ARUP

Research insights into an autonomous future

Investigating the potential and merits of Connected and Automated Mobility for public transport

Contents

Foreword

Public transport plays a vital role in the smooth running of cities across the UK. It intersects with many other public policy areas, including access to jobs, healthcare and education, initiatives to reduce carbon emissions, congestion, and air pollution, and an improved built environment with more efficient and people-centric use of space.

However, the implementation of public transport solutions is often a costly and disruptive endeavour, sometimes also resulting in unintended consequences for subsets of the population.

Recent advances in autonomous vehicle (AV) technology have the potential to significantly impact public transport systems. It is therefore valuable to explore how such autonomous public transport systems might work, and assess the associated opportunities and risks. While Connected and Automated Vehicle (CAV) trials are prevalent throughout the UK and further afield, trials using CAVs for public transport are limited. Only a handful of trials are taking place across the UK, with the success of these schemes till to be determined.

In January 2023, the UK's first zero emission automated bus began a trial in Oxfordshire. This was a funded trial for a 16-seat, fully accessible single decker bus with a safety driver on board at all times to provide a personalised service and information to passengers. The trial was designed to demonstrate the application of AV technology to real-world service provision and concluded at the end of 2023.

Another notable example is CAVForth, a trial of fully autonomous full-sized buses in Scotland, providing mobility between Fife and Edinburgh. With the first passengers carried in 2023, the fleet is comprised of five buses which can carry up to 10,000 passengers per week. The buses operate at SAE Level 4, meaning they have a trained safety driver onboard who is not expected to touch the controls while the vehicle is in autonomous mode[1].

During 2023/24, Arup was involved in three feasibility studies with multi-partner consortiums to assess the possibility of autonomous public transport trials in Cambridge, East Birmingham and Milton Keynes. Commissioned by The Centre the Connected Autonomous Vehicles (CCAV) and InnovateUK, these studies were intended to provide evidence of the case for change in the three regions. The studies also examined the economic, social and environmental effects of the schemes as well as high-level costings and challenges to commercialisation.

This report aims to disseminate the findings associated with the three studies. It offers key insights into how Connected and Automated Mobility (CAM) could revolutionise the public transport landscape and considers the next steps for deploying these services across the UK.

The studies found that CAM could have clear advantages for public transit, bringing wider social, economic, and environmental benefits. We concluded that, once a scalable solution is identified within a suitable context, CAM could have an obvious and far-reaching impact on public transport in the UK and beyond

Recent advances in autonomous vehicle technology have the potential to significantly impact public transport systems. It is therefore valuable to assess the associated opportunities and risks.

A note on terminology

Throughout this report we use *"Connected and Automated Mobility (CAM)"* to align with the latest BSI Flex 1890 v5.0 2023-04. While we use *"CAM"* as an all-encompassing term, some use cases we describe are *"autonomous"* rather than just *"automated"*, capable of entirely automating the driving task with no human intervention. We use the term *"autonomous"*, where needed, to be clear on our intended meaning.

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Overview of the status quo

An introduction to the background of CAM, why it is needed, the history of its development and the various sub-modes and vehicle providers.

Why do we need Connected and Automated Mobility?

Mobility is an essential part of our modern way of life. Without it, our economic and social wellbeing, human interactions, and business transactions would be significantly compromised. It is not surprising, therefore, that there is continual pressure to provide more and better levels of mobility. However, improved mobility can result in undesirable consequences in our cities, including congestion, transport-related accidents, air quality, and greenhouse gas emissions. Reducing or removing these downsides is a prerequisite for developing successful national and local mobility strategies for the future.

One way of delivering improved mobility while reducing or eliminating the downsides is to encourage a large-scale migration from private transport (mainly the car) to shared transport (mainly public public-transit systems). However, the scale of the migration required is huge. In the UK, more than 90%[2] of passenger-kilometres are currently provided by road transport, and most of this is by car.

Traditional forms of public transit (heavy rail, light rail, metro, trams and buses) face significant challenges when it comes to solving the problem of migration from private to public transport. Rail-based systems are becoming increasingly unaffordable, and buses can be seen to be unreliable[3]. To meet future mobility challenges, our cities and other public transport providers must find new ways of delivering attractive, affordable mass transit services.

'Attractive' public transport means different things to different people. For instance, for the regular, pre-planned traveller (as exemplified by the commuter), 'attractive' largely comprises of journey time certainty and service frequency. For the more unpredictable traveller (as exemplified by the retail or leisure traveller), 'attractive' is related to spontaneity and convenience. Both have a heavy overlay of ticket price sensitivity.

CAM has the potential to address some of these issues for all types of travellers. At the same time, public transit applications offer low-hanging fruit for CAM technology developers. This report explains how this meeting of societal need and maturing technology might be capitalised on to deliver attractive and affordable public transit systems for large scale public use within the coming decade.

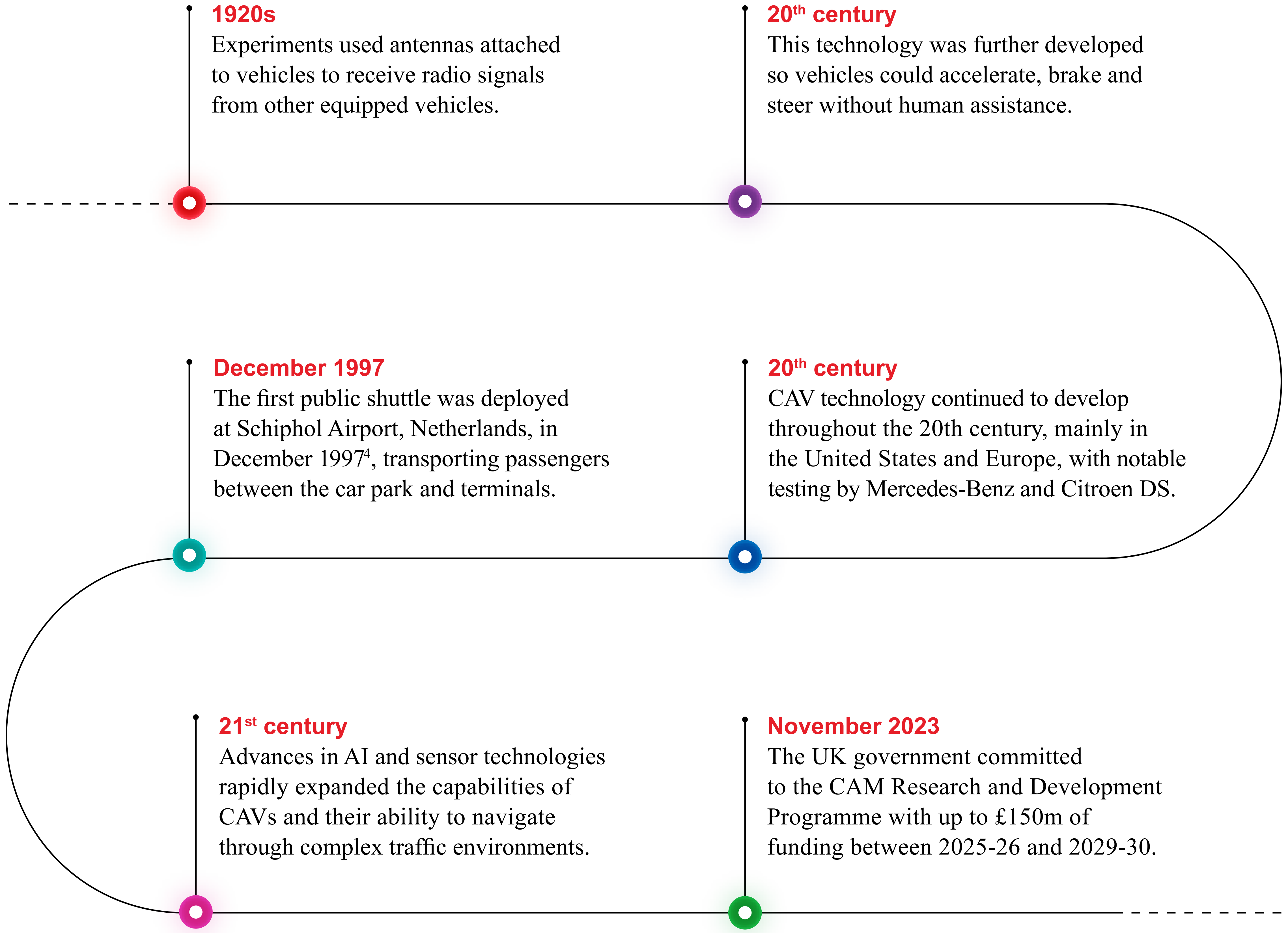


Figure 2-1
Brief history of CAVs

Brief history of CAM

CAVs are vehicles that can travel along roads and through urban environments without a human driver. They use a combination of technology to gather information about conditions around the vehicle (sensors, LiDAR and more). They process and respond to this information using Artificial Intelligence (AI) to recognise and respond to obstacles or to judge braking distances, for instance. They also use vehicle-to-vehicle and vehicle-to-infrastructure communication. This means CAVs can learn from other vehicles and devices about the world around them. A timeline of CAVs is outlined in Figure 2-1.

The emergence of CAVs was primarily technology-led rather than outcome-led. In most cases, the business need and model were not yet defined, and there was a lack of understanding of their applications within the transport sector prior to their advancement[5]. Pilot projects were, therefore, critical. Testing in multiple global cities, generally in controlled environments, was crucial to showcase the practical potential of CAM[6,7], and demonstrate the feasibility of CAVs in complex urban environments.

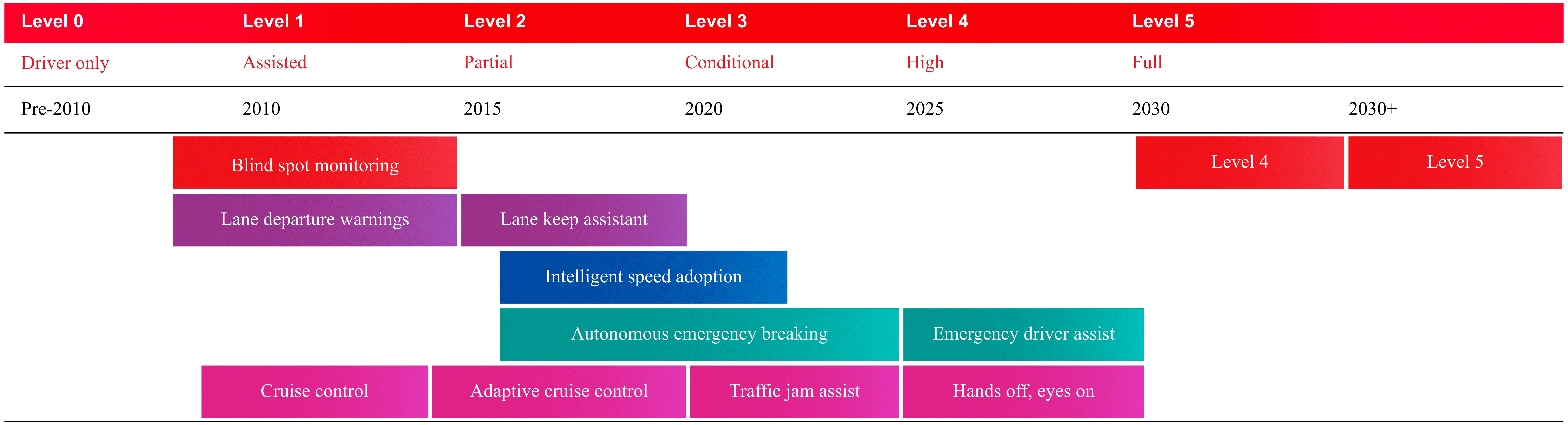
Pilots also provided an opportunity to showcase the technology and gather support from governments, urban planners and transport authorities to continue advancements and collaboration between academia, industry and regulatory bodies, furthering investment in research and development initiatives to take this technology from concept to practical implementation.

In the UK, the Connected and Automated Mobility Research and Development Programme oversees CAV pilot schemes, among other responsibilities. In November 2023, the UK government announced a commitment to extend the programme with up to £150m of funding between 2025-26 and 2029-30.

Developing technology and testing deployment of CAVs has resulted in the need for regulations and legislation to ensure their safe design and development with a way to control and mitigate their use, considering the many legal challenges surrounding their deployment.

The emergence of CAVs was primarily technology-led rather than outcome-led and there was a lack of understanding of their applications within the transport sector prior to their advancement

Figure 2-2
CAV timeline
(Iclodean et al., 2020, Fig 2.)



CAM will continue to be defined by two key factors:

– Technological advancements, including enhanced sensor capabilities, vehicle-to-everything communication, and AI as well as the development of robust connectivity infrastructure.

– Regulatory frameworks which have and must continue to adapt to accommodate the nuances and challenges associated with deploying CAM public transit systems, ensuring a balance between innovation and safety.

The former depends on continued research and development, considering how to make the systems more ‘intelligent’ and increase vehicles’ learning capabilities to improve public safety. The latter is a key area of research and an important gap in the current route to implementation. Legal and regulatory oversight is needed to ensure new technologies are deployed in a safe manner, while giving manufacturers clarity.

The UK government’s CCAV runs a variety of competitions intended to accelerate the development of CAM public transit solutions. Several competitions are planned or are currently underway (and discussed in Chapter 3). However, operational services outside of a trial are still in development and remain some years off.

