MI-LINK

MultiCAV Project Partner Perspectives on the Mi-Link Autonomous Bus Services

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Executive Summary

The MultiCAV research and development project, co-funded by Innovate UK and the Centre for Connected and Autonomous Vehicles (CCAV), was established to deliver sustainable transport services in a 'Mobility as a Service' environment. The centrepiece of the project was a series of three phases of electric autonomous bus service trials, first operating on public roads within Milton Park Technology and Science Park, Didcot (Oxfordshire) and later linking to Didcot Parkway railway station. The demonstration services took place in 2023 and were branded to the public as part of the Mi-Link[1] suite of transport services. The project was conducted by a consortium which brought together First Bus as lead, Milton Park, Oxfordshire County Council, Nova Modus, Fusion Processing[2], Zipabout, and the University of the West of England (UWE Bristol).

This report summarises consortium member reflections on the planning and operation of these novel autonomous bus services – the first of their kind on public roads in the UK, although sharing commonalities with the CAVForth[3] diesel-powered automated bus trials conducted concurrently near Edinburgh. Findings are presented from several research activities undertaken by UWE Bristol, which set out to address the following research questions:

- What initially motivated consortium members to engage with a project to deliver autonomous vehicle trials?
- What have the autonomous bus trials revealed in relation to how to plan and operate autonomous bus services on public roads in the UK?
- To what extent did the autonomous bus trials meet the expectations of consortium members?

The research activities involved two rounds of one-to-one interviews with consortium members held 18 months into the project (in March 2020) and in the last six months of the project (in June and July 2023), and a stakeholder workshop (in July 2023) that brought together representatives of most consortium partners to share perspectives on the experiences of developing the demonstration bus services.

The Vehicle

The trials employed a conventional 15-seat[4] electric mini-bus manufactured by Mellor which was retrofitted by Fusion Processing with its CAVstar® automated driving system (Figure 1, overleaf).

[1] See https://www.mi-link.uk/ for the public-facing website
[2] Initially a subcontractor to the project appointed through a procurement exercise, later a full project partner.
[3] https://www.cavforth.com/
[4] One seat foldable to enable access by a passenger using a wheelchair.

Figure 1: The electric autonomous Mellor Orion minibus used on Services 001 and 002

The Routes

The first phase of the trial required the vehicle to travel on a circuit within the business park (Figure 2). Although the business park road network is privately owned, it is not a protected space in the sense that roads are not clearly distinguishable from the neighbouring public road network adopted by the local highway authority.

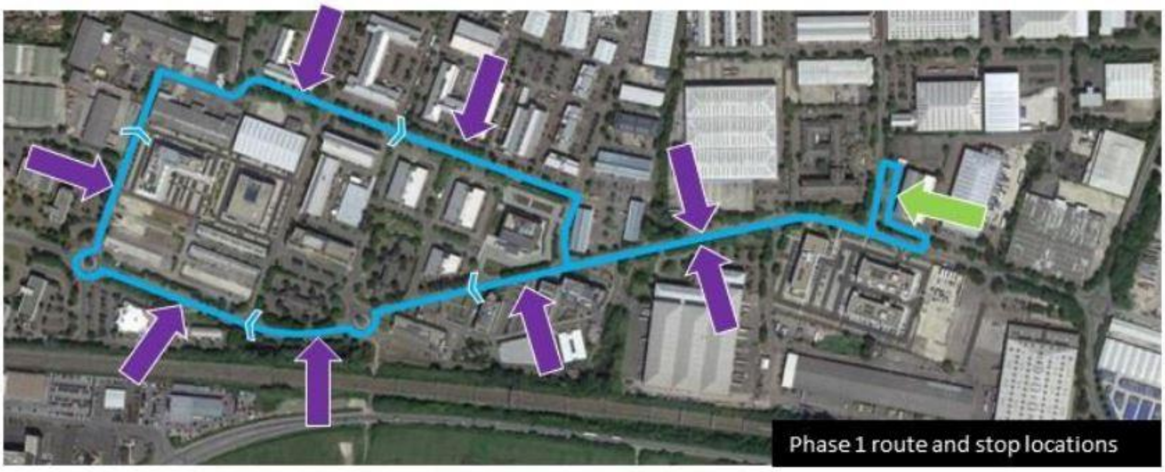

Figure 2: Service 001 route – business park circuit

The second phase of the trial required the vehicle to use the public road network between Milton Park and Didcot Parkway railway station completing a 10km route which included some intermediate stops (Figure 3).

Figure 3: Service 002 route – business park to railway station

Key Findings

1. ***What initially motivated consortium members to engage with a project to deliver autonomous vehicle trials?***

Consortium members were motivated to take part in the project as it aligned with objectives to (i) develop their knowledge and capacity in relation to producing and delivering autonomous bus vehicles and services and (ii) to strengthen and project their organisation's reputation for innovation and sustainability. The latter was seen as important (for both public and private sector bodies) from the perspective of being market leaders and as a means of attracting investment.

2. ***What have the Mi-Link autonomous bus trials revealed in relation to how to plan and operate autonomous bus services on public roads in the UK?***

Findings related to this question are summarised under five subheadings (a to e).

a. Autonomous bus vehicle technology continues to mature

When tested through a formal procurement process in 2019, the 'off the shelf' autonomous shuttle vehicles (pods) available on the market were found to be not capable of meeting the legal safety requirements for a Public Service Vehicle operating on public roads in mixed traffic. Three fundamental requirements were not met by the 'off-the-shelf' autonomous shuttle base vehicles:

- They did not meet UK 'type approval' regulations, required for the safe operation of a bus service.
- They were not equipped with an adequate manual control system. Previous autonomous bus trials had typically been operated by the vehicle manufacturer in controlled environments. The Mi-Link trials involved handing the vehicle over to a third-party bus operator and this introduced a requirement for a manual control mechanism that could be easily handled by an experienced driver of conventional buses.
- Their performance meant they would not be able to adopt the speed of the prevailing traffic in the area, so impacting on traffic flow, possibly leading to unwanted behavioural responses by drivers of other vehicles.

There was a sense from the consortium members that 'off the shelf' autonomous shuttle vehicle capabilities had been oversold by companies, leading to a gap between expectations at the outset and what it was possible to deliver at an early stage in the project. It may be that vehicle manufacturers had, at the time: (i) not fully understood the legal safety standards for base vehicles used as Public Service Vehicles in mixed traffic, (ii) had not fully understood the types of control systems that would be required by third party operators to satisfy their safety procedures, and (iii) that there is a natural tendency in marketing to not draw attention to vehicle limitations. Such limitations emerge when tested through procurement processes involving legal contracts.

The project was subsequently delivered by retrofitting automation technology to a conventional and hence 'type approved' electric minibus.

b. Avoiding delays in delivering future autonomous bus services

The trials revealed two significant sources of delay in preparing for the operation of an autonomous bus service. These were:

1. Difficulty acquiring a vehicle that was suitable for the trials. This could be avoided in future trials by having a realistic understanding of: (i) the different requirements introduced by different operating environments (e.g. fully segregated vs mixed traffic); (ii) the different requirements introduced by different types of operating model (manufacturer operated vs third party bus operator) and (iii) the capabilities of different types of vehicles (bespoke and retrofit of conventional vehicles) and the environments and operating models to which they are suited.
2. The unanticipated emergent requirement[5] was for independent reviews of the project's Vehicle Operating Safety Cases and the Operational Safety Case to be undertaken prior to services starting. This indicated a need for a standardised process for planning autonomous bus services (backed by regulation) and a need to create a market for organisations with the knowledge required to undertake independent reviews of the safety cases for autonomous bus vehicles and services – few such organisations existed at the time of the trials.

c. Preparing the street environment for autonomous bus services

The trial revealed a need for some changes to street environment maintenance cycles to accommodate autonomous bus vehicles. Specifically, the project revealed that, at the time of the trial, autonomous vehicles require:

- Vegetation clearance at the roadside. Autonomous vehicle systems are not yet able to determine the nature of vegetation near the highway (i.e. distinguish it from other objects, confirm it presents a low risk). Hence, the system responds cautiously, interrupting smooth motion. This limitation implies a need for modified highway vegetation maintenance cycles and practices, for example as they relate to other strategies to 're-wild' verges and protect bird nesting seasons.
- A higher standard of road marking – degraded road markings, which would otherwise be manageable for human drivers, may need to be re-painted to enable reliable detection by automated vehicle technology.
- Some retrofitting of traffic signal control infrastructure – the trials revealed that it is not necessary to replace traffic signal controllers with the most up-to-date controller. The DSCR technology can be retrofitted into older traffic signal sites allowing the SPaT and MAP messages to be sent to the communication systems required by autonomous bus vehicles to detect traffic signal aspects.

