Commercialising Connected and Automated Mobility

# Blythe & Rural Automated Vehicles Operations (BRAVO)

InnovateUK Project No. 10088448

Mass Transit Feasibility Study 2

November 2024

# Contents



Further reference tables and glossary of terms can be found in **Additional Tables of Contents**

# Executive Summary

## Study Background

Solihull Metropolitan Borough Council is home to an area of intense commercial activity termed 'The Hub' which contains some of the West Midlands' key trip attractors, including Birmingham Airport (BHX), the National Exhibition Centre (NEC), Birmingham Business Park (BBP), a major Jaguar Land Rover (JLR) production facility and Birmingham International rail station (BHI). With the arrival of a High Speed 2 (HS2) station (Birmingham Interchange) within the coming decade and all associated residential and commercial growth within the development site, growth projections for road transport demand on both the Strategic (M42) and Key (A45) Route Networks are significant.

Shared public transport services are seen as a central pillar of achieving connectivity goals due to their inherent capability to provide for high volumes of journeys while taking relatively little space. However, traditional public transport services are less frequently actually, *or perceived to be*, capable of providing the same level of utility, convenience, reliability, comfort, safety and value for money as members of the public feel the increasingly ubiquitous private car offers them, undermining the ability of transport operators to deliver services, and municipalities to realise the place-making benefits of public transport.

*Automated transport has for many years promised to offer a step change to mobility. Within public transport that step change is most commonly applied to the delivery of shared public bus / shuttle services. In short, the ambition is to be able to reduce operational costs allowing for increased investment in overcoming the well understood reasons why people do not readily use buses today: frequency; density; reliability; and safety.*

## Study Route

This study focused on a route that is considered a link that would likely be considered commercially unviable due to projected ridership, yet highly desirable for future introduction due to its potential replicability across national use cases.

Approximately 8 miles south of The Hub is Blythe Valley Park (BVP), a commercial centre home to over 25 businesses with a combined workforce of c.3,500 employees. In addition, the Park is approaching completion of 750 new homes. Similar to many 'out of town' business park developments across the country BVP is relatively isolated, it's primary means of connectivity being road - nationally the M42 and locally the A34. The direct route linking the Hub and BVP, the focus of this study, utilises a short 'junction hop' length of the Strategic Road Network – the M42, as well as public and private roads at the beginning and end of the route.

## Study Approach

To arrive at an assessment of feasibility – whether a future CAM system can deliver a service that shifts the dial on four foundational pillars of public transport, namely Safety, Reliability, Affordability and Accessibility – this study addressed three questions:

1) *What "Needs to be True" for this service to be considered feasible?*
2) *Where are we today?*
3) *What are the gaps (if any), that the consortium and / or the wider CAM eco-system needs to focus on to realise the feasibility of this (or similar) use-case?*

The study proposed six umbrella statements that are reasonably expected as 'needing to be true', these statements acted as Lines of Enquiry.

*Within the analysis two separate focuses were used – that of the user, and that of the technology.*

## Study Findings

Each chapter starts with presenting the "Needs to be True" statement, presenting the related findings, and finishes by providing statements summarising any identified gaps within each of the 'Needs to be True' statement / line of enquiry. Each of the gap statements are then assigned a Red, Amber, Green (RAG) rating based upon the authors' collective assessment of the extent to which current gaps are deemed able to be overcome having understood the future development in the automated technology / driverless service sector.

The table overleaf summarises the findings.

| Ch | Pillar | Focus | "Needs to be True" Statement *(Bar that must be met)* | Gap-Statements ("Where we are today") that need to be overcome to realise feasibility | RAG |
|---|---|---|---|---|---|
| 1 | Safe | User Focus | An automated service should be perceived, and experienced, as being as safe, or safer than a traditional public transport service | **Evidence collected through this study indicates significant concerns exist among the general public relating primarily to the safety of CAM services.** The need for gradual introduction, education and development alongside target users *and* the communities that services will run through will be crucial to ensure the best chance of successful implementation. Although evidence suggests that sentiment improves following engagement with the technology, the universal adoption and acceptance of new solutions cannot be assumed. | Amber |
| | | | | **The length, speed and relative complexity of this study route is not expected to ease perceptions of safety.** Although commercial examples of driverless, rubber-on-tarmac, shared public transport systems do exist – they are in controlled environments over short routes travelling at a maximum speed of 40 km/h. Ensuring riders feel, and are, safe over longer distances remains a crucial area for development, but indications suggest solutions can and will be developed | Amber |
| 2 & 3 | Safe, Affordable | Vehicle/System Focus | The vehicle/service must be capable to operate within the static, dynamic, and environmental conditions of the route with risk as low as reasonably practicable. | **The AV's considered in this study are unable to join the motorway safely at the peak traffic densities/ speeds on the M42 due to reduced traffic spacing on carriageway and vehicle top-speeds** (note: the consortium are unaware of any CAM system that publicly claims such level of performance). The feasibility study has considered solutions of: on-slip-lane becoming an additional lane and installing V2X radar detector technology and connected vehicle capability to support the vehicle. Given the additional investment this item is Amber, turning to Red if further work identifies these solutions unfeasible. | Amber |
| | | | | **The AV's considered cannot operate through unmanaged junctions**. There are currently fourteen junctions on the route of which only five are signalised. Solution for all signal information to be available digitally would be required via the installation of connected traffic lights/signals to all junctions, crossings, and ramp meters. Red as most junctions on the route are not currently signalised and would require infrastructure and/ or operational changes. | Red |
| | | | | **If sufficient connectivity were to become unavailable, one of the vehicle systems in this study would perform a minimum risk manoeuvre** (and come to a safe stop). This would not be acceptable or safe in a live traffic lane on the motorway (including its impacts on the existing dynamic hard shoulder). More understanding around the safety implications of MRMs on the SRN is needed. Red, as sufficient connectivity to avoid un-necessary MRM's would require investment and the implications of MRM's on the SRN needs to be better understood. | Red |
| | | | | **It's unclear if existing connectivity provision along the route is sufficient (C-ITS)**. Amber as a robust assessment of this would be required to determine required bandwidth (and signal strength) in relation to number of potential users. A more detailed (resource intensive) mapping of connectivity resilience across the route is needed, with a cross reference to vehicle capability and safety implications to establish if further cellular V2X would be required. | Amber |
| | | | | **For the conceptual vehicle specification to operate along the proposed route a minimum infrastructure cost in excess of £7m estimated** (estimate solely for information purposes). Amber at feasibility stage as further work would be needed to firm up exact costs (including whole life cycle costs) and its relationship to a wider business case for the service. | Amber |
| 4 | Reliable | User Focus | An automated bus service should be as, or more, resilient, robust, and reliable as traditional public bus options. | **There is yet to be a sufficient body of evidence to suggest future CAM systems will be capable of operating to the same level of robustness in the study ODD as a manually driven service**. This is particularly in relation to atmospheric conditions, where although there is significant levels of research and development, no equivalent commercial services running at motorway speeds are yet able to demonstrate automated control systems that can reliably meet human driven capability. Future CAM-based public transport services should be expected to need to meet higher levels of up-time (resilience) than private "robo-taxi" use cases due to the foundational role they play in communities. | Amber |
| | | | | **Without the ability to provide a segregated lane to provide journey time reliability, there would remain limited benefit / incentive to those who currently have access to a private car.** The direct route proposed within the study would improve journey times against current public transport options between the two locations, however, for those currently relying on private car, the service would be stuck in congestion around peak commute times, offering little benefit. | Red |
| 5 | Accessible | User Focus | An automated service must be as, or more, available and accessible as traditional public bus options. | **A service that seeks to deliver an end-to-end trunk route with limited / no flexibility is unlikely to maximise potential ridership.** To maximise access for future users, services should be considered as being required to have a degree of flexibility, primarily at the start and end of routes. This flexibility will however increase complexity significantly but will better mirror the nature of the private car. | Amber |
| | | | | **Providing accessibility (e.g. level-access) by design will be imperative to minimise operational conflict and issue.** Future users should be able to access vehicles without need for delay, specific personal technology or additional human assistance. Automated vehicle technology within road-based public transport systems cannot be expected to operate effectively without supporting operational infrastructure / solutions, adding cost to address issues traditionally managed by human drivers. | Amber |
| 6 | Affordable | User Focus | The economic case for investment must work for commissioners, suppliers, operators and future users | **Demand for this study route was not found to be sufficient to cover projected operational costs against any of the operational models considered.** Revenues were modelled using reasonable public transport fares, in line with municipality expectations that services must be affordable and not exclude on any grounds, including income / relative wealth. When modelled against manually driven services, a service of this scale would not be expected to be the most cost-effective solution to deliver desired outcomes. | Red |

Safe | Reliable | Affordable | Accessible | User Focus | Vehicle/System Focus

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# Keywords

Automated; CAM; BRAVO; Blythe Valley Park; Birmingham International Rail Station; M42; CCAV; InnovateUK; Aurrigo; Liftango; National Highways; Solihull; SMBC; Syselek; WMCA; TfWM; ZF; Feasibility Report; Report;

# Introduction

## The 'Hub' at the heart of the Midlands, benefiting the UK

Solihull Metropolitan Borough Council (SMBC) is a metropolitan borough council within the West Midlands region of England and a constituent member of the West Midlands Combined Authority (WMCA). SMBC is home to an area of intense commercial activity termed 'The Hub' (Figure 1), which contains some of the West Midlands' key trip attractors, including Birmingham Airport (BHX), the National Exhibition Centre (NEC), Birmingham Business Park (BBP), a major Jaguar Land Rover (JLR) production facility and Birmingham International rail station (BHI). With the arrival of a High Speed 2 (HS2) station (Birmingham Interchange) within the coming decade and all associated residential and commercial growth within the development site, growth projections for road transport demand on both the Strategic (M42) and Key (A45) Route Networks are significant.

*By 2030, the Hub, incorporating Arden Cross and the NEC, will become an environment to deliver:*

- *36,000 new and existing jobs*
- *Up to 8,000 homes*
- *650,000 m² commercial space*
- *£6.2bn GVA per annum*
- *1.3m people within a 45-minute public transport commute*

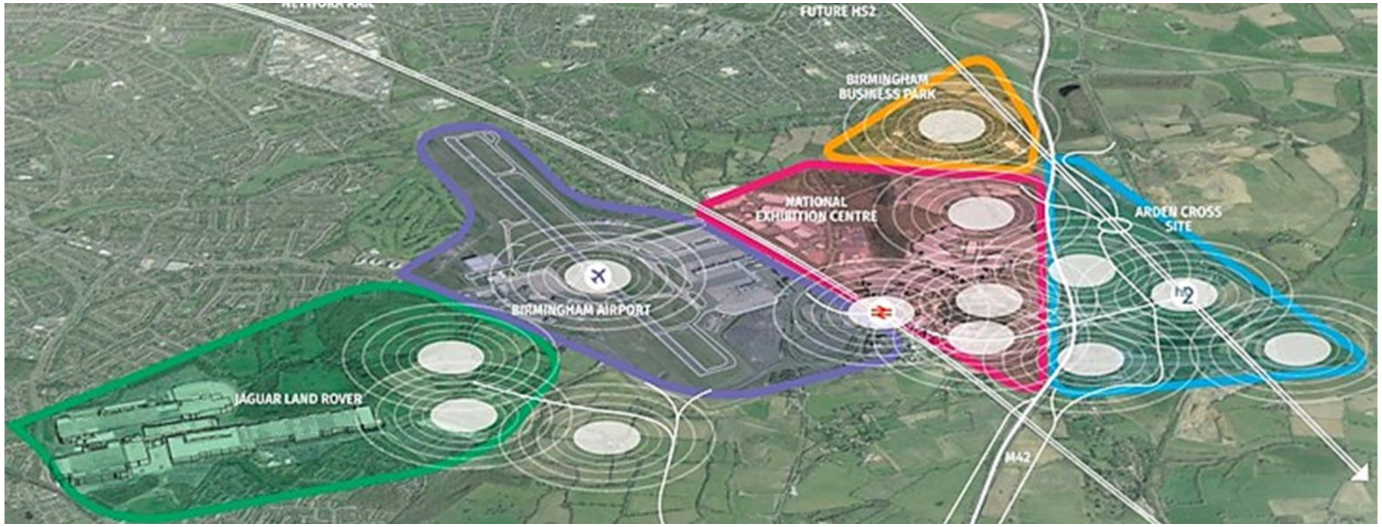



*Figure 1 Hub Area, Solihull MBC*

## The Challenge

Against the backdrop of this projected growth, the push for carbon and congestion reduction; increased accessibility, improved public realm and road safety are collectively driving the need for at-scale mobility solutions in the area.

Major transport hubs such as BHI, BHX and HS2 require efficient public transport options that link travellers to onward destinations. Likewise, major trip attractors such as NEC, BBP and JLR require efficient and reliable means of access and egress.

Shared public transport services are seen as a central pillar of achieving such connectivity goals due to their inherent capability to provide for high volumes of journeys while taking relatively little space. However, traditional public transport services are less frequently actually, *or perceived to be*, capable of providing the same level of utility, convenience, reliability, comfort, safety and value for money as members of the public feel the increasingly ubiquitous private car offers them, undermining the ability of transport operators to deliver services, and municipalities to realise the place-making benefits of public transport.

Specifically in relation to the impact of this trend on public bus services, the Department for Transport's (DfT) 2021 'Bus Back Better' National Strategy for Bus, framed the challenge as a 'cycle of decline':

> *Our system isn't working. With some encouraging exceptions, bus services have been in decline for a long time, as we have become an increasingly car-focused society. In many areas, we are stuck in a vicious cycle where ever-increasing congestion slows down buses and makes them less attractive, pushing people further towards the car and compounding the problem.*

This statement is demonstrated most effectively by four DfT 2022 UK Transport Statistics charts, each building a picture of a more car-centric society that is undermining public transport ridership, and therefore provision.

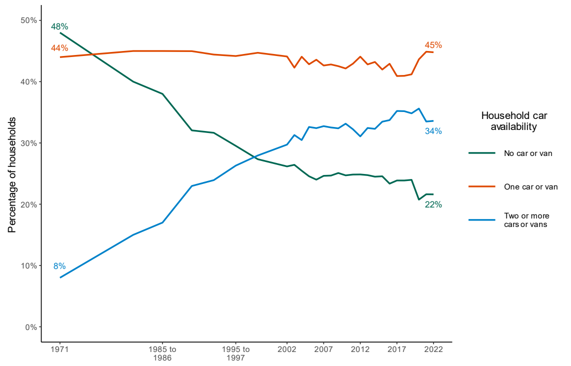



*Figure 2 Household car availability trends[1]*

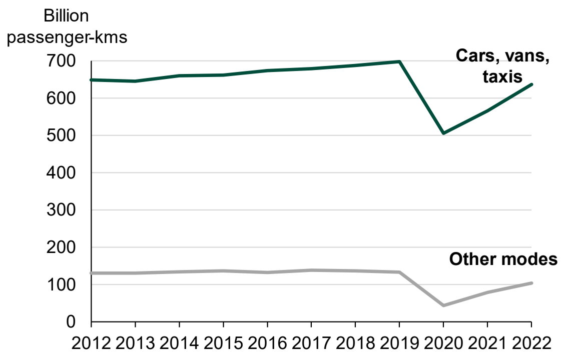



*Figure 3 Passenger kilometres by mode[2]*

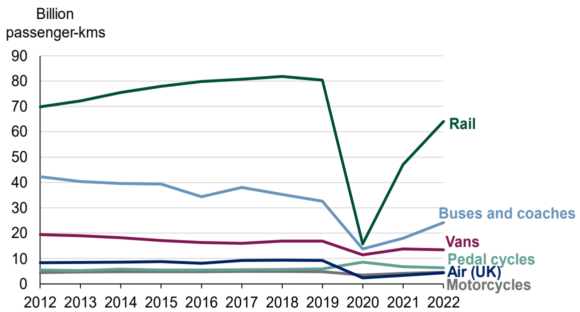



*Figure 4 Passenger kilometres by mode excluding cars[3]*

[1] National Travel Survey 2022: Household car availability and trends in car trips - GOV.UK

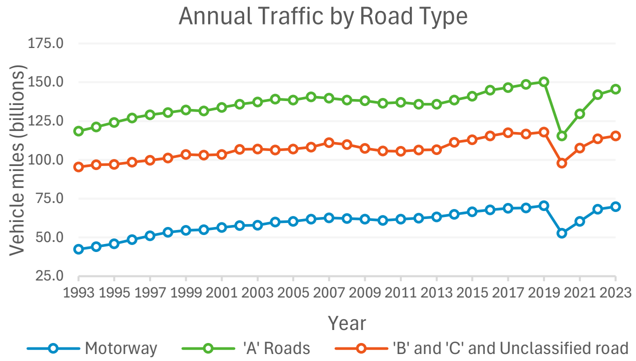



*Figure 5 Annual traffic miles travelled by road type[4]*

Understanding the root causes of the decline is a central requirement before plans to arrest it can be made with any confidence. TfWM's own quarterly research provides insight into what *current bus users* find most dis-satisfying regarding regional bus services, which helps to add local context to this national challenge. By far the greatest complaint from bus users relates to services being unreliable / not turning up on time. Road congestion and bus capacity are frequently the cited under-lying causes for this source of dissatisfaction.

| Reason for dissatisfaction | % |
|---|---|
| Bus service unreliable/didn't turn up on time | 72 |
| Buses don't run often enough | 18 |
| Bus fares are too expensive | 16 |
| Buses are dirty | 16 |
| Felt unsafe/anti-social behaviour | 14 |
| Services overcrowded/too busy | 14 |
| Driver was rude/unhelpful | 11 |

*Table 1 Reasons for customer dissatisfaction with bus services*

As well as understanding how to improve services from the point of view of *existing* users, attracting *non-bus users* away from private cars is central to the 'Bus Back Better' strategy, which states:

> *… we want to increase patronage and raise buses' mode share. We can only do these things by ensuring that buses are an attractive alternative to the car for far more people.*

The strategy identifies 12 headline requirements to arrest the decline:

- Increased frequency
- faster and more reliable
- cheaper
- more comprehensive
- easier to understand
- easier to use
- better to ride in
- more integrated
- accessible & inclusive by design
- safer
- greener
- more innovation

These requirements broadly match a 2023 Transport Focus study that sought views on what would encourage *non-bus users* to use their local bus service. Improved frequency, value, reliability, coverage and safety were the top five asks.

[2] Transport Statistics Great Britain: 2022 Domestic Travel - GOV.UK

[3] Transport Statistics Great Britain: 2022 Domestic Travel - GOV.UK

[4] Road traffic statistics - Summary statistics

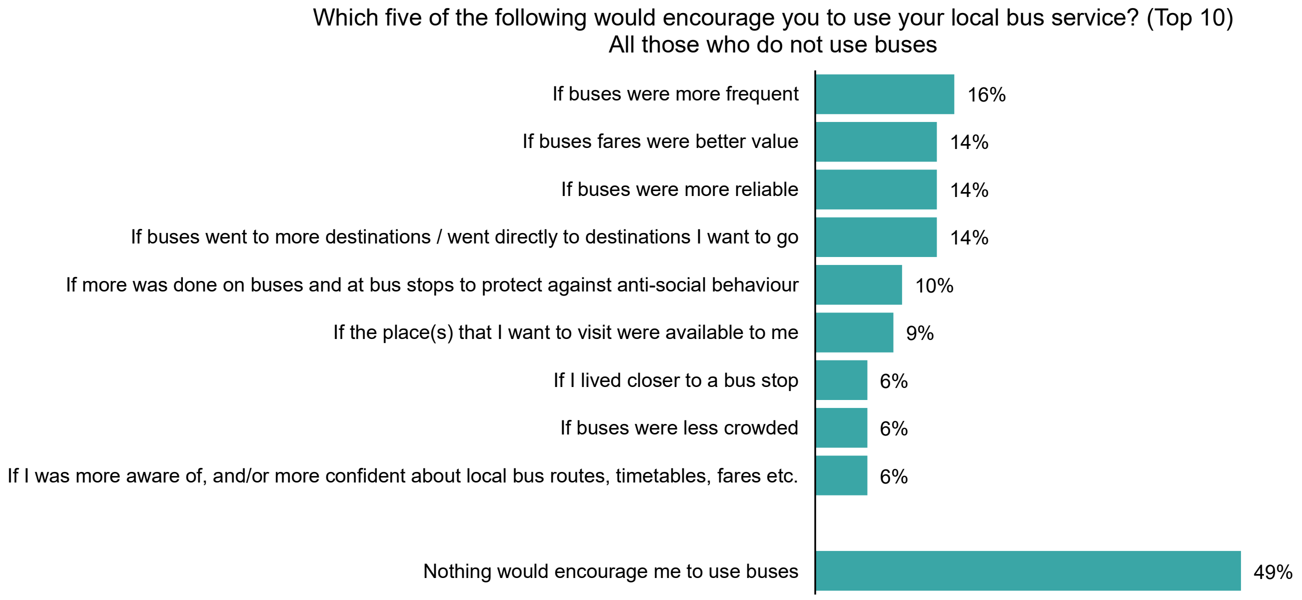



*Figure 6 Motivations and barriers to bus use[5]*

Despite the range of theoretical improvements being offered, perhaps most starkly nearly half of respondents suggested that 'nothing would encourage me to use buses'.

## Commercial Impact

Against this stark back drop, it should be little surprise that commercial delivery of traditional bus operations is difficult.

Within the UK, with the current exclusion of London, bus services are de-regulated, meaning bus operators are free to introduce, change and cease services within a set number of parameters. The ability of an operator to be able to deliver a route at a profit is therefore a central consideration. Currently, unless running along primary, dense transport arteries, public bus operators cannot be expected to be able to deliver commercially viable services that link transport hubs with many standalone locations such as business parks, universities, housing estates, rural towns, and retail parks, due to projected ridership missing commercial thresholds.

Where purely commercial parameters are not met (costs + margin are not met by fare box receipts), but a particular route is deemed socially essential by the relevant Local Authority, the route will be considered for subsidy by the state – to ensure a service of some description is maintained. Since 2010 subsidies for bus routes have however reduced by some 58%, with Local Authorities under continued budgetary pressure.

Journeys on these "non-commercial" routes are typically repetitive, below 10 miles and involve hundreds (not thousands) of trips per day. Delivering such journeys via commercially viable public transport represents a core mobility challenge to transport commissioners. Figure 7 offers a simplified illustration of this dynamic.

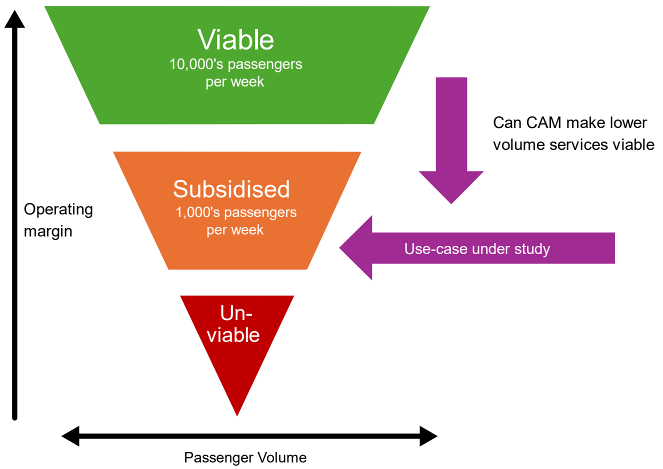



*Figure 7 A diagram of public transport subsidy levels*

[5] Motivations and barriers to bus usage

## Project response

Automated transport has for many years promised to offer a step change to mobility, and within public transport that step change is applied most commonly to the delivery of shared public bus / shuttle services. In short, the ambition is to be able to reduce operational costs whilst maintaining, if not increasing, fare box receipts. In turn, this reduction in operational cost can be re-invested in addressing the identified reasons why people do not use buses: frequency; density; reliability; safety; and so on, and / or used to offer new routes that would not traditionally be considered commercially viable due to lower ridership numbers.

This study seeks to understand to what extent this could be true when applied to one such route, and what conditions must be met before such a system could be commissioned. By systematically identifying requirements for a service on a specified route, the current realities, and remaining gaps this study seeks to present the feasibility of a future Connected Autonomous Mobility (CAM)-based system.

The study builds on existing experience, knowledge and expertise within the project consortium members, and within the wider region. SMBC, Transport for West Midlands and National Highways are leading public sector bodies, each with extensive experience in the delivery of previous CAM trials, including UKCITE, A2M2, SCALE, EBNS CAM, SPACES. The largest UK public realm testbed, Midlands Future Mobility (MFM, part of the UK CAM Testbed network), has enabled early infrastructure investments across the region. Research, methodologies and knowledge generation is led by WMG a project member. Two of the UK's leading CAM developers are based in the region and will contribute to this study: Aurrigo and ZF. Key perspectives on safety and operability will be enhanced by technology experts Syselek and Liftango. This consortium results in a multi-stakeholder approach which is essential to exploring all aspects of a feasible CAM service.

## Study Route

**Approximately 7.8 miles south of The Hub is Blythe Valley Park (BVP), a commercial centre home to over 25 businesses with a combined workforce of c.3,500 employees**. In addition, the Park is approaching completion of 750 new homes. Similar to many 'out of town' business park developments across the country BVP is relatively isolated, it's primary means of connectivity being road - nationally the M42 and locally the A34. The direct route linking the Hub and BVP (Figure 8), the focus of this study, utilises a short **'junction hop' length of the M42**. The outputs from this study will enable an informed evaluation of CAM to equivalent mobility challenges nationwide, primarily those that would seek to utilise the Strategic Road Network (SRN).

- Three lane 70mph motorway
- Entry & Exit Slip road
- Local road network
- Three lane roundabout
- High density traffic at peak times
- Diverse weather conditions
- 14 junctions

## Study Methodology

Could CAM potentially deliver a service on the SRN, and many other similar mobility challenges? There is **little existing data or knowledge of commercialised CAM services to draw upon.** Decision makers require confidence in CAM for it to deliver the value it promises. Given the lack of historic evidence, as CAM technology solutions mature, innovative approaches to the detailed assessment of scalable, repeatable use cases is urgently needed.

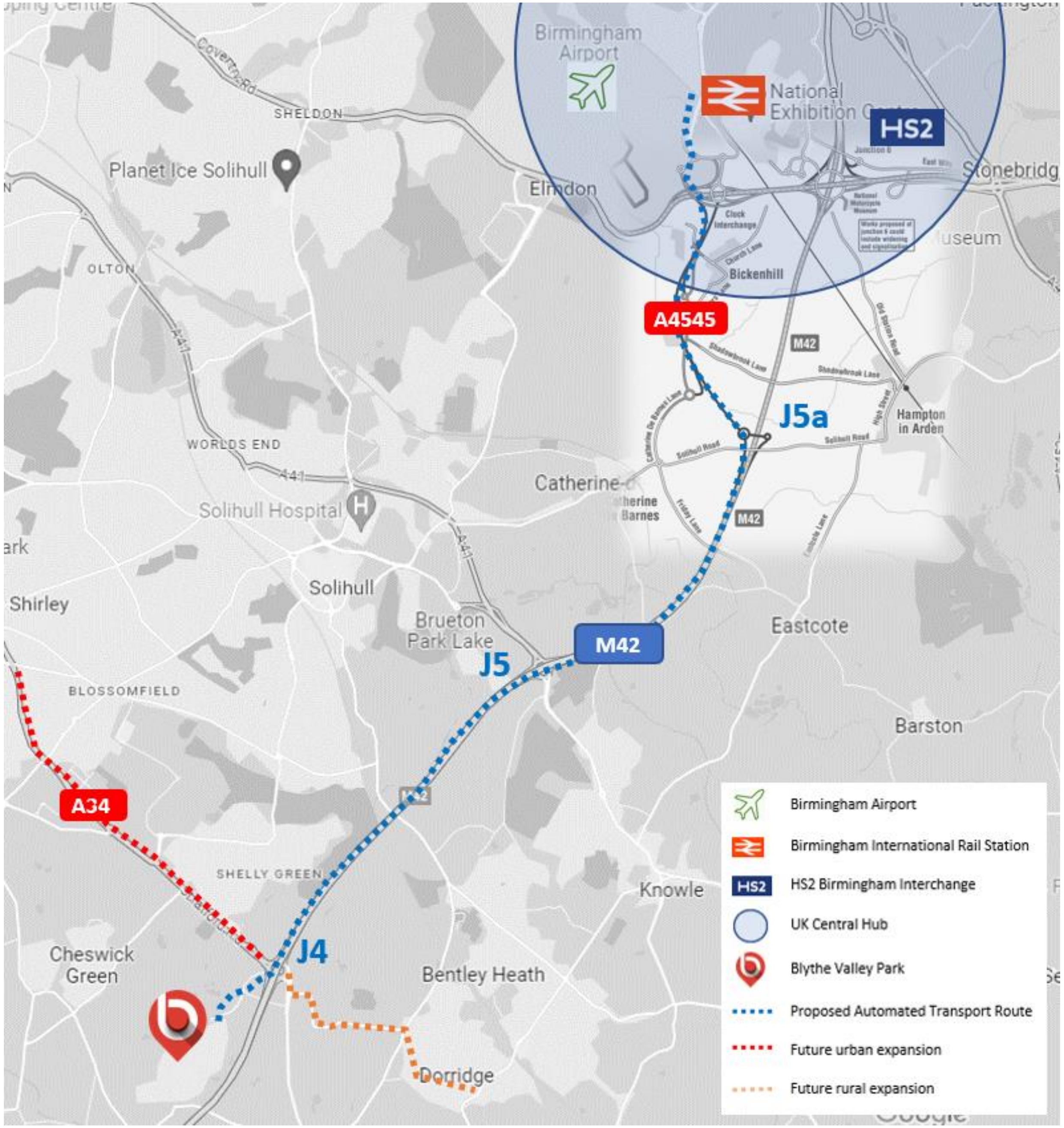



*Figure 8 High-Level Route Map*

## The Vision: A Safe, Reliable, Affordable, and Accessible network

**This study methodology centres around the user**. Consolidating work undertaken examining what current and non-bus users would want from a future public transport offer, a small amount of which is detailed within *The Challenge* section, Transport for West Midlands has developed a vision for connectivity in the region that states:

*"Our choices will create safe, reliable and affordable connections for everyone that are healthy, sustainable and efficient. This will create great places where generations will thrive."*

A foundational requirement for any future transport mode / system that will be accepted and adopted is therefore that it is **Safe, Reliable, Affordable and Accessible** – should any one of these four pillars not be met; public transport schemes, of which bus services are central, should be considered as failing.

These four Pillars are therefore the gauge against which feasibility of a future CAM-based public transport system should also be assessed. **Can a CAM-based system be, *as a minimum*, as safe, reliable, affordable and accessible as traditional modes of transport in the near, medium or long term?** Of course, the ambition must be that it can in fact *exceed* current levels, as future services must offer improvements on the current offer that is being widely rejected in favour of the private car.

TfWM expand on their four Pillars:

### Safety

*Making our roads and services the safest they can be will be central to our aims to reduce traffic and improve accessibility. Thankfully the numbers of people killed and seriously injured on the region's roads continues to fall, however, there is still more to be done if we are to create the conditions where people choose to increasingly use sustainable modes for their journeys and as the preferable safe choice.*

*Perceptions of bus safety during the hours of darkness were low compared to daylight hours. Respondents were more likely to feel unsafe waiting at the bus stop in hours of darkness (46% not very/not at all safe), than felt unsafe walking to the bus stop (38% not very/not at all safe) or travelling on the bus (31% not very/not at all safe). Regular bus users and females were consistently more likely to feel unsafe in the hours of darkness compared to other passenger sub-groups.*

### Reliability

*Reliability of journey times is a key factor in shaping people's travel choices. Experiences of public transport users suggest that unreliable journeys are a key concern and research undertaken by TfWM suggests that people's perception of the reliability of public transport is getting worse.*

### Affordability

*The average family spends 8-10% of household budget on transport. It is often cheaper to drive, or even fly than to use a train or bus.*

*The cost of public transport in general and particularly "anywhere to anywhere" trips across the West Midlands using different combinations of rail, metro and bus presents a real challenge for creating options which start to give affordable and understandable options for people to make informed decisions on how and when to travel.*

*The availability of funding to operate services, maintain and ultimately develop the network is a huge area of challenge.*

*Much uncertainty exists about the levels of funding – revenue and capital that might be available in the future to allow us to support and improve these services.*

*The current economic context presents a double challenge where increasing costs (fuel, drivers) and reduced demand (people make less journeys to save money) combined will further impact the viability of public transport and shared mobility services…*

### Accessibility

*Appreciating our regions demographic profiles by different subgroups is required to understand their accessibility levels, between the population as a whole and those more socially excluded groups. For example, access for disabled people or those having specific mobility requirements need to be fully considered if good transport provision is to serve areas of social deprivation.*

*The needs of other excluded groups including ethnic minority groups, young people, and older people, who predominantly are more prone to* *inequalities of income, witnessing relatively lower levels of car ownership and exposure to geographical and time-based determinants also need to be fully considered.*

Within the context of these four pillars, to arrive at an assessment of feasibility – whether a future CAM system can deliver a service that shifts the dial on Safety, Reliability, Affordability and Accessibility – the study seeks to address three questions:

1) What "Needs to be True" for this service to be considered feasible?
2) Where are we today?
3) What are the gaps (if any), that the consortium and / or the wider CAM eco-system needs to focus on to realise the feasibility of this (or similar) use-case?


*Figure 9 High Level Study Methodology*

## What "Needs to be True"?

This study proposes six initial *high-level* umbrella Statements that should be considered by future commissioners / suppliers / operators / legislators / buyers / investors / users as **'Needing to be true' before a CAM system can be considered as feasible** for introduction into a public transport system. The Statements are each linked to one of the four identified Pillars and act as Lines of Enquiry.

The study has approached assessment of feasibility from two distinct vantage points – *User* and *Vehicle / System*.

The ***User* focus** considers feasibility in relation to how future operators, commissioners and ultimately riders' requirements will be met. This includes costs and operational delivery of an on-road public transport service, without an on-board driver. The ***Vehicle / System* focus** considers capability and ultimately on-road safety of future CAM systems. This dual focus ensures, for example, that the study considers 'safety' of a future CAM service with regards to both a system being capable of navigating a route *on-road* without incident, and an operational service being able to ensure *on-board* safety of a rider.

Umbrella "Need to be True" Statements:

1. An automated service should be perceived, and experienced, as being as safe, or safer than a traditional public transport service
*PILLAR: SAFE*
2. The vehicle / service must be capable to operate within the static, dynamic, and environmental conditions of the route with risk as low as reasonably practicable.
*SAFE*
3. The safe and reliable behaviour of the system/ service must not require any change or investment to existing infrastructure, unless the service itself can fully absorb the cost and the change does not adversely impact current network performance/ capacity
*AFFORDABLE*
4. An automated service should be as, or more, resilient, robust, and responsive as traditional public transport options
*RELIABLE*
5. An automated service must be as, or more, available and accessible as traditional public bus options.
*ACCESSIBLE*
6. The economic case for adoption must work for commissioners, suppliers, operators and future users
*AFFORDABLE*

## Where are we today?

Each chapter uses the "Needs to be True" statement to explore the study routes feasibility. It does this by defining where current technology / systems / services are today in relation to the bar that has been set. In recognition of the fast-paced rate of development within the CAM sector, to provide a greater breadth and depth to assessment, the study, where appropriate, is augmented with references to work underway / completed outside of the immediate study consortium.

## A defined gap

Each chapter finishes by providing statements summarising any identified gaps within each of the 'Needs to be True' statement / line of enquiry. Each of the gap statements are then assigned a RAG rating based upon the authors' collective assessment of the extent to which current gaps are deemed able to be overcome having understood the future development in the automated technology / driverless service sector.

Whilst a feasibility study evaluates various factors to determine whether the project is practical and beneficial, by its very nature it lacks depth and nuance. A feasibility study should identify the areas that after initial review appear viable but require further depth and nuance to their investigation.

This is especially important context for a CAM feasibility study. There is not a library of previous successful studies into CAM mass transit systems that have gone onto enable those actual deployments and therefore generate a feedback loop of knowledge the study can draw upon. Whilst many of the study consortium have been involved in prior automated vehicle projects these have largely been technology trials rather than consideration of the wider installation of mass transit systems.

This study methodology therefore consciously reflects this reality in such a way that the outcome of the feasibility study can have benefit to the use-case under analysis *and* to the wider CAM eco-system. We achieve this through this gap-analysis approach.

This 'gap analysis' approach addresses the progressive challenge of CAM technology. The technology itself is evolving rapidly, but the way in which the technology then fits with use expectations (people) and standards and regulations (policy) requires a multi-stakeholder approach. This study therefore seeks to combine the perspectives of these multiple stakeholders and provide recommendations back to those stakeholders and Government itself as to where the gaps are before such a use case can be realised.

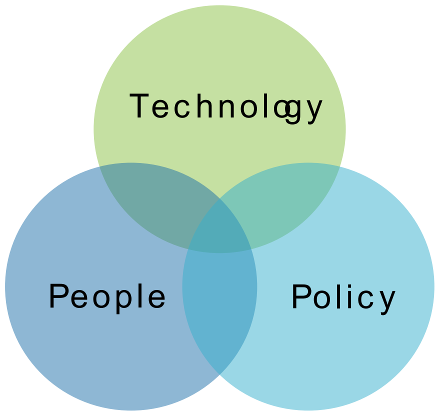



*Figure 10 Technology. People, Policy Venn dig, adopted from the MFM strategy*

# Chapter 1 – User Trust, Safety & Acceptance

*"An automated service should be perceived, and experienced, as being as safe, or safer than a traditional public transport service."*

*Pillar:*
*Safe*

*Focus:*
*User*

***"An automated service should be perceived, and experienced, as being as safe, or safer than a traditional public transport service."***

*It is reasonable to suggest that public perception of new technologies, particularly where there are perceived to be significant direct and indirect personal safety implications, will have a direct impact on societal acceptance and adoption of said technologies. In the context of CAM public transport, services would not only impact upon future riders but also the neighbourhoods and communities within which they operate. Feasibly future services could be the target for anti-social behaviour – on a sliding scale of relatively harmless 'coning' to more insidious vandalism and targeted destruction. Understanding the relative likelihood for acceptance and adoption will help assure commissioners / investors of the future. This chapter explores the attitudes to CAM services & vehicles and seeks to understand how on-board safety can be, and in some cases is, assured.*

## Where are we today?

## 1.1 Sector Insight

### 1.1.1 General Attitudes to CAM Vehicles

KMPG's 2020 Autonomous Vehicle Readiness Index ranked 30 countries on their readiness for CAM, across five factors, one of these factors being Consumer Acceptance. The UK was placed 12th on this measure, which is derived from six different data points related to awareness of CAM and general adoption of new technology. This suggests that the UK public is, in theory, ready to entertain CAM services, although isn't in a position in the ranking that could be considered to remove all doubt at this stage.

The Great Self-Driving Exploration[6] published in June 2023 explores this area by way of conducting an in-depth study into the public's view of CAM technology. The insights highlight the existing view of CAM services and the potential for CAM vehicle's role in local transport systems.

#### 1.1.1.1 Existing View of CAM Services

The summary of the publics existing view of CAM is:

- There is a strong correlation between positive attitudes towards technology and positivity towards Self Driving Vehicles (SDV). Those most likely to be positive include men, younger people, those with higher incomes, those with higher education levels, and those living in urban areas.
- While awareness of SDVs is high and almost two thirds of the national control sample report having talked to others about SDVs in the past, there is low accuracy of understanding of user responsibilities when travelling in SDVs and what vehicles can currently legally do on UK roads.
- Comfort with using or sharing the road with SDVs is low, with the proportion giving the lowest comfort ratings consistently and significantly outweighing the proportion giving the highest comfort ratings in the control survey.
- However, the low, medium, and high exposure audiences in this research were consistently more comfortable with the prospect of SDVs than the national control sample, indicating higher starting positivity among research participants compared to the wider UK public.
- People are most willing to use a private SDV with shared responsibility for the driving task compared to other types of SDVs.
- Views were mixed in the national control survey about whether SDVs would make the local transport system better, worse or no different, as well as whether there were more advantages or disadvantages to their use.
- By contrast, the medium and high exposure audiences were significantly more positive about the potential impact of SDVs, and while many were still unsure or wanted more information, there was limited outright negativity.

6 Great Self Driving Exploration: A citizen view of self driving technology in future transport (publishing.service.gov.uk)

1.1.1.2 Potential role of CAM in local transport

The summary of this section from The Great Self-Driving Exploration report is:

- Initial thoughts
  - Initial views tend to be neutral to positive among study participants
  - There are multiple assumptions that study participants brought to the study
  - Safety is a key area of interest, both of the system and to road use
- Opportunities
  - Benefits identified as study participants learnt more
  - Town and rural participants identified a range of use cases
  - CAM Vehicles could improve public transport services
  - Urban participants see CAM services 'plugging gaps' in the transport network and for longer journeys
  - Expectation for CAM to be used in public transport first
- Drawbacks
  - Participants raised concerns over the safety of the vehicle over a human controlled vehicle
  - Risks around personal safety (physical abuse) and data (hacking/data breach)
  - Poor real-world integration and functionality, especially early on
  - Concerns of job losses in local communities
  - High cost of implementation and lack of funding available in local government
  - Dehumanisation of services leading to higher levels of isolation
  - Inequality due to potential high cost, physical accessibility and digital literacy
- Expectations
  - Majority of study participants expect a gradual roll out of CAM systems based on safety and convenience of users
  - CAM services will be in addition to and not replace existing transport networks in the short to medium term
  - Safety and security assurances with redundancy systems and potentially a human presence for shared vehicles
  - Large scale communications campaign to educate the public on CAM vehicles, along with updates to driving tests on CAM interactions

The report includes many recommendations to drive behaviour change on the public during the adoption of CAM systems. This report demonstrated that while there is hesitancy and questions in the publics collective mind around CAM deployments, there is significant optimism and potential acceptance in their use.