CAM Sub-Modes for Public Transport

CAM has various applications within the transport ecosystem, spanning logistics, freight, private vehicles and public transport. CAM technology is already being operated in controlled and semi-controlled environments for logistics purposes. This piece focuses on public transport uses cases, examining how CAM can maximise the benefits of public transit and unlock new opportunities.

Within public transport, CAM technology can be implemented across a range of sub-modes. Similarly to conventional public transit, different solutions cater to a variety use cases at differing operational capacities, speeds, and levels of segregation. These factors influence where solutions can be introduced and which existing modes of transport they may compete with. Beyond simply removing the driver from conventional modes of public transit (bus, light rail, etc.), the automation of the driving task can enable the introduction of new modes catered to specific use cases and opportunities within existing transport systems.

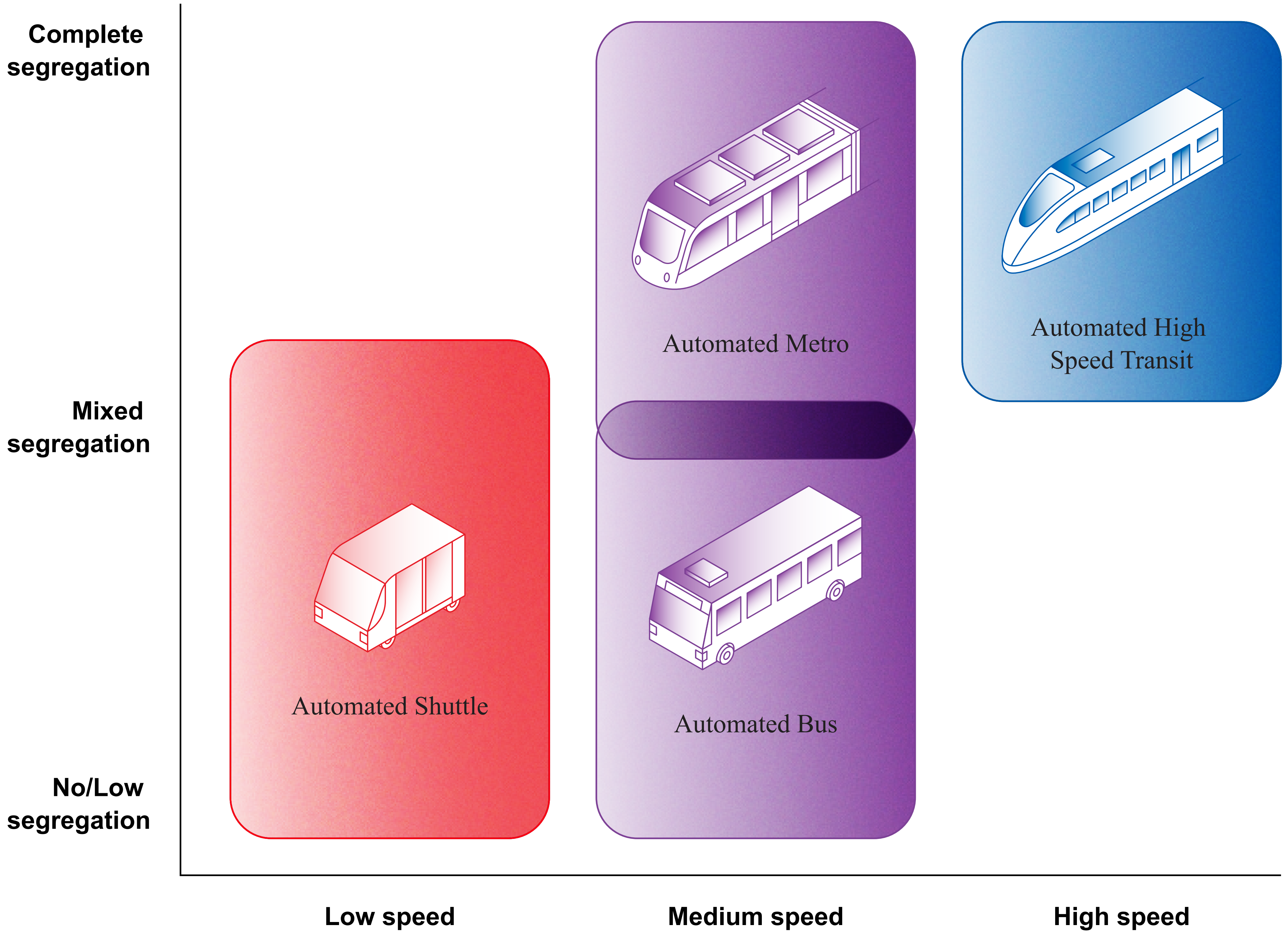


Figure 2-3
Overview of Capacity and speed

CAM for public transit

An overview of notable pilots and trials around the globe

The Loop Driverless Bus, San Francisco, USA

A free shuttle with 7 stops that "loops" around Treasure island, an artificial island in the San Francisco Bay.

The marketing was clear that the shuttle was a solution to first mile-last mile travel and is not intended to replace existing buses. The service ends in April 2024 to gather feedback from the public.

Operator	Beep
Years in service	2023-
Route length (KM)	3
Frequency (V/h)	3
Vehicle capacity	10
Funding	Grant funded
Segregation	Mixed-traffic
Safety driver / attendant	Yes

CAVForth, Edinburgh, UK

A trial of five automated buses in East Scotland connecting Fife and Edinburgh.

The Level 4 autonomous pilot is one of the most advanced in the world and navigates a mixed-traffic, multi-infrastructure environment. Passengers can also provide feedback after travelling to improve the service offering.

Operator	Multi-consortium (PPP)
Years in service	2023-
Route length (km)	22.5
Frequency (v/h)	n/a
Vehicle capacity	43
Funding	Public-private
Segregation	Mixed-traffic
Safety driver / attendant	Yes

Autonomous Shuttle Bus, Hong Kong

Airport trial transporting staff internally. Operates 12 hrs/day on a fixed route, travelling 200km on 1.5hr charge.

Initially, a bus operator ensures safety. Long-term plans include expanding bus services to transport passengers to and from the airport and beyond. The current buses have travelled 130,000km without a safety incident.

Operator	Hong Kong Airport
Years in service	2021-
Route length (KM)	1.5
Frequency (V/h)	n/a
Vehicle capacity	14
Funding	Private airport funding
Segregation	No segregation
Safety driver / attendant	Yes

Trackless Tram, Perth, Australia

Trial to assess technology capabilities between Glendalough Station and Scarborough Beach.

First of its kind trial in Australia to understand charging capacity, sensor reliability, obstacle detection, communication, manoeuvrability and user experience. Trial ongoing.

Operator	Government of Australia/CRRC
Years in service	2023-
Route length (KM)	7
Frequency (V/h)	2
Vehicle capacity	150
Funding	Government
Segregation	Dedicated lane
Safety driver / attendant	Yes (driver)

CAM for public transit

An overview of notable pilots and trials around the globe

Heathrow Terminal 5 (ULTRa PRT), UK

The urban light transit connects Terminal 5 to its business passenger car park.

The system, originally supplied by UK company 'ULTRa PRT', has been in operation since 2011. In May 2013, it completed 1M vehicle miles of accident-free service.

Operator	ULTRa PRT
Years in service	2011-
Route length (km)	3.8km
Frequency (v/h)	10
Vehicle capacity	6
Funding	Private
Segregation	Yes
Safety driver / attendant	No

Masdar City PRT, Abu Dhabi

The personal rapid transit provides on-demand, private transit from origin to destination.

The PRT is a zero-carbon emission transportation solution. The entire network generates no harmful emissions. And as the PRT removes the need for personal vehicles, the PRT's net carbon impact is zero.

Operator	Continental
Years in service	2010
Route length (km)	n/a
Frequency (v/h)	5
Vehicle capacity	4
Funding	Government
Segregation	Yes
Safety driver / attendant	No

Park shuttle, Rivium, Rotterdam

A shuttle that runs between Kralingse Zoom metro station to the Rivium business park.

ParkShuttle is an automated system of driverless electric buses connecting the Kralingse Zoom metro station and car park with the Rivium business park

Operator	Continental
Years in service	1999-
Route length (km)	2
Frequency (v/h)	2.5
Vehicle capacity	20
Funding	Government
Segregation	Yes
Safety driver / attendant	Yes

ART 'Trackless Tram', Zhuzhou, China

A lidar guided articulated bus system for urban passenger transport.

The ART runs on roads like a bus, but only on designated paths like a tram. It's modular like a train, and carriages can be added or removed to accommodate different numbers of people.

Operator	CRRC
Years in service	2017-
Route length (km)	6.5
Frequency (v/h)	10-15
Vehicle capacity	300
Funding	Government
Segregation	Partial
Safety driver / attendant	Yes

Innovative feasibility studies

Key insights from three feasibility studies of CAM mass-transit projects in the UK.

CAM for mass transit studies

In 2023, Arup was commissioned by CCAV and InnovateUK to explore how CAM technology could be deployed in three cities in England – Cambridge, East Birmingham and Milton Keynes – to solve real world transport problems in complex conditions that are shared by cities across the country and around the world.

This chapter provides an insight into the work undertaken, includes an overview of the challenges and opportunities for the deployment of CAVs in these locations, and explores how implementation of CAM could tackle key transport constraints in each of the cities studied.

Unlike other studies into CAV technology that focus on opportunities where CAVs could be rolled out quickly, this project was intended to focus on how CAM could be used to solve complex problems. For each study, Arup worked within a consortium of technology providers, Original Equipment Manufacturers (OEMs) and consultants. Each consortium was led by the relevant local transport authority, providing expert knowledge of the local transport context.

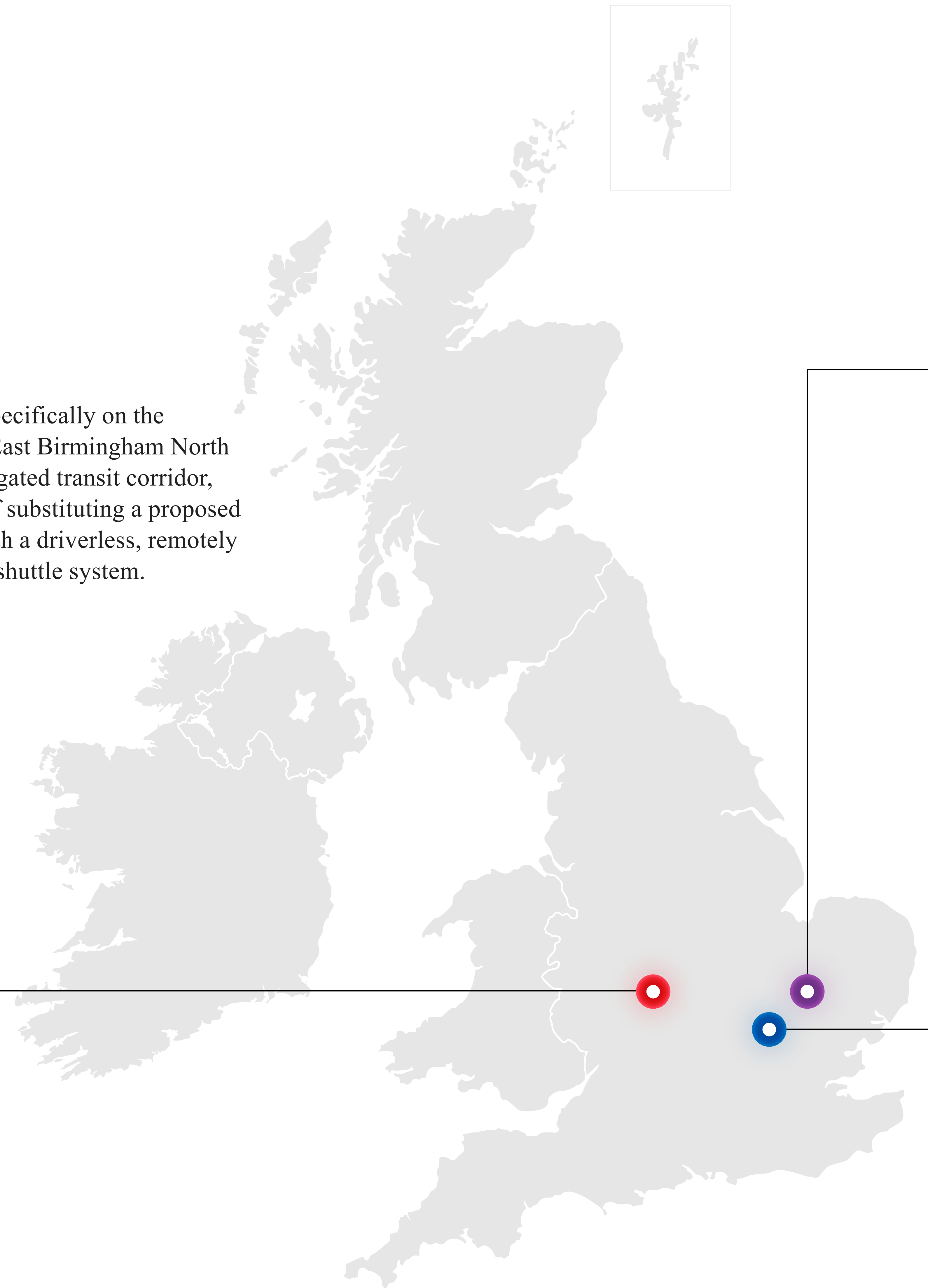


Figure 3-1
The three CCAV studies for mass transit

East Birmingham:
The study focused specifically on the currently unfunded East Birmingham North Solihull Metro segregated transit corridor, and the possibility of substituting a proposed light rail solution with a driverless, remotely supervised, rail-less shuttle system.