[5] CCAV introduced this requirement for all the projects it funds involving automation trials after the grant agreement was signed, when the project was underway. MultiCAV was one of two projects piloting the independent review approach. Establishing and procuring these first-of-kind independent reviews was itself a complex procedure.

d. The importance of partnership working and mutual learning

The project trials revealed how the delivery of an autonomous bus service relies on a complex set of interactions between highway authorities, bus operators, vehicle manufacturers, connected autonomous vehicle (CAV) technology providers and regulatory bodies. Each stakeholder organisation needs to understand its role and how this relates to the requirements of the other stakeholders involved.

Consortium members identified that every party needed to learn something to deliver its own part, and in addition there needed to be a collective learning as to how to put those parts together. For example, the vehicle manufacturers brought knowledge of the technology, but needed to combine this with the expertise of the bus operators to understand how this could be applied to a bus service on public roads. This suggests that the ongoing development and deployment of autonomous bus vehicles and services will benefit from mechanisms that allow close partnership working between all of the core industry stakeholders. Table 1 identifies the principal experience and knowledge that partners brought to the consortium.

Table 1: Principal expertises of the MultiCAV partners

FirstBus	Fusion Processing	Milton Park	Oxfordshire County Council	Zipabout	NovaModus	UWE Bristol
Legal and regulatory context of bus operations; Practical experience of bus operations (e.g. drivers); understanding of the market for bus services	AV technology: hardware, software, and their systems integration Practical experience of earlier AV trials	Understanding of employees and their mobility patterns;	Legal- financial e.g. for procurement; Highways management; Understanding of Oxfordshire population and local politics	Understanding of technology and mobility patterns	Autonomous vehicle consulting; Management of R&D project consortia	Evaluation of interventions in the transport sector; transport policy and planning context

The range of expertise identified suggests that the ongoing development and deployment of autonomous vehicles and services will benefit from mechanisms that allow close partnership working between all of the core industry stakeholders.

e. The need for system resilience

Compared to conventional buses, in order to operate without a driver, autonomous buses are more reliant on auxiliary technical systems such as satellite communication systems and mobile phone networks. On a small number of occasions, the autonomous minibus was not able to operate in autonomous mode due to an issue with connectivity to such auxiliary systems. This suggests a need for a level of redundancy to be built into auxiliary systems and how they are accessed (i.e. building-in access to fall-back auxiliary services) to enable fully autonomous bus services to operate reliably.

The operation of the autonomous electric bus also introduced a requirement for new operational practices for the bus operator to ensure service reliability. Procedures to ensure the right level of charge in the battery needed to be introduced once experience on the specific duty cycles had been established. One practical and minor example included a laptop password not being available to members of staff on site (a laptop needed to access and initiate the vehicle systems), which delayed the start of the bus service on a particular day.

3. ***To what extent did the Mi-Link autonomous bus vehicle trials meet the expectations of consortium members?***

Consortium members explained that the autonomous bus service trials had at the same time exceeded and not met the expectations that they held at the outset of the project. Given the complex nature of the project these perspectives are not inconsistent.

Exceeded expectations: There was a consensus amongst consortium members that the performance of the vehicle in autonomous mode had exceeded expectations in demonstrating an ability to reliably undertake complex manoeuvres in mixed traffic and to operate at speeds of up to 40mph (65kmh).

Unmet expectations: Some consortium members admitted to disappointment that the vehicle used in the trials was, and hence looked like, a conventional minibus, and this contrasted with their earlier expectation that the vehicle would look and feel like a futuristic pod vehicle (an expectation formed through engagement with marketing materials, and in some cases exposure to other autonomous vehicle trials). Linked to this, there was a sense that the project had not delivered a 'human-independent' service demonstration that had been envisioned at the outset, as the onboard safety operatives were not there 'just in case' but needed to intervene quite often, for a range of reasons.

There was also a feeling that the whole process had being delayed for too long, due to three main factors: i) the Covid-19 pandemic, ii) semiconductor shortages, and iii) legal and technological requirements.

Recommendations

The Mi-Link trials revealed that the wider deployment of novel autonomous buses on UK public roads will require:

- **Credible information, backed by evidence, on vehicle performance.** There is a need for reliable information on what forms of vehicles are currently available on the market and what forms of operating environments and public transport services different vehicles are suitable for. This would make it easier to procure suitable vehicles for different applications. Some form of certification process could assist with confirming for which operating and business models different vehicle types would be suitable.
- **Capacity building** across the autonomous bus services sector. A lack of capacity in the sector was evident in the trials through (i) the small number of suppliers that were able to meet the vehicle tender specification and (ii) the small number of suppliers that were suitable for undertaking new roles such as the independent review of safety cases. There therefore remains a need to stimulate the market in all parts of the sector. Government involvement through on-going grant funding for research and development and fostering development of the regulatory framework for autonomous vehicle operation, including buses, are important here.
- **Continued partnership working between industry stakeholders** so that individual stakeholders develop knowledge of their own requirements and how they relate to the requirements of other stakeholders involved in the delivery of autonomous bus services. Research and development funding for projects such as MultiCAV provide one such mechanism to bring industry stakeholders together. Funding could also be made available to sustain ongoing networking channels – enabling secondments for staff to move between organisations for short time periods, for example.
- **Mechanisms to manage stakeholder risks, including delays.** Committing to the deployment of novel public transport vehicles and services requires all organisations involved to take financial and reputational risks. Partnership working was viewed as an important mechanism to manage risk, both between consortium members who were working towards shared goals, and the funders

which wish to see projects reach their potential. Partnership working inevitably brings with it the need to accept the wider consequences of delay affecting specific partners.

- **A regulatory framework for autonomous bus services**. The MultiCAV Project has needed to define a regulatory framework for its own activities at every stage. Going forward, it would be important that there is international alignment of a clearly defined and agreed regulatory framework. This would help to address a number of the aforementioned recommendations including: (i) ensuring vehicle manufacturers develop vehicles that meet legal safety standards, (ii) ensuring that autonomous vehicles and services support users with mobility impairments or needs, (iii) creating a market for the provision of services such as the conduct of independent safety review (if these were to become a legal requirement), and (iv) providing a means of managing stakeholder risks, if the legal framework places a requirement on stakeholders to mutually meet each other's needs.
- **Measures to ensure that autonomous bus services are reliable and resilient**. To build-in redundancy for a fully operational[6] autonomous bus service will require:
    - The maturation of the vehicle technology and auxiliary systems (including efficient production processes) such that vehicles run reliably;
    - The availability of multiple operational vehicles to bus operators, implying a need for commercially viable autonomous vehicle purchase and leasing costs;
    - The maturation of operational procedures to ensure that the additional requirements linked to the running of autonomous vehicles are met (such as access to satellite positioning signals and software);
    - The development of a mature maintenance industry; and
    - The development of road infrastructure maintenance procedures to align with the needs of autonomous vehicle technology.

[6] A service registered with the Traffic Commissioner and on which fares are collected.

1. Introduction

The Mi-Link research and development project, co-funded by Innovate UK and the Centre for Connected and Autonomous Vehicles (CCAV), was established to deliver sustainable transport services in a 'Mobility as a Service' environment. The centrepiece of the project was a series of three phases of electric autonomous bus service trials, first operating on public roads within Milton Park Technology and Science Park, Didcot (Oxfordshire) and later linking to Didcot Parkway railway station. The demonstration services took place in 2023 and were branded to the public as part of the Mi-Link[7] suite of transport services. The project was conducted by a consortium which brought together First Bus as lead, Milton Park, Oxfordshire County Council, Nova Modus, Fusion Processing[8], Zipabout, and the University of the West of England (UWE Bristol).

This report summarises consortium member reflections on the planning and operation of these novel autonomous bus services – the first of their kind on public roads in the UK, although sharing commonalities with the CAVForth[9] diesel-powered automated bus trials conducted concurrently near Edinburgh. Findings are presented from several research activities undertaken by UWE Bristol, which set out to address the following research questions:

- What initially motivated consortium members to engage with a project to deliver autonomous vehicle trials?
- What have the autonomous bus trials revealed in relation to how to plan and operate autonomous bus services on public roads in the UK?
- To what extent did the autonomous bus trials meet the expectations of consortium members?

The report summarises the method followed in Section 2, followed by the substantive part of the report considering findings (Section 3) before concluding, in Section 4, by drawing out the key lessons learned.

Project timeline

The project planned three autonomous bus service trials:

- The first demonstration (Service 001) took place in February and March 2023 and involved an electric autonomous minibus operating on a circuit around the Milton Park Science Park (see **Error! Reference source not found.** for a plan of the route).
- The second demonstration (Service 002) took place during June and July 2023 and involved the same electric autonomous minibus connecting Milton Park Science Park to Didcot Parkway railway station (see **Error! Reference source not found.** for a plan of the route).
- The final demonstration (Service 003) ran with a full-size single-deck electric bus on a route similar to the second demonstration, but adapted to the large vehicle. However, it had to be terminated after two days' operation due to a mechanical problem with the bus unrelated to the automation system (see Figure 6 for the slightly modified route).

A schedule of key project events relating to the development of autonomous vehicles by the project is provided in Table 2.

