible for approvals, operations, and post-market obligations.

National strategies reinforce the same clustering logic. Luxembourg’s national automated driving strategy (Automatiséiert Fueren 2028) explicitly frames automation-related skills through three profiles: Technology Experts, Field Operatives, and Facilitators, and links them to concrete measures such as continuous education modules, a certified skills label, and simulation platforms for training on real-world use cases with local authorities. This provides a practical template for structuring the skills map across the value chain: (i) engineering and system assurance, (ii) operational implementation and supervision, and (iii) governance, legal, risk, and human-factors functions.

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[206] Implementing regulation - 2022/1426 - EN - EUR-Lex

[207] The regulations are applicable in the 54 countries that are Parties to the 1958 Agreement, including the European Union.

Skill cluster	Main sectors/functions	Typical roles affected	Time horizon of strongest demand	Current readiness (EU-wide indicative)	Main gap type
Digital and systems literacy (incl. software-centric work practices)	Passenger and freight operations; maintenance/repair; public authorities; education/training	Drivers/dispatchers in transition; technicians; supervisors; local regulators/procurement teams	Short	Uneven baseline, linked to wider digital-skills gap	Training lag
Safety assurance, V&V, and evidence management (incl. safety cases, scenario-based testing, simulation)	OEMs/suppliers; technical services; approval authorities; operators	Safety engineers; test/simulation engineers; compliance/evidence managers; auditors	Short–medium	Concentrated in specialist organisations; hard to scale quickly	Supply shortage + training lag
Data governance and interoperability (incl. data access, API/interface governance, lifecycle data management)	OEMs; fleet operators; mobility service platforms; public sector data use	Data stewards; integration architects; compliance leads; platform engineers	Medium	Rising demand driven by connected-device data rules	Cross-domain capability gap
Cybersecurity and digital resilience (incl. cybersecurity management, vulnerability handling, secure updates)	OEMs/suppliers; ICT; operators; infrastructure; public authorities	Product security managers; cybersecurity engineers; auditors; incident-response leads	Short–medium	Structural shortage and compliance-driven growth	Supply shortage + institutional capacity gap

Software update and lifecycle assurance (incl. update governance, change control, toolchains)	OEMs/suppliers; maintenance ecosystems; fleet operators	Software release/update managers; diagnostics specialists; configuration/change-control roles	Short–medium	Increasingly required; uneven outside large firms	Training lag + supply shortage
Remote supervision, exception handling, and intervention roles	Passenger transport; logistics corridors; hubs/terminals; control centres	Remote intervention/supervision operators; fleet supervisors; control-room staff	Medium	Low standardisation; formalised only in some jurisdictions	Certification gap + role ambiguity
Systems integration across vehicle–infrastructure–service ecosystems (incl. V2X, cloud/edge integration)	ICT; infrastructure operators; road operators/cities; OEMs	Systems engineers; V2X specialists; infrastructure integration leads	Medium–long	Partial; depends on local ecosystem maturity	Cross-sector coordination gap
Human factors, customer-facing, and trust-related skills (incl. escalation communication, accessibility, ethics/AI literacy)	Passenger transport; shared mobility; public authorities; service platforms	Stewards/support staff; service managers; incident-communication roles; oversight staff	Short–medium	Under-recognised as “skills” in some technical roadmaps	Pathway gap

Table 11: Cross-sector skills mapping matrix for CCAM.
Source: CCAM-ERAS.

4.4.2 Main gaps between expected demand and available skills

The most significant gaps are unlikely to sit in generic labour supply alone; they concentrate in specific combinations of technical, digital, operational, and regulatory competences, and in the pace at which those combinations can be developed at scale. A first, structural gap concerns the availability of digital talent. EU Digital Decade targets include at least 80% of the population with basic digital skills and 20 million ICT specialists by 2030. The 2024 Digital Decade reporting cited by the Commission's digital-skills ecosystem shows only 55.6% of the EU population had at least basic digital skills, and that at the current pace the number of ICT specialists would reach ~12 million by 2030, well below the 20 million target.[208] Because CCAM demand draws heavily on software, data, connectivity, and cybersecurity capabilities, this baseline shortage increases competition across sectors and amplifies mismatch risks for transport operators, public authorities, and SMEs.

A second gap concerns cybersecurity capability, which is both scarce and increasingly mandatory. ENISA has explicitly stated that a lack of human resources with cybersecurity expertise is "a major obstacle" for connected and automated mobility security adoption. EU initiatives such as the Cybersecurity Skills Academy have been launched to address the cyber talent gap, reflecting the expectation that regulatory obligations (e.g., cybersecurity legislation and product-security requirements) will raise demand for qualified staff in both private operators and public administrations. For CCAM, the key issue is not only "more cybersecurity jobs," but more people able to embed security into safety-critical engineering and operational processes.

A third gap involves role definition and certification, particularly in remote oversight and intervention functions. Germany provides one concrete illustration of formalisation: its AFGBV ordinance sets explicit qualification requirements for the "Technische Aufsicht" role, including an engineering/technical qualification, successful manufacturer training, and an appropriate driving licence. Luxembourg's strategy likewise emphasises structured pathways (including certified labelling and simulation-based training) for operational profiles supporting automated services. Where such requirements are absent or inconsistent, recruitment and training become harder, skill portability decreases, and competence assurance can remain uneven across service chains and Member States.