Cambridge:
The city has overly congested roads, a desperate need for more homes to support jobs and a dense, historic, urban form that makes delivering transport interventions hugely challenging. The project considered a potential autonomous rapid transit route in East Cambridge.

Milton Keynes:
The study considered the development of a strategic public transit system that linked Milton Keynes with its surrounding sub-regions. The system would comprise several small corridors reaching out approximately 25km from the city and enabling the populations of the surrounding towns and villages to participate in the economic growth of the city – doubling the size of the connected population and increasing economic activity. If successful, it would provide a 'first-of-a-kind' demonstration of such an extensive system.

Cambridge Autonomous Rapid Transit (CART)

To investigate how new Automated Vehicle Technologies can be deployed in the east of Cambridge to solve a complex transport problem.

The project investigated the feasibility of providing a CART system between the Newmarket Park & Ride and Cambridge Train Station. The study set out the context and strategic case, developed critical success factors (CSF), and considered various route and vehicle options for this link. The scope included cost and benefit assessments, as well as regulatory, safety and sustainability considerations.

Cambridge suffers from a challenging transport problem. It is the 16th most congested city in the UK, has a need for more homes to support jobs, but has a dense, historic, urban form that makes delivering transport interventions complicated. Historic efforts to solve these issues have left extensive experience to build on – but are likely to impact on public acceptability of a new autonomous system.

Despite these challenges, Cambridge is a global hub of technology and innovation with significant potential for mode shift and a strong policy position to encourage sustainable travel. CART therefore offers an opportunity to tackle the city's problems and enable Cambridge and other cities to unlock their full potential.

Subject	CART	Bus lane	Tram
Journey time savings	Beneficial	Adverse	Beneficial
Marginalised economic costs	Beneficial	Adverse	Adverse
Wider economic benefits	Highly beneficial	Adverse	Beneficial
Accidents	Neutral	Beneficial	Neutral
Physical activity	Beneficial	Neutral	Beneficial
Security	Neutral	Beneficial	Beneficial
Severance	Adverse	Highly beneficial	Highly adverse
Journey quality	Highly beneficial	Beneficial	Highly beneficial
Option and non-use values	Highly beneficial	Highly beneficial	Highly beneficial
Accessibility	Highly beneficial	Highly beneficial	Highly beneficial
Affordability	Highly beneficial	Highly beneficial	Beneficial
Land use optimisation	Beneficial	Beneficial	Neutral
Capital carbon	Beneficial	Beneficial	Neutral
Operational carbon	Neutral	Beneficial	Highly adverse
User carbon	Beneficial	Neutral	Beneficial

AV in Cambridge
Self-driving Aurrigo vehicle being trialled in Cambridge.

Key
- Highly adverse
- Adverse
- Neutral
- Beneficial
- Highly beneficial

Key insights

1 It would not be beneficial to scale CART in this form through the city centre. Similar to any public transit solution, the preferred routing option and associated infrastructure, costs, and benefits, is highly dependent on project boundaries, CSFs and integration with the wider transport network.

2 The main benefits of CART compared to regular buses operating within the same segregation conditions pertain to operating hours, the potential for Demand Responsive Services in the future, and ride quality, depending on the CART vehicle used.

3 There remains a risk around the regulatory aspects associated with CART for public transit falling in a grey area that is not currently being specifically explored by any parties. In particular, the applicability and variability of regulation depending on the level of segregation is currently unclear.

Milton Keynes Advanced Very Rapid Transit (AVRT)

To deliver an affordable and attractive mass-transit system which is accessible for most of the population living with a 25/30km radius of the city.

This study explored the possibility of introducing an AVRT automated transport system to promote increased economic activity in and around the geographic sub-region centred on Milton Keynes. It reviewed the overall system performance, vehicle requirements, planning, regulatory, safety/system security issues and the overall outcome of expert reviews. The study also outlined progress on the economic assessment and business case being undertaken.

Milton Keynes and its surrounding area is an economically vibrant, rapidly expanding, sub-region which expects to almost double in size over the next few decades. Local growth is driven by the city of Milton Keynes which currently has a population of 290,000. This is expected to grow to more than 400,000 by 2050 and it is likely that a significant number of those working in the city by that time will live outside the current urban boundary.

There are several centres of population which sit within a 25km radius of the city centre (such as Olney, Towcester, Buckingham, Bedford, Ampthill, Aylesbury) and it is likely that these towns and villages will expand as people move into the sub-region. Creating better public transport links between these centres of population will be essential if the Local Authorities are to avoid a daily commuter rush of low-occupancy cars sweeping across the sub-region.

Conventional systems such as light rail transit (LRT), tram and Heavy Rail are inordinately expensive, while road-based alternatives (bus or coach) are slow and subject to congestion delays. Neither of these solutions provide an attractive way forward for Milton Keynes. A novel solution is therefore required which has passenger transfer capabilities to match the projected levels of demand and provides a quality of service which can match the best public transport systems to be found in other UK cities.

It must also be delivered at much less cost than conventional solutions. AVRT has the potential to provide this solution. The 100% segregated pathway confers the ability to provide the fast, frequent, and reliable services which are essential if the travelling public are to use it as the system of choice.

Key insights

1 When CAM vehicles are designed to require smaller infrastructure and to operate at high frequency, they have the potential to provide a public transit solution that is significantly more affordable than rail solutions, while providing comparable benefits. This opportunity would apply on corridors where the existing railway network could not feasibly or viably be extended, and where the benefits easily balance the detrimental impact of interchange between modes.

2 In the case of vehicles operating at high speeds on fully physically segregated routes, there is a possibility that the Railways and Other Guided transport Systems (ROGS) regulations 2006 may apply. There is also an opportunity to use the Urban Autonomous Guided Transport standards to define the safety case for the system.

3 The AVRT is reliant on a new vehicle being designed. This presents opportunities for vehicle optimisation for the local conditions, although there is a cost risk as a manufacturer will need to design and build a new fleet that does not currently exist.

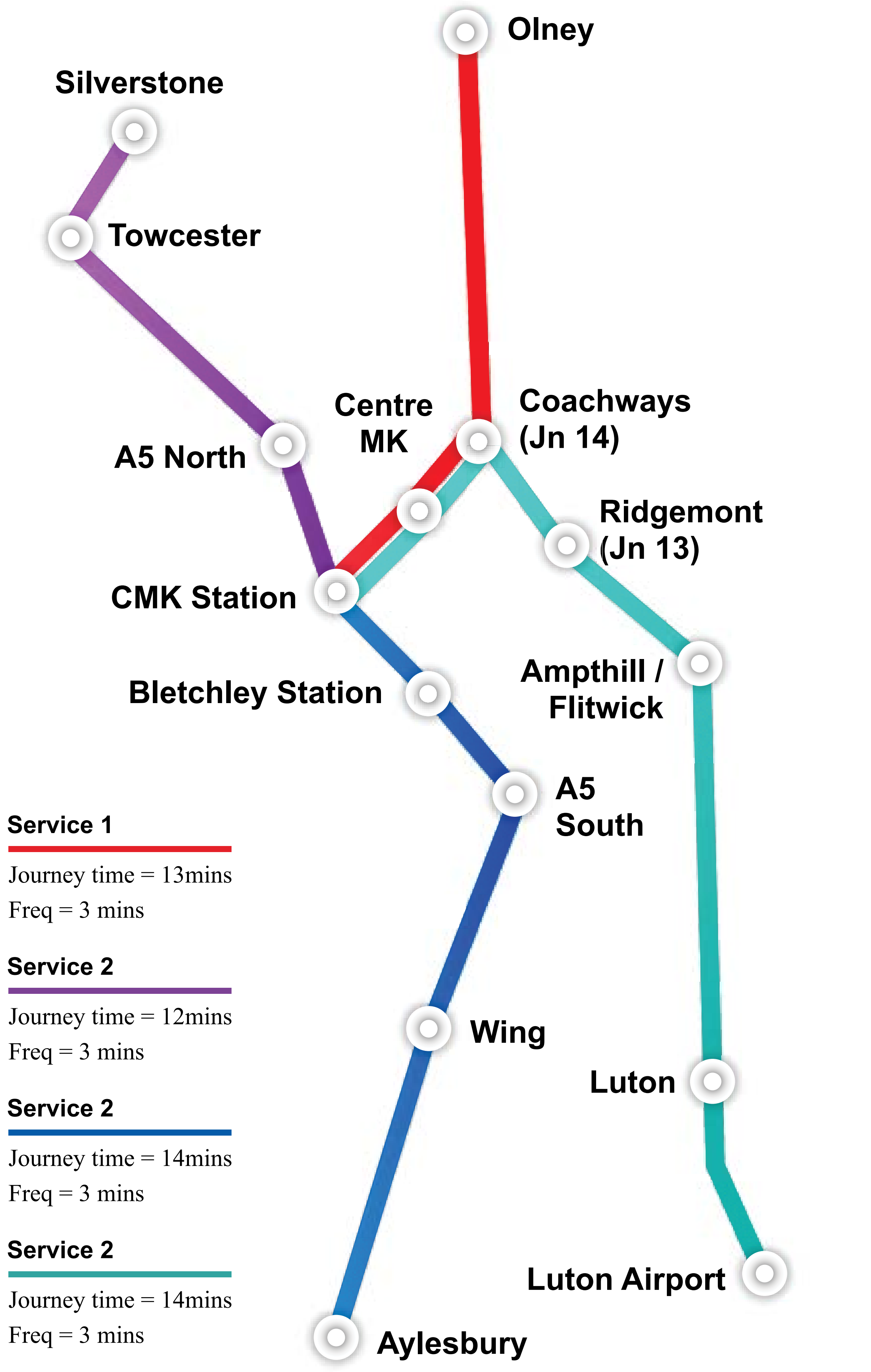


Figure 3-2
Potential network for a MK AVRT

syselek | Solihull Metropolitan Borough Council | West Midlands Combined Authority | ZF | ARUP

East Birmingham

To understand whether a CAM mass transit solution could be deployed to link East Birmingham and North Solihull, and how a CAM-based solution compares with conventional transit solutions.

The need for a high-volume arterial link is well understood but the cost has always been prohibitive. This study uses the previously produced business case for a conventional LRT system on this segregated corridor and compares it to a CAM public transit solution.

This study examined the strategic context, constraints and opportunities along the route, operational feasibility, optimal levels of segregation, costs, safety, and risks, to understand if a CAM system could feasibly deliver the same benefits at lower cost. The East Birmingham system aligns closely with the West Midlands Combined Authorities and Solihull Metropolitan Borough Council goals of shifting mode usage to public transport over private vehicles.

Limited bus and metro routes along the corridor lead to overcrowded services and congestion during peak hours, causing long travel times and high pollution levels. Bus driver shortages since 2021 exacerbate the situation, alongside the need for compulsory purchase orders to widen certain sections of the route.

Feasibility was evaluated using a RAG scale, with 11 out of 21 questions rated Green and 10 rated Amber. None reached a Red rating threshold. Key questions are outlined below:

Feasibility aspect	RAG score
Based on the agreed Solution Requirements, can a CAM solution deliver target outcomes within this urban context?	🟢
Could a CAM solution be delivered at a lower CAPEX when compared to LRT?	🟢
Could a CAM solution be delivered at a lower OPEX when compared to LRT?	🟡
Can the route be delivered with acceptable safety?	🟡
Could a CAM solution be expected to provide value for money?	🟡
Will an CAM solution that can technically serve this route be ready within target timeframes?	🟡
Can appropriate levels of segregation be provided along the route?	🟡

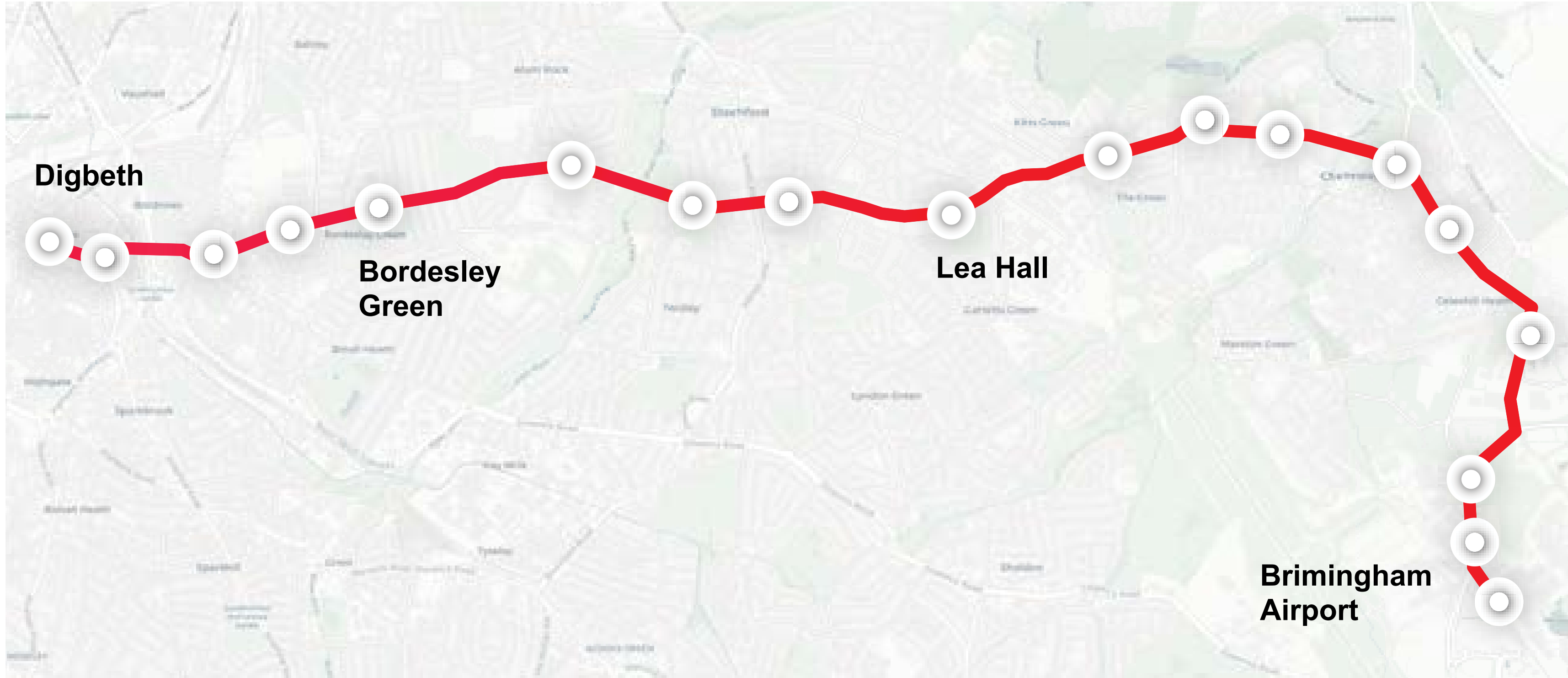


Figure 3-3
Proposed route for the EBNS shuttle service

- Stop
- Line

Table key

- Maybe / it depends
- Yes

Key insights

1 The type and fleet size of CAM vehicles used for public transit has a significant impact on operational costs, in terms of monitoring costs, fuel usage, and maintenance. Maintaining an outcome-led, vehicle agnostic approach can help to ensure an efficient and affordable solution is identified.