[7] See https://www.mi-link.uk/ for the public-facing website
[8] Initially a subcontractor to the project appointed through a procurement exercise, later a full project partner.
[9] https://www.cavforth.com/

Table 2: Schedule of key project events relating to the vehicles

Date(s)	Key project events with respect to passenger vehicle development
September 2017	Grant call issued by Innovate UK.
September 2017	Project consortium formed (led by First Bus, supported by Nova Modus, and involving Oxfordshire County Council, Milton Park, University of the West of England, Zipabout, and Arrival[10].
October 2017	Grant application submitted.
February 2018	Application selected for funding.
November 2018	Project commenced.
November 2018	Arrival works on autonomous taxi and bus vehicles.
February 2019	1st tender issued for the procurement of an autonomous shuttle bus.
June 2019	1st procurement round concludes unsuccessfully in respect of acquiring a suitable autonomous shuttle vehicle.
December 2019	2nd tender issued for the procurement of an autonomous shuttle vehicle.
March 2020	2nd procurement round successful in securing a suitable autonomous shuttle bus. Contract awarded to Fusion Processing.
March 2020	Start of the COVID-19 pandemic lockdown periods in UK. COVID-19 which introduced project delays due to working practice changes and supply chain delays globally reducing the rate of vehicle development.
September 2020	CCAV requirement emerged for MultiCAV to participate as a pilot of a new Independent Safety Case Review procedure.
October 2020	Autonomous electric taxi to be developed by Arrival is dropped from project objectives due to mounting development delays.
April 2022	Arrival reports unresolvable supply-chain constraints with autonomous bus development and withdraws from the consortium.
May 2022	Fusion Processing joins the consortium as a partner to automate an electric single-deck bus to be provided to the project by Switch Mobility.
February/March 2023	Service 001 operated by autonomous minibus around Milton Park.
June/July 2023	Service 002 operated by autonomous minibus between Milton Park and Didcot Parkway railway station.
September 2023	Service 003 operated by autonomous electric single-deck bus begins operation but experiences automotive technical issues unrelated to the Autonomous Drive System and the operations are halted.
November 2023	It is concluded that the technical issues with the Switch Bus cannot be resolved within the project schedule.
December 2023	The electric minibus provides a further two weeks of demonstration service on the Milton Park-Didcot Parkway route.
December 2023	Project concludes at end of month.

The autonomous bus trial location and routes

The Milton Park Science and Technology Park is located in South Oxfordshire, 5 km west of the town centre of Didcot and 20 km south of Oxford. It can be characterised as an ‘out of town’ (single land

[10] Automated electric vehicle manufacturer Arrival left the project in 2022 and was replaced by Fusion Processing.

use) employment park, which attracts regional and local commuters. The park is well served by the strategic road network and also by the 'Great Western' main line train services between London Paddington and Bristol/Swansea, which call at Didcot Parkway station in the town centre, to the east of the park. Conventional bus services connect the railway station to the business park and employees also benefit from a discounted annual bus pass to support public transport access to the park.

Service 001 route

The first demonstration service required the vehicle to travel on a circuit within the business park (Figure 2**Error! Reference source not found.**). Although the business park road network is privately owned, it is not a protected space in the sense that roads are not clearly distinguishable from the neighbouring public road network adopted by the local highway authority.

The roads on Milton Park are typical of those of business parks in the UK, which are typically two-lane single carriageways (likely following Design Manual for Roads and Bridges (Highways Agency 1994) standard specifications), with kerb-separated pavements, kerbside bus stops and subject to a speed limit of 20mph (32km/h). The Milton Park road network presents a mixed-traffic environment, with typical traffic volumes of 14,000 vehicles per day (1,400 vehicles per hour in one direction in the peak period) on the main business park distributor road (Park Drive). Heavy Goods Vehicles are a feature of the traffic mix[11]. To give a sense of the complexity of the mixed-traffic environment to be negotiated by the autonomous vehicles (in for example 'gap acceptance' manoeuvres), this is equivalent to about one vehicle passing a point every 2.5 seconds.

Route for Services 002 and 003

The full demonstrations required the buses to use the public road network between Milton Park and Didcot Parkway railway station (**Error! Reference source not found.**), avoiding the busy A4130 connector to the nearby Strategic Road Network (A34 trunk road) but crossing it at a roundabout, and encountering busy traffic along the route at peak times. Service 003 had a simplified route for Service 003, with the vehicle U-turning at a large roundabout, to avoid using roads on Milton Park less suitable for full-size buses Figure 4).

Figure 4: Service 003 - route adapted for larger vehicle

[11] Kenny, L., 2017. Park Drive improvements. Vectos.

The minibus

The intention at the project outset was to subcontract provision of a vehicle for the first phase of the project. The initial requirement was for an electric, eight-seater, fully accessible vehicle that was capable of full automation at speeds of up to 40mph (65 km/h). However, an early challenge was procuring a vehicle suitable for use in the trials. A first round of procurement was published in February 2019 and in June 2019 concluded without a contractor being appointed. Time was then taken to explore options before a second tender was issued in December 2019, which resulted in a contract being awarded in March 2020. The challenges faced during the procurement process are examined later in the findings section.

The contract awarded was for Fusion Processing to purchase a conventional 15-seat electric minibus produced by Mellor and equip it with Fusion's CAVstar® automated driving system (see Figure 1).

2. Conceptual context of the research and data collection

As noted in the introduction, the report summarises findings in relation to the following three research questions:

- What initially motivated consortium members to engage with a project to deliver autonomous vehicle trials?
- What have the Mi-Link autonomous bus trials revealed in relation to how to plan and operate autonomous bus services on public roads in the UK? and
- To what extent did the Mi-Link autonomous bus trials meet the expectations of consortium members?

Three data collection exercises were used to capture evidence of how the trials unfolded and to examine the differing perspectives and experiences of consortium members:

1. Individual interviews were conducted with consortium members in March 2020 around the time that the second round of vehicle procurement was concluding. These interviews were designed to understand perspectives on why it was not initially possible to subcontract a suitable vehicle for the project.
2. Follow-up individual interviews were conducted with consortium members during the operation of Service 002 (during June and July 2023), to understand perspectives on the planning and operation of both this and the earlier 001 service.
3. A stakeholder workshop was held (on 7th July 2023) during the Service 002 operating period, which brought together most of the consortium members. The workshop was designed to allow consortium members to share and respond to their different perspectives on and experiences of the demonstration services.

Table 3 summarises which consortium members were represented during each of the three research activities. Running the second and third data collection activities whilst Service 002 had been in operation for some weeks enabled reflection in the context of experience, but also ensured recollections were current.

Table 3: Consortium representation in each research activity

Consortium Member	Procurement process individual interview (March 2020)	Post-Service individual interview (June and July 2023)	Stakeholder workshop (July 2023)
Bus operator	✓	✓	✓
Local authority	✓	✓	✓
Business park	✓	✓	✓
Connected Autonomous Vehicle technology provider	X	✓	X
Autonomous vehicle specialist consultant	✓	✓	✓
Journey information platform provider	X	✓	✓

Theoretical insights from Gartner

The methods used to evaluate consortium member perspectives on the trials have been informed by Gartner's 'hype cycle' model (reproduced in Figure 5). Gartner developed the model in 1995 to describe how the narrative surrounding a new technology tends to evolve according to its maturity[12]. Gartner argues that innovations are initially typically accompanied by unrealistic expectations at the outset which reaches a 'peak of inflated expectations'. One way these unrealistic expectations present is via media representations which are over-optimistic in terms of achievements to date and the rate of technological advancement. Evidence presented can be thin or misleading. This early stage is followed by a period of 'disillusionment', created by inevitable technology failures which occur whilst the technology matures, and reinforced by a realisation that earlier media claims were over-optimistic. However, as the technology becomes reliable, an 'eventual understanding' of its 'relevance and role' is established, as represented by the 'plateau of productivity' phase of the model.

Gartner suggests that early adoption coincides with the 'slope of enlightenment' whilst 'high growth' commences after reaching the 'plateau of productivity' when adoption has reached around 30 percent of the target market.

Figure 5:Gartner's Hype Cycle

Gartner also draws a distinction between 'fast track' technologies that can be rapidly adopted and 'long fuse' technologies which can take decades to emerge. He identifies characteristics of each. In Table 4, the present authors apply these to the case of automated vehicles. The evaluation suggests that autonomous vehicles (in all their various guises) offer an example of a long fuse technology, given their 'inherent complexity' and dependence on changes to infrastructure, regulatory frameworks, business models and consumer preferences.

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[12] Linden, A. and Fenn, J., 2003. Understanding Gartner's hype cycles. Strategic Analysis Report Nº R-20-1971. Gartner, Inc, p.88.