It should also be noted that The Great Self-Driving Explorations and similar studies have focused on the public acceptance of potential customers and *not on residents or other road users*. As evidenced by news reports on the Cruise and Waymo deployments in San Francisco, there are more negative feeling towards CAM systems when sharing the environment with them but not making use of them. Further specific studies will be needed to understand the acceptance of CAM solutions by other road users and residents who may not directly experience the benefits of such a system.

## 1.1.2 PAVE UK

Partners for Automated Vehicle Education (PAVE) UK is a joint government industry initiative to respond to these findings. UK regulatory environment has uniquely identified end users and societal needs as a priority as CAM technology evolves. The recently introduced AV act 2024 makes numerous references to the importance of bringing society on the technology journey. Primary legislation addressing factors such as misleading marketing the inclusion of disabled groups and consultation with road users are all now built into law. However, the UK CAM ecosystem must convert this into detailed secondary legislation and deliver on the ask of actively engaging end users and society in the development of this technology. PAVE UK is therefore being set up to act as a focal point to enable the trust and acceptance of connected and automated mobility through accurate and inclusive engagement and educational campaigns.

PAVE UK will address this challenge in four ways firstly by engaging with the public understanding their concerns and raising the general awareness of the technology. Secondly through the undertaking of robust research and data collection so the ecosystem can form informed and data-driven decisions. Thirdly through the creation of engagement and educational material and tools co-created with societal groups that will both enable PAVE UK itself to reach a much wider audience but also assist key stakeholders such as the media policymaker's insurance and charities understand and communicate the possible benefits and challenges of the technology. Finally PAVE UK will advocate for inclusion of end users and societal concerns in the way secondary legislation forms over the coming years.

The findings from feasibility studies such as this when combined with real world data such as PAVEs own research studies and actual technology deployments will start to paint a very rich picture what is needed from industry and from government to ensure we take SoC on the journey of developing and implementing this technology.

### 1.1.3 Local Perception of CAM

There have been two prior local studies that have asked residents of Solihull on their perceptions of CAM solutions. These are *Solihull Low Carbon Future Mobility Travel Behaviour Change* (Oct 2023) and *Self-Driving Buses - Keep WM Moving! Online Community Topic* (Feb 2023)

Both studies show that residents in these areas are **curious to use CAM solutions but have reservations on the deployment of the solutions**. Additionally, it was noted that while residents express that they would switch to automated vehicles for some journeys, they would not replace all journeys.

Graph 1 shows the reasons for resident's opinions on CAM solutions, which were based on the launch of the CAVForth project.

Figure 11 shows the comments made by Solihull residents on why they would not use CAM options.

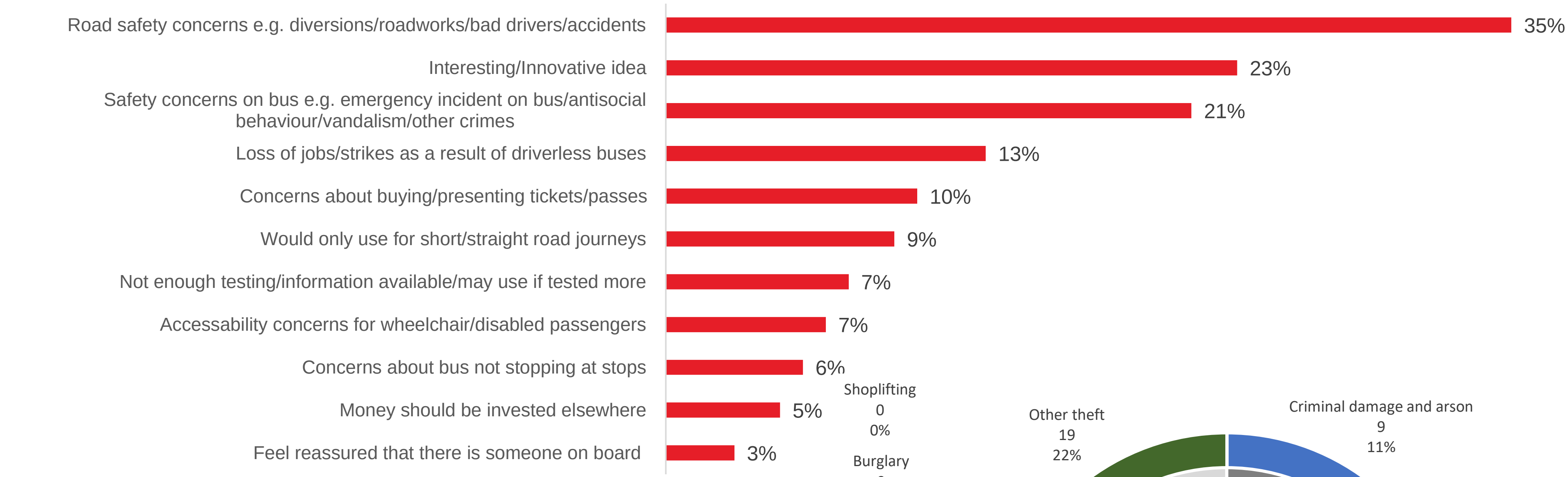
In both outputs the concerns **generally surround the safety of the vehicles** which may stem from a lack of understanding of the level of technology development. **This is in line with the national survey (1.1.1), and the key to overcoming these concerns is communication and experience**. Despite the understandable reservations shown locally, research also indicates that a CAM system holds the most potential to replace car journeys.

SMBC have deployed their Aurrigo CAM shuttle at the NEC, Birmingham Airport and Birmingham Business Park over two years (2021 – 2023) as part of a GBSLEP funded project. **The post-ride surveys illustrate a high satisfaction with the ride experience, and a significant reduction in concern/cynicism post-ride.**

- 94.6% of riders stated they enjoyed their experience.
- 98.2% of riders stated they felt safe at all times.87.9% of riders felt they could become accustomed to riding without any safety operator on board.
- 96.5% of riders stated they would readily ride on an automated vehicle again.

Observations of the deployed vehicle were that very few times did passersby/other road users act maliciously or dangerously, indicating a general default position of behaving cautiously around the technology.


*Figure 11 Comments made by respondents related to why they will not use automated vehicles.*



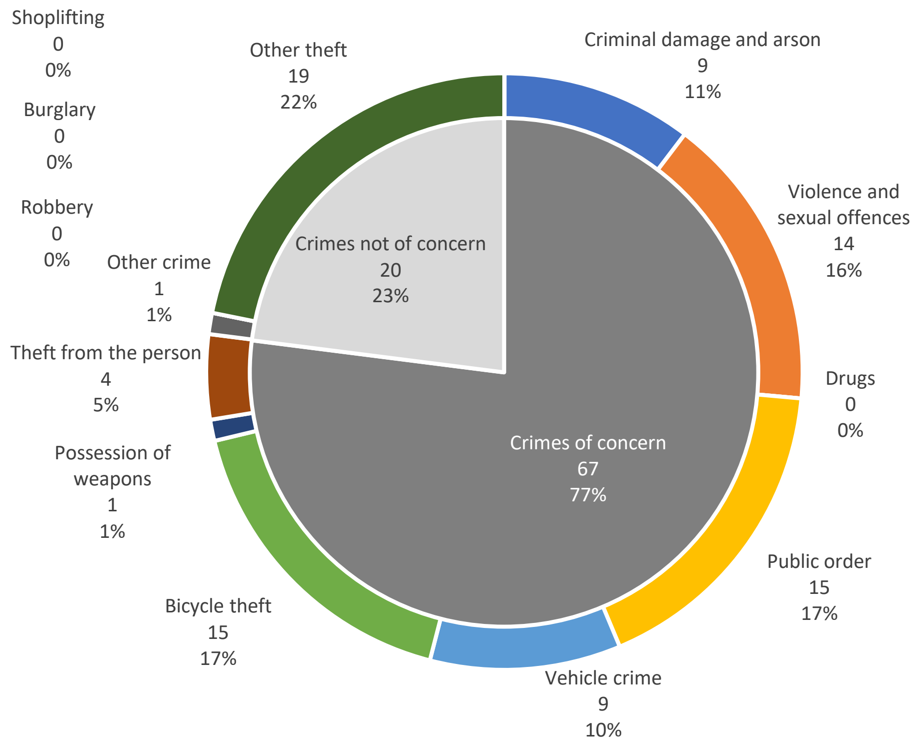

*Graph 1 Reasons for opinions on CAM solutions Self-Driving Buses.*

## 1.2 Crime Statistics

Personal safety of passengers will be needed for mass adoption of a public transport CAM solution. The Great Self-Driving Exploration noted the following as part of the perceived drawbacks of CAM systems.

*Dangers onboard: There were concerns that passenger safety and security while travelling would decrease due to the absence of staff on shared and public transport, removing a 'neutral' third party in the event of disputes or antisocial behaviour. Particularly among urban participants, it was felt that the use of Self Driving Vehicles (SDVs) could lead to an increase in anti-social behaviour on public transport. The removal of staff was also seen as potentially providing opportunity for criminals (e.g. for drug dealing, theft). These perceived drawbacks and risks were raised particularly often by women and people who tended to travel at night.*

Graph 2, below, shows the crime statistics reported by British Transport Police for the period July 2023 to July 2024 of crimes that occurred in or near Solihull rail stations[7]. The outer ring shows the Crime Type, while the centre shows which crime types,



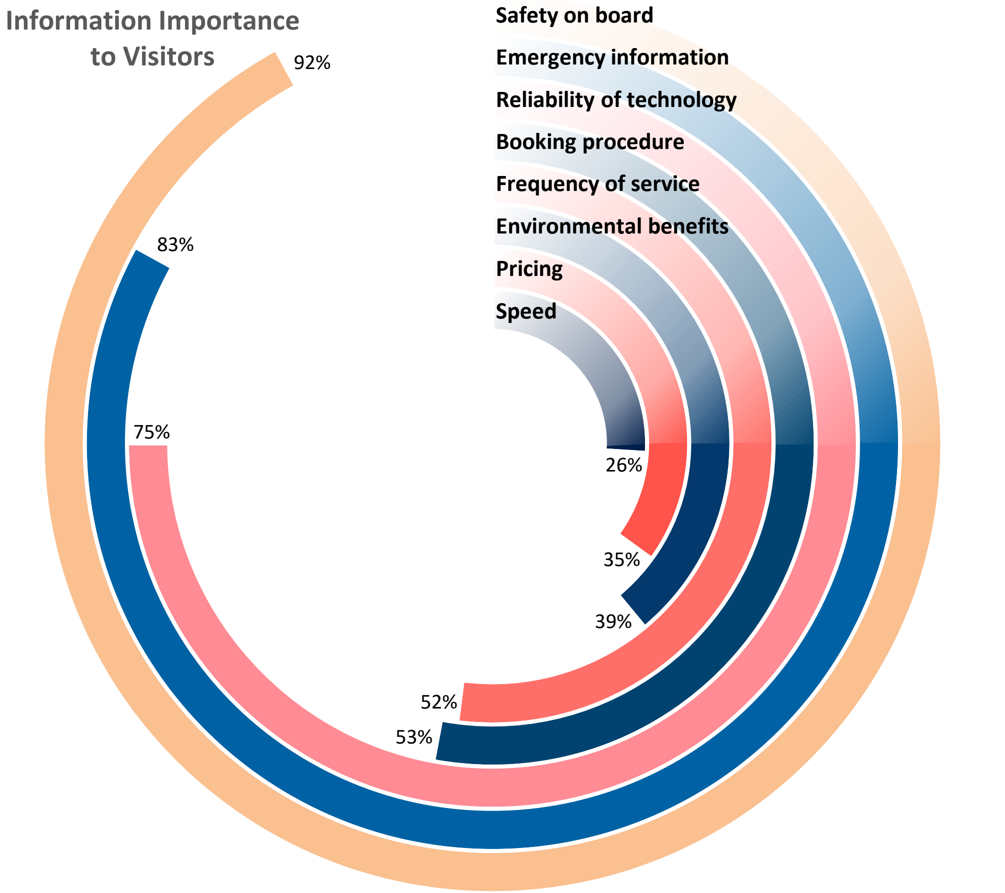

*Graph 2 British Transport Police Crime Statistics July 2023 to July 2024 for Solihull rails station LSOAs.*

[7] [Data downloads | data.police.uk](https://data.police.uk)

should be considered of concern due to different infrastructure.

As shown, more than ¾ of the crimes committed in the period would be a concern. These crimes relate to potential actions against other passengers, allowing for criminal activity to be carried out or damage to the vehicle itself. It is reasonable to assume an increase in these crimes without the presence of an authority figure in the form of a driver or attendant. **If these crimes were to go unchecked, public perception and acceptance of a CAM solution may be irreparably damaged**.

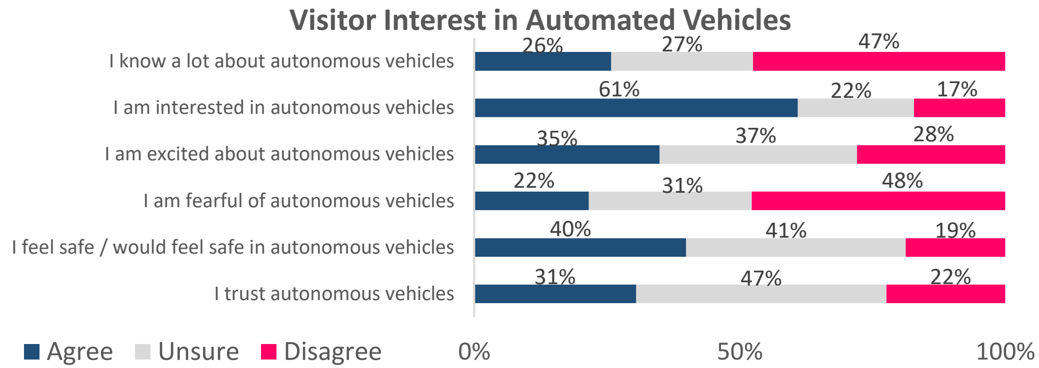
## 1.3 Parallel Project Findings




*Graph 3 Question: How important is the following information in your decision to use autonomous shuttles?*
*Visitors = 602 responses.*

In a parallel project, Solihull and Coventry Autonomous Link Evolution (SCALE), visitors and staff to the hub area were surveyed on their feelings towards automated vehicles. In relation to this project the visitor responses are the most relevant.

These graphs (Graph 3 and Graph 4) show that while there is interest in automated vehicles, there is also a lot of uncertainty. **This is most evident in the shift in attitude between feeling safe in an automated vehicle and the level of trust in an automated vehicle.** This is carried over to the importance of information on aspects of automated vehicles. Safety on board, emergency information and reliability of technology are the most important information that would encourage automated vehicle use.




*Graph 4 Question: Please indicate your level of agreement with the statements below.*
*N = 602 visitor responses.*

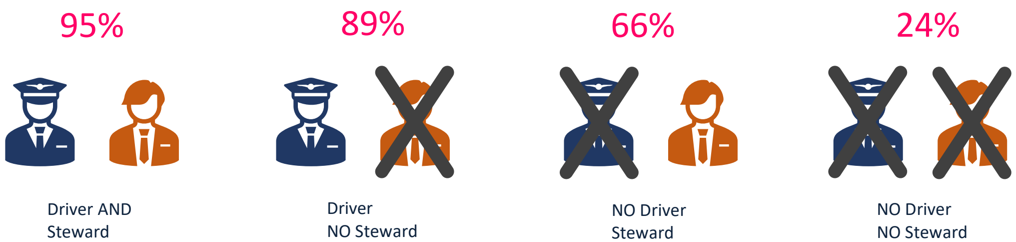



*Figure 12 Question: In the future, autonomous shuttles may operate without a human operator onboard. In such circumstances, there may be a steward on board to provide customer care. They would be able to move around the shuttle and offer passengers support and assistance when both boarding and in transit, sell / check tickets as well as acting as an authority figure.*
*Please select 'Yes' or 'No' for the following. N = 602 visitor responses.*

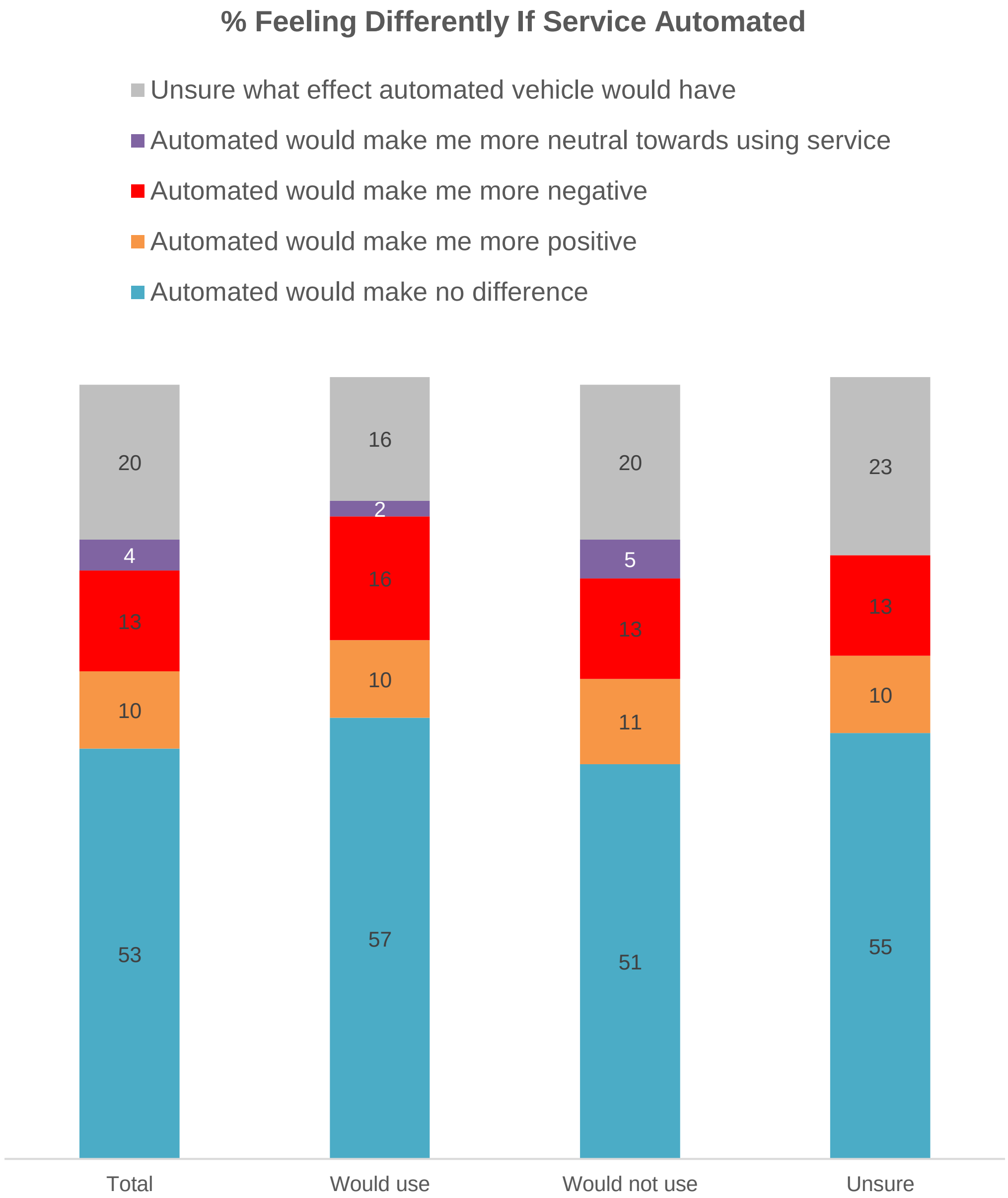
From the same study, it can be seen in Figure 12 that even though there is interest in automation there is still distrust if a human is not obviously involved. Visitor confidence in a CAM service is significantly eroded as the level of human involvement is reduced. **This points to the importance of retaining a human presence until the technology has proven itself in the public collective consciousness.** The removal of onboard staff could be phased out as CAM services become more common and less novel. However, close monitoring would be needed to understand the timing of the phased removal as it is currently unclear how quickly the public would become accustomed to an unattended CAM vehicle.

## 1.4 Blythe Valley CAM Service

For a deeper understanding, the workers and residents of BVP and surrounding areas were invited to complete a survey. The responses from these surveys were collected by processed by a team in TfWM via a General Data Protection Regulation (GDPR) compliant database. The resident survey is based on the employee survey but has been modified to be resident specific. The following are the results from these surveys regarding sentiments on the service being automated. Further Survey results can be found in 6.5.

### 1.4.1 Employees Sentiments on an Automated Service

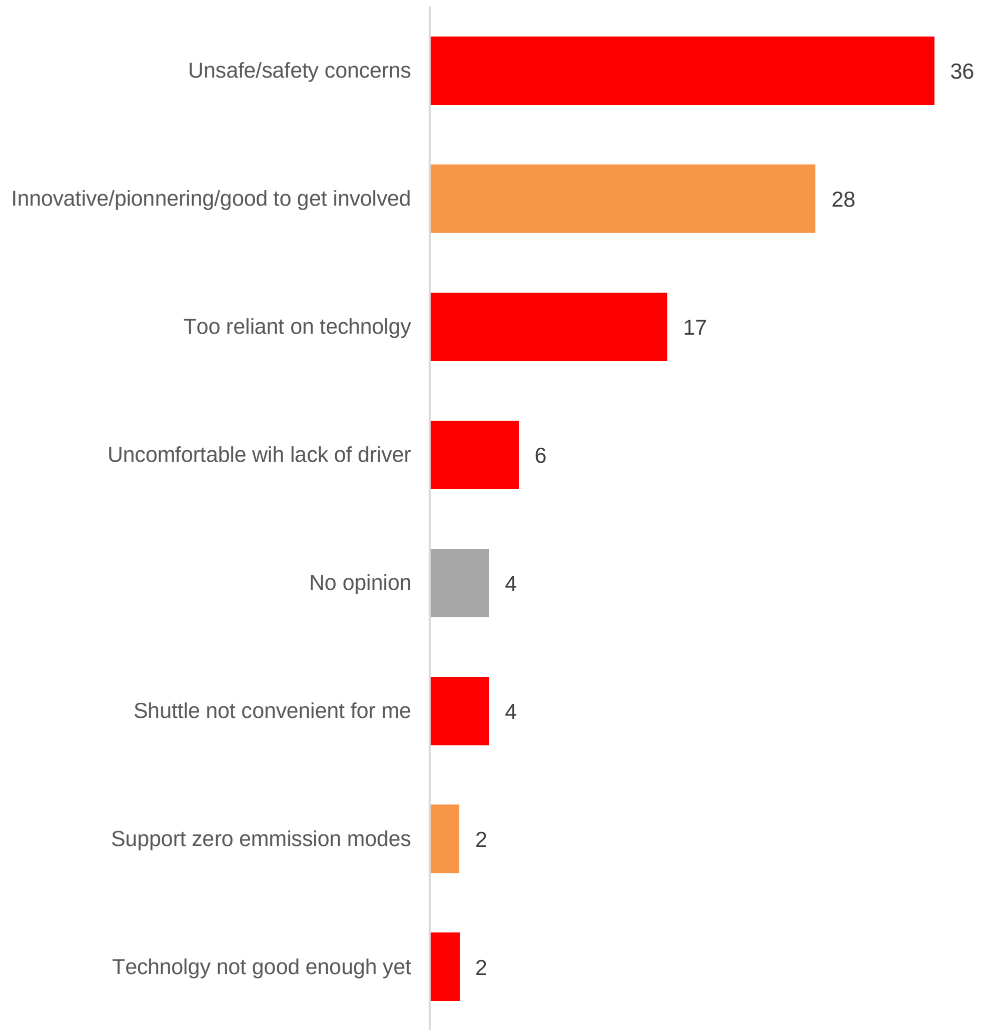
If the shuttle service was automated 10% would feel more positive towards using the service, however 13% would feel more negative (Graph 5).




*Graph 5 Question: If this service was one of the UK's first automated ('driverless') services, would you feel differently about using it?*
*Base – 210*

Negative sentiments rose to 16% amongst those who said they would use the service, however, 11% of those who said they would not use the service would feel more positive towards it, if it were automated (Graph 6).

**Reasons for positive/negative opinion (%)**

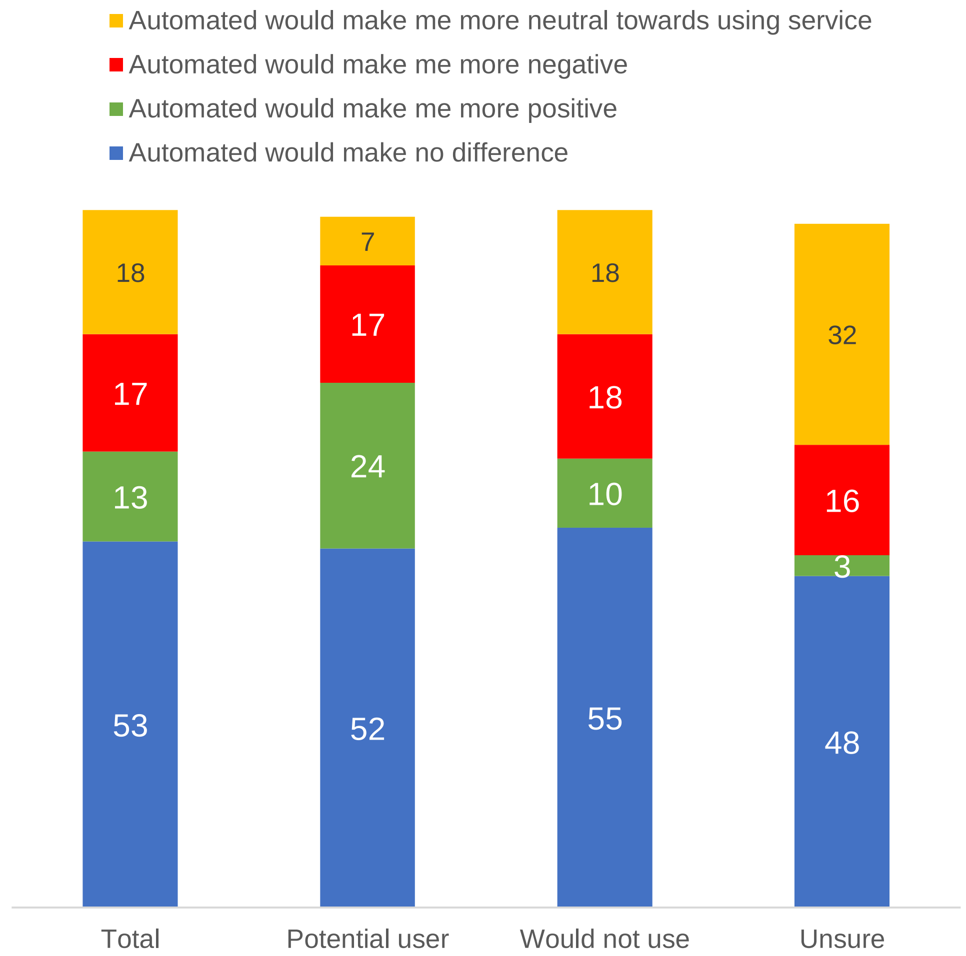



*Graph 6 Question: Please tell us in more detail how you feel about the service being automated? Base – 58 who felt that a driverless service would make them feel differently about using service. Question: Please explain why you feel this way: Base 47 valid responses.*

## 1.4.2 Residents Sentiments on an Automated Service

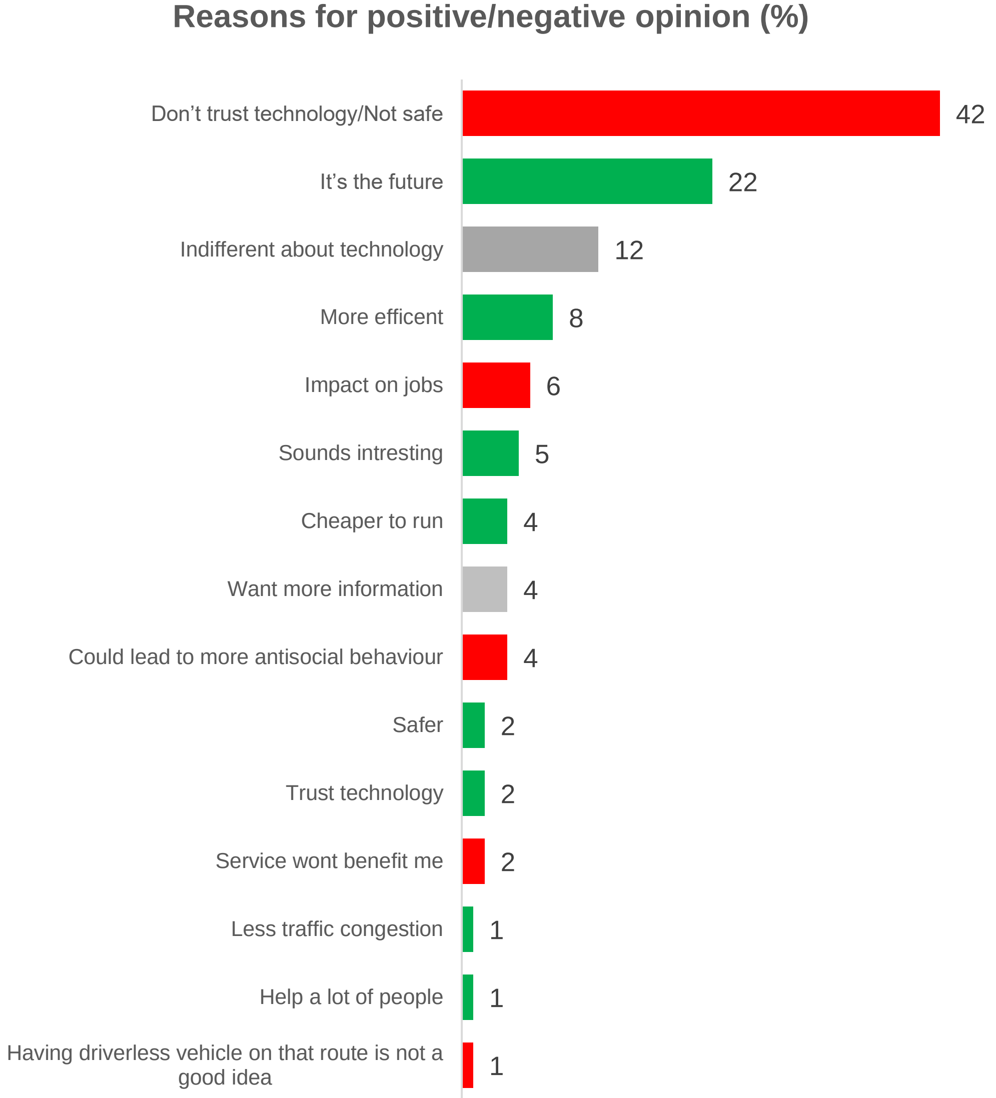
If the shuttle service was automated 13% would feel more positive towards using it, however, 17% would feel more negative. Positively 24% of potential users felt automation would make them more positive towards using it, however it made 18% of non-users feel more negative towards it (Graph 7).

**% Feeling Differently If Service Automated**




*Graph 7 Question: If this service was one of the UK's first automated ('driverless') services, would you feel differently about using it?*
*Base – 135*

**The main reason for feeling more negative towards the service if it were automated were don't trust technology/safety related (42%).** The main reason for feeling more positive was that the use of such technology was *the future* (22%) and *more efficient* (8%) (Graph 8).




*Graph 8 Question: Please explain why you feel this way: Base 83 valid responses*

## 1.5 Building trust

Building trust in new technology is clearly an important aspect to consider, and the extent to which the public will accept a technology should form part of the feasibility of an investment. The deployment of 5G cellular communications networking equipment in the UK, which coincided with the tail end of the COVID pandemic, offers an example of how communities can respond when not engaged. A lack of communication on how 5G, and cellular systems in general, operate was mixed with a public primed to be suspicious following a period of lockdowns due to the coronavirus. The result was, in pockets, a backlash and confrontations while the equipment was being installed leading to extensive damage and postponed roll outs. To avoid a similar situation with CAM services, and as mentioned in The Great Self-Driving Exploration, an open communication and experience approach must be taken.

To build trust and address concerns regarding safety, learning from existing services where possible is critical. One of the few commercially deployed road-based CAM public shared transit systems globally is at the Rivium Business Park, Rotterdam.

The segregated system consists of six 22-person shuttles that ferry riders from a metro station to five stops within a suburban business park, a 1.7km route. The system, first installed in 1998, is now a fixture at the business park, providing a service to 2,200 passengers per day. The service runs from 0600 to 2200 hrs Monday – Friday.

Evidently, perceptions and experiences relating to rider safety have been addressed, and learning how should be considered as an important step for assessing feasibility of the service within this study.

A high-level summary of how perceived and actual safety is ensured is provided below:

- On-route control centre
- Intercoms at all stops and on all shuttles so that passengers / passersby can contact control centre immediately
- Two internal cameras, clearly signed, covering all aspects of on-board activity
- Four external cameras on the vehicles. Record locally (on the shuttle) in HD, but send lower quality live feed to control room
- Extensive CCTV along route (but not full route – a cost saving decision).
- PA system on shuttles for external speaking, i.e. in event of evacuation
- Alarm will sound in control centre if / when a shuttle stops unexpectedly - it

plays back 10 seconds of video to the controller (to provide context of the event) who then decides whether its ok to instruct vehicle to continue

- The system has different driving modes based on weather classifications. Classifications are based on national weather centre codes. These are updated by the control room if they change
- The system auto-downloads video that relates to specific auto-alerts (i.e. incidents / issues) – saving the HD footage to their server overnight. Auto-erased after 5 days on board if not downloaded
- Line barrier and pressure sensors for doorways to ensure no one is trapped when boarded / before departing
- If Lidar senses something in the path of the vehicle it will automatically sound the horn – i.e. pigeon
- Shuttle slows at barriered crossings along route, in case of requirement to suddenly emergency brake
- Emergency stop buttons on board the riders can operate if they foresee an issue on the road ahead
- Left luggage / loitering – camera technology is starting to come through that can identify this. Important in case of leaving suspicious packages in vehicles at airports

The outcomes of this comprehensive approach to rider safety, and their perception of feeling safe, is clear:

- Very low levels of ASB ever experienced. They do get incursions into the route – as it is only lightly segregated. They have had cars, bikes, frequently people getting in the way.
- Have had examples of children throwing stones / lying in path – but very infrequent. Level of CCTV means culprits easily identified and can be addressed
- Suggest that it soon became 'boring' to interfere with the vehicles

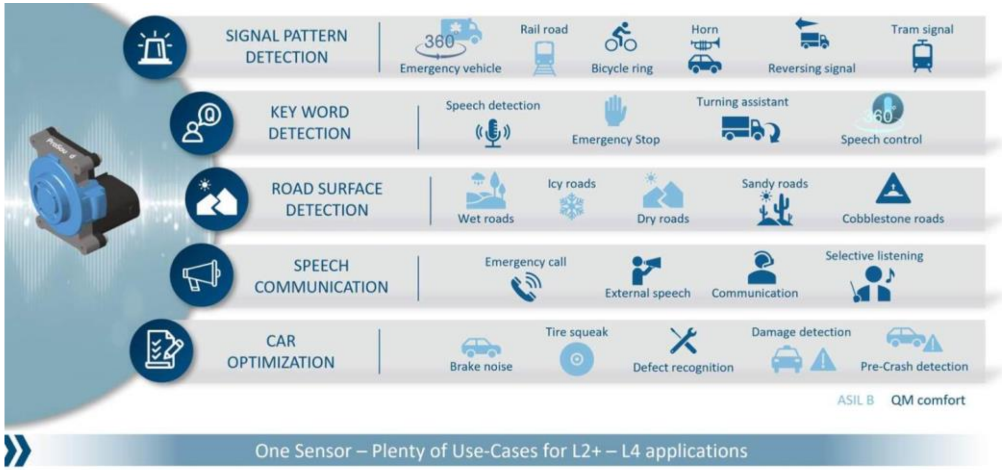
The under-lying factors that have built this seemingly safe and effective deployment of driverless technology must be noted and understood:

- A relatively short route (1.7km)
- On-route, manned, control centre
- Segregated route, with priority at junctions – greatly reducing risk of on-route conflict that could cause nervousness / concern
- No late night / early morning running
- Sub-urban environment
- Maximum speed of 30mph
- Deployed in a country assessed at #1 in KPMG's 'CAV readiness' global index
- Accessible to the public, but not generally used by members of the public (rather employees of & visitors to business park)
- Fully flood-lit route

The ability to deliver the level of adoption at Rivium, real and perceived rider safety across a route that shares *none* of these characteristics must however be a central consideration of feasibility.

Although commercial deployment of *Robo-Taxis* (private hire vehicles with no on-board human driver) is nearing realisation in North America, one critical distinction with this use case is the private nature of the services, with no requirement to share a vehicle with a stranger – greatly reducing an aspect perceived risk.

Examples of the application of technology to address concerns of sharing vehicles with no authority figure physically on board are coming to market, such as ZF's 'Pro-Sound' sensor, which promises a step change in the capability for ensuring rider safety. Increasingly the application of Artificial Intelligence is being applied to video images to be able to interpret even small changes in behaviour which may indicate unease / escalation, allowing alarms to be raised, however whether such 'remote' assistance could provide sufficient reassurance is still to be seen.



Copenhagen Metro

Although not directly equivalent, examples do exist of public shared transport that do cover large routes. Learning from these systems and how they ensure a sense of safety for on-board riders is valuable.

1. Driverless System

- The Copenhagen Metro, 43km in total length, is one of the first fully automated metro systems in the world. Trains are driverless, which means that there are no conductors or operators on board the trains themselves.
- Train operations, including starting, stopping, and speed regulation, are controlled centrally from a control centre.

2. Central Control Room Staff

- Despite the trains being driverless, the Metro is monitored 24/7 from a central control room. Staff in this facility oversee the entire operation of the metro lines, including train schedules, signals, track conditions, and responses to emergencies or technical problems.
- The control room staff can intervene remotely if necessary and communicate with passengers via onboard announcements or the Metro's public address system.

3. Ticket Inspectors (Kontrollører)

- Ticket inspectors are responsible for checking whether passengers have valid tickets, enforcing the fare system, and ensuring compliance. These inspectors are often the only visible staff passengers encounter on regular Metro journeys.
- They work both in uniform and plain clothes, carrying out random checks and issuing fines for fare evasion.

4. Customer Service and Station Staff

- While many Metro stations are largely unmanned, there are customer service agents who are present at key stations and hubs, especially during peak hours or special events.
- These staff members assist passengers with ticketing issues, provide directions, and handle any problems or concerns that arise at stations. They also help manage the flow of passengers during busy times or disruptions.
- Staff members may also monitor the platforms and station areas to ensure passenger safety and security.

5. Security Personnel

- The Metro system has a security presence, though much of the security is handled through CCTV cameras and remote monitoring. Security personnel can be dispatched in case of emergencies, disturbances, or suspicious activity.
- Some security officers patrol Metro stations and trains to ensure safety, particularly late at night or during special events.

6. Emergency Response Teams

- In the event of technical failures, accidents, or other emergencies, specialized teams can respond quickly to deal with the issue. This could include Metro staff, external contractors, or collaboration with the city's emergency services.
- The Metro has procedures in place for evacuations, medical emergencies, and other crisis situations, which the control room staff and emergency teams manage.

## 1.6 Where are the Gaps?

- Public (and societal) perception and understanding of CAM should be ready for CAM services to be adopted at scale
- Clear systems for ensuring on-board rider safety must be in place

While great strides in the technical solutions for CAM vehicles have been made this has evidently not yet resulted in the easing of concern in the publics collective mind. Services such as Rivium have shown that an automated service can be successfully deployed, however, this is in a highly controlled route and run in an area which, while open to the general public, is not frequented by the general public.

There is a clear level of discomfort from the public with the idea that the technology is safe, but this has been shown to improve with exposure. One of the key findings from the Great Self Driving Exploration is how attitudes changed in a positive way towards the technology with experience. This suggests that as services are developed and deployed significant public engagement will be required to encourage adoption. At present the factor of the vehicle operating at high speed along a motorway is not sufficiently well understood as there are no existing equivalent deployments to reference. While motorway travel is traditionally the safest form of road transport due to separation of vehicles from vulnerable road users and opposing traffic, the impact of an incident is commonly greater due to increased speeds.

It is critical that safety is considered wholistically to enable the successful deployment scalability of CAM services from a user perspective. This includes a robust national-level regulatory framework for assuring safety of vehicles and infrastructure for the intended operation, a corresponding operational safety assurance that considers the nuanced and specific case of an individual deployment (or the Target Operational Domain [TOD]) and effective provisions that ensure passenger safety and comfort. An effective feasibility study should therefore implement a framework that can address these challenges and identify possible gaps or risks that arise.

Recommended steps to make users feel comfortable with future CAM services are:

- Exposure to the shuttles with a safety driver and/or bus captain to show that the service is being monitored.
- Remove the safety driver if one is in place to build confidence in the system's ability to do the driving task safely.
- Run operations of floating bus captain where some journeys would be completed without a member of staff present.
- Reduce the number of floating bus captains and increase the number of unmanned journeys to take place.

For each of the stages above close monitoring of customer comfort levels will be needed to ensure the removal of staff is not done too early.

# Chapter 2 – System Safety

*The vehicle / service must be capable to operate within the static, dynamic, and environmental conditions of the route with risk as low as reasonably practicable.*

---

*Pillar:* *Safe*

*Focus:* *System*

***"The vehicle / service must be capable to operate within the static, dynamic, and environmental conditions of the route with risk as low as reasonably practicable."***

*As a fundamental part of the development of CAM services, the system must be capable of safely operating in its environment, consisting of static attributes (i.e. physical infrastructure), environmental attributes (i.e. weather) and dynamic attributes (i.e. other road vehicles). Establishing a sufficient level of confidence requires effective systems engineering analysis between the vehicle system and infrastructure realised through an Operational Design Domain (ODD) taxonomy. Defining the environment as an ODD taxonomy will enable hazard and scenario analysis of the route, the exploration of mitigations between vehicle and infrastructure, and the identification of current gaps that would require further investment to enable the services safe operation.*

## Where we are today

This chapter will discuss the safety analysis undertaken to ensure the safe vehicle operation in the operational design domain (ODD).