2 The assumptions around staff costs are crucial to the economic viability of a CAM solution for public transit. In particular, the assumption around the eventual decrease of remote monitoring costs is to be verified, and the expectations around the role of staff to mitigate anti-social behaviour and improve the perception of safety is to be clarified.

3 A fully segregated corridor provides the safest and quickest way for an automated public transit service to get from A to B. However, in an urban area, land use requirements and costs can make full segregation highly challenging to deliver. A suitable level of segregation should ensure safe and efficient operations while balancing deliverability. Operations in mixed traffic or with partial segregation are believed to be possible given current expectations of technology maturity.

Insights from practitioners

As part of this research, we engaged with 13 regional/local policy practitioners from across the UK. The sessions provided the opportunity to discuss the current attitude and appetite for CAM for public transport services.

Role of Transport authorities in the deployment of CAM for public transport

Over 85% of participants in the engagement sessions indicated that they believed their authorities have a very important, indispensable or crucial role to play in the deployment of CAM for public transport. Participants were asked to rank this role on a scale from 1 to 5, as shown in figure 4-1.

Discussing their ratings, participants believed that CAM should not be implemented without the input of relevant authorities who have an important role in setting the direction of public transport and the implementation of new technology in their region. They consider their authorities uniquely placed to understand the attitude and appetite of residents and public acceptability of the technology, and say their authorities are able to advocate on residents' behalf for the most appropriate solution.

Many participants expressed the view that, should the provision of public transport services be left to private operators, a sub-optimal solution might be put forward that does not take into account local context and regional ambitions.

The engagement session also revealed that the governance framework of each authority will impact on their ability to fund and deliver new public transport solutions, particularly for solutions such as CAM that can have a higher associated up-front capital expense. Authorities who have devolved powers appear to be in a slightly better position to consider the implementation of CAM for public transport as they have access to additional funding from Department for Transport (DfT) as part of their devolution agreement.

Central government will play a key role in setting the direction of CAM implementation and prioritising adoption in public transport

Many of the participants who indicated that they see significant opportunities for the deployment of CAM in their region expressed the view that there is a current gap in the market when it comes to innovation funding. Participants noted that they see a large majority of the innovation funding being funnelled towards technology companies for development of the technology, as opposed to towards the public sector to trial CAM in their region or investigate their merit as public transport solutions.

Participants in the engagement sessions also discussed their role in navigating and facilitating cross-boundary schemes that could provide benefits for residents across many regions. The concept of a champion from one authority who could coordinate and drive the process was raised. This would ensure that someone was responsible for progressing the project and coordinating roles, responsibilities and inputs from all parties involved. It would also require wider input from National Highways and other national/regional bodies. For example, central government will play a key role in prioritising the adoption of CAM within public transport. This can be achieved through new national policy which prioritises an outcome led approach - encouraging the adotption of CAM technology to address gaps in provision and deliver more efficient, sustainable and equitable public transit systems.

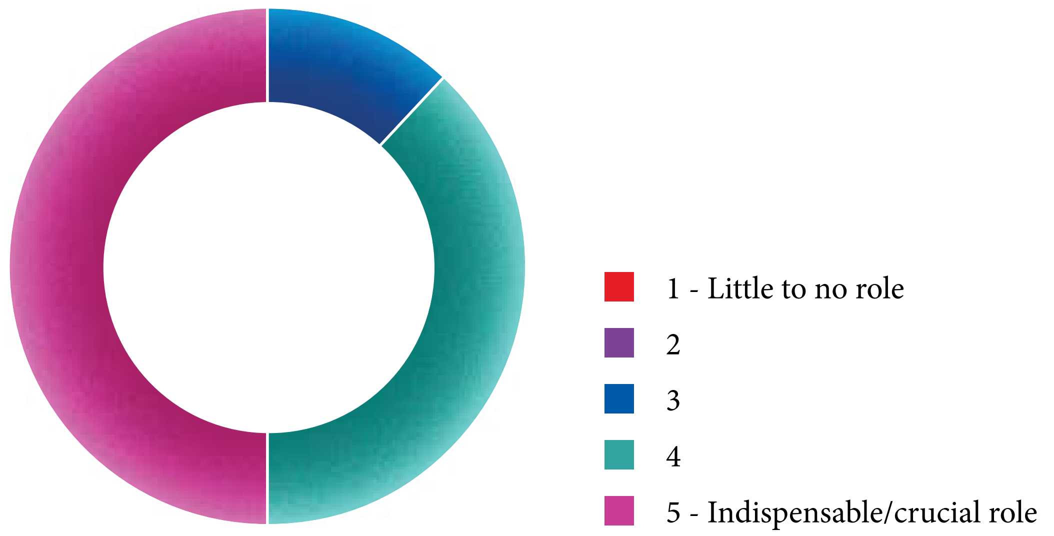


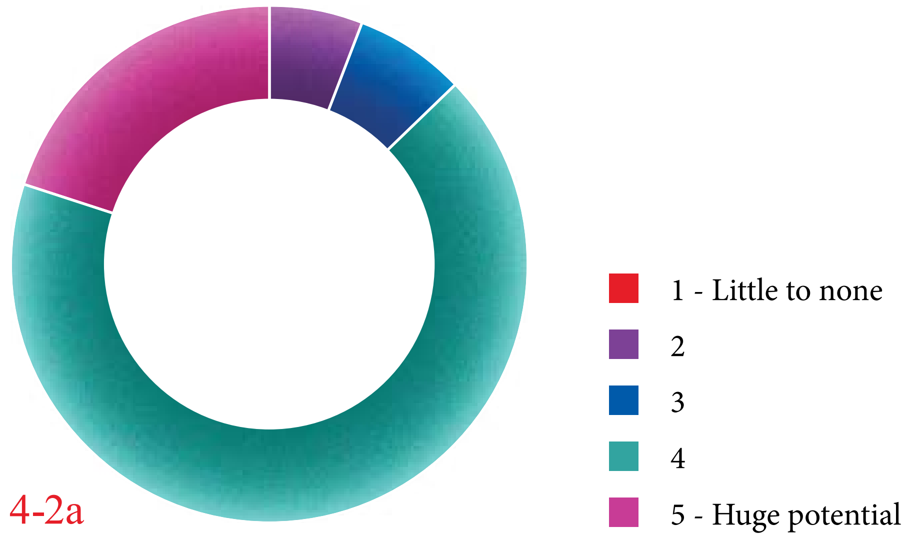
Figure 4-1
Industry insight into the importance of the role of Local, Regional and Transport authorities in the deployment of CAM for public transport.

Potential opportunities of implementing CAM

Over 85% of participants saw merits in implementing CAM systems across the UK, while 60% agreed that there were merits in implementing CAM for public transport in their region. One third (33%) adopted a neutral middle ground, and the remaining 7% were less convinced with regards to CAM's future role.

A number of the participants raised the need to consider whether CAM will lower operating costs and the extent to which it provides a lower cost 'flexible' alternative to current rapid transit. Others noted the current failing local bus services that are not working despite investment, with CAM having the potential to reduce overheads and meet demand by enhancing efficiency, reducing congestion and improving accessibility in rural areas.

The session also highlighted the potential first-mile/last-mile and nighttime economy uses cases of CAM, extending services and serving confined areas such as university campuses, supplementing or replacing on-demand transport options. Participants noted the potential for CAM services to act as shuttles to existing Park & Rides to create mobility hubs, with the potential to link into other micro-mobility services. CAM could be a solution to provide mobility where public transport is not available.



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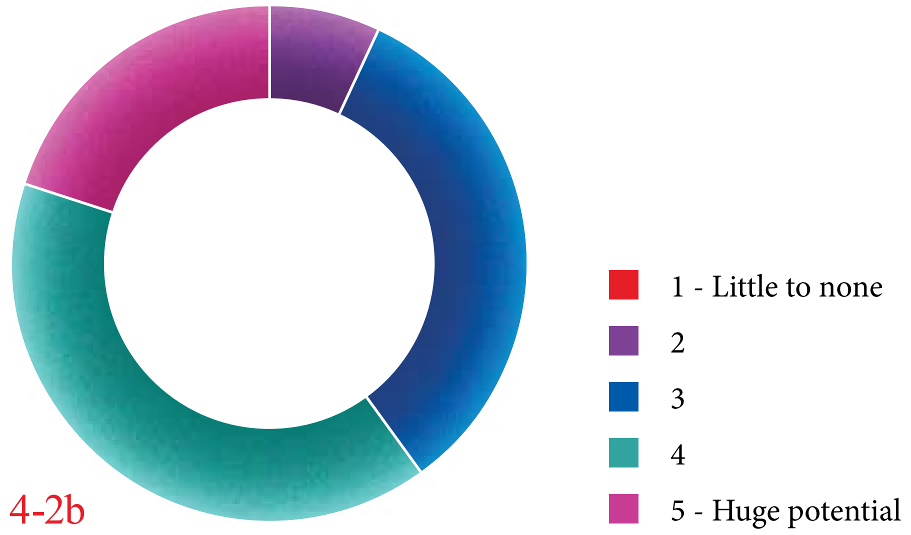

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Figure 4-2
Industry insights into the potential that CAM brings for public transport in the (a) UK and (b) survey participants region.

Challenges of implementing CAM

The majority of participants (87%) consider CAM to be challenging to implement in their region, and 7% specified it would be too challenging and therefore not something being considered at the moment.

When asked to score which elements would be most challenging, economic feasibility and legal and regulatory emerged as key issues with safety and security a close third. Technological feasibility and applicability in the real world were scored the 'best', although they were still considered somewhat challenging. Refer to figure 4-4 overleaf.

Discussing their ratings and other challenges beyond those scored, participants concerned about the identification of routes to maximise patronage and whether transport operators would be willing to accept the technology. Cost was also noted by several participants, with the upfront CapEx costs high and potentially difficult to gain political support for.

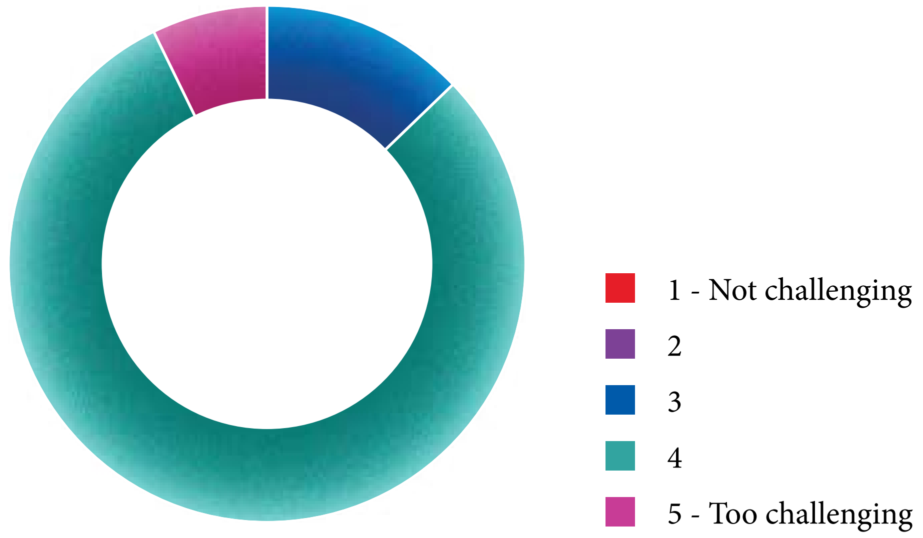

Figure 4-3
Industry insight into how challenging CAM is to implement in the survey participants region.