Table 4: 'Fast track' and 'long fuse' technologies

Fast Track Technology Indicators	**Applicable to Autonomous Vehicles**
High value	✓
Simplicity of use by enterprises and users	X
Several strong vendors that support the technology	✓
Use of the current infrastructure	X
A rapid transition from consumer to corporate use	X
Long Fuse Technology Indicators	**Applicable to Autonomous vehicles**
A science fiction style fascination with the technology that is far ahead of its capabilities	✓
Inherent complexity	✓
Adoption / regulation issues	✓
Reliance on new infrastructure	✓
Dependence on professional skills that are in short supply	✓
Major changes to business processes	✓

3. Findings

Findings, drawing across all three research methods, are now summarised in relation to the following six topic areas, which are presented in a chronological sequence aligned with how the trials unfolded:

- Motivations for engaging in the autonomous bus service trials;
- Perspectives on the autonomous bus vehicle procurement process;
- Perspectives on the planning of the autonomous bus services;
- Perspectives on the operation of the autonomous bus services;
- Reflections on positive and negative outcomes from the trials; and
- Reflections on whether the trials have met consortium member expectations.

3.1 Motivations for engaging in the autonomous bus service trials

Participants were asked to reflect, in the second-round interviews (June and July 2023), on their organisations' motivations for joining the consortium at proposal stage. This revealed two common motivations that were shared by several of the consortium members:

1. Reinforcing the organisation's practice and identity as an innovator; and
2. Knowledge and capacity building in autonomous vehicle technology.

Practice and identity as an innovator

The local authority, business park and bus operator interviewees all expressed their organisations' aspirations to cultivate a reputation for being at the forefront of innovation. This had been a central motivation for joining the project.

For example, the local authority had a longstanding strategy to be positioned as a "living laboratory" for cutting-edge transport systems. This aligned with local area's high-tech research and development-oriented economy and identity:

> *"We were the first local authority in the UK to talk about CAVs [Connected Autonomous Vehicles] within our local transport policy…We had something called the science transit corridor with organisations that are at the forefront of developing innovative solutions in transport"*.
>
> *Local Authority*

Developing a track record in transport technology innovation was perceived to be important when competing for central government and private sector investment in the area.

> *"To be a leading example of a highway authority, to be seen as excellent, it helps with funding."*
>
> *Local Authority*

Similarly, the business park recognised an opportunity to simultaneously meet objectives to develop sustainable transport connections to the park (linked to the local area's spatial plan), at the same time as reinforcing the business park's ethos and market positioning as a driving force for technological innovation. This was seen to be beneficial from a public relations point of view and aligned with the business interests of many of the park occupants:

> *"We're reinventing ourselves as…the innovation district really of [the county] and we wanted really to embrace all things…innovation wise….it was also to raise the profile of the park as*

somewhere that was at the cutting edge of innovation…the AV kind of appealed to us because we thought: that's the future of transport."

Business Park

The bus operator similarly recognised that an important organisational aim and strategy was to be:

"…the company that is leading the future of public passenger transport in the UK… We consider ourselves to be at the forefront of technology, so we must keep abreast with new developments in technology".

Bus Operator

Knowledge and capacity building in autonomous vehicle technology

Linked to these market positioning objectives, the bus operator recognised the unique opportunity to develop knowledge of how to run autonomous bus services on public roads, in mixed traffic with real engagement from the travelling public. Previous autonomous bus trials had been undertaken in more protected environments which did not reflect the reality of everyday bus service provision:

"This was going to be a trial in an open environment interacting with the public and all the random constraints and random factors that affect bus operation. So, it was the ideal point for us to get involved".

Bus Operator

The journey data analytics company also valued the opportunity to develop knowledge of how journey planning data can be used to deliver more flexible, optimised timetables and services for passengers e.g. fixed schedules that adapt on a weekly basis. There was perceived to be an opportunity for a new model of demand responsive transport linked to autonomous public transport, since conventional human-operated services face additional constraints with needing to have drivers in the right place at the right time.

3.2 Perspectives on the autonomous bus vehicle procurement process

A first major project activity was to acquire an eight-seater, electric and autonomous vehicle that the bus operator could deploy on what would become Services 001 and 002. The first procurement round, held in February 2019, received three bids from autonomous vehicle suppliers, but none of these bids sufficiently met the tender specification. Two of the bids were received from manufacturers of bespoke 'pod'[13] type vehicles and the third was received from a company that would retrofit a conventional vehicle with automation technology.

Barriers to procuring a suitable vehicle are now examined based on insights from the procurement process interviews held in March 2020.

3.2.1 Barriers to procurement

The 2019 first-round procurement process revealed two fundamental issues with the submitted bids, that were not resolvable:

1. The bespoke pod-type vehicles did not meet the roadworthiness safety standards required for a Public Service Vehicle i.e. a vehicle that a bus operator could run as a bus service on public roads.

[13] Vehicles of lightweight construction with a maximum operating speed of around 25km/h and a capacity of 4-12 passengers. This type of vehicle is designed solely for autonomous operation, with no facility for routine handover to a driver for scenarios beyond the scope of the automated drive system.

Base vehicles needed 'type approval' to guarantee a baseline level of safety against defined criteria when operating a public service, in mixed traffic, on publicly-accessible roads. Neither of the bespoke shuttle vehicles had achieved or would be able to achieve type approval within the project timeframe.

2. The conventional vehicle proposed for conversion did have type approval, but did not comply with the accessibility requirement to be able to side-load a wheelchair. The proposed vehicle could only have a wheelchair loaded from the rear, meaning from the carriageway rather than the footway. From the perspective of the bidding company, this had been a necessary consequence of value-engineering to meet the financial and operational requirements of the tender specification. Two vehicles had been required in the first procurement round, and the bidding company had needed to select a lower specification vehicle for reasons of cost.

The sections that follow summarise some further detailed issues that emerged from the 2019 procurement round.

Limited capabilities of the bespoke pod-vehicles

There was a consensus across the interviewees that the bespoke autonomous vehicle technology was not as advanced as consortium members had expected at the outset of the project. It was considered that while the bidding companies were able to reasonably claim that their vehicles could perform most of the manoeuvres required for the Milton Park trials to a certain standard, the procurement process, and particularly cross-examination during interview, revealed that reliable performance was only possible in much more controlled environments i.e. not in mixed traffic, and not at a consistent speed of around 20 mph (32km/h). The speed of performance, 20 mph on the Park itself but ideally up to 40 mph outside it, was important to avoid queues of impatient motorists forming behind the vehicle.

Some key limitations of the two bespoke autonomous shuttle vehicles included (amongst other constraints) much lower operating speeds than anticipated (particularly when undertaking complex 'gap acceptance' manoeuvres), and significant limits in relation to the ability to turn right across opposing traffic and to negotiate roundabouts consistently (without operator input). One interviewee summed this up by suggesting that the market could at the time deliver:

> *"lower capability, productionised vehicles or higher capability, experimental vehicles."*

The Milton Park shuttle trial, by contrast, requires a

> *"high capability, productionised vehicle".*

The nature of the shuttle trial operating model

One interviewee explained that, in 'experimental' trials and demonstrations that had previously been conducted internationally, it has been typical for the technology provider to also operate the vehicle. By contrast, the Mi-Link project was to involve a vehicle being handed over and operated independently by a third-party public transport operator[14]. Aside from the fundamental problem with the bespoke vehicles not meeting type approval, the operator handover interface and operator controls were also not considered to be sufficiently developed for operation by a third party e.g. the

[14] In this regard, the MultiCAV project was expected to provide an intriguing opportunity to examine and contrast the efficacy of two different trial operating models: the shuttle trial was to involve the acquisition and handover of a vehicle from a third party to the consortium public transport operator, whereas, separate to the procurement of the shuttle, a full-size automated bus was being delivered by a consortium member and so was to be operated in a close partnership between the technology company and the public transport operator.

interfaces may have displayed outputs from different sensors, but without a sufficient indication of whether handover was necessary. This would have required interpretation and hence a more detailed technical understanding of the vehicle than the bus operator's driver pool could reasonably be expected to achieve within the project timeframe.

Uncertainty over safety

Three factors in combination (i. limited capability of the automation technology to perform manoeuvres in mixed traffic, ii. lack of vehicle 'type approval' and iii. a handover interface not sufficiently specified for a PSV driver who would have some specialist training for the vehicle but not having the experience of an R&D 'test-pilot') meant that the bespoke shuttle vehicles were not able to meet a minimum safety requirement for a trial involving a public transport service, on public roads. As one interviewee commented:

> *"The risks outweighed the benefits"*.

3.2.2 Overcoming barriers to procurement

The first procurement round thus revealed that the autonomous vehicle market, in 2019, was not able to deliver an off-the-shelf vehicle that complied with Public Service Vehicle specifications and that could travel at sufficient speed in mixed traffic, at least for the available maximum contract value. Ultimately, the issue was resolved by removing the tender specification requirement for two vehicles, enabling investment to be focussed on a single vehicle. The company which eventually won the contract was then able to propose retrofitting a single, higher-specification type-approved vehicle, which met the side-loading (ramp adjacent to the pavement) accessibility requirement.

