Deliverable 1.3

Understanding the Gap of CCAM solutions deployment

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Executive Summary

The purpose of this report is to initially investigate current practices of Cooperative, Connected and Automated Mobility (CCAM) assets and services deployments, considering key enabling factors and integration aspects of CCAM into the transportation network. Studying the factors that hinder demonstrating the maturity at a large scale and assessing current CCAM solutions and deployments comparing them with the mobility needs, and requirements and needs of CCAM stakeholders is key to understand. SINFONICA project aims to overcome these gaps.

SINFONICA reviewed CCAM assets and services developed through research projects, focusing on their objectives and key aspects. This considered key enabling technologies, human-centred and non-technological enablers, and operator-centred enablers. From this, SINFONICA considers the following as key enabling technologies:

- Artificial Intelligence (AI),
- Connectivity (ITS-G5, Cellular, Wi-Fi),
- Simulation and Digital Twins,
- Navigation, Global Positioning System (GPS),
- High Definition (HD) Maps,
- Localization,
- Internet of Vehicles (IoV),
- Sensor technologies,
- Cybersecurity, and
- High performance edge and cloud computing

Enabling factors for CCAM operators and deployers are:

- the utilization of Traffic Management Centres
- remote control rooms,
- surveillance, and
- data management systems.

From a human-centred perspective, the key enablers are:

- collaboration schemes with technology providers and governments.
- Developing digital skills and familiarization with new technologies,
- meeting citizens' mobility needs (in terms of accessibility, availability, affordability, and acceptability),
- on-board presence of personnel,
- accelerating the adoption of digital technologies,
- legal and regulatory frameworks,
- public perception and acceptance,
- social and behavioural factors,
- business models, and
- economic factors.

Integration aspects of CCAM have also been considered, which has been developed into the SWOT analysis presented in the following table.

SWOT analysis for large-scale CCAM deployment

Strengths	**Opportunities**
• Cooperation • Connectivity • Automation • Mobility on Demand • Mobility-as-a-Service • Personalized services • Real-time data • Human error elimination • Free of driving task • Direct emergency response • Positive effect on industries/sectors	• Improved safety • Increased traffic efficiency • Improved infrastructure capacity • Improved quality of life • Environmental sustainability • Increased revenues and cost savings • Improved traffic management • Services optimization • First and last-mile services • New business models • New job opportunities • Investment and growth opportunities • Urban sprawl and improved urban planning • Inclusivity and Equity • Accessibility • People with mobility challenges independency • Personal time utilization
Weaknesses	**Threats**
• High initial cost • Limited deployment • Technology and safety gaps • Empty trips • Mixed traffic conditions until full-deployment • Ambiguous legal environment • Cyber-vulnerability • Negative effects on industries/sectors • Lack of familiarization with automation • Lack of trust • Lack of personal space • Need for digital skills	• Abrupt CCAM deployment • Safety implications • Increased energy consumption • Reduced traffic efficiency • Unexpected/unpredicted situations • Social gap enlargement • Public transport depreciation • Liability and accountability issues • Cybersecurity and privacy risks • Unwillingness for data sharing • Infrastructure challenges • Economic implications • Potential job displacement / Unemployment • Active travel discouragement • Non-acceptance

Effects and implications from large-scale CCAM deployment are also investigated focusing on the strengths and opportunities, and the weaknesses and threats. Cooperation, connectivity, automation, mobility on demand, Mobility-as-a-Service (MaaS), Personalized services, real-time data are recognized among others as strong assets of CCAM deployment, having the potential to lead to improved safety, increased traffic efficiency, improved infrastructure capacity, improved quality of live, environmental sustainability and more. On the other hand, high initial cost, limited CCAM deployment so far, technology and safety gaps, mixed traffic conditions until full-scale deployment are some of the weaknesses considered, accompanied with the risk to lead to abrupt CCAM deployment, safety implications, increased energy consumption, reduced traffic efficiency and more.

Gaps and barriers for large-scale deployment have also been examined focusing on four clusters,

- Information and Communication Technology (ICT);
- Safety;
- Users' acceptance;
- Regulatory and legislative framework.

The following table summarises the key gaps and barrier for each cluster:

Gaps and Barriers for each cluster

Field		Gaps and barriers
ICT	Connectivity & communication systems	Latency, IoV, Communication protocols, Security & privacy, Quality of Service, Financial cost, Lack of Infrastructure, Signal reliability
	Software & Hardware	Interoperability, System failure, Sensor performance, Big data, Processing speed and transfer, Data storage, Communication, Cost, Cybersecurity, Advanced algorithms (perception, data fusion, planning, decision-making)
	Navigation	Connectivity and Communication, Latency, Positioning, Mapping, Sensors, Advanced algorithms, Object recognition and avoidance, Data fusion, Path planning, Decision making, Safety performance
Safety	CAV performance and interactions	Common approach to CAV safety behaviour, Interaction between CAVs and other road users
	Technology	Interoperability, Standardisation, Communication systems, Fusion systems, Sensors, Big data, Recognition, Computation power
	Infrastructure	Cost, Traffic management, Vulnerability of infrastructure, Infrastructure requirements, Regulatory framework C
	Shareability	Risk of attacks, Personal space, Insurance issues, Suitability for children, Ownership, Accessibility

Field		Gaps and barriers
Users' acceptance	Perception	Perceived safety, Reliability and ethics, Socio-economic and demographics, Security and privacy, Personal data sharing, Distrust, Unaware of real benefits of CCAM, Unfamiliarity
	CAV performance and services	Transparency regarding intention of CAVs, Unwillingness to use if decision-making is not based on protecting the passengers, Liability of passengers, Unwillingness to use shared mobility
	Cost	Shared services cost, Individual vehicles cost
Regulatory and legislative framework	Certifications / regulations	Common framework for CCAM deployment, Certification model for cybersecurity & data privacy, Open data policies, Standards for CAV safety behaviour, System failure, Clear and fair distribution of obligations, culpability and liability, Insurance framework, Training for drivers of CAVs (type of driving licence), Immaturity of technology, Public trust
	Ethics	Standards for ethical and safety design principles of CAVs, Models and algorithms for ethical reasoning and choice, User acceptance

Based on the outputs of this report as well as the SINFONICA deliverables D1.1 – "Mobility needs and requirements of European citizens" and D1.2 – "CCAM Vocabulary and stakeholders needs and requirements for CCAM solutions", a taxonomy capturing the inter-relationships in the CCAM ecosystem is created. The taxonomy will constitute the basis for the SINFONICA Knowledge Map, where the inherent complex and strong inter-relationships between stakeholders and end-users needs, requirements, desires and expectations will be further detailed. Several instances of the taxonomy are presented herein.

Abbreviation list

Abbreviation	Description
5G	5th Generation
ACC	Adaptive Cruise Control
ADAS	Advanced Driving Assistance System
ADS	Automated Driving System
AI	Artificial Intelligence
AV	Automated Vehicle
CAD	Connected and Automated Driving
CAV	Connected and Automated Vehicle
CCAM	Cooperative, Connected, and Automated Mobility
C-ITS	Cooperative Intelligent Transport System
DDT	Dynamic Driving Task
DRT	Demand Responsive Transport
DSRC	Dedicated Short Range Communication
EC	European Commission
EU	European Union
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HD Map	High-Definition Map
HMI	Human Machine Interface
HSM	Hardware Security Module
ICT	Information and Communication Technologies
IoT	Internet of Things
IoV	Internet of Vehicles
ITS	Intelligent Transport Systems
LTE	Long-Term Evolution

MaaS	Mobility-as-a-Service
NAP	National Access Point
OBU	On-Board Unit
ODD	Operational Design Domain
PKI	Public Key Infrastructure
QoE	Quality of Experience
RSU	Road-Side Unit
SAV	Shared Automated Vehicle
SRIA	Strategic Research and Innovation Agenda
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TMC	Traffic Management Centre
V2I	Vehicle to Infrastructure communication
V2N	Vehicle to Network communication
V2P	Vehicle to Pedestrian communication
V2V	Vehicle to Vehicle communication
V2X	Vehicle to Everything communication
VANET	Vehicular Ad-hoc Network
VMS	Variable Message Sign
VRU	Vulnerable Road User
Wi-Fi	Wireless Fidelity
WP	Work Package

1. Introduction

1.1 Purpose and structure of this document

This document includes an overview of current practices of CCAM assets and services deployment realized through research projects, highlighting their objectives and key aspects. Enabling factors for CCAM deployment are recognized through the projects and literature review, focusing on key enabling technologies, enabling factors for the operators and deployers of CCAM solutions, human-centred and non-technological factors. Several integration aspects of CCAM are then discussed.

Focusing on large-scale CCAM deployment, the effects and implications are presented, and a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis is performed. Gaps and barriers towards large-scale CCAM deployment are then recognized, classified and presented. An overview of ongoing research in CCAM launched within 2021-2027 Horizon Europe is also captured in order to validate the outcomes of this research concerning the research gaps.

A structured taxonomy based on the findings of this research as well as on the outputs of D1.1 – "Mobility needs and requirements of European citizens" and D1.2 – "CCAM Vocabulary and stakeholders needs and requirements for CCAM solutions", is presented, aiming to capture the inter-relationships between end-users and stakeholders needs, requirements, goals and dilemmas, and the gaps and barriers towards large-scale CCAM deployment.

1.2 Methodology

An extensive literature and projects review has been carried out in order to identify the enabling factors, including key enabling technologies, human-centred enablers and operators-centred enablers, integration aspects of CCAM deployment, effects and implications of as well as gaps and barriers towards CCAM large-scale deployment. The output of this research was critically compared and assessed with stakeholders' needs and requirements, and goals and dilemmas as presented in SINFONICA's Deliverables D1.1 – "Mobility needs and requirements of European citizens" and D1.2 – "CCAM Vocabulary and stakeholders needs and requirements for CCAM solutions". The acquired knowledge and information, as well as insights from already existing taxonomies in the field of ITS and CCAM, was finally structured as a taxonomy aiming to capture the inter-relationships in the CCAM ecosystem.

1.3 Intended audience

The main target group for this Deliverable is all partners and stakeholders of the project as well as all the people, stakeholders, researchers and public administration that are interested in dealing with CCAM. As a public deliverable, it is also relevant to other CCAM-related research projects and deployments. It focuses on a common well-defined framework which will facilitate the engagement of all different stakeholders to get a comprehensive and concise view of the undergone and ongoing research in CCAM, the complex inter-relationships in the CCAM ecosystem, the effects and implications of and the gaps and barriers towards large-scale CCAM deployment.

1.4 Interrelations

This Deliverable will set the ground for the creation of the SINFONICA Knowledge Map which will be realized in WP4. The SINFONICA CCAM Taxonomy will be enriched with data derived from the surveys and participatory activities of the project in WP2 and WP3 with the aim to constitute a comprehensive knowledge base capturing the societal aspects towards large-scale CCAM deployment.

2. Current practices of CCAM assets and services deployment

CCAM is a rapidly evolving field with significant potential to enhance mobility and safety through the integration of automated technologies, connectivity and cooperative systems. As technology continues to improve, and standards and regulations are developed, it is expected to see increased adoption of CCAM technologies in the coming years. The CCAM ecosystem is a complex, multidisciplinary and interconnected network of stakeholders, technologies and infrastructure, all working together to create a safer and more efficient and sustainable transportation system.

The Strategic Research and Innovation Agenda (SRIA) is a comprehensive roadmap for implementing the CCAM Partnership and its objectives. Figure 1 provides an overview of the three phases in the CCAM Partnership to monitor the SRIA progress (CCAM Partnership, 2022).

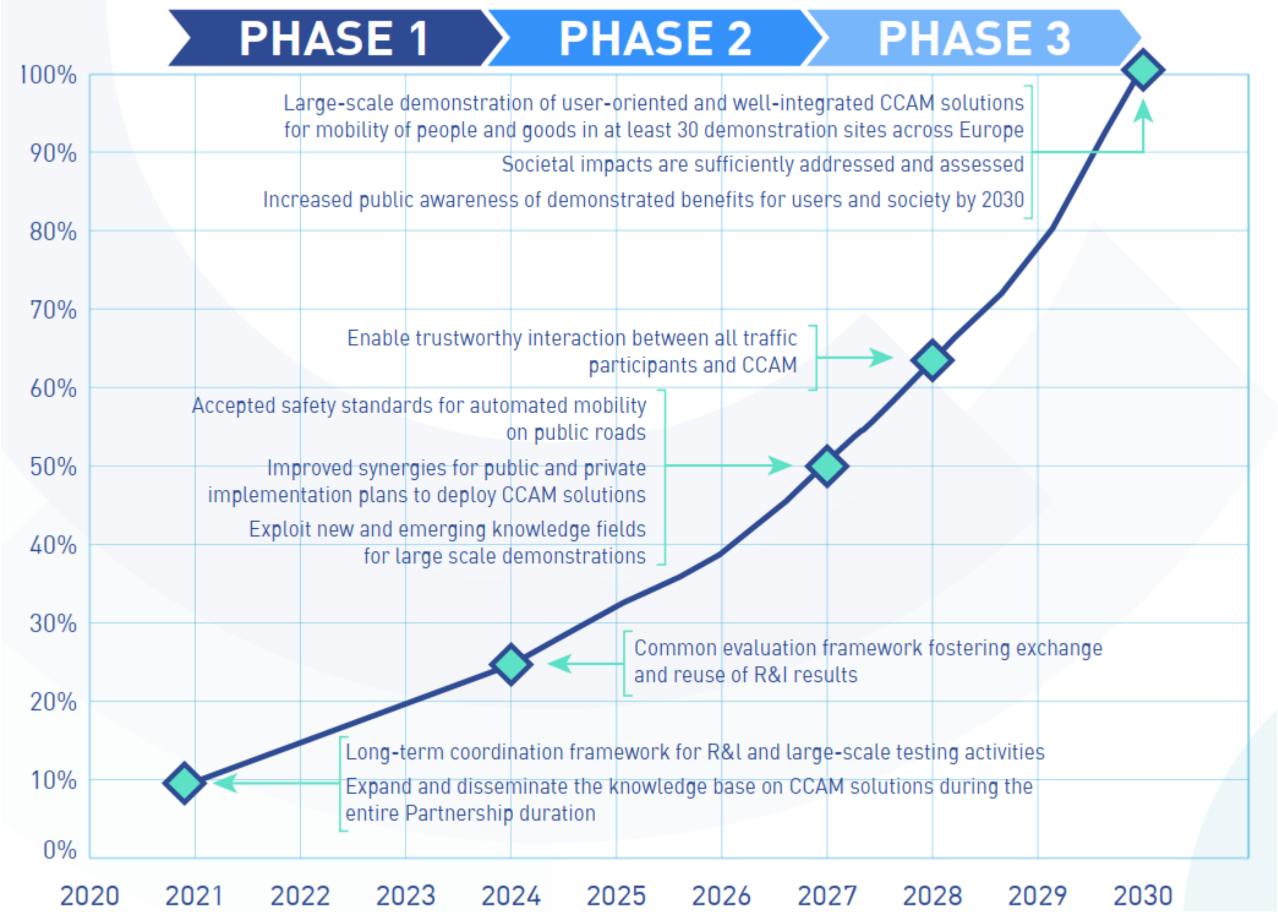

Figure 1: The three phases in the CCAM Partnership to monitor the SRIA progress (CCAM Partnership, 2022)

There are many projects underway to test and validate CCAM technologies in real-world settings in Europe. These aim to identify potential issues and barriers to implementation, as well as demonstrate the benefits of CCAM to stakeholders and the public. The following sections of this Chapter provide an overview of some important completed or undergone projects related to CCAM aiming to capture key enabling factors and integration aspects of CCAM, as well as gaps and barriers towards large-scale CCAM deployment.

2.1 Overview

The following Table 1 presents an overview of completed or undergone CCAM related research projects capturing their objective and key aspects.

Table 1: CCAM Research projects overview

Project title	Acronym	Duration	Objective	Key aspects	Website
5G for Connected and Automated Road Mobility in the European UninoN	5G-CARMEN	11/2018 – 7/2022	Leverage on the most recent 5G advances to provide a multi-tenant platform with the goal of enabling high levels of automation	- Develop an autonomously managed hybrid network, combining V2V and V2I DSRC with long-range V2N communications - Deployment of enabling technologies such as 5G New Radio, cellular V2X, and secure, multi-domain, and cross-border service orchestration system -	link
5G HarmoniseD Research and TrIals for service Evolution between EU and China	5G-DRIVE	0/2018 – 6/2021	Boost 5G harmonization and R&I cooperation between EU and China	- Trial and validate the interoperability between EU and China 5G networks operating at 3.5 GHz for enhanced Mobile Broadband and 3.5 & 5.9 GHz bands for V2X scenarios - Three large-scale trials in five cities to evaluate synergies and interoperability issues and provide recommendations for technology and spectrum harmonization - Research on key innovations in network slicing, network visualization and real-world deployment	link
5G Intelligent Automotive Network Applications	5G-IANA	6/2021 – 11 2024	Provide an open 5G experimentation platform for the automotive sector	- Specify and implement a repository environment for Network Applications and Virtual Network Functions to ease the design and chaining of automotive services to be integrate with 5G-PPP open repositories	link

Project title	Acronym	Duration	Objective	Key aspects	Website
				- Define, implement and trial CAD relevant use cases to assess and validate the platform	
AUTOmated driving Progressed by Internet Of Things	AUTOPILOT	1/2017 – 2/2022	Develop IoT-architectures and platforms to enable automated driving	- Deployment, test and demonstration of IoT-based services in five driving modes – urban driving, highway pilot, automated valet parking, real-time car sharing, and platooning – in real traffic situations - Create and deploy new business products and services for automated driving vehicles - Contribute to the IoT standardisation	link
Autonomous Vehicles to Evolve to a New Urban Experience	AVENUE	5/2018 – 4/2022	Deploy and validate via full-scale trials of the usage of Autonomous Minibuses as a complement to public transport in urban and suburban regions to pave the way for full-scale introduction of disruptive door-to-door services and “Mobility Cloud” strategies	- 4 city demonstrators and 2 city replicators of electric mini-buses deployment in urban areas of low or medium demand, and low or medium accessibility - Data fusion, data & visual analytics, communication and IoT technologies deployment	link
Artificial Intelligence based cybersecurity for connected and automated vehicles	CARAMEL	10/2019 – 3/2022	Proactively address modern cybersecurity challenges applying advanced Artificial Intelligence (AI) and Machine Learning (ML) techniques and seek methods to mitigate associated safety risks.	- Cybersecurity solutions for autonomous mobility, 5G connected mobility, electromobility, Remote Control Vehicle (RCV)	link

Project title	Acronym	Duration	Objective	Key aspects	Website
Connected Autonomous Vehicles Forth	CAVFORTH	2019-2027	Deliver a scheduled passenger service deploying Level 4 full sized buses	- Deployment of ADS consisting of AI controller and sensing system deploying sensors and GPS - Digital Twin of the entire route enabling the rapid development and roll out of the ADS, and digital model of physical bus able to take inputs from the simulator - Safety case integrating safety and cyber relevant standards - Fleet of 5 Level 4 full sized buses	link
Cities demonstrating cybernetic mobility	CITYMOBIL2	9/2012 – 8/2016	Implement and demonstrate large-scale pilots of Automated Road Transport System platforms in different cities, in order to validate the process and to evaluate the technical and socio-economic performance of automated transport systems in urban environments.	- 3 large-scale demonstrations & 4 small-scale demonstrations of automated road transport systems - Address the main barriers & remove the uncertainties which hamper procurement and implementation of automated systems - Proposal for a common legal framework to certify automated transport systems	link
Accelerating C-ITS Mobility Innovation and deployment in Europe	C-MOBILE	6/2017 – 11/2020	Develop a common overall system architecture for C-ITS services and demonstrate C-ITS solutions in large-scale in urban and extra-urban environments by providing C-ITS services and service bundles to several end-users' groups, including Vulnerable	The C-MOBILE architecture is intended to: - address the common challenges of secure, private and reliable communication for C-ITS, - provide a standardised mechanism for large-scale service delivery of C-ITS applications and - ensure compatibility between existing pilot sites and serve as baseline for uptake in new locations	link