## 2.1 Route Analysis

### 2.1.1 Introduction

The first aim was to deliver a systems-engineering understanding of the route, to underpin subsequent safety requirements analysis in vehicle safeguards and infrastructure design. This initial work was led by WMG with tasks owned by Syselek, National Highways and SMBC.

### 2.1.2 Systems engineering approach

The work followed the structure of undertaking an Operational Design Domain (ODD) analysis of the route, using this analysis to underpin a safety and hazard assessment of the route, leading to safety recommendations in subsequent activity in the study, along with wider recommendations for route analysis by future feasibility studies. Before detailing the study findings, we will define the key frameworks of ODD and safety used followed by a detailed breakdown of data flow.

An ODD specifies the operating conditions under which a CAM system is designed to operate, they include the scenery elements (such as junctions, road structures), the environmental conditions (such as rainfall, lighting conditions), and the dynamic elements (such as macroscopic traffic conditions, maximum designed speed of the system). The high-level ODD structure is shown in Figure 13.

When the evaluation process of the CAM system to be deployed on the route is decoupled from the system's ODD, the results carry little meaning towards its safety operation. For example, if a system is designed to operate only for suburban driving but is predominantly driven on motorways roads as part of its safety assurance, then these results will not guarantee the system is safe for motorway driving since the operational conditions are totally different. The ODD methodology enables us to take a systematic approach to aligning the domain into which the CAM will operate and the capability of that CAM technology. This approach has wide acceptance within the industry. One of the project partners, WMG, are lead technical author on the ODD standard ISO 34503. The ODD also underpins capability to undertake a systematic safety and hazard analysis.

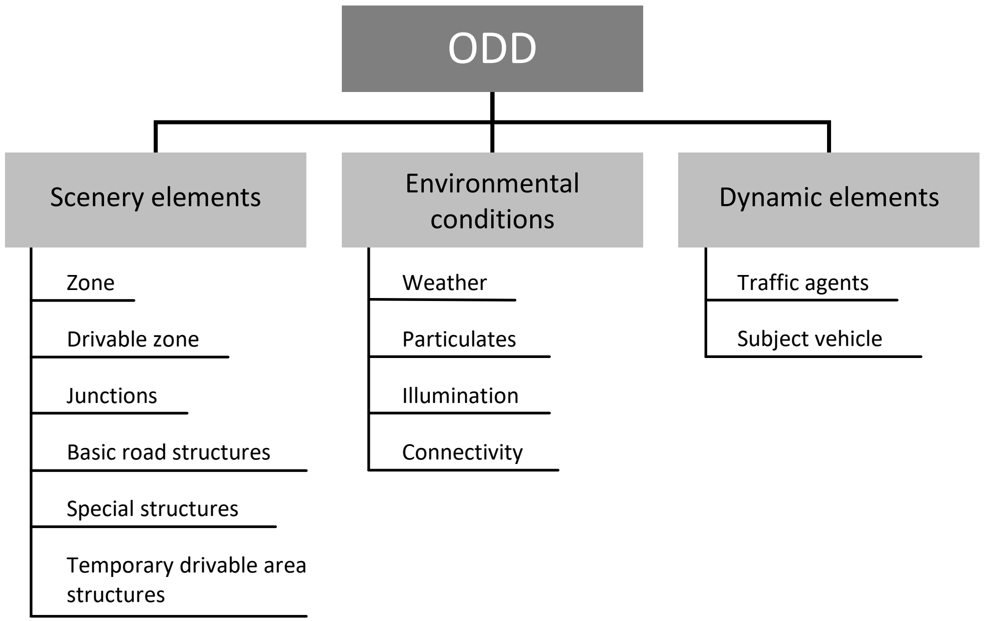



*Figure 13: ODD top-level Taxonomy taken from the ISO 34503 standard.*

The role of the ODD definition in underpinning subsequent work packages is illustrated in Figure 14. We began by defining the ODD, which enabled a high-level hazard analysis. A high-level analysis has been undertaken as this is a feasibility study with the objective of highlighting and understanding the major hazards. A more detailed analysis would follow if the feasibility study was deemed applicable for further development. Together this ODD taxonomy and hazard analysis allows us to consider mitigations at a vehicle level. Finally, this has underpinned infrastructure analysis of 1) any remaining essential mitigations that the vehicle has been unable to sufficiently address, and 2) optional infrastructure requirements that may support the proposed deployment.

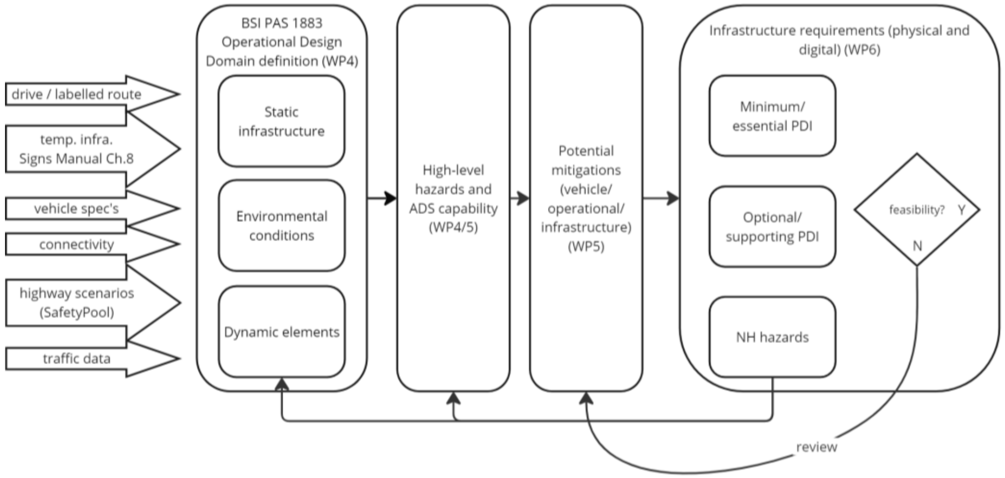



*Figure 14: Feasibility data flow from route definition (WP4) to vehicle (WP5) to infrastructure requirements (WP6)*

The report will now provide a narrative on how the detailed ODD taxonomy was generated.

### 2.1.3 Route ODD taxonomy

The static ODD tagging work was undertaken by Syselek with guidance and review from WMG, National Highways and SMBC. Using an open-source street view mapping tool each step of the route was analysed against the ISO 34503 ODD standard. A subsequent drive through was undertaken capturing video footage of the infrastructure from forward-facing and rear-facing dashcams. This footage was used to refine the route infrastructure analysis (the footage cannot be shared externally due to privacy requirements related to personally identifiable information).

#### 2.1.3.1 Static elements

In total 124 static ODD attributes were reviewed with 108 found to be applicable to the study route. For all attributes found to be applicable to the study the number of instances that attribute occurred was recorded along with an example image of the attribute. Figure 17 provides an example of one data point in this analysis.

Figure 15: Illustration of complex ODD definitions

Figure 16: Illustration of friction between the route and existing road markings.

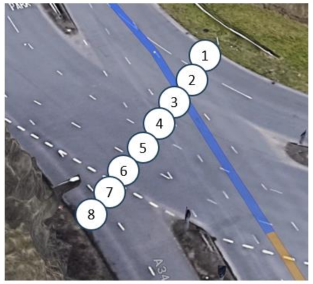
| BSI PAS 1883 Reference | BSI PAS 1883 ODD Term | BRAVO Applicable? | Evidence | No. BRAVO Instances | Preliminary Hazard Analysis |
|---|---|---|---|---|---|
| 5.2.3.4.d | Number of lanes | Yes |  | Up to 8 | Camera confusion when lane following. Complex Other vehicles using other lanes being passed or passing. Other vehicles crossing vehicle path with potential of collision |

Figure 17: Example data point from the route's ODD static analysis.

The ODD static analysis illustrated the difficultly that emerges when undertaking real-world safety analysis. Two specific points to raise are 1) where temporary infrastructure, general wear and tear, and natural elements make ODD definitions complex shown in Figure 15 and 2) where existing road markings and rules of the road may contradict the route as it has been defined shown in Figure 16.

### 2.1.3.2 Temporary road infrastructure

As we have seen in Figure 15, particular area of focus is temporary road structures. The M42 is currently undergoing significant works and contains a number of temporary road structures, and the ISO 34503 ODD definition includes a section on temporary road structures. Given this complexity we undertook a separate task on Temporary Road infrastructure ODD definition.

We undertook a review of the Traffic Signs Manual, Chapter 8 "Traffic Safety Measures and Signs for Road Works and Temporary Situations", Parts 1 Design and 2 Operations (2009), and Part 3 Update (2020). These documents are substantial and in order to constrain the challenge within the scope and resource of the project we selected examples for analysis that aligned with the ODD definition to provide vehicle developers with a selection of high level examples of temporary infrastructure that might be encountered on the proposed route, illustrated in Figure 18.

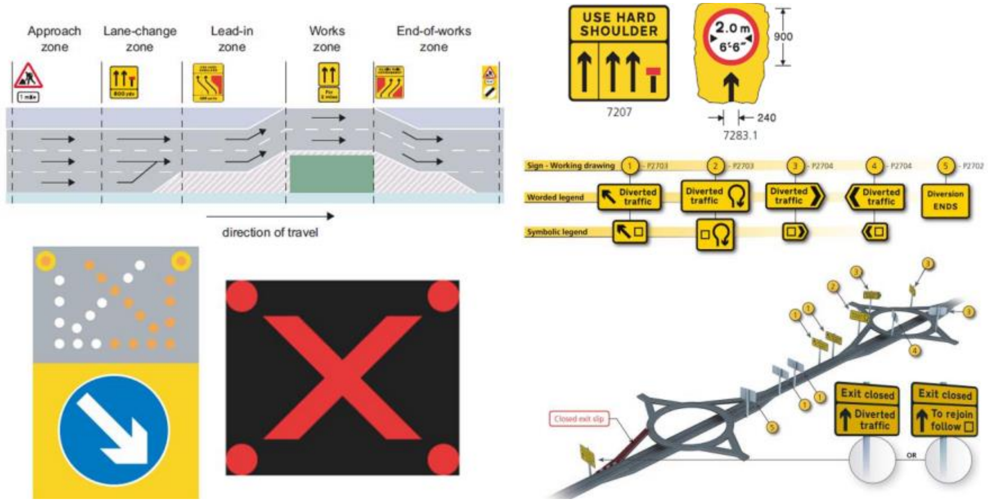


Figure 18: Temporary Infrastructure analysis of the Traffic Signs Manual

2.1.3.3 Dynamic elements

The Safety Pool Scenario Database (SPSD) is a secure repository of test scenarios for Connected and Automated Vehicle (CAV) technologies. Developed to support the development, verification, and validation of CAV technologies, it provides a diverse set of curated driving scenarios for testing and certifying Automated Driving Systems (ADS) and Advanced Driver Assistance Systems (ADAS). Industry, academia, and governments can leverage these scenarios to create policy guidelines and validate new ADAS innovations and autonomous driving platforms. The database is powered by WMG, University of Warwick (project partner), and it organizes scenarios based on specific Operational Design Domains (ODDs) following industry standards. This enables us to undertake a scenario analysis of the route based on our ODD taxonomy.

Scenarios held on the databased have been generated from a wide range of ‘database’ and ‘knowledge based’ sources such as Stats-19, safety analysis and Systems Theoretical Process Analysis (STPA), and standards and regulations.


*Figure 19: Example SafetyPool™ Scenario database dynamic scenario in Scenario Description Language level 2, level 1 and visualisation (please note SDL 1 and 2 are right hand drive scenarios, and the visualisation has been converted to represent left hand drive through the relevant toolchain).*

An initial input of the full route ODD returned over 34,000 test scenarios. This is unsurprising given the diversity of the route that includes the motorway, A-roads, junctions and roundabouts. Further many of these scenarios relate to the static ODD attributes. As such a targeted search was undertaken to select a manageable subsection of scenarios that would a) Enable the project analysis to expand to dynamic actors, b) Would enable an initial hazard analysis of dynamic actors on the route, and c) Would be manageable in the context of a feasibility study. Given the motorway element of this study is unique we focused our attention on motorway-based scenarios.

A test suite of 10 test scenarios were refined and stored on the SafetyPool™ database and extracted in Scenario Description Language (SDL) format (codified description) and in MP4 (simulation). The 10 scenarios are listed below and an image of an example SDL and simulated representation of on scenario provided in Figure 19:

1. Stopped in lane obstruction. Ego stop
2. Stopped in lane obstruction. Ego lane change
3. Following. Stopped in lane obstruction. Following vehicle lane change. Ego stop
4. Cut in. Ego slow
5. Rearend shunt on ego
6. Following. Stops in lane. Ego stop
7. Stopped in lane queue. Ego stop
8. Following. Stopped in lane queue. Following vehicle lane change. Ego stop
9. Following. Following vehicle swerves
10. Stopped in lane obstruction. Further road user in middle lane. Ego passing in free space

From here scenarios were extracted in SDL level 1 and level 2, along with visualisations. SDL 1 presents the scenario in a natural language format that is relatable for policy makers, the public and other key stakeholders. SDL 2 makes the same scenario available in a codified structure making the scenario available for execution in simulation and other system-engineering environments. This SDL 2 also enables us to employ SafetyPool™ tool chains and extract a simulated representation of the visualisation. All three file formats for one of the scenarios ‘’Partially Blocking Target’ is show in Figure 19

Taking this approach has enabled us to undertake a hazard analysis which is not confined to engineers. The visualisation and SDL level 1 representations of the scenario enable us to include all stakeholders in the processes. In the presented example we can see a stationary vehicle with the ego (AV) vehicle approaching it. This presents a range of options for the ego vehicle for example stopping, pulling out, impact on traffic flow etc. As such the selection of scenarios stimulate a sample analysis of scenarios that allowed us to undertake a more complete analysis of the AV vehicle's ability to handle scenarios that are likely to occur along the route The scenarios will be handed to WP5 to stimulate such analysis.

In addition, traffic flow data was considered. National Highways have shared their traffic intensity measurements for March 2019 and February 2017 (all days in the month) as representative worst case pre-COVID traffic levels. The data covers J4-5 and J5-6 of the M42, both northbound and southbound directions. The data details are minute-by-minute recordings for average traffic speed (mph), traffic volume (vehicles per minute), and average journey time between junctions (minutes). From this data, average traffic spacing is also determined, which will inform OEM project partners' assessment of their AV capacity to complete traffic merges on ramps. While it is recognised that further analysis of this data could be undertaken i.e. identifying average and extreme space distribution ranges, for the purpose of this study average spacing distribution makes it possible to evaluate initial vehicle capability and performance.

2.1.3.4 Environmental elements

The relationship between environmental ODD attributes, systems safety and in life operational safety is both critical to the operation of a service of this type and highly complex to define and assure for, along with monitoring on an ongoing basis. This is as a result of wide-ranging weather conditions, the increasing prevalence of extreme weather conditions, and the intricate data-points involved. Within the context of CAM this is known as 'ODD awareness' i.e. the ability of a vehicle (and often its stakeholders i.e. road operators) to define when environmental conditions move outside of the vehicle capability. The project partners are involved in technical projects that seek to advance this capability, such as the MODDEST project working with the Met Office, National Physical Laboratory and Local Authorities to define the available data and the degree of close-to-real time availability of that data that is needed to have sufficient levels of confidence in ODD awareness, and the TM4CAD project with the Confederation of European Directors of Roads to understand the role of road operators in defining and monitoring the ODD conditions.

However, in the context of this feasibility study a detailed systems-safety analysis of behaviour in different environmental conditions is out of scope (such an analysis would come later in the processes). Our aim within this feasibility is to broadly understand the impact changing environmental conditions would have on the operation of the defined service, such that those broad implications i.e. estimate of none-operational days per year, would have on the wider feasibility analysis. A much more detailed ODD awareness assessment would be required at outline stage and beyond.

A key question of importance at this stage is understanding what, if any, impact adverse weather would have on the ability of the service to operate. In order to understand this OEM project partners (Aurrigo, ZF) have shared their specifications for operation in several environmental conditions. These cover the following:

- Temperature operating range
- Visibility (relates to smoke/ smog/ fog/ airborne particles)
- Rain
- Snow
- Humidity

Actual environmental conditions outside of these specifications would mean vehicle operations would need to temporarily halt. Estimating these lost days is a critical data point required for the wider feasibility study.

### 2.1.4 Further data

Full data for all the analysis discussed in this section is available in the following documents:

Static element: The identification of all (181) relevant ODD attributes within the route: full document 'BRAVO_ODD_Taggged_Syselek_Aurrigo_ZF''

Static element: An analysis of the National Highways temporary infrastructure manual: full report 'BRAVO_ODD_Scenery_tempuary_infasturtcure_V1.0'

Dynamic element: An ODD based analysis of the SafetyPool™ scenario database resulting in a suit of Bravo test scenarios in Scenario Description Language 1, 2 and in visualisation. Nice test scenarios, each in SDL1, SDL2, and MP4.

Dynamic element: National Highways sample traffic data: full report 'National _Highways_M42_J4-6_Pre_Covid_Data'

Environmental elements: OEM ODD environmental ranges: full report within WP5

Documentation of all the above items are available upon request, subject to specific data sharing agreements and limitations.

## 2.2 Vehicle & System

### 2.2.1 Introduction

Following this ODD analysis the feasibility study applied these outcomes to progress to identify the vehicle-related considerations of operations on the proposed route and expected service which in turn will inform any infrastructure change requirements to be considered. The work was led by Syselek, with input from ZF and Aurrigo.

### 2.2.2 AV capability for proposed route

This task involved a review of the route physical infrastructure analysis, by the AV developers ZF and Aurrigo, to identify static and temporary infrastructure features that may pose hazards to an AV, or may not be compatible with AV operations. The detailed review is captured in the report "Route ODD Gap Analysis", dated 04/06/2024, with important content repeated here. References align with BSI PAS 1883 numbering.

#### 2.2.2.1 Connectivity

Loss of connectivity by an AV will lead to execution of a Minimum Risk Manoeuvre.

The connectivity requirements including technology solution (5.9GHz C-ITS / 4G LTE / 5G), signal strength, or bandwidth, are not yet determined. Furthermore, connectivity service measurements for the current route from existing mobile networks are not yet available.

Therefore, expectations on National Highways are unclear.

#### 2.2.2.2 Vehicle speed

AV developers ZF and Aurrigo have not yet developed and tested AV operations at UK motorway speeds.

#### 2.2.2.3 Marker Correction. Paint Over

Changes to any infrastructure, including repainting of road markings, will require edits to the ODD definition used by AV developers and intended path programmed to AVs. This is a key consideration of temporary infrastructure changes, such as road works.

#### 2.2.2.4 In-vehicle messaging

AV traffic sign detection is not robust. All signage should be provided digitally through in-vehicle messaging and integrated with National Highways' traffic management application.

#### 2.2.2.5 Gantry signage

As above (2.2.2.4 In-vehicle messaging).

#### 2.2.2.6 Cracks

The current AV products from AV developers ZF and Aurrigo are capable to operate with road defects up to 5cm size, but no larger. They do not have any road defect detection capability. Therefore, National Highways operations teams will be responsible to inspect and maintain road conditions and clear debris.

### 2.2.3 AV capability for expected environmental conditions

This task involves definition by the AV developers ZF and Aurrigo of the worst-case environmental conditions under which AV operation can be permitted based on existing test results at low speeds. The environmental conditions specifications from AV developers ZF and Aurrigo are:

- Temperature operating range [-10 to +45]°C
- Visibility [0 to 100]m
- Rain [0 to 50] mm/h
- Standing water depth [unknown]
- Snow [0 to10]mm/ h
- Snow thickness [unknown]
- Ice thickness [unknown]
- Humidity [0 to 99]%
- Salt [unknown]
- Visibility due to smoke / smog / fog / airborne particles (sand/dust/insects) [unknown]

The likelihood of local environmental conditions at the route exceeding these specifications and initiating a temporary halt to the service is unknown. Furthermore, secondary conditions, such as road spray from passing vehicles in standing water, have not been assessed, and are highly likely to impact the capability of the AV's.

Comparison with statistical records from the Met Office could help determine the frequency of temporary halts to service, and therefore predict the average number of days lost per year.

Note, although specified under environmental conditions in BSI PAS 1883, Connectivity has been addressed in this study under Physical and Digital Infrastructure.

### 2.2.4 AV capability for highway operation scenarios

This task involved a review of the National Highways sample traffic data: full report 'National _Highways_M42_J4-6_Pre_Covid_Data', to identify the dynamic traffic conditions encountered by AVs on the route, and to review the capability of AVs from developers ZF and Aurrigo to operate in these traffic conditions.

#### 2.2.4.1 Traffic speed

Figure 20 illustrates the average traffic speed between M42 J4-6 (weekdays only), both northbound and southbound. This indicates a highest frequency average speed around 100kph.

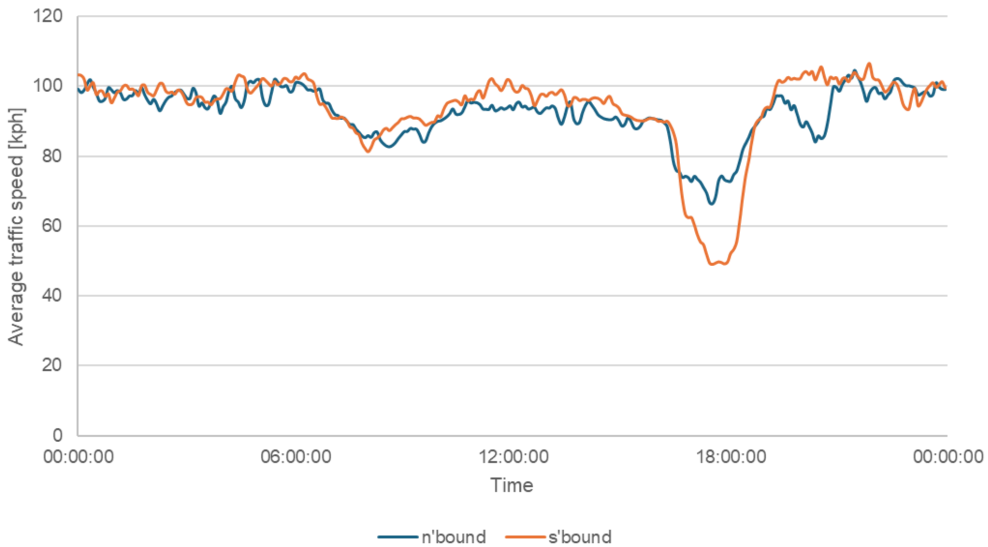



*Figure 20: M42 average traffic speed (weekdays only)*

The average speed dips during morning rush hour to around 85kph and during evening rush hour to around 70kph northbound and 50kph southbound. Table 2 provides the minimum and maximum average speeds.

*Table 2: minimum and maximum M42 average traffic speed*

| | n'bound | s'bound |
|---|---|---|
| **Min [kph]** | 66 | 49 |
| **Max [kph]** | 105 | 107 |

As already established, although slower than UK motorway speed limits, AV developers ZF and Aurrigo have not yet developed and tested AV operations at these speeds.

#### 2.2.4.2 Traffic volume

Figure 21 illustrates the average traffic volume between M42 J4-6 (weekdays only), both northbound and southbound, by link (J4-5, J5-6). This indicates pronounced peaks during morning and evening rush hours, and highest average volume around 100vpm (0.6spv).

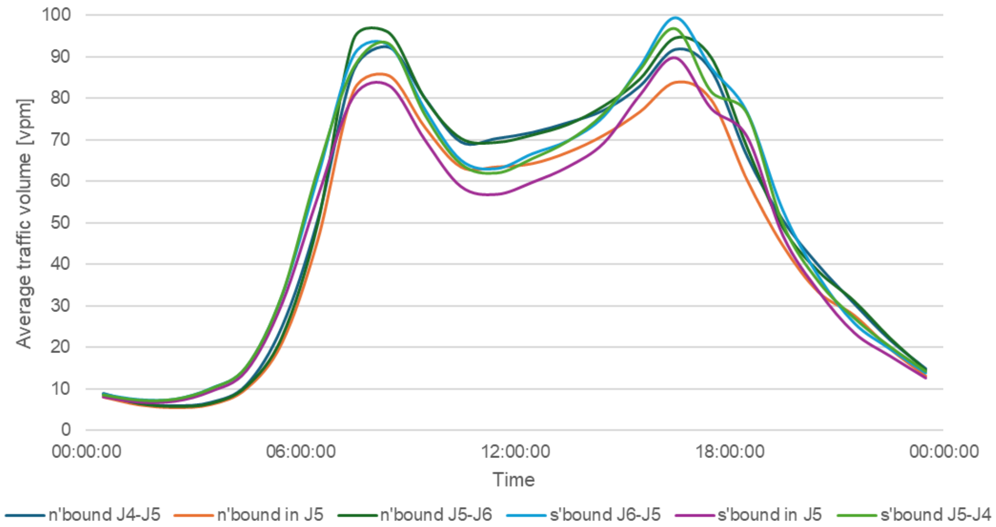



*Figure 21: M42 average traffic volume each hour (weekdays only)*

The data reports average traffic volume per link (J4-5, J5-6), allowing an estimate of the average traffic volume leaving and joining the M42 at J5. This peaks during morning rush hour to around 10vpm both northbound and southbound.

#### 2.2.4.3 Traffic spacing

The worst case for traffic spacing occurs during morning rush hour. With average volume around 90vpm, there is an average 0.67sec between vehicles across all lanes. With average speed around 90kph, this gives an average distance between vehicles around 16.75m across all lanes. With dynamic hard shoulder during rush hour providing 4 lanes running, this gives an average distance between vehicles in lane around 67m.

This is a crude estimation, but sufficient to identify where issues are likely to exist for the purposes of the feasibility study. This traffic spacing has implications for AVs joining the carriageway. There are no proven vehicle-based solutions for an AV merging from on-ramp to the main carriageway with this traffic speed and spacing. Infrastructure-based solutions will be required.

### 2.2.5 Outcome

This phase of the study undertook an analysis of AV capabilities, (i) to operate the proposed route, (ii) to operate in the expected environmental conditions, and (iii) to manage interactions with other road users, has identified the challenges undermining this deployment in its current plan. The areas identified for further investigation and design improvements, and summarised in this chapter, are currently not compatible with AV operations on the route.

## 2.3 Physical security

Several physical security risks are unique to automated vehicles. These include any malicious intent, changes to road infrastructure, objects, or behaviour of other road users, etc. This is a large area and relatively unresearched for automated vehicle public deployment.

### 2.3.1 Interference

In San Francisco there are relatively large deployments of automated vehicles in the public urban environment (c.100 by Waymo and c.100 by Cruise). These have led to negative behaviour from some other road users who perceive automated vehicles to be unsafe for public deployment. These road users have identified weaknesses in automated vehicle perception systems, which can be exploited through simple actions, to leave individual automated vehicles incapacitated. Further forms of low-level interference concerning automated vehicle perception systems vulnerabilities in object detection, lane detection, etc., by manipulation of infrastructure.

It is important to clarify at this point however that California's regulations are different to the UK. In California AV deployments are based on self-certification. The UK's legislative approach aims to ensure safe and secure deployments with rigorous approval, authorisation and in-use monitoring process. In a world where UK CAM services are delivered under a high safety threshold, a main challenge for a future UK service could be to manage public perceptions, and ensure the public is aware of the safety and security of CAM services in a bid to mitigate hostile public behaviour. Public education of operational safety will be important to build public trust and mitigate the cause of such low-level interference.

### 2.3.2 Risk impact

The risk and impact of malicious physical damage to automated vehicles is potentially greater than to human driven vehicles. The high value of perception system sensors, and their prominent/exposed position on automated vehicles, raises the potential of malicious damage or theft. Any occurrence will likely result in much higher cost repairs than human driven vehicles would incur, raising insurance costs. The impact of incapacitated vehicles on a public passenger transport service, particularly users relying on the service, could be severe.

### 2.3.3 Risk deterrent and protection

Current automated vehicles have relatively low resilience to physical attack. Malicious behaviour towards human driven vehicles is deterred by the witness account that a human driver can provide investigating authorities. However, automated vehicles' perception systems are currently designed with a field of view to cover relevant infrastructure and the normal behaviour of other road users. It is not designed to track other suspicious actors. Once incapacitated through disruption of the perception system, an automated vehicle has no recourse.

Public engagement will be important to build a sense of public ownership and care. (See also 1.1.1)

Further work is recommended to address this physical security threat, incorporating examination of existing mass transit solutions; CCTV footage of incidents; edge case testing; integration with police forces

## 2.4 Digital security

Current best practices in automated vehicle technology provide relatively high resilience to digital security threats since this is a well-researched area. Digital security can be described by the CIA triad illustrated in Figure 22.

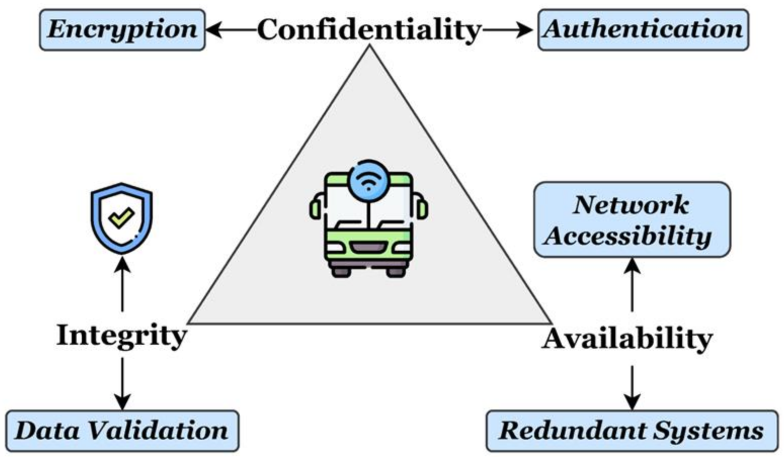



*Figure 22 The Confidentiality-Integrity-Availability (CIA) Triad*

CCAV funded cybersecurity research, such as ResiCAV, has determined the UK's digital security engineering approach to ensure digital resilience of automated vehicles through high level assessment and mitigation requirements (although without detailed prescription of specific cybersecurity solutions). A formal method to establish legal arguments that the digital vulnerabilities of an automated vehicle are reduced ALARP now exists.

Digital security includes an expectation to match or surpass the digital security of conventional human-driven vehicles, as defined by UNECE regulations (UNECE R155 and ISO/SAE 21434). Type approval expectations are also under review and are expected to be updated to allow continuous monitoring of emergent threats from in-life updates. This area will develop further over the coming years, but manufacturers, operators, and TfWM/ SMBC can already plan based on the CIA triad.

**Confidentiality**

This concerns the prevention of unauthorised data access. Malicious misappropriation and exploitation of sensitive information could compromise safe automated vehicle operation.

**Integrity**

This concerns the detection of unauthorised access and prevention of unsanctioned data modification to preserve data authenticity, accuracy, and consistency over the life cycle, critical to maintaining trustworthiness of data.

**Availability**

The automated vehicle's effective operation depends upon the consistent availability of necessary data, which if compromised could present safety implications.

In addition to the CIA triangle, digital security attributes include privacy, authenticity, accountability, non-repudiation, and reliability. Consideration of these characteristics are part of an integrated security framework to protect automated vehicles from possible threats.

Prior to any future deployment extensive consultation with CAM cyber security providers would be undertaken.

## 2.5 Gap analysis: Vehicle system

Following the analysis laid down in this chapter a number of 'gap's' have been identified as requiring deeper analysis should the feasibility findings be taken forward. These have been categorised as 'Gateways condition, Amber or Red.

### 2.5.1 Gateway condition:

- The system vehicle will be subject to all national and international level regulatory approvals
- An enhanced safety risk assessment and scenario-based testing would be needed following feasibility approval.

### 2.5.2 Amber at feasibility stage

- The system vehicle can safely handle or adequately mitigate most initial scenarios and hazards identified. Several of the unmanaged junctions were identified as scenarios and hazards that the AVs are not capable to operate through without infrastructure or operational changes. The implications of this are further detailed in the next point and which would inform a further hazard and scenario assessment if implemented.

### 2.5.3 Amber/ Red at feasibility stage

- The vehicle can't negotiate non-signalised unmanaged junctions (including slip roads) which may be addressed through limited investment whether that be slip road modification or detectors (see infrastructure section). If the slip road is modified, then it would have some impact on network performance as it could not be a running lane for the main carriageway until after the junction – there is also ramp metering at these sites which could also be affected and impact on network performance. The identification of these point informed the infrastructure assessment undertaken on the project, developed in the following chapter.

- If connectivity (cellular V2X) was to fail mid-route and sufficient connectivity were to become unavailable, one of the vehicles under test (ZF) would perform a minimum risk manoeuvre and come to a safe stop. A robust assessment of this gap would require “sufficient” connectivity to be determined in terms of available bandwidth (and signal strength) in relation to number of potential users. A more detailed (resource intensive) mapping of connectivity resilience across the route is needed, with a cross reference to vehicle capability and safety implications to establish if further digital (i.e. Cellular Roadside Units [RSU’s]) would be required.

# Chapter 3 – Infrastructure

*The vehicle/service must be capable to operate within the static, dynamic, and environmental conditions of the route with risk as low as reasonably practicable.*

*Pillar:*
*Affordable*

*Focus:*
*System*

*The vehicle/service must be capable to operate within the static, dynamic, and environmental conditions of the route with risk as low as reasonably practicable.*

*The safe and reliable behaviour of the system/service should require only minimum change or investment to existing infrastructure, where the service itself can fully absorb the cost and the change does not adversely impact current network performance and capacity. The aim of the infrastructure work is to deliver a detailed set of potential physical and digital infrastructure requirements for the route and the AV's running along it, together with an estimation of costs and possible funding models for the suggested infrastructure changes. WP6 is led by National Highways.*

## Where we are today

### 3.1 Approach

The infrastructure work is underpinned from the outputs of the ODD analysis of the route and the conceptual vehicle system specification for operation on the proposed route and expected service (Chapter 2). Figure 23 shows the links between the ODD analysis and infrastructure analysis. The input information sources (arrows on the left) have been used in the various analyses and assessments, and a feedback loop was in place between the project team members to enable continuous improvement in delivery.

A larger version of Figure 23 can be found in the section B.1 of the companion Appendix document.

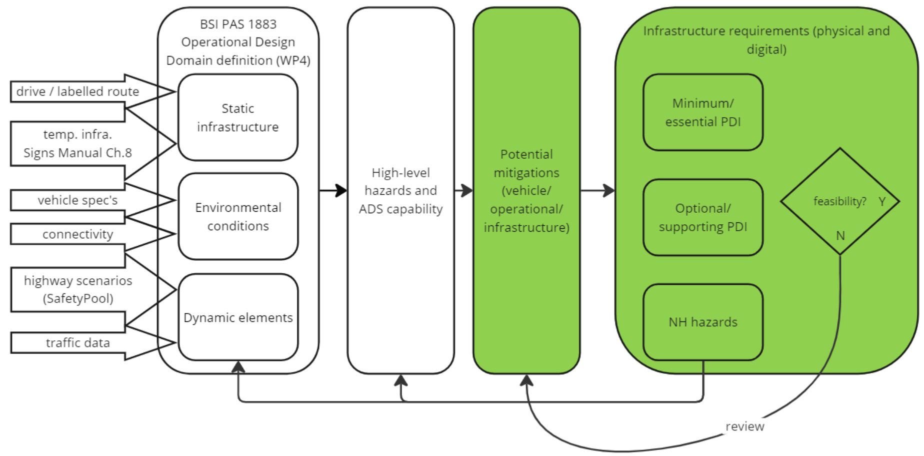



*Figure 23: ODD – Infrastructures analyses links*

From the route analysis and the conceptual vehicle system specification we have identified that there were three infrastructure related focus areas for further exploration within the study that would be essential for the service to operate on the proposed route:

1) Ability for the vehicle to interact safely with other road users and pedestrians
2) Ability for the vehicle to join and leave the motorway safely especially during high traffic volumes
3) Ability to have 100% connectivity along the route

For each focus area, the following approach has been undertaken to understand:

- *'Where we are?'* An assessment of existing physical and digital infrastructure along the proposed route
- *Where we need to be?* An assessment of potential solutions and future workstreams that would be required for the service to operate along the proposed route

Each focus area is based on assumptions that have been captured from Chapter 2 conceptual vehicle system specification (further details on these assumptions can be found in section 3.3). We recognise that not all infrastructure categories have been covered by this work and this is due to the infrastructure assessment being based on the conceptual vehicle system specification provided by the study. Alternative technology equipped vehicles have not been considered for this assessment so we recognise the recommendations outlined may not be suitable for other automated vehicles. Further work may be required if the vehicle system specification were to change, if an alternative technology equipped vehicle was to be used, or if there were a continuation of this study in the future.

Figure 24 shows the infrastructure categories highlighted in green that are within the scope of the study, and those in red that are out of scope. A larger version of Figure 24 is available in section B.2 of the companion Appendix document.

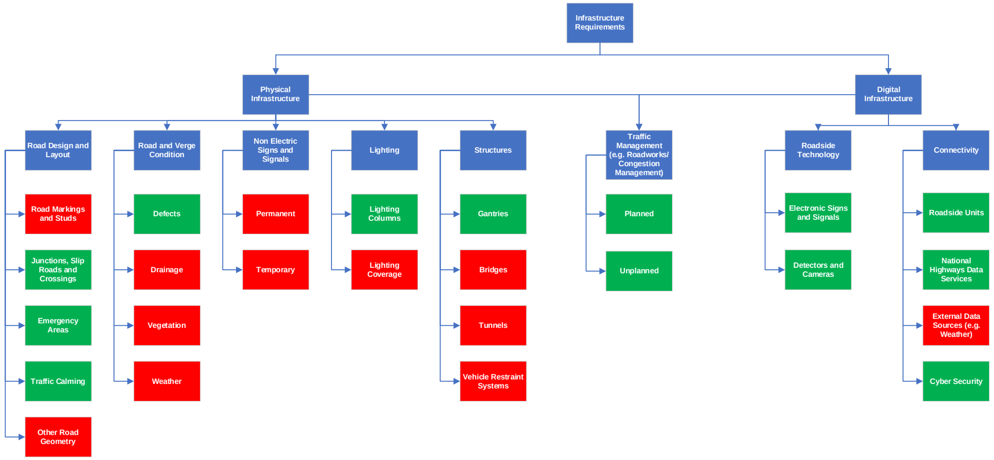



*Figure 24: Infrastructure categories*

## 3.2 The route

The route proposed for the study between the Hub and BVP is diverse, and includes private roads, A roads, roundabouts, motorway merges and motorways. We have considered the private roads of BVP, SMBC's local roads, and NH's strategic road network as part of this infrastructure assessment.

To give an understanding of the sheer scale of physical infrastructure assets on road networks e.g. barriers, signs, road markings, drainage, we have approximately 14,000 physical infrastructure assets between M42 J4-6, and this includes about 300 structures. Figure 25 shows how populated the SRN is with existing physical infrastructure.

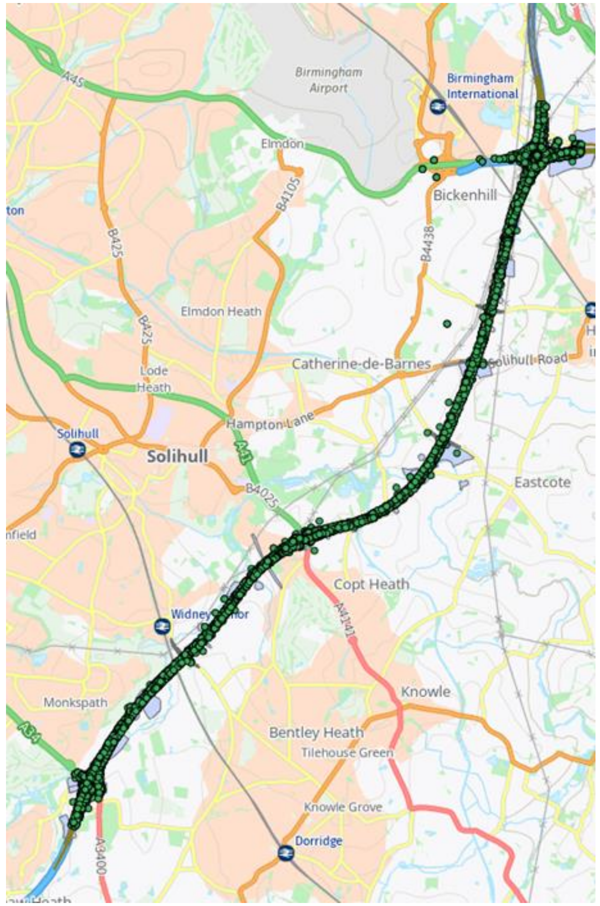



*Figure 25: Existing physical infrastructure assets M42 J4-6*

## 3.3 Assumptions and exclusions

The following assumptions and exclusions that are shown below have been formulated from the scope of this study and are informed by the work detailed in Chapter 2. The assumptions outline how we anticipate the vehicle should operate along the proposed route and have directly fed into the assessment of the three infrastructure focus areas identified. The exclusions summarise the limitations of the infrastructure assessment.

| No. | Assumption |
|---|---|
| 1 | There will be no onboard safety operator or supervisor, and the vehicle will not be able to be remotely operated. |
| 2 | The vehicle will follow a pre-defined path along the route, and will not follow road markings. |
| 3 | Any planned changed to the route e.g. roadworks would require an update to the ODD. |
| 4 | The vehicle will be able to dynamically change lanes if required. |
| 5 | The vehicle will be equipped with detection capability to safely interact with other road users and infrastructure. |
| 6 | The fail-safe minimum risk manoeuvre (MRM) for the vehicle is to come to a complete stop. |
| 7 | The vehicle will be able to travel up to 70mph, and will obey all applicable speed limits along the route. |
| 8 | The vehicle will not be able to negotiate non-signalised junctions and crossings. |
| 9 | The vehicle will be able to join and leave the motorway safely. |
| 10 | The service will require 100% connectivity along the route to operate, and the connectivity will be secure. |
| 11 | The vehicle will establish a full connection along the route before the service commences. |
| 12 | The vehicle will receive all communications digitally, it will not use a camera to read physical infrastructure e.g. signs and signals. |
| 13 | If connectivity was to fail mid-route, the vehicle would perform a MRM and come to a complete stop. |
| 14 | The route will not consist of any dedicated or segregated lanes for the service to operate. |
| 15 | The vehicle will be road legal (e.g. comply to government legislation). |

*Table 3 Operating Assumptions*

| No. | Exclusion |
|---|---|
| 1 | The conceptual vehicle specification defined for this project has been used to make this infrastructure assessment. Alternative technology equipped vehicles have not been considered so we recognise the recommendations outlined may not be suitable for other automated vehicles. |
| 2 | The infrastructure assessment is based on the outputs of WP4 and 5, so not all infrastructure categories have been covered in this work package. Further assessment of these categories may be required if the project proceeds past the current phase. |
| 3 | The infrastructure assessment does not include off road facilities such as vehicle storage, charging and control/ operational centre |

*Table 4 Exclusions*

## 3.4 Infrastructure focus area 1: Ability for the vehicle to interact safely with other road users and pedestrians.

CAM services may transform how road users travel, creating more integrated, reliable and safer journeys but it is vital that they interact safely with other road users and pedestrians when they operate.