During the follow-up interviews held in June and July 2023, consortium members were asked to reflect on how the challenges faced during the first procurement exercise were overcome. This revealed the following common themes:

Enforcing the requirements in the tender specification

There was a general sense that the technical and operational vehicle specifications developed for the first procurement exercise were actually appropriate, but that these criteria needed to be used as a 'harder filter', to eliminate submissions that did not meet fundamental requirements, such as vehicle type approval, the ability to operate as a public service vehicle, and the provision of adequate handover interfaces. Indeed, the CAV technology provider acknowledged that:

> *"When we were considering whether to even put in a bid [for the first procurement round], we thought, well, OK, no one's going to be able to tick all the boxes. We'll just do something which ticks as many as we can. So, we selected what was a reasonably low-cost vehicle… And then the feedback was that it absolutely did have to be low floor, etcetera, etcetera"*.

CAV technology provider

Removing the requirement for two vehicles

Indeed, the first procurement exercise had provided greater understanding of the budgetary constraints presented by the shuttle vehicle trial service. The tender specification was therefore modified to require the provision a single vehicle. This was central to enabling the procurement of a suitably specified conventional vehicle that could be retrofitted with automation technology.

Realism about market maturity

Several interviewees noted that the high expectations about what would be offered by tenderers through the first-round procurement process (and therefore the high expectations of the first tender specification), were a result of the 'over-marketing' of vehicle capabilities by technology companies. The CAV technology provider explained that the first tender specification was:

> *"…a big long wish list for the shuttle vehicle…And I think that had come from looking at what was out there in the marketing material for Pod vehicles that were in development at the time and…what those companies were saying about where they would be in a year's time... And of course, it didn't necessarily bear that much resemblance to reality".*

CAV technology provider

The business park reflected that they:

> *"…just saw a growing realisation [through the procurement process] that the technology, the industry, the kind of off the shelf vehicles, were still a long way from being able to be deployed… on public roads".*

Business Park

Mutual learning and knowledge exchange between partners

Several interviewees identified that no single stakeholder had institutional expertise in all of the different domains that are brought together through the operation of an autonomous, road-going, public transport service. For example, vehicle innovators have expertise in automation technology, but not necessarily in developing 'type approved' base vehicles. Public transport operators have expertise in running services, meeting regulatory requirements and understanding the different needs of public transport users, but are not yet experts in automation technology or its operation. Indeed, the specialist autonomous vehicle consultant described the procurement process as:

> *"…a mutual learning of the different partners"*.

Autonomous vehicle consultant

This suggests that the wider development and deployment of autonomous bus vehicles and services, will benefit from mechanisms that allow close partnership working between all of the core industry stakeholders.

3.3 Perspectives on the planning of the autonomous bus services

Having acquired a suitable subcontracted vehicle, the next phase of the project involved preparing for the autonomous operation of bus services 001 and 002. This involved four main activities:

1. Preparing the vehicle;
2. Preparing for the operation of a public transport service;
3. Preparing the street environment; and
4. Public engagement and information provision.

3.3.1 Preparing the vehicle

Adapting the conventional minibus for autonomous operation required close partnership working between the vehicle manufacturer and the CAV technology provider, making the vehicle 'drive-by-wire' first and then fitting the sensor kit required to support autonomous operation. This process involved multiple rounds of testing and calibration to ensure the vehicle behaved consistently and reliably.

Although the base vehicle was 'type approved[15]' as meeting the required safety standards prior to modification, the type approval needed to be renewed by the Driver Vehicle Standards Agency (DVSA) after the automation equipment had been fitted. This requirement was triggered by the general modifications to the vehicle – mainly, because many controls were made electronic - and was not related specifically to the automation of the vehicle. As the autonomous vehicle consultant noted:

> *"They [the DVSA] don't focus on the electronic [automation] control. They just care that you haven't messed up the vehicle controls when it's being manually driven".*

Autonomous vehicle consultant

Preparing the safety case

In parallel with the adaptation of the vehicle, two 'safety cases' were being prepared: one demonstrating the safety of the vehicle itself and the second demonstrating that the vehicle could be safely operated as a public transport service. This required close partnership working between the CAV technology provider and the bus operator. As noted by the technology provider:

> *"there's a lot of work that is not necessarily to do with the vehicle and technology and testing… well, it is to do with it, but it's not about [only] installing technology and getting it all working nicely... It's about proving that it's safe".*

CAV technology provider

Absence of safety regulations

The CAV technology provider further reflected on the unusual circumstances of the time, where there were no statutory regulations to enforce the requirement for safety checks and procedures.

> *"…the regulations…aren't really there…on this [safety]. If you see what I mean, it's more …there's various standards… which we adhere to, but…there's no law or regulation which says we have to do them…it's a little bit bizarre".*

CAV technology provider

The regulations are expected to catch-up with the technology as prototype autonomous buses become productionised:

> *"…and ultimately this is… going to be a product, that is sold much more widely. And at that point the regulation will come and that will be based on those same standards".*

CAV technology provider

An emergent need for an independent safety case review

To build a safety case – i.e. evidence of the bus's safe operation - the bus operator had initially set up an independent 'B-Team' with the remit of internally auditing the vehicle and its operational safety. Indeed, it had originally anticipated that the safety case would take the form of a:

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[15] Type approval is required when Public Service Vehicles are modified: https://www.gov.uk/government/publications/notification-of-an-alteration-to-a-public-service-vehicle-vtp-5

> *"…self-policing documented evidence trail that you as a bus operator believed that it would be safe to operate the autonomous vehicle."*

Bus Operator

However, as Government awareness of a need for greater standardisation of safety assurance in public domain trials rose, CCAV introduced a requirement for independent reviews to be undertaken of the project's safety cases. MultiCAV was advised that it was potentially to be a pilot for this procedure in September 2020 and participation was confirmed in November 2020. This had not been anticipated at the outset of the project and incurred a significant delay, as the form of the review needed to be developed, the remit for who would undertake the review confirmed, and then that reviewer had to be procured:

> *"…that held us up quite a lot actually thinking about it because… we weren't sure what was needed for a very long time, who was going to pay for it, how it was going to happen…it was a bit of an afterthought."*

CAV technology provider

The unprecedented nature of the independent review of the safety cases posed multiple challenges. For example:

- The engineering side of autonomous vehicle technology had been reviewed before in relation to autonomous operation of cars, but there were not many organisations that had the knowledge to conduct an independent review for autonomous road-based public transport services. Identifying relevant organisations or agencies was challenging.
- The independent review needed to be procured by the local authority (as a fully-funded partner) and this introduced additional administration and contractual arrangements which added delay.

As the bus operator explained:

"So, the concept of having an independent safety case review - no problem at all. But you have to find somebody who had the knowledge and the experience and the competence to do it, because this is ground breaking stuff, particularly on the operational side, less so on the engineering side because of all the vehicles that have been developed for autonomous operation as cars."

Bus operator

In the event, the bus operator noted that their own internal review procedures meant they were very well prepared for the independent safety review as they were able to evidence the outcomes of their internal peer review and immediately respond to queries.

3.3.2 Preparing for the operation of a public transport service

Having adapted the vehicle and proved it was safe, the next activity was preparing to operate the vehicle on public bus services. This was led by the bus operator and involved several processes:

Engagement with the Traffic Commissioner

Traffic commissioners[16] oversee the regulation and registration of buses and local bus services. One of the requirements operators must demonstrate is to be of "good repute". The bus operator needed to consult with the Traffic Commissioner to ensure that the trial:

[16] https://www.gov.uk/government/organisations/traffic-commissioners

"would not impair our reputation and therefore would not have any adverse impact on our operator's licence".

Bus Operator

Engagement with the Traffic Commissioner did not follow a standard process and was "ad-hoc" [Bus Operator] as there was no precedent for running an autonomous public transport service. Indeed, the trial service was not "registrable as a bus service", because the bus operator was not allowed to charge fares due to the nature of the project funding model. This was advantageous as a registrable service would have required 70 days advance notice which would have been impossible to arrange, given the regular short notice for task stages to be achieved and quite significant delays that were experienced in getting the novel vehicle ready for the trials.

Recruitment of safety drivers

The bus operator sought to recruit safety drivers from its existing pool of employees. The opportunity to apply for the role was advertised on a noticeboard in a depot and applications were scrutinised against criteria including driving experience, number of collisions in the last five years, and number of public complaints. The bus operator emphasised that a positive attitude orientation towards the trial was a key safety driver attribute:

"What we were more concerned about, I think was almost attitude…are they enjoying [it], are they enthusiastic…? It means the project is more likely to succeed. The passengers are going to get a better experience… where we need feedback from the drivers, they're going to give it rather than say 'no'…"

Bus Operator

Arrangement of a local depot and bus stops

The bus operator also coordinated, in partnership with the business park, the provision of a local depot on site, to store and charge the vehicle, provide amenities for drivers, and enable the mandatory walkaround checks to be performed, which are required every time a vehicle goes into service. This involved more resource than the business park had anticipated, due to the need to provide adequate welfare spaces for the drivers and to meet required health and safety standards:

"I think you know [the bus operator] clearly had some very stringent health and safety regulations which we fully supported but… things like putting in a pedestrian walkway around the compound and welfare units for the safety drivers…things like that…were in addition."