4.4.3 Gaps in current education and training provision

Education and training provision relevant to CCAM already exists, but it remains unevenly distributed, often fragmented by discipline, and not yet scaled to the hybrid profiles CCAM requires. Formal higher-education provision is emerging in some locations. For example, Technische Hochschule Ingolstadt offers an English-taught B.Eng. in Autonomous Vehicle Engineering that explicitly teaches engineering sciences, mathematics/statistics, computer science, and specialised knowledge for automated and networked driving.[209] Such programmes help build deep talent pipelines for "Technology Expert" functions, but they cannot alone resolve short-term needs for incumbent workers, regulators, technicians, and supervisors.

[208] European Commission (2024) State of the Digital Decade Report https://digital-skills-jobs.europa.eu/en/latest/news/commission-publishes-2024-state-digital-decade-report

[209] Technische Hochschule Inglostadt, Autonomous Vehicle Engineering https://www.thi.de/en/electrical-engineering-and-information-technology/degree-programmes/autonomous-vehicle-engineering-beng

Rapid adaptation mechanisms therefore matter. The EU's Council Recommendation on micro-credentials establishes a common European approach and standard elements (e.g., learning outcomes, workload, assessment) to support portable, short-form learning across borders and sectors.[210] Micro-credentials and modular formats are particularly relevant where CCAM changes tasks faster than conventional qualification cycles, and where hybrid profiles need targeted "bridging" (e.g., safety for software professionals; data governance for operators; cybersecurity hygiene for technicians).

Trainer capacity and institutional readiness remain limiting factors for scaling provision. CEDEFOP notes that digitalisation and "Industry 4.0" trends imply different ways of teaching and require teachers and trainers to have increased IT and media competences; national measures (e.g., investments in digital infrastructure and teacher upskilling) are explicitly framed as complements to equipment upgrades.[211] In parallel, cybersecurity education has begun to develop common role/competence language through frameworks such as ENISA's European Cybersecurity Skills Framework (ECSF), which is intended to support recognition and training programme design. Similar "shared competence language" remains less mature for CCAM-specific oversight roles (e.g., remote intervention, operational supervision), which reinforces the need for interim competence frameworks and clearer occupational profiles at national/EU level.

[210] Council Recommendation of 16 June 2022 on a European approach to micro-credentials for lifelong learning and employability 2022/C 243/02

[211] Cedefop (undated) Digital education and upskilling of VET teachers https://www.cedefop.europa.eu/en/tools/timeline-vet-policies-europe/search/28145

Table 12: Emerging CCAM-related role clusters, competence needs, provision gaps and suitable training responses				
Role / role cluster	**Main competence need**	**Current provision**	**Main gap in provision**	**Most suitable response**
Remote supervision / intervention and exception handling	Situational judgement; anomaly detection; escalation protocols; interface fluency; safety responsibilities	Emerging national/company approaches; e.g., formal role requirements exist in some jurisdictions; strategic plans propose simulation and continuous modules	Limited harmonisation of learning outcomes; uneven certification/recognition; unclear entry/progression routes	Simulator-supported short courses; micro-credentials; interim competence frameworks; pathway into formal qualifications
CCAM policy, regulation, and market surveillance roles	CCAM/AI literacy; safety-case interpretation; cyber-risk awareness; data governance; procurement/oversight	CPD in public administration; general policy/law education; growing AI literacy obligation	Missing CCAM-specific layer; uneven institutional capacity; limited cross-domain training	Targeted CPD; short accredited modules; cross-domain workshops with technical services/industry
Software-enabled maintenance and diagnostics technicians	Sensor calibration; software-based fault identification; secure update practices; connected subsystems	VET and OEM tool-based training; update-management requirements increasing	Uneven equipment access and trainer capacity; curricula can lag behind vehicle software complexity	VET curriculum updates + vendor/OEM modules + work-based learning + micro-credentials
Cybersecurity and product/security assurance roles in mobility	Secure engineering; vulnerability handling; audit; incident response	Cybersecurity training exists; EU coordination via skills academy and ECSF	Persistent shortage and high competition; weak mobility-specific specialisation pipelines	Role-based pathways using ECSF; targeted sector modules; apprenticeships/industry-academia partnerships
Data stewardship / interoperability roles for connected fleets and	Data access governance; interface/API security basics; data quality; interoperability	Data/IT education; emerging compliance-driven enterprise training	Fragmentation across legal/technical domains; limited “translator” profiles	Mixed-track modules (legal + technical); micro-credentials; in-company applied projects

mobility services				
Fleet coordination and service quality roles (passenger and freight)	Platform-mediated operations; exception management; customer-service escalation; risk awareness	Operations/logistics training; in-company practices	Weak integration of CCAM-specific oversight tasks and digital workflows	Short modular upskilling; scenario-based exercises; organisational playbooks

4.4.4 SWOT summary for CCAM skills readiness

Strengths	Weaknesses	Opportunities	Threats
Europe has strong engineering, transport-operations, and regulatory capacity foundations, and a growing base of formal CCAM-relevant programmes (including dedicated automated-mobility degrees in some regions).	Digital and cybersecurity skills shortages are structural, and many CCAM roles require cross-domain integration that is difficult to develop through existing siloed pathways.	Micro-credentials and modular learning approaches can accelerate targeted upskilling/reskilling; while emerging national strategies show how to define profiles and deploy simulation-based training at scale.	If training provision and role frameworks remain uneven, CCAM deployment readiness may diverge across regions and organisational types (especially SMEs and local authorities), creating bottlenecks in approvals, operations, and assurance as compliance expectations expand.