### 3.4.1 Collision data on M42 J4-6

STATS19 is a dataset containing collision and casualty information, it contains data on incidents across Great Britain that involve a vehicle, result in an injury, occur on a public highway and are reported to the police within 30 days.

Between 2011 and 2021, there was 193 reported collisions on the M42 J4-6. The severity of accidents saw 178 slight, 13 serious, and 2 fatal accidents within the time period. The location of the accidents was that 12 occurred at roundabouts, 19 on slip roads, 156 on the main carriageway, and 6 unspecified, and these can be seen in Figure 26. No details are provided within the data set on how or why the collisions happened.

For further work beyond this study, it would be beneficial to work with external stakeholders to see if further insight can be gained into the reasons behind the collisions. This additional understanding would be valuable for the development of a safety case.

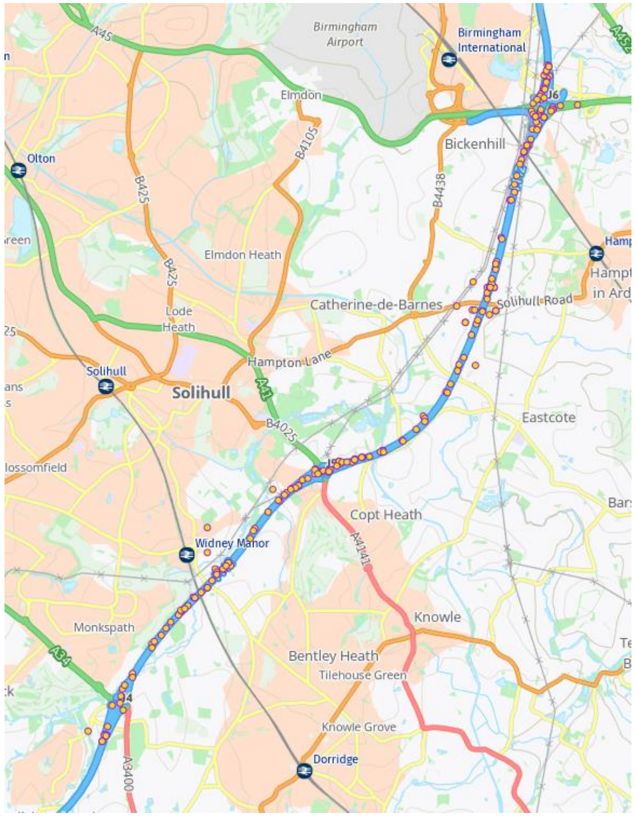



*Figure 26: STATS19 data for M42 J4-6*

## 3.4.2 Where we are, and where we need to be?

### 3.4.2.1 Dedicated and/ or segregated lane

| No. | Assumption |
|---|---|
| 14 | The route will not consist of any dedicated or segregated lanes for the service to operate. |

Traffic congestion and poor journey reliability are a regular occurrence between M42 J4-6. Having almost reached capacity, this part of the motorway network has become a bottleneck, causing subsequent delays across the wider road network. Figure 27 shows the average traffic speed between M42 J4-6 (weekdays only), both northbound and southbound. It indicates a highest average speed around 100 kilometres per hour (kph). The morning rush hour drops to around 85kph, and the evening rush hour drops further to around 30kph northbound and 40kph southbound.

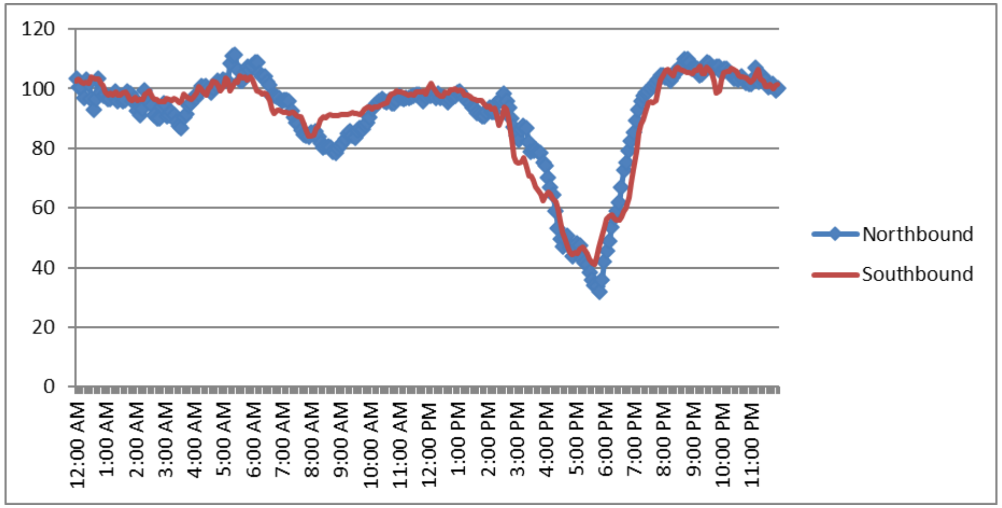



*Figure 27: M42 average traffic speed (weekdays)*

The M42 J4-6 has a dynamic hard shoulder, where the hard shoulder is turned on and off as a traffic lane in response to traffic flow. Traffic congestion is still a problem so a new junction (5a) on the M42 and a new 2.5km dual carriageway link road (A4545) is being built to increase capacity and improve access to the Hub. The benefits of the new junction and road will not be fully realised until they are open to traffic.

The proposed route along the M42 would mean the vehicle must integrate with traffic, as it would not be feasible to provide a dedicated or segregated lane for the service to operate. There is a lack of capacity across the wider road network (motorways, a-roads and local roads), and large investment would be required to create or add dedicated road lanes.

It may be beneficial to consider other routes for a CAM service and explore the possibility of segregated lanes on less strategic and congested roads. This could show if a hybrid approach of some segregation of lanes and some full integration with other traffic could be deployed where highly automated vehicles are used.

3.4.2.2 Junctions, crossings and signals

| No. | Assumption |
|---|---|
| 3 | Any planned changed to the route e.g. roadworks would require an update to the ODD. |
| 4 | The vehicle will be able to dynamically change lanes if required. |
| 5 | The vehicle will be equipped with detection capability to safely interact with other road users and infrastructure. |
| 8 | The vehicle will not be able to negotiate non-signalised junctions and crossings. |
| 12 | The vehicle will receive all communications digitally, it will not use a camera to read physical infrastructure e.g. signs and signals. |

The route includes roundabouts, road merges, ramp meters, a T junction and pedestrian crossings as shown in Figure 28, Figure 29, Figure 30 and Figure 31. There are currently fourteen junctions on the route of which five are signalised. There are also eleven pedestrian crossings of which four are signalised and these are located near Fore Business Park. The vehicle must be able to safely negotiate all these junctions and crossings in order for the service to be viable. As the conceptual vehicle specification does not have the ability to read any traffic lights/signals on the route and it cannot negotiate any non-signalised junctions or crossings an alternative solution for any signal information to be available digitally would be required.


Figure 28: Junctions and Crossings on BRAVO Route (BVP)

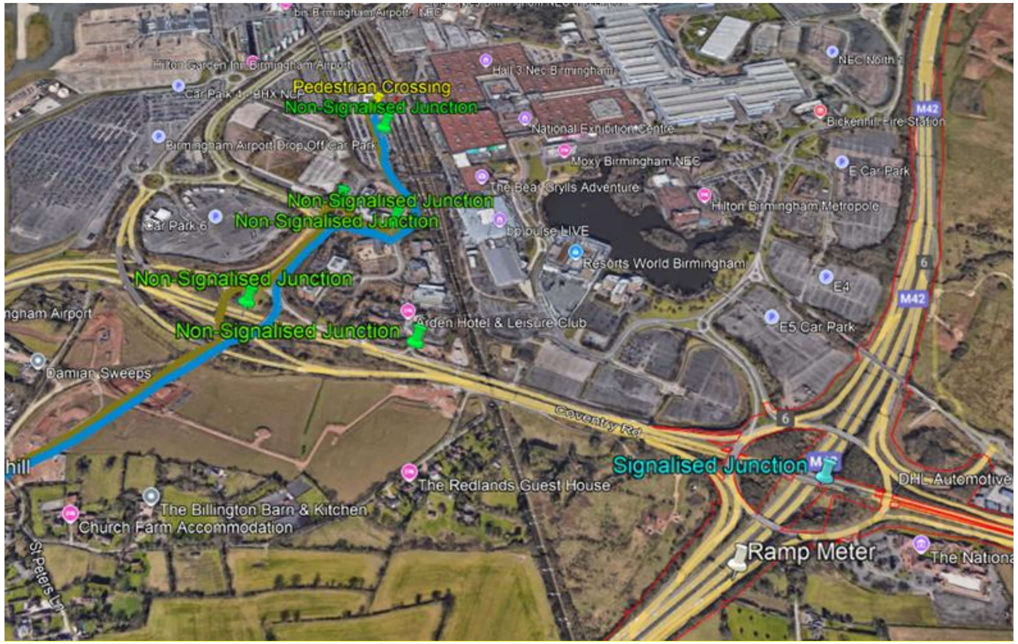



Figure 29: Junctions and Crossings on BRAVO Route (BHI)


Figure 30: Example of BVP Zebra Crossing


*Figure 31: Monkspath Interchange*

A potential solution for this study route would be to install connected traffic lights/signals to all junctions, crossings, and ramp meters along the route. This would involve introducing new connected traffic signals where none are currently installed and replacing or upgrading existing traffic lights with connected technology. Pedestrian crossings would also need to be replaced with puffin crossings of which the traffic lights would also be connected. This would allow the vehicle to communicate directly with the traffic signals in order to safely navigate the route and prevent possible incidents with other road users and pedestrians.

Further studies should explore the possibility of installing connected traffic lights/signals along the route. To determine the viability of installing these, consideration would need to be given to site specific requirements, and an impact analysis of the effect additional signals may have on existing traffic flows and pedestrian behaviour. The installation of connected traffic lights/signals would be dependent on being safety critical for service operation.

#### 3.4.2.3 Minimum risk manoeuvres

| No. | Assumption |
|---|---|
| 1 | There will be no onboard safety operator or supervisor, and the vehicle will not be able to be remotely operated. |
| 6 | The fail-safe MRM for the vehicle is to come to a complete stop. |
| 13 | If connectivity was to fail mid-route, the vehicle would perform an MRM and come to complete stop. |

The current fail-safe MRM for the vehicle is to come to a complete stop. This is likely to be acceptable for the non-motorway section of the route but would not be acceptable or safe in a live traffic lane on the motorway. This could be somewhat mitigated by ensuring the vehicle moves to the left when completing an MRM on motorways with a hard shoulder that are not being used as a running lane.

However, the proposed route along the M42 has a dynamic hard shoulder where the hard shoulder is turned on and off as a traffic lane in response to traffic flow. When the hard shoulder is opened as a running lane the vehicle in this instance would still stop in a live lane, even if it moved to the left. The MRM could lead to secondary incidents and increased congestion. Therefore, if an MRM occurred on the M42, it would be necessary to close the dynamic hard shoulder and apply relevant traffic management. This scenario would worsen traffic flow and reduce capacity as the hard shoulder running lane would become unavailable.

A potential safer solution would be for the vehicle's MRM to stop safely in an emergency area. Figure 32 shows the location of these in blue on the M42 along the route. Emergency areas offer a place to stop in an emergency if you cannot exit the motorway or stop at a motorway service area. They are safe refuges off the main carriageway and hard shoulder, where the vehicle could stop and request further help or support. This would prevent the vehicle stopping in a live lane, thus preventing secondary incidents and not impacting existing traffic capacity and flow.

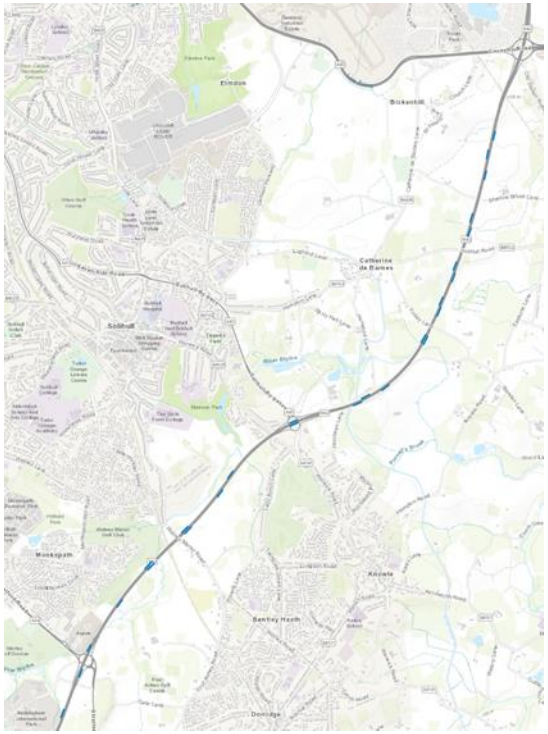


*Figure 32: Emergency Areas on M42 J4-6*

Further discussions would be required with the automated technology supplier to gain more understanding around the safety implications of MRMs on the SRN and whether an MRM stop could ensure the vehicle moves to the left. It would also be beneficial to determine if the use of an emergency areas could be incorporated into the MRMs, perhaps by adding relevant information and data to the ODD, so that they could be used wherever possible when an MRM is required. It is recognised that this may not be possible in all incidences when an MRM is required, as there may be situations where the vehicle is not able to reach the next emergency area e.g. due to sudden engine failure.

3.4.2.4 Traffic calming

| No. | Assumption |
|---|---|
| 5 | The vehicle will be equipped with detection capability to safely interact with other road users and infrastructure. |

There are currently no traffic calming measures on the route however we are aware that BVP are proposing the installation of traffic calming measures in the form of speed bumps in the near future.

We have been unable to include an assessment of these within the project at this stage, as the information relating to the proposed traffic calming measure has not been made available.

Future work would be needed to determine the locations of the traffic calming measures and to ensure that the vehicle would be able to safely navigate them i.e. not misinterpret them as foreign objects or unsafe defects on the road.

3.4.2.5 Road defects (cracks)

| No. | Assumption |
|---|---|
| 5 | The vehicle will be equipped with detection capability to safely interact with other road users and infrastructure. |

The conceptual vehicle system specification is capable to operate with road defects up to 5cm in size. It does not have any road defect detection capability. As it currently stands, any identified defects would be dealt in line with road authorities' inspection and maintenance procedures.

For the next phase of the study, consideration should be given to undertaking a detailed route survey to understand the existing level of road defects. Upon the completion of this work, a review of road authorities' inspection and maintenance procedures would be beneficial to understand if any changes would be required.

## 3.5 Infrastructure focus area 2: Ability for the vehicle to join and leave the motorway safely especially during high traffic volumes

### 3.5.1 Where we are, and where we need to be?

#### 3.5.1.1 Applicable assumptions

| No. | Assumption |
|---|---|
| 2 | The vehicle will follow a pre-defined path along the route, and will not follow road markings. |
| 4 | The vehicle will be able to dynamically change lanes if required. |
| 5 | The vehicle will be equipped with detection capability to safely interact with other road users and infrastructure. |
| 8 | The vehicle will not be able to negotiate non-signalised junctions and crossings. |
| 9 | The vehicle will be able to join and leave the motorway safely. |
| 12 | The vehicle will receive all communications digitally, it will not use a camera to read physical infrastructure e.g. signs and signals. |

#### 3.5.1.2 Slips roads

On the M42 section of the route there are two on slips and two off slips that the vehicle will need to safely negotiate to enter and leave the motorway. Figure 33 shows the on and off slip of J4. Ramp meter signals, which control the flow of vehicles joining the main carriageway at peak periods, are present at both on slips.


*Figure 33: M42 J4 Northbound On Slip and Southbound Off Slip*

Traffic congestion and poor journey reliability are a regular occurrence on the M42 due to high volumes of traffic and the road nearly reaching capacity. Figure 34 shows the average traffic volume between M42 J4-6 (weekdays only), both northbound and southbound. The graph indicates noticeable peaks during the morning and evening rush hours, and the highest average hourly volumes of around 100 vehicles per minute.

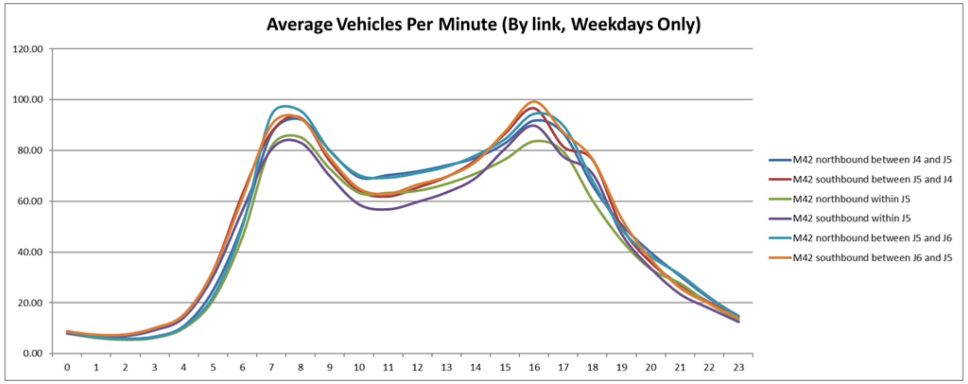



*Figure 34: M42 Average Traffic Volume Each Hour (Weekdays Only)*

While it is not thought that leaving the motorway will cause any issues for the proposed vehicle. The high volume of traffic on the M42 at peak periods will be problematic for the vehicle to safely merge onto the main carriageway due to the lack of spacing between vehicles. As the vehicle will not have the ability to determine traffic conditions on the main carriageway as it merges from a slip road (i.e. look for suitable gaps in the traffic that it could use to merge) an alternate solution would be required for the vehicle. Alongside this, the vehicle would also need to be able to safely comply with any ramp meter signals that are active on the on slips.

3.5.1.3 On slip lane becomes additional lane

A potential solution for the study route would be that the on slip becomes an additional running lane as shown in Figure 35. This would allow the vehicle to increase its speed and to join the main carriageway safely without the need to change lane. The on slip on the M42 would therefore become the hard shoulder running lane which in turn would need to be open at all times. This solution could be used along with detectors (see section 3.5.1.4).

*Figure 35: Slip Road Becomes a New Lane on the Motorway*

Further consideration would be required on a site-by-site basis as to whether the slip road could become an additional running lane and what modification(s) may be required. This could involve lengthening the slip road or redesigning the road geometry on both the slip and the main carriageway. We would also need to consider the implication these changes would have on existing traffic flows and capacity through scenario-based testing. Any required changes would have to be in line with the relevant motorway standards and specifications, including the Design Manual for Roads and Bridges (DMRB).

3.5.1.4 Detectors

Another possible solution for this route would be to install radar technology on the M42 to enable dynamic merging onto the main carriageway. The radar would be situated on the main carriageway and would be able to detect vehicle locations on a lane-by-lane basis. This would be communicated to the automated vehicle allowing it to identify a suitable safe gap for it to join the main carriageway of the motorway. National Highways have previously trialled a similar technology in the AutopleX project at the J15 merge on the M40, however this used both radar technology and connected vehicles (Probe Vehicle Data - PVD) on the main carriageway which reported their location, to enhance the radar data and determine suitable gaps.

Further investigation would be required to determine whether the detector solution could work in isolation, without PVD from connected vehicles, to allow the automated vehicle to merge onto the motorway. Consideration would also be required around placement of radars, and cameras may also be needed initially to ground truth the detector performance. However, it is noted that as a planned deployment is likely to be some years away the availability of PVD from connected vehicles in the future could be sufficient to successfully work alongside the radar detectors. Consideration of how this solution would work with the existing ramp metering installation would be required to ensure no detrimental effect on traffic flows and congestion.

3.5.1.5 Ramp metering

If changes are made to the on slip to become an additional running lane, then consideration would be needed to determine whether ramp metering is still viable at these locations. If it is removed, then the solution would need to ensure that there is no detrimental effect on either traffic merging onto the motorway or existing traffic on the carriageway. If the ramp metering signals remain then they would need to be upgraded to connected traffic lights/signals (see section 3.6.2.2) so information could be transmitted digitally to the automated vehicle.

## 3.6 Infrastructure focus area 3: Ability to have 100% connectivity along the route

Connected automated vehicles utilising vehicle to vehicle, vehicle to network and vehicle to infrastructure communications will help enable a future where no-one should be killed or seriously injured on the road network. Connected vehicles will be able to know and adapt to changing traffic conditions to allow for safer, quicker and more productive journeys for road users.

It is vital that road authorities work with others to prepare the physical road network for higher levels of vehicle connectivity and autonomy. Improved data and connected services that provide real-time personalised information will increase customer safety.

### 3.6.1 Connectivity definition

Cooperative Intelligent Transport Systems (C-ITS) use wireless technology to enable direct communication between vehicles, roadside infrastructure and other nearby users (e.g. pedestrians). C-ITS collects information and distributes real time messages and warnings about the road environment directly to the driver or automated driving system to help improve decision making. C-ITS vehicles and infrastructure can work together to communicate changing speed limits, road works, congestion, and the status of traffic signals etc.

Communication channels for C-ITS can include dedicated short-range or cellular (4G, 5G) communication systems. The conceptual vehicle system specification has the capability to use hybrid communications channels to exchange data.

### 3.6.2 Where we are, and where we need to be?

#### 3.6.2.1 Applicable assumptions

| No. | Assumption |
|---|---|
| 3 | Any planned changed to the route e.g. roadworks would require an update to the ODD. |
| 10 | The service will require 100% connectivity along the route to operate, and the connectivity will be secure. |
| 11 | The vehicle will establish a full connection along the route before the service commences. |
| 12 | The vehicle will receive all communications digitally, it will not use a camera to read physical infrastructure e.g. signs and signals. |
| 13 | If connectivity was to fail mid-route, the vehicle would perform an MRM and come to a complete stop. |

#### 3.6.2.2 Existing cellular coverage on the proposed route

Figure 36 shows the existing cellular coverage on the proposed route between the Hub and BVP along the M42. It indicates that overall, there is currently a good level of 4G and 5G cellular coverage along the route that may be able to support C-ITS communications for the service to operate.

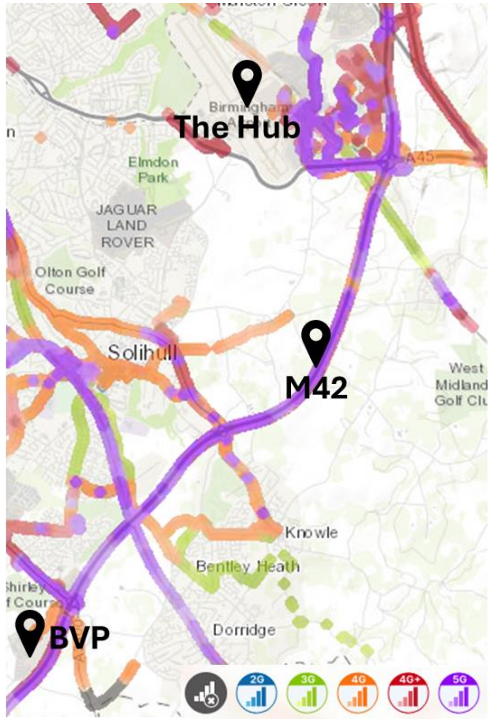



*Figure 36: Existing cellular coverage*

For the next phase of the study, it would be beneficial to undertake a more in-depth assessment of the cellular network coverage along the proposed route, working with commercial network providers to understand how cellular communications can be made resilient, secure and future proof for CAM services.

#### 3.6.2.3 Placement of roadside units to support connectivity

Roadside units (RSUs) are a device which are installed alongside roads to facilitate communication between vehicles and roadside infrastructure. National Highways, SMBC and BVP don't currently have any existing RSUs on the route to support connectivity for the service.

There is a high degree of existing roadside infrastructure on the proposed route, Figure 25 (as seen previously) shows approximately 14,000 physical infrastructure assets between M42 J4-6. With this in mind, we don't propose installing additional RSUs along the route. Instead, we are planning to use commercial 4G / 5G networks to enable connectivity along our roads.

However, if RSUs are deemed safety critical for service operation, we would explore installing them on existing suitable physical roadside infrastructure. Possible options for this could include lighting columns on BVP's private roads and SMBCs local roads, and gantries on the motorway. For example, the M42 J4-6 has gantries located at a maximum of every 500 metres along the route. Figure 37 shows examples of existing infrastructure that could be used to install RSUs if deemed safety critical.

*Figure 37: Possible infrastructure options to install RSUs*

For the next phase of the study, it would be beneficial to explore any additional RSU requirements (e.g. power, size, weight, range) to support an assessment of what existing roadside infrastructure would be suitable to install RSUs on.

3.6.2.4 National Highways data services

National Highway' Digital Roads strategy will harness data, technology and connectivity to improve the way the SRN is designed, built, operated and used. This will enable safer journeys, faster delivery and an enhanced customer experience for all. One core theme of Digital Roads is Digital for Customer (DfC), where its ambition is for our customers to be better informed and have trust in the journey information they access, ensuring that they feel safe and in control of their journeys.

As part of the existing DfC programme, five data services will be shared with third parties for free as part of the Government Open Data Service. The five data services are shown in Figure 38, and these could be used by the service to receive real-time information on road and lane closures, speed managed areas, and road features etc. This information would be essential as the vehicle system specification has a fixed ODD, so any planned changes to the route (e.g. roadworks) would require an update to the ODD.

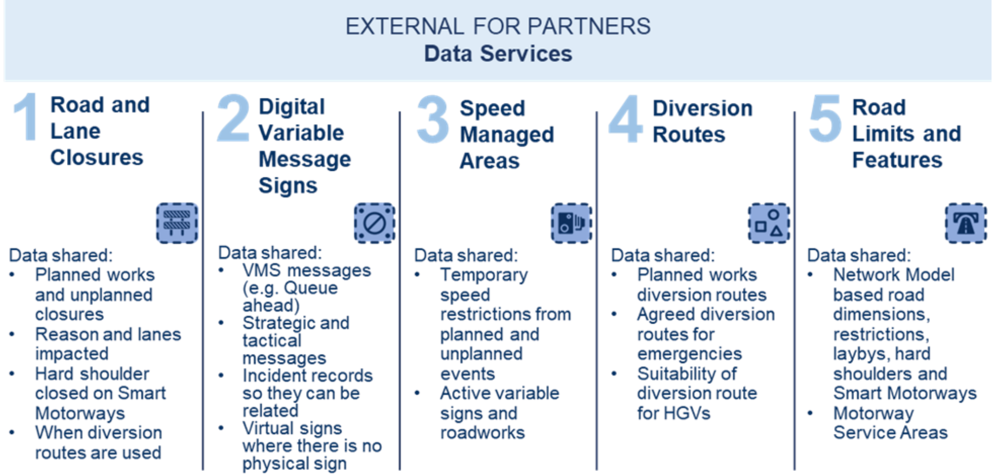



*Figure 38:National Highways DfC data services*

National Highways are planning to expand the existing DfC programme in due course, and the next phase of this study could support the exploration of additional DfC data services that could be shared with third parties, and that would be beneficial for this CAM service e.g. dynamic road signs.

3.6.2.5 External data sources

External data sources have not been looked at as part of this feasibility study, however it would be beneficial to consider data inputs that would affect the service. This could include weather data that would inform whether the current environmental conditions are suitable for safe service operation.

## 3.7 Estimation of costs and possible funding models

As part of the evaluation to determine the commercial viability of deploying a CAM service, it is important to take into consideration the potential costs that may arise from making modifications to existing road infrastructure to enable the service to operate, and what type of funding model could be used to implement these suggested modifications on the proposed route.

### 3.7.1 Infrastructure cost estimates, and cost exclusions

The costs outlined within this sub-section have been provided solely as information for this project on an "as is" basis and with no guarantees of completeness or accuracy. The estimated costs are based on existing similar technologies where costs are known. The costs outlined are just for the main infrastructure units e.g. RSUs, detectors, connected traffic light signal controllers. It is not possible to provide estimates for whole life costs (that would include design, development, construction, ancillary and auxiliary services) in this project as there are still many unknowns related to site specific requirements and technical specifications. Future cost estimating will be necessary as the study progresses and as the CAM service requirements are fully defined.

Below is a breakdown of indicative cost estimates for suggested infrastructure solutions that could support the deployment of the service, and total costs have been provided where possible. For the conceptual vehicle specification to operate along the proposed route, a minimum total cost of installing the suggested main unit infrastructure modifications is estimated to be in excess of £7 million. This figure does not include any additional costs that would be incurred with the design, development, and construction of suggested modifications, so it should be anticipated that the final total cost for the study route would be considerably higher.

| Infrastructure Category | Suggested Modification | Estimated Unit Cost | Number Of Locations / Arms of Junctions | Estimated Total Cost for Route |
|---|---|---|---|---|
| Junctions: Signalised | Traffic signals present so only install connected traffic light signal controllers | £20,000 | 5 / 31* | £620,000 |
| Junctions: Non-Signalised | Install traffic signals and connected traffic light signal controllers | £170,000 | 9 / 33* | £5,610,000 |
| Pedestrian Crossings: Signalised | Puffin crossings present so only install connected traffic light signal controllers | £20,000 | 3 | £60,000 |
| Pedestrian Crossings: Non-Signalised | Install puffin crossings and connected traffic light signal controllers | £140,000 | 7 | £980,000 |
| Slip Roads: On Slip Lane Becomes Additional Lane | We are not able to provide costs as an expected Departure from Standards would be required for this suggested modification. | | | |
| Slips Roads: Detectors for On Slip Merge | Install radar detectors on main carriageway to facilitate dynamic merging | £15,000 | Still to be determined (TBD) due to unknown technical specifications | TBD |
| Slip Roads: Ramp Metering Signals | Traffic signals present so only install connected traffic light signal controllers | £20,000 | 2 | £40,000 |
| Connectivity: Cellular Coverage | Costs have not been determined due to expected third party responsibility. | | | |
| Connectivity: Road Side Units (RSUs) | RSUs installed on existing roadside infrastructure e.g. gantries to facilitate communication between vehicles and infrastructure | £14,000 | Still to be determined (TBD) due to unknown technical specifications | TBD |
| Connectivity: National Highways Data Services | Costs have not been included as this is an already funded National Highways service provision. | | | |

*A decision on whether all arms of a junction would require installations of connected traffic signals and controllers would be determined on site-by-site basis.

### 3.7.2 Possible funding models

Several funding models could be used to deliver on-demand automated vehicle (AV) transport services, including making necessary modifications to road infrastructure. The chosen model will depend on the CAM service's goals, the stakeholders involved, and the financial sustainability required.

Common funding models can include Public-Private Partnerships, government subsidies and grants, corporate and private funding, and venture capital and private investment.

The appropriate funding model for an AV on-demand service will depend on various factors, such as service goals, user demand, and the national and local economic environment. In terms of road infrastructure modifications, a hybrid approach combining multiple funding sources (e.g., public subsidies with private investment) may be needed to provide end-to-end service enablement across different road networks (i.e. private, local, and SRN). This combined funding model could also ensure the long-term sustainability and scalability of CAM services in the UK.

# Chapter 4 – A Service That Appeals

*An automated bus service should be as, or more, resilient, robust, and reliable as traditional public bus options.*

*Pillar:*
*Reliable*

*Focus:*
*User*

*"An automated bus service should be as, or more, resilient, robust, and reliable as traditional public bus options"*

*New transport services must seek to overcome the reasons people don't currently adopt bus services; "Does this new solution provide tangible improvements over current solutions or is this technology for technology's sake?" must be asked. This chapter details existing public and private transport services, to provide a baseline for the CAM service. Through this lens an understanding of if, and how, a future CAM service on this route could meaningfully provide improvements against solutions that already exist.*

## Where we are today

## 4.1 Current Transport Options

### 4.1.1 Public Bus Services

Currently, it is possible to travel between BVP and BHI via public bus services although it would be considered difficult to do so. To complete the journey a customer will need to change at Solihull as there is no direct service. Figure 39 shows the services that allow the journey to be completed.

| Operator | Service | Link |
|---|---|---|
| LandFlight | A7 & A8 | BVP and Solihull |
| Stagecoach | A9 | BVP and Solihull |
| NX | X12 | Solihull and BHI |

*Table 5 Current bus services linking BVP and BHI*

Table 5 shows these services in relation to the study and illustrating the circuitous route they follow.

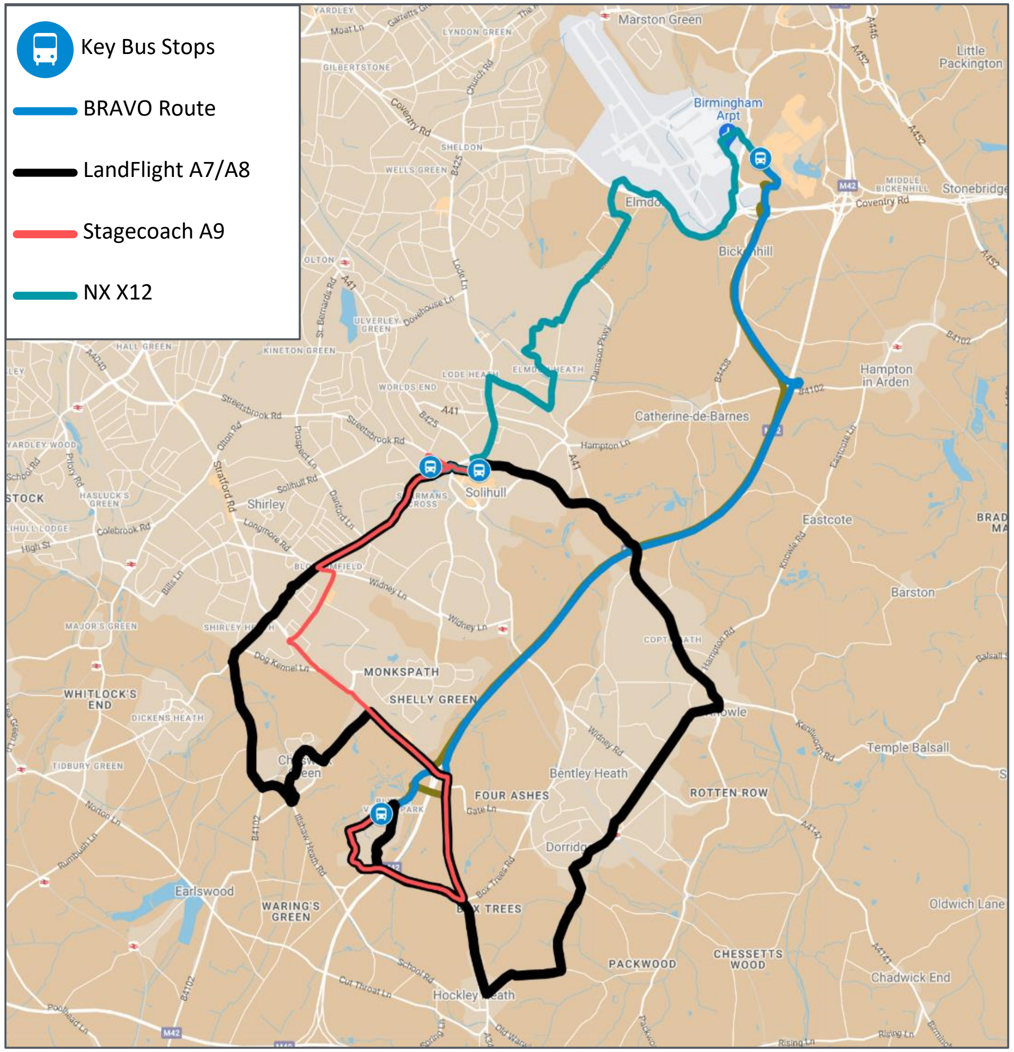
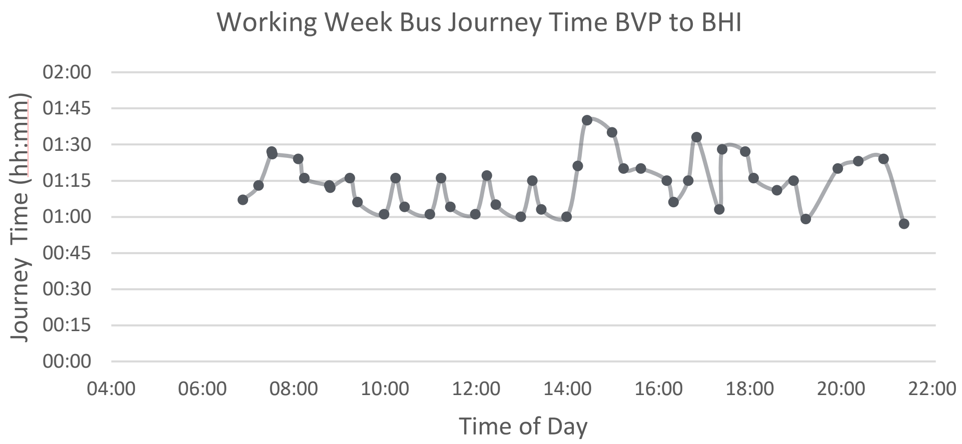
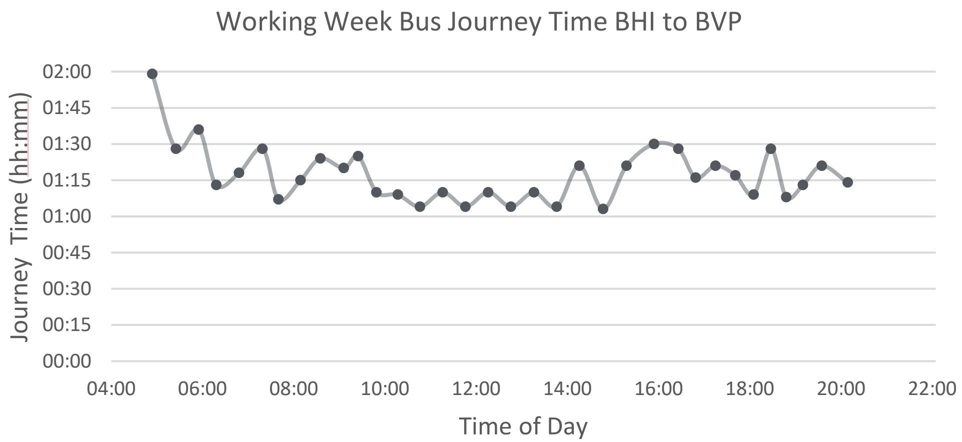



*Figure 39 Map of the bus service routes.*

Graph 9 and Graph 10 show the journey times between BVP and BHI, both inbound and outbound, based on published timetables. Table 6 shows the average, maximum and minimum journey times for these directions.




*Graph 9 Outbound journey times between BVP and BHI across the working week.*




*Graph 10 Inbound journey times between BVP and BHI across the working week.*

| Direction | Journey Time | Time (Hour:Min:Sec) |
|---|---|---|
| Outbound | Average | 01:14:13 |
| Outbound | Maximum | 01:40:00 |
| Outbound | Minimum | 00:57:00 |
| Inbound | Average | 01:17:18 |
| Inbound | Maximum | 01:59:00 |
| Inbound | Minimum | 01:03:00 |

*Table 6 Journey times for current bus services*

What is interesting to note that the average and minimum journey times are similar but there is a significant difference of 19 minutes between the maximum journey times. This is due to a mismatch between each leg of the services in the early hours of the morning. In this situation, there would be little point in taking the first X12 service as the second X12 reaches Solihull before the first service to BVP.

The timetable data was also used to understand the transfer time between services in Solihull. For this an estimated average walking speed of 2.8mph/4.5kph[8] was used to take account of the time a customer would need to travel between stops to make the connection. With this taken in to account the average wait time for a customer would be approximately 15 minutes outbound and approximately 10 minutes inbound. Again, the variance between the maximum and minimum wait times was large. This is partly due to the early morning X12 service but even in the outbound direction there is a maximum wait time of 35 minutes. The minimum wait time for both directions is 1 minute, making the link susceptible to even minor delays during the initial leg.

The results shown here are for the services that operate during the work week and further analysis will be undertaken to understand the viability of public transport during non-work hours and at weekends.

[8] [Walkability Index for Elderly Health: A Proposal (mdpi.com)]

### 4.1.2 Bus Service Reliability

The average reliability of the services from Table 5 are shown in Table 7 below.

| Service/Leg | On-time (%) | Early (%) | Late (%) | Avg. Delay (seconds) |
|---|---|---|---|---|
| X12 | 80.59% | 8.73% | 10.66% | 144 |
| A7 | 68.76% | 14.70% | 16.55% | 498 |
| A8 | 72.75% | 12.60% | 14.64% | 526 |
| A9 | 59.49% | 12.51% | 28.01% | 239 |
| Solihull and BHI | 80.59% | 8.73% | 10.66% | 144 |
| BVP and Solihull | 67.00% | 13.27% | 19.73% | 421 |
| Total Journey | 70.40% | 12.14% | 17.46% | 352 |

*Table 7 Average on-time reliability of existing bus services*

This table shows the overall reliability of a journey is in the region of 70% with an average delay of 352 seconds. The leg between Solihull and BHI is only served by the X12 service, operated by NX and has the lowest average delay 144 seconds with ⅘ of the buses arriving on time. The second leg between BVP and Solihull is served by A7, A8, operated by Land Flight, and A9 operated by Stagecoach. The on-time reliability for this leg is worse with an average of 67% and the average delay for this leg is 421 seconds. Between the 3 services the A9 has the worse on-time reliability, while the A8 has the biggest delay.