Business Park

The business park was also required to relocate some existing bus stops and install some new ones at appropriate points around the park.

3.3.3 Preparing the street environment

It was necessary for both the local authority and business park to make some adjustments to the street environment to accommodate the autonomous vehicle sensor technology and to ensure reliable operation of the bus. This included repainting white lines, clearing vegetation and retrofitting communication systems on traffic signal controllers. The business park noted that the need for street maintenance had not been expected, based on early discussions with the bespoke vehicle providers that took part in the first procurement round:

"One of the things potentially we hadn't anticipated was that we would have to change anything about the environment in Milton Park when we first started the procurement process and we were talking to the likes of [vehicle provider]. Actually, when it came to it, it was obvious that we needed to repaint some white lines. So, we did all that at our expense which I don't think we'd anticipated doing."

Business Park

Vegetation clearance became a key maintenance activity that required ongoing attention throughout the operations, given that vegetation cover changes with the seasons and behaves differently according to weather conditions. Vegetation encroaching on the road or being agitated by the wind could be detected by the vehicle as a potential hazard, causing it to slow down or stop.

"In the latter stages it became clear we needed to do quite a lot of vegetation clearance… we've had to do almost on a daily basis at the beginning of the phase one trials, there will be another bit of vegetation that seemed to pop up."

Business Park

The local authority further recognised that a wider deployment of autonomous buses would have significant implications for the planning of their vegetation management cycles noting:

- the need for very specific information about what vegetation needs clearing and why, so that contractors can respond appropriately – this would need to be built into long term vegetation management plans; and
- the need to consider how the need for increased vegetation management fits alongside environmental considerations such as bird nesting seasons, and measures to re-wild verges.

The local authority representative explained:

"It's that balance between safety and the environment."

Local Authority

3.3.4 Service information provision and public engagement

All partners were involved in some way with the provision of service information and awareness-raising through public engagement activities. For example:

- The bus operator developed a timetable for the services, based on understanding of journey times, and the requirement for vehicle charging and driver breaks.
- A journey planning platform was developed so that passengers could access next departure information on scanning QR codes at bus stops. The journey planning platform provider worked closely with the vehicle provider to ensure data feeds operated between the ticketing machine and the journey planning platform. This was made easier when it was agreed that standard data protocols could be used.
- The local authority was involved in ensuring the timetable information was transmitted to real time information displays at bus stops and online via Oxontime[17] and local bus operator apps.

[17] https://oxontime.com/home

The business park took on an important role in raising awareness of the autonomous bus service, particularly amongst park occupiers, including hosting stakeholder engagement activities on site:

> *"Our other role in the project was to engage people, so in terms of marketing the project and promoting it to our occupiers, that was really the bulk of the work in the run-up to Phase One and obviously ongoing."*
>
> Business Park

3.4 Perspectives on the operation of the autonomous bus services

The lengthy and considered preparatory phase meant that the actual operation of Services 001 and 002 went largely as planned. Perspectives on how well the bus performed are summarised later in Sections 3.5 and 3.6. In relation to operational issues that were experienced during the operation of the services, consortium members identified the following minor issues that were encountered, but mostly resolved[18]:

- The CAV technology provider needed to calibrate the software to improve the operation of the bus. For example, dealing with two-lane roundabouts without lane markings, non-standard pedestrian crossings on the business park estate (a 'pride' or 'rainbow' zebra crossing), and responding appropriately to pedestrians on approaches to crossing points. This required some disruption to the service, which hadn't been allowed for in the operating schedule, even though a need to calibrate the software had been anticipated.
- There were some minor technical problems with auxiliary systems like: loss of access to the satellite communication systems and loss of access to cell phone networks used for data transmission. These issues highlighted how autonomous bus services are dependent on complex external systems to operate reliably.
- There were also some minor technical issues with the vehicle including (i) water ingress into a camera used for sensing, which was fixed by replacing the component; and (ii) a fault with the 'autonomous mode' button which was easily resolved.
- There was a more significant mechanical issue with the balance of the bus's brake fluid system. This was not a fault in the automation technology, but the automated driving system detected the issue, causing the bus to switch back to manual mode in order to 'fail safe'. A workaround was implemented to prevent this happening.
- During cold and wet periods, increased use of ancillary equipment, particularly the cabin heater, was found to drain the vehicle battery faster than was consistent with operating the timetable. This meant that additional charging periods were required, meaning some timetabled services had to be cancelled.
- Service 001 had quite low levels of passenger demand, partly due to inclement weather in March 2023, but also because the level of demand for internal movement by scheduled service within the business park proved to be low. The number of passengers on Service 002 was much higher, consistent with the connection to the railway station being an established market demand.
- There was an instance of the minibus not coming to a halt where specifically needed: on a level surface for wheelchair access. The driver had to relocate the vehicle manually.

[18] These issues were identified both through the Phase One and Two trial interviews held in June and July 2023 and discussions held during the stakeholder workshop held in July 2023. During the workshop, participants were asked to identify three categories of problems (noted on post-it notes which were then sorted and discussed): problems that were resolved; problems where workarounds were found; problems that had not yet been resolved.

- During Service 001, the passengers were not able to detect whether the bus was in autonomous or manual mode. For Service 002, a screen was installed to indicate when the bus was in autonomous mode (Figure 6)

Figure 6: On-bus autonomous mode passenger information sign

A number of longer-term issues were also identified and that were not possible to resolve within the timeframe of these trials. These included:

- The deployment of a demand-responsive element to the service such as weekly timetable optimisation in response to data generated by the journey planning application. Insufficient data were generated during the trials to drive such timetable optimisation.
- A small number of complex manoeuvres required manual operation to ensure safe and reliable operation. Specifically, manual operation was required at a narrow, traffic light-controlled railway overbridge crossing.
- A need for digital road signs that can communicate with autonomous vehicles.
- Developing autonomous vehicles so that they can deal with (i) temporary road works (planned or otherwise); and (ii) snow and heavy rain[19].
- Measures to avoid other human drivers tailgating autonomous vehicles. The safety drivers[20] perceived there to be a greater risk of rear-end collisions as the autonomous vehicle was more likely to slow down abruptly than a human driven vehicle.
- Developing safety driver confidence in the autonomous bus's ability to drive without intervention. There was a sense that safety drivers felt comfortable taking control of the vehicle in circumstances where the autonomous mode would work adequately, partly to provide a smoother journey experience for passengers.

[19] Heavy rain could result in droplets rebounding from the road surface, making it hard for the autonomous drive system to have certainty about the forward conditions on the carriageway.
[20] The experiences of and feedback from the safety drivers is the topic of a companion report.

3.5 Reflections on positive and negative experiences from the trials

This section now turns to summarise participants' overall reflections on positive and negative outcomes from the project. These reflections were captured during the second-round interviews (held in June and July 2023) and reflected upon collectively in the July 2023 workshop.

3.5.1 Positive experiences

Two common positive outcomes from the project, identified by most interviewees were

- the effective partnership working amongst consortium members and
- the performance of the vehicle.

Effective partnership working

There was a consensus that relations between consortium members had remained positive throughout the project, despite challenges. Consortium members expressed awareness, even at the outset of the project, that there was potential for relationships between partners to become strained, given the novel nature of the trials, and in particular, the arrangement whereby an adapted vehicle would be handed over to a public transport operator to run as a third party. As noted by the CAV technology provider:

> *"The relationship with [the bus operator] is good…with…a whole phase of testing completed successfully, …we have a good relationship with them…and with the other partners. Without careful management, all these things have the potential to go wrong. If things don't go quite as expected and with the stress of actually having to deliver something which is hugely complicated, there is always the potential for problems with relationships but this has not happened and it has been a very good collaborative spirit".*

CAV technology provider

This sentiment was similarly expressed by the bus operator, business park and AV technologist. As the bus operator noted:

> *"It's been great…We're all trying to achieve the same objectives."*

Bus operator

Performance of the minibus vehicle

The performance of the vehicle in autonomous mode, was independently mentioned in a positive light by most interview participants. For example, the bus operator explained:

> *"The actual technology and the ability of the vehicle to cope with real life conditions has surpassed my expectations…you've always got this nagging doubt at the back of your mind that as long as you passed all the safety tests and you make sure that you would always fail safe, your expectations are perhaps not that high. It will be always under driver control... And now it's really worked well".*

Bus operator

The business park highlighted the ability of the vehicle to travel at high speed:

> *"I didn't expect it would achieve speeds of 40 miles an hour. That's been phenomenal…one of the concerns at the beginning was 'is this going to hold up traffic?' 'Is it going to lead to road rage?'…"*

Business park

The perception of strong vehicle performance was often linked to recognition of having somewhat lower expectations of what would be achievable at the outset of the project:

> *"I've been super impressed with the actual operation of vehicle itself. I was a bit cynical that it would never happen".*

Journey information platform provider

Individual consortium members also identified that the project had demonstrated enthusiasm from the drivers and good levels of stakeholder engagement, as well as presenting emerging market opportunities as discussed in the subsections below:

Enthusiasm from the drivers

The CAV technology provider paid tribute to the constructive attitude of the drivers throughout the trials, given the potential for autonomous vehicle technology to be perceived as a threat to bus driver employment. This may be attributable to the effective nature of the recruitment strategy implemented by the bus operator, which prioritised identifying staff with a positive attitude towards the trials:

> *"it's nice working with the drivers and seeing their level of enthusiasm for it because you know…it might not have been that way..."*

CAV technology provider

Stakeholder engagement

Several participants identified that the project had generated a good level of positive stakeholder engagement, including from the public.

