European CCAM Outlook 2023

A Review of CCAM Advancements and Applications in Europe's Public Transport Sector

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1. EXECUTIVE SUMMARY

CCAM

Cooperative, Connected, and Automated Mobility (CCAM) is transforming the way we perceive transportation, forging a new era of seamless, intelligent mobility.

This report provides an in-depth analysis of the development and deployment of CCAM in public transport within the European market.

The development of CCAM in public transport is pushed and pulled by the following factors:

Expert input

Drivers & Barriers

Technology

Regulation

Social acceptance

Market

Drivers and Barriers determine the key milestones that impact the business case of CCAM deployment

Key Milestones

- No safety operator required
- No teleoperation required
- Vehicle commercially viable
- Simplified permit process
- Efficient incident response
- Efficient route mapping
- Enhanced mobility performance
- Advanced accessibility features

Which specific public transport use case components are impacted by automation?

Specific components of the use cases

- Route length
- Service coverage
- Fleet size
- Special assistance needed
- Traffic type

Milestones are connected to specific use case components and their impact on the business case is assessed

Business Case

is impacted in terms of:

- Profitability
- Feasibility
- Service quality

Public transport use case designs are assessed by identifying the milestones needed to unlock their business case

Use case assessment

- Service models
- Deployment areas
- Target groups

2. INTRODUCTION

Objective of the study

This report gives a holistic overview of the current and future developments of connected, cooperative and automated mobility (CCAM) for public transport in Europe by diving into the effects of technological, regulatory, societal and market forces. The study dives into the main drivers and barriers which determine the future deployment of connected, cooperative, automated vehicles (CCAVs). Further, business cases of distinct public transport use cases are assessed, and key milestones are identified that improve these business cases.

The challenge of public transportation

Ineffective public transport services lead to high private car dependency and the isolation of people[1], resulting in high carbon emissions and inaccessibility to public services and labour markets.
A core reason for this is the everlasting challenge for public transport to offer high-quality mobility services while using limited resources. Often, the revenues generated through the fares, particularly in low density areas, struggle to match the high costs associated with the investments required for fleets and associated infrastructure, as well as the costs of operations.

CCAM: the solution?

CCAM is recognised by researchers and the transport sector as a potential solution to offer higher-quality transport services while reducing operating costs. [2, 3, 4, 5] Specifically, public transport operators could therefore offer public transport at a larger scale with the following benefits:

1. Seamless mobility: Connected and smart automated driving has strong potential to reduce transport congestion, travel time and traffic accidents, particularly with higher market penetration rates of CCAM.[6]

2. Improved accessibility: by reducing operating costs, CCAM has the potential to increase transport offerings at affordable prices, boosting transport accessibility and inclusivity.[7]

3. Environmental benefits: affordable and accessible public transport has the potential to challenge the role and benefits of the private car in future societies, which can lead to significant transport emission curbs.[8]

Scope of the study

This report focuses on future CCAM deployment in European public transport systems. Through qualitative research design, by combining literature research and bilateral interviews with leading experts in the realm of CCAM, the study evaluates best practices from Europe and the United States, and integrates expertise from industry players, policymakers and academics in Europe.

About PAV

This report is a result of the Interreg North Sea Region project 'Planning for Autonomous Vehicles (PAV)' which supports cities in incorporating CCAM into their Sustainable Urban Mobility Plans.

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(European Passengers Federation)

Tom Alkim
(MAPtm)

Henriette Cornet
(UITP)

Koen Schietecatte
(De Lijn)

Suzanne Hoadley
(POLIS)

Eric Silva
(ROSAS)

Suzanna Kraak
(European Commission)

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(University of San Francisco)

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(DB Regio Bus)

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(Ruter)

In collaboration with:

3. STATE OF THE ART OF CCAM

CCAVs have come a long way since they were first introduced in the late 1970s.[9] Today, they are an increasingly viable option for improving the efficiency and accessibility of public transportation systems around the world.

In the past, CCAVs were mainly used in controlled environments, such as airports and industrial parks. However, advances in technology have made it possible for these vehicles to operate in more complex and dynamic environments, such as city streets. In Europe, several countries have already tested small scale CCAV deployment in their local public transportation systems. Companies, including EasyMile and Navya, have provided their own automated shuttles and buses that are being used in various European cities.

While there are still many challenges to overcome, including regulatory hurdles and societal concerns about safety, the state of the art of autonomated vehicles in public transport is continuously evolving. This section will highlight notable examples of recent CCAM deployment.

Figure 1: Announced ZF shuttle[10]

Example 1: PT integration, Geneva (CH)

The AVENUE (HORIZON 2020) pilot project in Geneva was led by Transports Publics Genevois (TPG). The project was one of the world's first fully autonomous public transport services, offering an on-demand, door-to-door service through a digital application with 78 virtual stops. Since 2020, the project deployed four Navya shuttles in the Belle Idee site of the Geneva University Hospital in mixed traffic. The shuttles continue to operate after the end of the project and are fully integrated into the local PT system.[11]

Figure 2: Geneva AVENUE pilot[11]

Figure 3: SHOW megasite Frankfurt pilot[12]

Example 2: AMOD, Frankfurt (DE)

The SHOW (HORIZON 2020) pilot site in Frankfurt takes place in the district of Riederwald, in the east of the city. Frankfurt's two EasyMile EZ10 Gen3b automated shuttles operate on a route of 2,7 km long with 30 virtual stops (including wheelchair-friendly stops), serving as a first/last mile feeder to two metro lines. The service can be booked for free via the on-demand application "RMV EASY". The shuttles are equipped with AI systems, with a voice bot for information about public transport connections and an AI-based camera system for the detection of dangerous situations.[12]

Example 3: Waymo robotaxis, Phoenix (USA)

Waymo, a subsidiary of Alphabet, runs its autonomated taxi service, Waymo One, in the Phoenix metropolitan area, making it one of the first commercial robotaxi deployments in the United States. The service, which began operating in 2020, utilizes a fleet of modified Chrysler Pacifica minivans equipped with Waymo's proprietary self-driving technology. The vehicles navigate through a combination of complex traffic situations and diverse environments. The success of the Waymo One service has set a precedent for the potential of robotaxi deployment, demonstrating the viability of autonomated mobility as a practical and accessible transportation alternative.