Project title	Acronym	Duration	Objective	Key aspects	Website
			Road Users (VRUs), across various transport modes		
“AV-Ready” transport models and road infrastructure for the coexistence of automated and conventional vehicles	CoEXist	5/2017 – 4/2020	Prepare the transition phase during which automated and conventional vehicles will co-exist on cities’ roads	- Extension of existing microscopic traffic flow simulation and macroscopic transport modelling tools to include different types of CAVs - Develop tools to assess the impact of CAVs on traffic efficiency, space demand and safety, and provide guidance on infrastructure development - Models validation with real-life AVs on public test tracks in 4 cities	link
C-ROADS Platform	C-ROADS	2/2016 – 12/2022	Cooperation on a holistic level in order to cover all dimensions linked with the deployment of C-ITS. National pilots to form basic elements for a later pan-European C-ITS implementation.	- Harmonization, implementation and demonstration of C-ITS deployment in Europe - Cross-site testing in order to achieve transnational interoperability and ensure cohesion of C-ITS deployment in EU with regards to large-scale deployment	link
Drive2TheFuture	Drive2TheFuture	5/2019 – 10/2022	Development of a concise approach towards enhancing user acceptance for the upcoming invasion of automated vehicles	- Model the behaviour of the automated vehicle and forecast development of acceptance - Define the optimal HMI for the different clusters of users, transport modes and levels of automation - Identify training needs of all user categories and define training tools and material - Perform demonstration pilots with different tools and testbeds, i.e., VR/AR simulations, driving simulators, real-life environments	link

Project title	Acronym	Duration	Objective	Key aspects	Website
Future Automated Bus Urban Level Operation Systems	FABULOS	1/2018 – 3/2021	Prototyping and testing of smart systems that are capable of operating a fleet of self-driving minibuses in urban environments.	- Pre-Commercial Procurement to steer development of solutions to meet pilot cities' needs - Three selected prototypes, based on 9 functional and 3 non-functional requirements, tested as small fleets of automated buses in 5 cities	link
High Precision Positioning for cooperative ITS applications	HIGHTS	5/2015 - 4/2018	Production of an advanced highly-accurate positioning technologies for C-ITS	- Combination of 'traditional' satellite systems with on-board and infrastructure-based wireless communication technologies - Development of an enhanced European-wide positioning service platform built on Local Dynamic Maps	link
ICT Infrastructure for Connected and Automated Road Transport	ICT4CART	9/2018 – 8/2021	Design, implement and test in real-life conditions a versatile ICT infrastructure enabling the transition towards up to 4 level of automation.	- Identify functional and technical connectivity requirements - Implement and test a standards-based distributed IT environment for data aggregation in an automated and interoperable way, leveraging also cloud technology - Implement cyber-security and data protection privacy mechanisms - Improve localization and adapt tools ang algorithms for data fusion - Validate and demonstrate the ICT infrastructure	link
Road Infrastructure ready for mixed vehicle traffic flows	INFRAMIX	6/2017 – 5/2020	Prepare the road infrastructure with specific affordable adaptations and support it with new models and tools to accommodate	- Design and develop elements for the digital road infrastructure - Adapt and upgrade elements of the existing physical infrastructure - Develop traffic flow models integrating real vehicle algorithms and human driver behaviour to	link

Project title	Acronym	Duration	Objective	Key aspects	Website
			the step-wise introduction of automated vehicles	examine mixed traffic scenarios under various penetration rates of different levels of AVs - Design a scheme for classifying road infrastructure into "automation-appropriate" levels	
Managing Automated Vehicles Enhances Network	MAVEN	9/2016 – 8/2019	Provide solutions for managing automated vehicles in an urban environment with signalized intersections and mixed traffic	- Solutions development for managing Level 4 AVs at (urban) signalized intersections - Roadmap for the introduction of future traffic management systems	link
Shared automation Operating models for Worldwide adoption	SHOW	1/2020 – 12/2023	Support the deployment of shared, connected and electrified automation in urban transport, to advance sustainable mobility.	- Real-life urban demonstrations in 20 cities across Europe - Integration of fleets of automated vehicles in public transport, demand-responsive transport (DRT), Mobility-as-a-Service (MaaS) and Logistics-as-a Service (LaaS)	link
Transition Areas for Infrastructure-Assisted Driving	TransAID	9/2017 – 2/2021	Traffic management procedures and protocols to enable smooth coexistence of automated, connected and conventional vehicles, especially in Transition Areas	- Simulation to find optimal infrastructure-assisted management solutions to control connected, automated and conventional vehicles at Transition Areas - Development of communication protocols for the cooperation between connected/automated vehicles and the road infrastructure	link
Automated Urban Parking and Driving	Up-DRIVE	1/2016 – 12/2019	Development of an automated valet parking service for city environments	- Advances in 360° object detection and tracking employing low-level spatio-temporal association, tracking and fusion mechanisms - Advances in localization and mapping in large-scale, semi-structured areas	link

2.2 Enabling factors for CCAM deployment

Based on the projects and literature review, several enabling factors are recognized and classified as key enabling technologies, enabling factors for operators/deployers of CCAM solutions, human-centred and non-technological enablers.

2.2.1 Key enabling technologies

Transport sector, during the last decade, has a need to address socio-economic challenges that arise as the environment gets more and more complex and competitive. It will be achieved if novel quality standards are created through Research and innovation (R&I). The Strategic Transport Research and Innovation Agenda (STRIA), was adopted in 2017 by the European Commission, and states the main R&I priorities intending to clean, connected and competitive mobility, within seven road maps, one of which is associated with cooperative, connected and automated transport (European Commission, 2018b). STRIA deployment needs to be supported by appropriate mechanisms which also prioritize R&I in transport.

Apart from STRIA, a holistic information system, funded under the Horizon2020 Work Programme 2016-17 on smart, green and integrated transport, called TRIMIS (Transport Research and Innovation Monitoring and Information System). This provides an assessment of transport R&I capabilities, and capacities and pioneer ideas in the field, informs and develops analytical tools for the European transport system, has also been deployed (Tsakalidis et al., 2018). TRIMIS is utilized as a transport R&I database where a regular reporting on evolving and future technologies is created. Respectively, several key enabling technologies are recognized and reported.

Artificial Intelligence

Artificial Intelligence (AI) is fundamental for the decision-making process of automated and connected systems such as Connected and Automated Vehicles (CAVs). It includes the sub-processes of learning, reasoning and behaving (Hakak et al., 2023). AI makes use of heterogeneous data, analyses them, and utilizing various prediction algorithms, provides information related to road, traffic or weather conditions, supporting smart driving and leading to optimal decisions for smoother, safer and more efficient CAV routes. Furthermore, computational intelligence and big data processing techniques can provide efficient and novel applications such as automated accidents detection systems, by analysing traffic flow data collected from multiple sources (Ozbayoglu et al., 2016), while vision-based AI, enhances solutions in the fields of obstacle recognition and avoidance (Davies, 2019). A recently initiated EU-funded project, ALTHENA, opts to build explainable AI (XAI) in CCAM frameworks, in terms of data, models and testing, while another recent project, AI4CCAM, will deploy and test AI-based scenarios for vulnerable road users anticipated behaviour in different traffic conditions.

Simulation & Digital Twins

A traffic simulation is a virtual replication of real traffic scenarios. Commonly, in user-friendly digital environments, called simulators, a transport planner can model road links, intersections, bus depots and public transport stations, among other infrastructure, and insert real-life traffic data and traffic signal rules and programs (PTV Group, 2023), in order to analyse possible outcomes of an intervention in a transportation network; this could be a road construction, a one-way implication, a new bus route, a parking lot, or even a new means of transport as it is the case of CAVs. The simulator is able to provide a detailed overview about multimodal traffic flows and the interaction of different vehicles and road users, in many different scenarios. This way, a planned intervention in the transport network of a city and its possible effects can be tested and analysed before being implemented in the real world. Digital twins take simulation one step further by creating a virtual representation of an actual vehicle or system (TWI, 2023). This virtual representation includes all of the sensors, controllers, and other components of the vehicle, enabling real-time monitoring and control of the system. Digital twins can be used to optimize the performance of the vehicle, identify potential issues before they occur, and improve maintenance and repair process.

EU-funded projects such as CoEXist introduced simulation procedures to analyse the impacts of automated mobility co-existence with conventional vehicles, so that corresponding authorities could act accordingly at any level of CCAM integration in conventional traffic, in other words prepare the transition towards a new mobility perception. Existing microscopic traffic flow simulation and macroscopic transport modelling tools were extended in order different AV and CAV types and vehicles with different automation levels to be included.

Navigation

Navigation applications, whose goal is to optimally calculate a source-to-destination route, are considered a critical component of a CAV. Some key features of navigation are optimal path detection, safer route planning, as well as obstacle detection and avoidance (Jing et al., 2022). Motion control, lane detection, and path planning algorithms and discrete kinematic modelling are the backbone of navigation applications. Navigation of CAVs is prone to uncertainties, either static ones like a vehicle traversing a tunnel, or dynamic ones, such as weather conditions which could affect image quality; rain, for example, could add noise and decrease a sensor image quality and decrease navigation quality (Hakak et al., 2023).

GPS (Global Positioning System) / Galileo

Global Positioning System is one of the pioneer technologies in the field of outdoor navigation, and is the basis of all navigation application conventional cars use up to today. Its deliverable error, can vary – depending on what correction is applied. It can be down to 1m (Galileo) but could be as high as 100 meters in dense urban environments (Paiva et al., 2021) and even after being improved, should not be used as the single source of location information in applications such as pedestrian navigation in cities with skyscrapers, where it proves to be unable to find the exact position of the mobile phone of the user.

HD (high precision) maps

High precision maps are tools that opt to improve localization functionality, which is a key element of automated driving as well as a supportive tool of planning and control. HD maps can operate as a database of road networks, helping localization of the ego vehicle (a vehicle carrying sensors – perceivers of the external environment). Vehicle’s position in 3D environment along with map data can create the perception module for modelling and, consequently, the planning and control module that actually is involved in decision making. Most commonly, a HD map is made of 3 consistently geo-referenced layers; the road network model, the HD lane model and the HD localization model. (Liu et al., 2020). Some notable map providers that could be referred to, are and.com, HERE.com and Baidu.com.

Localization/Positioning

Localization is a critical component of the CAV overall system that enables navigation. It uses various sensors and data sources to accurately determine the location of a vehicle in relation to its surroundings. One of the key challenges in developing effective localization technology for CAVs is the need for extremely high levels of accuracy and precision. To address this challenge, sensor fusion techniques are widely deployed, combining data from multiple sources to improve accuracy and reliability.

Connectivity

- LTE [3G/4G/5G]

LTE is a cellular access system for mobile communication which is built based on existing mobile technologies such as the Global System for Mobile Communications (GSM) and the Universal Mobile Telecommunications System (UMTS), but is characterized by better bandwidth capacity and transfer speeds. Public transport utilizes LTE to deliver data relevant to passenger capacity and vehicle performance to network administrators, for real-time surveillance, remote management, rail signalling etc. This type of cellular networks can pave the way to overcome difficulties associated with limited satellite visibility, due to their indoor positioning capabilities; their accuracy can be as high as 10 meters for a bandwidth between 10 and 20 MHz (del Peral-Rosado et al., 2017).

5G is, as its name indicates, the fifth generation of cellular systems which uses mm-wave technology as a building block. Until now, it is the latest cellular standard developed by 3GPP (3rd Generation Partnership Project). Data rates up to 20 Gbps are supported by 5G, whilst the minimum latency reaches 1 ms (Ojanperä et al., 2019). Their aim in what concerns vehicular communication and automated driving, is to provide extremely low end-to-end latency, enhancing connectivity between vehicles, infrastructure and other devices as well as high data rate and capacity, and as a result they can handle and cover dense networks with many elements located close one to another (Tahir & Katz, 2021). Eco-routing, for example, can be achieved by utilizing vehicular edge networks which are based on 5G cellular systems (Pervej et al., 2020). Apart from that, the low and ultra-low latencies that 5G cellular networks provide, can enhance CCAM services such as Proximity Service (ProSe) which generates information of awareness about devices, other vehicles or objects located in proximity to a CAV, and it is able to detect a moving vehicle on the road ahead (Hakak et al., 2023). Furthermore, due to the wide range it can support, 5G can operate as a 'roof' that hosts every existing access technology. Via a method called network slicing, each application is included in a different slice, since each of them has different needs; e.g., reliable message transmission and low latency are key factors for safety applications while mission critical systems must be able to efficiently handle huge amounts of data being transmitted simultaneously. This technique can optimize integrity and security of vehicular networks (Khan et al., 2022).

EU-funded projects such as 5G-CARMEN showcased how 5G can enhance automated driving, leading towards Level 4 automation. More precisely, cooperative manoeuvring (lane-change manoeuvres and in-lane manoeuvres) as well as situation awareness were thoroughly examined in project's scenarios since they could make efficient use of 5G features and qualities over previous network generations, such as 5G-NR (New Radio), Mobile Edge Computing (MEC) and Edge-to-Edge Service Orchestration. In another European project, 5G-IANA, an open 5G experimentation platform will be created, providing an opportunity for the third-party stakeholders such as Small Medium

Enterprises (SMEs) to deploy and test their services. A number of different Network Management and Service Orchestration (MANO) frameworks will be deployed in On-Board Units (OBUs), Road-Side Units (RSU) and data centres/cloud resources, enhancing the opportunity of end-to-end networking across the above domains, as well as taking full advantage of both the two different types of nodes in the infrastructure, OBUs and RSUs (Sourlas et al., 2021).

- ITS – G5

ITS-G5, this is a European standard used for vehicular communications with a range of 1 km that can operate in urban, suburban and urban environments, serving AV with a maximum relative speed of 100 km/h, while its bandwidth ranges between 10 and 20 MHz. It exploits the Geo-networking protocol for V2V and V2I communications (Tahir & Katz, 2021).

The above connectivity technologies are usually implemented altogether in a single, hybrid, environment. Tahir & Katz (2021), e.g., deployed a real-time ITS system providing advanced road weather services. 5GTN (5G test network) seemed to perform slightly better than ITS-G5, both when examined separately and in a hybrid vehicular networking environment. More precisely, 5GTN was more effective in terms of V2I, while in V2V communication, both standards performed well. The EU-funded project HIGHTS aims to mitigate the issue of inaccurate position information of Cooperative Intelligent Transport Systems (C-ITS), which are provided by satellite-based positioning systems such as GPS or Galileo.

- Combined solutions

The combination of GPS with on-board sensing and infrastructure-based wireless technologies like ITS-G5, Bluetooth or LTE, utilizing a series of enhanced localization algorithms, can lead to optimal position estimation (below 25 cm). Traffic safety of vulnerable users as well as automated driving and platooning are considered the most challenging use cases.

- Wi-Fi (IEEE 802.11)

Connected / Autonomous vehicles require significant updates be it to software or to digital maps. This could be done over the air using GSM / 5G technologies but there may be a preference to do this at a depot or parking facility, using Wi-Fi.

Sensor technologies

During the last decade, sensors have been utilized in a sophisticated way, in the context of driving assistance systems. More precisely, adaptive cruise control (ACC), traction control (TC), lane departure warning and electronic stability control have been implemented making proper use of sensors, paving the way to automated driving (Fleming, 2013). On the other end of infrastructure, street lights and traffic signals, if smart, can be equipped with sensors which can help them make optimal, intelligent decisions for real time cases and optimize traffic (Paiva et al., 2021). CAVs utilize on-board heterogeneous intelligent sensors of 3 types; detection sensors (e.g., ultrasonic sensors), ambient sensors (e.g. GPS/GNSS), backscatter sensors (infrared cameras, LIDar). Ambient sensors can communicate within a long rage but have limited bandwidth, while backscatter ones can provide more detailed information about the external environment (Jameel et al., 2019).

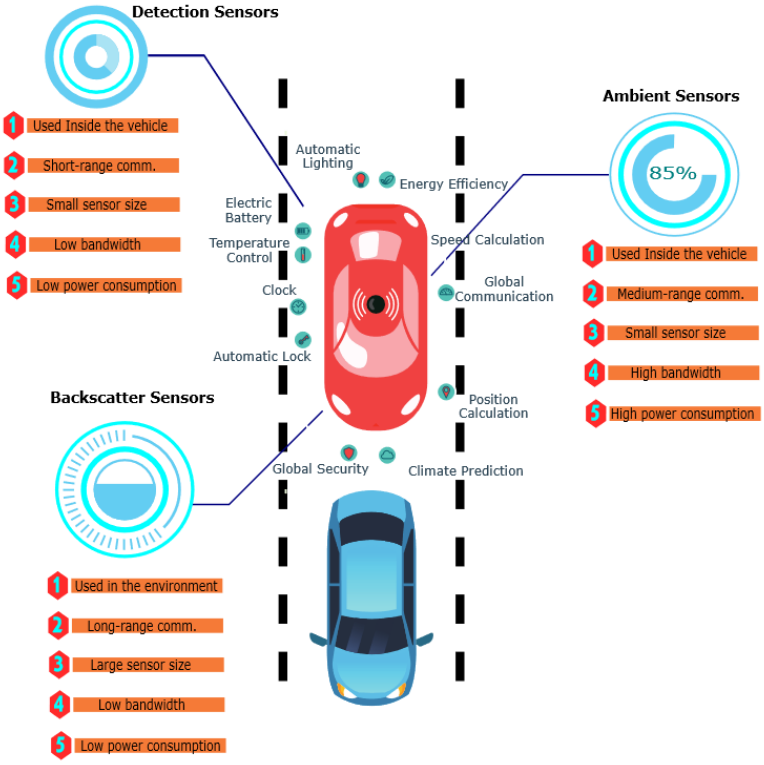

Figure 2: Types of sensors and their main characteristics and operations regarding CCAM, an overview (Jameel et al., 2019)

Ultrasonic sensors operating on road lanes that also take into account real-time traffic density are beneficial in terms of traffic flow optimization, while real-time CAV monitoring via Frequency Modulated Continuous Wave (FMCW) also proves very accurate. In general, radars, cameras and inertial sensors are commonly utilized hybrid multi-sensor technologies that can act complementarily to GNSS, especially in cases when satellite visibility is diminished, for example inside tunnels, or because of weather conditions. One could also refer to LRF (Laser Range Finder) is more precise both indoors and outdoors and can minimize localization standardized errors (Hakak et al., 2023).

Cybersecurity

A network consisting of CAVs, RSUs and other networking equipment, makes an attractive target for data theft. Particularly as this may include personal data, financial, contact or travel data of the users. Other dangers include identity theft, device hijacking, since the attackers can take control of the vehicle software and alter the algorithm so that they can remotely control the vehicle or render a vehicle immobile, service denial, mostly targeted to inadequately secured devices of the network, as well as financial fraud. Thus, security walls should be built, especially when legacy issues coexist with automated mobility. Physical layer security (PLS) has been recently introduced as a successor of cryptography. This novel technology can prevent AVs from false data broadcasting and is able to make use of jamming techniques between the transmitter and the receiver (Jameel et al., 2019). Furthermore, trust models which are built via blockchain techniques can provide some additional cybersecurity policies (Khan et al., 2022). For example, blockchain or other technologies could guarantee trust and transparency between all agents within shared AV systems (Ghimire et al., 2021), as well as diminish the legal gap that currently exists between the various agents in case of an accident, making possible to thoroughly investigate the 'history' of the involved CAV (Feng et al., 2021).

A recent EU-funded project namely CARAMEL, opted to introduce cybersecurity technologies and novelties, utilizing Machine Learning (ML) and advanced statistical techniques –part of AI- as well as V2X protocols and connectedness to cloud servers for the efficient detection of external sensor threats such as physical adversarial attacks on traffic signs and location spoofing, GPS spoofing and cyberattacks on charging stations. SELFY, a project that was initiated in 2022, is anticipated to provide a tool offering self-protection, self-recovery decisions and self-response to many scenarios of malicious cyber activity, while in CONNECT, another ongoing EU-funded project, is expected to support data sharing between entities with no previous trust relationship, and, thus, investigate the prospects of cooperativity between them.

High Performance - edge computing & cloud computing

Connected autonomous driving is strongly associated with high computing performance. Although the latter could be achieved by deploying powerful computers inside each vehicle, this could prove extremely costly. Thus, a smart resource allocation scheme should be selected, by thoroughly examining which task is the most difficult latency-wise (Baidya et al., 2020). In the meantime, cloud-based technologies as well as fog, edge and roof computing could be utilized to access large amounts of vehicular data, which are emitted from sensors in, on and all-around a CAV, and transmit them to other vehicles in the network, to infrastructures or to appropriate local authorities. In particular, fog computing has the potential to provide the best possible information about the internal and the external environment and it can be used for optimal V2V communication (Gkoumas et al., 2018; Hakak et al., 2023).