The autonomous vehicle consultant also identified a positive spirit of cooperation from other local transport operators:

> *"it's also true to say that… the various other bus companies, with whom we are competing on our Phase Two and Three routes: they also seem to have been very happy...My gut feeling is that the bus companies are keen to find out if this is ever going to work…Without any cost [to them]".*

Autonomous vehicle consultant

Emerging market opportunities

For the journey information platform provider, the duration of the project had provided space for their products to mature and secure new market opportunities:

> *"We have an agreement in place with lots of county councils now…that's not a direct result of this project, but it's certainly aligned."*

Journey information platform provider

3.5.2 Negative experiences

With respect to negative experiences, all consortium members identified delays as the main 'negative', along with the experience of reliability issues and the absence of a demand-responsive element to the service.

Delays

Multiple sources of delay had meant that the vehicles started operating much later than originally planned, although project extensions meant the expected durations of service were achieved, and in fact exceeded, for Services 001 and 002. Delays were partly a result of the COVID-19 pandemic and subsequent supply chain issues, although other delays were linked to challenges posed by the novel nature of the trials and the inclusion of the independent review. As noted by the local authority:

> *"nobody's actually done this before…" and there are "unknown unknowns".*

Local authority

The need for two vehicle procurement rounds and the emergent requirement for an independent safety review were identified as two key causes of delay.

> *"The independent safety case review…took such a long time to actually organise because of the procurement, we had to go through. I mean, we must have lost six months through that easily".*

Bus operator

The requirement for the vehicle to be re-approved for type approval, following modification had also added to the delay.

The CAV technology provider reflected on how difficult it was to either foresee or build in contingency time to accommodate such unknowns:

> *"That's really unusual to have something big like that [the independent safety case review] dropped on you…they were wild cards really…such an unusual set of things to happen that I'm not sure really what we can do in future [in terms of mitigation]..."*

CAV technology provider

The autonomous vehicle consultant also reflected on the notion that a more mature regulatory framework for autonomous public transport operation would assist with reducing delays and also accelerating the development and deployment of the technology:

> *"…we [the UK] have been behind the curve…in getting the special regulations that allow these things to happen."*

Autonomous vehicle consultant

Technical faults and lack of system resilience

Technical faults, like the issue with the brake fluid balance, took some time to implement a technical workaround, meaning that the bus had to be taken out of service and or driven in manual mode. Service reliability was also interrupted by issues with auxiliary systems that the autonomous bus vehicle depends on, such as intermittent satellite communication signals and straightforward operational practices such as staff not having access to a password for a tablet that interfaced with the control systems.

Such factors prompted the autonomous vehicle consultant to reflect that:

> *"So that was an interesting learning, I think for me anyway: if you're operating a bus service, the thing has to be reliable."*
>
> Autonomous vehicle consultant

Absence of a demand responsive, integrated service:

There had been aspirations at the start of the project to integrate multiple transport services for the business park, via the bespoke journey planning app, and to then use data from the journey planning platform to create a service environment that could be dynamically optimised in response to passenger journey searches. This was not possible due to the level of traveller engagement in practice with the journey planning platform.

> *"I would have liked to have got to the stage where…the data we're generating from people interacting with the system…we could use that to change the timetable, say on a daily basis. And see how much more efficient that made the service in terms of the number of people it was carrying…For the vast majority of the project, [there] has been nobody travelling…to do that we do need a reasonable volume of data, otherwise it's not statistically valid."*
>
> Journey information platform provider

3.6 Comparing expectations to reality

Participants were also asked to reflect on whether the services operated matched expectations at the start of the project or were in some way different. Consortium members explained that the autonomous bus service trials had at the same time exceeded and not met the expectations that they held at the outset of the project.

Exceeded expectations

There was a consensus amongst consortium members that the performance of the vehicle in autonomous mode had exceeded expectations in demonstrating an ability to reliably undertake complex manoeuvres in mixed traffic and to operate at speeds of 40mph (65km/h). Indeed, during the stakeholder workshop, consortium members were asked to rate (via an instant digital poll) how well they thought the vehicle was able to handle roundabouts, right turns, pedestrian crossings, and proceeding at 40mph. For all manoeuvres, the average view was that the vehicle had exceeded expectations (see Appendix A).

Unmet expectations

Some consortium members admitted to disappointment that the vehicle used for the services was, and hence looked like, a conventional minibus, and this contrasted with their earlier expectation that the vehicle would look and feel like a futuristic 'pod' vehicle (an expectation formed through engagement with marketing materials, and in some cases exposure to other autonomous vehicle projects).

The extent to which the delivery of the services had met expectations was found to be related to the level of knowledge of the capabilities of autonomous vehicle technologies. For example, for consortium members with specialist knowledge of CAV technology, the operations had generally met expectations. The CAV technology provider had a clear idea of what they could offer at vehicle procurement stage, and this aligned with the reality of the trials:

> *"I don't think [the services are] that much different to what we thought they would be…I think we had a reasonably good view of what it would be. And I don't think…what's actually being delivered is too far off what we envisaged really."*

CAV technology provider

The local authority, who had some prior experience of autonomous vehicle trials, noted that they were prepared for there to be changes to the nature of the trials:

> *"I think…we were prepared for the fact that this is doing something completely new. And there were going to be challenges and things that were going to have to change".*

Local authority

The business park, who had less direct experience of the development of autonomous vehicle technology, noted that they had anticipated that a more futuristic looking vehicle would have been deployed in the trials:

> *"I think everyone had seen pictures, CGI, or maybe even had a go on some of the pod-like autonomous vehicles. And there was this assumption that they would look different in some way to regular transport. And I think that was just this kind of myth that was created by the that burgeoning industry…I think even in the Didcot Garden Town plan there were pictures of very futuristic looking pods."*

Business park

Indeed, the business park expressed some initial disappointment with the conventional look and feel of the minibus vehicle:

> *"I think perhaps the most disappointing thing at the time was that…the vehicle that we were going to acquire, didn't look particularly futuristic for want of a different word. And I think everyone hoped that this would look different and feel different and…it became more and more apparent that we were going to end up with a regular looking minibus with a driver behind it. Albeit, you know, I appreciate the huge amount of technology that goes into that."*

Business park

Linked to this, there was a sense through the July 2023 workshop discussions that the project had not delivered a 'human-independent' service demonstration that had been envisioned at the outset, as the onboard safety operatives were not there 'just in case' but needed to intervene quite often, for a range of reasons.

4. Lessons learnt

The report now concludes by drawing out key lessons learnt from the Mi-Link Services in relation to enabling the wider deployment of autonomous buses on UK public roads. The MultiCAV project experiences revealed that wider deployment would require:

1. Realism over what forms of vehicles and public transport services are suitable for different operating environments;
2. Ongoing development of capacity in the autonomous bus services sector;
3. Mechanisms to support effective partnership working between industry stakeholders;
4. Mechanisms to manage stakeholder risks and delays;
5. A regulatory framework for autonomous vehicles and services; and
6. Measures to ensure that deployed autonomous bus services are reliable and resilient.

1. Realism

In line with Gartner's theoretical model of technological evolution, there was agreement across the consortium that at the time of the first procurement exercise in 2019, there was excessive optimism in the sector in relation to autonomous vehicle capabilities. Interviewees accepted that it was the nature of commercial competition that companies would use marketing to show their products in the best possible light, e.g. demonstrating the range of manoeuvres that vehicles could in principle perform, but it was considered that companies would benefit from being more transparent about the conditions under which such operation is possible. It was felt that the true picture of the technological potential of the MultiCAV project in Didcot at that time (2018-19) only became evident through the process of conducting the procurement interviews, during which the various claims about technology capabilities were fully examined and ambiguities clarified, in the context that contractual commitments would need to be made about those capabilities when the subcontract was to be awarded.

Different perspectives on these issues included:

1. Companies would benefit from being more transparent about technology capabilities and viable operating environments, because they have nothing to gain from failing to meet the expectations that their own marketing creates.