One participant also stated that in their opinion CAM was still an unproven form of public transport and queried whether it would really solve current problems. Participants asked how local policy practitioners could demonstrate value for money if the infrastructure and technology is likely to be more expensive and there is minimal OPEX cost savings – particularly during early phases where a human driver is likely to also be required for safety purposes.

Equally, job losses from moving to a fully autonomous system could be politically challenging with compelling messaging required to bring the public along on the journey.

Economic feasibility and legal and regulatory considerations emerged as key challenges for CAM for public transport

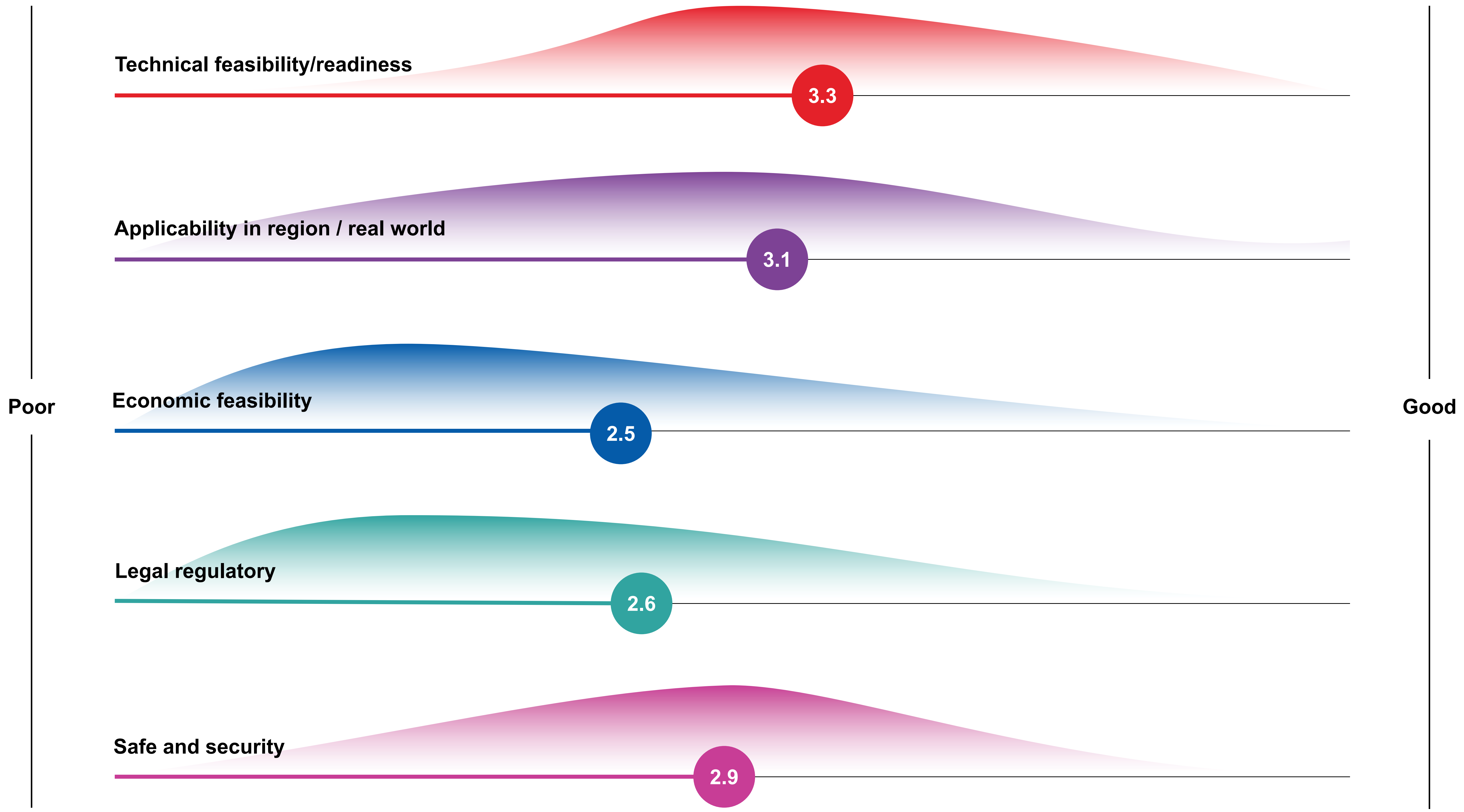

Figure 4-4
Participants rating of readiness of CAM against key aspects explored further in the research.

A future of autonomous public transport?

Answering the question 'how does CAM do?'. Discussing factors that are and could affect the deployment of CAM as a public-transport system and the key insights gained from industry knowledge and experience. Including technical readiness, use cases, economic feasibility, legal and regulatory, and safety and security

Findings: Technical readiness

Participants were mostly unsure about the technical readiness of CAM as a public transport option – with half scoring a neutral 3. Just under two fifths (38%) of participants scored a 4 and 6% scored a 1, indicating they do not believe the technology to be ready or appropriate at all.

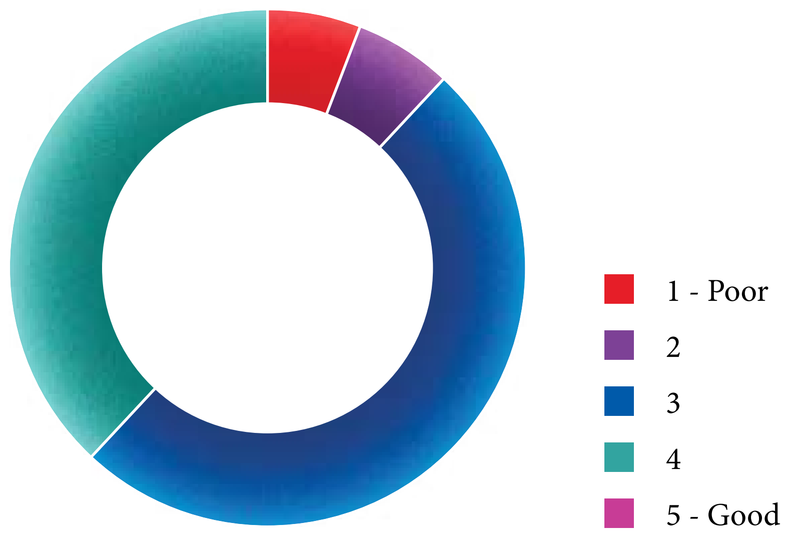

Figure 5-1
Industry insights into the technical feasibility/readiness of CAM for public transport.

Numerous studies[8] have been conducted to quantify the 'readiness' of cities to embrace CAM technology. Studies range from quantifying the readiness of people, to the readiness of infrastructure or a combination looking at the readiness of a geography overall. For users, a technical readiness index measures people's propensity to use new technologies and change their behaviours. It consists of categories that measure motivators and inhibitors that collectively showcase a person's likelihood to use new technologies. For example, those with an existing exposure to autonomous technologies could be more likely to use the technology and therefore have a higher technical readiness[9].

A more general CAM readiness index focuses on infrastructure capabilities as well as user opinion with categories exploring policy and regulations, cyber infrastructure, and physical infrastructure – defining numerical values and weighting the factors through survey responses to build decision tree models that predict a city's overall 'readiness'.

Finally, Technology Readiness Levels (TRLs) can also be used to assess the maturity level of a specific technology. TRLs are assessed for individual technology systems and in combination for a full vehicle product. The highest TRL level (TRL9) will have to be achieved by suppliers prior to commercialisation.

Key insights

1 Cyber infrastructure rapidly evolves and cities must respond to this

A city's ability to evolve to rapidly changing technology will significantly impact upon its current and future readiness score. This includes network availability; mobile data networks access; vehicular communication technology availability; fibre network availability; data analytics on urban streets for pedestrian/obstacle detection; data centre availability; mapping quality; Intelligent Transportation System availability; and cyber security.

2 Policies, regulations and central investment are key to advancing technical readiness

Polices and regulations can facilitate utilisation by residents – with a city's overall CAM readiness directly reflected in the dedication of local government to put forward CAM policies. This will have a knock-on effect on CAM investment and CAV privileges. Investment is a result of policy prioritisation and the subsequent investment or propensity to invest is vital when considering the city's readiness for CAMs. Since 2015, CCAV has worked on over 100 projects totalling £600 million of joint investment with industry. CAV privileges leverage this investment, with powers to reallocate road space and enable CAVs to operate safely in the city to improve accessibility.

Findings: Technical readiness

Key insights

3 Physical infrastructure is key to unlocking CAM potential

A change in road conditions will be required to facilitate CAV infrastructure and is generally perceived to contribute significantly to a city's readiness. Physical infrastructure can relate to the quality of existing infrastructure, including the frequency of signage and road markings to aid the autonomous technology; technological roadside facilities such as sensors and EV charging stations; and CAV compatibility, relating to how well the existing infrastructure can adapt and make space for CAVs, or considering the CAM infrastructure that is already provided and its usage.

Public transit corridors designed for CAM vehicles can be used by human-driven vehicles until the switch to autonomy can be made safely and cost-effectively. Developing CAM-ready infrastructure ensures immediate benefits while also futureproofing investment.

4 Timescales to technology readiness are linked to levels of segregation and speed

In highly segregated environments, such as dedicated autonomous lanes or controlled environments, CAM technology can advance rapidly because the driving is less complex due to minimal interaction with other road users.

These controlled settings also allow for easier standardisation of infrastructure and communication protocols, accelerating the testing and deployment of autonomous fleets. Examples include the ULTra System at Heathrow Terminal 5 and the 2getthere system in Rotterdam, both of which have been operating for many years.

Lower-speed environments, like urban areas or controlled non-road zones, could see earlier adoption of CAVs (low speed autonomous vehicles) due to reduced complexity and enhanced safety. Examples include the Aurrigo shuttle in Milton Keynes that is fully autonomous, but travels at speeds under 20mph. Integrating CAVs into mixed traffic at higher speeds requires advanced technological capabilities to ensure safe interactions, resulting in a longer timeline for achieving widespread readiness.

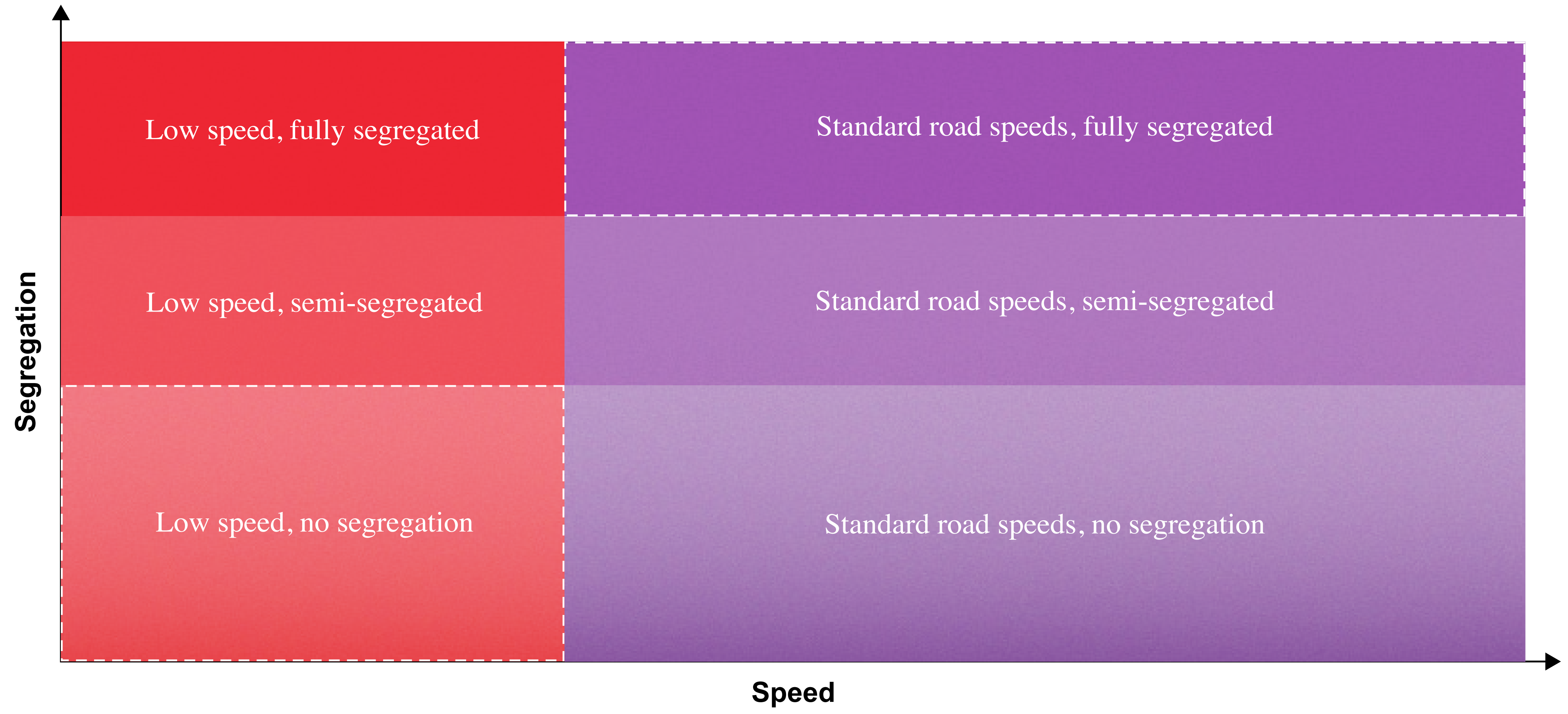

Figure 5-2
Ease of CAM implementation relative to segregation levels and speed

The trade-off between segregation and speed has, broadly, led to (1) fast, segregated, autonomous transport systems or (2) low speed, mixed traffic, autonomous transport systems, with a sliding scale between models (highlighted in red in Figure 5-2).