2.2.2 Enabling factors for CCAM operators/deployers

Focusing on the operators and deployers of CCAM solutions, several enabling factors can be considered important towards the safe, efficient and sustainable CCAM deployment.

Traffic Management Centre

Traffic Management Centres can play a significant role in enabling the deployment of CAVs by providing various services to support their operation. Real-time traffic data, incident management, traffic signal optimization and data sharing are some critical functions that can be performed to ensure the safe and efficient operation of CAVs.

Remote control rooms

Remotely monitoring and controlling CAVs can ensure their safe and efficient operation in cases of failure, emergency situations or other unpredictable conditions. Remote control rooms and specialised personnel can also provide technical support to CAVS when encountering technical issues or malfunctions. This can include diagnosing and troubleshooting problems remotely or sending a technician to repair a vehicle on site. Remote monitoring and control from a centralized location can also help minimize the need for on-site personnel and reduce overall operational cost.

Surveillance / Sensing

Surveillance can also support CCAM deployment and CAVs operations in several ways. Monitoring CAVs performance can ensure their seamless operation by analysing data from different sources (e.g., cameras) in order to detect any issues or anomalies in their behaviour. Furthermore, it can improve safety by analysing and detecting hazards and/ obstacles and alerting CAVs towards potential dangers.

Data management

CAVs are expected to generate large amounts of data when they are deployed in a large-scale. Data management systems can be utilized in order to ensure the safe integration and operation of CAVs in the road network. Data collection and analysis is critical for identifying patterns, trends and anomalies, which can be used to optimize CAVs operation, improve safety and enhance the overall performance of the system. Furthermore, making data available and accessible to different stakeholders involved in CCAM can enable better collaboration, facilitate data-driven decision making, and support innovation. Real-time data processing and predictive analytics can provide timely and accurate information about the operation of CAVs and forecast their performance and behaviour respectively.

Maturity of technology

Tested and validated mature technologies can undoubtedly foster large-scale CCAM deployment. CCAM operators and deployers should be able to trust the technology they rely on. Therefore, demonstrating mature technologies concerning sensors, connectivity, mapping and localization, AI and cybersecurity could enable large-scale CCAM deployment.

2.2.3 Human-centred and non-technological enablers

Several human-centred and non-technological enablers can be recognized. Some of them are recognized and briefly discussed.

Collaboration

Collaboration between transport operators, technology providers, and governments is essential for the successful CCAM deployment. Working together, stakeholders can identify and address barriers to deployment and develop solutions that meet the needs of all parties.

Digital skills & familiarization

The introduction of key enabling technologies developed within the C-ITS and CCAM systems entails the need to support the diffusion and growth of digital skills among users. Digital experience, knowledge in the use of smartphone applications and the ability to interact with IoT and AV devices introduced to support technologically advanced automation are necessary aspects to consider as they ensure the effectiveness of the investments made in the CCAM. Based on data provided by Eurostat[1], in 2021 the percentage of the population with at least basic digital knowledge in Europe was around 54%. There is also the requirement for those working in CCAM to have knowledge of advanced technologies such as machine vision, big data and machine learning.

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[1] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20220330-1

Furthermore, the percentage of people with at least a basic digital education is not homogeneous across Europe[1]. In fact, the distribution of this value underlines a strong gap between Northern European countries, such as Finland, the Netherlands and Ireland, where digitally educated people are over 70% of the entire population, and Eastern European countries where this value is around 30%. Therefore, the implementation of mobility technologies in the CCAM environment presupposes the need to face, on the other hand, the current barriers constituted by the digital skills of a large part of the users.

Thus, alongside the implementation of CCAM technologies capable of incentivising and implementing public transport, various programs and actions have been introduced aimed at implementing digital skills and familiarity with modern IoT and IoV technologies, such as European Digital Skills and Jobs Platform, operated under the program “Connecting European Facility” (CEF)[2], and the “Digital Europe Programme”[3].

Ensure that CCAM technologies meet citizens’ mobility needs (accessibility, availability, affordability, acceptability)

The effective functioning of the CCAM technologies introduced in public transport presupposes that the latter are capable of fully satisfying the needs of the various categories of users. From the literature studies carried out on the matter, the mobility needs of users can be traced back to four fundamental groups, i.e. “availability”, “accessibility”, “affordability” and “acceptability” (Arup, Urban Transport Group, 2022; Shrestha et al., 2017). In particular, CCAM technologies must necessarily be accessible to the majority of users and therefore limit the physical and cognitive impediments that can compromise the use of transport services, must have a cost of use that guarantees the provision of services to a large number of people, must be available and therefore effectively distributed geographically to allow equal access to the service. CCAM technologies must therefore satisfy various needs, the definition of which passes through a careful analysis of the needs of the different categories of users, especially the ones who are more possible to face mobility challenges, such as the elderly, people with disabilities, LGBTQI+ people, young, people living in rural areas and those with limited digital knowledge. In order to ensure the effective use of the CCAM technologies introduced in the framework of the SINFONICA project, the needs of the different categories of stakeholders are subjected to a careful and targeted analysis, which focuses on the involvement of the different groups of users in defining the operating framework of the developed technologies. The four aspects that define the framework of mobility needs in the various categories of stakeholders will be used to define the functioning of the CCAM technologies adopted in SINFONICA, in order to ensure their ability to meet the needs of users in daily life.

On-board presence of personnel

The introduction of AV is a key element of the CCAM. Among the expected results, there is the overcoming of the current barriers linked to the use of traditional means in public transport, including the risks linked to the safety of driving personnel and the limits linked to satisfying the

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[2] https://digital-strategy.ec.europa.eu/en/policies/technologies-digitalisation-transport

[3] https://digital-strategy.ec.europa.eu/en/activities/digital-programme

most vulnerable to exclusion categories (Alčiauskaitė et al., 2020; S. Harms, 2020; Hatzakis et al., 2021).

Through the implementation of CCAM it will be possible to employ personnel in a more incisive way to support users in the use of services, integrating these technologies with the constant use of the human factor in order to ensure more efficient public transport that is functional to needs of the single individual. Launonen et al. (2021) emphasize the role played by social norms in interactions with automated vehicles. In particular, it should be noted that for some categories of people, such as the elderly and women, the presence of personnel on board performs a dual function. On the one hand, there is a psychological dimension linked to the perception of safety on the automated vehicle. In this sense, human presence plays a reassuring role for those people who have a limited level of trust in innovations, or may experience episodes that can affect safety on public transport. On the other hand, there is a need to have an on-board assistant who acts as a support in using the public transport service.

It is likely that in the short-term, the human presence will be necessary even in automated vehicles (especially when operating in shared / public transport environments), where staff will have the function of assisting passengers and ensuring vehicle safety. However, this may affect business models as there will be limited cost saving as one motivation of CCAM technologies is the reduction in staffing costs.

In time, there may well be a transition from the traditional public transport model to the use of automated vehicles with IoT and IoV technologies, which enables the use of CCAM technologies with the absence of on-board personnel.

Accelerating the adoption of digital technologies

In the framework of the implementation of urban public transport, a fundamental role will be given by the development of innovative CCAM solutions. This will entail the need to invest more in IoT and IoV technologies, with the expectation of accelerating technological development and, in particular, encouraging the change towards new systems of digital technologies in urban mobility. The co-participatory approach of the different categories of stakeholders will play an important role in accelerating the implementation of CCAM solutions. Regarding SINFONICA's approach, this will happen thanks to the involvement of users in the Groups of Interest falling within the SINFONICA framework. Through the administration of questionnaires and demonstrations, it will be possible to adopt CCAM solutions capable of meeting and satisfying the interests and needs of the various categories of users. It also allows testing of the solutions adopted in the field and improving their operation, thus ensuring their application and future development.

Legal and regulatory framework

In addition to technological standards and guidelines, legal and regulatory frameworks will need to be developed and updated to accommodate the deployment of automated vehicles. These frameworks will need to cover a range of issues, including safety, liability, insurance, and data privacy. The Artificial Intelligence (AI) Act is a robust example of the new legal framework that EU is considering in order to harmonise the rules concerning advanced technologies utilizing AI, such as in the case of CAVs (European Commission, 2021b).

Public perception and acceptance

The successful CCAM deployment will depend on public perception and acceptance. It will be important to educate the public about the benefits of automated vehicles and address any concerns related to safety, security, and privacy.

Social and behavioural factors

CCAM deployment will require changes in social and behavioural factors, including new attitudes towards vehicle ownership, driving, and commuting. It will be important to understand how people use and interact with CAVs in order to optimize their deployment.

Business models

The deployment of automated vehicles will require new business models, including vehicle ownership and usage models. Transport operators will need to identify and implement viable business models that can support the CCAM deployment. An immediate challenge is the additional cost of CCAM technologies compared to conventional vehicles. However, this will create new value propositions, new business and operating models.

Economic factors

CCAM deployment is expected to have significant economic impacts, including changes in employment, investment, and productivity. It will be important to understand these economic factors in order to ensure that CCAM deployment is sustainable and beneficial. Funding initiatives and incentivizing schemes are expected to boost and accelerate CCAM deployment and citizens' engagement.

2.3 Integration aspects of CCAM

Several integration aspects are recognized through the projects review presented in Table 1. There are different strategies for deploying CAVs in road transport, such as deploying them in dedicated lanes or gradually introducing them into mixed traffic. Each strategy has its own advantages and disadvantages, and the optimal strategy may depend on factors such as local regulations, infrastructure, and public acceptance.

Nevertheless, integrating CAVs into road transport requires collaboration between various stakeholders, including, automotive manufacturers, technology providers, infrastructure operators, regulators and policy makers, insurers and more. Strong collaboration schemes can help ensure that the integration process is coordinated and that the benefits of automation are maximized while minimizing any potential negative impacts, meeting stakeholders' needs and expectations.

CAVs integration in the road network poses for changes in the current road infrastructure which is designed for human drivers. Infrastructure-related requirements for CAVs are examined by Tengilimoglu et al. (2023) identifying thirteen key topics around physical road infrastructure that need to be considered towards full automation including road surface and markings, traffic signs and control signals, parking facilities and pick-up / drop off areas, structural elements and geometric design, facilities for Vulnerable Road users and road infrastructure assessment and maintenance among others. Liu et al. (2019) also made a review of road infrastructure requirements for CAVs taking into consideration digital infrastructure and connectivity requirements. Furthermore, INFRAMIX EU project has proposed a simple classification scheme to classify and harmonize the capabilities of road infrastructure to support and guide AVs paving the way towards the concept of hybrid infrastructure to support both conventional vehicles and AVs towards the transition path to full automation (Carreras et al., 2018).

One of the key challenges is to ensure that CAVs can safely interact with other road users, including pedestrians, cyclists, and conventional vehicles. Traffic management strategies need to be designed to facilitate safe and efficient movement of all road users, with appropriate infrastructure and traffic management systems. Traffic management systems are also required to be able to anticipate and respond to changing traffic patterns and adjust traffic flow accordingly, using technologies such as advanced sensors, intelligent traffic management systems, and real-time data analysis. Traffic management regarding the integration of CCAM and CAVs will require a multifaceted approach that brings together a range of stakeholders to develop innovative solutions that meet the needs of all road users while ensuring the safety and efficiency of the transportation system.

Integrating CAVs with mobility platforms, such as MaaS, is expected to provide additional benefits, like increased flexibility and convenience for the users, reduced operating costs for transport operators, and improved traffic flow. In this way, intermodality and multimodal transportation could bring added value to CCAM services providing the potential to plan a trip including first and last-mile services. Nevertheless, interoperability between different transportation modes and technologies, standards for data exchange and privacy protection are some of the challenges to be addressed.

Connectivity and communication are inherent characteristics of CCAM and play crucial role in the integration of CCAM into road transport, providing the potential for enhanced safety and efficiency. In order to fully realize the benefits of connectivity and communication for automation in road transport, it is considered important to establish common communication standards and protocols to ensure interoperability between different systems, as well as to develop appropriate cybersecurity and privacy strategies establishing common security standards and protocols.

System and data interoperability as well as the existence of open data are also considered critical elements for the integration of CAVs in the transport network. Accessibility to static and dynamic real-time data ensuring at the same time the desired quality of the data is prerequisite for the optimal cooperation between CAVs, the infrastructure and other road users. Furthermore, open repositories and APIs could potentially leverage the uptake of CCAM.

In this sense, data governance and processing of data are fundamental to the development and integration of CAVs and large-scale CCAM deployment. A common regulatory and legal framework towards availability and accessibility of data ensuring personal data protection and fundamental rights is therefore imperative to ensure the sustainable transition towards automation in road transport and the realization of the EU’s vision of CCAM (Andraško et al., 2021).

Overall, legal and regulatory issues are critical considerations in the integration of automated vehicles into road transport. By developing appropriate legal and regulatory frameworks, regarding aspects like cybersecurity and privacy, liability and accountability, insurance etc., policymakers can help to ensure the safe and effective CCAM deployment.

Trials and pilot projects of CCAM solutions are proven to be a useful way to test and refine the integration aspects. They can provide valuable data on user behaviour, technical performance, and operational challenges, which can be used to inform future deployments and policy decisions. Furthermore, simulation models and digital twins are emerging technologies that are becoming increasingly important in the integration of CAVs. These technologies enable the testing and validation of automated vehicle systems in a virtual environment, reducing the need for expensive physical testing and enabling more rapid and cost-effective development and deployment. They also allow vehicle manufacturers and developers to identify and address potential issues before the vehicles are deployed in real-life, improving safety and reliability.

In general, there are several challenges that must be overcome in order to successfully integrate CCAM and CAVs into road transport. These include operational, technological, regulatory, financial, and social challenges, such as ensuring the safety and reliability of the technology, updating existing infrastructure to accommodate automated vehicles, and addressing public concern about the impact of automation on jobs and privacy. These factors are considered in more detail in the next Chapter concerning the effects and implications of and the gaps and barriers towards large-scale CCAM deployment.

3. Towards large-scale CCAM deployment

Marletto (2019) recognizes three transition pathways towards automated driving following a socio-technical approach and representing urban mobility in year 2040 using socio-technical maps. Each one is led by a different network of innovators:

- In the first scenario, the today's automotive industry manages to integrate technology and components supplies for CAVs into their network, and successfully lead the transition to automation through public investments.
- In the second scenario, cooperation between leaders of the Internet and managers of shared and collective transport systems, considering shared mobility as the core element of the new transport system, gains support from policies and leads the transition.
- In the third scenario, energy agents integrating AVs and smart grids take over urban mobility fostering a new political discourse on energy efficiency and sustainability.

Furthermore, Milakis & Müller (2021) emphasises the socio-technical dimension of mobility system transition identifying three key dynamics accounting for the societal dimension of the transition, namely societal acceptance, societal implications and governance.

The following sections aim to capture the effects and implications from large-scale CCAM deployment. Respectively a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis is performed. Furthermore, gaps and barriers towards large-scale CCAM deployment are recognized and classified. A critical analysis and comparison between gaps and barriers recognized and stakeholders' needs, requirements, goals and dilemmas as recognized in D1.2 – "CCAM Vocabulary and stakeholders needs and requirements", is performed. Then, on overview of ongoing research projects launched within 2021-2027 Horizon Europe is presented.

3.1 Effects and implications from large-scale CCAM deployment

Several researchers have attempted to capture the effects and implications of automated driving and vehicles. Based on literature findings, a SWOT analysis capturing the potential positive and negative effects and implications that CCAM large-scale deployment may have, is presented.

3.1.1 Strengths and Opportunities

CCAM is expected to improve traffic safety and reduce accidents caused by human error. This is highlighted as a clear benefit at a significant number of studies (Han et al., 2017). Human error is considered to be significant cause in over 90% of road incidents. AVs will not be prone to fatigue, poor or foggy judgment and decision-making or attention distraction, whilst they are faster in calculating and decision-making than people. These qualities are extremely positive towards vehicle crash avoidance. Full presence of AVs in an urban environment could also mitigate an accident's fatal outcomes even after it happens, since they possess e-call functions (European Commission, 2018a). Most studies, deploying simulation models, reveal that the full potential of benefits would be achieved with high AVs penetration rates (Papadimitriou et al., 2022).

Generally, CCAM technologies will allow to improve public transport services especially regarding the satisfaction of the needs relating to the categories of users with mobility challenges. The benefits for the security of CCAM technologies are declined in this sense on the basis of the needs expressed by the various categories of users. The implementation of surveillance and warning technologies can help gender issues, as there is the concern about personal safety on public transport. As far as the elderly are concerned, it is possible to implement technologies useful to assist people in using public transport, such as communication systems designed to support the user in the event of illness. Other benefits of the CCAM technologies may concern the use of safety systems aimed at guaranteeing adequate control allowing the use of public transport by families with young children or people with disabilities, who may have problems of movement or space on vehicles.

General public perception regarding mobility could undergo a significant alteration, since service-based mobility and sharing systems will gradually replace individual vehicle ownership, creating a new ecosystem of connectivity and automation, provided that new mobility systems are reliable and safe (Gonzalez-Gonzalez et al., 2019). Large-scale usage of AVs could prove beneficial for non-car-based mobility like public transport services, creating an opportunity window for sustainability, altering the current regime to a certain extent, as many people, especially younger ones, seem extremely willing to use the new services, and are familiar with technology (Schippl et al., 2022).

A thoroughly studied positive aspect of AVs is the limitation of the total number of vehicles in road networks, since AVs can be utilized in car-sharing and ride-sharing services (Fagnant & Kockelman, 2014). More precisely, it has been suggested that a shared AV (SAV) is equivalent to up to 11 private vehicles due to its capacity and, as a result, road occupancy will undergo a significant decrease, positively affecting city networks (Chen et al., 2016). Occupancy decrease can be translated to road capacity increase; a significant enhancement of road capacity is anticipated when full-scale deployment of AVs will be a reality. The increase can reach up to 75% for lane capacity and 40% for intersection capacity (Friedrich, 2016). As far as congestion-related topics are concerned, queues, travel times and congestion, especially on links with high traffic demand, are expected to be reduced because of the AV/CAV implementation (Levin & Boyles, 2016), paving the way towards a more reliable transport system as a whole.

Connectedness of CAVs can help at handling flows optimally, utilizing cooperation of vehicles and infrastructure, like adaptive signalling, prioritisation of public transport vehicles, and First-Come-First-Served signal reservation, leading to traffic optimization (Dresner & Stone,2004) delay minimization at signalized intersections (Fajardo et al., 2012). Furthermore, platooning can enhance road capacity up to 500% (Fernandes & Nunes, 2012. Less vehicles on the roads mean reduced number of engine-starts and less fuel needed to find and capture a parking place. Along with platooning, they could altogether lead to a 35% reduction of carbon dioxide (CO2) and Volatile Organic Compounds (VOC) emissions (Fagnant & Kockelman, 2014). In general, vehicles and infrastructure are anticipated to be more environmentally-friendly, since they will be based on electricity and alternative fuels, instead of fossil fuels, and constructed by sustainable materials, respectively. It has been shown that electric cars prove to be 3 times more effective in terms of fuel efficiency than the conventional ones. In the case of shared automated mobility, carbon monoxide (CO) and volatile organic compounds (VOC) are anticipated to undergo a significant decrease, up to 45% (Wadud et al., 2016).

Further urban sprawl can also be achieved due to the improved accessibility AVs will provide at suburban areas; Low-income people seem to be more significantly affected, since they will have easier access and connection to urban centres, without being forced to live there (Meyer et al., 2017). It is showcased in a number of studies that AV availability and relocation willingness are positively correlated (Bansal et al., 2016). SAVs can enhance accessibility only if they coexist with privately owned vehicles, while personal AVs seem to be beneficial towards it in any case (Zhou et al., 2021). In other words, SAVs could enhance community cohesion and strength, enhancing overall city multi-functionality and diversity, with less people feeling “left out” (MacMillan et al., 2020). People not owning a vehicle will be able to access their basic needs in terms of goods, services and employment, without wasting a lot of time, thus free time of those societal groups will increase. This factor is often neglected or partially studied but seems to be extremely important, especially for people working for many hours per day whilst having to commute for hours too, ending up to not having enough time for anything beyond their job, losing attachment to their city and community. Passengers spending their time inside vehicle in productive activities instead of driving can create an opportunity for them to expand their free time and do things that distract them (Othman, 2022).