The CAM service proposed in this study would intend to have better on-time percentage figures if the service were to be run as a scheduled one. If the service were an on-demand service, the metric would be comparing the predicted arrival time communicated to the customer and the actual arrival time. This would require taking into account the traffic conditions along the M42 to ensure accurate reporting and predictions.

It should be noted that the methods for reporting of the on-time metrics in Table 7 do have flaws that could lead to inaccurate accounting. Unfortunately, this cannot currently be accounted for, and the reader should be aware of this inaccuracy.

## 4.2 Route Journey Time

To understand the travel time along the M42 link between BVP and BHI, journey time data has been collected to estimate the speed of the service that could be provided. Additionally, this data can be used to compare against the existing bus and express services.

| | Direction | Journey Time | Time (Min) |
|---|---|---|---|
| Inrix | Outbound | Average | 15.47 |
| | Outbound | Maximum | 73.87 |
| | Outbound | Minimum | 12.87 |
| | Inbound | Average | 13.26 |
| | Inbound | Maximum | 92.64 |
| | Inbound | Minimum | 10.57 |
| Uber Spot Check | Outbound | Average | 17.18 |
| | Outbound | Maximum | 24 |
| | Outbound | Minimum | 13 |
| | Inbound | Average | 16.3 |
| | Inbound | Maximum | 20 |
| | Inbound | Minimum | 14 |

*Table 8 Recorded average and predicted average journey times between BVP and BHI*

The first part of Table 8 is taken from an Inrix dataset for January 2024 and shows the average, maximum and minimum journey time. The second part of Table 8 shows the predicted journey time collected from an Uber service spot check in early September 2024 (see section 6.5.3). The average journey time to drive via the M42 is quicker by about an hour when compared to the equivalent bus service. It also shows the inbound journey is quicker than outbound by approximately 2 minutes. This is partly due to the inbound journey being shorter that the outbound journey.

The predicted times collected from Uber show a similar difference between the inbound and outbound journeys but not the same overall volatility between the maximum and minimum journey times. This is likely due to Uber putting a restriction on the maximum wait time for a customer before showing that no rides are available.

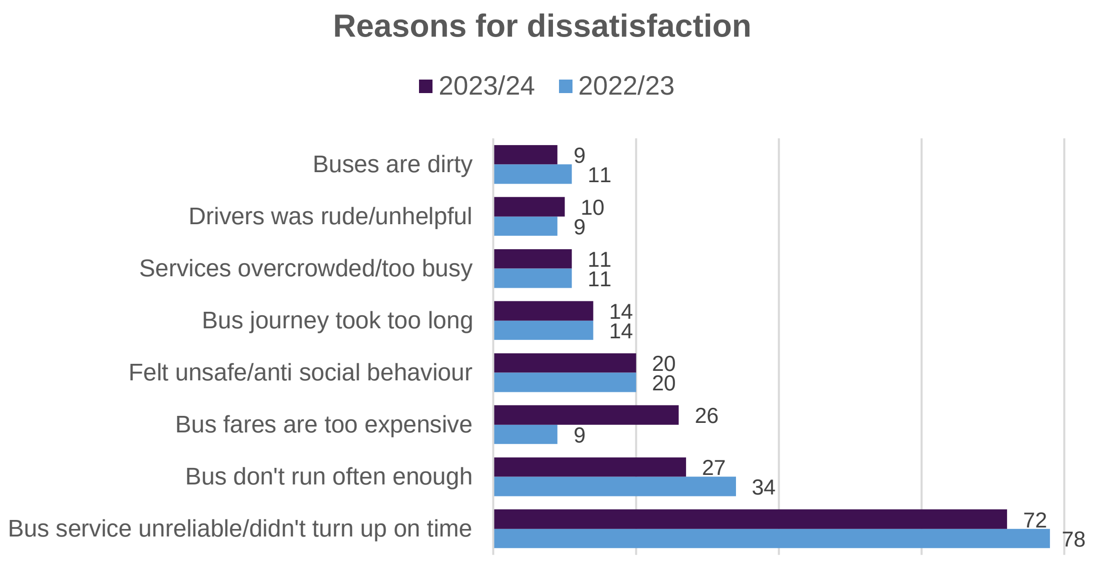
## 4.3 West Midlands Travel Trends and Behaviours

The following information are extracts from annual travel trends and Behaviours report produced by TfWM. This report covers public satisfaction surveys of users of cars, buses, rail, tram, cycles and walking more than 10 minutes. The most relevant to this service are bus and car travel modes.

### 4.3.1 Bus

Bus customers were asked the reasons for dissatisfaction in bus services they use (Graph 11) 54% of bus users were dissatisfied with some element of their bus journey, mainly due to poor reliability, buses not running often enough, and bus fares being too expensive. Indeed, there was a significant increase in the proportion of users complaining about fares being too expensive.

The annual comparison (Graph 12) shows there has been a significant increase in satisfaction with punctuality (50% v 44%), and a significant decline in satisfaction with value for money. While personal security on bus did not improve significantly this year, it has improved steadily since 2021/22 (80% v 74%).




*Graph 11 Question: What were your main reasons for feeling dissatisfied?*
*Base 402 respondents dissatisfied with aspect of bus journey. Percentage exceeds 100 due to multiple responses.*

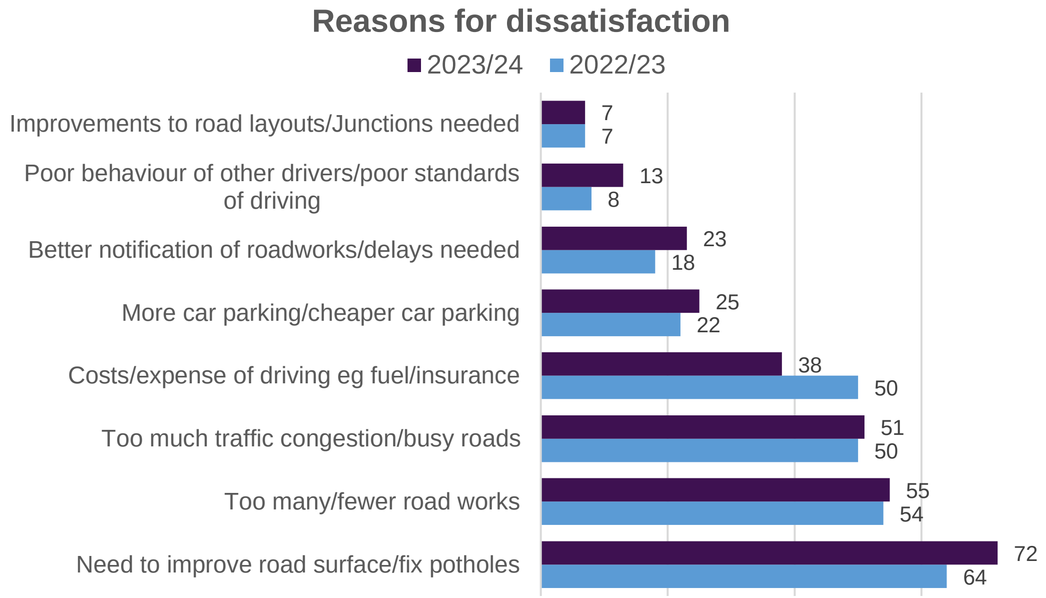

*Graph 12 Question: How satisfied or dissatisfied were you with the journey you made by bus in terms of: Base 745 bus users in last 7 days. VFM only asked of fare paying passengers – base 642.*

### 4.3.2 Car

When comparing the reasons for dissatisfaction (Graph 13) of car users on the west midland's road networks, 74% of car users were dissatisfied with some element of their car journey. This is mainly due to the need to improve the quality of road surfaces (72%) and/or too many road works (55%). Fewer respondents complained about the cost of driving this year (38% v 50%).

In an annual comparison (Graph 14) it is apparent that car users are increasingly dissatisfied with maintenance and upkeep of roads and amount of traffic congestion. However, as the costs of fuel decreased compared to 2022/23 motorists' satisfaction improved with value for money, albeit remaining lowly rated. It should be noted that although satisfaction with information on delays did not decrease significantly this year, it has declined steadily from 2021/22 (54% to 46%)

When asked about the likely use of alternatives (Graph 15)[9], there was an increase in the proportion of car drivers who would definitely consider a change of mode. This would be to avoid congestion relating to road works or other planned events (19% v 16%). Weekend travellers (26%) and younger respondents (27%) were most likely to consider a change of mode; weekday peak travellers were least likely to do so (16%).




*Graph 13 Question: What were your main reasons for feeling dissatisfied?*
*Base 855 respondents dissatisfied with aspect of car journey.*


*Graph 14 Question: How satisfied or dissatisfied were you with the journey you made by car in terms of: Base 1167 car users in last 7 days* ***Highlights indicate significant yearly changes in satisfaction following statistical testing.***

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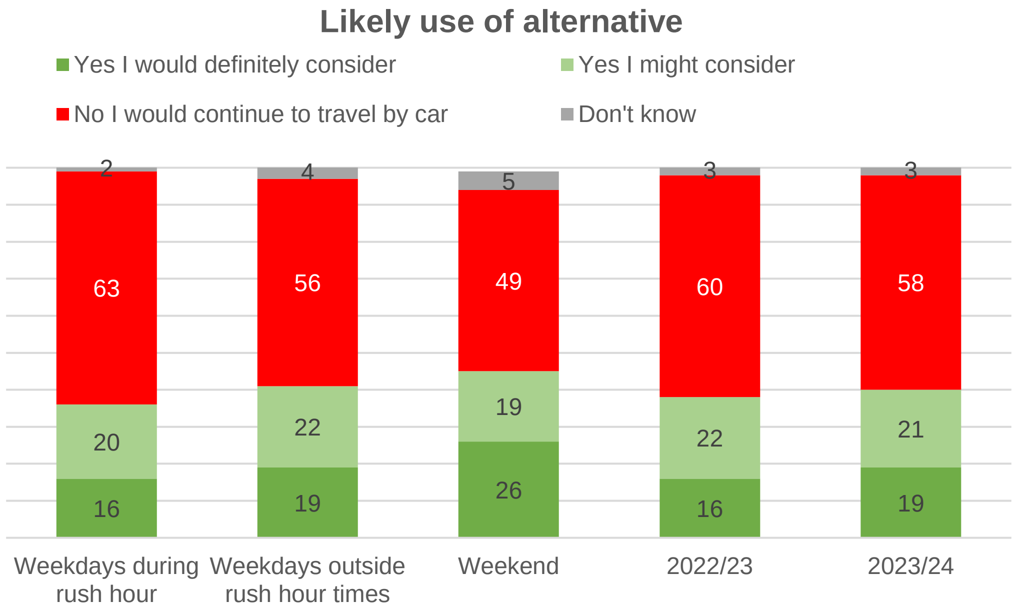
[9] The original version of Graph 15 included the breakdown of likelihood to change mode by age, gender and ethnicity. These are omitted here for clarity.




*Graph 15 Question: If there was a lot of congestion relating to road works or other planned events would you consider switching your mode of travel away from the car?*
*Base 1164 car drivers in last 7 days*

When looking at the West Midlands Travel Trends and Behaviours (4.3) there is potential for a CAM service to improve on the satisfaction of both car and bus users. Car users have shown the most dissatisfaction with the conditions of the roads, followed by road works and congestion. It would seem logical to draw a connection between these issues and all three could be alleviated to an extent with a CAM services. A CAM service could reduce the number of individual cars on the road, leading to less wear and tear on the road surface and reducing the likelihood of congestion. Additionally, it would be expected that a CAM service would be capable of some level of dynamic routing where roadworks are accounted for. Something that must be kept in mind is that the young and weekend travellers were most like to switch modes while commuters were least likely. This would indicate that the people affected by congestion the worst would also be the most difficult to convince to switch modes. It should be noted that the complexity of commuter's journeys are not currently well understood.

## 4.4 Sector Insight

Ensuring more direct routes, more frequent services and the promise of better journey time reliability (primarily delivered by providing a shorter route and therefore reducing the risk of variance) is all positive, however, understanding whether a future CAM service will be as robust (i.e. run in all the same conditions as a traditional bus service) is also important to understand at this feasibility stage. Persistent failure for the future CAM system to run and instead relying on manual 'back up' services will quickly undermine confidence and any economic case for the system.

The speed of development of Autonomous Control Systems (ACS) is significant, with evermore intelligent solutions capable of fusing data from a variety of sources to continually improve capabilities of systems to run. Due to this rapid evolution, and the fact that it is invariably hard to understand the actual performance of systems under private development, only a brief summary of some of the latest known capabilities relating to the most common atmospheric condition in the UK – rain – are provided below.

Rainfall is measured in mm/h. The most extreme 'cloudburst' rain is rated at 50mm/h, and "heavy rain" being rated at 30mm/h. The UK has 110-130 days of rain per year, with between 15 and 30 days per year being considered heavy rain. There is, on average, between 3.5 and 7 days per year of 50mm/h within the West Midlands. Wales, Scotland, Northern Ireland, and High Peaks receive up to 50 days per year of "heavy rain".

Rain in the UK is more common between October – February and the long-term trend is 2011-2024 being 9% rainier than the previous 50 years. As the climate warms and increasing energy is held in the atmosphere climate scientists predict increasing extreme weather events, including heavy rain.

Currently, unsurprisingly, autonomous vehicles perform best in clear, stable weather conditions but struggle in adverse conditions such as snow, heavy rain, and fog. Many AV systems are not yet considered fully reliable in these scenarios, with manufacturers working to improve sensor robustness and machine learning algorithms to handle diverse weather conditions better.

Rain and snow present unique challenges for autonomous vehicles. By leveraging and fusing multiple sensors (radar, LiDAR, and cameras) and developing advanced machine learning algorithms, AV companies are working toward making autonomous vehicles more reliable in adverse weather. Radar typically performs much better in rain conditions than LiDAR and Cameras.

However, heavy rain still poses challenges, especially with sensor visibility and road traction.

Recent research[10] assessed the functionality of the VLP-32 LiDAR sensor, which serves as the principal sensor for object recognition in autonomous vehicles. This is the standard specification for lidar technology in the automotive industry. Performance of object recognition deteriorates in poor weather conditions. Laser points reflect off rain and water droplets (in rain and fog) and impact the performance and efficacy. In tests, as fog and rain escalate, the performance of LiDAR sensors correspondingly deteriorated. Specifically, the studies found that in foggy conditions, the scattering of light due to atmospheric particles adversely affected the LiDAR's ability to detect point clouds. During rainfalls, sensing efficacy began to decline at a rainfall intensity of 10 mm/h (light rain) (80% detection), and at 50 mm/h (Heaviest of rain), target detection was essentially nullified (9.8% detection).

The ability for AV developers to provide a robust, reliable service must not be undervalued. Although mitigations (manually driven services) could work operationally for times when services couldn't run due to, for example, atmospheric conditions such as heavy rain, fog, snow), this would come at significant cost – the need to have standby drivers and vehicles. These costs could very quickly overwhelm an operator who has committed to provide a shared public transport service upon which communities depend and can not be simply switched on and off as & when the technology works.

## 4.5 Where are the Gaps?

A future CAM service must appeal to target users – which must include current bus service users, but also to private car users. The proposed CAM service would be expected to offer a service on a par with, if not better than an equivalent driven bus service.

For bus users the top reason for dissatisfaction is the service not running on time. This could be caused by factors such as congestion on the route, long boarding or alighting times. Comparing Table 6 and Table 8, we can see a significant time saving between existing *public transport* options (note – not private car) and this proposed service. It should be noted that any service that is not using a segregated lane, would be affected by general traffic conditions. Table 8 shows that, while rare, there are extreme 90-minutes of travel time along the M42. The extent to which a new public transport service that will be impacted by congestion at peak travelling hours will appeal to current car drivers is expected to be low.

Current transport solutions are expected and capable of continuing operation and most weather conditions. Any CAM service that is intended to be put into full operation would be expected to cope with any weather condition a driven vehicle can. This is an area of significant and rapid research and development, but still requires further exploration before a definitive confirmation can be provided that services should be expected to be run with the same level of 'up time' as a driven service.

The points raised in this chapter will require further research in the travel behaviours of potential customers and further development of systems to ensure safety of passengers from antisocial behaviour.

[10] Performance Verification of Autonomous Driving LiDAR Sensors under Rainfall Conditions in Darkroom - PMC (nih.gov)

# Chapter 5 – Access For Everyone

*An automated service must be as, or more, available and accessible as current public transport options*

*Pillar:* *Accessible*

*Focus:* *User*

***"An automated service must be as, or more, available and accessible as current public transport options"***

*A CAM service would be expected to be able to provide equal, or greater, accessibility over traditional public transport services. There are two senses within which public transport must seek to be 'accessible' to be considered as adding real value to communities. First, the ability for a user to reach the service and second, the ability for the user to board and confidently use the service. The first factor needs to account for the distance between the access point, e.g. a bus stop, and the customers origin, e.g. home, work, etc. The second factor focuses on the vehicle & peripheral infrastructure design needed to allow a person with an impairment, e.g. mobility issues, blindness, deafness, etc., to safely board and leave the service.*

*This chapter explores options for the general operational service design to maximise potential access to the service, as well as understanding operational implications of removing an on-board driver.*

## Where are we today?

### 5.1 TransitScan Results

A TransitScan of the area was completed to assess the available public transport options connecting BVP and the Hub. This tool allows us to understand local network connectivity to each site by a range of different measures:

- **Modes** – the number of public transport modes required to complete the journey
- **Travel Time** – end to end journey time by public transport, expressed as ratio of the equivalent journey by car (i.e. 3x longer etc)
- **Walking Time** – how much walking time is required for each public transport journey to the specified destination.

Each of these measures is plotted to create heatmaps of the surrounding area, to show the quality of public transport connections to each site, as shown in Figure 40. Scans have been conducted for different arrival times to demonstrate how available public transport options vary at different times of day.

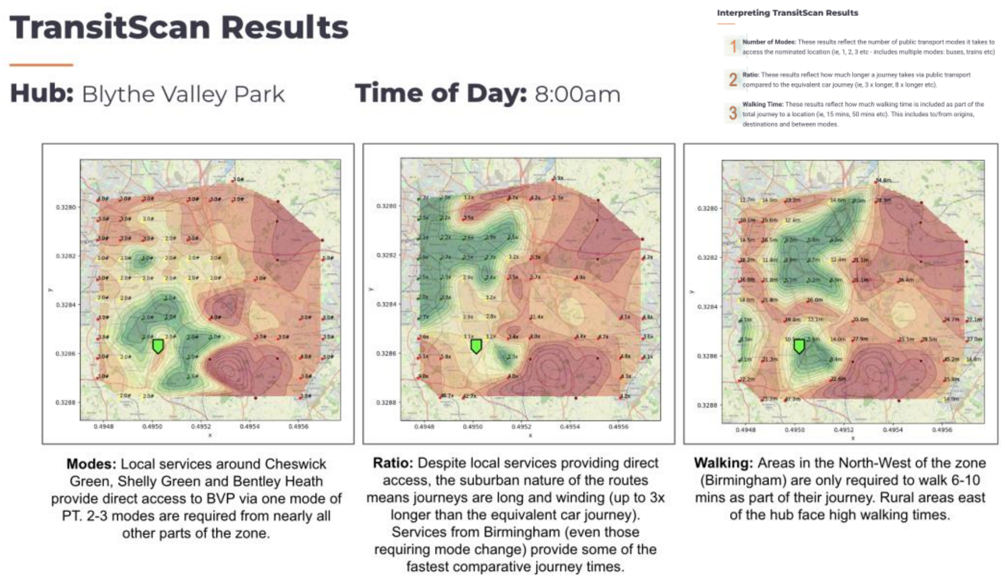
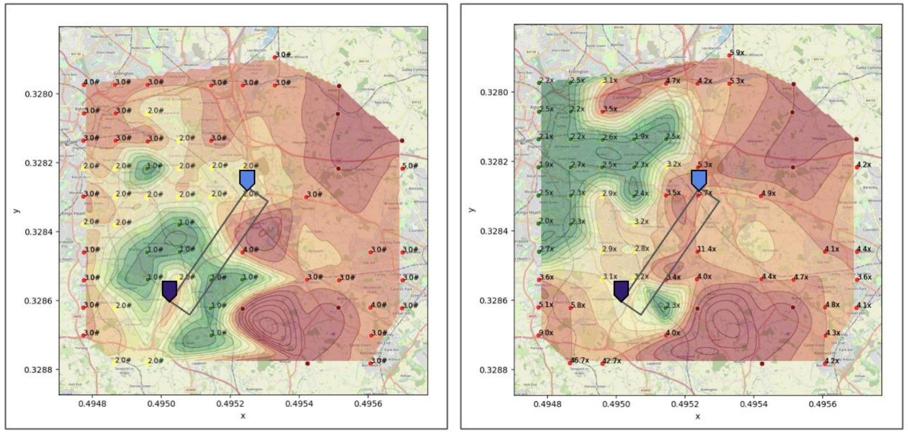



*Figure 40 Liftango TransitScan analysis results and visualisation.*

### 5.1.1 Results

Journeys between the BVP and The Hub require at least 2 modes of public transportation with passengers required to change modes in Solihull. The bus routes involved are also generally circuitous mean travel times of over an hour peak times, nearly 6x longer than the equivalent car journey (12-20 mins). An example scan showing an 8am arrival into BVP can be seen in Figure 41.



**Modes:** Individuals travelling from NEC and Train Station Hubs need two modes of public transport to access BVP with a mode change at Solihull (see following slide).

**Ratio:** Given this mode change as well as the winding nature of local routes near BVP, public transport journeys are nearly 6x longer than the equivalent car journey

*Figure 41 Transport connections from the Hub to BVP - 8am arrival.*

**National Exhibition Centre & Train Station**

**East-West (E-W) Accessibility:** Individuals traveling from Birmingham and Balsall Common/Meriden to the NEC benefit from direct public transport (PT) options with good access coverage, especially from Birmingham.

**Journey Time Comparison:** Public transport journeys are approximately twice as long as car journeys, taking around 40 minutes versus 20 minutes by car.

**Walking Access:** Birmingham travellers have short walking distances to public transport. However, travellers from Balsall Green and Meriden face extended walk times (up to 44 minutes) despite direct PT access.

**North-South Accessibility Challenges:** Traveling to the NEC and train station from northern and southern areas requires multiple modes (2-3 PT modes), resulting in journeys up to seven times longer than by car and extensive walking distances.

**Blythe Valley Park**

**Local Accessibility:** Direct services from Cheswick Green, Shelly Green, and Bentley Heath offer good coverage to BVP but follow lengthy, indirect routes. While this reduces walking time to bus stops, it extends overall journey time relative to car travel.

**Birmingham Accessibility:** Despite often requiring two modes of PT, journeys from Birmingham to BVP remain relatively convenient, with minimal walking and shorter journey times than local routes, making PT a competitive option to driving.

**Conclusion**

Current public transport journeys between the NEC/Train Station hubs and Blythe Valley Park require around one hour. This lengthy travel time is due to the need for a mode transfer in Solihull and the long, circuitous bus routes that prioritize coverage over directness.

In contrast, the same trip by car takes just 12-20 minutes. The proposed AV shuttle would streamline this route by providing a direct, single-mode transport option, eliminating the need for mode changes and significantly reducing both travel and wait times. This would greatly improve convenience and efficiency for travellers on this corridor.

The TransitScan analysis was conducted to evaluate public transport connectivity between BVP and key regional hubs, particularly focusing on improving operational efficiency for the next phase of CAV service planning. By assessing transit modes, journey times, and required walking times, TransitScan provides a detailed understanding of the current public transport network performance for travellers across various routes.

The findings reveal significant gaps in public transport efficiency. Trips between BVP and the NEC/Train Station hubs, for instance, demand two or more transit modes and lengthy transfers, particularly at Solihull. Typical journey times reach an hour or more due to circuitous bus routes aimed at maximizing coverage. In contrast, an equivalent car journey takes just 12-20 minutes, a considerable time saving that highlights the need for more direct transit solutions.

East-West transit routes between Birmingham, Balsall Common, and the NEC exhibit relatively better access, with fewer required transfers. However, trips from Balsall Green and Meriden still involve extended walking times. Conversely, North-South routes to the NEC and train station involve up to three transit modes and travel times that are up to seven times longer than car trips, presenting notable barriers to effective connectivity.

The analysis underscores that introducing a direct, single-mode AV shuttle service could significantly enhance transit convenience, particularly by reducing travel times, minimizing required transfers, and simplifying passenger movement between BVP and the NEC. The TransitScan results offer valuable insights for modelling the future CAV service, aligning transit service enhancements with passenger needs for efficient first- and last-mile connections.

## 5.2 High Level Initial Operational Concept

**Hours of Operation**

Monday – Sunday 5am – 12 midnight initially, with the option / ambition to extend to 24/7 service, 365 days/year.

**Route & Stops**

- Blythe Valley Business Park
- Birmingham International Rail Station.

Via M42 Jnc4 to Jnc5a, B4438 replacement link,

Additional optional stops considered:

- FORE Business Park
- Blythe Valley Park (residential development)
- Birmingham Airport

36 second boarding/disembarking time

**Route Infrastructure**

- Dedicated, identifiable stops throughout route with shelter and electronic service information boards
- Level boarding stops
- Cellular communications throughout
- Vehicle charging facilities

**Performance Capability**

On par with other public transport services. Service operational irrespective of weather conditions (within defined parameters); time of year; events taking place along route.

**Service Levels**

15-minute maximum headway

Ability to flex service patterns for short-term changes (including the addition of capacity).

**Assets and Facilities**

Storage & maintenance depot & control centre located at suitable premises on / very near route

Vehicles capable of 60 mph

Service capable of integration into existing rail/bus interchange / system

**User Interfaces**

- Ridership data collection
- Farebox collection
- Integration into Swift ticketing systems
- 24/7 emergency contact / support
- On-board standard and emergency call buttons; monitoring and information screens

**Accessibility**

The system must be capable of safely and comfortably on-boarding, conveying and disembarking wheelchair users and visually, aurally and audibly impaired customers

## 5.3 Operational & Technology Requirements

The removal of a human presence in an on-road shared public transport service requires significant consideration. The role of the "bus driver" goes above and beyond that of steering the vehicle and understanding. Understanding where and how issues / impacts will be felt is crucial at a feasibility stage, as the impact upon ensuring accessibility across all future users is a central pillar of any public service.

For the purposes of this study, we have assessed the operational and technology requirements for the commercial delivery of a CAM service. This section is intended to cover the expected operational and technology requirements to support the transition from a manually driven public transport service delivered today into a fully commercial CAM public transport service. We have taken into consideration the role of the operator and the technology providers. Splitting the approach into three key phases which allow us to analyse the transition of the services to the ultimate goal of a fully autonomous commercial transport service:

**Phase 1:** Human driven vehicles, utilising autonomous driver systems to test, develop and transform traditional public transport services to a fully autonomous service. Within phase 1, we have therefore assessed a traditional public transport service operating model which forms the baseline across operational requirements, technology and also cost.

**Phase 2:** Autonomous vehicle providing public transport services, with the support of onboard steward. This phase is a critical component of the transition from an operational perspective, as it allows us to begin to assess where the functional gaps are identified in anticipation of having no steward onboard.

**Phase 3:** Fully autonomous vehicle, with no presence of an onboard steward. The vehicle(s) are controlled remotely, utilising a control centre delivery model.

Each phase will build upon technological advancements and regulatory approvals, moving towards a service that operates independently while maintaining high safety standards and improving operational efficiency.

Aligning to these phases, we have outlined four operational concepts, which are used to support the technology, operational and functional requirements of delivering the service

As shown in the table below, we have assessed the phasing outlined above, through the lens of the provision of a public transport service, utilising demand responsive technology. This assessment has allowed us to analyse the operational, functional and technology challenges and opportunities when making this transition.

| Operational Component | Phase 1 Approach (Human Driver) | Phase 2 Approach (Human Steward) | Phase 3 Approach (Fully automated) |
|---|---|---|---|
| Passenger boarding/disembark | Traditional service allows for a driver to assist with passenger boarding. Aided by technology, where services are pre booked utilising passenger applications, digital or physical ticketing. | A Hybrid service, with the presence of a steward, would perform the same service, with limited to no impact on the passenger experience. | A fully autonomous service would require technology to bridge the gap to ensure a consistent passenger experience.<br>This would cover requirements for:<br>• Digital Vehicle Access for boarding and departing<br>• Automated passenger counter / validation<br>AV Infotainment systems where virtual stewards are able to communicate with passengers provide an additional functionality to ensure effective boarding / departures |
| Passenger Booking | Technology provided for the passenger to book via a passenger application or online. | No significant changes to the delivery and technology approach to phase 1 | No significant changes to the delivery and technology approach to phase 1 |
| Passenger Validation/ ticketing | Ticketing validation can take a number of forms within a traditional service:<br>• Driver Validation<br>• QR Scanning / RFID Systems<br>• Digital tickets | No significant changes to the delivery and technology approach to phase 1 as the steward would provide the same service as the driver would previously. | Alignment required to the technology approach for onboarding and disembarking the vehicle.<br>Technology exists and is deployed, where passengers can validate their ticket through digital ticketing systems, QR scanning supported by passenger counting systems.<br>There is an operational risk, that passengers may board the vehicle without a valid ticket, or with multiple companions. |
| Passenger Accessibility | Driver manually supports accessibility requirements for the passengers. Critical to note that, the vehicle and service design will need to consider the ability to ensure that passengers still board and disembark from the kerb side. This will support the transportation into phase 1 and 2.<br>The passenger application would inform the driver ahead of the trip, of the accessibility requirements of each individual passenger. | There is no significant change from phase 1, as within phase 2 the steward would provide the same level of service.<br>The passenger application would warn the steward ahead of the trip, of the accessibility requirements of each individual passenger. | There is a significant change and challenge within a service without the presence of a driver or steward.<br>The accessibility requirements of the passenger would be need to be dynamically supported by an on the ground operational team until the technology is advanced enough and passengers are fully comfortable with accessibility assistance without the presence of physical aid. |

| Operational Component | Phase 1 Approach (Human Driver) | Phase 2 Approach (Human Steward) | Phase 3 Approach (Fully automated) |
|---|---|---|---|
| Passenger Communication | Delivered through SMS, in app notifications and in some services through a call centre.<br>Where a driver is present, in vehicle communication and assistance can support the passengers experience. | In addition to the communication offered within phase 1, passenger communication can be tested through automated AV infotainment systems, with a transport away from the requirement for in person support.<br>The AV infotainment system can be tested to integrate with the passenger booking platform and operational management portal. | Further development required here, to allow for real time information and two way passenger and service provider communication. Reliance will be heavily placed on having a remotely accessed support service team through a call centre, however with the continued development of technology the AV can provide a first touch point for customers. |
| Operations Portal / Control Centre | The operations portal, is a live interface to enable operators to deliver the transportation service. Managing fleet, shifts, schedules, drivers, users and bookings.<br>Within phase 1 there is now requirement for any significant changes to the functionality to deliver the services. | Within phase 2 there is now requirement for any significant changes to the functionality to deliver the services.<br>There must be a consideration however to the hardware and sensor software utilised on the vehicle which enables performance monitoring.<br>Providing an integration between the operations portal and the fleet performance management system would provide the most optimal step towards a fully autonomous service, allowing for all service information within one intuitive dashboard system. | Further system development and bespoke functionality required here, in particular for:<br>- Full control and management of autonomous vehicles remotely.<br>- Real-time data streaming from AV systems for fleet management, route optimization, and incident handling. |
| Shift/ Schedule Management | Service configuration utilising live dynamic routing algorithm to control the shift and schedule management. | No significant functionality requirements to be developed to deliver a service within phase 2.<br>Consideration must be taken where the operations system will be integrated into the vehicle performance monitoring system as this will determine the vehicles available to be in service.<br>Where a steward is present, this allows for a semi-automated transportation | Functionality development required to transform the overall operational system to account for a dynamic approach to shift and schedule management.<br>It's intended that a control centre approach would be taken, to oversee however the overarching objective of this requirement to ensure that the system, has an ability to manage dynamic routing autonomously and based on demand. |

*Table 9 Operational components broken down by phase approach*

To further support analysis, we conducted a site visit to the Rivium CAM deployment in Rotterdam, operated by Transdev. An overview of the service is provided in 1.5.

This service provided a benchmark, in particular, for our analysis of the technology requirements to deliver a fully autonomous service. Irrespective of the segregation approach, which differs to the directive as part of the project, what this does critically offer is an understanding of the transition from a fully human driven service to a fully autonomous service.

Our findings, summarised below, have supported our overall assessment of the requirements mapped in Table 9;

The ***passenger boarding*** approach is supported by sensor-based technology to detect passengers approaching the vehicle, allowing for opening and closing of the doors without human interaction. Critically, the system isn't integrated with a ticket validator which highlights the risk of fare evasion.

The vehicle has sensors to allow for the total weight of pax to be analysed but this doesn't give a true representation of live capacity or data on passenger usage.

Passengers are expected to tap on and off to validate their ticket. Where the data is available, this enables a good opportunity for service and demand performance analysis. It must be considered that there is a baseline of inaccuracy where passengers fail to tap on and off or have boarded without a valid ticket.

The ***passenger accessibility*** components of the service from a technology perspective, particularly with the objective of creating a CAM service which is accessible for all is critically important. We observed that the Rivium service utilises a number of technologies and systems to mitigate the challenges with relation to access to the vehicle for those with wheelchair requirements. Their system has implemented GPS supported docking at each station, which creates wheelchair level platform access, removing the need for a vehicle steward or other assets such as



wheelchair ramps deployed through a sensor type system like we'd see on a rail or light rail system.

***Passenger communication*** is a key component of the service where a driver and or onboard steward is removed from the vehicle. Communication has been assessed within the vehicle and whilst planning/boarding/disembarking the vehicle.

It's important to note the Public Service Vehicles (Accessible Information) Regulations 2023[11]. Between 2024 and 2026 all local bus services will be required to incorporate accessible information provisions. This is particularly important regarding those passengers who are disabled. It's intended to provide passengers with:

- Access to high-quality and accurate on-board information
- Limiting access barriers to services
- Improvement in journey experience for all passengers

The Rivium service is delivered with the support of a control centre. The control centre has the ability to fully control the service, including the vehicle and communication with the passengers on-board where needed. There are real time information screens for passengers to use at each station and onboard.

Onboard, passengers have access to a live intercom system, which is to be used in the case of emergencies, connected to the control centre operators.

Where an on-demand CAM service is proposed, passenger communication is required to become much more dynamic, through the provision of a passenger app. This must be then considered, where a vehicle is routed dynamically and so not on a dedicated route. As such, the gap that needs to be addressed is the ability to communicate across a number of platforms/systems with the passenger throughout the journey (from the time of planning/booking to arrival).

We've observed the criticality of utilising a **control centre** to support the driverless service for Rivium. Our analysis from providing an on-demand service has highlighted the requirement for the live operations portal to be a key system for the control centre to deliver a service. The operations portal provides a live and dynamic overview of the performance of the service across vehicles, users, schedules and shift

[11] Providing accessible information onboard local bus and coach services - GOV.UK (www.gov.uk)

management. The operations portal also provides the opportunity for those in the control centre to better manage the service, where intervention is required.

In order to transition an on-demand service from Phase 1 to Phase 3, there would need to be significant integration of the operations portal system and control centre to enable the functionality we believe to be critical.

The **shift and schedule management** operational components of the Rivium service are built on the operational model of having an entirely fixed route, with pre-defined stations/stops. The service can be operated in both a pre-defined timing schedule and can be in a purely on-demand mode

Whilst operated in the on-demand mode, passengers can call upon a vehicle, utilising a call button at each of the stations. As with an on-demand service, utilising a dynamic passenger app, there is a key transition from this approach. As passenger bookings will therefore come from a passenger system, that's live, considerations must be made as to the integration requirements of this, along with the dynamic routing algorithm which is part of the overall system. This integration will enable the vehicle, it's schedule, routing and shift management to be managing dynamically based on demand.

## 5.4 Service Design

TransitScan's were conducted to assess the public transport options connecting BVP and the Hub. This tool evaluates network connectivity by examining the number of transport modes required, the total travel time compared to the same journey by car, and the amount of walking time involved for each public transport journey. The data is used to understand the efficiency of public transport for these routes.

The results of the TransitScan's were visualized through heatmaps, showing the quality of public transport connections in the area. These scans were done for different times of day to illustrate how the availability and convenience of public transport options change throughout the day.

Following this, the results were used to establish three different potential future service designs for the proposed AV service. These are described below:

### 5.4.1 Trunk Route - Classical AV Service Design

The Trunk Route concept for an on-demand autonomous vehicle (AV) transport service involves high-frequency connections along the primary, predefined corridor or main route (BVP – BHI). This approach mirrors traditional public transport systems but leverages AV technology to, in theory, increase efficiency and reduce operational costs. The vehicles in this design follow the fixed route with limited deviation, focusing on transporting passengers between the hubs.

5.4.1.1 Summary of Operational Requirements:

- Predefined Corridors: The route is fixed along a main travel corridor, such as major roads or transport pathways, ensuring reliable and predictable service.
- High-Frequency Service: AVs operate at frequent intervals to reduce wait times, which requires robust fleet management to maintain consistent vehicle dispatches.
- Fixed Stops: There are designated stops along the route for pick-up and drop-off. AVs stop at these fixed points, requiring clear signage and infrastructure at each stop.
- Traffic Management: Since the route sticks to main corridors, integration with local traffic management systems is essential to optimize travel times and prevent delays.
- Passenger Scheduling: The service needs to integrate with passenger apps that allow for scheduled pick-ups at these fixed locations, with minimal deviations from the main route.
- Fleet Size and Vehicle Capacity: Larger, more frequent vehicles may be required to handle higher volumes of passengers typical of trunk routes, which increases the need for efficient vehicle maintenance and scaling.
- Safety and Compliance: Ensuring that the AVs meet regulatory standards for safety and accessibility is critical, particularly for high-capacity routes with a diverse passenger base.
- Data Integration: The system must collect and analyse ridership patterns to adjust frequency based on demand and optimize fleet deployment.

This design emphasizes efficiency on core travel routes, leveraging the reliability of AV technology to provide consistent, high-frequency service along established transport corridors.

### 5.4.2 Feeder Service - AV On-Demand Design

The Feeder Service concept for an on-demand autonomous vehicle (AV) transport service is designed to connect residential areas, business parks (such as BVP), and other key locations with major transport hubs or AV shuttle stops. Rather than sticking to fixed routes, the service covers a flexible area, acting as a connector between local neighbourhoods and the primary transport network. It brings passengers from their nearby dwellings or transport stops to the larger trunk route or shuttle system for long-distance travel. This use case specifically is to be applied to the example of BVP and creating a flexible feeder service to and from a proposed AV trunk route service.

5.4.2.1 Summary of Operational Requirements:

- Dynamic Routing: Unlike the fixed Trunk Route, the Feeder Service requires dynamic, flexible routing based on real-time passenger demand. AVs will need advanced route optimization algorithms to ensure minimal detours while picking up and dropping off passengers.
- On-Demand Scheduling: Passengers use an app to request rides, and the service responds dynamically. This requires seamless integration with passenger booking systems that can handle ad-hoc trip requests and intelligently route vehicles to maximize efficiency.
- Expanded Coverage: The service must cover a broader geographic area, including residential neighbourhoods and key transport nodes. This requires precise mapping and vehicle tracking to manage an expansive service zone and ensure accurate navigation to less frequented areas.
- Shorter Distances: As the feeder service operates over relatively short distances, vehicle utilization needs to focus on maximizing the number of trips per hour, meaning quick turnarounds and minimal idle time.
- Smaller Vehicle Fleet: Given the shorter, more localized trips, the feeder service may require smaller, more agile AVs that can navigate residential streets and areas with limited road space. These vehicles should be optimized for short, frequent trips rather than high passenger volumes.
- Passenger Accessibility: The system must provide reliable access for a diverse passenger base, including residents and workers who need connections to the AV shuttle stops or transport hubs. Ensuring that all vehicles are accessible to individuals with mobility issues is crucial.
- Integration with transport Network: The service needs to synchronize its operations with the larger transport system (e.g., AV shuttles, bus lines, or metro systems), ensuring timely connections for passengers transferring from the feeder service to long-distance transport options.
- Data-Driven Deployment: The system must continuously collect and analyze data to understand travel patterns and adjust service zones, vehicle deployment, and schedules to meet varying demand across different times of day.
- Regulatory and Safety Compliance: Feeder AVs must comply with safety regulations for operating in residential areas, including adhering to speed limits, pedestrian safety protocols, and traffic laws.

This service design focuses on improving accessibility for local communities, offering a convenient connection between residential or business areas and major transport hubs, ultimately enhancing the effectiveness of the broader AV transport system.

### 5.4.3 Flexi Feeder Service - AV On-Demand Design

The Flexi Feeder Service concept is designed to provide flexible, door-to-door or point-to-point transport for passengers. This service not only connects riders to key transport hubs or connectors but also takes them directly to their final destination, whether it be a home, workplace, or public facility. It is a highly adaptable and demand-responsive service that adjusts in real-time to passenger requests, offering the convenience of direct transportation with the efficiency of a shared ride model.