Table 13: SWOT Summary for CCAM skills readiness
Source: CCAM-ERAS.

5 Recommendations for skills, education and transition governance

The following recommendations draw on the previous analysis to address current and future skills needs across the CCAM value chain. They are intended for EU and national policymakers, training providers, industry stakeholders, and public authorities as actionable guidance for preparing the workforce for Connected, Cooperative and Automated Mobility. The focus is on ensuring a smooth transition in the short, medium, and long term by focusing on hybrid skill profiles, cross-disciplinary training, regulatory preparedness, and the adaptation of vocational and higher education systems. The recommendations are structured by time horizon (0–5 years, 5–10 years, 10+ years) to align with the phased deployment of CCAM technologies identified in the foresight study.

Across all timeframes, the foresight findings indicate that CCAM deployment will demand new combinations of expertise. Workers will need to blend traditional technical know-how with digital and data-oriented competencies, forming hybrid technical–digital skill profiles. Training approaches must therefore break down silos and encourage cross-disciplinary skill sets, for example by integrating automotive engineering skills with ICT, data analysis, and cybersecurity knowledge. Institutions and regulators must be proactive and prepared – both in updating curricula and in equipping regulatory staff with the know-how to evaluate and oversee automated systems. The analysis has shown that without regulatory and institutional readiness, technology adoption can be slowed, or safety risks can increase. Finally, stakeholders must recognise that traditional vocational and higher education structures need to adapt rapidly. More flexible, modular learning (e.g. micro-credentials) and continuous upskilling will be essential to keep pace with CCAM's evolution. The following sub-sections outline guiding principles for CCAM skills policy and specific recommendations for the short, medium, and long term.

5.1 Framing principles for CCAM skills policy

Effective CCAM skills development requires close cooperation between industry, education providers, and public authorities. Partnerships across these sectors should be strengthened to align training content with real-world needs and share resources for faster curriculum updates. Joint industry-academic initiatives (e.g. co-design of courses, instructor exchanges) can ensure training keeps up with technological advances and operational realities.

A culture of continuous upskilling and reskilling is vital given the rapid pace of change. Policies should promote lifelong learning by supporting modular training options like short courses and micro-credentials, which allow workers to update specific competences on demand. Training formats must be flexible (e.g. online and work-based learning) to accommodate working professionals and enable quick skill refreshment as new CCAM technologies emerge.

Training programs and curricula should be oriented toward producing hybrid skill sets that combine technical, digital, and transversal competencies. Rather than educating narrow specialists, the emphasis must shift to cross-disciplinary proficiency – for example, blending mechanical engineering with software and data analysis skills, or combining ICT expertise with knowledge of transport operations. This principle applies across the value chain, from vehicle manufacturing and maintenance to traffic management and mobility services. By cultivating hybrid profiles, employers can fill roles that require understanding both physical and digital aspects of CCAM systems.

Policymakers should ensure that CCAM-driven changes in the job market do not leave portions of the workforce behind. An inclusive skills strategy means identifying workers in occupations likely to be disrupted (e.g. professional drivers, routine manufacturing and maintenance roles) and providing them with accessible pathways to new roles. This includes targeted retraining programs and bridge courses to help mid-career workers (especially those with lower formal qualifications) gain the digital and technical foundations needed for CCAM jobs. Supporting these transitions is critical to avoid skill polarisation, where demand rises for highly skilled hybrid profiles while others face unemployment or stagnation. Social partners and public employment services should be involved in designing reskilling pathways that acknowledge practical barriers (like time away from work or lacking prerequisites) and provide the necessary support (e.g. stipends, preparatory courses in basic IT).

Regulatory authorities and public bodies must be equipped with the knowledge and tools to keep up with CCAM innovations. This principle entails upskilling regulators, inspectors, and relevant public officials on automated systems, data governance, and cyber risks. Just as industry needs technical skills, regulators need technical literacy to evaluate safety cases, certify new vehicle functionalities, and update standards in step with technological progress. Embedding CCAM topics into the professional development of public servants (through workshops, updated guidelines, and staff exchanges with industry) will help ensure that regulations and oversight mechanisms support safe and timely CCAM deployment. A proactive regulatory approach, for example by learning from pilot projects and international best practices, can prevent delays and build public trust in new mobility services.

Vocational and higher education institutions should modernise curricula and teaching infrastructure to meet CCAM skill needs. This means updating courses to include content on vehicle automation, connectivity, artificial intelligence, and data analysis, as well as providing hands-on experience with relevant technologies (simulators, sensor kits, etc.). Investments are needed to equip labs and training centres with up-to-date tools (for instance, hardware and software for autonomous systems) and to train the trainers on the latest CCAM developments. Without increasing educators' capacity and industry exposure, even well-designed curricula may not be effectively delivered. Education authorities should encourage new interdisciplinary programs (e.g. joint degrees or specialisations combining automotive engineering and computer science) and strengthen links with employers to offer internships or apprenticeships in CCAM-related fields. Agile governance of educational programs is crucial, for example, faster accreditation of new courses and regular refresh cycles for curricula, so that formal qualifications remain aligned with industry demand.