People with mobility challenges are also expected to enhance their mobility due to the increased accessibility and freedom they will be experiencing (Brown et al., 2014). An important societal impact for aging population is their independence when AVs will be an implemented reality; they will be able to reach dedicated points of pickup, and return close to their home afterwards, without feeling a ‘burden’ that should be carried by others, and without relying only on public transport availability. Moreover, AVs can fill the transport gap created in first and last-mile services, which, currently, prevents many citizens from utilizing public transport more often, even though they should prefer it over car ownership, as the latter proves to be costly, and is connected with parking problems in the city centres.

Furthermore, less resources are anticipated to be needed for infrastructure such as parking lots, parking garages, as well as for the implementation of the relevant restrictive policies by local authorities. Parking lots and facilities could be reshaped to cover less space and relocated out of city centre, since parking demand will be significantly limited there (Nourinejad et al., 2018). Furthermore, off-street parking is expected to be optimally designed compared to the current situation, using space more efficiently, since distances between side doors of AVs are expected to be tighter (Nourinejad et al., 2018). As per Alessandrini et al. (2015), CAVs can lead to parking space savings up to 75%, while Nourinejad et al. (2018) report 62% reduction on average, which could reach 87% in an optimal scenario. Consequently, parking cost at previously congested central locations of cities might significantly decrease, since parking demand is expected to be reduced too (Litman, 2017). The authorities of each city where AVs will be fully penetrated into, may use the previously occupied parking places for housing and commercial land uses (Llorca et al., 2022), while city outskirts and suburbs will be sprawling even more due to better time utilization by potential users who prefer suburban regions in comparison with congested urban cores (Hiramatsu, 2022).

Although one could only project and anticipate what could happen in the financial sector once CCAM will be an implemented reality, studies showcase that by 2030 the expected revenues are going to be doubled in the USA; 40% of them are savings from collisions avoidance, 15% is gained due to fuel limitation, and another 45% from productivity increase (Romer et al., 2016). In general, Information and Communication Technology (ICT) sector is expected to gain the most from this advancement. With the software sector tending to be more profitable as of today, a significant growth is expected in the CAVs hardware market (Romer et al., 2016). Telecommunication and digital media sectors, along with data services, are also projected to grow; huge amounts of data will be exchanged every minute between CAVs via 5G networks. As Bertoncello et al. (2016) refer to in their study, the potential benefit in the field of vehicle data could be somewhere in the region of 500 billion dollars in a global scale by 2030. Low operational costs of commercial AVs could lead to cost minimization for transport services combined with increased service levels (Engholm et al., 2020).

As a survey conducted by KPMG showcased, job fields like software engineering, decision-making, vehicle cybersecurity and data engineering will see a boost in demand in the forthcoming years. Up to 230.000 job opportunities could be placed by 2030 only in UK. The digital media industry is also expected to be beneficiated from the AV expansion, since users will be more and more engaged to it during their trips (Clements & Kockelman, 2017).

The full-scale implementation of AVs can provoke car manufacturers to produce lightweight cars which consume significantly less fuel than the conventional cars. More precisely, reduced weight of a car by 10% means about 6% decrease in fuel consumption (Anderson et al., 2014). As for the insurance market, the expected revenues from new insurance categories that could be introduced along with the large-scale AV implementation, such as product liability for software and hardware, and cyber-security, could create research as well as employment opportunities in this sector.

3.1.2 Weaknesses and Threats

There is a risk of increased traffic demand on city centre road networks, since commuting trips are anticipated to be scheduled and operated more often with the use of personal AVs (and SAVs, to a lesser extent). This is a negative situation that could emerge from large-scale CCAM deployment and, consequently, an increase up to 35% in VKT due to ‘empty’ journeys is possible. Thus, there lurks the danger the already congested urban centres to worsen traffic-wise (Aittoniemi et al., 2020). Gas emissions would also be increased in this case, while more kilometres covered also means heavier use and increased exposure, and, thus, mechanical issues could appear (European Commission, 2018a). Empty trips or ‘empty-cruising’ of CCAM has, moreover, been connected with a significant increase in parking demand in suburban areas and unnecessary trips within central areas. Due to costly hourly parking in dense city centres, AVs will probably be encouraged to circulate in low speed around the city centre to minimize travel costs, and may not even decide to park at all until a new ride request is on (Millard-Ball, 2019). Furthermore, because of cheaper parking solutions outside city centre, it is anticipated that pick-up waiting times might occur, especially for unplanned, short-term or emergency requests, and studies show that at this type of trips the user tends to have lower willingness-to-wait (WTW) (Bahk et al., 2022). In case of shared vehicles (SAVs), kerbside pickup and drop-off locations in the suburbs should be located every 30 to 50 m to be highly beneficial for the potential user, and AVs will serve these points quite often, leading to increase in congestion and vehicles miles travelled (VMT) (Fayyaz et al., 2022).

As Bagloee et al. (2016) state in their survey, demand increase, as a side effect of large-scale AV deployment, can be viewed both as an opportunity and as a threat. If the increase is extreme, traffic congestion will deteriorate instead of improving. Governments such as the Dutch one, have been advised to do whatever needed in terms of travel demand management, not to allow an exponential travels growth, as indicated by Milakis et al. (2015). The fact that users will not be engaged in driving, being able to conduct more productive activities inside AVs, is possible to make them want to travel more inside the city, move further from their workplace since they can work in-vehicle, and, as a result, the congestion problem may not be solved, with longer trips and more. It is also possible that

AVs will gain passengers from existent public transportation, which is not necessarily beneficial in terms of congestion (Metz, 2018). Moreover, previously unserved demand is possible to be added to the network, mainly originating from users' categories that were not previously included and had difficulties to commute. Transport demand management, thus, could be a challenge for the CCAM service providers.

On the other hand, digital connectivity creates data warehouses, and results of data analysis can be utilized to develop pricing models and optimized services. This could lead to less competence with public transport which could be overlooked by individualistic CCAM (for example, charging more a CAV route that overlaps one of a public bus or a CAV with very few occupants/passengers, or lower charging of driverless public transport, in an effort to incentivize it). Cities representatives in some cases state that if large-scale CCAM deployment in their urban areas could not help achieve their goal to reduce individual motorized transport in favour of public transport, they would not decide to implement automated mobility although they are generally for it (Harrison et al., 2022).

Time and distance gaps between AVs/CAVs are anticipated to be diminished, leading to potential increase in speed limits due to the improved road capacity; this, though, could lead to diminishing of possible reaction time in case of an emergent or unforeseen event, for example an unexpected obstacle ahead. This should be thoroughly studied, so that a safety time margin to remain in any case, otherwise safety may not be guaranteed in unexpected situations (European Commission, 2018a).

It is highly possible that on-demand AVs will conduce to a less athletic general population, since users will be able to commute from their origin to destination walking the least possible or without walking at all. Dispersed urban growth, which has been stated as an outcome of the wide AVs implementation is also a restrictive factor when it comes to active travel, like cycling or walking, because of the long routes connecting a suburban place of residence with the city centre. Furthermore, on-demand automated mobility could lead to a slight increase (5%) in waiting time during peak hours (Oh et al., 2020). Another potential challenge could be the kerbside pickup time, which can be associated with decreased service rate. If users are not present when their requested AV arrives, waiting time and in-vehicle travel time for other passengers/users is anticipated to increase significantly. This added time, as well as long detours, could discourage many people to utilize on-demand CCAM (Hyland et al., 2020).

There are not many ways to test AV safety prior to their wide implementation, except from simulators and pilot operations. Simulators are not able to replicate every aspect of human behaviour and interaction with CCAM, thus their results, although extremely important research-wise, have limitations; a human's rationality and perception, e.g., seem to be the most difficult and complex characteristics to be replicated through AVs and CAVs (European Commission, 2018a). Since walking and cycling are gaining 'audience' in today's extremely urbanized environments, their role in the new era of mobility must not be overlooked, taking also into account that pedestrians, cyclist and micro-mobility users are considered the most vulnerable ones (Vissers et al., 2016). CCAM may encounter difficulties to appropriately interpret human mannerisms such as gestures (Van Loon and Martens, 2015), thus these users do not feel safe enough to use the urban network equally to AVs and public transport modes. In addition to this, many road users are neither drivers themselves nor even eligible to drive because of age, while others walk in an unconventional way or use means of micro-mobility such as roller-coasters or skateboards, which are not easily replicable (European Commission, 2018a).

Another valid safety concern, at least until the stage of full CCAM deployment, could be the difficulties in co-existence of AVs with manually driven cars and, thus, the safety of conventional drivers; cautious AVs could make an impatient driver try to overpass, increasing the possibilities of a fatal crash with another vehicle or with infrastructure (Innamaa et al., 2018). The coexistence of AVs and conventional vehicles might slightly worsen traffic safety, according to a study carried by Schoettle & Sivak (2015). Vehicles with different automation levels are expected to be simultaneously present on road networks during this phase, imposing a non-negligible threat to road users who will not be able to assume the level of automation, and therefore the behaviour, of each vehicle they will encounter in front of them, at street crosses or intersections.

Barreda et al., 2020 explored the heterogeneity in AV acceptance rates among users in a survey held in France and identified 5 distinct population segments, from 'conservatives' (22% of the sample), 'sceptics' (14%) and 'late adopters' (21%) to the so called 'explorers' (25%) and 'early adopters' (18%). Many people are technophobic, and will not be receptive of the idea of leaving their sanity, health or even life to a 'machine operation', although studies can prove that travels with CCAM are expected to be safer and more reliable. As far as shared automated mobility on demand is concerned, convincing someone who previously used his own car, an aspect of his own personal space, to share a ride with strangers, is not an easy task and can be seen as a potential challenge (Hyland et al., 2020).

Researchers are unsure if behavioural shifts which will promote AVs and their optimal utilization are really green and environmentally friendly (Miller & Heard, 2016). If political action is not taken on time, the effects of non-sustainable utilization of the new means of transport, will not be less severe than these of the currently used mobility system.

The large-scale CCAM deployment, especially when it reaches Level 5 automation, is not expected to be dependent on traffic stop signs and safety barriers. This could, though, introduce a barrier for non-motorized means of transport; pedestrians won't feel safe to cross an intersection without proper signage. This would mean that overhead or underpass pedestrian and cycling crossings should be built to mitigate this issue, increasing infrastructure costs significantly (Fraedrich et al., 2019; Heinrichs, 2016). Furthermore, CCAM seems to undergo many difficulties until it could be largely and safely implemented in developing countries, due to lack or inadequacy of infrastructure, although citizens in those regions seem more positive towards utilizing them. Indicatively, referring to marking and signings, complete lack of signalling at many junctions where right-hand priority is used at best, if not the driver's instinct by itself (Othman, 2022). Poor parking design and extremely heterogeneous traffic are also negative factors for the large-scale CCAM deployment. (Othman, 2022).

Nevertheless, studies conducted in this research area are unsure about the possibility of large-scale penetration of AVs in countries or regions with low median income as means of individual transport. If citizens of these areas cannot afford such services, societal impacts such as enhancing the gap between rich and poor, will be evident (Wadud et al., 2016). Social gaps in terms of educational levels might be enhanced too, since technologically illiterate or lowly educated citizens will feel falling behind their co-citizens (Clark et al., 2017). Measures taken by local authorities such as road pricing and parking fees to constrain the anticipated increase in VMT, which is a possible outcome of AVs introduction and deployment. This, although leading to improvements in current public transport services, could engender gentrification, which can negatively impact social equity, restricting low-income communities' presence at 'well-provisioned' areas of a city (MacMillan et al., 2020).

Financial drawbacks are not easily predictable although many studies have been conducted in this field. Albright et al. (2015) estimated that insurance companies could suffer 60% economic losses due to the positive impact CCAM is anticipated to have on safety. Insurance market could possibly also be harmed from new innovative digital platforms enabling telematics technologies (Martens & Mueller-Langer, 2018). Automotive and oil industries are also projected to belong in the ones losing the most during this transition. The maintenance sector, due to the limitation of road crashes, could also be negatively impacted by a large-scale CCAM deployment, in terms of demand for repairs. Although at the same time, there will be a demand for higher paid, more expertly skilled workers to fix damage to specialist CCAM equipment, along with higher repair costs, due to the more expensive materials used (Wadud et al., 2016). Maintenance prediction and scheduling in CCAM is expected to be implemented through telematics applications, limiting frequency of repairs to the lowest possible level and annihilating emergent visits to car mechanics (European Commission 2018a).

Society-wise, many people with low level of education or middle-aged ones, who will become unemployed, since their jobs as bus drivers or/and bus conductors will cease to exist, might encounter difficulties into getting another job, due to their lack of qualifications combined with the increasing demand for high-qualified persons in the AV reality marketplace. Truck drivers, which are millions around the world, will be replaced by AVs and, thus, their potential job opportunities will be delimited (Harrison et al., 2022). Driving license instructor's job will also be affected given the large-scale deployment of AVs, since education related to driving licenses will inevitably be altered in the future; new driving skills will tend more to ICT, while current driving permits will may be inadequate or even unnecessary (Romer et al., 2016).

A far from insignificant barrier of public acceptance of CCAM, and therefore a challenge to be mitigated, is the users' perception of losing control of movement, entrusting it to algorithms they cannot see or interact with. If one also considers the exponential increase in cybercrime, this is not an easy task to handle (Hui et al., 2017). AVs and CAVs, due to their nature, seek inputs from their external environment to self-improve and adapt to it, therefore they are more prone to cyber threats. About 1/3 of interviewees in a relevant study (Schoettle & Sivak, 2015) seem to be extremely concerned about cybersecurity issues. This, important if left unattained, burden, can be mitigated via collective decision making and knowledge sharing systems.

In terms of legislation, since CCAM constitutes a novel aspect of mobility, issues associated to it, arise. The most complex and important one seems to be the liability in case of an accident, while responsibility and accountability issues is also a challenge to address especially in the case of shared automated mobility services (Gleave et al., 2016).

3.1.3 SWOT analysis

The SWOT analysis is presented in Table 2.

Table 2: SWOT analysis for large-scale CCAM deployment

Strengths	**Opportunities**
• Cooperation • Connectivity • Automation • Mobility on Demand • Mobility-as-a-Service • Personalized services • Real-time data • Human error elimination • Free of driving task • Direct emergency response • Positive effect on industries/sectors	• Improved safety • Increased traffic efficiency • Improved infrastructure capacity • Improved quality of life • Environmental sustainability • Increased revenues and cost savings • Improved traffic management • Services optimization • First and last-mile services • New business models • New job opportunities • Investment and growth opportunities • Urban sprawl and improved urban planning • Inclusivity and Equity • Accessibility • People with mobility challenges independency • Personal time utilization
Weaknesses	**Threats**
• High initial cost • Limited deployment • Technology and safety gaps • Empty trips • Mixed traffic conditions until full-deployment • Ambiguous legal environment • Cyber-vulnerability • Negative effects on industries/sectors • Lack of familiarization with automation • Lack of trust • Lack of personal space • Need for digital skills	• Abrupt CCAM deployment • Safety implications • Increased energy consumption • Reduced traffic efficiency • Unexpected/unpredicted situations • Social gap enlargement • Public transport depreciation • Liability and accountability issues • Cybersecurity and privacy risks • Unwillingness for data sharing • Infrastructure challenges • Economic implications • Potential job displacement / Unemployment • Active travel discouragement • Non-acceptance

3.2

3.3 Gaps and barriers towards large-scale CCAM deployment

Several challenges need to be addressed in order to achieve large-scale CCAM deployment. Based on CCAM projects and literature review these challenges are mostly associated with the Information and Communication technologies (ICT), Safety, User-centric factors (especially public acceptance) and legislative and regulatory aspects. This is also confirmed by Bezai et al. (2021) who conducted research regarding the analysis of barriers to automated vehicles full adoption. Their research classifies barriers into two main categories, namely User/Government perspectives, including users' acceptance and behaviour, safety, and legislation, and Information and Communication Technologies (ICT), including computer software and hardware, communication systems, and localization and mapping. The following sections are based on the projects' review as well as on Bezai et al. (2021) findings aiming to address the most critical related aspects towards CCAM large-scale deployment.

3.3.1 Information and Communication Technology (ICT)

Connectivity and Communication

Two techniques are currently implemented for the communication between actors in the CCAM ecosystem, ITS-G5 and cellular communication. RSUs and OBUs are deployed in order to facilitate ITS-G5 communication, while cellular networks are utilized for the cellular communication. 5G is expected to provide high speed communication achieving the required latency for several critical operations of CAVs. Hybrid approaches may also be implemented aiming to communication redundancy. Several aspects should be considered in order to achieve safe, secure and timely communication.

IoV can facilitate communication between vehicles, infrastructure, and other road users, integrating computing and communication modules. To ensure on-road safety, it is critical to maximise the Quality of Service (QoS) in IoV in terms of security, system failure, signal strength and latency. Data dissemination and routing, data integration and operational management, and security and privacy are key challenges that need to be addressed in order to achieve the desired efficiency, reliability and safety of communication and cooperation. Another challenge is the infrastructure cost for communication. Furthermore, communication protocols, 5G mobile networks and cloud computing are some key topics under research concerning data dissemination and routing, and can potentially bring cost-effective solutions. Furthermore, IoV is inherently vulnerable to security threats concerning the integrity, confidentiality and availability of data which imperatively need to be ensured through appropriate security mechanisms (Tabassum & Reddyy, 2022).

Several cyber-attacks are already recognized, while more sophisticated ones are expected to become a reality in the future (Benyahya et al., 2022; Tabassum & Reddyy, 2022). Two groups of CAVs related attacks are mostly discussed in literature related to in-vehicle threats and communication threats. In-vehicle threats cover the potential vulnerabilities on the vehicle technologies like sensors, Electronic Control Units, in-vehicle communication networks, etc., while communication threats refer to the communication with other vehicles and road users, and the infrastructure. Classical prevention techniques remain essential to address cyber-attacks, while new mitigation strategies like Blockchain and Machine and Deep Learning are currently investigated. Benyahya et al. (2022) argues that a combination of multiple techniques in required, taking into consideration human factors. This lack of a comprehensive approach towards cyber-security threats may hinder the large-scale CCAM deployment in the near future.

Software and hardware

Advances in sensing technologies and computer software and hardware have made the idea of CAVs possible. Figure 3 provides an overview of a typical automated vehicle system highlighting core competencies.

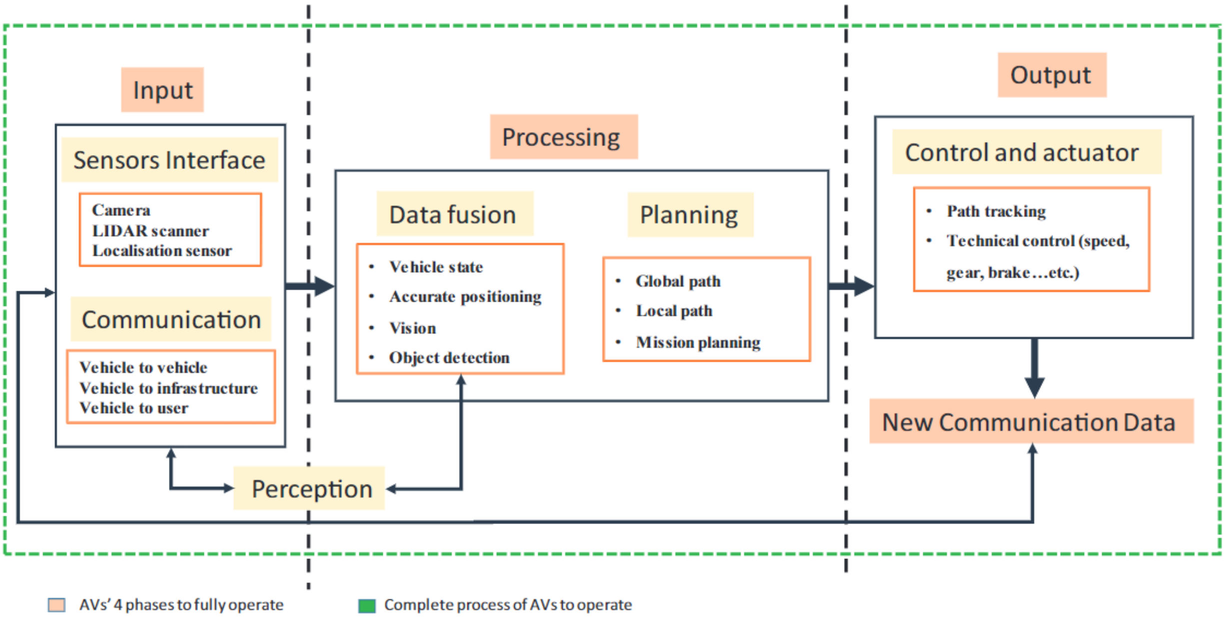


Figure 3: Connected and automated vehicle system architecture overview (Bezai et al., 2021)

Several hardware equipment is utilized by automated vehicles in order to achieve the desired perception of the environment, plan their behaviour and decide on how to proceed. Furthermore, software embedding different algorithms and advanced techniques like machine learning and neural networks are integrated into the system aiming to achieve optimal performance of automated driving (Pendleton et al., 2017). Very advanced computer software and hardware are needed in order to ensure optimal performance of AVs. Research is ongoing concerning advanced algorithms for object detection, decision-making, vehicle classification, computer vision and other critical functions for CAVs in order to ensure safety. Furthermore, data processing speed and sharing is a critical issue yet to be addressed both in terms of latency minimization and timely communication as well as of cybersecurity related issues. Nevertheless, when it comes to hardware systems, they are inherently prone to system failure. Thus, the systems' undisrupted function is another critical issue that needs to be imperatively be addressed. Furthermore, components' interoperability is not yet fully understood and cost may be excessive. Several sensors are utilized to achieve automated driving, each one serving a different purpose. It is critical that optimal performance of all components is achieved as well as data fusion from all sources is comprehensively addressed. Lastly, the huge amount of data that CAVs are expected to produce, requires powerful computers and big data storage spaces. IoV and cloud computing are some promising technologies to address this issue in a cost and space efficient manner and are currently under research (Bezai et al, 2021).