5.4.3.1 Summary of Operational Requirements:

- Fully Dynamic Routing: The Flexi Feeder Service requires an advanced dynamic routing system that optimizes routes in real-time based on passenger requests. This involves continuously calculating the most efficient way to pick up and drop off passengers at their homes or other key pickup locations while minimizing travel time and detours for all riders.
- On-Demand, Door-to-Door Service: Unlike traditional transport services, the Flexi Feeder allows for door-to-door or point-to-point pickups and drop-offs. The service must have a robust booking platform that lets passengers request rides from any location within the service area. This includes real-time updates on vehicle arrival times and route changes.
- Geographically Expanded Service Area: The Flexi Feeder Service must operate over a broad, flexible coverage area, which includes residential homes, businesses, and transport hubs. AVs must be capable of navigating complex road networks, residential streets, and high-density urban environments while optimizing the pickup and drop-off points to reduce unnecessary travel.
- Efficient Ride Matching: The service must deploy ride-matching algorithms that group passengers traveling in similar directions to maximize vehicle occupancy without causing significant delays for any individual rider. This ensures that the service remains efficient and cost-effective, while still offering flexible, direct transport.
- Adaptive Scheduling: Flexi Feeder vehicles must be available on-demand, but they also need to maintain flexible scheduling options that adapt to varying passenger demands at different times of the day. This requires smart fleet

management systems to ensure vehicle availability and efficient deployment during peak and off-peak hours.

- Passenger Communication: Since the service offers customized routing, passengers need to be informed about real-time updates to their journey, such as estimated pick-up times, route changes, and vehicle arrival times. This requires a responsive communication system, often integrated into the passenger app, to keep users informed.
- Seamless Integration with Broader transport System: While the Flexi Feeder Service may offer direct trips to destinations, it also acts as a connector for passengers traveling to transport hubs for long-distance travel. This requires integration with larger transport networks to ensure timely drop-offs and pick-ups that align with other modes of transport (e.g., trains, buses, or AV shuttles).
- Small to Medium-Sized AV Fleet: Since the service caters to individual passenger requests, a fleet of smaller AVs may be required to navigate residential areas and accommodate frequent stops. These vehicles must be capable of efficiently handling shorter, multi-stop trips, while still maintaining enough capacity for grouped passengers.
- Accessibility Features: Vehicles must be equipped to accommodate passengers with varying mobility needs, ensuring that door-to-door services are available to all, including those with disabilities. Automated accessibility features like ramps and real-time assistance through the app are critical.
- Data-Driven Operational Efficiency: The service relies heavily on data analytics to monitor travel patterns, optimize routing, and predict demand fluctuations. This data helps adjust vehicle deployment, route planning, and resource allocation to ensure operational efficiency and passenger satisfaction.
- Compliance and Safety: The Flexi Feeder Service must comply with local traffic regulations, particularly when operating in residential areas, and prioritize passenger safety through real-time vehicle monitoring, emergency intervention systems, and collision avoidance technologies.

This service design emphasizes maximum flexibility, offering highly personalized transport options that cater to individual rider needs, while still maintaining the shared efficiency of public transport. The ability to combine direct-to-destination and connector routes makes it ideal for areas with dispersed populations and varying transport demands.

The three identified service design concepts, along with the results from the transportscan activity and the results of the user profiling completed within work package 2, have informed our methodology and approach to conducting operational simulations.

## 5.5 Simulation Outputs

The operational simulation process used by Liftango to test service design concepts involves creating a digital model of the proposed on-demand transport service to assess its operational viability. This process allows for the evaluation of how the service would function in real-world conditions, testing different scenarios to optimise efficiency, performance, and passenger experience before implementation. Below is an overview of the key steps in the process:

### 5.5.1 1. Data Collection and Input

Passenger Demand Data: Liftango collects historical and projected passenger data, such as travel patterns, peak demand times, and popular routes, to understand the potential user base for the service.

Geographical Data: This includes mapping data of the service area, road networks, pick-up/drop-off points, transport hubs, and key locations. Geographic Information System (GIS) tools are often used to model these networks.

Vehicle and Fleet Data: Vehicle types, capacities, and operational characteristics such as speed, range, and energy consumption are integrated into the simulation.

Traffic and Environmental Factors: Traffic patterns, congestion points, weather conditions, and time-of-day variations are also accounted for in the simulation.

### 5.5.2 2. Scenario Modelling

Different service design concepts (e.g., Trunk Route, Feeder Service, Flexi Feeder Service) are modelled based on the collected data. Each design's parameters, such as route configurations, fleet size, vehicle types, and service zones, are inputted to simulate how they will function under various conditions.

Liftango creates multiple scenarios to test, such as high-demand periods, vehicle breakdowns, or adverse weather, to evaluate how well the service can adapt to different challenges.

### 5.5.3 3. Demand-Responsive Algorithm Testing

Liftango's simulation process tests demand-responsive transport (DRT) algorithms that dynamically allocate vehicles to passenger requests. These algorithms simulate real-time bookings, vehicle routing, and ride-matching to ensure passengers are picked up and dropped off efficiently.

In the case of flexible services, like the Flexi Feeder, the simulation tests the performance of routing algorithms in balancing direct trips and multi-stop shared rides, ensuring minimal delays and optimal resource utilisation.

### 5.5.4 4. Key Performance Metrics Evaluation

The simulation process evaluates a variety of operational metrics, including:

- Average wait time for passengers between booking and pick-up.
- Journey time for each passenger, including walking, riding, and connection times.
- Fleet utilization and the number of vehicles required to meet demand.
- Vehicle occupancy rates, ensuring that the service optimizes ridesharing without sacrificing passenger experience.
- Operational costs, such as fuel or energy consumption, driver/steward costs (in Phases 1 and 2), and maintenance.
- Service reliability under different operational scenarios, including traffic delays and vehicle malfunctions.

### 5.5.5 5. Cost-Benefit and Scalability Analysis

The simulation estimates the cost-efficiency of each service design, analysing operational costs against projected revenues. This helps assess the long-term sustainability of the service, as well as its capacity to scale to higher demand or expand to new areas.

Simulations can also explore different funding models, such as passenger fares, subsidies, and partnerships, to determine how to support the service financially.

### 5.5.6 6. Iteration and Optimization

The simulation process is iterative, meaning the results of the initial simulations are used to refine the service design. Liftango may adjust variables like fleet size, routing algorithms, or passenger booking methods to optimize performance.

This iterative process ensures that the service design is continuously refined until the optimal balance between cost, efficiency, and passenger satisfaction is achieved.

### 5.5.7 7. Operational Viability Assessment

After the simulation is complete, Liftango evaluates the operational viability of the service design concepts. This assessment is based on the performance metrics analysed during the simulation and helps determine whether the service is feasible to launch or needs further adjustments.

Feasibility reports are generated, highlighting key insights from the simulation, including potential challenges, areas for improvement, and recommendations for the service rollout.

### 5.5.8 8. Testing Real-World Scenarios

Simulations often include the testing of real-world scenarios, such as varying levels of passenger demand, emergencies, traffic fluctuations, and environmental impacts, ensuring that the service is resilient and adaptable to operational realities.

Liftango's operational simulation process is a critical part of ensuring that new on-demand AV services can meet the demands of passengers while being cost-effective, scalable, and reliable. By simulating these services, Liftango can fine-tune their design before implementation, reducing risks and enhancing overall service quality.

## 5.6 Simulation Results

### 5.6.1 Trunk Route - Classical AV Service Design

We conducted a number of simulations across a number of different service configurations and metrics with the below fleet sizes, specifically related to the fixed trunk route AV service:

| Scenario | Required Vehicles |
|---|---|
| 12 Seaters | 15 |
| 43 Seaters | 10 |
| 65 Seaters | 8 |

*Table 10 Simulation scenarios*

The simulation outputs using the metrics in Table 10, based on a forecasted demand of 500 trips per day, across both peak and off-peak services. The operational metrics from this section of the work package have been used to support the wider cost assessment exercise. A larger version of Figure 42 is available in section C.1 of the companion Appendix document.

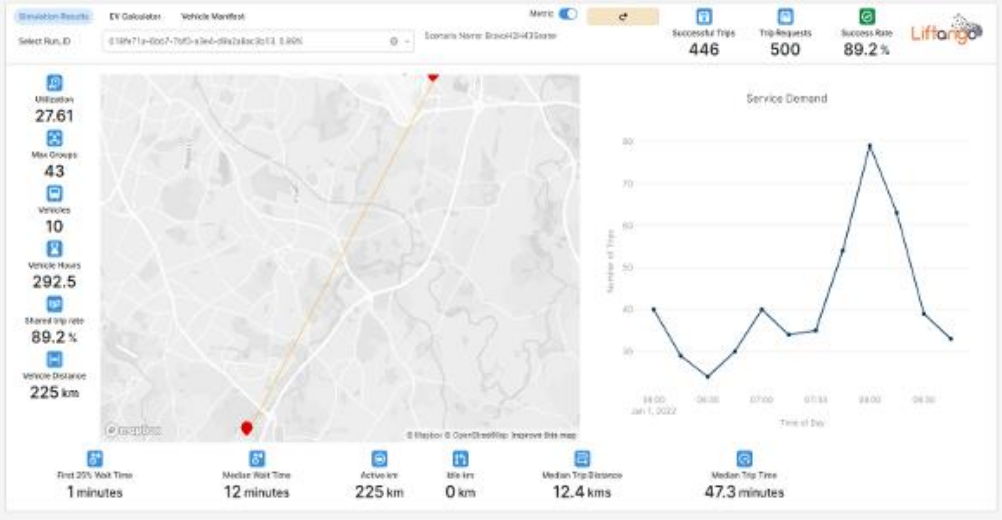



*Figure 42 Trunk route simulation result visualisation*

## 5.6.2 Feeder and Flexible Service Design Methodology

When we conducted simulations for the feeder and flexi services, we focused on three core service considerations, following our user group surveys and analysis we felt these were important metrics to consider in a more flexible transport service offering. These were the deviation level, trips provided (% success) and median trip time which we've explained further below.

*Deviation Level*

Deviation level refers to how much the vehicle's actual route deviates from the optimal or predefined route (for example, the most direct route from point A to point B). In an on-demand AV service, deviation occurs when the vehicle detours to pick up or drop off additional passengers who are traveling along a similar route.

- High deviation levels can negatively impact the passenger experience, as riders may experience longer travel times than expected. By simulating deviation levels, service providers can understand the balance between efficient ridesharing and minimizing passenger inconvenience.
- Minimizing deviations helps to maintain operational efficiency, as vehicles can stick closer to their optimal routes, reducing fuel/energy consumption and travel time. Simulations test how much deviation is acceptable without harming service quality.
- Simulations allow for the testing of algorithms that seek to minimize deviation while still accommodating multiple passengers. Understanding this helps to optimize these algorithms for real-world deployment, particularly in dynamic, flexible service models like Feeder or Flexi Feeder services.

*Trips Provided (% Success)*

This metric measures the percentage of successful trips provided compared to the total number of trip requests made by passengers. A "successful" trip is one where a vehicle is available to fulfil the request within an acceptable time frame, and the passenger reaches their destination.

- A high percentage of successful trips indicates that the service is reliable and able to meet passenger demand. Simulations assess how well the fleet copes with various levels of demand and how often it fails to provide timely service.
- Simulations test fleet size and deployment strategies to ensure that the service can meet demand without requiring an oversized fleet, which would increase operational costs. If the trips' provided percentage is low, it suggests the need for additional vehicles or more efficient vehicle dispatch.
- A higher percentage of trips provided ensures greater customer satisfaction, as passengers are less likely to face long wait times or cancellations. Simulations help test different demand scenarios (peak vs. off-peak times) to identify strategies that maintain a high success rate.

*Median Trip Time*

Median trip time refers to the median time it takes for passengers to complete their journey, from pick-up to drop-off, across all simulated trips. The median value provides a more balanced view than the average, as it's less affected by outliers (such as extreme delays or very short trips).

- Trip time is a critical factor in passenger satisfaction. A longer-than-expected trip can lead to frustration, particularly if it is significantly longer than the same journey by other modes of transport. By simulating median trip times, operators can assess how well the service is meeting passenger expectations for timely journeys.
- Efficient trip times indicate that vehicles are being used effectively, with minimal delays caused by detours, traffic, or system inefficiencies. Shorter trip times lead to faster vehicle turnaround, allowing more trips to be provided with the same fleet, thus improving service capacity.
- Simulations allow service providers to test how different variables, such as traffic patterns, routing algorithms, passenger demand, and fleet size, affect

trip times. Understanding median trip time helps in fine-tuning the service to reduce delays and ensure that passengers are reaching their destinations in an optimal time frame.

These metrics provide insights into how the system might perform in the real world under various conditions, such as peak demand, unexpected traffic, or varying fleet sizes. Achieving good results for all three metrics in the simulation phase ensures the operational viability of the service when implemented.

### 5.6.3 Feeder Service - AV On-Demand Design

We assumed a demand level of 300 trips per day for the feeder service, on the basis that the vehicle is smaller and a greater level of flexibility is required. This formed the basis of our simulations, which we performed over 3 different fleet sizes. As shown in the table below, we focused on three other core service considerations, following our user group surveys and analysis we felt these were important metrics to consider in a more flexible transport service offering.

| Number of Vehicles | Deviation Level | Trips Provided (% Success) | Median Trip Time |
|---|---|---|---|
| 5 | Low | 198 (66%) | 15.7min |
| | High | 248 (83%) | 19.8min |
| 7 | Low | 251 (83%) | 16.9min |
| | High | 285 (95%) | 19.3min |
| 10 | Low | 291 (97%) | 16.6min |
| | High | 295 (98%) | 19.2min |

From the table, we selected a high deviation level with 7 vehicles as a final service configuration to further analyse and feed into our operational cost assessment. The simulation output metrics are shown in Figure 43. A larger version of Figure 43 can be found in section C.2 of the companion Appendix document.

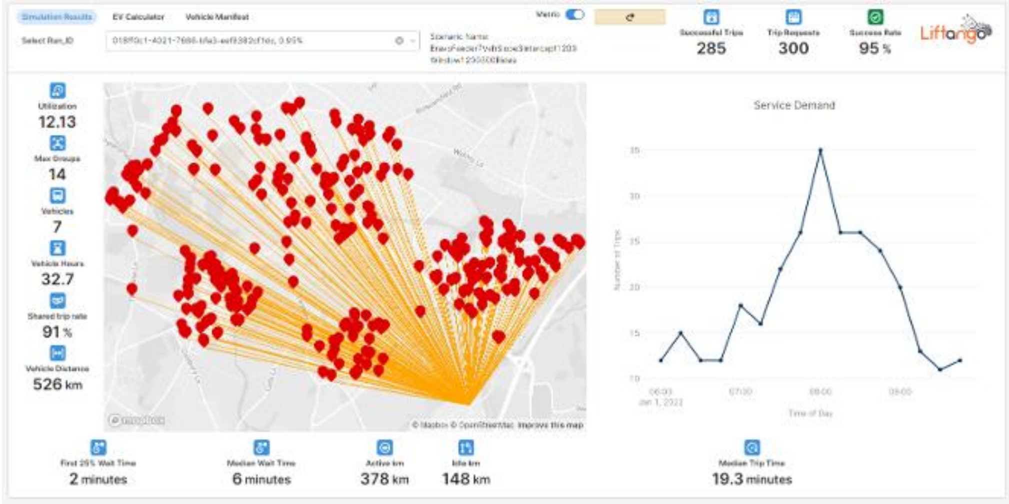



*Figure 43 Feeder service simulation result visualisation*

### 5.6.4 Flexi Feeder Service - AV On-Demand Design

We assumed a demand level of 500 trips per day for the Flexi feeder service, on the basis that there is a proposed larger fleet size to account for a combined feeder and trunk route service. As consistent with the simulations performed for the feeder service, we split our assessment across the deviation level, trips provided (% success) and median trip time.

| Number of Vehicles | Deviation Level | Trips Provided (% Success) | Median Trip Time |
|---|---|---|---|
| 15 | Low | 383 (76.6%) | 21.3min |
| | High | 398 (79.6%) | 28.4min |
| 20 | Low | 430 (86.0%) | 23.3min |
| | High | 474 (94.8%) | 27.0min |
| 25 | Low | 475 (95.0%) | 23.9min |
| | High | 477 (95.4%) | 26.9min |

From the table, we selected a high deviation level with 20 vehicles as a final service configuration to further analyse and feed into our operational cost assessment. The simulation output metrics are shown in Figure 44. A larger version of Figure 44 can be found in section C.3 of the companion Appendix document.

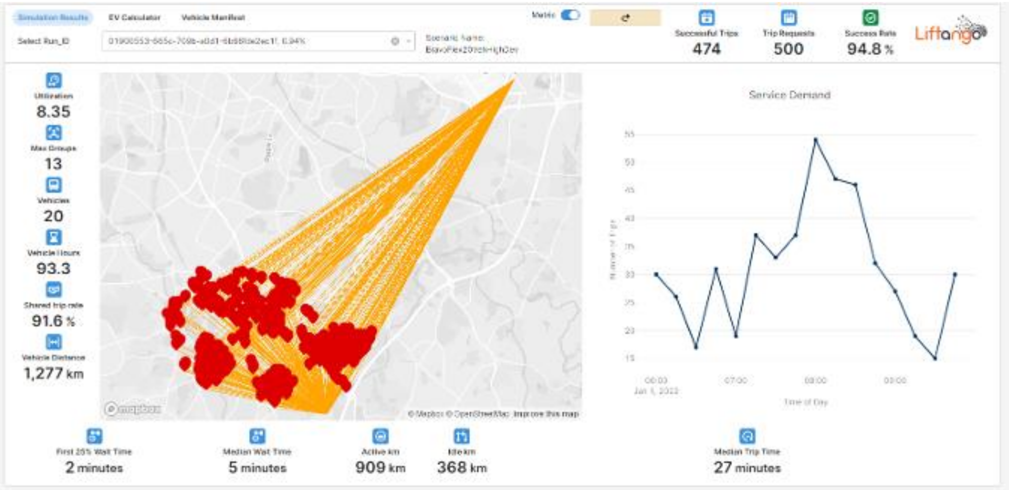



*Figure 44 Flexi feeder service simulation result visualisation*

## 5.7 Where are the Gaps?

A series of simulations were conducted for a classic trunk route autonomous vehicle (AV) service, based on various fleet sizes. A series of simulations were conducted for a classic trunk route AV service, based on various fleet sizes. For a forecasted demand of 500 trips per day, simulations tested different vehicle capacities: 15 vehicles for 12-seaters, 10 vehicles for 43-seaters, and 8 vehicles for 65-seaters. These operational metrics were critical in assessing the cost implications of the fixed-route AV service.

For the feeder service, simulations focused on deviation levels, percentage of successful trips, and median trip times. A demand of 300 trips per day was assumed, and fleet sizes of 5, 7, and 10 vehicles were tested. Results indicated that a high deviation level with 7 vehicles, providing a 95% trip success rate and a median trip time of 19.3 minutes, was the most optimal configuration for further cost analysis.

For the flexi feeder service, simulations were based on a higher demand of 500 trips per day, with a larger fleet accommodating both feeder and trunk routes. Fleet sizes of 15, 20, and 25 vehicles were tested. A high deviation level with 20 vehicles was selected as the most viable configuration, achieving 94.8% trip success with a median trip time of 27 minutes. This configuration was chosen for further operational cost analysis to ensure the service could handle combined feeder and trunk route demands efficiently.

Whilst the ‘Feeder’ service designs provide access to a wider potential audience and user base, it is recognised that this style of service is not the core study route. The fusion of a Demand Responsive feeder with the Trunk service might be optimal but would increase the complexity of the service by an order of magnitude.

Whilst the ‘Feeder’ service designs provide access to a wider potential audience and user base, it is recognised that this style of service is not the core study route. The fusion of a Demand Responsive feeder with the Trunk service might be optimal but would increase the complexity of the service by an order of magnitude.

Related to this improvement in access for users, a driverless ‘floating bus stop’ model should be expected to greatly increase the risk of ensuring accessibility for those with any form of physical impairment to utilise the service. The removal of an on-board driver must ensure far more than the on-going driving safety of the vehicle and passengers on board, it must also consider the day-to-day operations of a service and therefore the requirement to be ‘accessible by design’ is increased significantly. Level access boarding should be considered the best-in-class solution to this, a solution that is impossible to deliver via anything other than structured, purpose-built stops.

# Chapter 6 - Economics

*The economic case for adoption must work for commissioners, suppliers, operators and future users*

*Pillar:* *Affordable*

*Focus:* *User*

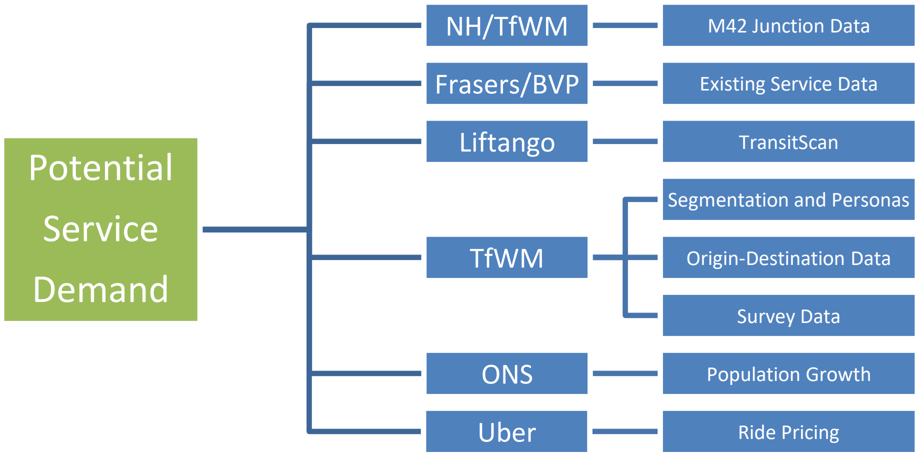
## *“The economic case for adoption must work for commissioners, suppliers, operators and future users”*

*Both private and commercial funding for new public transport routes is incredibly tight. For any service to continue, let alone be introduced at significant cost, it must be considered economically viable by all parties involved from the outset, with sufficient optimism bias built in to allow for the unexpected. A high-level analysis of projected revenue generation against capital and operating costs is required. This assessment allows a true picture of the potential of installing a CAM service on the study route. Starting by understanding likely demand is crucial.*

### **Where are we today?**

## 6.1 Data Sources

The following chapter will explore the economics of a future CAM service, which will starting by determining the likely demand for the service and then assessing expected costs of service delivery. The following diagram shows, in the right-hand column, the data sources used to determine the demand for the service.




## 6.2 Origin-Destination Analysis

### 6.2.1 Network Rail MND Datasets

The origin-destination information has been collected from Network Rail’s Mobile Network Data (MND) datasets. This is broken down to Lower Super Output Area (LSOA) resolution and shows trips to and from both BVP and NEC/BHI areas. These trips are where road is the main mode of travel (Bus, Car, LGV, HGV, Cycle) for the period of September 2023 to November 2023.

The time frame covered are:

- Weekday AM Peak (0700 → 0959)
- Weekday PM Peak (1600 → 1859)
- Weekday Off Peak (1000 → 1559 & 1900 → 0659)
- Weekend AM Peak (0700 → 0959)
- Weekend PM Peak (1600 → 1859)
- Weekend Off Peak (1000 → 1559 & 1900 → 0659)

The following figures are added here as examples.

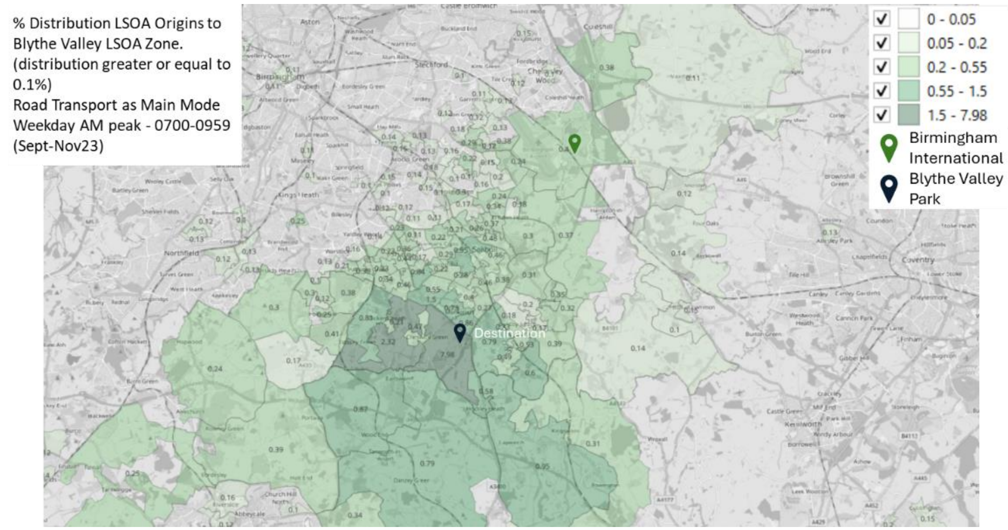



*Figure 45 A visualisation of Origins to BVP Weekday AM peak*

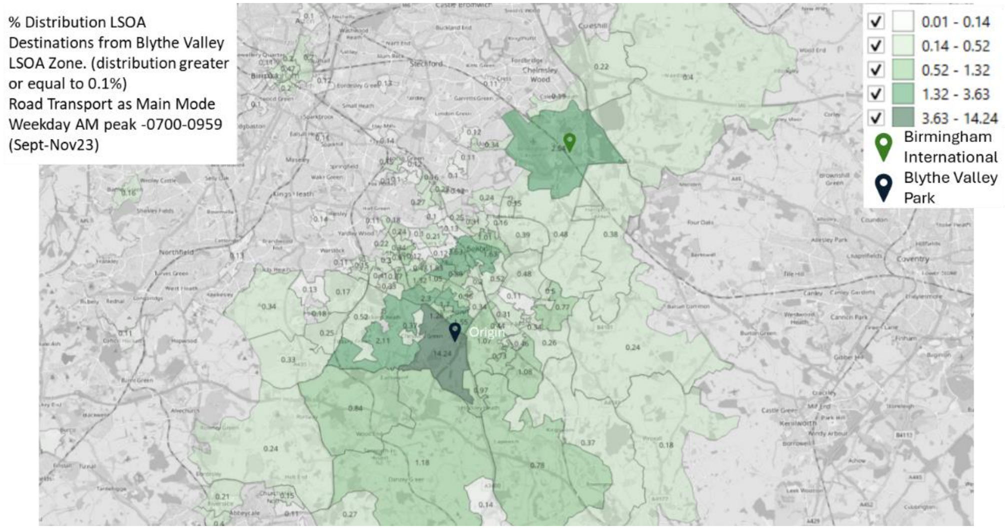



*Figure 46 A visualisation of Destinations from BVP Weekday AM Peak*

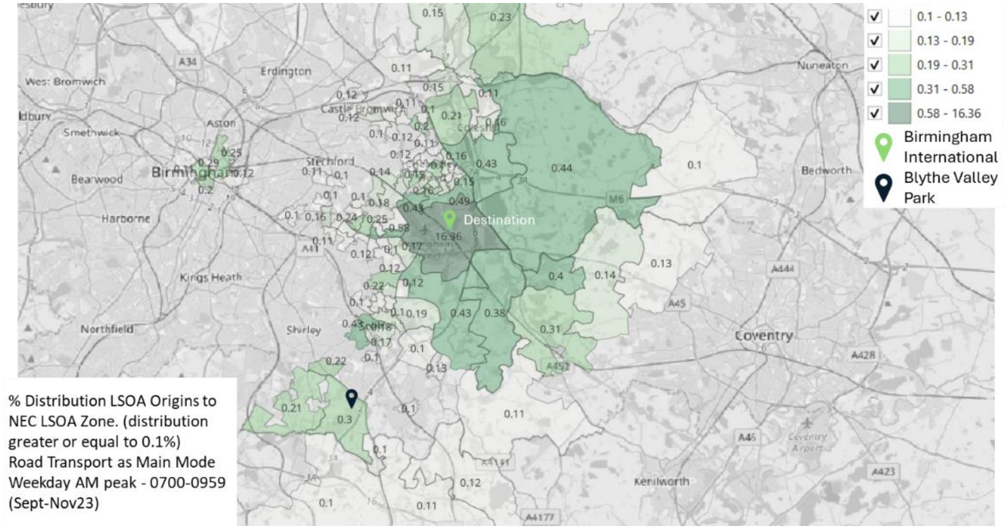



*Figure 47 A visualisation of Origins to NEC/BHI weekday AM Peak*

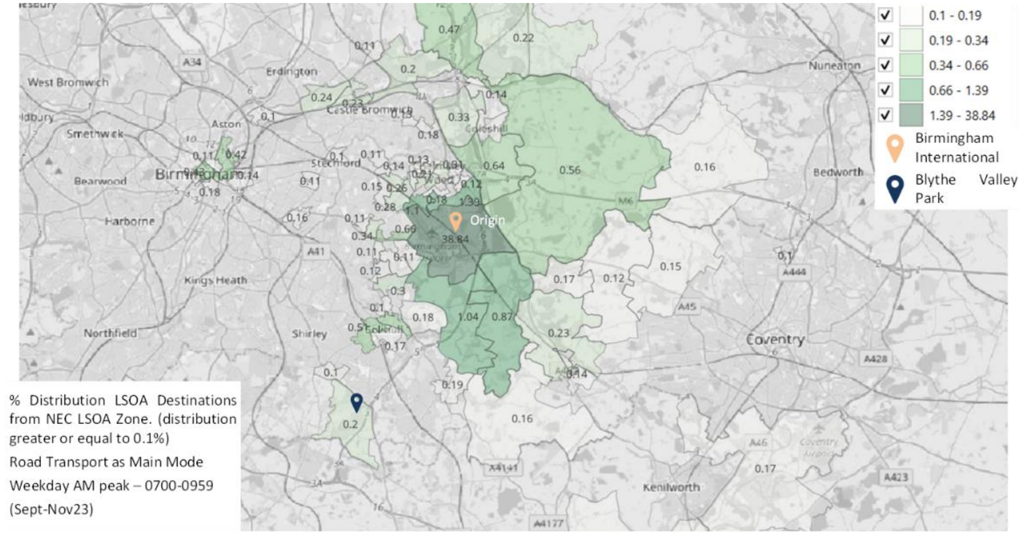


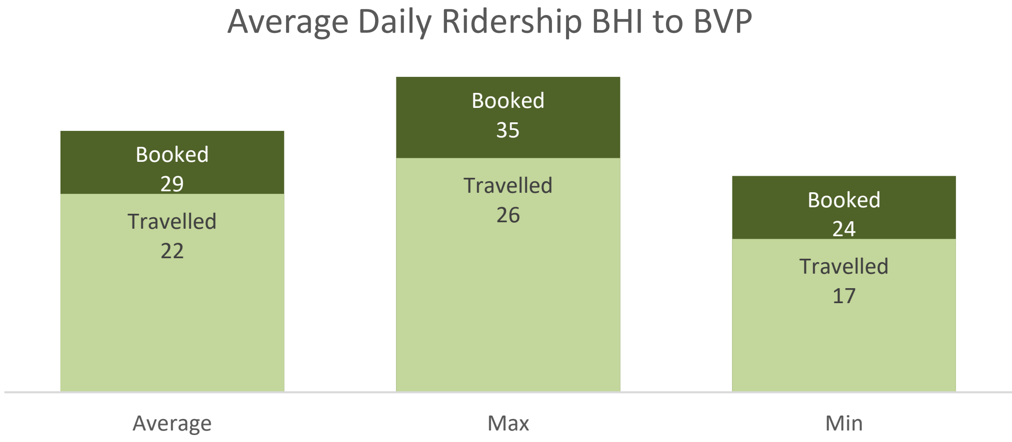

*Figure 48 A visualisation of Destinations from NEC/BHI weekday AM Peak*

The figures shown above are the most likely places where people will travel to and from to get to either BVP or NEC/BHI. For BVP, Figure 45 and Figure 46 shows that while the NEC/BHI area is reasonably common destination or origin location, it is not the most common location for either direction. Many people in the BVP area will travel from within the area or immediate surrounding areas. Likewise, they will travel to the immediately surrounding areas or local towns such as Solihull. For NEC/BHI, (Figure 47, Figure 48) again it appears that people living in this area will travel within the area or to the immediate surrounding areas. This pattern is repeated in all time frames during weekdays and weekends, these maps can be found in Appendix D.1 of the companion appendix document.

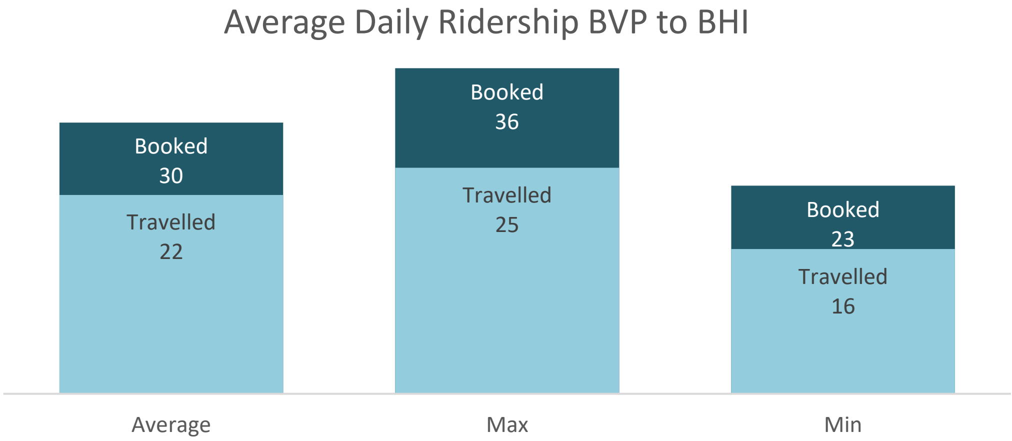
### 6.2.2 LandFlight Express Service

In addition to the public bus service, an express service is currently offered to workers at BVP. This service is not open to the general public and is offered at no cost to the workers. The service follows the study route along the M42 with two stops in BVP, one stop in FORE Business Park[12], and one stop at BHI.

[12] FORE Business Park is not linked to BVP but is in close proximity, located close to M42Jnc4.




*Graph 16 Average inbound daily ridership between Feb 2023 and Jan 2024*




*Graph 17 Average outbound daily ridership between Feb 2023 and Jan 2024*

Table 11 shows the timetable for this service. Each journey must be booked before boarding. This is only available during the working week as it is intended for commuters to BVP and FORE.

Information on the inbound and outbound ridership has been provided and is shown in Graph 16 and Graph 17. A graph of the daily usage of the LandFlight service for November 2023 is available in section D.5 of the companion Appendix document.

These charts show the daily average number of booked rides and travelled rides over the period February 2023 to January 2024. There is an approximate average of a 25% drop off between booked and travelled rides in either direction, with the highest drop off rate being 33%. Additionally, there are approximately 3,500 people working at Blythe Valley Park which indicates that the take rate for the service is approximately 0.6%.

This illustrates that when the service is offered at no cost, it does not attract customers in large numbers and has a not insignificant drop off. A part of this might be due to the drop off locations not sitting in residential area. As this service run at specific times during peak rush hour, this could make the service less appealing if the customer has doubts that they will make full use of the service.

| Direction | Time of Day |
|---|---|
| Inbound | 07:50<br>08:25<br>08:50 |
| Outbound | 16:12<br>17:07<br>17:37<br>18:07 |

*Table 11 Land Flight timetable schedule*

### 6.2.3 PRISM Datasets

In addition to this data, the following tables have been produced to investigate the number of vehicles that join the M42 and junction 6 and leave at junction 4 and vice versa. The data is taken from the Policy Responsive Integrated Strategic Model (PRISM) system, with a base year for the data of 2019 and the time frames for these tables are:

- AM Peak (0700 → 0930)
- Inter Peak (0930 → 1530)
- PM Peak (1530 → 1930)

Validation table for PRISM can be found in Appendix D.2 of the companion Appendix document. From the table collection shown in Table 12, we can calculate that on average 252 vehicles per hour make the inbound journey and 365 vehicles per hour make the outbound journey. For the inbound journeys we can see that the most popular destination direction in each time frame is Shirley. Blythe Valley is the second most popular destination directions with an average of 90 vehicles per hour. BHX/BHI is the most popular destination direction on the outbound journey, although it should be noted that both locations account for less than half the total number of vehicles exiting at their respective junctions. While the numbers suggest that there is a potential market to replace some of these journeys, it is not clear, for what percentage of these journeys, this would be appropriate.

**Total joining at Jct 6 and leaving Jct 4 = 228**

| | | Joins at Junction 6 | | | |
|---|---|---|---|---|---|
| | | Car commute | Car Business | Car Other | Total |
| Leaves at Junction 4 | Stratford Road Towards Hockley Heath | 13 | 4 | 8 | **25** |
| | Stratford Road Towards Shirley | 87 | 20 | 12 | **119** |
| | Towards Blythe Valley Business Park | 48 | 22 | 14 | **84** |

AM peak average hour inbound traffic

**Total joining at Jct 6 and leaving Jct 4 = 235**

| | | Joins at Junction 6 | | | |
|---|---|---|---|---|---|
| | | Car commute | Car Business | Car Other | Total |
| Leaves at Junction 4 | Stratford Road Towards Hockley Heath | 5 | 4 | 12 | **21** |
| | Stratford Road Towards Shirley | 34 | 41 | 69 | **144** |
| | Towards Blythe Valley Business Park | 14 | 26 | 30 | **70** |

Inter peak average hour inbound traffic

**Total joining at Jct 6 and leaving Jct 4 = 292**

| | | Joins at Junction 6 | | | |
|---|---|---|---|---|---|
| | | Car commute | Car Business | Car Other | Total |
| Leaves at Junction 4 | Stratford Road Towards Hockley Heath | 17 | 4 | 5 | **26** |
| | Stratford Road Towards Shirley | 88 | 32 | 32 | **152** |
| | Towards Blythe Valley Business Park | 52 | 36 | 26 | **114** |

PM peak average hour inbound traffic

**Total joining at Jct 4 and leaving Jct 6 = 376**

| | | Joins at Junction 4 | | | |
|---|---|---|---|---|---|
| | | Car commute | Car Business | Car Other | Total |
| Leaves at Junction 6 | A45 East | 70 | 29 | 28 | **127** |
| | A45 West | 0 | 0 | 0 | **0** |
| | Towards Airport/Int Station | 83 | 36 | 65 | **184** |
| | Towards NEC/A452 | 47 | 8 | 10 | **65** |

AM peak average hour outbound traffic

**Total joining at Jct 4 and leaving Jct 6 = 287**

| | | Joins at Junction 4 | | | |
|---|---|---|---|---|---|
| | | Car commute | Car Business | Car Other | Total |
| Leaves at Junction 6 | A45 East | 21 | 20 | 36 | **77** |
| | A45 West | 0 | 0 | 0 | **0** |
| | Towards Airport/Int Station | 15 | 26 | 71 | **112** |
| | Towards NEC/A452 | 20 | 13 | 65 | **98** |

Inter peak average hour outbound traffic

**Total joining at Jct 4 and leaving Jct 6 = 432**

| | | Joins at Junction 4 | | | |
|---|---|---|---|---|---|
| | | Car commute | Car Business | Car Other | Total |
| Leaves at Junction 6 | A45 East | 85 | 29 | 18 | **132** |
| | A45 West | 0 | 0 | 0 | **0** |
| | Towards Airport/Int Station | 66 | 47 | 59 | **172** |
| | Towards NEC/A452 | 65 | 12 | 51 | **128** |

PM peak average hour outbound traffic

*Table 12 PRISM average hourly traffic counts*

## 6.3 Segmentation & Personas

The origin-destination was used to highlight the primary customer segments that live in that area. Figure 49 and Table 13 show these segments, showing that MSOA E02002109 is dominated by three customer segments.

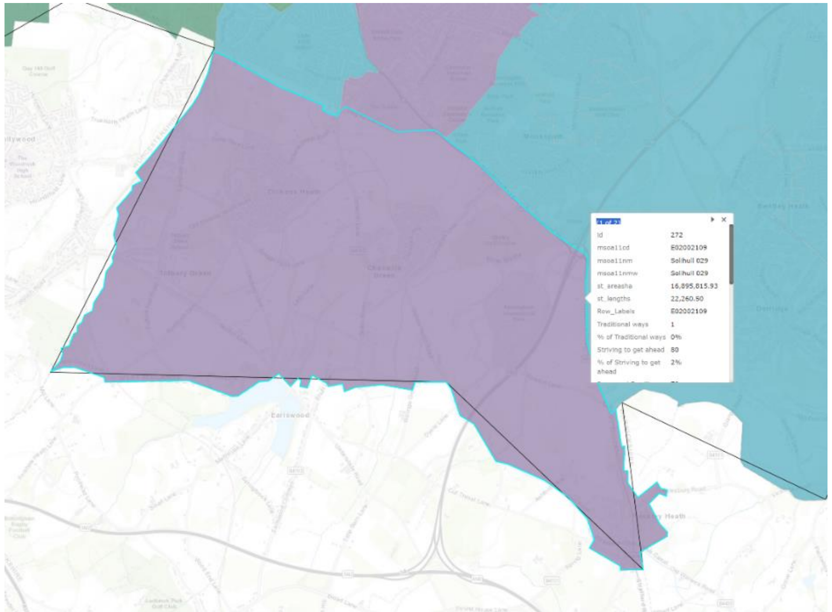
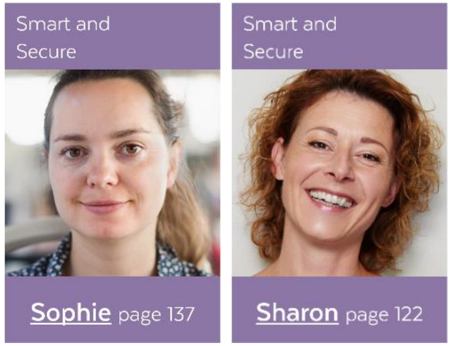


*Figure 49 Primary origin MSOA (E02002109) for visitors to BVP*

| Segment Name | Population | % of Population |
|---|---|---|
| Smart and Secure | 1,690 | 32% |
| Carefree Affluence | 1,671 | 32% |
| Progressive Families | 1,427 | 27% |
| Other Personas | 477 | 9% |
| **Total** | **5,265** | **100%** |

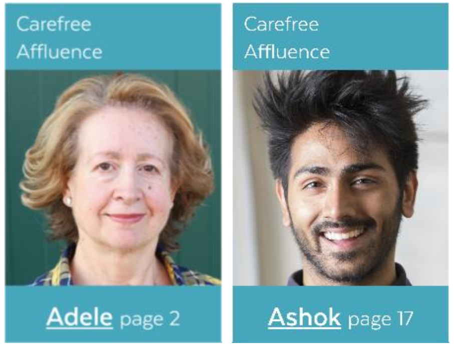
*Table 13 Segmentation breakdown for MSOA E02002109*

From these customer segments it is possible to identify customer personas, shown in Figure 50, Figure 51 and Figure 52 along with the respective segment descriptions.