2. Companies may themselves be over-estimating the maturity of their technology and under-estimating the time required to overcome problems presented by untested operating environments, i.e., there is a type of 'optimism bias' inherent within innovators; and

3. There should be stronger recognition that there are different products for different markets e.g. the types of autonomous vehicles operating in controlled environments, including new-build developments (where specific provision for autonomous vehicles can be built-in) are likely to be very different to the types of autonomous vehicles operating in less controlled, mixed traffic environments.

One factor that likely explains the positive framing of capabilities is that technology companies, in particular SMEs, face an ongoing need for funding and finance, and therefore a positive aura of achievement around the brand is a key financial marketing tactic. In other words, they may very well have something to gain by over-stating their capabilities, particularly if the business strategy is to sell the company to another entity before its products are mature.

2. Capacity building

As the technology and its application to bus services is in the early stages of development, it is self-evident that there will be a need to continue to develop capacity in the sector. The need for increased sector capacity was revealed in the trials with respect to needs for

- an enlarged autonomous bus vehicle supplier pool – evidenced by the small number of suppliers that were able to meet the requirements of the tender specification;
- specialist knowledge from organisations such as government agencies (CCAV, the DVSA), legal and insurance sectors so that they can provide advice to organisations involved in procuring and operating services on UK roads;
- capabilities such as the conduct of independent safety reviews; and
- a need for the different stakeholders involved in the delivery of autonomous bus services to develop understanding of each other's requirements and the dependencies that exist between them.

3. Effective partnership working

Linked to this latter point, a central positive outcome from the project was that effective partnership working had significantly enhanced different stakeholders' knowledge of each other's requirements and this was key to the successful delivery of the bus services. For example:

- the need for bus operators to meet necessarily stringent safety measures (as enshrined in regulation) drove up the specification of the vehicle, ruling out all of the bespoke vehicle providers. To meet the regulatory requirements of a bus service on public roads necessitated close partnership working between vehicle manufacturers, CAV technology providers, and the bus operator. This suggests a need for vehicle manufacturers to continue to partner closely with bus operators so that they develop knowledge of how to adapt vehicles for different operating environments.
- the local highway authority, business park and CAV technology provider mutually developed knowledge of how the road environment needed to be maintained such that road markings, roadside vegetation and traffic signal control infrastructure could be handled by the vehicle technology.

It follows then that there is a need to put in place mechanisms to enable close partnership working between industry stakeholders. Research and development funding for projects such as MultiCAV provide one such mechanism to bring industry stakeholders together. Funding could also be made available to sustain ongoing networking channels to bring industry stakeholders together – enabling secondments for staff to move between organisations, for example.

4. Mechanisms to manage stakeholder risks and delays

The delivery of novel autonomous transport systems that are serving the general public required all of the stakeholders involved to take managed financial and reputational risks and this will continue to be the case until the technology and its deployment reaches maturity. Effective partnership working was again seen to be central to risk management during this early stage of the innovation cycle, where there are more 'unknowns' and hence greater perceived and actual risk. For example:

- The bus operator noted that working as a consortium meant that financial risks were distributed across consortium members. These risks were managed because all parties had a stake in the project and were working towards the same objectives.

- The local highway authority noted that they needed to ensure that they would not be liable for incidents involving the vehicle on the highway and that this risk was managed by the operational procedures developed by the bus operator.
- The vehicle manufacturer needed reassurance from the CAV technology provider that the reputational risks linked to vehicle safety would be minimal after the vehicle was adapted.

5. Planning for delays

Building in contingency time to deal with delays is a standard practice in project management and indeed when developing novel technologies or services. Whilst it is good practice to seek to learn lessons to enhance project management in the future, there was a general retrospective sense that in this case some of the key delays experienced could not have been avoided or handled more effectively through contingency planning. The three main sources of delay were as follows:

- The requirement to run two procurement rounds to acquire a suitable vehicle. This could be avoided in future trials by a pre-tender process which sought to establish realistic representations of the vehicle capabilities in different environments (with appropriate allowance for within-project refinement in order to meet local conditions and the specifics of the operational design domain). A system of certification with more detail than the broad level of automation achieved (i.e. more than the SAE levels[21]) would be a way of generalising and formalising this process.
- COVID-19 and its impacts were only regarded as possible or likely by infectious disease specialists. MultiCAV was as prepared as the rest of the UK. The twin impacts of reduced technology development capacity due to temporary changes in the form of physically-distanced working practices in workshop environments and delays in the global supply chain for components, mainly arriving from the Far East, were not mitigated or mitigatable.
- The emergent requirement to undertake an independent safety review. For future projects this will be a known requirement, whilst the experience obtained in engaging with the Traffic Commissioners and DVSA will be of benefit to the planning of future projects.

6. A regulatory framework

The delivery of a regulatory framework (defined precisely to avoid ambiguities in interpretation) would act to clarify the requirements for the provision of autonomous bus vehicles and services. This would help to resolve issues such as unexpected delays due to emergent and unexpected requirements and act as an impetus to industry to develop the capacity to meet regulations. International standards and regulatory alignment between different geographic jurisdictions would also drive efficiencies in the global market for autonomous bus vehicles and services.

7. Autonomous bus service resilience

The public bus services demonstrated in MultiCAV relied on one vehicle and a small, specialist team which inevitably lacked full resilience as there were constraints on building resource redundancy into the operation. To build-in redundancy for a fully operational (registered and fare paying) autonomous bus service would require:

a. The maturation of the vehicle technology and auxiliary systems (including efficient production processes) such that vehicles run reliably;

[21] https://www.sae.org/blog/sae-j3016-update

b. The availability of multiple operational vehicles to bus operators, implying a need for commercially viable autonomous vehicle purchase and leasing costs;
c. The maturation of operational procedures to ensure that the additional requirements linked to the running of autonomous vehicles are met (such as access to satellite positioning signals and software);
d. The development of a mature maintenance industry; and
e. The development of road infrastructure maintenance procedures to align with the needs of autonomous vehicle technology.

Appendix A: Stakeholder Workshop – Expectations Exercise

During the stakeholder workshop, the attendees were asked to rate whether the vehicle had fallen short of, or had met, their expectations in relation to its ability to undertake specific manoeuvres. Ratings were provided using a Menti.com poll, using a scale of 1 to 4, where 1 represented 'fell short of' and 4 represented 'exceeded' expectations. This provided a basis for an open discussion about vehicle performance.

For specific manoeuvres, the average response across the eight attendees was towards the 'exceeded' expectations end of the scale (see Table 5). Interestingly, the overall performance of the bus was rated lower by workshop participants than its performance for individual manoeuvres.

The discussion revealed divergent views here, relating to people having different expectations about what would be possible at the outset of the project. For example, the bus operator and journey platform provider acknowledged that they had low expectations about the technology at the outset, but then were impressed with the actual performance of the minibus. By contrast, the business park had expected the service to use a 'level-5' fully autonomous pod style vehicle and this expectation had not been met. This participant acknowledged that they had perhaps been too "optimistic" and "naïve" about the capabilities of the technology when the project started.

Table 5: Stakeholder workshop attendee ratings on vehicle performance

Manoeuvre	**Average score**
Overall, how far has the performance of the automated bus matched the expectation you had in 2018?	2.4
What about performance at roundabouts?	2.9
What about turning right from a give way	3.0
What about pedestrian crossings	3.1
What about going straight ahead at speeds of 40mph	3.3

Qualitative comments on the vehicle's ability to handle different manoeuvres included, with reference to negotiation of roundabouts:

> *"most impressive thing on the whole project"*

Journey platform provider

But it was also noted that the bus could be hesitant at roundabouts:

> "it was a bit unsure … a bit like a learner driver"

Local authority

The bus operator noted that they had not expected the bus to be able to negotiate roundabouts or right turns on a regular basis without incident and without the driver taking manual control. Overall the perception of performance at give way junctions could be summarised as 'cautious' but 'reliable'.

With reference to pedestrian crossings, the bus operator also noted that the vehicle "*seemed to anticipate*" what pedestrians in the vicinity of a crossing were planning to do.

Bus operator

Indeed, the business park included a non-standard rainbow / pride zebra crossing and this had not caused the bus any problems. The business park representative had expected the bus to need to stop at the crossing every time and this had not been the case.

It was also noted that the bus has succeeded in operating under a wide range of conditions – in the dark, in 30°C temperatures, and during heavy rain. The bus operator highlighted that the bus can operate under any weather conditions apart from snow or very heavy rain as the sensors need to see the white lines on the road. The rain issue was caused by raindrops rebounding from the road surface and confusing the sensors.

The group were generally impressed with the vehicle's ability to operate at high speed (up to 40mph). This had met an important objective set in the vehicle procurement specification and differentiated the project from earlier (low speed) trials. However, it was also acknowledged that operating on an open road at speed is relatively straightforward compared to situations involving complex interactions between street users.

Overall then, this exercise revealed that the bus had impressed workshops participants in achieving specific technical challenges, but there was also a sense that this is not the 'human-independent' service demonstration that had been hoped for, as the onboard safety operatives were not there 'just in case' but needed to intervene quite often, for a range of reasons.