Navigation

Focusing on navigation of CAVs, connectivity has the potential to bring new intelligence to CAVs related to their environment and surroundings enhancing this way various driving aspects such as lane-changing, object detection and avoidance, forming of platoons and the application of smoother acceleration and deceleration (Typaldos et al., 2022). Localization and mapping are considered crucial aspects for optimal vehicle navigation and research is undergone in the field. Simultaneous localization and mapping (SLAM) is considered a promising technique to address this issue based on a hybrid approach allowing 3D map generation and localization based on in-vehicle equipment and sensors such as LiDAR, Inertial Measurement Unit (IMU) and GNSS antenna, and roadside equipment (Prasad, 2023). This becomes also evident from the projects' overview since research is focused on localization and mapping techniques and navigation aspects.

Advanced algorithms are also developed to address the problem of path planning and path planning updating. However, path planning for CAVs is a challenging task due to vehicles' high speeds and sophisticated approaches, such as optimal control methods and/or reinforcement learning, are required. Typaldos et al. (2022) proposed an optimal control approach to address path planning for CAVs moving on a highway taking into consideration connectivity of the vehicles and latency to achieve optimal time performance and argues that a similar approach for urban networks is possible with appropriate modifications or extensions. Diachuk & Easa (2022) addressed the path planning problem using a sequential optimization method achieving promising results. However, the model developed has some limitations and future research will be addressed respectively (Diachuk & Easa, 2022). CAVs' navigation and path planning are yet considered critical aspects to be addressed in order to ensure the efficient, collision-free, and user-acceptable operation of CAVs.

3.3.2 Safety

Among the strategic objectives set by the European Commission (2021a) regarding the improvement of road safety thanks to the CCAM implementation, it is important to mention:

- The improvement of road safety i.e., the reduction of road accidents and therefore the number of deaths or injuries while driving.
- The improvement of communication technologies in order to allow the vehicles implemented in the CCAM framework to interact effectively with conventional vehicles. This includes the need to implement safety systems capable of avoiding accidents and increasing user protection.
- The implementation of safety standards in technologies to support decision-making on board, such as tracking devices and technologies for dynamic maps, aimed at supporting operators and interactions between users and CCAM technologies.
- The creation of devices such as interfaces and other tools aimed at implementing the ability of users to interact with CCAM. In this sense, technologies are also included, such as surveillance and rapid intervention systems, to allow operators to maintain control of CCAM in the presence of anomalous conditions.

CAV performance and interactions

The way AVs are expected to behave while interacting with other vehicles and road users is still a matter of research. A unified approach is considered critical in order to ensure the compatibility of all vehicle types with the CCAM ecosystem and the minimization of discrepancies that may be caused due to different models and approaches used by vehicle manufactures (Papadimitriou et al., 2022).

Furthermore, CAVs' interactions with other vehicles and road users in mixed traffic is currently investigated. Numerous traffic and human factors are involved in the interaction with other vehicles or pedestrians (including VRUs). Unpredictable behaviour of pedestrians may lead to conflicts, while lack of transparency in the AV intention (e.g., to yield) may reduce trust and induce stress and confusion to pedestrians (Papadimitriou et al., 2022). Besides pedestrians, cyclists' interactions with AVs should also be considered. Bjørnskau et al. (2023) and Vlakfeld et al. (2020) showed that pedestrians and cyclists tended to yield to AVs more than to traditional cars. However, if the AV can communicate its intentions to the cyclists, they yield less often (Vlakfeld et al., 2020). Studies on AV-pedestrian interactions showed that pedestrians need the AV to express in some way that they have been detected (Schieben et al., 2019). For the EU project CityMobil2 (Madigan et al., 2019) the interactions of several road users with AVs were analysed with video data in Trikala in Greece and La Rochelle in France. The results showed that interactions of other road users with AVs 'generally adhered to existing interaction patterns. However, in cases of unpredictable situations of the AV and for very narrow road infrastructures, there might be risks of near-miss events with VRUs (Madigan et al., 2019). These results imply that CCAM services must accurately predict the behaviour of other road users and communicate their intentions not only implicitly (by driving dynamics), but also explicitly (visually by symbolic icons or textual messages).

For this reason, external Human Machine Interfaces (eHMIs) of AVs that communicate with other road users is a current matter of research. Some knowledge gaps might exist regarding communication's optimal features to ensure safe interactions (Dey et al., 2020). However, there are several reasons for and against eHMIs that partly contradict themselves. For instance, some authors argue that vehicle dynamics (implicit communication) are so important, that there is no need for explicit communication. Others argue that eye contact between VRUs and drivers has a crucial role in current traffic, which is why eHMIs for CAVs must fill this gap of social interaction (Dey et al., 2020). Nevertheless, communication of CAVs' intention is an issue that is yet to be fulfilled.

Technology

Interoperability and standardization of technical components and interfaces is widely recognized as a requirement in order to facilitate CCAM large-scale deployment. Communication is another critical technological brick of CCAM and significant advances are expected in the recent future. From the projects' overview it is clear that research is focused on safety standards, fusion systems, sensors, and HMIs and although critical aspects are already addressed, advances are also expected to enhance their performance and achieve the desired quality. Gaps are also recognized concerning big data management and the required computation power to process them. Yet, advanced technologies like 5G, IoV and cloud computing are currently researched providing promising results to address such issues.

Infrastructure

Several CCAM integration aspects were recognized concerning the infrastructure in the previous sections. Infrastructure adaption will require high initial cost in order to ensure safety for the operation of CAVs. Furthermore, new traffic management will be required and there is a research focus on addressing how CAVs will cooperate with the Traffic Management Centre. Furthermore, infrastructure may be vulnerable to externalities causes either by natural causes or human and external interference (e.g., vandalism). These are issues that need to be imperatively addressed in order to ensure the safety of operations of all components of the infrastructure. Lastly, the regulatory framework regarding the obligations of infrastructure players is still missing.

Shareability

Shareability is expected to boost CCAM's benefits to its full potential. Yet, it encompasses some risks. Several issues that are critical to be addressed concerning shared mobility concern flexibility in schedules and coordination, risk of attacks and insurance problems (Aguilera, 2019). Furthermore, lack of personal space may be a barrier towards large-scale deployment while discussion is also focused on the safety regulations accompanied with rear seat designated to children. Thus, parents may be reluctant to use shared mobility options (Grush & Niles, 2018), which may also be the case for others. As pointed out earlier, increased accessibility to on-demand services may act as a barrier to achieve the full potential of the benefits of large-scale CCAM deployment since it may lead to increased demand and congestion.

3.3.3 User acceptance

From a user perspective, AVs and CCAM could experience barriers in terms of acceptance and usage. Related to this, the SINFONICA deliverable D1.1 – 'Mobility needs of European citizens', provides an overview of mobility needs and requirements directed to CCAM that derive from combining a person's individual and situational factors when using mobility services (Anke & Ringhand, 2023). Future CCAM public transport systems, such as shared automated vehicles and mobility on demand, mitigate transport poverty and provide opportunities for improved accessibility and availability of transportation options (Shaheen et al., 2022). However, if equity and inclusion aspects are not considered when designing, planning, or installing those systems, contrary effects might occur, and acceptance cannot be guaranteed. Figure 4 shows four groups of mobility needs that are relevant for CCAM: availability, accessibility, affordability, and acceptability (Anke & Ringhand, 2023). Especially the last one, acceptability, is very important to deploy CCAM on a societal level.

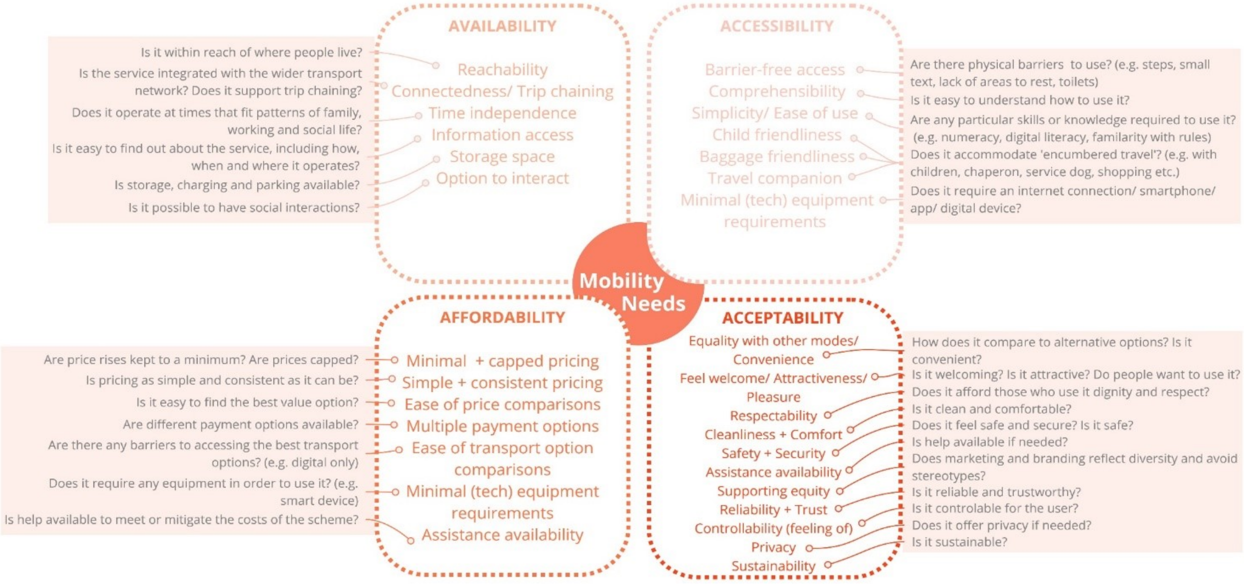


Figure 4: Mobility needs in SINFONICA D1.1 (Anke & Ringhand, 2023), adapted from Arup, Urban Transport Group (2022)

Deliverable D1.1 describes the approach of acceptance through technology adoption: "In the context of acceptance of AVs, technology adoption theories like the technology acceptance model (TAM) (Davis et al., 1989) and the unified theory of acceptance and use of technology (UTAUT) (Venkatesh et al., 2003) have gained importance. Studies have already demonstrated technology acceptance as a predictor for the intention to use autonomous bus shuttles (e.g., Wicki et al., 2019). Following technology adoption theories, the main factors for the adoption of CCAM are performance expectancy, reliability, security, privacy, and trust. Trust, as one factor in the context of technology acceptance, expresses the user's willingness to take a vulnerable position by using the technology due to the expectation of a positive outcome/experience (Mayer, 1995 as cited in Kaur & Rampersad, 2018) . As Kaur & Rampersad (2018) demonstrated, trust positively influences the adoption of driverless cars. Furthermore, the results of Launonen et al. (2021) indicate that attitudes towards autonomous vehicles are more positive if trust in technology, in general, as well as the perception of safety and security, are high. For large-scale deployment of CCAM this implies that users' trust must be increased by participatory approaches that include citizens and stakeholders."

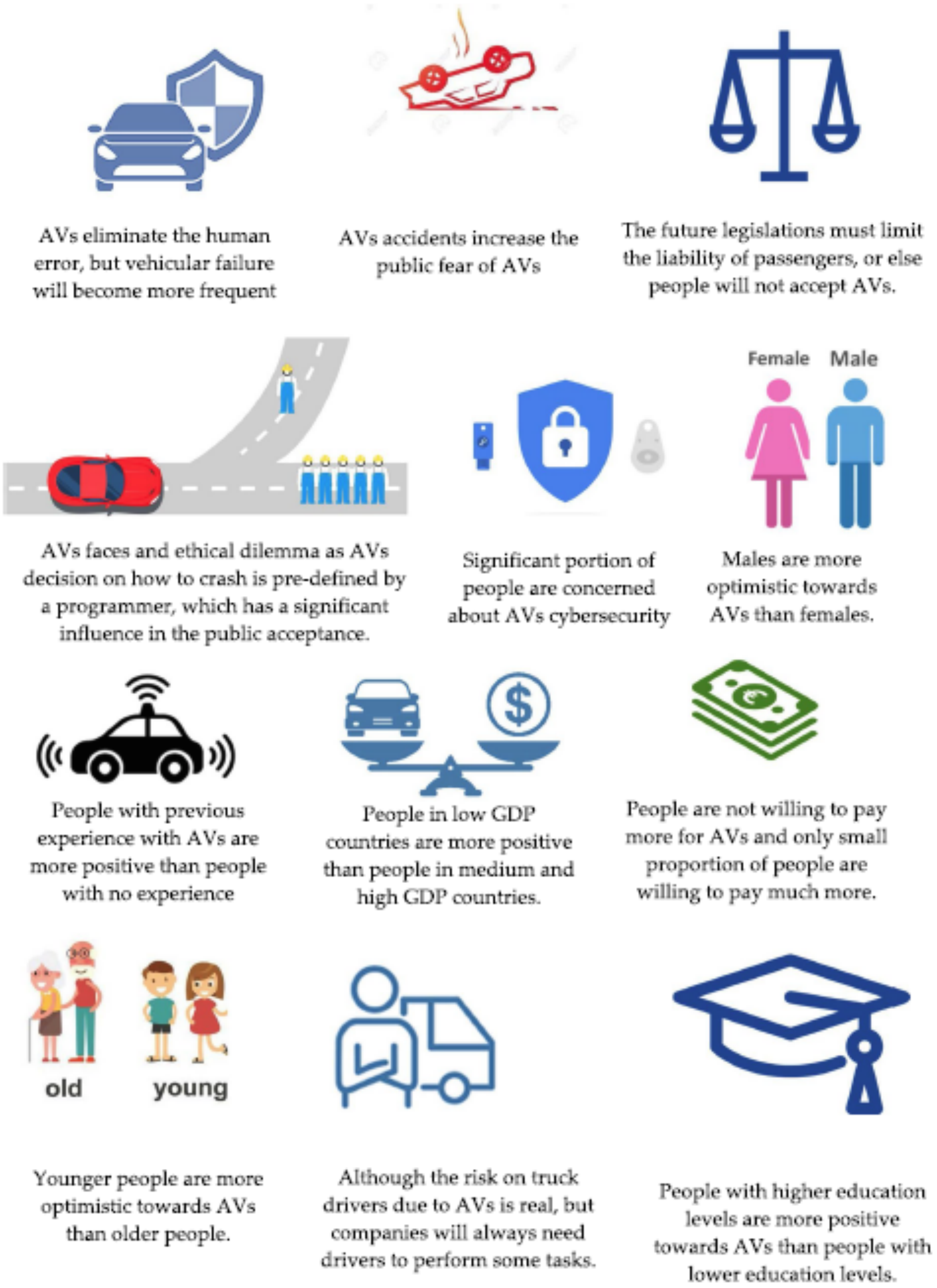
Users' expectations, perception, and acceptance of AVs present great variations in research studies (Papadimitriou et al., 2022). Accordingly, perceived safety and reliability of AVs as well as the uncertainty of moral decision-making by AVs are prominent factors that might affect AVs' widespread public acceptance and lead to mistrust and scepticism.

The purchase price of individual AVs as well as shared and on-demand mobility services deploying AVs will play crucial role in public acceptance and willingness to pay. Of course, willingness to pay and use will also depend on the effectiveness and reliability of the technology as well as on the accessibility to the technology and services (Bansal et al., 2016; Webb, 2019). Nevertheless, it is expected that AVs and CCAM services cost will decrease with higher AVs penetration rate (including mass production) and CCAM large-scale deployment followed by public acceptance.

Several researchers examined the acceptance and acceptability of shared automated vehicles and although there is no consensus about how socio-economic and demographic variables will influence the large-scale deployment of CCAM, they should certainly be further researched, as will be done in the SINFONICA co-creation steps, since several variables seem to have diverse effects (de Paepe et al., 2023).

Besides the acceptance of an individual user of CCAM services, the acceptance of other road users is also very important for large-scale deployment of CCAM. On the one hand, this concerns concrete interactions of individual persons or objects with CCAM or AVs. On the other hand, public and social acceptance are also key factors to ensure that CCAM will further success.

As mentioned in the beginning of this subchapter, the societal and public acceptance of CCAM and AVs is very crucial for the large-scale deployment. Othman (2021) made a review on studies and findings covering the public acceptance and perception of AVs. These included the influences of safety, ethics, liability, regulations, and the recent COVID pandemic on the public acceptance of AVs. The main conclusions are shown in Figure 5.



AVs eliminate the human error, but vehicular failure will become more frequent

AVs accidents increase the public fear of AVs

The future legislations must limit the liability of passengers, or else people will not accept AVs.

AVs faces and ethical dilemma as AVs decision on how to crash is pre-defined by a programmer, which has a significant influence in the public acceptance.

Significant portion of people are concerned about AVs cybersecurity

Males are more optimistic towards AVs than females.

People with previous experience with AVs are more positive than people with no experience

People in low GDP countries are more positive than people in medium and high GDP countries.

People are not willing to pay more for AVs and only small proportion of people are willing to pay much more.

Younger people are more optimistic towards AVs than older people.

Although the risk on truck drivers due to AVs is real, but companies will always need drivers to perform some tasks.

People with higher education levels are more positive towards AVs than people with lower education levels.

Figure 5: Main conclusions of Othman (2021) on public acceptance of AVs

3.3.4 Regulatory and legislative framework

The lack of a common framework for AV deployment may have significant impact on AV safety and security (Li et al., 2019). Higher levels of automation are expected to redistribute the responsibilities of individuals and organizations involved in AVs' manufacture, deployment, regulation and use. Respectively, vehicle failure conditions will be subject to new responsibility and liability aspects which are yet to be explicitly defined in future legislation. Furthermore, clear and fair distribution of responsibilities, obligations, culpability, accountability and liability across the different actors is identified as a key aspect to be addressed in order to ensure safety of AVs and public acceptance (Papadimitriou et al., 2022). However, the immaturity of and public trust in the existing technologies are considered as barriers in formulating regulations. Policies for CCAM deployment should encourage R&D innovation ensuring at the same time safety and reliability, and paving the way towards public trust and acceptance through performance, process, and purpose information about the technology (Li et al., 2019).

Furthermore, this situation triggers changes to the insurance framework which is necessary to take into consideration the shift in liability from drivers to CAVs, data sharing issues and the shared mobility market (Kester, 2022).

Cybersecurity and data privacy regulations are essential to any ICT infrastructure. Great efforts are made to address cybersecurity and data privacy issues concerning ITS, CAVs and IoV (Benyahya et al., 2022). Although a complete secure vehicular system seems to be impossible, an effective strategy to address and react to cyber-attacks' effects is imperative (Linkov et al., 2019). Therefore, current state of legislation and standards can be treated as a gap towards the large-scale deployment of CCAM, since a certification model using security- and privacy-by-design approaches to establish a thorough security audit is still missing (Benyahya et al., 2022). The production of huge amount of data, most of which may be considered personal data such as vehicles' location, passengers' identities, etc., may affect potential CCAM users' attitude and impact negatively to CCAM large-scale deployment. Although privacy can technically be ensured by current practices and techniques, legislation shall be adapted to address all possible scenarios of data sharing and processing (Benyahya et al., 2022).