*Smart and Secure are typically middle aged to older families who are likely to have children living with them. On higher incomes, and the least likely segment to have a disability. Likely to be working full time, part time or be a housewife.*

*Figure 50 Personas linked to the Smart and Secure segment*




*Carefree Affluence are the most affluent group on high incomes, they tend to invest their money and have the greatest financial resilience. They are older individuals who tend to be employed full time or retired.*

*Figure 51 Personas linked to the Carefree Affluence segment*


*Progressive Families are young to middle aged couples and families. Predominantly earning mid-range salaries, they are most likely to be working remotely since the pandemic. Those who do not work full time tend to work part time or a housewife.*

*Figure 52 Personas linked to the Progressive Families segment*

The personas were developed with the intention of understanding potential customers in the WMCA region. There are 14 personas split into 8 segments, each embodying the characteristics of that persona. These personas allow for a more detailed understanding of specific needs of the potential customers. For example, from Figure 50, Sharon has 2 pre-teen kids, one of whom has healthcare needs. This means Sharon will plan ahead to ensure things go smoothly while also trying to be prepared for issues and does not usually take spontaneous trips. By comparison, Sophie does not use public transport due to the complexity of her daily trips but is more likely to take spontaneous trips and is more open to using public transport for non-critical trips.

## 6.4 Population

The projected population growth for Solihull to 2028 and 2038 is shown in Table 14 below, taken from the Office of National Statistics (ONS) NOMIS[13] service. As can be seen, it is projected that the population of Solihull will gown by 5.33% by 2033 and 10.57% by 2043 when compared to 2023. Most of the growth will be driven by the 65+ age group but there will be growth in all age groups.

| Age | 2023 | 2033 | 2043 | % Change 2023 to 2033 | % Change 2023 to 2043 |
|---|---|---|---|---|---|
| Aged 0 to 15 | 44,010 | 44,699 | 47,784 | 1.57% | 8.58% |
| Aged 16 to 64 | 130,734 | 135,075 | 140,544 | 3.32% | 7.50% |
| Aged 65+ | 47,144 | 53,932 | 57,016 | 14.40% | 20.94% |
| Total | 221,879 | 233,706 | 245,342 | 5.33% | 10.57% |

*Table 14 Solihull Population projections by age group*

It should also be noted that MSOA E02002109 skews slightly younger than the general population of the Solihull local authority area. The largest age contingent for MSOA E02002109 is 35 to 49 year olds at 21.3%, while it the 50- to 64-year-old group is the largest contingent (20.4%) in the LA in general.

While the population is generally younger the population of the UK is becoming older[14]. This compounds factors such as health services, poverty and isolation. Age related health conditions can cause a person to lose their driving licence, taking with it their autonomy. A CAM solution can be used to supplement public transport or ambulance services and allow people to keep their autonomy and sense of freedom.

## 6.5 Surveys

For a deeper understanding, the workers and residents of BVP and surrounding areas were invited to complete a survey. The responses from these surveys were collected by processed by a team in TfWM via a General Data Protection Regulation (GDPR) compliant database. The resident survey is based on the employee survey but has been modified to be resident specific. The following sections will show the results of these surveys that relate to the service only. Chapter 1 discussed the views of workers and residents on the service being automated.

### 6.5.1 Employee Survey Results

#### 6.5.1.1 Employee Travel

The following results from the employee responses to the survey. The demographic breakdown is available in Appendix D.3 of the companion appendix document, and it should be noted that some demographic breakdowns of the results are not shown. The charts below show key information on the employees travel habits.

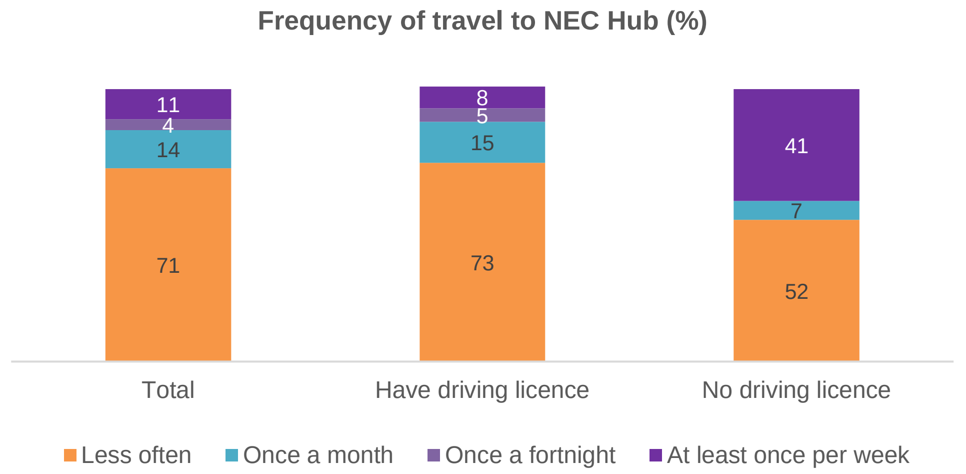
[13] Nomis - Official Census and Labour Market Statistics (nomisweb.co.uk)

[14] Our Ageing Population | The State of Ageing 2023-24 | Centre for Ageing Better (ageing-better.org.uk)

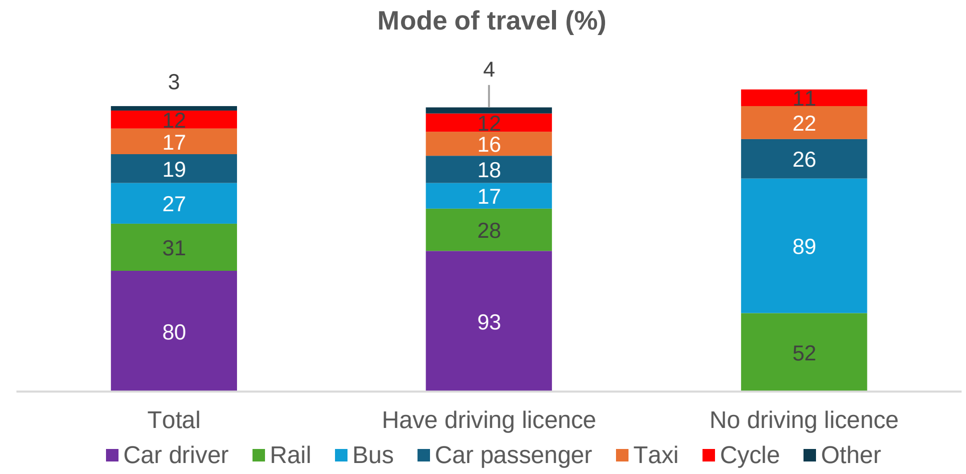
While 1 in 10 respondents travelled to the Hub once a week or more (11%), the majority travelled to the area less than once a month (71%). Younger respondents and those without a driving licence were most likely to travel to the Hub (Graph 18).

Most respondents generally travelled by car (80%, driver; 19% passenger; 17% taxi). Around a third used the train, while 27% used the bus. Younger respondents and those without a driving licence were least reliant on the car (Graph 19).

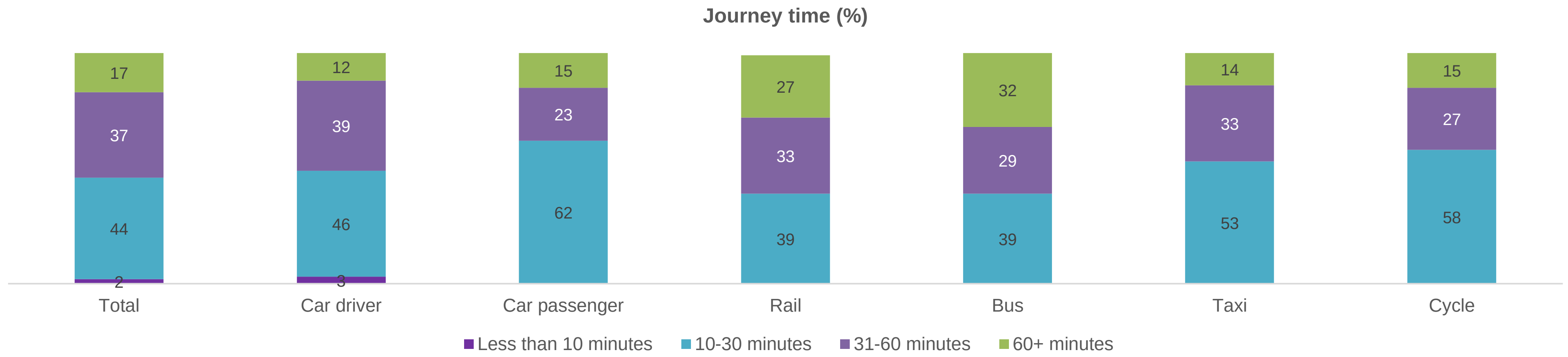
Over two fifths (44%) had a commute of between 10-30 minutes to Blythe Valley, with a further 37% travelling 31-60 minutes. 17% had a journey time of more than an hour. Those who used the bus travelled the longest with 32% travelling over an hour. 27% of rail users also travelled for over an hour (Graph 20).



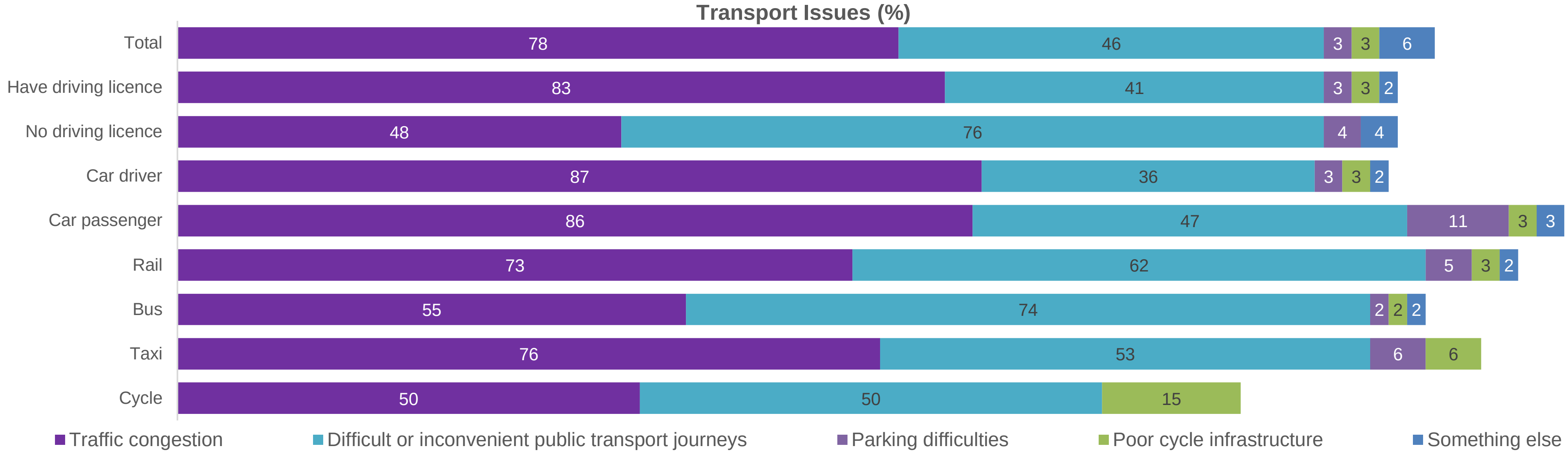

*Graph 18 Question: In general, how often do you currently travel to the NEC / Birmingham Airport / Birmingham International Rail Station?*
*Base – 211*




*Graph 19 Question: In general, what mode(s) of transport do you personally use to travel?*
*Base – 210 % exceed 100 due to multiple responses*

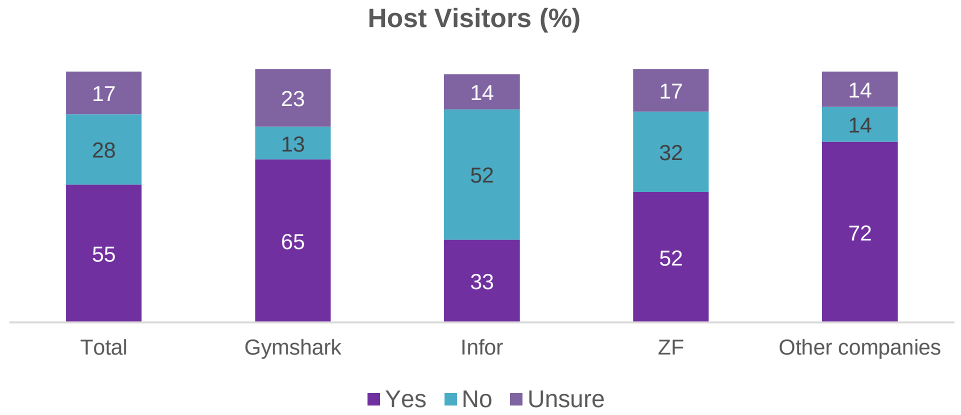



*Graph 20 Question: Roughly, how long does your trip from home to your destination at Blythe Valley/Monkspath (Junction 4 M42) take (one-way)?*
*Base – 211*




*Graph 21 Question: Do any of the following transport issues negatively impact your ability to travel to Blythe Valley/Monkspath (Junction 4 M42)?*
*Base – 193 % exceed 100 due to multiple responses*

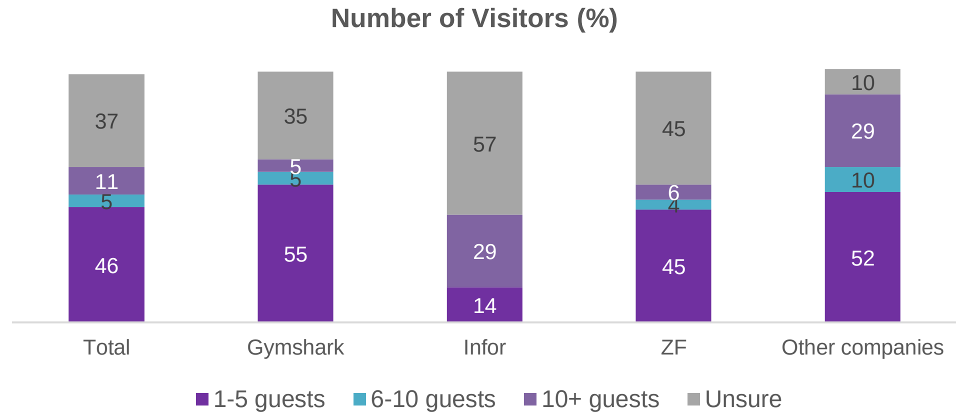
Three quarters of respondents said their journey to Blythe Valley was negatively affected by traffic congestion (78%), with this figure rising amongst car drivers (87%). 46% mentioned difficult or inconvenient public transport impacting their journeys, increasing to 74% amongst those who travelled by bus and to 67% amongst those who travelled by rail (Graph 21).




*Graph 22 Question: Does your team / department host visitors to your business premises?*
*Base – 211*

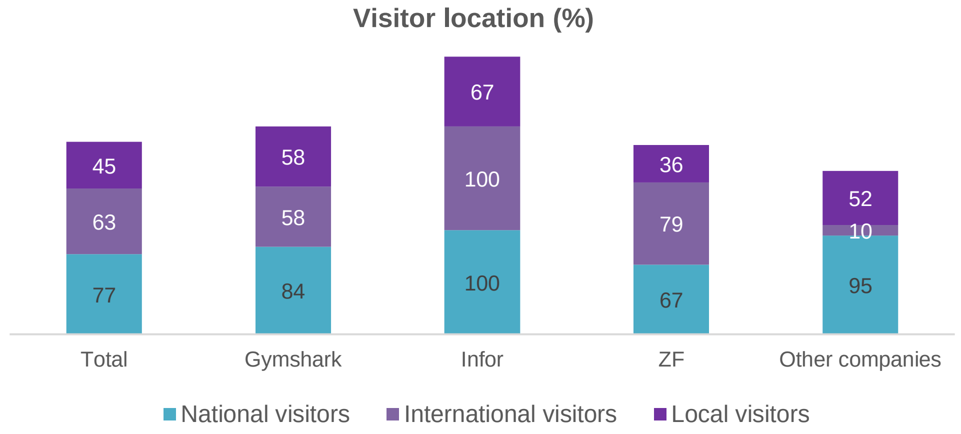
### 6.5.1.2 Visitor Travel

Over half of employees (55%) said their team/department hosted visitors to their premises (Graph 22). Most felt that their business hosted between 1-10 guests on a weekly basis (51%). However, over a third were unsure how many visitors there were to their premises (Graph 23).

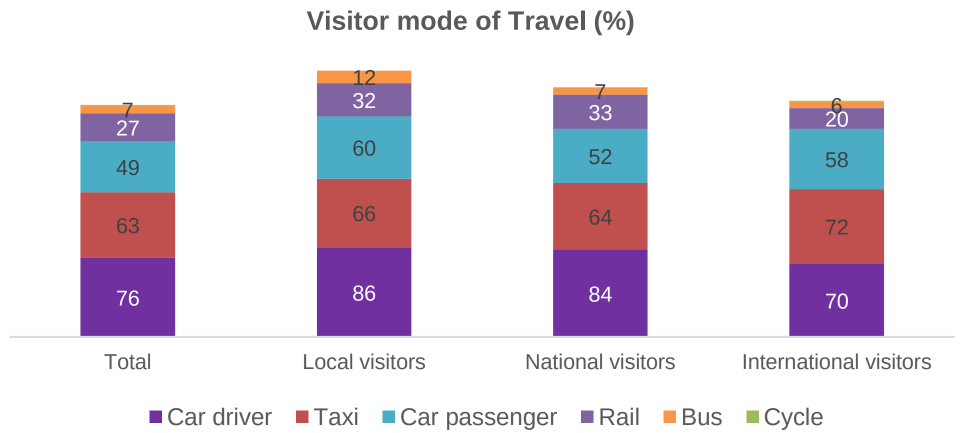



*Graph 23 Question: Roughly how many visitors would your team / department host on a weekly basis?*
*Base – 115*

Visitors travelled to the business park from national (77%) and international areas (63%), fewer were from the local area (45%) (Graph 24). Visitors mainly travelled to the Business Park by car (76% driver; 49% passenger; 63% taxi). However, around 27% travelled by train (Graph 25).



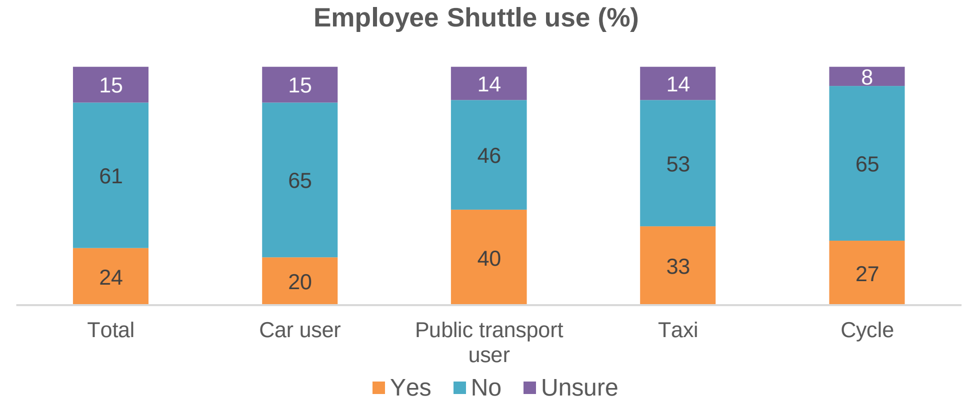

*Graph 24 Question: What kind of visitors do you usually host?*
*Base – 112*



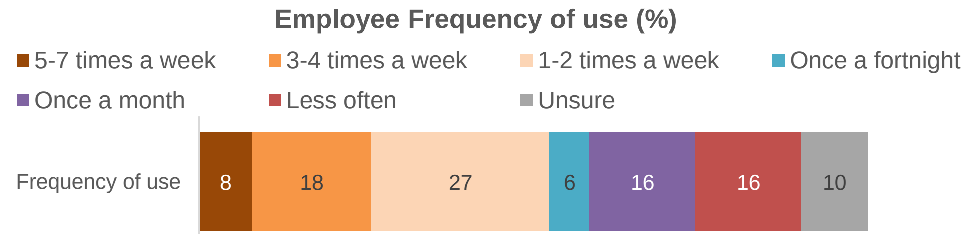

*Graph 25 Question: What is the usual mode(s) of transport that visitors use to travel to your business premises?*
*Base – 113*

6.5.1.3 Shuttle Service

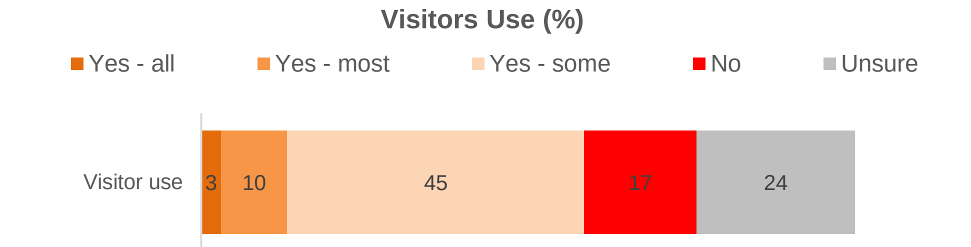
A quarter (24%) of respondents thought they would use a shuttle service, with potential use being highest amongst public transport users (40%), lowest amongst car users (20%) (Graph 26). Amongst those who would use the service around half would use it one a week or more (53%) (Graph 27). Only 13% thought all or most of their visitors would make use of the shuttle service, however 45% felt some of their visitors would use it (Graph 28).




*Graph 26 Question: Would you personally use the service described above?*
*Base – 211*




*Graph 27 Question: How often do you think you would use the service?*
*Base – 51*

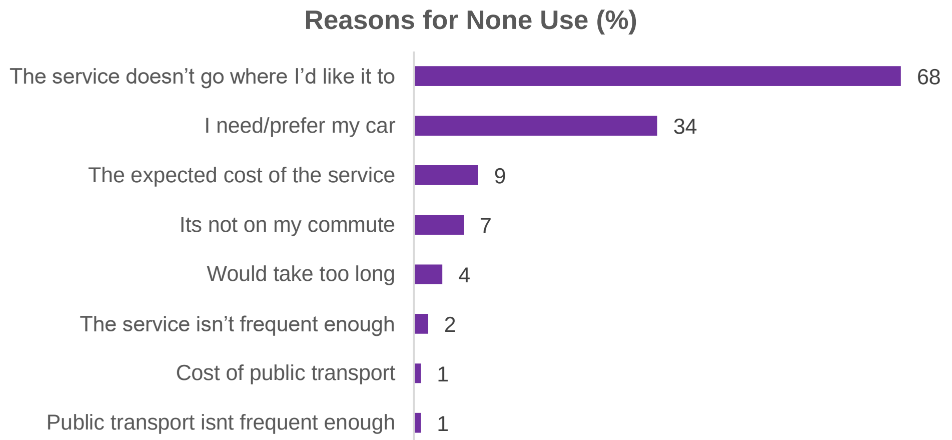



*Graph 28 Question: Do you think your visitors would use the service?*
*Base - 115*

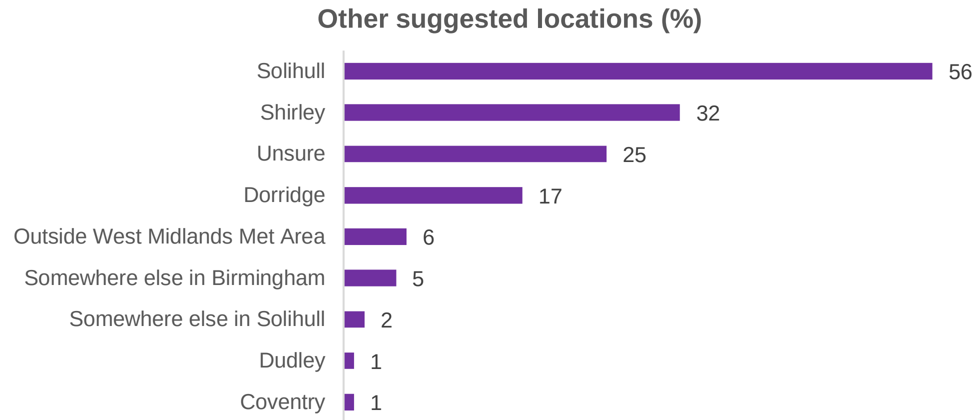
The main reasons for employees not making use of the service were service doesn't go where I would like it to (68%) and I need/prefer car (34%) (Graph 29).

Other than Blythe Valley the most popular locations for the shuttle to serve were Solihull (56%), Shirely (32%) and Dorridge (17%) (Graph 30).

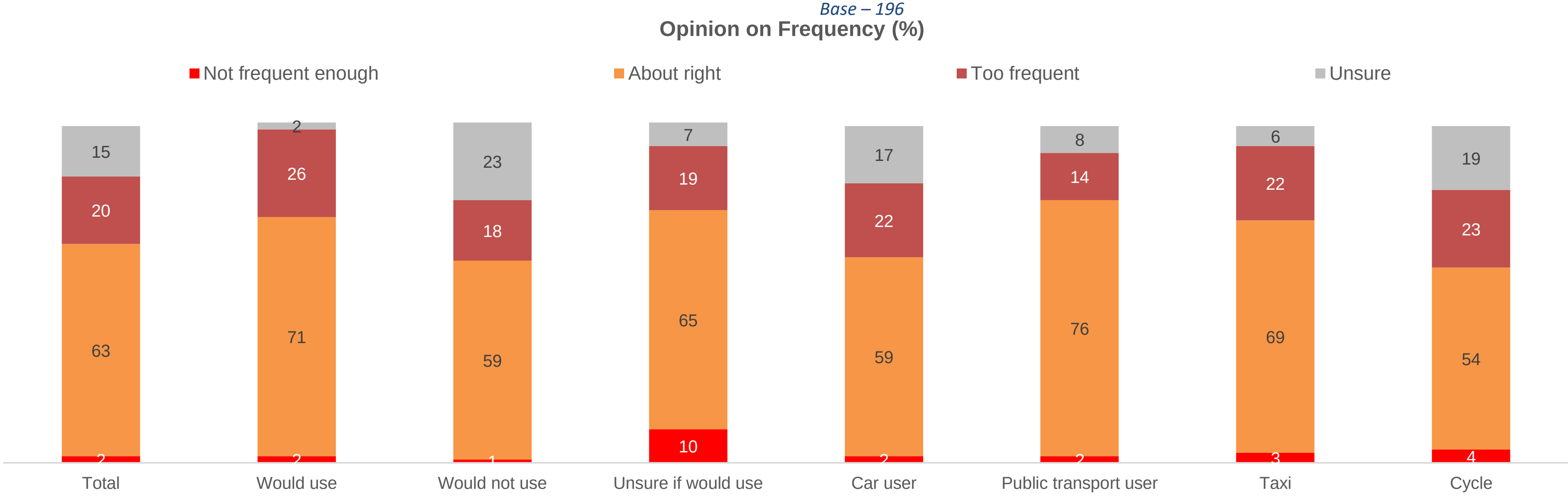
Three fifths (63%) felt that a 15-minute service frequency was about right, however, 20% thought this would be too frequent. Potential service users (71%) and public transport users were most likely to think the frequency was about right (76%) (Graph 31)




*Graph 29 Question: What would be main reasons for you not using the service?*
*Base – 134*




*Graph 30 Question: Other than Blythe Valley and Birmingham International Rail Station, where would you like the service to go?*
*Base – 196*




*Graph 31 Question: What is your opinion of the service running every 15 minutes?*
*Base – 211*

| Comments | Respondents | % |
|---|---|---|
| We need better public transport network/extend the shuttle | 26 | 58% |
| Lack of public transport options to get to Blythe Valley | 12 | 27% |
| Public transport is too slow | 10 | 22% |
| Shuttle won't impact | 3 | 7% |
| Shuttle feels too frequent for most of the time | 2 | 4% |
| More cycle options | 2 | 4% |
| Public transport too expensive | 2 | 4% |
| Don't always travel into office | 1 | 2% |
| Need to drive | 1 | 2% |
| **Base** | **45** | |

*Table 15 Question: If you have any further comments or feedback about the topics that have been discussed in this survey*
*please provide them below: Base – 45*

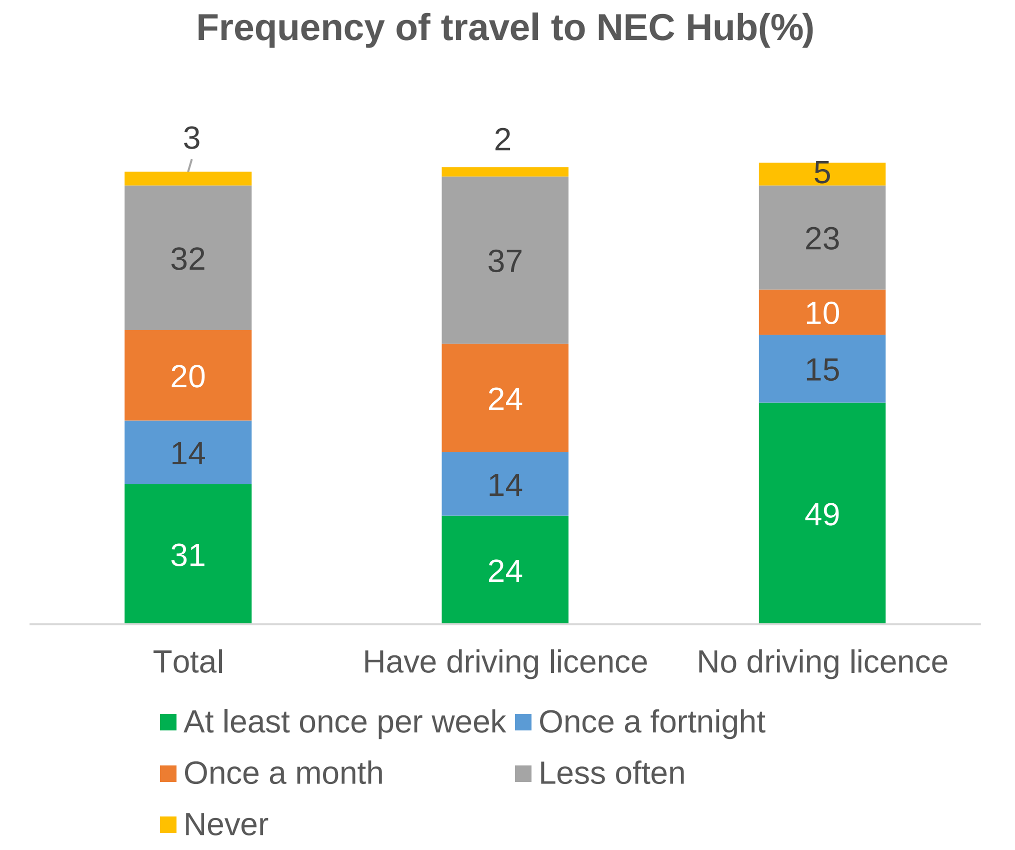
The table above (Table 15) shows the general comments on the shuttle service. As can be seen, most comments are around the need for public transport in general. The shuttle specific responses could both be considered negative in sentiment about the impact and frequency.

## 6.5.2 Residents Survey Results

The following results from the resident's responses to the survey. The demographic breakdown is available in Appendix D.4 of the companion appendix document, and it should be noted that some demographic breakdowns of the results are not shown.

### 6.5.2.1 Residents Travel

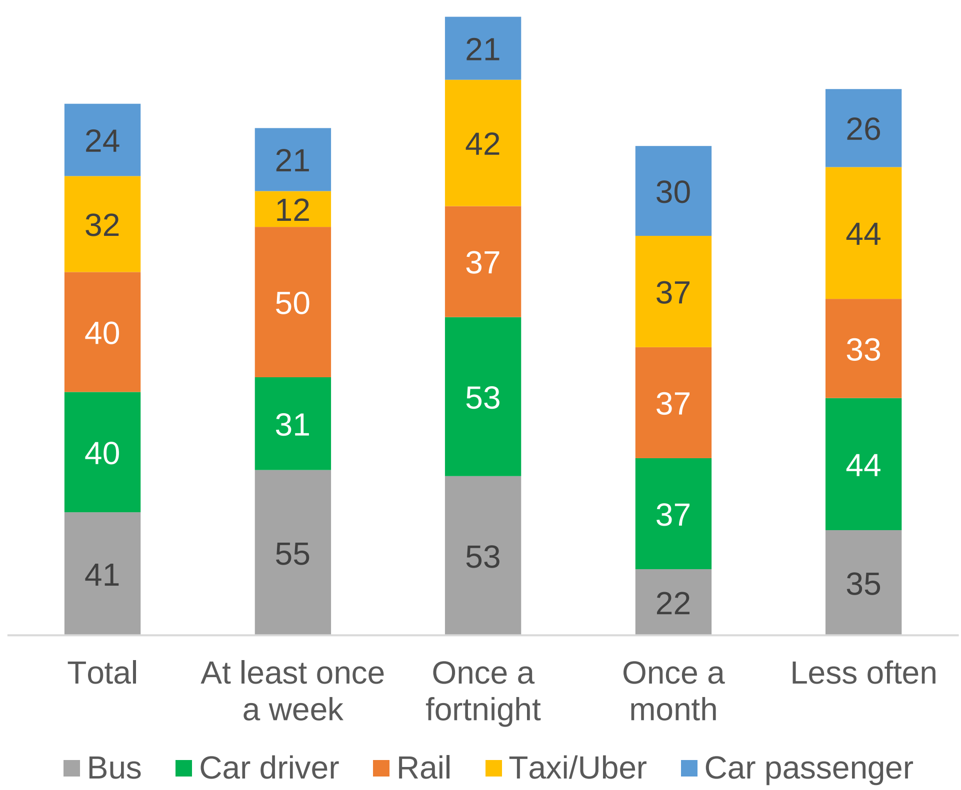
A third (31%) travelled to The Hub at least once per week, with 14% travelling once a fortnight and 20% travelling once per month. Younger respondents, females and those without a driving licence were most likely to travel to the Hub at least once per week (Graph 32).




*Graph 32 Question: In general, how often do you currently travel to the NEC / Birmingham Airport / Birmingham International Rail Station (The Hub)?*
*Base – 135*

41% used the bus to travel to the Hub, with 40% equally travelling as a car drivers or rail passenger. 32% used a taxi/uber. Younger and older respondents were most likely to travel by bus, while those aged 30-65 were most likely to travel as a car driver (Graph 33).

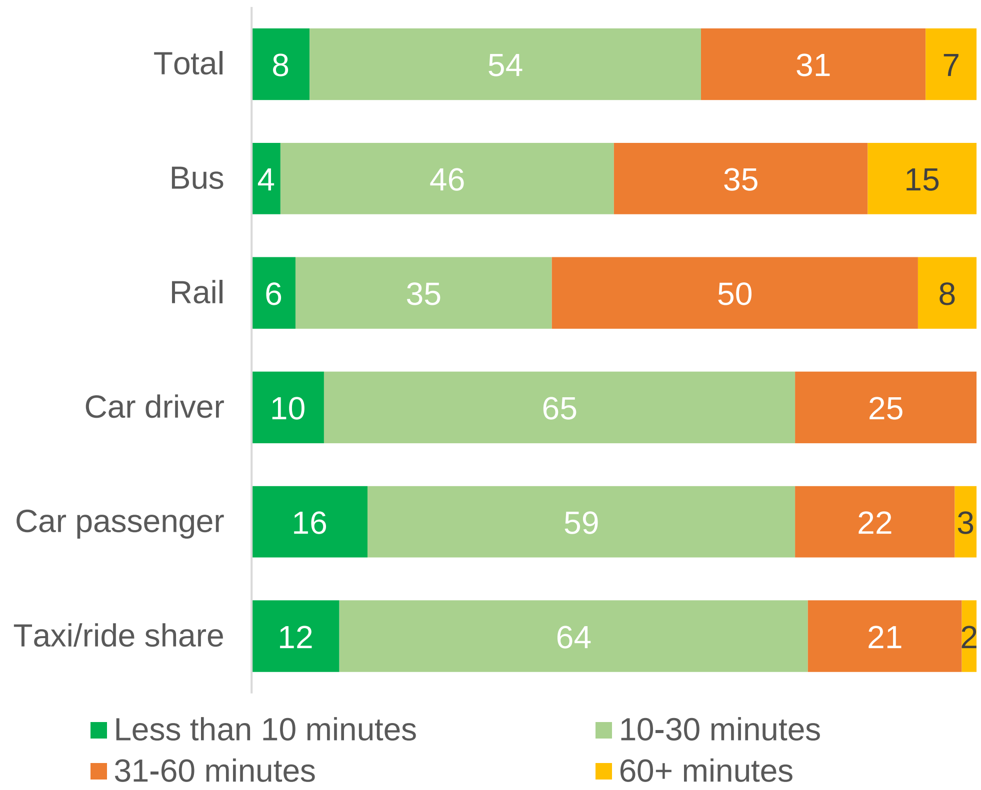
Mode of travel to NEC Hub(%)




*Graph 33 Question: In general, what mode(s) of transport do you personally use to travel to the Hub?*
*Base – 131 % exceed 100 due to multiple responses*

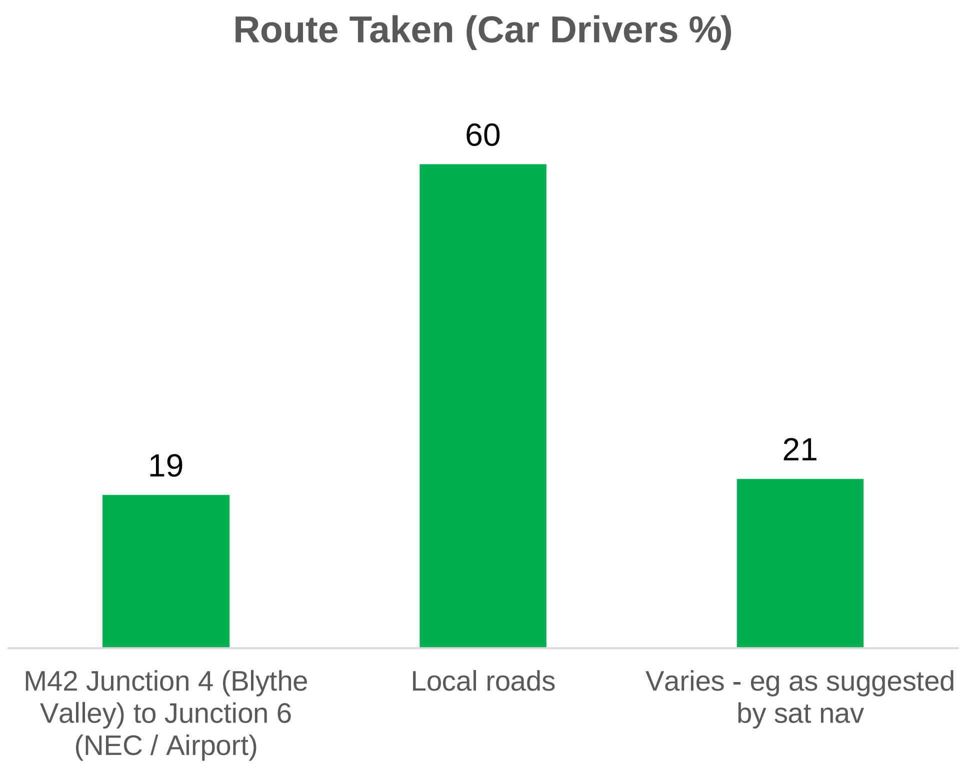
Half (54%) of respondents travelled 10 to 30 minutes to The Hub, and 31% of respondents took 31-60 minutes to get to The Hub. Bus and train users tended to have the longest journey times; car users had the shortest journey times (Graph 34).

Length of travel to NEC Hub(%)

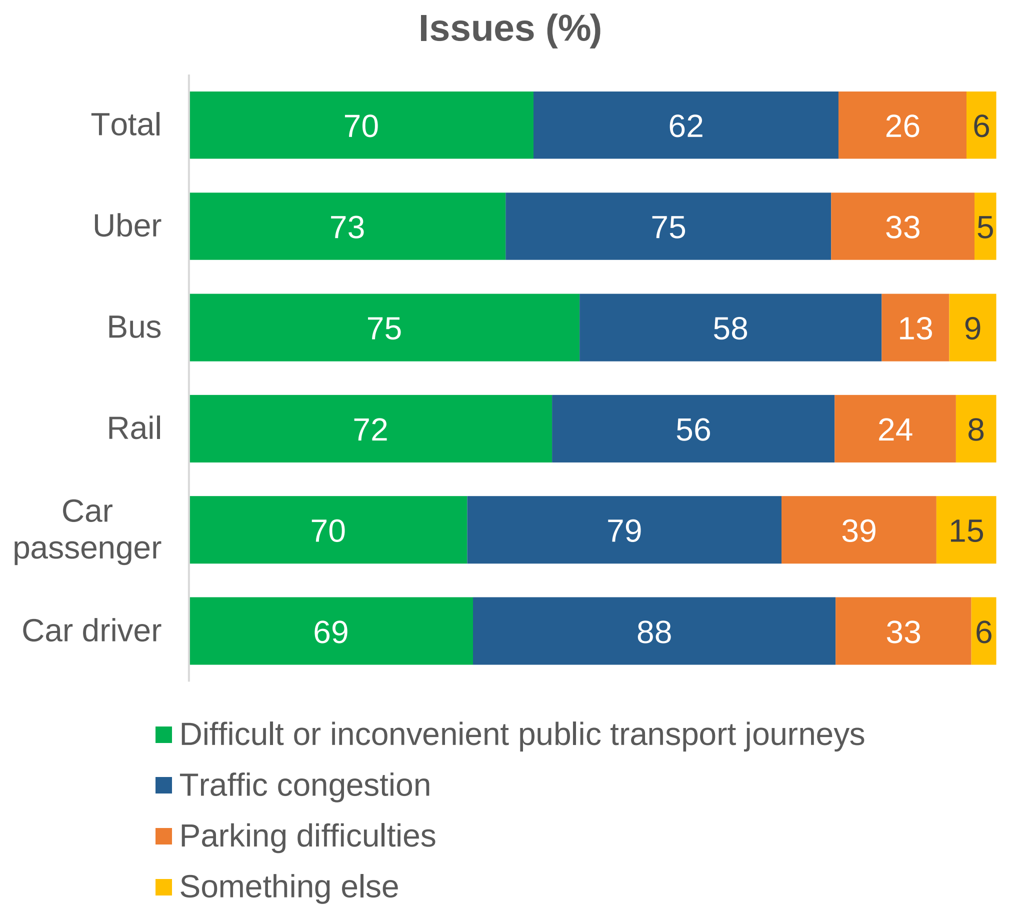



*Graph 34 Question: Roughly, how long does your trip from home to your destination at the Hub take? (one-way)?*
*Base – 131*

Car drivers tended to use local roads when travelling to the hub (60%), 19% used the M42, while 21% varied their journeys depending on traffic (Graph 35). When asked about issues encountered when making a trip the main complaint was difficult/inconvenient public transport journeys (70%), followed by traffic congestion (62%) (Graph 36).