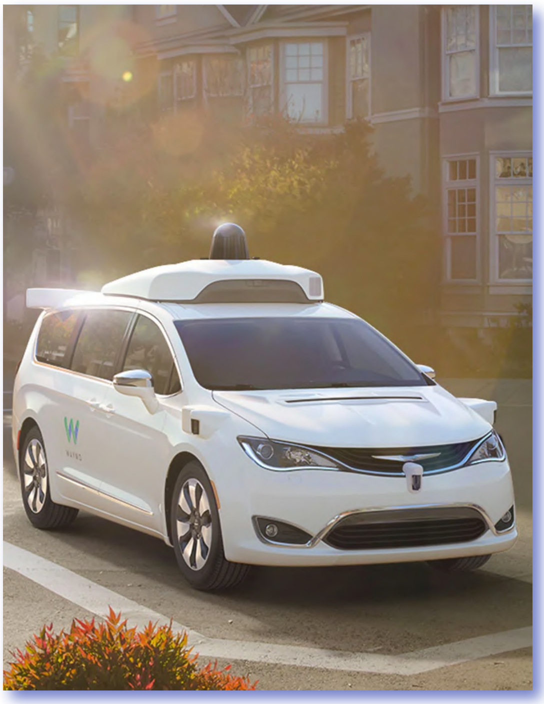

Figure 4: Waymo vehicle in Phoenix[13]

Example 4: Full-size bus, Stavanger (NO)

The full-size bus pilot project in Stavanger involved the deployment of an autonomated e-ATAK as part of regular public transport. The bus operated on a 2.5km long route in the centre of the city within mixed and complex traffic situations. The pilot site depicts a milestone for piloting full sized autonomated buses. The pilot is a collaboration between electric bus manufacturer Karsan, transport companies Vy and Kolumbus, AI and sensor technology provider Adastec, and Norwegian monitoring technology startup Applied Autonomy.[15]

Figure 5: Full-sized automated bus pilot[14]

4. DRIVERS & BARRIERS

To assess the future of CCAM in public transportation, a comprehensive understanding is needed of the enablers that drive CCAM deployment further, as well as the barriers that restrain it from reaching its full potential. This chapter provides insights into four key factors that will shape the future of CCAM in public transportation:

Technology: The impact of current technology and future breakthroughs and advancements.

Market: The CCAM ecosystem, including how manufacturers, operators and transport authorities interact.

Regulation: The regulator landscape, including policies that either support or limit CCAM deployment.

Social acceptance: Public perceptions of CCAM that either increase or limit the adoption of the technology.

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Technology

In recent years, significant progress has been made in the technology for CCAM. Despite advancements in sensors, intelligent algorithms, vehicle design and assembly, a substantial performance and technological maturity gap remains between non-automated vehicles and CCAVs, impeding their adoption in public transportation.

"The limitation has been the technology and the fact that the vehicles were just not ready"

Christian Bering Pedersen (HOLO)

A primary obstacle since the emergence of CCAM has been the technological readiness of vehicles, with both software and hardware limitations. Christian Bering Pedersen from Holo highlights that "for the last couple of years, the limitation has been the technology and the fact that the vehicles were just not ready." Factors such as speed, traffic fluidity, and the hyper-cautious driving of automated vehicles have contributed to the technological performance gap.

Suzanne Hoadley from POLIS emphasizes the need for increased mobility performance of automated vehicles, stating that "The vehicles drive cautiously, especially in mixed environments with other traffic." Currently, the speed of CCAVs is limited due to sensors being unable to distinguish between different objects on the road, the inability of software algorithms to accurately predict and calculate braking distance and duration, and safety concerns.

The hyper-cautious nature and reduced traffic fluidity of automated shuttles are closely intertwined. CCAM prioritizes safety, even when traffic disruption could lead to more severe accidents. For example, Carlo van de Weijer (Technical University of Eindhoven) says that "an automated vehicle will always choose risk-adverse option in any traffic situation, making it a clumsy nervous vehicle, braking too fast by definition." He goes on to explain that a major technical challenge will be to get vehicles to ´break traffic rules´ when needed, "for example, vehicles sometimes need to cross the line, both literally and figuratively speaking."

An additional technological limitation is how vehicles currently map and scan their environment. Eric Silva (ROSAS), explains that, "vehicles need to scan and map each road before being able to operate". Sensors are influenced by changes in the surrounding environment, such as seasonal changes to vegetation along routes, affecting the accuracy and responsiveness of the service. Additionally, it is crucial to consider the impact of external factors, such as route obstacles and weather conditions that currently impact the performance of CCAVs.

The integration of GPS and V2X (vehicle-to-infrastructure and vehicle-to-vehicle communication) systems is vital for the effective functioning of these advanced technologies. Consequently, understanding the interplay between these environmental factors and the vehicle's sensor systems is essential for optimising performance and ensuring safe and efficient operation in diverse conditions. Therefore, improved digital infrastructure, development of sensors and computing power are needed for CCAVs to operate on routes without pre-existing maps.

Koen Schietecatte (De Lijn) suggests that traffic infrastructure improvements can ease the introduction of automated mobility, although they are not strictly necessary. Examples include intelligent traffic lights and dedicated bus lanes for CCAV to reduce traffic complexity. Furthermore, Eric Silva (ROSAS) notes that wider and simpler roads in the US make CCAM implementation more straightforward, illustrating the importance of considering regional infrastructure differences.

At the same time significant advances in automated driving software can be seen, such as Mobileye's level 4 self-driving system. The integration of multiple sensors is expected to propel further developments.

Eric Silva (ROSAS) envisions that advancements in sensor fusion can lead to less emergency braking and improved overall performance.

While the last decade shows that CCAM technology has been pushed by smaller manufacturers, future leaps can be expected by established OEMs such as General Motors, Toyota, and Volkswagen as they have announced their plans to build their own automated vehicles. Moreover, the involvement of tech companies like Alphabet´s Waymo and Amazon´s Zoox in the development of automated technology showcases the accelerated technological progress in the field. As the CCAM market evolves, increased competition and innovation will likely drive the technology to new heights, resulting in safer, more efficient, and faster automated vehicles in public transportation applications.