In the context of proposing public transport systems which might be deliverable in the foreseeable future (i.e. before 2030), higher speed, semi-segregated vehicles are the most likely to reach maturity.

Findings: CAM use cases

Participants were mostly unsure about the applicability of CAM as a public transport option – with the majority scoring a neutral 3. Only 19% scored a 4 or above, although 0% scored 1.

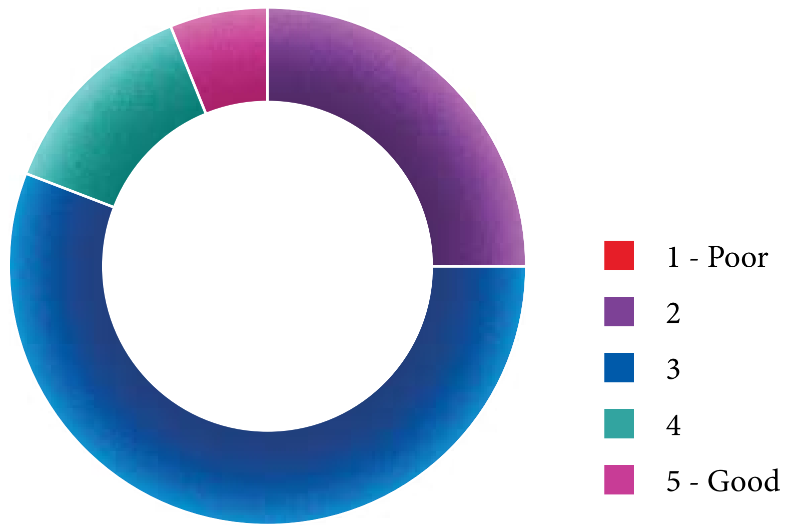

Figure 5-3
Industry insights into the applicability of CAM as public transport in the real world

There is no one-size-fits-all solution for applying CAM to public transit. Instead, solutions must be tailored to suit different use-cases, whether that be linking regions with high-capacity services or plugging gaps in first and last mile connectivity. CAM sub-modes address different problems within the mobility ecosystem. Some compete directly with existing conventional transit options, while others unlock new opportunities. Crucially, these solutions provide opportunities for CAM to deliver beneficial and feasible solutions which enable a shift away from private car ownership.

In engagement sessions with Local, Regional and Transport Authorities across the UK, many organisations indicated that they believe there are significant opportunities around implementing CAM as public transport. More than 85% of participants indicated that there is significant or huge potential and plentiful opportunities for CAM as a public transport solution, as shown overleaf in figure 5-4.

Key insights

1 The importance of a national strategy for CAM should not be overlooked

National strategy can play a crucial role in ensuring CAM technology works to resolve problems in our transport system and doesn't simply lead to more congestion on our roads. This strategy should emphasise an outcome-led approach - identifying problems first and then developing solutions in a technology agnostic manner in response. Solutions should focus on prioritising public transport and facilitating modal shift. Once an initial concept of operations has been developed, a suitable CAM vehicle or sub-mode can be determined.

2 CAM can efficiently connect city corridors without heavy infrastructure

Medium capacity driverless vehicle could provide a solution that is more attractive than buses, while being more affordable than light rail services. If operated on partially segregated corridors, these services could provide reliable journey times - without the need for expensive physical guidance infrastructure. In more constrained urban areas, operations in mixed traffic could be permitted, giving greater flexibility when designing routes. These services could help to alleviate issues with ongoing public transport driver shortages[10].

Findings: CAM use cases

Key insights

3 CAM provides efficient and shared first- and last-mile services

In smaller vehicles, driver costs make up a larger share of operating costs, rendering low-capacity first- and last-mile services connecting commuters to mobility hubs financially impractical. By removing costs associated with the driver, CAM services could unlock this use-case - plugging gaps in provision and providing better access to existing public transport services. Using intelligent route planning algorithms, a fleet of shared automated shuttles could despond more dynamically to user demand. These services could pick up passengers only where needed and deliver seamless journeys from doorstep to destination.

In rural areas and at off-peak times, low demand can mean conventional public transit solutions are unaffordable. This can lead to a reliance on private vehicles or taxis to provide access to key services and social infrastructure. CAM could provide a more flexible alternative, operating only when needed. By responding to passenger demand, services could plan custom routes - connecting individuals to key services at times or in locations where regular services aren't feasible.

4 CAM can deliver affordable regional connectivity

CAM vehicles do not rely upon expensive physical guidance infrastructure like rails and signalling equipment. This opens new possibilities for automated high-speed transit services to connect regions currently under-served by conventional public transit services, where high construction costs act as a barrier to the delivery of new schemes. On highly segregated inter-regional corridors, risks associated with automated vehicle interactions with other traffic or pedestrians are also eliminated.

This could enable safe high-speed, high-capacity services without compromising safety. One shortcoming of CAM systems compared to the extension of existing railways lines for example is the loss of network effect and need for interchange between modes.

Participants were more positive about the potential that CAM brings for public transport in the UK with 87% of people scoring 4 or above.

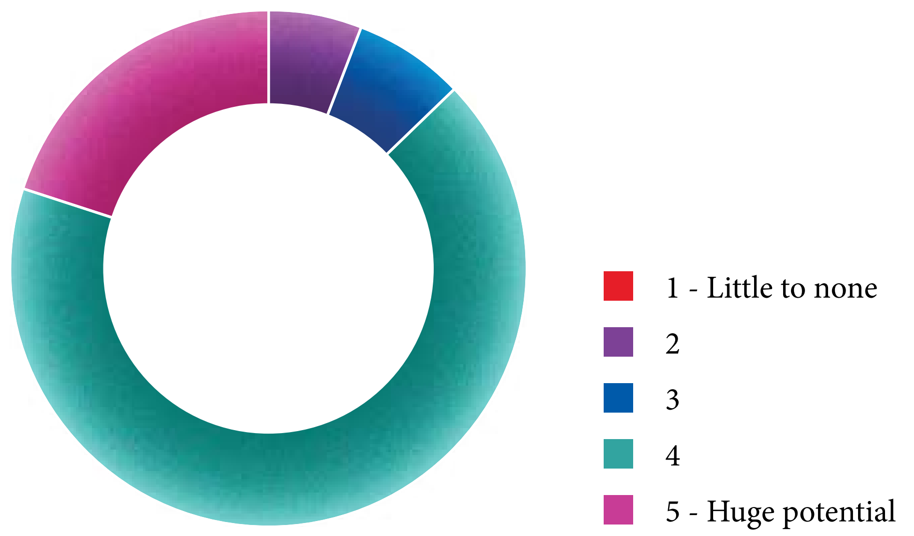

Figure 5-4
Industry insights into the potential impact that CAM brings to public transport in the UK

In rural areas and at off-peak times, low demand can mean conventional public transit solutions are unaffordable. CAM could provide a more flexible alternative, operating only when needed.

Findings: Economic feasibility

Participants largely do not believe that CAM is economically feasible, with 62% scoring a 2. Two fifths (38%) of participants scored a 3 or 4 and there were no scores of 1.

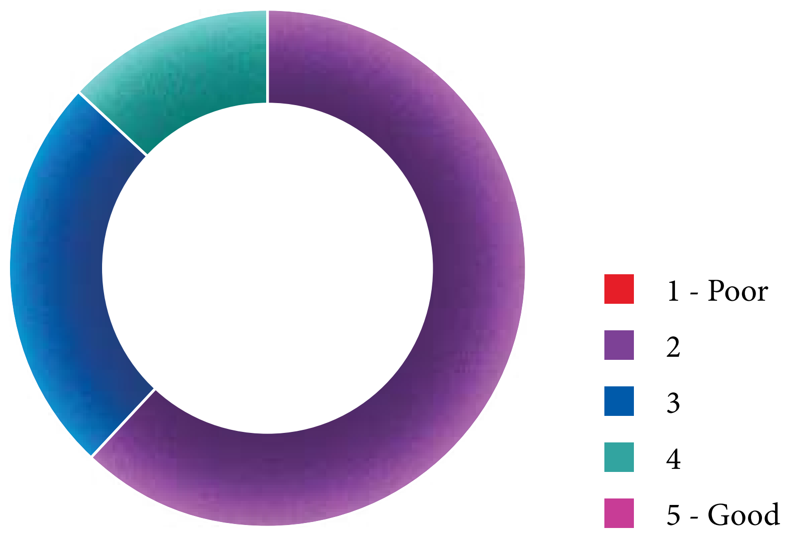

Figure 5-5
Industry insights into the economic feasibility of CAM for public transport.

Key insights

1 The operating cost for CAM is still significantly impacted by vehicle and fleet size

When implementing a public transport system, it's crucial to consider operating costs and opportunities for efficiency and cost savings. Autonomous public transit systems have the capacity to optimise route planning, minimising idle time and enhancing overall efficiency. Autonomous vehicles also allow for predictive maintenance, prolonging vehicle lifespan. By utilising real-time data and connectivity, operators can respond dynamically to changing demand – streamlining service provision.

A key contribution to operational cost saving for CAM is assumed to be the removal of driver costs. However, there is a risk that this saving may be offset by the need for remote monitoring as well as increased maintenance and vehicle costs, as shown in Figure 5-6. Note that these costs are expected to reduce over time as lessons are learnt and economies of scale develop. Many of these costs are proportional to fleet size which is linked to capacity and vehicle size. For public transit solutions, higher capacity CAM vehicles are therefore likely to be most suitable to achieve economic viability.

2 The need for human presence on board CAVs is the biggest "make or break" of the economic viability of CAM for public transport

If a human presence is required this will impact upon the overall OPEX costs and relative economic benefit over other modes such as buses.

The presence of a human on board can act as a critical safety net, instilling confidence in passengers and regulators alike. The lack of a human presence raises concerns related to emergency response, unexpected technical glitches, and the overall reliability of the autonomous system.

Moving forwards from trial to implementation, there is a need to strike the right balance between technological advancements and ensuring a reassuring human presence to achieve widespread acceptance and economic success of CAVs in the realm of public transport. Resolving this conflict will enable the full potential of CAVs to be unlocked.

3 Principles of Transit Orientated Development apply as long as measures are in place to achieve journey efficiency and reliability

Autonomous transit systems have the capacity to reshape urban planning dynamics, potentially reducing the need for extensive parking infrastructure, creating wider economic impacts such as agglomeration benefits, and encouraging mixed-use developments.

Studies, such as those by the Urban Land Institute and the American Public Transportation Association , suggest that the integration of autonomous public transit can lead to increased land values in areas well-served by these systems.

This is more likely to be the case, the more reliable and frequent the service provided. Reduced traffic congestion and enhanced accessibility could contribute to a more integrated urban fabric, potentially uplifting property values. However, careful consideration must be given to address potential issues of equity and social inclusion to ensure that the benefits of land value uplift are distributed equitably across communities.

Findings: Economic feasibility

Key insights

4 **Up-front capital costs can be high, although the sum of the benefits can outweigh this if CAM technology is implemented effectively and in the right geography**

The deployment of autonomous vehicles necessitates the need for new on-road infrastructure – with sensor, communication systems and advanced computer infrastructure (depending on the vehicle) contributing to higher upfront costs. The vehicles themselves may also initially be more expensive as they are yet to be commoditised. However, over time, economies of scale and advancements in technology could lead to cost reductions, contributing to the economic feasibility of the system in the long run. Compared to rail, the costs will be significantly less.

Higher capital costs may also lead to greater local economic activity by improving connectivity for shift workers or improving the frequency of the service – compared to traditional bus services. Autonomy on its own is not the sole reason for providing the service. The sum of the benefits, such as being able to run more services across 24 hours of the day, can outweigh the upfront costs.