Nevertheless, the importance of open data policies regarding valuable datasets related to AVs (spatial data, event-based data, etc.) is widely recognized in order to ensure ethical and safe deployment. Nevertheless, data from field tests of industry actors are not accessible hindering this way the large-scale deployment.

Merriman et al. (2021) have recognized several gaps in the current training for drivers of AVs focusing on Levels 1, 2 and 3 automation. Nevertheless, as Level 4 AVs are being developed and tested, driver training will be required in order to ensure the safe operation of AVs by human drivers. The type of driving license required for operating AVs still unclear and future research is needed to identify the training requirements for drivers of Level 4 AVs.

Safety in the context of AVs involves safety engineering and human factors issues as well as ethical issues. Papadimitriou et al. (2022) argues that a common understanding of machines' ethical and safety behaviour is necessary in order to achieve consistent behaviour of different types of AVs in different situations. Standards and regulations to address the inherently interdisciplinary aspect of safety, including ethical reasoning and decision-making, in the context of AVs have not yet been comprehensively addressed. Thus, further research in the ethical dimension of the operation of AVs as well as the methods, models and algorithms already proposed is imperative in order to promote a fair and ethical decision-making approach and minimize negative effects on public acceptance.

3.3.5 Aggregated results

Table 3 presents the aggregated results from the gaps and barriers towards large-scale CCAM deployment analysis.

Table 3: Gaps and barriers towards large-scale CCAM deployment

Field		**Gaps and barriers**	
ICT	Connectivity & communication systems	Latency IoV Communication protocols Security & privacy	Quality of Service Financial cost Lack of Infrastructure Signal reliability
	Software & Hardware	Interoperability System failure Sensors' performance Big data Processing speed and transfer Data storage Communication	Cost Cybersecurity Advanced algorithms • Perception • Data fusion • Planning • Decision-making
	Navigation	Connectivity and Communication Latency Positioning Mapping Sensors Advanced algorithms	Object recognition and avoidance Data fusion Path planning Decision making Safety performance
Safety	CAV performance and interactions	Common approach to safety behaviour of CAVs	Interaction of CAVs with other road users
	Technology	Interoperability Standardization Communication systems Fusion systems	Sensors Big data Recognition Computation power
	Infrastructure	Cost Traffic management	Infrastructure requirements Regulatory framework

Field		Gaps and barriers	
		Vulnerability of infrastructure	
	Shareability	Risk of attacks Personal space Insurance issues	Suitability for children Ownership Accessibility
User acceptance	Perception	Perceived safety Reliability & Ethics Socio-economic and demographics Security and privacy	Personal data sharing Distrust Unaware of CCAM real benefits Unfamiliarity
	CAV performance and services	Transparency of intention of CAVs Unwillingness to use if decision making is not based on protecting the passengers	Liability of passengers Unwillingness to use Shared mobility
	Cost	Shared services cost	Individual vehicles cost
Regulatory and legislative framework	Certifications / regulations	Common framework for CCAM deployment Certification model for cybersecurity & data privacy Open data policies Standards for safety behaviour of CAVs System failure	Clear and fair distribution of obligations, culpability and liability Insurance framework Training for drivers of CAVs (type of driving licence) Immaturity of technology Public trust
	Ethics	Standards for ethical and safety design principles of CAVs Models and algorithms for ethical reasoning and choice	User acceptance

3.4 Critical assessment and comparison between gaps and barriers towards large-scale CCAM deployment and stakeholders’ needs and requirements

Gaps and barriers can be strongly interrelated with the stakeholders’ needs, requirements, goals and dilemmas. Focusing on the ICT barriers, if comprehensively addressed, they can pave the way towards large-scale CCAM deployment. For example, if connectivity and communication systems are capable to ensure the desired reliability and security of the CCAM system, achieving at the same time the required latency for critical applications, safety demonstrations of CCAM solutions, which is considered an important factor towards validation of CCAM and users’ acceptance, will be potentially feasible in more unpredictable and complex real-world scenarios. Furthermore, interoperability and standardization of components, interfaces and services would enable stakeholders to effectively and efficiently achieve the integration of CCAM assets into their infrastructure and road network in a cost-efficient way. Focusing on navigation, the standardization and optimization of ODD could act as an enabler to achieve the desired performance of CAVs focusing on Level 4 automation, until Level 5 automation will be able to be addressed. Respectively, European Commission (2022) has released rules regarding uniform procedures and technical specifications for the type-approval of the ADS of fully automated vehicles, addressing ADS performance requirements for four uses cases, namely the ADS performing the DDT under nominal traffic scenarios, under critical traffic scenarios (emergency operation), at ODD boundaries, and under failure scenarios.

Furthermore, EC (2021b) has laid down harmonised rules of AI which is a rapidly developing field that requires novel forms of regulatory oversight and a safe space of experimentation, while ensuring responsible innovation and integration of appropriate safeguards and risk mitigation measure. Thus, Member States should be encouraged to establish AI regulatory sandboxes to facilitate the development and testing of AI systems under strict regulatory oversight before they are publicly available (European Commission, 2021b).

As far as safety barriers and gaps are concerned, they are also interrelated with ICT factors as well as with stakeholders' aspects of needs and goals. Demonstrating a common safety behaviour approach for CAVs as well as safety of the CCAM technology in terms of communication, computation power, recognition etc., ensuring the safe interactions between all road users, will foster CCAM deployment. Adoption of the infrastructure as well as related cost and safety implications are also addressed both from the perspective of barriers and gaps as well as needs to be addressed for CCAM stakeholders. Safety of shared services are also interrelated with the stakeholders' need to ensure the safety of operations and should therefore comprehensively addressed. The same is also considered about traffic management which needs to be adapted and reformed taking into consideration CCAM requirements and stakeholders needs and expectations, which are focused on the safety of operations and clear objectives.

Recently, a Dutch policy document setting the speed limits of automated vehicles depending on the context and the level of automation was published. Speed limits are presented in Table 4. This is a proof of national initiatives aiming to regulate automation in road transport and paves the way towards large-scale CCAM deployment. More Member States should be encouraged to proceed to enabling automation on road transport regulation adaptations and releases.

Table 4: Speed limits for automation (adapted from Ministerie van Infrastructuur en Waterstaat, 2023)

Automation on highways	**Speed limit**
Assisted driving comfort, slow speed (traffic jam)	<70kmh
Assisted driving safety	70-100kmh

Automation on slower speeds	**Speed limit**
Limited, transportation of goods or valet parking	<25kmh
Red carpet, transportation of goods	25-50kmh

Automation on highways	Speed limit	Automation on slower speeds	Speed limit
Partly automated, hands off, eyes on	70-100kmh	Residential areas, first and last mile transportation of goods and people	<30kmh
Partly automated, hands off, eyes off *light*	70-100kmh, right lane	Bus-like system, transportation of goods and people on a predefined route	<50kmh
Automated, hands off, eyes off *plus*	<130kmph	Taxi-service. transportation of goods and people in urban areas	<50kmh

The future of CCAM will finally rely on the users' acceptance. Users' perception will strongly rely on their experience, knowledge and familiarization with CCAM. Perceived safety, reliability and ethics are some factors that have an effect on users' acceptance and may lead to distrust and non-willingness to use CCAM solutions. On the other hand, if fully aware of the benefits that CCAM has the potential to bring, they might be positively affected towards using CCAM solutions. Building knowledge and providing training schemes and public awareness campaigns are already realized for addressing users' acceptance related risks.

3.5 Ongoing research to foster large-scale CCAM deployment

Research is ongoing in the field of CCAM in EU focusing in seven clusters:

- Key enabling technologies
- Vehicle technologies
- Integrating vehicles in the transport system
- Societal aspects and user needs
- Large-scale demonstrations
- Validation
- Coordination

Table 5 presents an overview of the ongoing research projects launched within 2021-2027 Horizon Europe, which SINFONICA deliverables will inform. The SINFONICA project is also listed focusing on societal aspects and user needs.

Table 5: Ongoing EU research projects launched within 2021-2027 Horizon Europe

Project title	Acronym	Duration	Cluster	Objectives	Website
Trustworthy AI for Connected, Cooperative and Automated Mobility	AI4CCAM	1/2023 – 12/2025	Key enabling technologies	Develop an open environment for integrating trustworthy-by-design AI models of vulnerable road user behaviour anticipation in urban traffic conditions, and accounting for improved road safety and user acceptance	link
AI-based CCAM: Trustworthy, Explainable, and Accountable	AIthena	11/2022 – 10/2025	Key enabling technologies	Build Explainable AI (XAI) in CCAM development and testing frameworks, researching three AI pillars: data (real/synthetic data management), models (data fusion, hybrid AI approaches), and testing, demonstrating the methodology in four use cases: perception, situational awareness, decision and traffic management.	link
Augmenting and Evaluating the Physical and Digital Infrastructure for CCAM deployment	AUGMENTED CCAM	9/2022 – 12/2025	Integrating vehicles in the transport system	Extend and harmonize Physical, Digital and Communication Infrastructure classification and support levels mapping requirements and adaptations, to advance its readiness for large-scale deployment of CCAM solutions for all. Findings' assessment on functional safety, driving behaviour, environmental footprint, service reliability, trust and security, supported by simulation models deploying AI and Big Data techniques and HD maps	link
Safety systems and human machine interfaces oriented to diverse population towards future scenarios with increasing share of highly automated vehicles	AWARE2ALL	11/2022 – 10-2025	Vehicle technologies	Address the new safety challenges posed by the introduction of Highly AVs in mixed road traffic, through the development of inclusive and innovative safety (active and passive) and HMI (interior and exterior) systems	link

Project title	Acronym	Duration	Cluster	Objectives	Website
Fleet and traffic management systems for conducting future cooperative mobility	CONDUCTOR	11/2022 – 10/2025	Integrating vehicles in the transport system	Design, integrate and demonstrate advanced, high-level traffic and fleet management that will allow efficient and globally optimal transport of passengers and goods, while ensuring seamless multimodality and interoperability, through dynamic balancing and priority-based management of vehicles. Next generation simulation models and tools development enabled by machine learning and data fusion, integration into a common, open platform, and validation in three use cases: traffic management with inter-modality, demand-response transport, and urban logistics.	link
Continuous and Efficient Cooperative Trust Management for Resilient CCAM	CONNECT	9/2022 – 8/2025	Key enabling technologies	Address the convergence of security and safety in CCAM by assessing dynamic trust relationships and defining a trust model and trust reasoning framework based on which involved entities can establish trust for cooperatively executing safety-critical functions	link
ReliablE in-Vehicle pErception and decision-making in complex environmental conditionS	EVENTS	9/2022 – 8/2025	Vehicle technologies	Create a robust and resilient perception and decision-making system, able to tackle challenges CAVs may encounter caused be unexpected situations, where the normal operation of CAVs is close to be disrupted, e.g., ODD limit is reached due to traffic changes, harsh weather/light conditions, imperfect data, sensor/communication failures, interaction with VRUs etc.	link
Framework for coordination of Automated Mobility in Europe	FAME	8/2022 – 6/2025	Coordination	Develop and validate common methodologies and tools to facilitate the sharing of best practices and lessons learnt to support the coordination within the community of CCAM stakeholders across the complex cross-sectorial value chain needed for the organization and evaluation of large-scale demonstration and future scale-up to the impacts of CCAM solutions	link

Project title	Acronym	Duration	Cluster	Objectives	Website
Integrated 4D driver modelling under uncertainty	i4Driving	10/2022 – 9/2025	Validation	Lay the foundation for a new industry-standard methodology to establish a credible and realistic human road safety baseline for virtual assessment of CCAM systems and proposition for a set of building blocks that pave the way for a driving license for AVs, based on two central ideas: 1) a multi-level, modular and extendable simulation library that combines existing and new models for human behaviour, in combination with 2) an innovative cross-disciplinary methodology to account for the huge uncertainty in both human behaviours and use case circumstances.	link
Enhancing Integration and Interoperability of CCAM eco-system	IN2CCAM	11/2022 – 10/2025	Integrating vehicles in the transport system	Define concepts for optimal fleet and traffic management in the CCAM ecosystem; develop suitable strategies for traffic optimization based on real-time traffic situations and the prediction of immediate future traffic conditions; design, test and implement a structure at both physical and digital level, favouring interoperability; design, test and implement advanced simulations and digital twins models for new traffic management strategies; explore and promote new lines of cooperation, governance and business models favourable to the effective integration of CCAM services and technologies in traffic management	link
A leap towards SAE L4 automated driving features	MODI	10/2022 – 3/2026	Large-scale demonstrations	Accelerate the introduction of CCAM vehicles for logistics by demonstrations and to overcome barriers for the roll-out of automated transport systems and solutions in logistics	link
MethOds and tools for comprehensive impact Assessment of the CCAM solutions for passengers and goods	Move2CCAM	9/2022 – 2/2025	Societal aspects and user needs	Encourage further research and uptake activities for CCAM, facilitate public acceptance and adoption of CCAM solutions, enhance capacity for governance and innovation in the transport and logistic sector, and ensure economic benefits for CCAM users through the connection of a multidisciplinary and multi-system network of representative actors across the whole CCAM ecosystem and the development of a novel and practical CCAM impact assessment modelling tool, which will enable	link

Project title	Acronym	Duration	Cluster	Objectives	Website
				stakeholders to discover new behavioural and operational elements on network efficiency and mobility.	
PDI connectivity and cooperation enablers building trust and sustainability for CCAM	PoDIUM	10/2022 – 9/2025	Integrating vehicles in the transport system	Identify and assess the connectivity and cooperation enablers to reach higher levels of automation and advance important Physical and Digital Infrastructure (PDI) technologies, through a multi-connectivity approach and interoperable and hybrid data management environment	link
Robust Automated Driving in Extreme Weather	Roadview	9/2022 – 8/2026	Vehicle technologies	Develop robust and cost-efficient in-vehicle perception and decision-making systems for connected and automated vehicles with enhanced performance under harsh weather conditions and different traffic scenarios, utilizing adaptive sensor fusion, early sensor noise filtering, collaborative perception, mathematically grounded sensor noise modelling and simulation-assisted methods including the development of digital twins of controlled and real-world environments	link
SELF assessment, protection & healing tools for a trustworthy and resilient CCAM	SELFY	6/2022 – 5/2025	Key enabling technologies	Promote a safe and secure operation amongst CCAM vehicles and mobility systems and services, enhancing trust and end-user adoption of CCAM solutions. Development of a toolbox made up of collaborative solutions focusing on trust, situational awareness, resilience and data sharing	link
Social INnovation to Foster Inclusive Cooperative, connected and Automated mobility	SINFONICA	9/2022 – 8/2025	Societal aspects and user needs	Develop functional, efficient, and innovative strategies, methods and tools to engage CCAM users, providers and other stakeholders (i.e., citizens, including people with mobility challenges, transport operators, public administrators, service providers, researchers, vehicle and technology suppliers etc.) to collect, understand and structure in a manageable and exploitable way their needs, desires, and concerns related to CCAM. Co-creation of final decision support tools for	link

Project title	Acronym	Duration	Cluster	Objectives	Website
				designers and decision makers to enhance the CCAM seamless and sustainable deployment, to be inclusive and equitable for all.	
Safety assurance fRamework for connected, automated mobility SystEms	Sunrise	9/2022 – 8/2025	Validation	Develop and provide a harmonized and scalable CCAM Safety Assurance Framework that fulfils the needs of different automotive stakeholders, for a continuously evolving number of use cases and scenarios	link
Advancing Sustainable User-centric Mobility with Automated Vehicles	ULTIMO	10/2022 – 9/2026	Large-scale demonstrations	Deployment of AVs in three sites across Europe, each with 15 or more multi-vendor vehicles per site, aiming to target the operation without safety-driver on board, in fully automated mode and with the support of innovative user centric passenger services. Development of open-source APIs for seamless integration of vehicles and fleet management, set the basis for a common and reusable model for HD maps, development and validation of cross-sectoral business models, realistic, long-term transition planning design for the deployment of AVs in MaaS and LaaS	link

4. SINFONICA's CCAM taxonomy

4.1 Introduction

Bailey (1994) argues that classification is the foundation not only for conceptualization, language and speech, but also for mathematics, statistics and data analysis. Taxonomy can be defined as the science of classification which structures information of a specific domain capturing the relations between entities and providing a conceptual framework for interpretation, analysis and information retrieval (Cledou et al., 2017).

4.2 Methodology

Bailey (1994) recognizes three taxonomy development approaches: the conceptual where only concepts are classified, the empirical where only empirical entities are classified and operational which is a combination of the previous two and is widely used in practice. An operational approach can be either conceptual to empirical, where concepts are first classified based on theory, domain knowledge, or experience, and then empirical entities are identified for each concept, or empirical to conceptual, where empirical cases are first identified, analysed and grouped, and then deductively conceptualize the nature of each cluster (Nickerson et al., 2013). For the construction of the SINFONICA CCAM taxonomy, an operational hybrid approach is utilized based on literature findings, as presented in the present report, SINFONICA's deliverables, D1.1 – 'Mobility needs of European citizens' and D1.2 – 'CCAM Vocabulary and stakeholders needs and requirements', and already existing taxonomies and classifications. Thus, several concepts were initially identified and classified, and, then, empirical cases were identified and clustered accordingly.

4.3 Taxonomies in ITS and CCAM

Society of Automotive Engineers (SAE) has published reports concerning terms and definitions for terms related to cooperative driving automation for on-road motor vehicles (SAE, 2021a), and taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles (SAE, 2021b). Already mentioned, INFRAMIX EU project has proposed a simple classification scheme to classify and harmonize the capabilities of road infrastructure to support and guide AVs (Carreras et al., 2018). Cledou et al. (2017) proposed a taxonomy for planning and designing smart mobility services with the aim to serve as a tool for guiding policy makers by identifying a spectrum of mobility services that can be provided, to whom, what technologies can be used to deliver them, and what I the delivered public value justifying their implementation. Shibayama & Emberger (2020) classified new and emerging mobility services based on the role of ICT for service conceptualization and the types of innovation. Castellanos et al. (2022) proposed a taxonomy for shared mobility that can be used by policymakers, private stakeholders and academics in order to ensure a shared and common understanding of solutions under this term. Remane et al. (2016) developed a taxonomy of car-sharing business models. Damaj et al. (2021) proposed a taxonomy for Quality of Experience (QoE) in Electric CAVs with a rich set of quality indicators and a framework that facilitates the integration of QoE concepts in system development. Gupta et al. (2021) proposed a taxonomy focusing on the attacks on CAVs concerning the components and behaviour of CAVs, classifying them as attacks on authentication, communication and routing, data integrity, and data confidentiality. Furthermore, they proposed a blockchain-based CAV architecture aiming to exploit the advantages of blockchain technology to address CAV cybersecurity. Arthurs et al. (2022)

provided taxonomies for edge cloud computing use in ITS and Connected Vehicles as well as for their use cases.

4.4 SINFONICA CCAM taxonomy

The SINFONICA CCAM taxonomy was built with the use of the visual platform Miro[4] (SINFONICA CCAM Taxonomy, 2023). It is based on the findings of the present report as well as of D1.1 and D1.2. Several instances were created and presented in the following Figures. Specifically, in Figure 6 the CCAM functional areas are classified as the Operational Road Infrastructure, Digital Roads and associated Infrastructure, in-vehicle technologies and Cyber-security and Privacy. Following, in Figure 7, CCAM is classified respectively into the three inherent characteristics of CCAM, namely cooperation, connectivity and automation and accordingly analysed. In Figure 8, interrelations between stakeholders' needs, requirements, goals and dilemmas, and citizens' mobility needs towards large-scale CCAM deployment are captured. Figures 9 and 10 present stakeholders' needs and requirements, and goals and dilemmas respectively classified as operational/organizational, technical, regulatory, financial and social. Figures 11 and 12 captures the gaps and barriers towards large-scale CCAM deployment from the perspective of safety and users' acceptance respectively. Figure 13 captures the interrelations between users' characteristics and situational factors towards mobility needs and CCAM deployment, as well as users' perception and experience. Finally, large-scale CCAM deployment interrelations with stakeholders needs, requirements, goals and dilemmas, as well as users' requirements related to mobility needs, are presented along with the enabling factors, the gaps and barriers as well as other deployment related aspects in Figure 14.