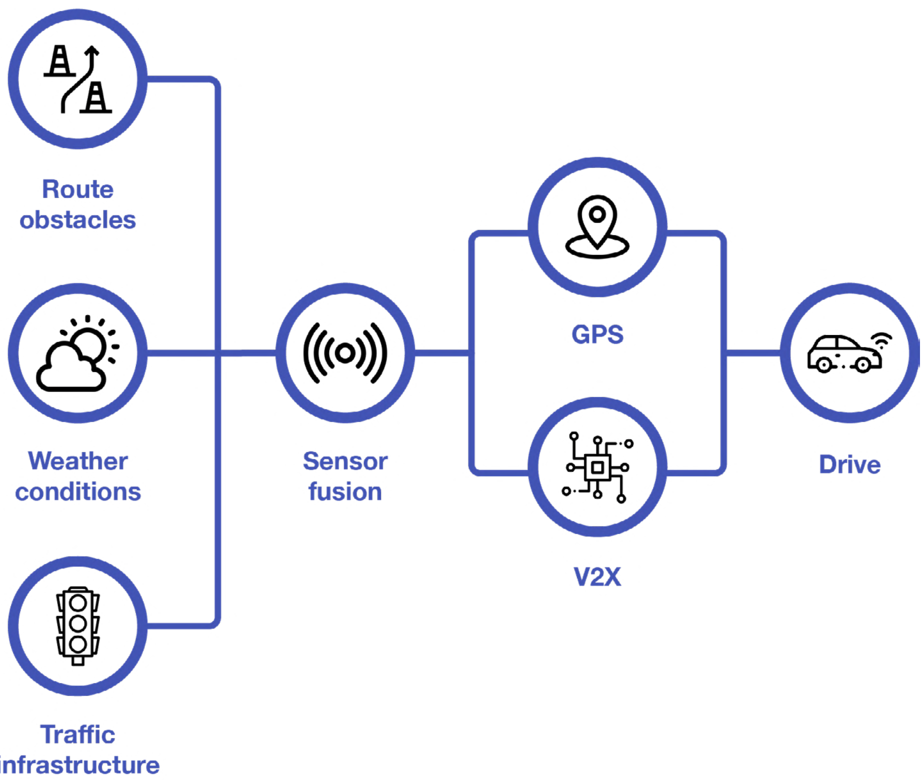


Figure 6: Illustrating the key technological components that are relevant to CCAM development

Regulation

The European Union (EU) is developing a uniform framework for regulating the deployment and operation of CCAM[16], and various EU countries have already started developing their own regulations and permit systems.

The main objectives of the permit system are to ensure safety and to facilitate the integration of CCAM into the existing transport system. The permit application processes are often time consuming and complex, as multiple permits need to be obtained.

These include: vehicle permits (homologation), operating permits (allows for operating the vehicle and the service in mind), site permits (allows you to operate the vehicle, and operating models on specified routes).

Henriette Cornet from UITP emphasizes the importance of alignment between national and local policies and regulations.

"Through political wish, deployment will happen"

Henriette Cornet (UITP)

Several regulatory barriers impede the adoption of automated vehicles in the EU. These include strict rules on deployment, preventing large scale production and roll-out of CCAVs.[17,18]

Furthermore, regulation varies per country in the EU. As Lars Abeler (DB Regio Bus) states, "CCAM regulation should be better harmonized and simplified in the EU".

Furthermore, Europe is known for its methodical and cautious approach to regulating automation, in contrast to the US. Tom Alkim (MAPtm) points out that, in the US, "everything is allowed until it is explicitly forbidden; in Europe, it's the other way round."

Critics argue that the current EU regulatory approach is too conservative and that the stringent requirement for authorization may act as a barrier to market entry by leading CCAM providers and hamper large-scale deployment of CCAM in public transport.

Nonetheless, it is crucial for public authorities to establish the appropriate policy and regulatory framework. Strategic regulation can serve as a catalyst for CCAM to deliver better connected and accessible public transport. Moreover, by strategically regulating the private sector, authorities can mitigate risks and enhance access to affordable and equitable transportation.

CCAM Market

The CCAM market consists of multiple stakeholders, each playing a crucial role in shaping and driving the industry forward:

Vehicle manufacturers are responsible for designing and producing the vehicles, ensuring they adhere to regulatory standards.

Self-driving software providers integrate machine learning models that form the backbone of autonomated driving technology.

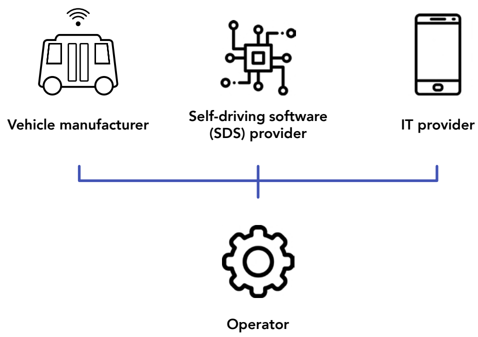
Operators, either as a public or private entity, oversee the deployment, management, and maintenance of CCAM fleets.

IT providers provide software solutions, data management, and user interfaces, enabling seamless integration and connectivity between the vehicle and the user.

The CCAM market is characterized by high volatility, with numerous entrants and exits from various industries. Notable market entries into the CCAV market range from subsidiaries from the technology sector like Waymo (Alphabet) and Zoox (Amazon), to OEMs, such as Cruise (General Motors).

In contrast, smaller established players such as Local Motors were discontinued in 2022 and Navya filed for bankruptcy in 2023.

CCAM collaboration structure



The undersupply of automated shuttles and the necessity of funding for public transport is seen as a major limitation for industry players. Henriette Cornet from UITP emphasizes the need for more shuttle manufacturers producing robust CCAVs at larger scale, stating: "We need a large-scale industrialisation of CCAM."

Since profitable CCAM business models hardly exist yet, CCAV providers are hesitant to enter the market. The supply gap results in high purchasing costs of automated vehicles, acting as a barrier for public transport operators to incorporate them into their fleets. Despite concerns about profitability, Koen Schietecatte from De Lijn states that "The tipping point for commercially viable services for AVs will be reached between 2025 and 2027"

This forecast, re-iterated by McKinsey[19], suggests that, with time, CCAM may become an increasingly attractive and viable market for both public and private players.

"The tipping point for commercially viable services for AVs will be reached between 2025 and 2027"

Koen Schietecatte (De Lijn)

Collaboration between market players can act as a driver for CCAM adoption. Particularly it can address the undersupply by establishing effective market standards for vehicle manufacturing and software development.

Christian Bering Pedersen of Holo envisions a future where OEMs collaborate with advanced software providers such as Mobileye to jointly scale up the offering of CCAVs. Notable collaborations in the industry include those between software provider Mobileye and OEM Schaeffler, between shuttle provider HOLON and intermediary Beep, and between Mobileye and Goggo Network, which equips its shuttles with autonomated software.

Koen Schietecatte suggests a potential collaboration model: "As a PTO, we could collaborate with leading shuttle providers by taking care of the operations". This approach may be more suitable for public transport operators with CCAM experience or those with dedicated departments or teams to address the issue, such as De Lijn in Belgium or Ruter in Norway.