At both European and national levels, efforts should be made to harmonise skill standards and certifications for emerging CCAM roles. The foresight analysis revealed that many new roles (such as remote vehicle operators, AV fleet supervisors, and data-driven mobility coordinators) are not yet clearly defined in terms of competencies or qualifications. Developing common frameworks, for instance, defining the core competencies for a "CCAM remote operator" and creating a certification or training curriculum for it, will help labour mobility and mutual recognition across countries. Clear definitions and standards also guide training providers in what to teach and give workers transparent career paths. European initiatives can facilitate this by exchanging best practices and possibly creating EU-wide occupational profiles or guidelines for CCAM-related jobs. In tandem, regulations (such as licensing or safety regulations) should be reviewed to incorporate these new role definitions, ensuring that accountability and skill requirements are well-aligned (e.g. determining what qualifications a safety operator must have). Harmonisation will support a truly European talent pool for CCAM, where skills and credentials are portable and trusted across the Union.

With these guiding principles in mind, the following recommendations detail specific short-, medium-, and long-term actions to operationalise them. They aim to be practical and targeted, recognising the urgent needs in the next few years as well as the structural changes required over the coming decade and beyond.

5.2 Short-term recommendations (0–5 years): preparing the transition

In the immediate term, CCAM deployment will largely involve pilot projects and incremental automation that augments human roles rather than fully replaces them. The priority is to rapidly upskill the existing workforce and put foundational measures in place to handle early CCAM systems safely and effectively. Short-term actions should focus not only on addressing current skill gaps with urgency, but also on creating the structures needed to guide a coordinated transition.

Some AV- and CCAM-specific training provision already exists, including specialised university programmes and company- or supplier-led training for functions such as safety driving and system supervision. However, this provision remains fragmented, unevenly distributed, and insufficiently standardised for wider deployment. Short-term action should therefore focus both on expanding access to existing provision and on closing the gaps that remain. Key recommendations are:

- **Launch targeted upskilling programs for current workers in CCAM-related roles**: To support early deployments, existing staff such as drivers, vehicle technicians, traffic operators, and fleet managers should receive focused training on the new tools and procedures CCAM brings. This includes courses on digital literacy, basic data handling, sensor technology, and system monitoring for those with primarily mechanical or operational backgrounds. For example, bus and truck drivers participating in automated shuttle trials might be trained in supervising autonomous driving systems and responding to handover requests. The foresight indicates that in this initial phase, roles expand to include new tasks like first-line diagnostics of ADAS/ADS or remote oversight of vehicles. Short, modular courses (potentially leveraging micro-credentials) can be an effective way to quickly impart these specific skills needed for safe human–machine interaction and to build confidence in using automation. Importantly, CCAM-ERAS survey feedback highlights that rapid upskilling of existing staff is seen as a more pressing challenge than wholesale role changes in the short term, so these programmes should be implemented without delay.

- **Embed CCAM fundamentals into existing training and education pathways**: Mainstream education and training systems should build on emerging provision and respond more systematically so that newcomers to the workforce are CCAM-aware from the start. In vocational education and training, update relevant curricula (e.g. automotive mechanics, ICT, logistics) to cover emerging competencies like working with advanced driver assistance systems, electric and electronic vehicle systems, connectivity (V2X), and cybersecurity basics. For instance, a car mechanic apprenticeship should now include diagnosing issues in vehicles equipped with sensors and software, not just traditional engine repair. At the higher education level, engineering and transport management programs should introduce foundational courses on automated mobility and data analytics. These updates ensure that graduates in the next 5 years enter the job market with at least basic CCAM-related skills, reducing the training burden on employers. Moreover, upskilling educators is a part of this effort – instructors need exposure to CCAM technologies to teach them effectively. Governments and institutions can use train-the-trainer workshops, industry secondments for teachers, and new teaching materials (developed in collaboration with industry or EU projects) to support this curriculum refresh.

- **Promote cross-disciplinary and hybrid skills through short courses**: Because CCAM jobs cut across traditional skill domains, short-term initiatives should encourage cross-disciplinary learning opportunities. For example, offer crash courses or certificates that bring together participants from IT and automotive backgrounds to learn each other's language – software engineers learning vehicle safety and mobility concepts, and automotive technicians learning coding, data interpretation or IT troubleshooting. These could be bootcamps or online programmes co-designed by automotive and ICT companies. The goal is to quickly build a cohort of workers who can act as "bridges" in their organisations, linking departments (and knowledge) that previously worked in silos. Stakeholders repeatedly stress the need for such hybrid profiles even in the very near term, particularly in areas like system integration and software-supported maintenance. Early investment in cross-disciplinary training will help prevent critical skills bottlenecks as pilot projects scale up.