It is noted that the taxonomy is expected to be enriched with new knowledge from the surveys and the participatory activities of the SINFONICA project in WP2 and WP3 and it will constitute the basis for the SINFONICA Knowledge Map which will be developed in WP4. The Knowledge Map is intended to capture in more detail the complex and strong interrelations in the CCAM ecosystem.

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[4] https://miro.com/

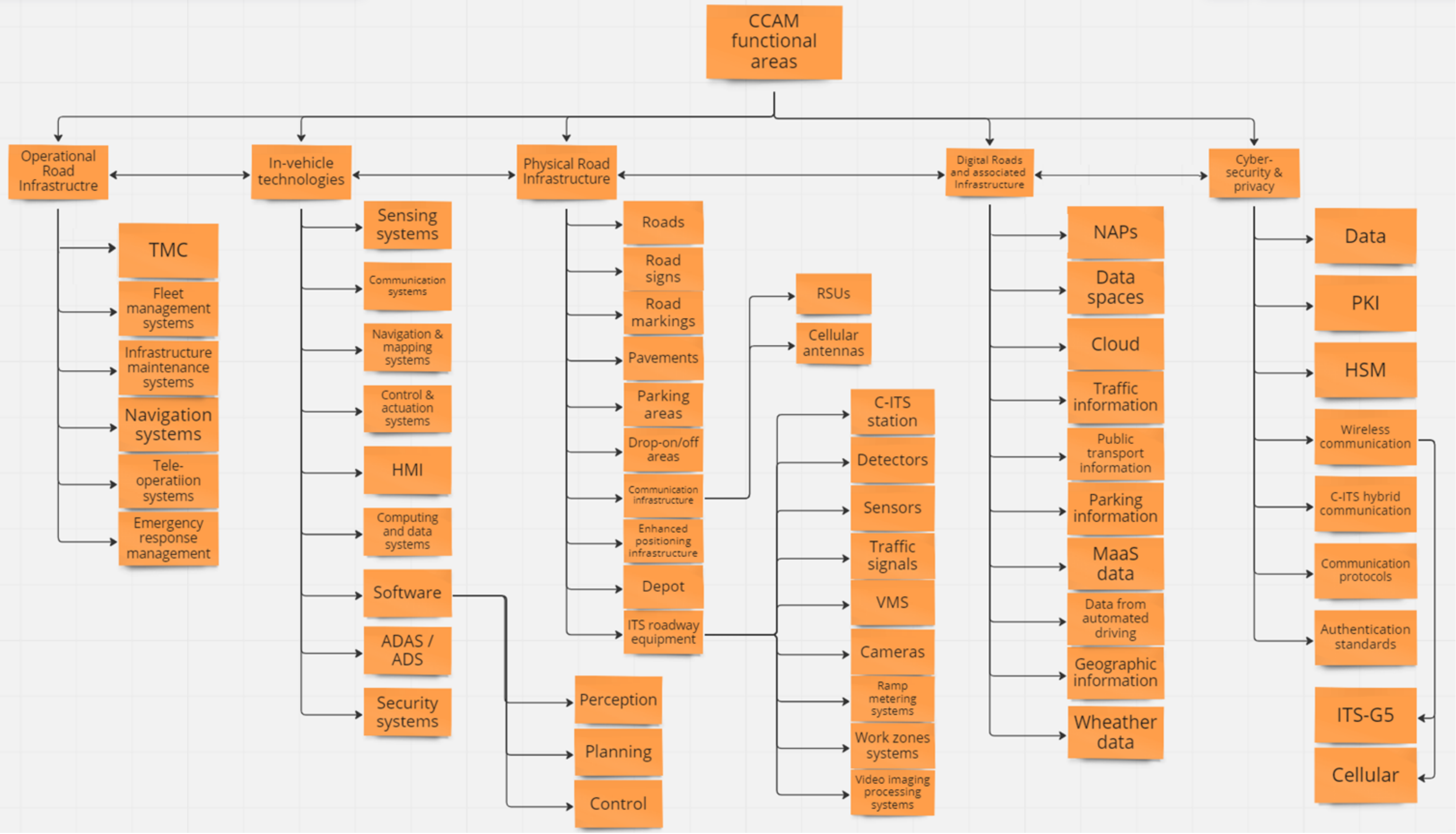

Figure 6: CCAM functional areas classification

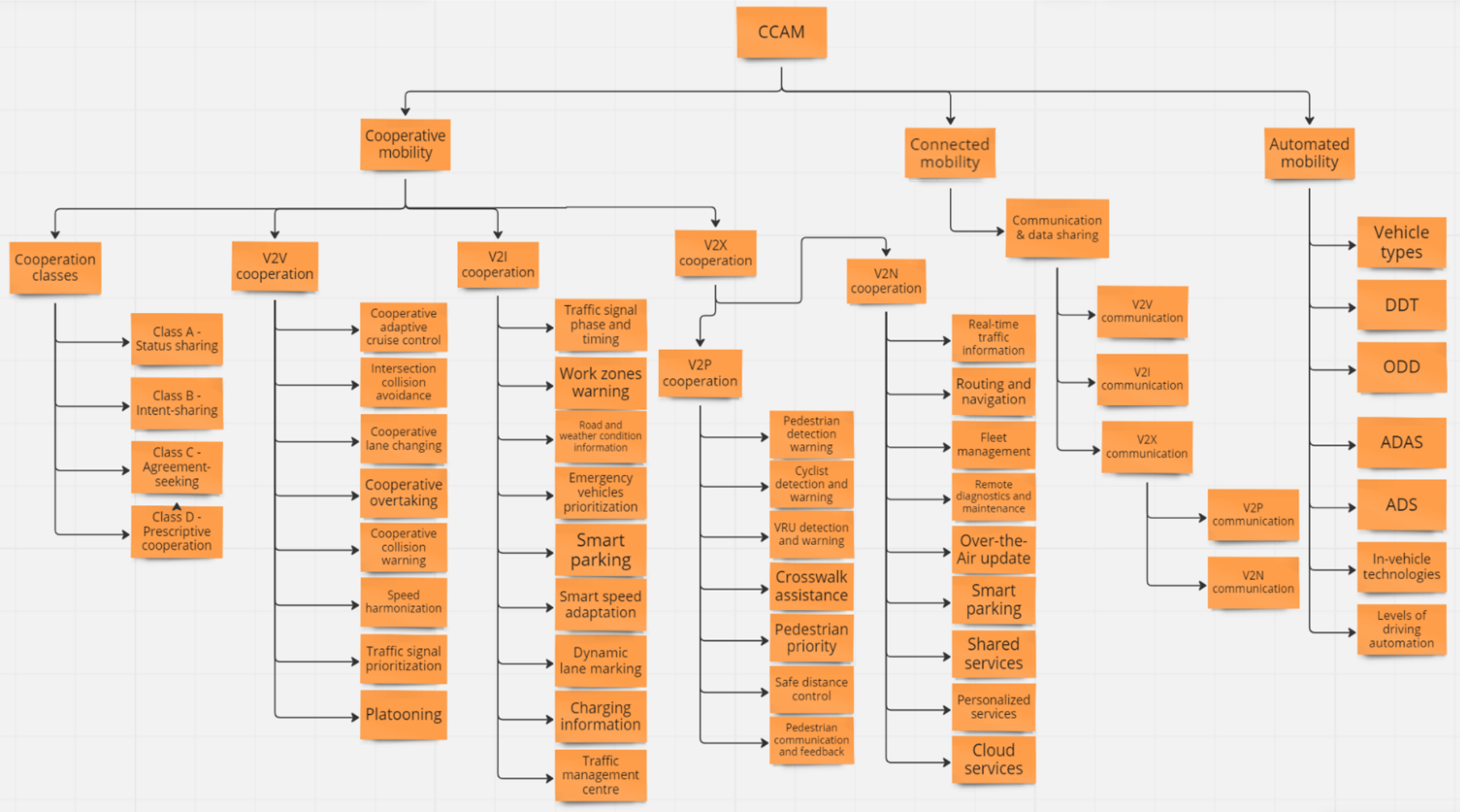

Figure 7: CCAM technologies classification scheme

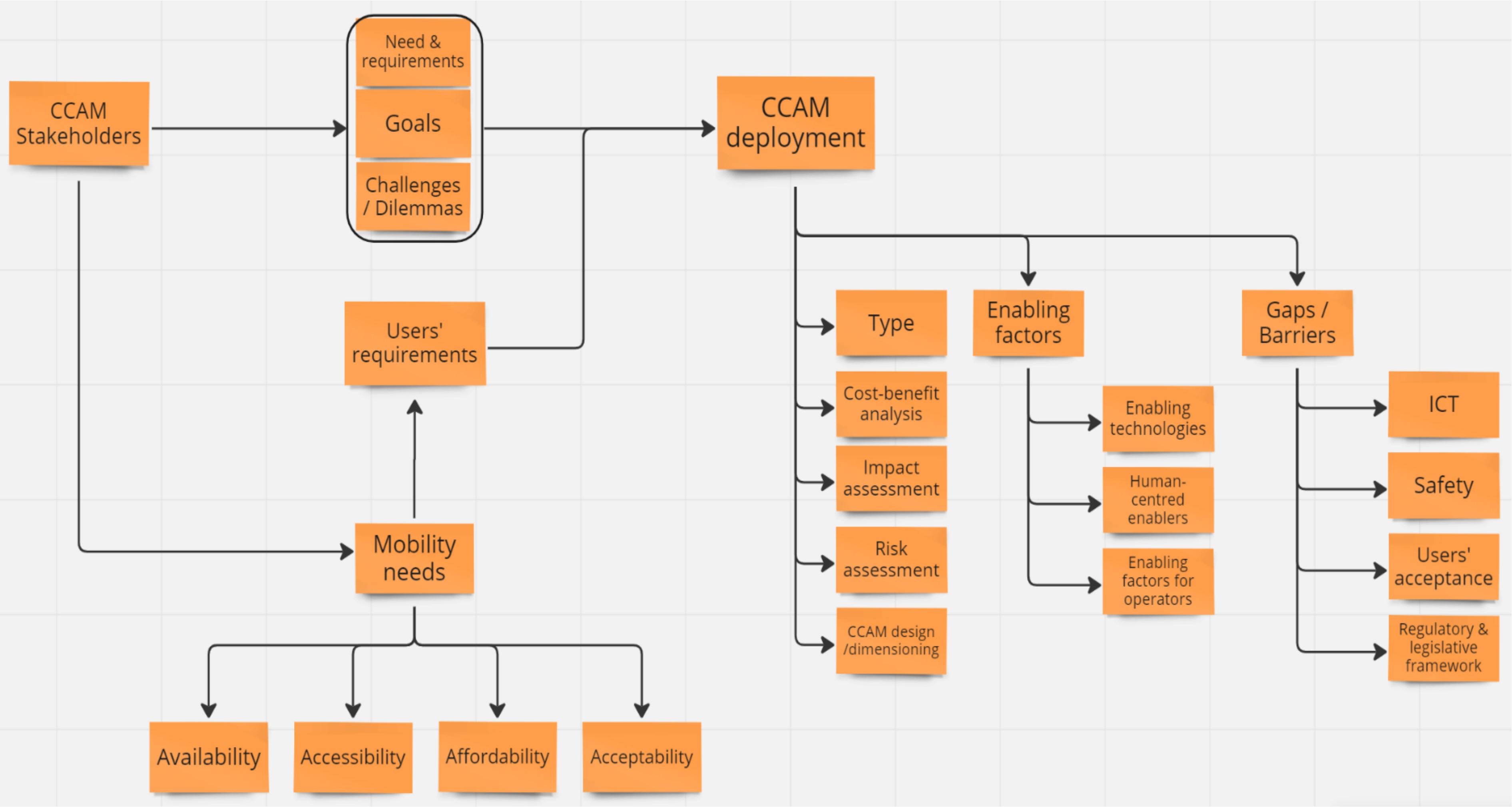

Figure 8: Inter-relationships between CCAM stakeholders' needs, requirements, goals, challenges and dilemmas, and citizens' mobility needs towards CCAM deployment

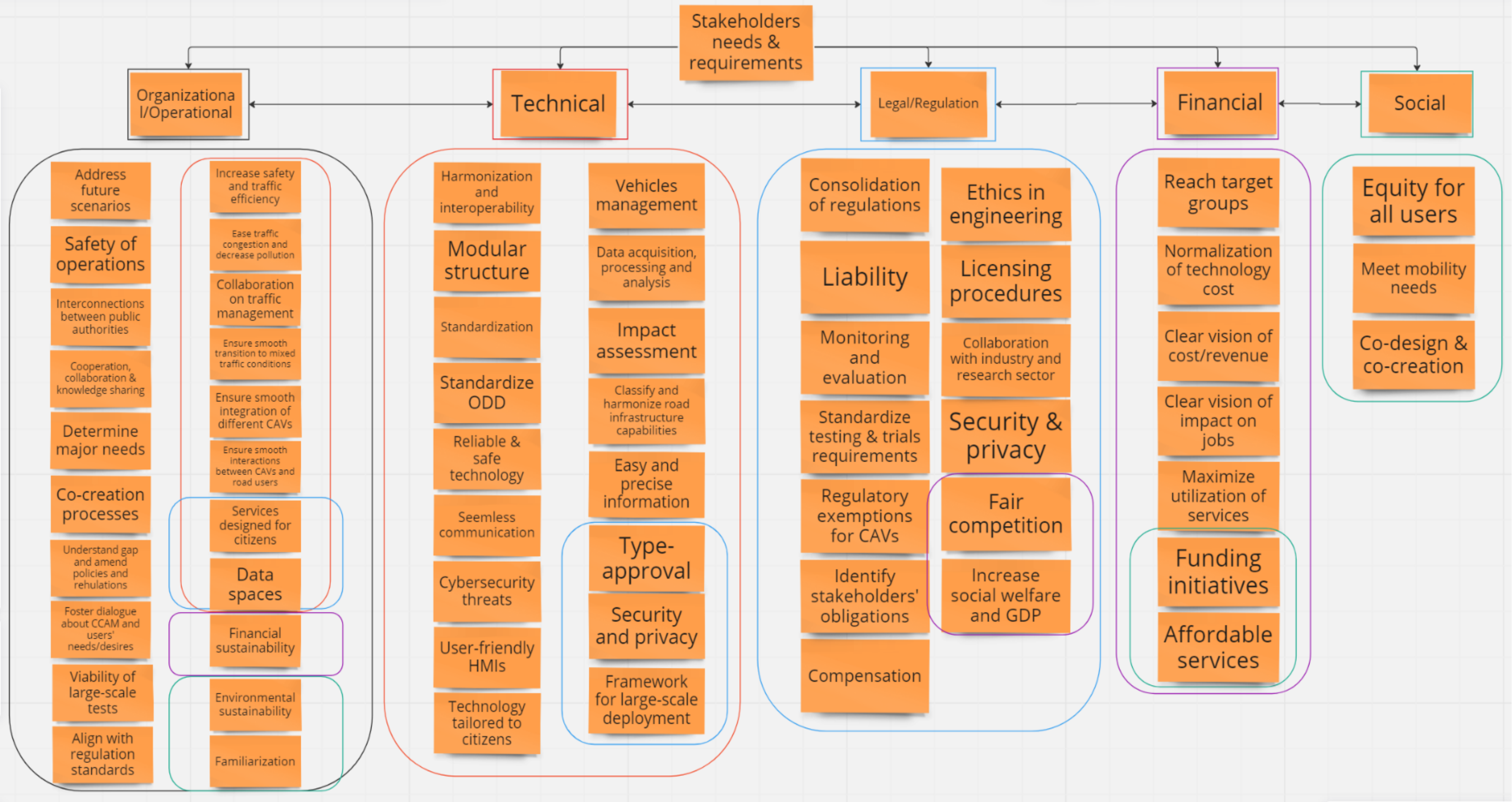

Figure 9: CCAM stakeholders' needs and requirements classification

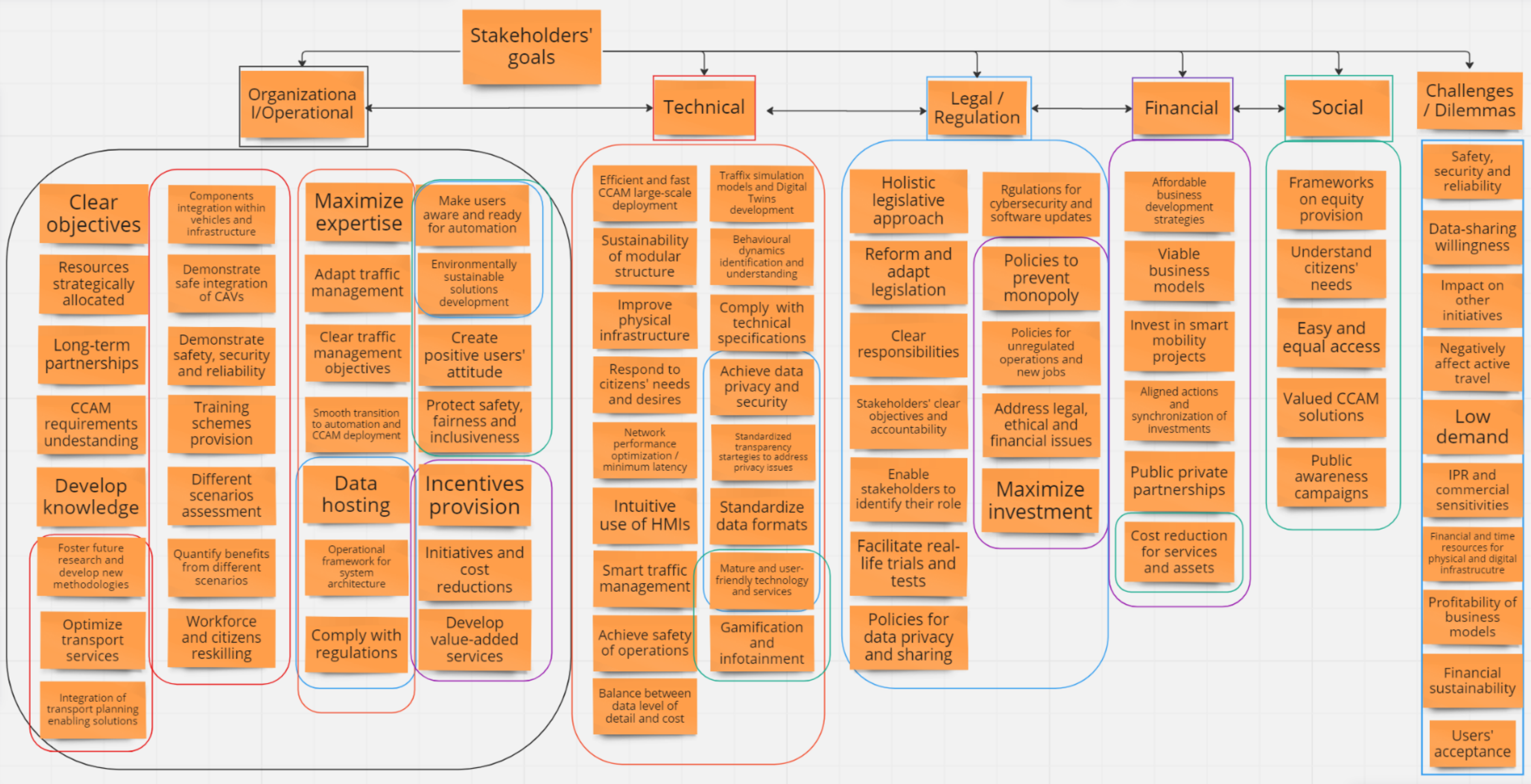

Figure 10: CCAM stakeholders' goals and dilemmas/challenges classification and inter-relationships