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Social acceptance

At present, concerns about CCAM remain among the general public. Delphine Grandsart (EPF) emphasises how CCAM must address various levels of social needs, which include [20]:

Basic needs: Ensuring safety and accessibility of the service for all users.

Intermediate needs: Offering quality service that considers factors like speed, cost and frequency.

Higher needs: Providing comfort and additional services that enhance the overall user experience.

As CCAM is still relatively immature, the focus remains on basic needs. As the technology develops, a stronger focus will be needed for intermediate and higher level needs to ensure wider social acceptance and adoption of CCAM.

However, as pointed out by Suzanna Kraak (European Commission), adoption in itself is not the end goal, stating "We don't just want people to adopt [CCAM], it needs to serve a purpose." The services offered by CCAM must meet passengers' social needs, including safety, comfort, and quality of service, to gain widespread acceptance and uptake. As the level of service and corresponding social benefits of CCAM surpass those of conventional transport, significant advancements in social acceptance can be anticipated.

"We don't just want people to adopt [CCAM], it needs to serve a purpose."

Suzanna Kraak (EC)

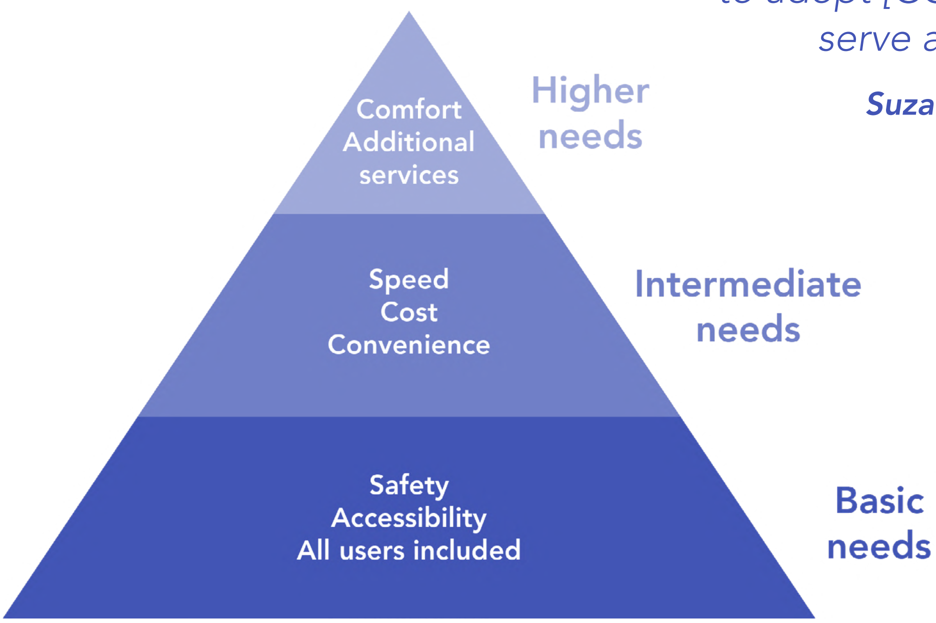


Figure 8: Pyramid of social needs to be addressed by CCAM

Social acceptance serves as both a driver and barrier for the adoption of CCAM in public transport. On one hand, CCAM has the potential to significantly enhance the connectivity and accessibility of public transport. As Delphine Grandsart points out, “CCAM needs to help decrease congestion, improve accessibility, [and] be affordable to people who cannot afford a car. If it serves a purpose like this, then people would be more willing to accept it.”

“Driving is only one of the many jobs of a bus driver”

Carlo van de Weijer (TUE)

On the other hand, social acceptance can also act as a barrier to CCAM adoption in public transport. Conventional bus transit provides a high level of service to passengers, particularly the elderly and those with reduced mobility.

The removal of the bus driver or safety operator from vehicles raises concerns about the potential drop in service quality and perceived safety, which some argue to be a major barrier to CCAM adoption. Carlo van de Weijer explains, “Driving is only one of the many jobs of a bus driver”. He further adds, “The perceived safety in the vehicle remains a barrier, which you can’t just solve with cameras.”

While perceived safety is an important factor when considering social acceptance, transport services are becoming increasingly automated such as trains and metros. Additionally, in-vehicle safety technology is continuously improving

Social acceptance

- **Barrier:** Service quality that is usually provided by the bus driver is missing.
- **Barrier:** In vehicle safety concerns.
- **Driver:** Acceptance increases when it solves a problem (e.g. decreases congestion, improves accessibility)

CCAM environment

- **Barrier:** Hesitant market entry by providers leads to low supply and high purchasing cost of CCAVs.
- **Driver:** Collaboration and market standardisation between market players

Regulation

- **Barrier:** Multiple permits need to be obtained which is time-consuming and complex, discouraging large-scale roll-out of CCAVs
- **Barrier:** Current lack of regulatory harmonization within the EU makes it difficult for providers to operate in different countries.
- **Driver:** Technological progress and regulatory adaptation in Europe can foster innovation and growth in the CCAM market.

Technology

- **Barrier:** Technological readiness of vehicles, including software and hardware limitations impacts speed and driving fluidity, constraining where and how CCAM can be deployed.
- **Driver:** Improved automated driving software and sensor fusion can increase speed and driving fluidity.
- **Driver:** Improved (digital) traffic infrastructure such as 4G connectivity and dedicated bus lanes can ease CCAM deployment.

Figure 10: Summary of the key drivers and barriers for CCAM deployment in public transport.

5. CCAM BUSINESS CASES FOR PUBLIC TRANSPORT

Using the identified drivers and barriers that influence CCAM's successful integration into public transportation systems, we can now comprehensively evaluate the potential of future CCAM deployment. The business case of automation in public transport depends to a large extent on its specific use case. Given that public transport can take on many different service models in various deployment areas, and cater to specific demographics such as students or the elderly, the impact of automating a PT service relates to its specific context. In this report the business case is evaluated, in terms of feasibility, profitability, and quality of service for different PT use cases which consist of different service models, deployment areas, and target groups.