- **Develop interim guidelines and certifications for new CCAM functions**: As automated mobility pilots expand, new job functions such as remote vehicle operators, teleoperators, and safety drivers are becoming more visible. Some role-specific training already exists, often led by manufacturers, operators, or specialised providers, but competence requirements and certification approaches remain uneven across countries and organisations. In the short term, it is therefore important to establish clearer interim competence frameworks and recognised training standards for these roles. Policymakers and industry associations should work together to define what skills and knowledge such roles require (drawing on input from early deployments) and endorse short-term certification courses. For instance, a basic training module for "remote operation of level 3–4 vehicles" could be developed, covering communication protocols, remote driving interfaces, emergency procedures, and legal responsibilities. Even if an informal certificate, it provides employers and workers a reference and can later feed into formal qualifications. This helps reduce role ambiguity, which the foresight analysis flagged as a problem: without clarity, employers struggle to hire and train for these positions. Early guidance will also support regulators in knowing what to expect in terms of operator competence when granting pilot permits. In sum, regulatory bodies (at national or EU level) should collaborate with industry to publish competency frameworks or guidelines for critical emerging roles by leveraging knowledge from demonstration projects and safety research.

- **Invest in CCAM awareness and training for public authorities**: Short-term preparedness isn't just needed in industry – local and national authorities involved in transport and vehicle regulation must also build capacity now. Agencies responsible for approving automated vehicle trials, licensing drivers, managing traffic management centres, or procuring advanced transit systems should initiate staff training on CCAM fundamentals. This might involve seminars on automated driving concepts, data protection and GDPR implications for connected vehicles, cybersecurity practices for transport infrastructure, and safety assessment for AVs. The findings note that public administration staff need understanding of automated driving technology, safety, and cross-domain coordination even in the short-to-medium term. Given that many public bodies currently lack this expertise, creating dedicated programs (potentially funded or organised by European platforms or national transport ministries) will pay off in smoother project approvals and better oversight. For example, a city transport authority could run workshops with experts from ongoing Horizon Europe CCAM projects to learn about best practices for safety management in AV pilots. Building this knowledge base early helps regulators and administrators become facilitators of innovation rather than unintentional bottlenecks.

- **Support SMEs and supply chain partners in skills adaptation**: Many small and medium-sized enterprises in the mobility and logistics sector will be touched by CCAM (for instance, smaller logistics firms implementing fleet management software, or auto repair shops dealing with new sensor-equipped vehicles). These smaller actors often lack the budget and internal expertise for training, raising the risk of uneven adoption. In the short term, targeted support for SMEs is crucial so they can keep up. This could include government-subsidised training vouchers for CCAM-related courses, free or low-cost access to online training modules, and industry association initiatives to pool resources for SME training. Larger companies in the automotive and tech value chain can also mentor or train their suppliers and contractors – an approach of "cascading knowledge" down the supply chain. The research highlighted that limited training capacity in SMEs can create a cycle where they delay adopting new systems due to lack of skills, but then miss out on acquiring skills because they haven't adopted the systems. Breaking this cycle with upfront support will ensure broader participation in CCAM deployment. For example, an auto OEM rolling out connected fleets could host training days for mechanics from independent garages on how to service these vehicles, ensuring maintenance competence is widespread. Likewise, public funding could be directed to SME-focused digital skill programs in the transport sector (building on models like Digital Innovation Hubs or the Pact for Skills in automotive), explicitly covering CCAM technologies.

- **Develop a CCAM skills and talent roadmap to coordinate short-term action:** Alongside immediate training and curriculum measures, policymakers, industry, education and training providers, and social partners should jointly develop a dedicated CCAM skills and talent roadmap. Rather than being an abstract strategy, this roadmap should translate short-term recommendations into a sequenced implementation plan with clear priorities, responsibilities, milestones, and indicators. It should identify priority occupations and skill gaps, clarify who leads on curriculum reform, upskilling, SME support, public authority training, and certification development, and establish a mechanism for review as technologies, regulation, and labour market conditions evolve. A roadmap of this kind would help avoid fragmented action, improve coordination across sectors and governance levels, and provide a practical bridge between pilot activity and longer-term workforce transformation.

Overall, the short-term recommendations concentrate on urgent upskilling and preparation. The measures above also start to address structural issues (education curriculum updates, SME inclusion, role standards) in a preliminary way, setting the stage for more comprehensive actions in the next phase.

5.3 Medium-term recommendations (5–10 years): managing reconfiguration and mismatch

Looking towards 2040, CCAM is expected to scale up significantly. In this period, many CCAM applications should move from pilots to more routine operations, and higher levels of automation (SAE Level 3 and 4 in specific domains) will likely be deployed commercially. The medium term will be characterised by more pronounced shifts in job profiles and the emergence of new occupations, as well as intensified demand for advanced technical and systems skills (e.g. AI, cybersecurity, systems integration) that go beyond the basics. It is also a period when initial skill gaps could widen into serious mismatches if training systems and policies do not keep pace. Thus, medium-term recommendations focus on scaling up and systematising skill development: moving from ad-hoc or pilot initiatives to institutionalised programs, standards, and investments that can handle the broader deployment of CCAM. Key recommendations in this time horizon are:

- **Establish formal qualification frameworks and certifications for new CCAM occupations**: By the mid-2030s, roles that are nascent today will solidify into common job categories – for example, autonomous fleet supervisor, remote operations manager, CCAM systems engineer, or mobility data analyst. Education and training authorities (in collaboration with industry and standardisation bodies) should develop recognised qualifications and certification pathways for these roles. This may involve creating new vocational training programs or specialisations (e.g. a vocational qualification for "Connected and Automated Vehicle Operations" that trains remote operators and fleet monitors), as well as new professional certifications (for instance, a certified course for cybersecurity specialists in transport systems). Having formal qualifications will not only professionalise these careers but also help employers recruit talent with the right skill sets. The foresight indicates a clear need for standardisation: CCAM-ERAS workshops and surveys pointed out that between 2030-2040, lack of harmonised professional standards for roles like remote operators could be a serious bottleneck. EU-level coordination can add value here – for example, by developing a European competence framework for CCAM that defines core skills for key roles, ensuring that a "remote driving operator" in one country has comparable training to one in another country. This harmonisation will facilitate labour mobility and trust in the qualifications. Furthermore, aligning these frameworks with regulatory requirements is crucial (if, say, operating an autonomous shuttle will require certification, that should be anticipated and built into the training programs).

- **Expand cross-disciplinary higher education and vocational programs**: To produce the hybrid experts needed, educational institutions should, in the medium term, roll out integrated programs that span multiple disciplines relevant to CCAM. This can take various forms: dual-degree or interdisciplinary master's programs (e.g. an MSc in "Autonomous Systems Engineering" blending computer science, automotive engineering, and human factors), new apprenticeship tracks (for instance, a "mechatronics and AI technician" apprenticeship combining elements of IT and automotive VET), or conversion courses for graduates of one field to acquire another (such as coding bootcamps tailored for mechanical engineers). The goal is to significantly increase the pipeline of talent with multi-domain knowledge. The analysis highlighted growing demand for profiles that combine engineering with operational awareness of mobility, or ICT expertise with knowledge of transport workflows – by the medium term, these should be mainstream offerings in the education system. The EU Pact for Skills in the automotive and mobility sector can be leveraged to encourage partnerships between universities, technical colleges, and companies in designing such programs. Additionally, curricula in these programs should be co-created with industry to stay relevant (e.g. including content on the latest sensor fusion techniques, or real case studies from city AV deployments). By 2040, every country should ideally have flagship training programs producing CCAM specialists who are versed in both the digital and physical aspects of automated mobility. This will mitigate the current shortage of engineers with hybrid digital skills and ensure Europe's talent pool supports competitiveness in CCAM innovations.

- **Invest heavily in training infrastructure and educator capacity**: The medium term is when initial pilot initiatives must evolve into scaled-up training capacity. Governments and training providers should allocate significant resources to modernise labs, equipment, and teaching tools for CCAM skills. For example, regional training centres might be established or upgraded with simulation facilities where transport operators can practice managing autonomous vehicles in various scenarios, or with state-of-the-art EVs/AVs for mechanics to train on. Funding (public or public-private) should also target the train-the-trainer bottleneck identified in the foresight: there must be enough instructors who are themselves skilled in the new technologies. Over the next decade, initiatives such as scholarships or incentive programs to attract ICT professionals into teaching, continuous professional development for VET teachers in automation and AI, and networks for trainers to exchange knowledge will be essential. By boosting the capacity of educators, it can be ensured that training supply can meet the rising demand. This also includes updating pedagogical methods – incorporating more e-learning, virtual reality (VR) training for hands-on skills, and remote labs – so that even smaller or resource-constrained institutions can deliver high-quality CCAM education. Public investment in these areas will pay dividends by preventing a lag where technology advances but training lags behind. Policymakers should consider earmarking portions of recovery and innovation funding (or using instruments like the European Social Fund+) specifically for CCAM skills infrastructure, focusing on regions or institutions that risk falling behind.

- **Implement large-scale reskilling programs to transition workers from declining roles**: As automation matures in this period, certain jobs (such as conventional vehicle assembly line work, or long-haul truck driving without automation support) will see reduced demand. It is critical to proactively manage the labour transition through structured reskilling and upskilling programs. Medium-term actions could include establishing transition training funds (possibly supported by industry contributions and public funds) that subsidise training for affected workers in new CCAM-aligned skills. For example, a programme could help a professional driver retrain as a "remote fleet supervisor" or a warehouse worker learn to oversee automated logistics systems. These programmes must be accessible (offering flexible scheduling, recognition of prior experience, and career counselling) since many mid-career workers may be apprehensive about switching fields. It is clear from the analysis that not all workers can easily leap into technical roles due to gaps in foundational knowledge. Therefore, these reskilling initiatives should include bridge courses (e.g. basic IT or math refreshers) to bring participants up to speed, and potentially a staged approach (first improving basic digital skills, then specific CCAM technical training). An example action could be an EU-wide "Automated Mobility Skills Conversion" program, which identifies the most at-risk occupations per country and offers tailored training tracks to move those workers into in-demand CCAM jobs, with the support of employers who pledge to hire from these pools. By the end of the decade, the aim is to have clear pathways for people to move from shrinking job areas to growing ones within the CCAM ecosystem, thereby minimising unemployment and ensuring a supply of experienced workers who bring valuable domain knowledge (like driving experience) into new roles.