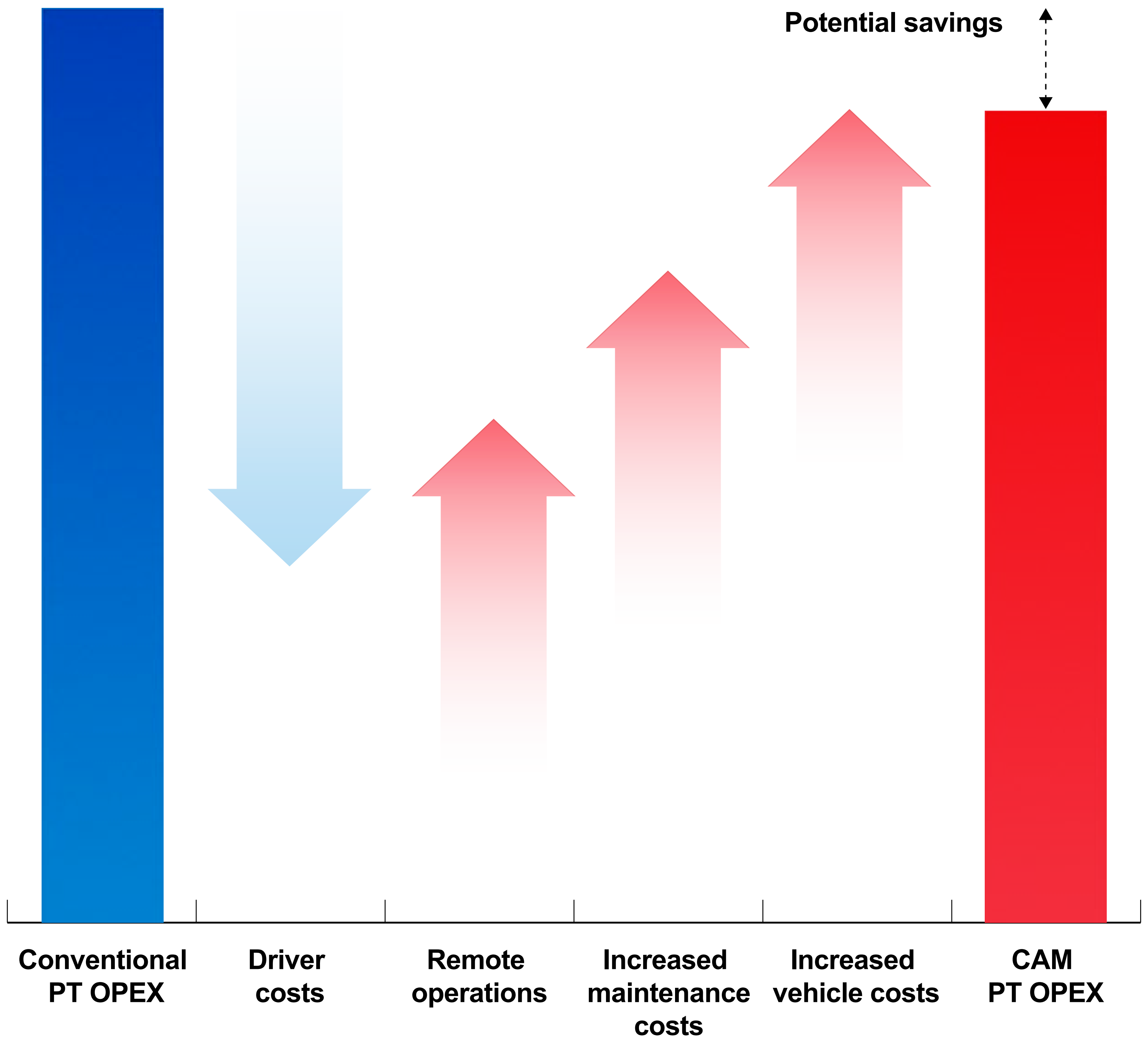

Figure 5-6
Waterfall diagram illustrating the impact of removing drivers on operating costs, and how this is offset by the cost of remote operations, as well as increased maintenance and vehicle costs.

Moving forwards from trial to implementation, there is a need to strike the right balance between technological advancements and ensuring a reassuring human presence to achieve widespread acceptance and economic success of CAM in the realm of public transport.

Findings: Legal and regulatory space

Participants were unsure about the legal and regulatory space of CAM as a public transport option, with 53% scoring a neutral 3 and 40% scoring either a 1 or a 2. The commercialisation of CAM will not be achieved without an enabling legal and regulatory eco-system. This is even truer for CAM applied to public transport.

This chapter does not constitute legal advice. The information shared in this chapter synthesises information available in the public domain. The team makes no warranty, expressed or implied, as to the accuracy of the information contained in this chapter.

In August 2022, the UK Government set out its plans to deliver a legal and safety framework to enable the safe introduction of self-driving vehicles on UK roads. Renewed action to deliver this framework was announced during the King's Speech in late 2023, in the shape of the Automated Vehicles Bill.

The Automated Vehicles bill will provide a framework of best practice that can be adapted and applied to some elements of segregated public transit applications. Key principles of planned government legislation which could guide best practice for public transit applications include:

- Approval and authorisation of vehicles – determining whether vehicles are technically safe and if vehicles can be permitted to drive themselves.
- Operator licencing – establishing the legal responsibilities of remote operators, and processes for getting licences and permits for Automated Passenger Services (APS) in place.
- In-use regulation – ensuring that vehicles are safe to operate throughout their lifecycle.
- Incident investigation – requirements relating to data gathering and sharing throughout vehicle operations.

Note that while planned legislation will establish powers to enact this safety framework, further supporting secondary legislation will be required to provide detailed requirements and processes.

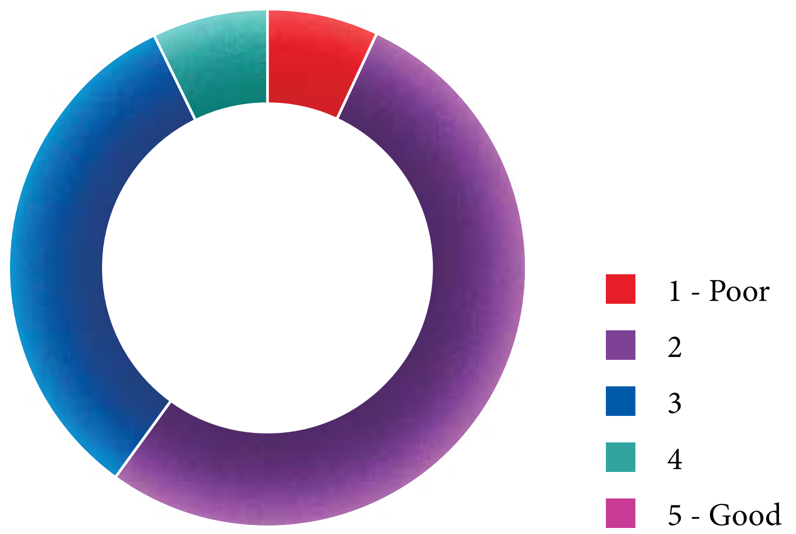

Figure 5-7
Industry insights into the legal and regulatory space of CAM as public transport.

Findings: Legal and regulatory space

Key insights

1 **Segregated public transit applications may not be fully covered by the Automated Vehicles Bill**

The Automated Vehicles Bill applies to services operating on publicly accessible roads in mixed traffic conditions. Separate legislation will therefore be required to fully cover applications on segregated infrastructure or private land. Segregated public transit applications are thought to fall within a legislative grey area – being partially covered by the Automated Vehicles Bill, and partially under existing arrangements for Rail, Tram and Bus Rapid Transit (BRT). The relevance of different existing public transit legislation and regulation depends on the specific use-case. Crucially, the level of segregation a CAM scheme operates within will determine which existing frameworks are relevant.

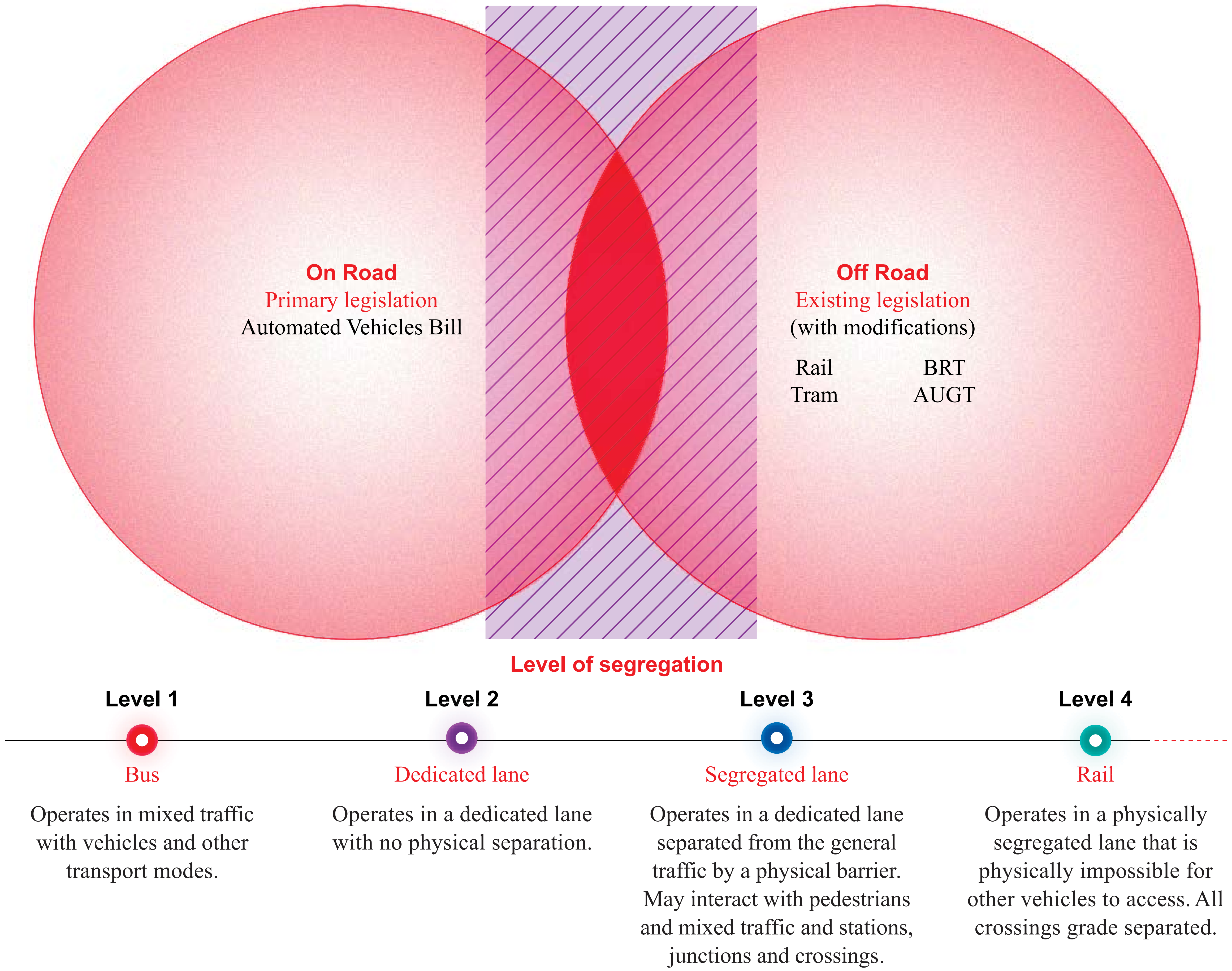

Figure 5-8
On-Road and Off-Road regulations potentially applicable to CAM for public transport.

Findings: Legal and regulatory space

Key insights

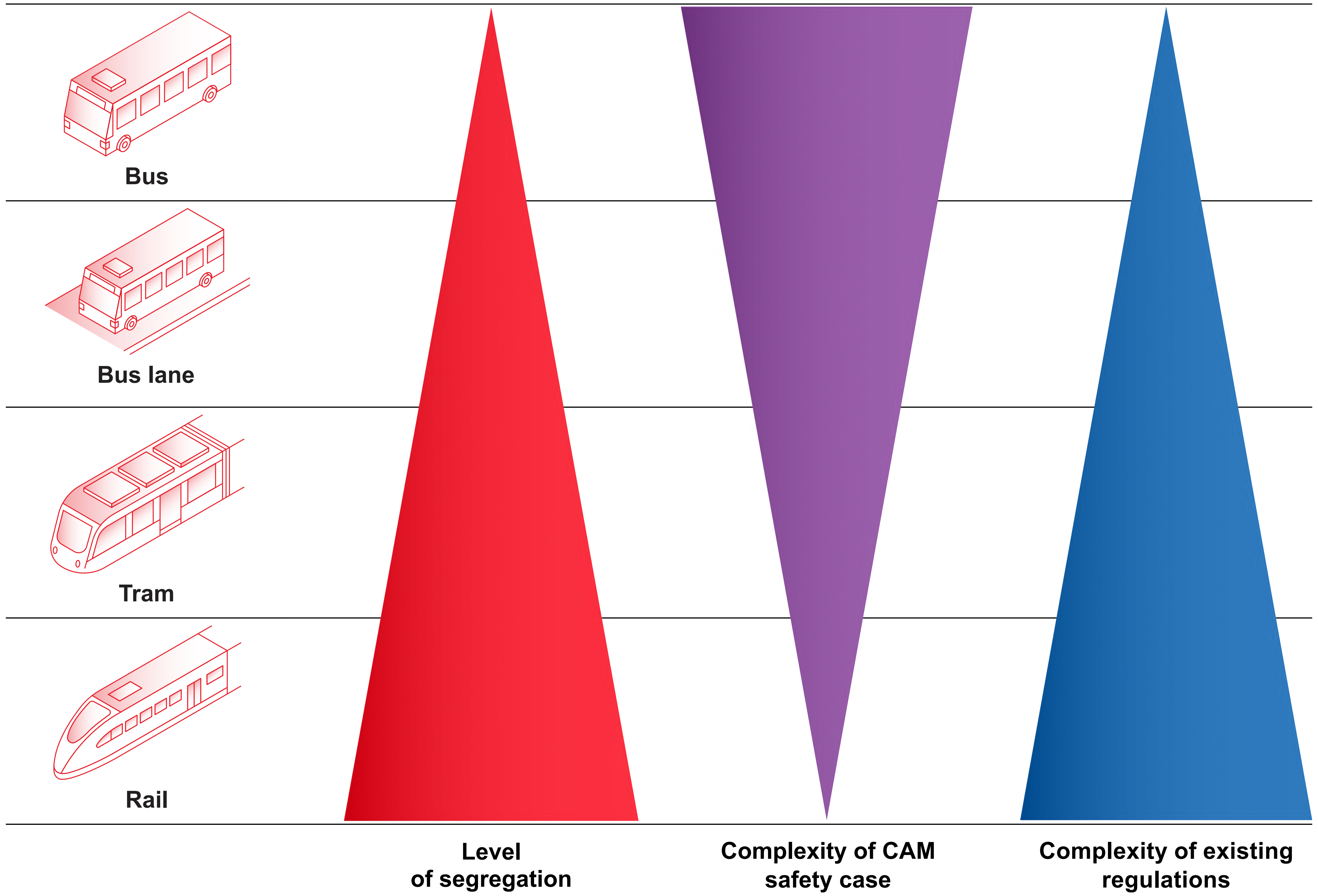

Figure 5-9
Mapping complexity of CAM safety case and regulations for different Sub-modes.