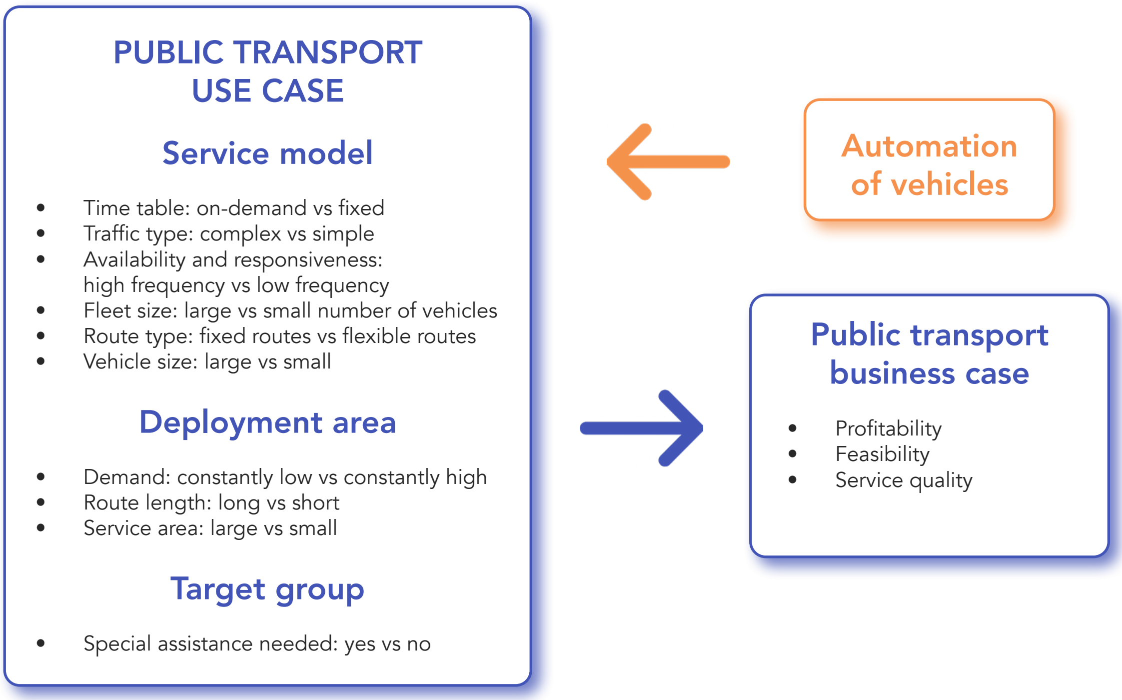


Figure 11: Conceptual framework for assessing the business case of public transport use cases.

Use case components

The experts in this study have identified the specific use case components (see highlighted components in figure 12) that directly influence the business case of CCAVs in public transport, including:

Fleet size: At present, increasing the size of a fleet requires drivers and safety operators. If these are no longer needed due to automation, this will affect the operating cost structure and therefore profitability.

Service coverage: Currently, AVs are more suited to covering shorter routes due to the lesser number of traffic obstacles and the limitations in their speed, which have a lesser impact on the service for shorter distances. Furthermore, permits are required to deploy Avs on public roads. The larger the area, the more complicated the permit application process.

Special assistance needed: Some transport users such as the elderly and people with reduced mobility require more human assistance than others. Therefore, automation might make it less attractive for them to use public transport.

Traffic type: To maintain a similar quality of service, complex traffic situations such as dense traffic and busy junctions require higher levels of autonomy for CCAVs.

Vehicle type: Different types of CCAVs exist, with each type having their own mobility performance, cost and market availability.

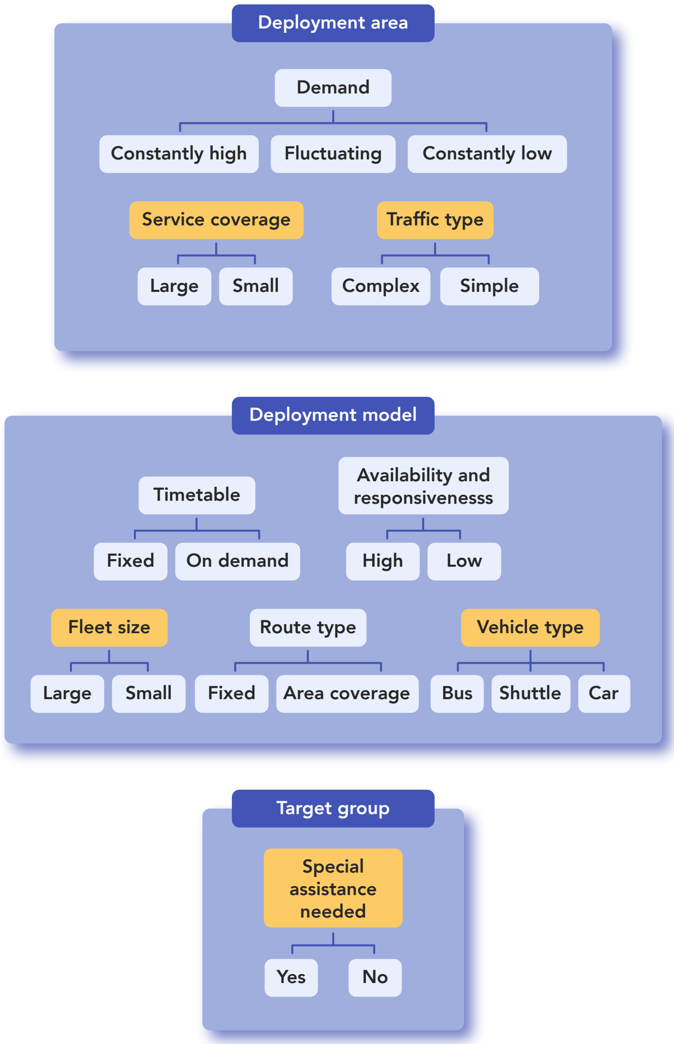


Figure 12: Overview of the use case components

As discussed in the drivers & barriers chapter, CCAM technology, regulation, as well as its market and social acceptance are continuously evolving. According to the foreseen changes to its drivers and barriers, this study has identified eight key milestones in relation to individual use case components that are required to 'unlock' the business case of automating a public transport service. An overview of these milestones, plotted against their related use case components can be found in the table below. The following section describes the individual use case components along with the specific milestones that are needed to 'unlock' their business case in terms of profitability, feasibility or service quality. The absence of one or multiple milestone(s) for a given use case component implies that it's impact on the business case is not significantly reliant on that milestone, and is therefore already 'unlocked'.