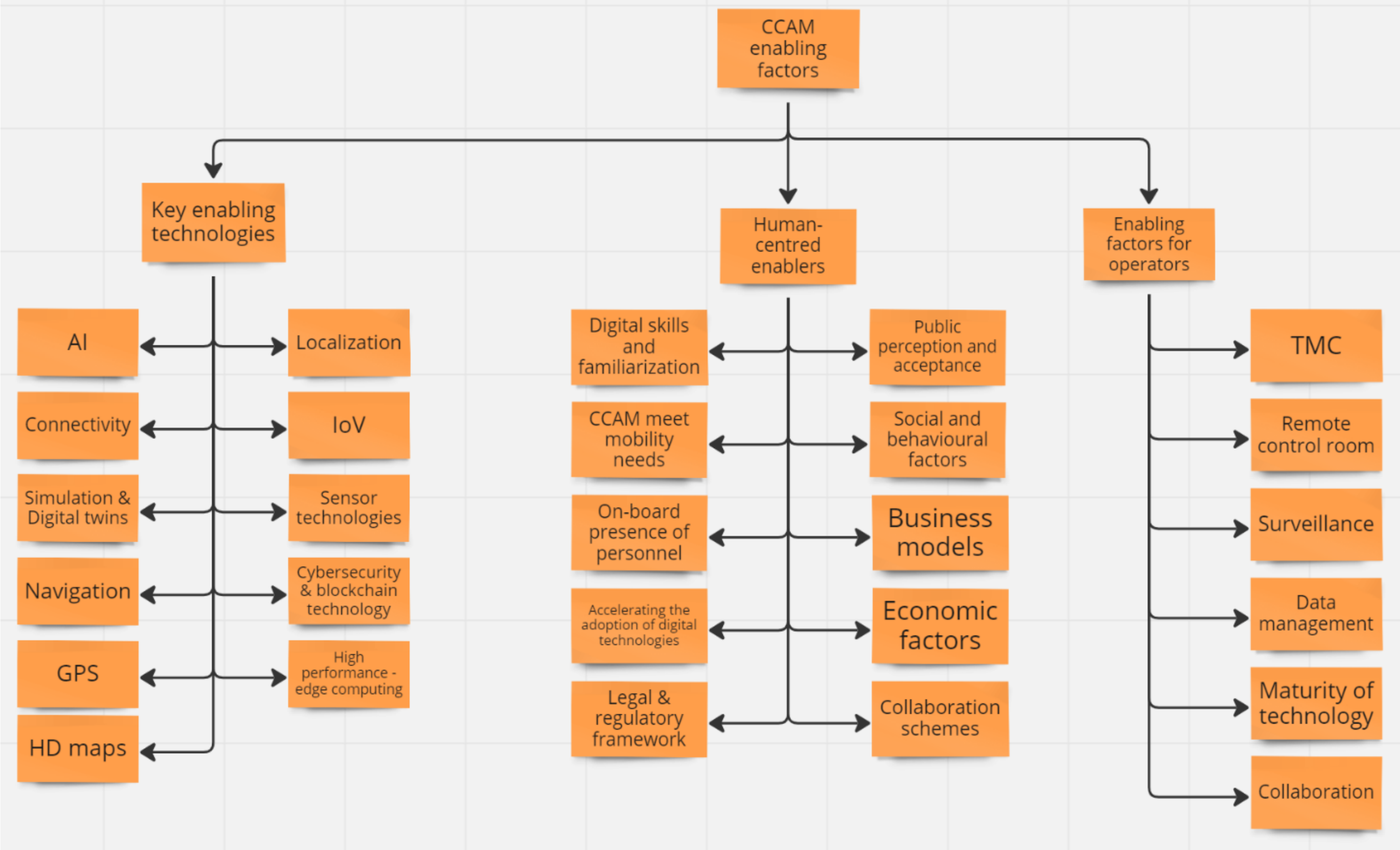

Figure 11: Enabling factors towards CCAM large-scale CCAM deployment

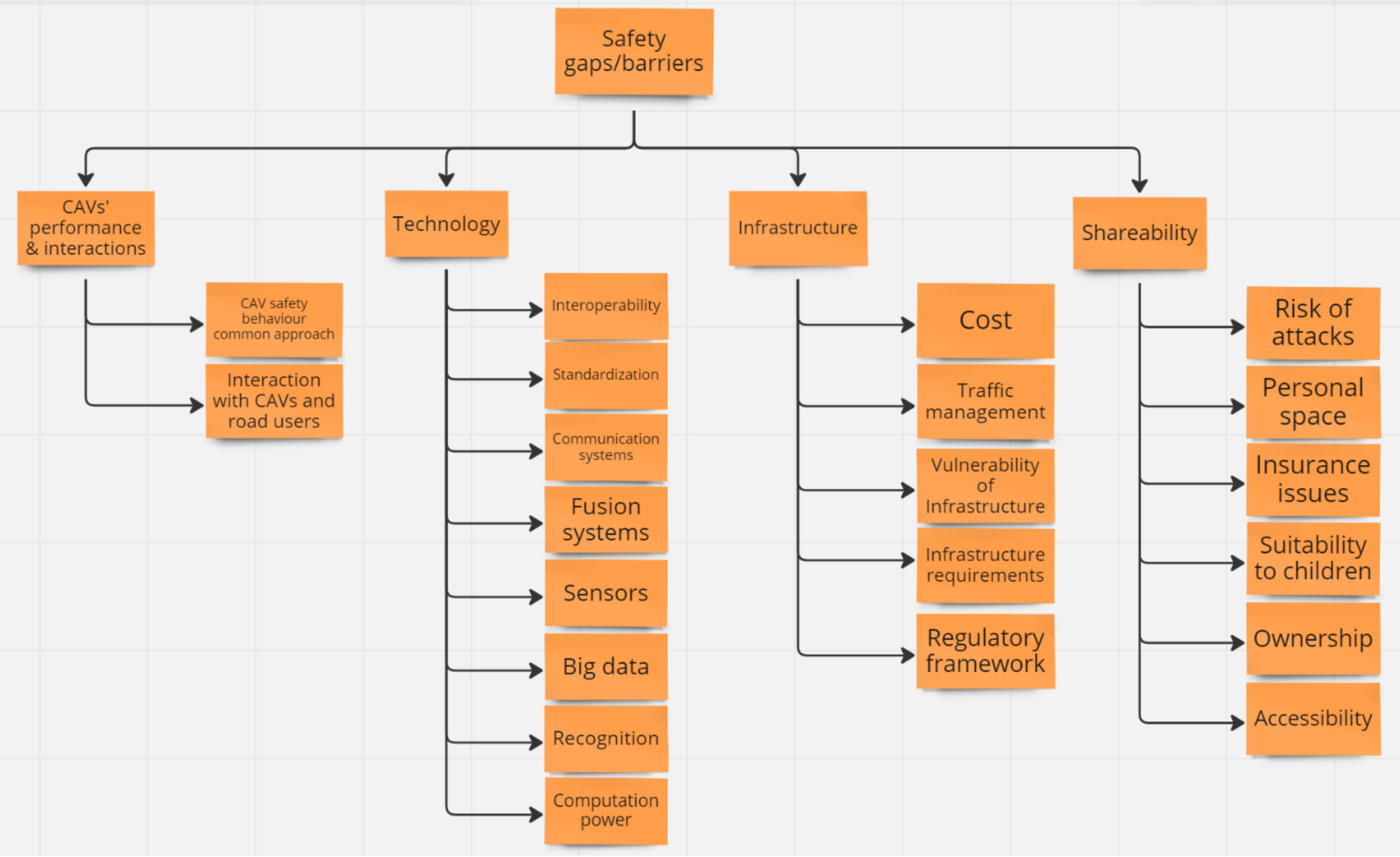

Figure 12: Classification of CCAM safety related gaps and barriers towards large-scale CCAM deployment

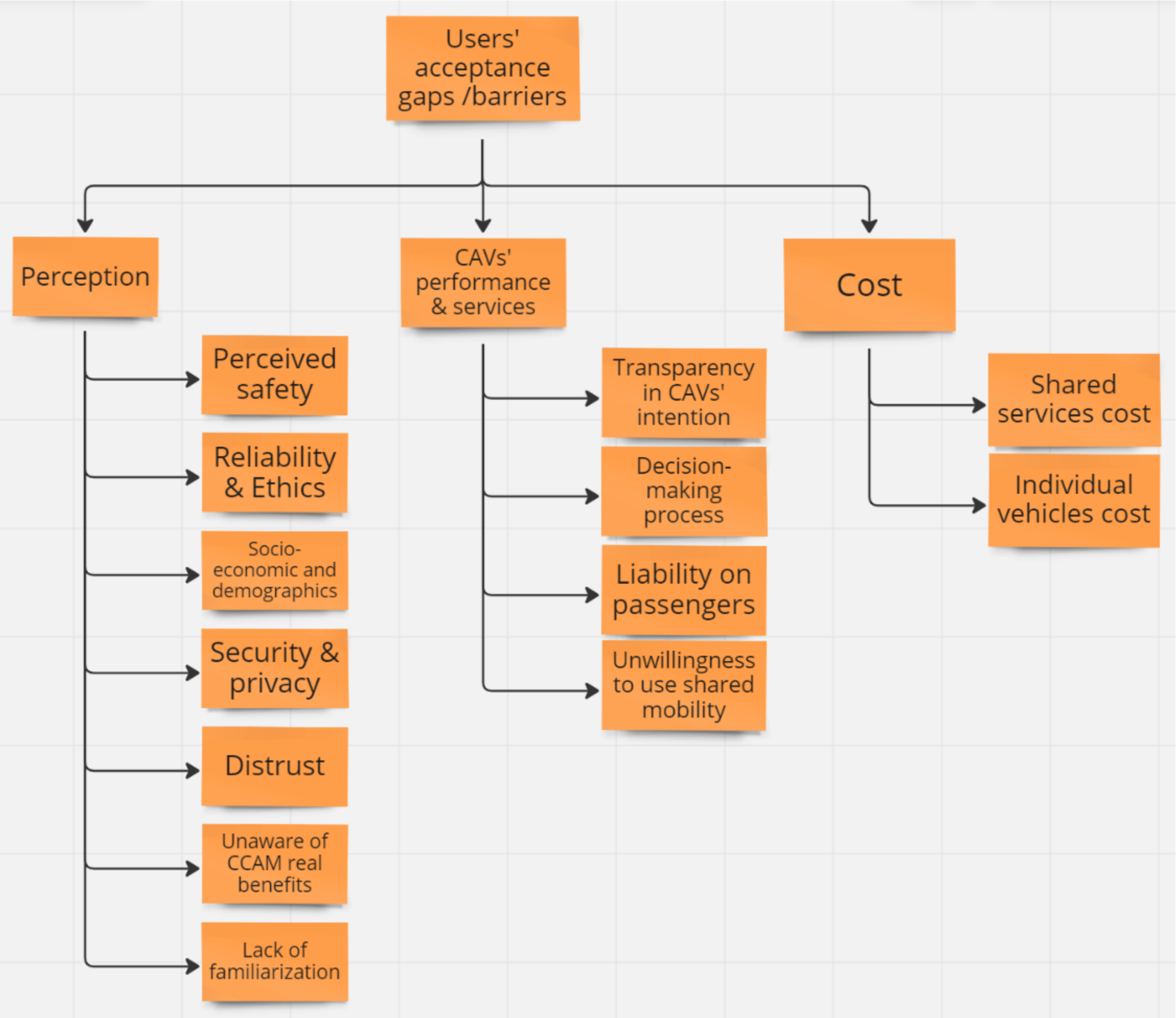

Figure 13: Classification of CCAM users' acceptance related gaps and barriers towards large-scale CCAM deployment

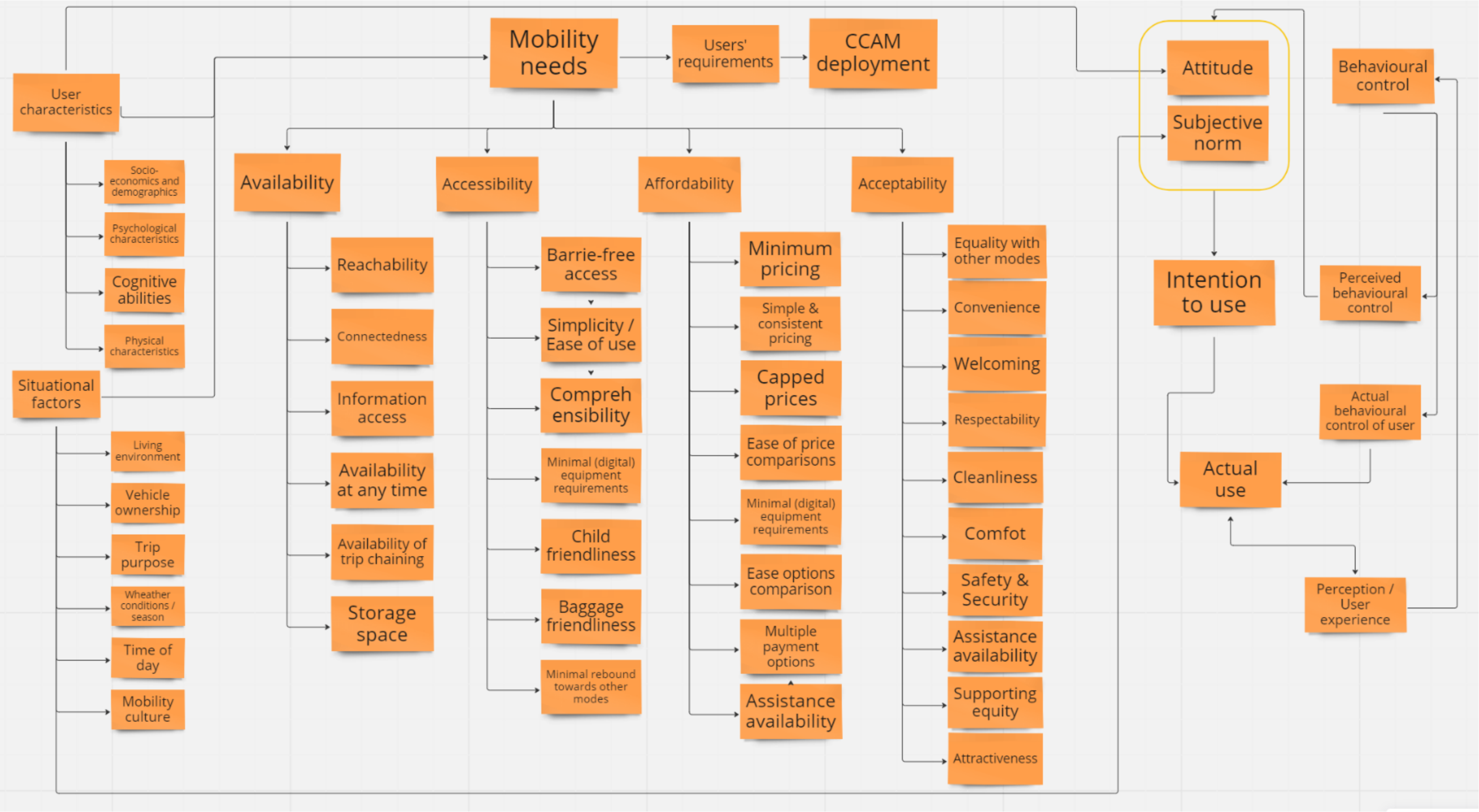

Figure 14: Users' characteristics, situational factors and mobility needs classification and inter-relationships between actual use and perception/user experience, towards users' requirements and large-scale CCAM deployment

5. Conclusions and next steps

Research in the field of CCAM has already provided useful insights about the potential that CCAM has in order to contribute to a safer, more efficient, sustainable, equitable and inclusive transportation system. Research is ongoing with the aim to address technological, operational, legislative, financial and societal aspects related to large-scale CCAM deployment. Enabling factors are considered from a technological perspective as well as from a non-technological. AI, connectivity, simulation models and digital twins, navigation, GPS, HD maps, sensor technologies, IoV, cybersecurity and blockchain technologies and high-performance – edge computing are considered some of the key enabling technologies that are already deployed and researched, and have the potential to bring new intelligence and added-value to CCAM services. From the CCAM operators and deployers perspective, TMCs, remote control rooms, surveillance, data management systems and collaboration schemes are considered enabling factors towards large-scale CCAM deployment. From a human-centred perspective, enabling factors are focused on digital skills and familiarization with new technologies, meeting citizens' mobility needs, accelerating CCAM deployment through collaboration schemes, and the on-board presence of personnel.

Integrating vehicles in the transport network is one of the seven clusters EU research is focused within 2021-2027 Horizon Europe. Deployment strategies in road transport, collaboration schemes, physical and digital infrastructure requirements, traffic and fleet management strategies and advanced simulation and digital twins are some key aspects under research with the aim to explore and promote suitable integration strategies based on sustainable cooperation, governance and business models.

Effects and implications from CCAM and automated vehicles are widely studied with the aim to foresee the potential changes and address the risks that encompass. Nevertheless, the anticipated benefits are considered to overbalance the related risks related to large-scale CCAM deployment, if some critical aspects towards the safe, secure, reliable and inclusive CCAM deployment are comprehensively addressed. A SWOT analysis was performed in order to capture the strengths and opportunities, and the weakness and threats of large-scale CCAM deployment. Cooperation, connectivity, automation, mobility on demand, MaaS, Personalized services, real-time data are recognized among others as strong assets of CCAM deployment, having the potential to lead to improved safety, increased traffic efficiency, improved infrastructure capacity, improved quality of live, environmental sustainability and more. On the other hand, high initial cost, limited deployment so far, technology and safety gaps, mixed traffic conditions until full-scale deployment are some of the weaknesses considered, accompanied with the risk to lead to abrupt CCAM deployment, safety implications, increased energy consumption, reduced traffic efficiency and more.

Gaps and barriers towards large-scale CCAM deployment were also examined based on literature and projects review. **ICT related gaps and barriers are considered in connectivity and communication regarding issues such as communication protocols, network performance and latency, security and privacy mechanisms.** Furthermore, considering software and hardware deployed in CCAM and CAVs, interoperability, system failure, sensors' performance, big data, processing speed and transfer are some critical aspects that should be imperatively addressed for the safe integration of CAVs into the transportation network. Navigation is a critical function for

CAVs and was separately examined concerning the related gaps and barriers, focusing on aspects of localization and mapping, advanced algorithms, data fusion, path planning, decision making and safety performance.

Focusing on safety, several issues are recognized as barriers and gaps to achieve the desired performance of CCAM. CAV performance and interactions, technological aspects like interoperability, standardization, communication systems, fusion systems, big data related issues, recognition and computation power, infrastructure aspects like traffic management, vulnerability of infrastructure, and aspects of shared mobility like the risk of attacks, personal space issues, insurance issues, ownership, accessibility and more, are some critical aspects that might have an effect on safety of CCAM and should be further examined and comprehensively addressed.

Users' acceptance is expected be the ultimate factor that will decide CCAM's future and deployment. Aspects regarding users' perception concerning safety, reliability and ethics, security and privacy, personal data sharing will certainly have an effect on their willingness to use CCAM services. Undoubtedly, this will also rely on the performance of CAVs taking into consideration aspects like transparency in CAVs' intentions and decision making, liability issues as well as the quality of services like shared mobility. Cost is considered another factor that will play a role in users' acceptance.

As far as the regulatory and legislative framework is related, gaps and barriers are realized concerning the lack of a common framework for CCAM deployment, open data policies, standards for safety behaviour of CAVs, liability and accountability issues, the immaturity of technology and more. Furthermore, standards for ethical and safety design principles of CAVs, models and algorithms for ethical reasoning and decision making as well as users' acceptance are some critical aspects considered from the ethics perspective.

Gaps and barriers were interrelated with the needs, requirements, goals and dilemmas of CCAM stakeholders as captured in SINFONICA's deliverable D1.2 – 'CCAM Vocabulary and stakeholders needs and requirements', showcasing the strong inter-relationship between them. For example, **if connectivity and communication systems are capable to ensure the desired reliability and security of the CCAM system, achieving at the same time the required latency for critical applications, safety demonstrations of CCAM solutions will be potentially feasible in more unpredictable and complex real-world scenarios.** Such demonstrations are considered critical towards the validation of CCAM and users' acceptance. Interoperability and standardization of components, interfaces and services would enable stakeholders to effectively and efficiently achieve the integration of CCAM assets into their infrastructure and road network in a cost-efficient and sustainable way. Furthermore, the need for the adoption and classification of the infrastructure as well as related cost and safety implications are also addressed from both perspectives. Building knowledge, providing training schemes and public awareness campaigns have the potential to address users' acceptance issues, **and certainly the adjustment of legislation is considered both as an enabler towards large-scale CCAM deployment and a critical issue yet to be comprehensively addressed.**

Based on the outputs of this report as well as the SINFONICA deliverables D1.1 and D1.2, a taxonomy capturing the inter-relationships in the CCAM ecosystem is created. The taxonomy will constitute the basis for the SINFONICA Knowledge Map, where the inherent complex and strong inter-relationships between stakeholders and end-users needs, requirements, desires and expectations will be further detailed. Several instances of the taxonomy were presented herein, with the aim to capture some of the critical inter-relationships between stakeholders' and end-users needs and requirements towards large-scale CCAM deployment and the barriers and gaps yet to be addressed.

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