2 ROGS May Apply to Highly Segregated CAM Public transit Services

As the level of segregation is increased, schemes may be bound by the ROGS regulatory framework. CAM public transit schemes operating at high speeds in highly segregated environments and systems that are, in part, controlled centrally may have to abide by these regulations. At lower levels of segregation, planned CAM regulations may be more applicable, but the complexity of the operating domain for the automated driving system will be much greater. Legal investigation and early consultation with the regulator is recommended to identify which regulatory regime is most relevant to specific use-cases.

3 Existing public transit standards could provide a basis for building up suitable requirements

Standards developed for existing public transit modes may provide a useful basis for the development of suitable requirements for CAM public transit schemes. This could save schemes from developing new frameworks entirely from scratch and provide the basis for the development of a safety case. Automatic Urban Guided Transit (AUGT) standards may be particularly relevant. AUGT standards set out six high level functional groups which could be considered and provide structure during the identification of key hazards.

Findings: Safety and security

Participants were largely unsure about the safety and security considerations of CAM as a public transport option. Half (50%) scored a neutral 3 and a further 37% scored either a 1 or a 2. 13% of participants gave a score of 4 and none scored a 5.

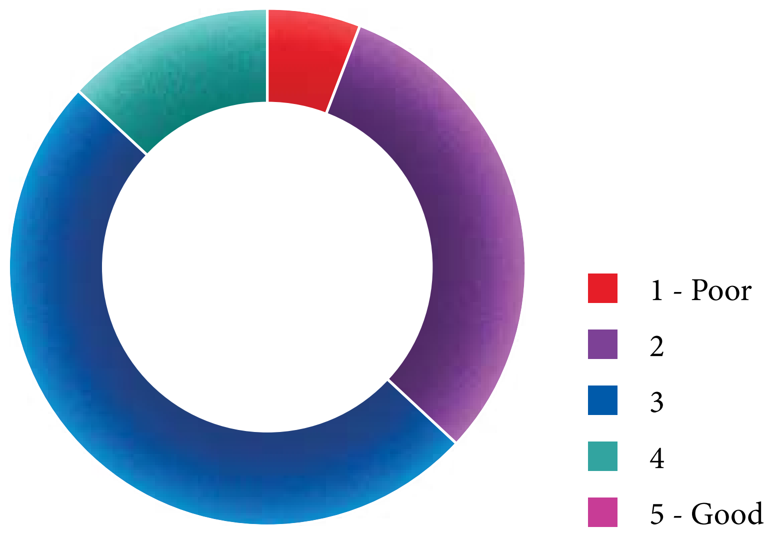

Figure 5-10
Industry insights into safety and security considerations for CAM as public transport.

Key insights

1 A robust safety case should be developed for any CAM public transit system

As discussed in Section 5.4, regulations for CAM public transit schemes operating on segregated routes will not be fully covered by the Automated Vehicles Bill. Regardless of the relevant legislative regime, a detailed and robust safety case should be developed for any CAM public transit system.

A suitable safety case should consider the CAM public transit solution as a whole system, covering the vehicle, route infrastructure and remote operation capabilities. Responsibility for completing a full safety case would be the responsibility of the local authority planning to put in place a CAM public transit scheme. Since this task would require detailed knowledge of a particular system, it is likely be a joint exercise carried out with support from the technology supplier and system operator.

2 Drivers do more than just drive the vehicle – removing them may lead to an increase in anti-social behaviour onboard.

The absence of a driver might lead to an increase in anti-social behaviour on CAM public transit. Currently, drivers can act as a deterrent to intimidating or violent behaviour, even though they do not have a specific duty to address such conduct. Studies have shown that one of the strongest deterrents for vulnerable persons choosing public transport is the lack of safety[11].

For women and girls, public transport can represent unsafe environments and is a known hotspot for sexual violence and harassment[12], particularly at night or at quieter travel times. By adapting adequate safety measures, such as remote monitoring, and promoting a safe, inclusive and respectful environment, CAM public transit services can address the potential risks of increased anti-social behaviour and gendered barriers to uptake.

Note that adequate provision of remote monitoring or in-person mitigations may negate cost-saving benefits of removing the driver in the first place.

3 CAM services may be more vulnerable to deliberate physical interference

In the UK, as part of the Government's Connected and Automated Vehicles: Process for Assuring Safety and Security (CAVPASS) programme, standards, testing and monitoring processes to ensure CAM services are resilient to cyber-attacks have been developed. On the other hand, measures to protect CAM public transit services from physical security threats are less established. Whether hostile or not, deliberate interference with CAM services acts as a significant threat to efficient and safe operations.

Large scale trials with automated vehicles in the USA have shown that CAVs are vulnerable to simple interference, such as pedestrians covering sensors with cones[13]. During day-to-day operations, drivers or pedestrians may be more likely to act more recklessly around CAM vehicles if they assume they will always stop for them. Further research is required to identify suitable mitigations to protect vehicles from physical security threats and maintain efficient operations. Maintaining positive public perceptions will be a key mitigation to reduce deliberate interference.

Findings: Safety and security

Key insights

4 Remote operators will be essential to help vehicles navigate uncertain scenarios

Automated driving systems are trained using millions of simulated driving events to learn safe navigation in real-world scenarios, continuously enhancing their performance. Despite this, not all potential scenarios can be simulated and planned for in advance. To deal with these edge cases, remote monitoring and human intervention is essential to ensure vehicles can navigate uncertain scenarios and maintain robust CAM operations. Even on segregated routes where interactions with other road users and pedestrians are largely avoided, remote operation remains a necessity. In addition to dealing with edge cases, remote operations staff can help to monitor on-board safety, respond to anti-social behaviour, and manage emergency evacuation scenarios.

Schemes should be able to respond effectively to edge cases like emergency service vehicles making use of segregated or dedicated lanes. Connected infrastructure (i.e. sensors placed along the route) can help to detect edge case scenarios before vehicles interact with them, and allow remote operators time to respond accordingly.

5 Managing public perceptions is key to ensuring the acceptable introduction of CAM public transit

Public perceptions of the safety of a CAM public transit scheme can have a significant influence on its eventual success. As a new technology, services are likely to be viewed with additional scrutiny in the public eye. Any accident involving a self-driving vehicle is likely to garner much more controversy than an equivalent accident caused by a human driver.

Even if the safety of a CAM public transit scheme is proven, negative public perceptions and distrust in the technology could lead to reduced usage and even the eventual scrapping of schemes. Recent DfT research[14] as shown that early engagement, education and demonstrations can help to improve public perceptions of safety. This research has provided recommendations for improving understanding of CAM technology and ensuring acceptable introduction.

Where do we go from here?

A roadmap for the implementation of CAM for public transport noting the role of the different actors and the various workstreams required to evolve in order to make CAM a reality for public transport.

Roadmap to implementation

The roadmap below illustrates the many actors and work streams relevant to the implementation of CAM for public transport.

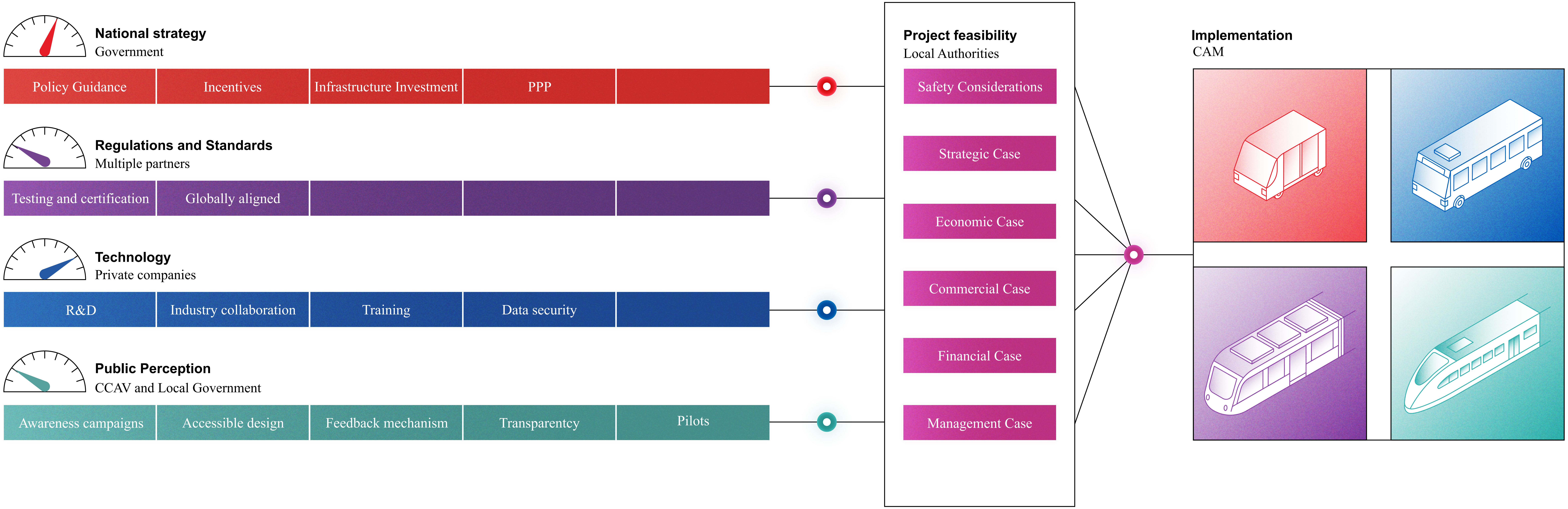

Figure 6-1
A roadmap for implementation of CAM for public transport

A promising technology posed to transform transport

Worldwide, there is great interest in the subject of CAM as a promising technology poised to transform the transport sector.

The UK has dedicated substantial funding and effort to establish a leading position in this field through its CCAV, Zenzic, and several other initiatives. It is now important to bring these efforts to practical fruition as soon as possible and public transport systems offer an attractive and meaningful starting point.

The potential for CAM technology to bring social benefit is significant, but the timeframe for practical delivery is still unclear. There are many different views within industry and government, and a wide spectrum of dates are offered in answer to the (apparently simple) question: "when will driverless vehicles appear on our roads?". Much of this confusion results from differences in the perception of what is meant by 'driverless vehicles' but also which use case for CAM should take priority.

While many insights from our research are transferable across projects and applications, the fundamental recommendation remains the adoption of an outcome-led approach for each case where CAM is identified as a beneficial solution.

Finally, the role of national government as well as that of National Highways, is not to be overlooked with regards to the direction setting and enabling of CAM for public transport.

Should the evolution of CAM be fully left to the market providers, a sub-optimal solution that does not take into account local context, or regional and national ambitions might materialise. An intentional strategic direction is key to ensuring CAM supports modal shift and the UK's journey towards net zero.

Contact us

Our research team are keen to connect and discuss your thoughts or queries on Connected and Automated Mobility for public transport, anywhere in the world.

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Isle of Wight Council

Transport for Greater Manchester

Transport for the South East

Transport East

Transport for West Midlands

Luton

Endnotes

1 https://www.cavforth.com/

2 Transport Statistics Great Britain: 2021 - GOV.UK (www.gov.uk)

3 https://www.sciencedirect.com/science/article/pii/S2590123021000815

4 ParkShuttle. Available online: http://faculty.washington.edu/jbs/itrans/parkshut.htm (accessed on 11 April 2020).

5 Iclodean, C., Cordos, N. and Varga, B.O., 2020. Autonomous shuttle bus for public transportation: A review. Energies, 13(11), p.2917.

6 Anderson, J. M., Kalra, N., Stanley, K. D., Sorensen, P., Samaras, C., & Oluwatola, T. (2014). Autonomous Vehicle Technology: A Guide for Policymakers. Rand Corporation.

7 Levinson, D., & Asaro, L. (2017). Autonomous taxis could greatly reduce greenhouse-gas emissions of US light-duty vehicles. Nature Climate Change, 7(10), 687-690

8 O'Hern, S. and Louis, R.S., 2023. Technology readiness and intentions to use conditionally automated vehicles. Transportation research part F: traffic psychology and behaviour, 94, pp.1-8.

9 O'Hern, S. and Louis, R.S., 2023. Technology readiness and intentions to use conditionally automated vehicles. Transportation research part F: traffic psychology and behaviour, 94, pp.1-8.

10 https://www.iru.org/resources/iru-library/driver-shortage-report-2023-passenger-europe-executive-summary

11 OECD, "Understanding Urban Travel Behaviour by Gender for Efficient and Equitable Transport Policies," Discussion Paper No. 2018-01, 2018.

12 Loukaitou-Sideris, A., & Ceccato, V. (2020). Sexual harassment on transit: evidence from the literature. In Transit Crime and Sexual Violence in Cities (pp. 12-23). Routledge

13 Kevin Truong, https://sfstandard.com/2023/07/07/we-spoke-to-one-of-the-activists-coning-cruise-and-waymo-robotaxis-in-san-francisco/

14 Department for Transport, 2023, The Great Self-Driving Exploration: A citizen view of self-driving technology in future transport systems

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3 Portrait © Arup

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