Milestones to unlock the business case	Use case components										
	Fleet size		Service coverage		Special assistance needed		Traffic type		Vehicle type		
	Large	Small	Large	Small	Yes	No	Complex	Simple	Bus	Shuttle	Car
No safety operator required	€	€									
No tele-operation required	€										
Vehicles commercially viable	€ ⚙	€ ⚙							€ ⚙	€ ⚙	€ ⚙
Simplified permit process	⚙		⚙				⚙				
Efficient incident response			👍 ⚙								
Efficient route mapping			€ ⚙								
Enhanced mobility performance			👍 ⚙				👍 ⚙		👍 ⚙	👍 ⚙	
Advanced accessibility features					👍						

The yellow fields represent milestones that are required to unlock the business case, in terms of: Profitability € Feasibility ⚙ Service quality 👍

Table 1: Use case assessment

1. Fleet size:

CCAVs need to become commercially viable in terms of affordability and availability on the market to ensure increased profitability of public transport fleets. The milestone removal of safety operators will improve the profitability of any fleet size. However, cost reductions can be significantly scaled with larger fleet sizes. In addition, the removal of the teleoperator further improves the profitability for large fleet sizes as cost reductions are scaled even further, however it is less important for small fleet sizes, as a single teleoperator could supervise up to seven vehicles. Lastly, the deployment of large fleets also requires simplified permit processes, as many countries require individual permits for each CCAV deployed. This milestone is therefore less crucial for small fleet sizes.

Milestones to unlock the business case	Use case components: Fleet size	
	Large	Small
No safety operator required	€	€
No tele-operation required	€	
Vehicles commercially viable	€ ⚙	€ ⚙
Simplified permit process	⚙	

Table 2: Milestones related to fleet size

Milestones to unlock the business case	Use case components: Service coverage	
	Large	Small
Simplified permit process	⚙	
Efficient incident response	👍 ⚙	
Effcient route mapping	€ ⚙	
Enhanced mobility performance	👍 ⚙	

Table 3: Milestones related to Service coverage

2. Service coverage:

For use cases that need larger service coverage, deploying an automated vehicle will require simplified permit processes, as getting permits approved for multiple and/or longer routes is currently less feasible than for shorter and fewer routes. Secondly, efficient incidence response is needed to ensure feasibility and service quality when operating in large service areas.
Third, efficient route mapping is required as it becomes more complex and costly to map large areas. Lastly, automated services running on longer and multiple routes need enhanced mobility performance including service speed and driving fluidity to offer similar service quality and feasibility compared to non-automated services.

For use cases with a small service coverage, a positive business case is not reliant on the above milestones being reached since the permit process, incident response, and route mapping are far less complex, and enhanced mobility performance is less important when the service coverage is small.

3. Special assistance needed:

Removing human-driver assistance when automating a vehicle can impact its business case when serving use cases where Persons with Reduced Mobility (PRM) use the service. In order to offer an adequate level of service quality for PRMs, advanced accessibility features such as automated ramps and secure wheelchair seating are required. In addition, CCAVs also need to address in-vehicle safety features to ensure passenger safety when human drivers are removed.

Milestones to unlock the business case	Use case components: Special assistance needed	
	Yes	No
Advanced accessibility features		

Table 4: Milestones related to Special assistance needed

Milestones to unlock the business case	Use case components: Traffic type	
	Complex	Simple
Simplified permit process		
Enhanced mobility performance		

Table 5: Milestones related to Traffic type

4. Traffic type:

The traffic situation for a given use case also impacts the business case of deploying a CCAM service. Complex traffic situations, such as busy junctions, dense traffic and high speed require enhanced mobility performance of CCAVs, as deployment with the current autonomy level is not feasible and would not offer acceptable service quality in complex traffic situations. Secondly, simplified permit processes are required to improve the feasibility of CCAV deployment, as traffic considerations are important assessment criteria when granting permits to operate.

For services deployed in simple traffic situations, such as those operating in dedicated bus lanes, obtaining permits is more feasible and current CCAV mobility performances are adequate.

5. Vehicle type:

The type of CCAV being deployed is another critical component when assessing the business case. At present, all vehicle types (buses, shuttles and cars) need to achieve commercial viability to guarantee the profitability and feasibility of their deployment.

This is due to the fact that CCAVs necessitate more financial investments compared to non-automated vehicles, and, as of now, automated buses and cars have not yet become commercially available on the European market.

Additionally, buses and shuttles require enhanced mobility performance to ensure rollout feasibility and minimum levels of service quality as the vehicles still struggle with many technical deficiencies and slow operating speeds. CCAM cars on the other hand, such as the robotaxis deployed in the US by Waymo and Cruise, have proven high levels of all-round mobility performance.

Milestones to unlock the business case	Use case components: Vehicle type		
	Bus	Shuttle	Car
Vehicles commercially viable	€ ⚙	€ ⚙	€ ⚙
Enhanced mobility performance	👍 ⚙	👍 ⚙	

Table 6: Milestones related to Vehicle type

Use case assessment

After determining the specific components of public transport that are affected by automation, and identifying the milestones that unlock their business case in terms of profitability, feasibility, and service quality, it is now possible to evaluate any CCAM use case design By examining a use case design consisting of any combination of use case components, the necessary milestones to unlock the business case for that specific use case can be identified.

The table below shows the milestones needed to unlock three examples of CCAM use cases, which specific compositions and related milestones will be further explored in the next section. It's important to note once more that the absence of a milestone for a use case design means that the given milestone is not essential to unlock its business case.

Milestones to unlock the business case	Use case components		
	Campus service	Suburban feeder service	Dense urban coverage
No safety operator required	€	€	€
No tele-operation required			€
Vehicles commercially viable	€ ⚙	€ ⚙	€ ⚙
Simplified permit process		⚙	⚙
Efficient incident response		⚙	⚙
Efficient route mapping		€ ⚙	€ ⚙
Enhanced mobility performance	⚙ 👍	⚙ 👍	⚙ 👍
Advanced accessibility features		👍	👍

The yellow fields represent milestones that are required to unlock the business case, in term of: € Profitability, ⚙ Feasibility, 👍 Service quality

The milestones have been weighted according to their importance as follows: Low, Medium, High

Table 7: The milestones needed to unlock three example CCAM use cases

Use case example 1: Campus service

Table 9 shows the use case composition for an example of a 'simple' public transport CCAM use case design, for instance, serving a university campus.