- **Align regulatory frameworks with skills development needs**: In the medium term, many CCAM-specific regulations will likely be introduced or come into effect (for instance, detailed rules on automated vehicle safety assurance, data sharing mandates like the Data Act, or updates to driver licensing for automated systems). Policymakers should ensure that these regulatory changes explicitly consider and embed skills requirements and guidance. For example, if remote driving is permitted, regulations might stipulate that remote operators undergo certified training – thus formalising the need for such training programs. Another aspect is harmonising requirements across countries: for cross-border transport services using CCAM, mutual recognition of operator training or certification will be important. Regulators should collaborate through European forums to converge on essential competency standards. Additionally, regulatory bodies themselves will need to upgrade their internal skill sets to implement new laws effectively. It is recommended to set up dedicated CCAM knowledge units or working groups within agencies (at both EU level, like CINEA/EC, and national transport authorities) that continually train staff and exchange best practices on evaluating automated driving tech. By 2030, regulators should also start routinely engaging with academia and industry on foresight – essentially institutionalising a feedback loop where skill demand signals from industry and innovation pipelines inform regulatory workforce planning and vice versa. This ensures that as new policies roll out, there is parallel progress in preparing the people who must enforce or comply with them.

- **Foster knowledge-sharing networks and skill alliances**: To sustain momentum and avoid siloed efforts, medium-term policy should strengthen networks for CCAM skills at the European and national levels. An example would be creating a “CCAM Skills Alliance” – a platform where stakeholders (companies, training institutes, road operators, city authorities, etc.) regularly share updates on skill needs, successful training approaches, and emerging gaps. This could be an outgrowth of existing initiatives (like the automotive Skills Alliance under the Pact for Skills) with a dedicated CCAM focus. Similarly, sector councils or observatories for CCAM jobs could be established to continuously monitor labour market evolution and inform education providers of upcoming needs. The foresight shows that different sectors and regions will experience CCAM impacts at different paces, so a coordinated network can help diffuse learnings from front-runner areas to late adopters. Between 2030-2040, these networks should also produce updated skill foresight studies and scenario analyses, building on what was learned in the initial phase – essentially keeping the strategic outlook current (since CCAM technologies and adoption rates might change). Policymakers at EU level can support this through funding Erasmus+ partnerships, facilitating communities of practice, and encouraging Member States to include CCAM skills in their national skills strategies. The result will be a more synchronised approach where, for instance, a breakthrough in one country’s training programme (say, a new way to train safety drivers using VR simulations) can be quickly disseminated and replicated elsewhere, avoiding duplication of effort and accelerating overall preparedness.

In summary, the medium-term agenda is about scaling and integrating: scaling up the training ecosystem to handle greater demand, and integrating CCAM skill development into the fabric of our education, labour, and regulatory systems. By 2040, well-defined career paths in CCAM should be visible, a workforce that is much more digitally and technically proficient, and institutions that are significantly more agile in responding to technology-driven skills needs. These measures ensure that as CCAM moves from experimental to everyday, Europe's workforce and training systems move in tandem, averting severe skills shortages or mismatches during this crucial transition period.

5.4 Long-term recommendations (10+ years): sustaining specialised human roles

Beyond 2040, CCAM might be approaching full maturity in certain domains – envisioning deployments of highly automated (SAE Level 4/5) vehicles at scale, fully smart infrastructure ecosystems, and perhaps new mobility models that can only partially be anticipated today. In this long-term period, the nature of human work in transport and mobility will likely be substantially transformed. Many routine driving or control tasks could be fully automated, meaning the human roles that remain are concentrated in oversight, exception handling, ethical decision-making, and system optimisation. The skill profile of the workforce will thus become even more weighted towards advanced technical expertise on the one hand and strong transversal abilities on the other. Additionally, because technology will keep evolving, the concept of a "finished" education will be obsolete – continuous adaptation will be the norm. Long-term recommendations therefore focus on creating a resilient, future-proof skills ecosystem that can handle whatever new requirements arise, and on sustaining the human-centric elements in a highly automated environment. Key recommendations for the 10+ year horizon are:

- **Institutionalise continuous learning and skills forecasting**: In the long run, ensuring the workforce can continuously adapt is paramount. This calls for institutionalising mechanisms for lifelong learning – for instance, encouraging the adoption of personal learning accounts or regular training sabbaticals for workers to update their skills every few years. Governments might incentivise employers to allocate a certain percentage of time or budget to employee retraining annually, recognising that skills acquired in 2030 may need significant refresh by 2040. On a system level, regular skills foresight exercises (building on previous efforts) should be regularly embedded into policy planning, to update stakeholders on plausible future skill needs and adjust strategies accordingly. By continuously scanning the horizon (e.g. monitoring emerging technologies like 6G communications, quantum computing for traffic optimisation, or AI advancements) and linking them to education planning, Europe can avoid being caught off guard. In practice, this could mean maintaining a permanent CCAM skills observatory or task force that brings together labour market data, tech trend analysis, and stakeholder input to advise universities, training bodies, and policymakers. Such forward-looking capacity will help navigate the uncertainties of the post-2040 landscape, where entirely new occupations might emerge (or known ones vanish) with relatively short lead time.