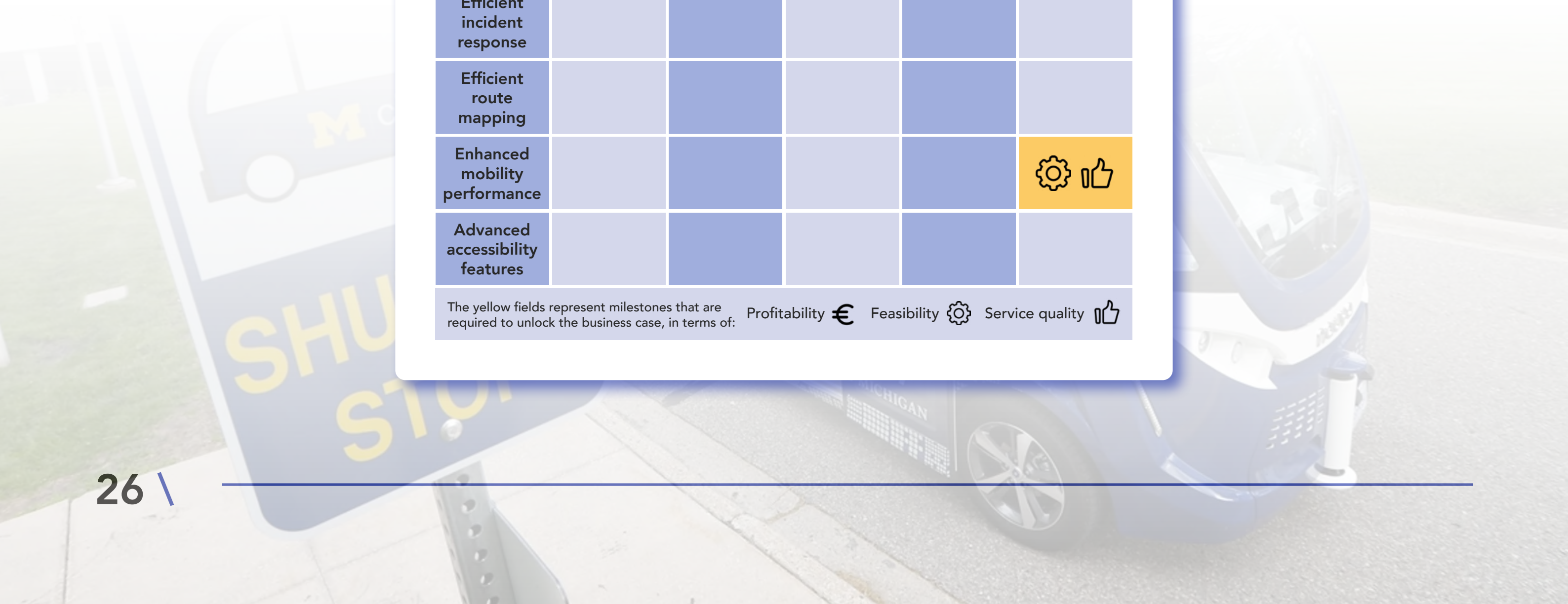
The use case consists of a shuttle service with a small fleet size (1-5 vehicles), operating in a small service area with simple traffic where passengers don't require special assistance. Due to this straightforward use case, few milestones are required to unlock the business case compared to more complex use case designs. The milestones removal of the safety operator, enhanced mobility performance and the vehicles becoming commercially viable are key milestones needed to unlock the business case in terms of profitability, feasibility and service quality.

As the least complex deployment model, it is likely to be the first commercially viable deployment design for CCAV in the coming years once the mentioned milestones are reached. Besides serving campus-type use cases, similar designs can be found for connecting (air)port terminals, business centres, or touristic destinations.

Table 8: Assessment of the use case example 1

Milestones to unlock the business case	Use case components: Campus service				
	Fleet size	Service coverage	Special assistance needed	Traffic type	Vehicle type
	Small	Small	No	Simple	Shuttle
No safety operator required	€				
No tele-operation required					
Vehicles commercially viable	€ ⚙				€ ⚙
Simplified permit process					
Efficient incident response					
Efficient route mapping					
Enhanced mobility performance					⚙ 👍
Advanced accessibility features					

The yellow fields represent milestones that are required to unlock the business case, in terms of: Profitability € Feasibility ⚙ Service quality 👍



Use case example 2: Suburban feeder service

Example 2 shows a larger use case design, consisting of a shuttle service with a small fleet size, operating in a large service area with simple traffic conditions, where passengers at times require special assistance.

An example of such a use case design could be a suburban feeder service. Due to the increased complexity of the use case design, particularly the large service area, more milestones are needed to unlock its business case. For this use case example, a simplified permit process, as well as efficient incident response and route mapping are needed to ensure the feasibility, service quality and profitability of the use case respectively.

Furthermore, enhanced mobility performance becomes an even more important milestone to unlock feasibility and service quality, as the distances travelled are longer and minimum speeds higher. Given that the mentioned milestones are addressed, feeder type services offer a promising use case for CCAM, as they can provide more cost-efficient services and connect areas where currently reliance on private cars prevails.

Table 9: Assessment of the use case example 2

Milestones to unlock the business case	Use case components: Suburban feeder service				
	Fleet size	Service coverage	Special assistance needed	Traffic type	Vehicle type
	Small	Large	Yes	Simple	Shuttle
No safety operator required	€				
No tele-operation required					
Vehicles commercially viable	€ ⚙				€ ⚙
Simplified permit process		⚙			
Efficient incident response		⚙			
Efficient route mapping		⚙ 👍			
Enhanced mobility performance		⚙ 👍			⚙ 👍
Advanced accessibility features			👍		

The yellow fields represent milestones that are required to unlock the business case, in terms of: Profitability € Feasibility ⚙ Service quality 👍

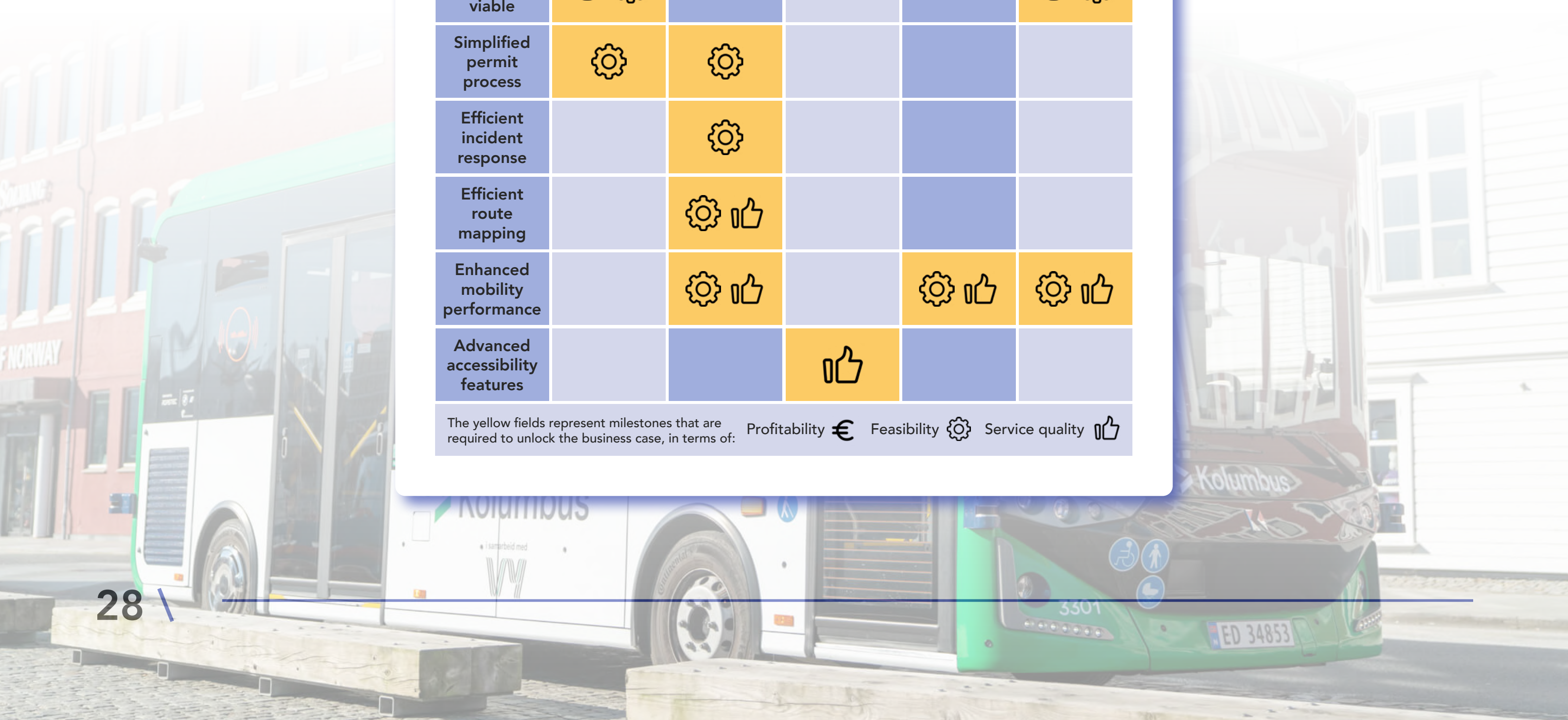
Use case example 3: Dense urban area coverage

The final example illustrates the most complex use case design, such as one serving a dense urban area.
The use case consists of a large bus fleet, operating within a large service area in complex traffic with passengers who may require special assistance. Increasing the fleet size requires the milestone removal of the teleoperator to enable a profitable service, as cost savings can only be scaled when large fleets are supervised through a control centre (as is currently the case for Cruise and Waymo robotaxis in the US). In addition, the increased traffic complexity requires simplified approval processes to ensure regulatory feasibility, while at the same time reinforcing the need for enhanced mobility performance of CCAVs for technical feasibility and adequate service quality. While changing the vehicle type from shuttles to buses does not add additional milestones, it is important to note the importance of vehicles becoming commercially viable to ensure their profitability and feasibility. CCAM buses are not readily available in EU markets and prototypes, such as Karsan's e-ATEK require large financial investments.

Table 10: Assessment of the use case example 3

Milestones to unlock the business case	Use case components: Dense urban area coverage				
	Fleet size	Service coverage	Special assistance needed	Traffic type	Vehicle type
	Large	Large	Yes	Complex	Bus
No safety operator required	€				
No tele-operation required	€				
Vehicles commercially viable	€ ⚙				€ ⚙
Simplified permit process	⚙	⚙			
Efficient incident response		⚙			
Efficient route mapping		⚙ 👍			
Enhanced mobility performance		⚙ 👍		⚙ 👍	⚙ 👍
Advanced accessibility features			👍		

The yellow fields represent milestones that are required to unlock the business case, in terms of: Profitability € Feasibility ⚙ Service quality 👍



6. CLOSING REMARKS

CCAM's uncertain future

Automating transport has long been a tempting prospect, due to the will of transport authorities to revolutionize public transportation and reap the benefits of the cost effective technology. However, despite the potential benefits, European CCAV providers are lagging behind their US and Chinese counterparts. Viable business cases for automated transport remain largely out of reach, with improvements in the mobility performance of the technology and the affordability and commercial availability acting as key milestones needed to make CCAM profitable, feasible and of good quality compared to non-automated services.

Factors impeding the development and deployment of CCAM in the European market

The key challenges lie in policy approaches. While EU policy has been at the forefront of promoting other mobility innovations such as electric vehicles, where economic incentives were pushed, low-emission zones were implemented, and infrastructure investments were made, similar measures have not yet been adopted for CCAM. While the EC is focussing efforts on research and safety regulations for CCAM, a similar technology push by policymakers as in the EV market remains to be seen. This is largely due to the current unclear benefits and relatively niche use cases that CCAM can address, compared to the more tangible impact electric vehicles have on combating climate change. To bring beneficial use cases of CCAM to the fore, along with the development of CCAM technology as a whole, continued testing and cross-sector collaboration are essential. As Suzanna Kraak (EC) states, all use cases "need to contribute towards making transport greener, safer, and more inclusive".

Furthermore, in the United States, laissez-faire policies enable large-scale commercial deployment of CCAVs, providing a bigger market for investment and innovation. In contrast, Europe's legislation remains restrictive as policymakers await proven benefits and technological advancements of CCAM. Currently, only small scale demonstration-type deployments are permitted leading to tentative investments in technology and fleet development.

Do we foresee a change in the European CCAM landscape?

Though the exact societal challenges that CCAM can solve remain to be seen, several emerging trends are reshaping the transportation landscape. OEMs like General Motors[25] recognise that urbanisation and resource scarcity are leading to a decline in private vehicle ownership, increasing the demand for shared and public transportation options. As OEMs are likely to sell fewer cars, their business models must evolve to become the manufacturers and/or operators of various types of vehicles, including taxis, shuttles, and large buses.

Is there a call to action?

As cities face growing challenges like climate change and urbanization, citizens and politicians must advocate for a transformation in public transportation and urban planning. The authors suggest that by promoting innovative public transport solutions over car-centric designs, we can create cities that encourage more sustainable and accessible mobility options. Forward-thinking politicians must collaborate with the CCAM industry to drive this change, ultimately shaping more liveable, people-centric cities.

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