- **Develop advanced and specialised skills programs**: As CCAM systems reach high sophistication, there will be a need for top-tier experts in areas like AI algorithm training for autonomous navigation, edge computing and cloud systems for mobility, cybersecurity for vehicle fleets, high-performance sensor fusion, and human–machine interface design for transport. The long-term strategy should invest in cultivating these advanced skills through specialised educational and R&D programmes. This might involve expanding PhD and research opportunities in CCAM-relevant fields (robotics, autonomous systems, etc.), creating centres of excellence that combine research with training (so that breakthroughs in safety engineering, for example, are quickly translated into training modules), and maintaining strong links between academia and industry to funnel talent into critical niches. Moreover, interdisciplinary doctoral schools or innovation hubs could be fostered – for example, programmes that produce graduates who are both AI scientists and transport engineers, able to push the boundaries of what CCAM technology can do. By the 10+ year mark, it should also be encouraged to exchange talents globally: attracting experts from other regions and sending trainees abroad to learn from leading deployments (since automated mobility will be a global domain). The emphasis here is on depth and innovation – making sure Europe has not just a workforce that can operate CCAM systems, but also one that can design, improve, and lead in CCAM technologies at the frontier.

- **Maintain a human-centric and ethical focus in skills development**: Even as automation becomes pervasive, the human element remains crucial as the final arbiter of safety and ethical decisions. Long-term training efforts must therefore include well-developed components on ethics, safety culture, and human oversight. Professionals overseeing fully autonomous systems (be it in control centres or in policy roles) should be equipped with frameworks for ethical decision-making, understanding of biases in AI, and the ability to manage rare but high-impact incident scenarios. For example, a future "mobility oversight officer" might need to decide when to intervene in an AI-driven service during anomalies – their training should cover not just technical responses but also legal and ethical principles. It is recommended that universities and professional bodies integrate ethics and social responsibility modules into all advanced CCAM-related curricula (similar to how medical education treats ethics as fundamental). Additionally, scenario-based training for emergency and exception handling should be standard for roles managing autonomous operations, ensuring that people remain capable of stepping in when automation fails. Emphasising transversal skills like complex problem-solving, critical thinking, communication, and emotional intelligence will be just as important as technical prowess. Essentially, the workforce of the future needs to be both highly skilled with technology and deeply grounded in human judgment. This human-centric skills approach will help maintain public trust in CCAM: users and citizens will feel more confident knowing that competent people are in the loop to guarantee safety and address concerns when needed.

- **Adapt and innovate in education systems governance**: From 2040 onwards, education and training systems themselves should evolve structurally in response to CCAM (and other emerging sectors). This may involve new types of educational institutions or credentials. For instance, micro-credentials and stackable certificates might become a primary mode for people to acquire skills over a lifetime, requiring quality assurance mechanisms and perhaps an EU-wide credit system so these credentials are widely recognised. Traditional boundaries between vocational and academic education could soften – hybrid learning pathways might allow someone to oscillate between work and study fluidly, which suits a fast-changing field like CCAM. Policymakers should be open to experimenting with and scaling up innovations in education delivery that suit long-term needs: virtual reality-based training simulations, AI-driven personalised learning for technical skills, and international collaborative courses (given CCAM's global nature) are some examples. Furthermore, keeping educators up-to-date will be a never-ending task; hence, long-term planning should include programs that continuously rotate educators through industry sabbaticals or certification renewals. The foresight mentions that education services will need institutional adaptability and sustained investment in educator skills to keep up with technology cycles. In effect, learning systems must become as agile as tech companies – iterating curricula frequently, partnering with industry on the fly, and embracing new pedagogies. Governments will need to ensure funding and incentive structures reward this adaptability (for example, providing grants for universities to overhaul programs in emerging fields, or performance metrics that value curriculum innovation).

- **Ensure inclusive access and regional cohesion in long-term skills development:** Finally, as CCAM becomes mainstream, it is vital to avoid a future where certain regions or groups are left without the skills to participate in the CCAM-enabled economy. Long-term policy should continue to bolster inclusivity – this might mean maintaining scholarship programmes or apprenticeships for youth in economically transitioning regions (like areas heavily dependent on legacy automotive manufacturing) to enter CCAM careers, so that the benefits of new mobility are widely shared. It also means addressing gender gaps and diversity in STEM fields related to CCAM from an early stage, to broaden the talent base. Additionally, special attention should be paid to SMEs and smaller regions in the long run: while major companies and tech hubs might flourish with CCAM, smaller actors will need ongoing support to not fall behind in skills. This could involve long-term funding for regional training centres of excellence, mobile training units that travel to remote areas, or online platforms that make world-class CCAM training available anywhere. The future vision should be one where regardless of location or background, individuals have the opportunity and resources to train for the new types of jobs that automated mobility will create. Maintaining this equity is both a social goal and economically sensible – CCAM will only reach its full potential if a broad base of society can work with and trust the technology. Continuous monitoring of skills supply and demand across different regions and social groups, using data-driven tools, can help target interventions where needed in the long term (a practice that could be coordinated by the aforementioned observatory or through EU agencies). In summary, no worker or region should be left behind in the shift to automated mobility, and planning for that inclusive outcome starts now and extends through the coming decades.

The long-term recommendations above are oriented toward resilience and foresight. They recognise that while every detail of the post-2040 landscape cannot be predicted, a flexible and inclusive skills ecosystem can be built.

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