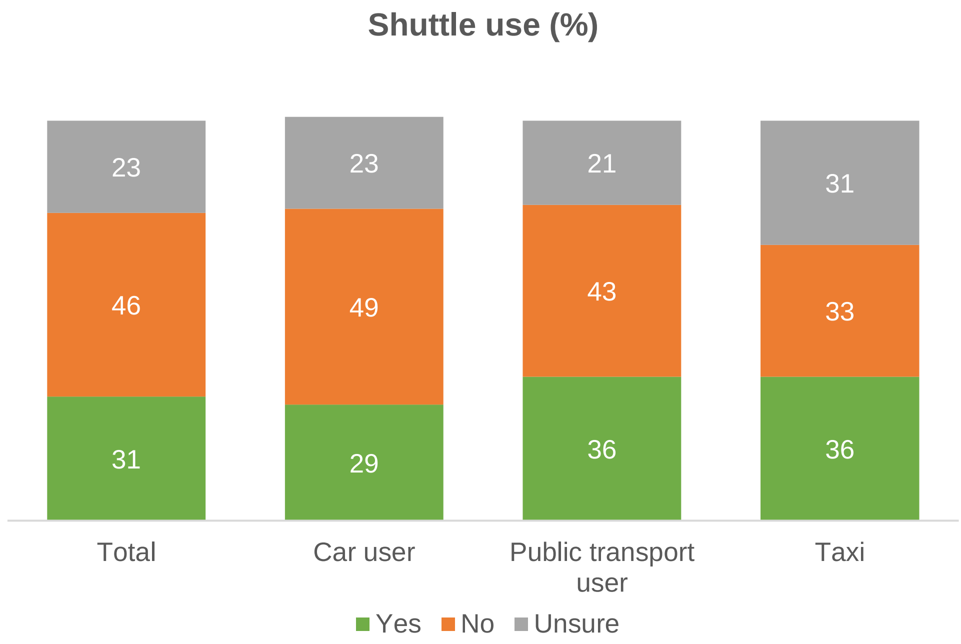

*Graph 35 Question: Which route would you generally take?*
*Base – 52 car drivers*



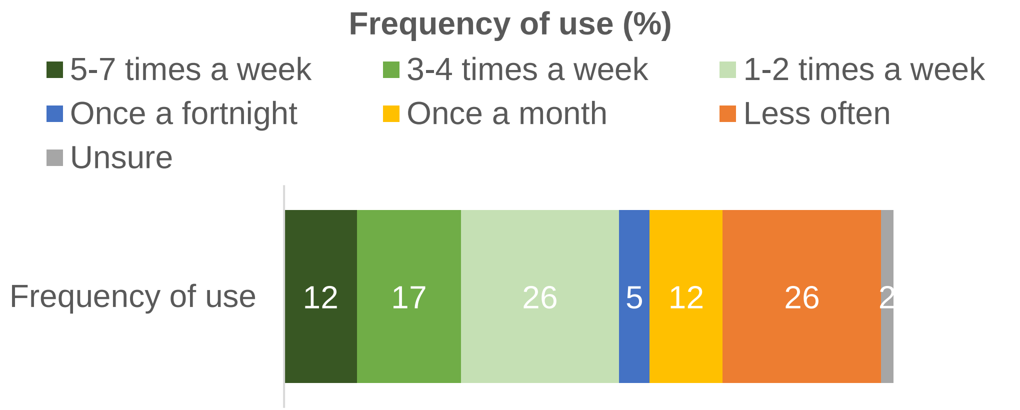

*Graph 36 Question: Do any of the following transport issues negatively impact your ability to travel to in the Hub?*
*Base – 125*

6.5.2.2 Shuttle Service

A third (31%) of respondents thought they would use a shuttle service, with potential use being highest amongst public transport and taxi/ride share users (36%), lowest amongst car users (29%) (Graph 37). Amongst those who would use the service around half would use it once a week or more (55%) (Graph 38).

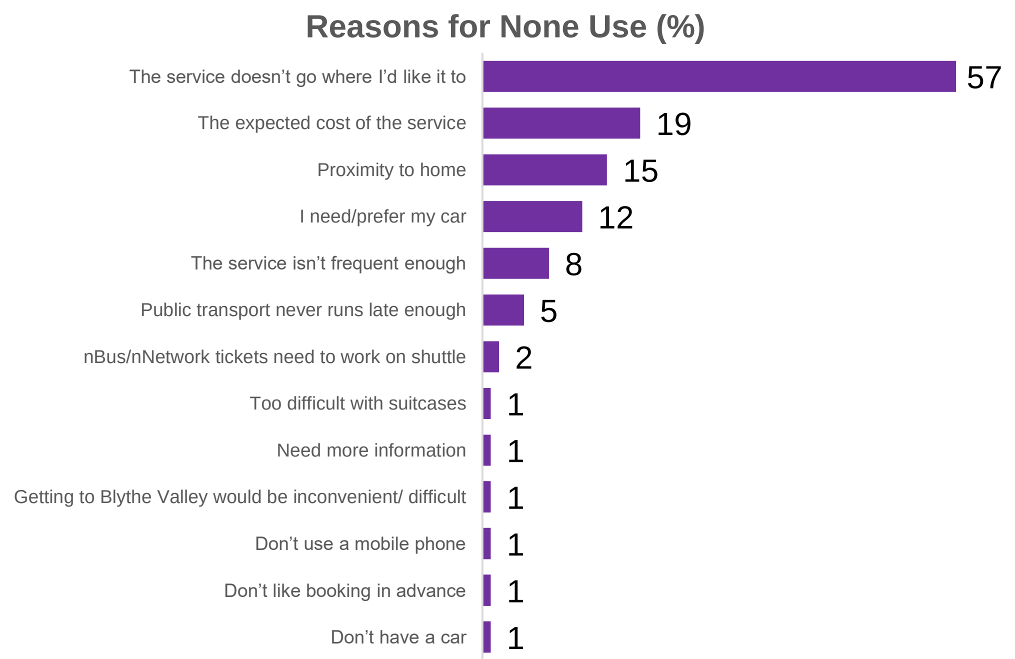



*Graph 37 Question: Would you personally use the service described above?*
*Base – 135*

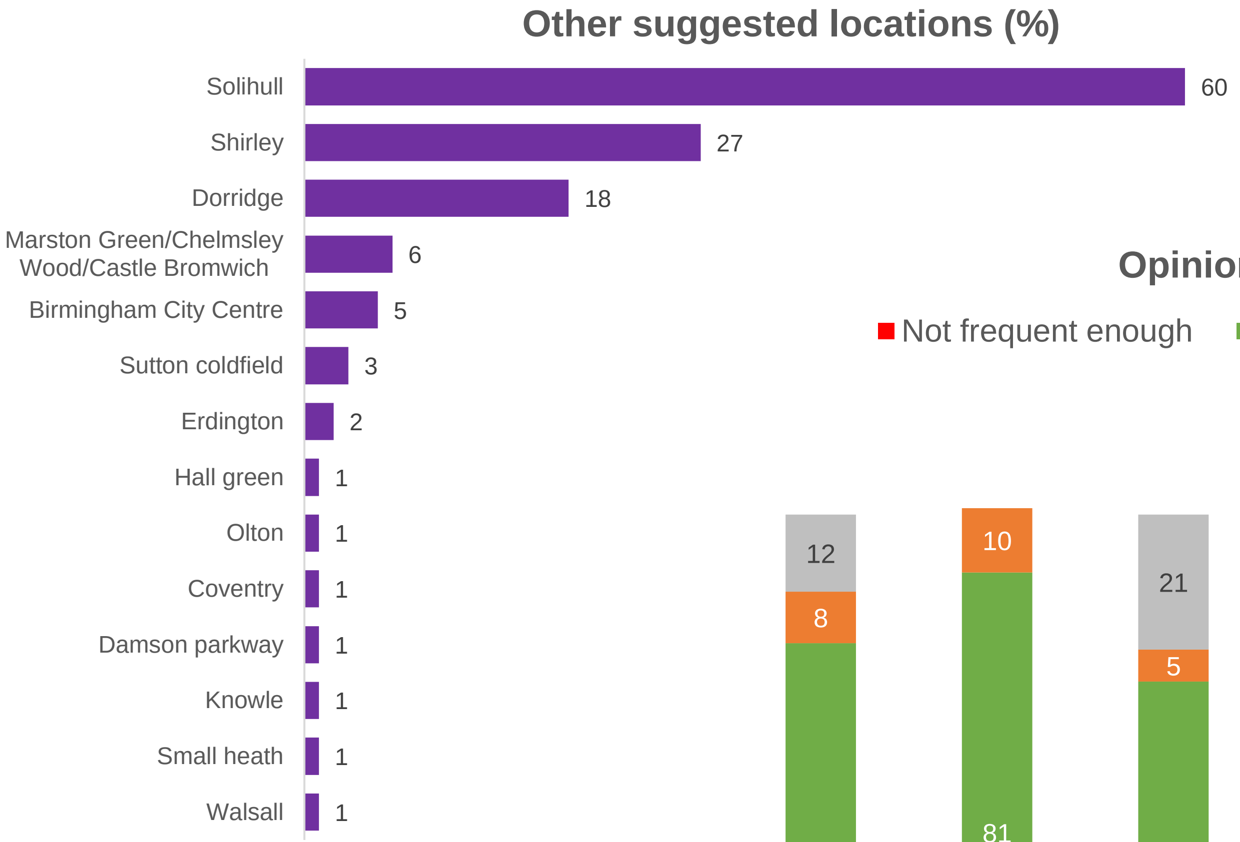



*Graph 38 Question: How often do you think you would use the service?*
*Base – 42 potential users*

The main reasons for not making use of the service were that the service doesn't go where I would like it to (57%) and the expected cost of the service (19%) (Graph 39).



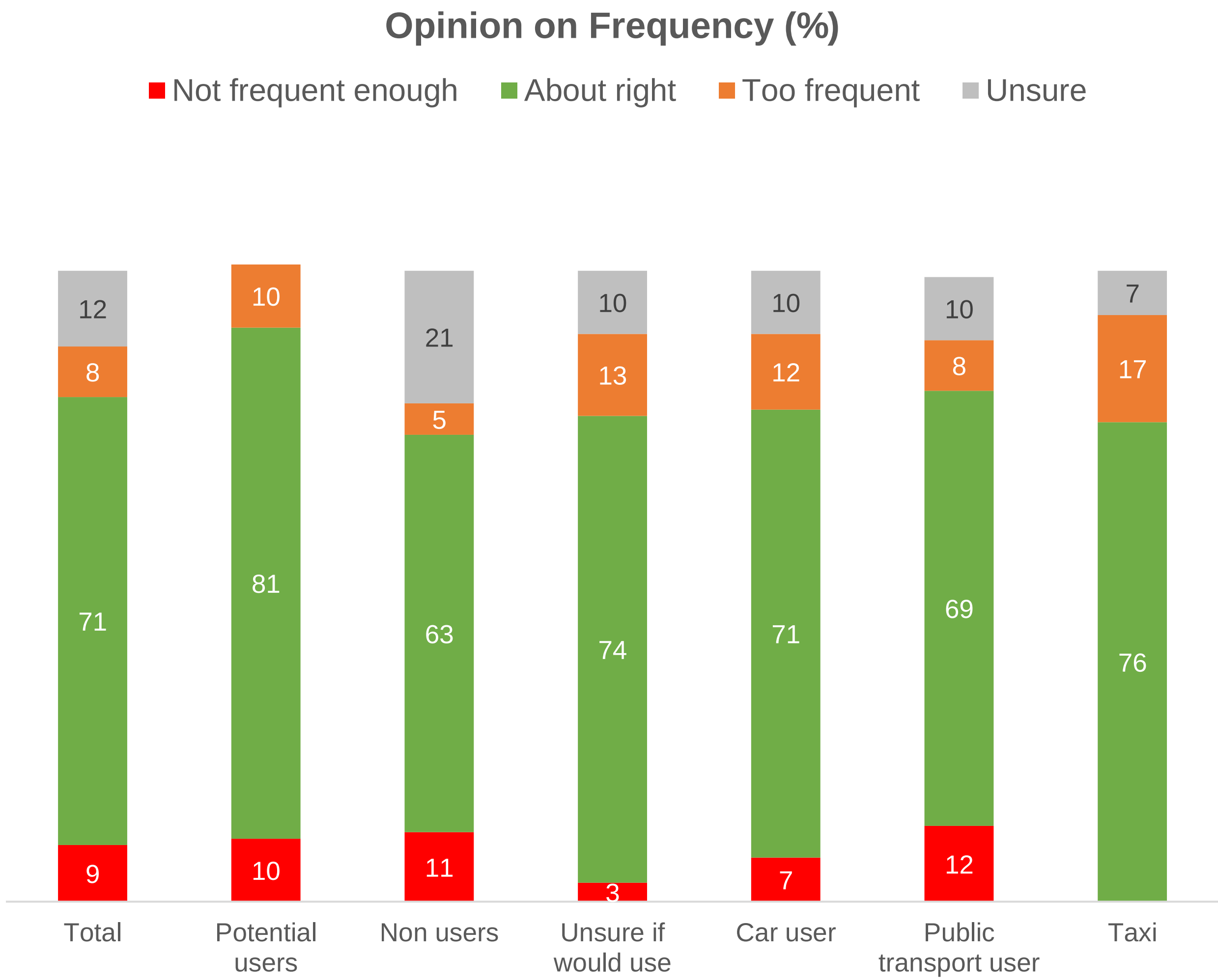

*Graph 39 Question: What would be main reasons for you not using the service?*
*Base – 93*




*Graph 40 Question: Other than Birmingham International Rail Station, where would you like the service to go?*
*Base – 134*

(Graph 41) Almost three-quarters (71%) felt that a 15-minute service frequency was about right, however, 8% thought this would be too frequent, 9% that it was not frequent enough. Potential service users (81%) and taxi users were most likely to think the frequency was about right (76%), however only 69% of public transport users felt this way.

(Graph 40) Other than Birmingham International Rail Station the most popular locations for the shuttle to serve were Solihull (60%), Shirely (27%) and Dorridge (18%).




*Graph 41 Question: What is your opinion of the service running every 15 minutes?*
*Base – 134*

## 6.5.3 Taxi Service

To get an idea of possible pricing, a spot check of the cost of four Uber ride options in early September 2024 was done. The data was collected for the ride options UberX, Comfort, UberXL and Exec. There are four other ride options, Uber Pet, Assist, Access, and ExecXXL, which have been omitted as they are relatively niche products.

Three time periods were used for this data collection of:

- 07:30 → 09:15 for AM peak
- 12:30 → 14:30 for inter peak
- 16:30 → 18:30 for PM peak.

This data was manually collected from the Uber website, hence it is only a spot check. Longer term data collection would be needed to refine the averages for the cost along with an insight to the seasonality of pricing changes. However, due to the manual nature of this particular data collection method, this is not practically feasible.

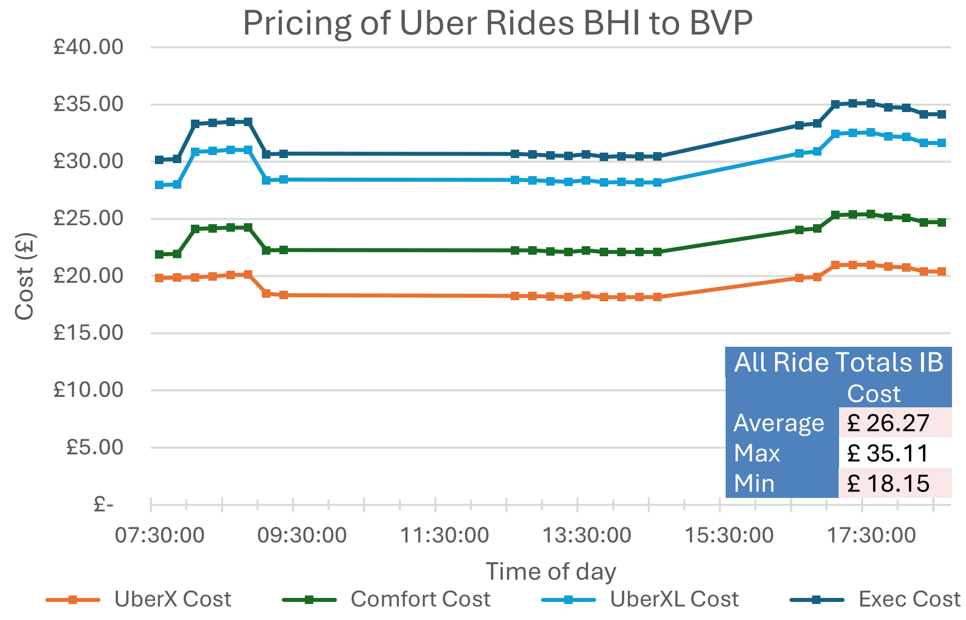
As we can see in Graph 42, the cost of an Uber increases during the AM peak and PM peak which was expected. In contrast, Graph 43 shows a reduction in cost for the AM peak and inter peak periods, with no meaningful increase at the PM peak. This is counter intuitive to the general understanding of how Uber sets ride pricing.

Comparing the graphs to each other and we see that the inbound journeys are approximately £6 more expensive compared the outbound journeys. This trend is across all ride categories, with the largest difference being £17.62 for an Exec ride at 08:15 and all ride options having their biggest price differences between 08:00 and 08:45.

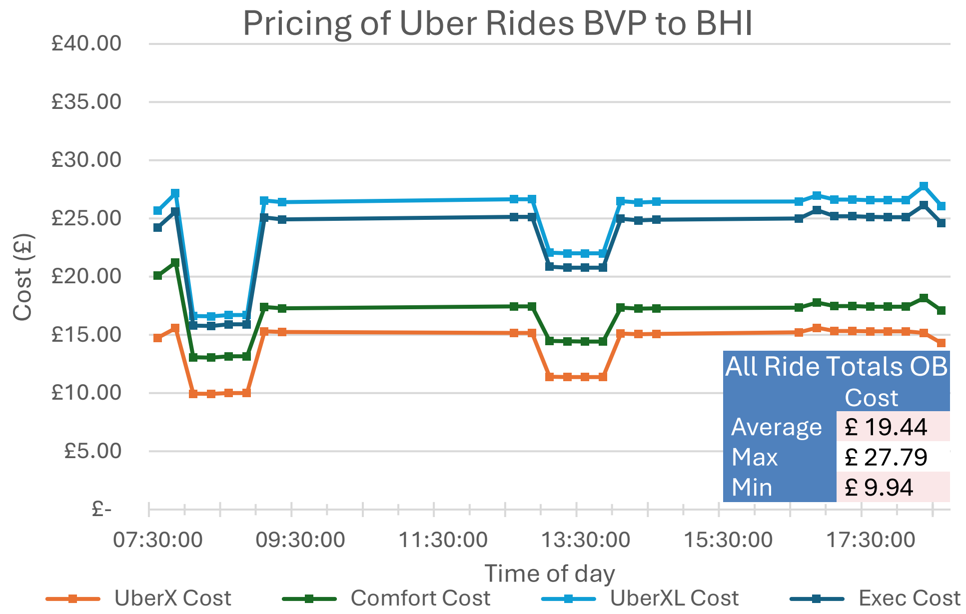
We can speculate that BHI has many potential customers, for various locations, and so competition for any given ride is high. BVP on the other hand, will have far fewer potential customers and thus the competition is less intense. This will result in the pricing strategy illustrated here, where high demand areas command high prices and low demand areas, low prices.

A key takeaway would be that the cheapest Uber ride is £9.94 for an 08:15 UberX ride, while the most expensive is £35.11 for a 17:45 Exec ride. This implies these are the lower and upper limits of customer price tolerance for this route. There are a couple of caveats with this assumption.

1. This data is a spot check and would need to be verified over more dates and time frames.
2. The maximum occupancy for an Uber ride is between 4 and 7 passengers,




*Graph 42 Advertised pricing of inbound (IB) Uber rides*




*Graph 43 Advertised pricing of outbound (OB) Uber rides*

many rides are completed alone.

3. We do not have any usage data to understand how many trips between BVP and BHI are requested daily.
4. Many travellers to and from BVP may be business travellers who will expense the cost to their company lessening or removing personal concern for the cost.

## 6.6 Operational Cost Assessment

To evaluate the commercial viability of deploying a CAM transport service, a structured operational cost assessment methodology is required. Below is an overview of the methodology, incorporating key steps from demand analysis, fleet design, simulations, and cost benchmarking:

### 6.6.1 Step 1: Demand Projections & User Group Identification

- Objective: To establish an accurate baseline of potential demand by identifying the key user groups that will likely utilize the AV transport service.
- Approach:
  - User Surveys & Data Collection: Conduct surveys targeting specific user groups (e.g., commuters, students, elderly) to gather data on travel patterns, preferences, and current transport pain points.
  - Demand Projections: Use the survey data to estimate future ridership for the AV service. Segment demand by factors like time of day, origin-destination pairs, and demographics.
  - TransitScan Analysis: Perform a TransitScan analysis to identify existing public transport options and create heatmaps that visualize key demand areas, travel time comparisons, and public transport gaps. This helps assess potential demand for the AV service based on the user group data and geographical trip attractors.
  - Outcome: Develop demand projections that will guide fleet size, service design, and cost assumptions.

### 6.6.2 Step 2: Fleet Design & Service Configurations

- Objective: Design fleet and service configurations to meet the projected demand and to simulate different operational scenarios.
- Approach:
  - Fleet Size & Vehicle Types: Determine optimal fleet sizes and vehicle capacities (e.g., 12-seaters, 43-seaters) based on the demand projections from Step 1.
  - Service Configuration: Define key service models such as trunk routes (high-frequency, fixed corridors), feeder services (local area connections), and flexi feeder services (demand-responsive, flexible routes).
  - Simulation Inputs: Use the fleet design and service models as inputs for operational simulations to test real-world feasibility.
  - Outcome: Fleet design tailored to demand projections, ready for testing in simulations.

### 6.6.3 Step 3: Operational Simulations & Key Metrics Analysis

- Objective: Run simulations to assess key operational metrics that will form the foundation of the cost model.
- Approach:
  - Simulation Scenarios: Conduct simulations across different fleet sizes, demand levels, and service configurations (e.g., trunk route, feeder service, flexi feeder service).
  - Key Metrics:
    - Deviation Level: Measure route deviations from optimal paths (for on-demand services).
    - Trips Provided (% Success): Analyse the percentage of successful trips delivered.
    - Median Trip Time: Assess how long it takes to complete trips under varying conditions.
  - Analysis of Outputs: Evaluate the outputs of the simulations, focusing on how fleet size, routing algorithms, and service demand impact operational efficiency, user satisfaction, and trip success rates.
  - Outcome: Performance data from simulations used to inform operational costs and service scaling.

### 6.6.4 Step 4: Operational Expense (OPEX) Cost Assessment

- Objective: Estimate the operational cost per vehicle per day (cost-per-vehicle metric) using the simulation outputs and industry benchmarks.
- Approach:
  - Cost Components:

- Vehicle Operating Costs: Include energy/fuel, maintenance, insurance, and depreciation for each vehicle type.
- Labour Costs: If applicable, include costs for on-board stewards, maintenance personnel, and control centre staff (for remote monitoring).
- Technology Costs: Account for AV technology integration (sensors, cameras, software), control centre operations, and telecommunication infrastructure.
- Overhead Costs: Include costs related to operations management, customer service, software licenses, and support functions.

  - Cost-per-Vehicle Calculation: Using simulation outputs (fleet size, trips per day, trip duration), calculate the operational cost per vehicle per day. This will guide scaling decisions for larger fleet deployments.
  - Outcome: Create a daily operational cost model, providing insight into the cost of scaling the AV service.

### 6.6.5 Step 5: Cost Benchmarking

- Objective: Validate the OPEX costs by benchmarking against existing autonomous vehicle services globally.
- Approach:
  - Industry Comparisons: Compare your AV service's cost structure with that of similar AV services operating in different regions (e.g., Waymo, Navya, or other commercial AV projects). Use metrics such as cost-per-trip, cost-per-mile, and cost-per-vehicle-day.
  - Operational Efficiency: Identify where your AV service can optimize costs relative to industry peers by leveraging economies of scale, technological advancements, or service design improvements.
  - Outcome: An industry-validated cost model that provides confidence in the financial projections and informs pricing and funding strategies.

### 6.6.6 Step 6: Scenario-Based Cost Assessment

- Objective: Evaluate the cost impact of different operational strategies and scaling approaches.
- Approach:
  - Cost Scenarios: Develop multiple cost scenarios based on varying fleet sizes, service areas, and demand levels.
  - Sensitivity Analysis: Perform sensitivity analysis to understand the cost implications of demand fluctuations, vehicle utilization rates, and technology advancements.
  - Scaling Approach: Use the cost-per-vehicle metric to assess the impact of scaling the service from a pilot program to full city-wide operations. Analyse break-even points and potential profit margins based on different ridership levels.
  - Outcome: A comprehensive commercial assessment of the AV service's viability, based on multiple operational and cost scenarios.

This operational cost assessment methodology outlines a comprehensive, step-by-step process that integrates demand forecasting, fleet design, simulation testing, cost-per-vehicle calculations, and industry benchmarking.

Our methodology has included a lease-based financing model for the vehicle, spread over the operational life of the asset. This has enabled us to create a “cost per day” metric. For the purposes of this assessment, this has therefore enabled us to benchmark existing on-demand and public transport services (manually driven) as many operators utilise these metrics to assess true commercial viability.

By analysing multiple operational scenarios and validating costs against global standards, this approach ensures a robust commercial assessment for the viability of funding and deploying an autonomous vehicle transport service.

### 6.6.7 Cost Assessment Assumptions

Below, we have outlined the assumptions we have made in this assessment.

Any infrastructure required for the operation of the autonomous vehicle (AV) service, such as charging stations, or other physical assets, is assumed to be covered separately from the operational cost assessment. Additionally, any support costs provided by the Local Authority (e.g., road infrastructure upgrades, AV-friendly signage) are not included in this assessment. The focus is solely on operational costs. The cost assessment includes four different service models:

- Trunk Route Shuttle: Fixed-route, high-frequency services using smaller vehicles.
- Trunk Route Bus: Larger vehicles for high-capacity fixed routes.
- Peak Feeder Service: Services that operate during peak times to connect neighbourhoods to main routes.

- Peak Flexi Service: Flexible, on-demand services designed for peak times.

All vehicle costs are based on a full leasing model rather than outright ownership. The lease terms assume an asset life of up to 10 years. This enables the spreading of vehicle costs over a longer period, helping to ensure cost predictability and reduce upfront capital requirements.
The vehicle kilometres (KMs) and efficiency assumptions are based on standardized electric vehicle (EV) models. These vehicles follow a depot-based charging model, where they return to a central depot for charging after each shift. This approach allows for controlled charging times and reduces the need for distributed charging
Demand projections are calculated using a global benchmark metric, Passengers per Vehicle Hour (PVH). PVH is an industry standard that measures the efficiency of transport services, allowing for normalising comparisons across different sizes and scales of operations. Regardless of fleet size, this metric offers a comparable measure of how well each vehicle serves the demand during operation.
Driver costs are calculated at a ratio of 1.2 drivers per vehicle. This accounts for scenarios where both a driver and a steward may still be required, especially in the transitionary phase toward full autonomy. It also considers additional labour for shift overlaps, rest breaks, and operational contingencies where manual intervention may still be necessary.
These assumptions provide the foundational cost drivers for the operational cost assessment and ensure that all aspects of service delivery are taken into consideration when calculating viability.

### 6.6.8 Cost Assessment Output

Below is the breakdown of the cost assessment outputs, which we have aligned to 4 service designs described earlier in the report. We have added 2 additional service models to support the assessment. The rationale for including the manually driven shuttle & bus, is to create a direct comparison within our methodology, for a traditionally operated public transport service

- Manually Driven Shuttle
- Manually Driven Bus
- Trunk Route Shuttle
- Trunk Route Bus
- Feeder Service
- Flexi Feeder Service

| | **Shuttle** Manually Driven | **Bus** Manually Driven | **Trunk Route** (AV Shuttle) | **Trunk Route** (AV Bus) | **Peak Feeder** (AV Shuttle) | **Peak Flexi** (AV Shuttle) |
|---|---|---|---|---|---|---|
| OPEX | £1,797,114 | £2,062,003 | £3,275,824 | £3,516,003 | £2,951,259 | £4,442,215 |
| Seat Capacity | **13** | **43** | **13** | **43** | **13** | **14** |
| Average Fare/Pax | **£3.00** | **£3.00** | **£3.00** | **£3.00** | **£3.00** | **£5.00** |
| No. of Vehicle(s) | **10** | **10** | **10** | **10** | **7** | **15** |
| No. of Operational Days in a Month | **22** | **22** | **22** | **22** | **22** | **22** |
| Daily Km/Veh | **225** | **225** | **225** | **225** | **526** | **1,277** |
| Cost Per Vehicle Per Day | **£680.72** | **£781.06** | **£1,240.84** | **£1,331.82** | **£1,597.00** | **£1,121.77** |
| **Demand Projections** | | | | | | |
| Total Daily Trips | **312** | **1032** | **312** | **1032** | **273** | **693** |
| Total Daily Trips Per Vehicle | **31** | **103** | **31** | **103** | **39** | **46** |
| Total Daily Trips Per Vehicle Per Hour | **4** | **13** | **4** | **13** | **5** | **6** |
| **Per Person (Cost)** | | | | | | |
| Cost Per Day Per Person | **£15.78** | **£5.47** | **£28.77** | **£9.33** | **£29.62** | **£17.56** |

*Table 16 Cost comparisons for AV and non AV service models*

The table compares different AV operational models: Trunk Route (AV Shuttle), Trunk Route (AV Bus), Peak Feeder, and Peak Flexi. Each model is evaluated based on projected income, OPEX, profit/loss, and various operational metrics.

6.6.8.1 Cost Analysis Comparison

Following the TransitScans, along with the in-depth user analysis, we conducted a cost assessment, based 2 approaches. The first approach is intended to assess the viability of launching a service, based on a fleet size viable to launch a new public transport service that's autonomous (varied fleet sizes of 7-15 depending on demand) as shown in **Table 16.**

The second approach, was to take the same assessment methodology and apply this to a scaled version of the service (fixed fleet sizes of up to 120), with the output results shown in shown in Appendix D.7

We felt this was particularly important, as the transition of a public transport service from a traditional operational model, utilising a driven service, requires considerable investment. We wanted to utilise the opportunity to identify where perhaps there is a tipping point within the commercial and economic viability that the scale becomes "economically viable" for suppliers, operators and future users.

The cost assessment we completed for Blythe Valley Park (BVP) and the associated service models provides insights into the operational expenditure, capacity, fare structure, demand projections, and per-person costs across different service types.

Traditional and autonomous vehicle (AV) models vary significantly in terms of cost-effectiveness and demand handling. Below provides a breakdown of our findings also shown in Appendix D.7:

1. **BVP Staff Shuttle (Model 0A)**: Operating with an OPEX of £20'075'372, this shuttle deploys 120 vehicles with a seating capacity of 13 each. Despite lower capacity, the service completes 7 trips per vehicle per hour and has a per-person cost of £7.78, reflecting moderate efficiency for smaller groups.
2. **BVP Staff Bus (Model 0B)**: With a higher OPEX of £27'096'770, this model uses 120 larger vehicles (43 seats each). It achieves greater trip frequency and efficiency, reducing the per-person cost to £4.80, making it more cost-effective for higher passenger volumes.
3. **Trunk Route Shuttle (Model 1A, AV)**: This AV model operates at a high OPEX of £21'053'002. With 13-seat vehicles, it maintains lower trip frequency and results in a high cost per person of £9.24, emphasizing an ability at scale to close the per person cost gap compared to the previous model.
4. **Trunk Route Bus (Model 1B, AV)**: This AV model utilizes larger 43-seat vehicles, operating at an OPEX of £27'620'744. It achieves better cost-efficiency than the Trunk Route AV shuttle, with a per-person cost of £4.89, though it still incurs slightly higher operational expenses compared to traditional buses.
5. **Peak Feeder (Model 2, AV)**: Designed for peak times, this AV model has an OPEX of £26'493'934, deploying 120 vehicles with 13 seats each. It offers moderate frequency and flexibility at peak hours but has a high per-person cost of £10.34.
6. **Peak Flexi (Model 3, AV)**: This model features a higher OPEX (£33'918'269) and utilizes 120 vehicles with 13 seats each. The fare is increased to £5.00 per passenger. Despite flexible routes and frequent trips, it incurs a high per-person cost of £11.91, indicating a trade-off between flexibility and cost-effectiveness.

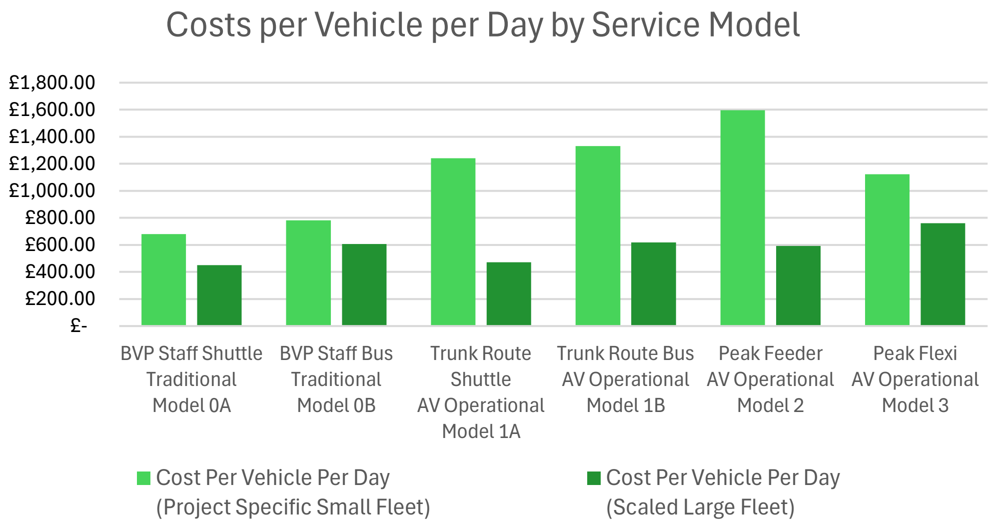
The analysis highlights that traditional models (0A and 0B) generally offer greater cost efficiency, especially for high-capacity routes. AV models, while offering advanced features and flexibility, have significantly higher operational costs per person, particularly in low-capacity, peak-demand configurations. The findings support strategic assessments for AV deployment feasibility and cost management in future phases where there are larger fleets, to benefit from the system efficiencies which directly correlate to, higher cost savings.

**Vehicle Leasing and Operational Costs**: Traditional buses and shuttles generally have lower leasing costs and maintenance expenses compared to autonomous vehicles (AVs). AV technology requires advanced sensors, cameras, software, and continuous system updates to operate safely and reliably, which raises the leasing and maintenance costs. Additionally, traditional vehicles benefit from a mature supply chain and established maintenance infrastructure, whereas AV support systems are still developing, leading to higher operating expenses.

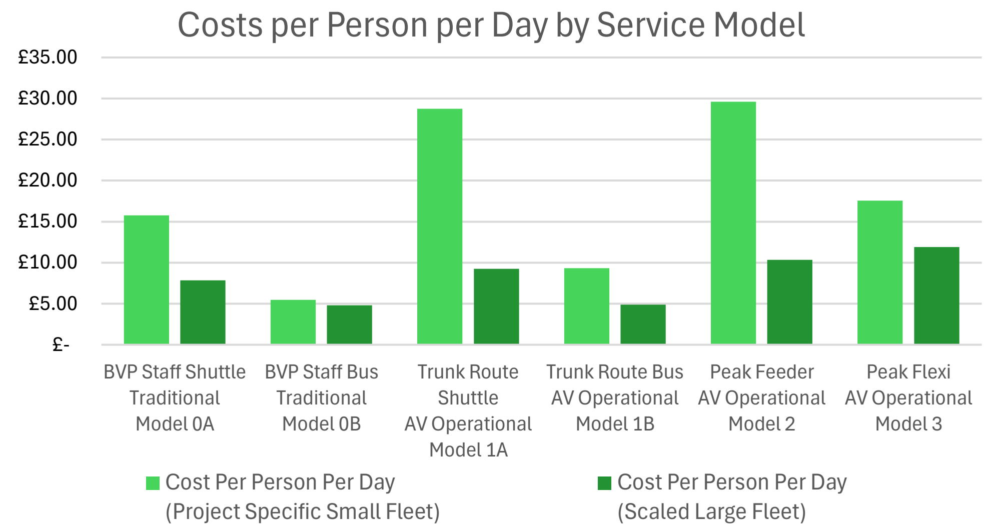
**Higher Per-Trip Cost and Lower Efficiency in AVs**: While AVs offer direct routes and flexibility, they often have lower trip efficiency per vehicle due to technological limitations and the complexity of their routing algorithms, especially during high-demand periods. AV shuttles (Model 1A) and buses (Model 1B) show significantly higher per-person costs because their average occupancy remains low (around 10%), which dilutes the operational costs across fewer passengers. By contrast, traditional models (0A and 0B) maintain higher average occupancies and trip frequencies, enabling them to distribute costs more effectively.

**Technological and Regulatory Overheads**: Autonomous vehicle operation will involve additional regulatory and compliance costs, including safety oversight and testing requirements that traditional vehicles bypass. The proposed AV systems are equipped with complex software that needs regular updates, cybersecurity measures, and troubleshooting, increasing the cost and frequency of technical support needed. Traditional models lack these advanced systems, making their operation more straightforward and less costly.

**Passenger Handling and Route Flexibility**: AV models provide dynamic routing and flexibility (e.g., Peak Flexi, Model 3), which allows them to better serve high-demand or remote areas. However, this flexibility also adds operational complexity, leading to inefficiencies when compared to traditional fixed-route services, which can streamline scheduling, staffing, and fuel efficiency on established routes.




*Graph 44 Comparison of cost per vehicle per day between a varied fleet size and a fixed fleet size*




*Graph 45 Comparison of cost per vehicle per day between a varied fleet size and a fixed fleet size*

### 6.6.8.2 Operational Funding Model

Several funding models can be used to deliver on-demand AV transport services, particularly for trunk routes, feeder, and flexi-feeder services. The chosen model will depend on the service's goals, the stakeholders involved, and the financial sustainability required. Below are common funding models:

*Public-Private Partnerships (PPP)*

In a PPP model, public entities such as local governments or transit agencies collaborate with private companies to deliver the service. The public sector may provide funding or subsidies, while private companies manage the operational aspects, including technology, maintenance, and service delivery.

Advantages:

- Shares financial risks between the public and private sectors.
- Encourages innovation and efficiency by involving private expertise.
- Public entities can ensure that public transit goals are met.

*Government Subsidies and Grants*

Government subsidies or grants from local, regional, or national authorities can support the development and implementation of AV services, especially in cases where such services are viewed as public goods.

Advantages:

- Ensures the service is affordable for users, especially in underserved areas.
- Helps cover initial capital expenditures for fleet acquisition and infrastructure.
- Grants can spur innovation and trial of new technologies.

*User-Pay Model (Fare-Based Revenue)*

In this model, users directly fund the service through ticket sales or fares, making the service self-sustaining through its own revenues. This could include distance-based pricing, peak-hour pricing, or subscription models for frequent users.

Advantages:

- Directly links revenue to service demand.
- Can incentivize efficient service design and cost management.
- Provides long-term financial sustainability without reliance on external funding.

*Corporate and Private Funding*

Businesses or institutions (e.g., universities, business parks, or large employers) might fund AV services to provide transportation solutions for their employees, students, or visitors. This model could involve direct payments to the service provider or partnerships for reduced fares for specific user groups.

Advantages:

- Provides reliable funding by targeting a specific user group.
- Helps businesses or institutions reduce their carbon footprint and transportation costs.
- Often leads to guaranteed ridership, improving financial viability.

*Venture Capital and Private Investment*

Private investors, including venture capital firms, may fund AV services in exchange for equity or profit-sharing. This model is commonly used by technology startups to scale innovative mobility services.

Advantages:

- Provides large capital injections, especially during the early stages of service development.
- Encourages rapid innovation and growth.

The appropriate funding model for an AV on-demand service will depend on various factors, such as service goals, user demand, and the local economic environment. Often, a hybrid approach combining multiple funding sources (e.g., public subsidies with private investment or advertising revenue) can provide the financial stability needed to ensure the service's long-term sustainability and scalability.

## 6.7 Where are the Gaps?

A key part of this study is to understand if a CAM service along this study route would make financial sense, either being fully self-funded or subsidised. To understand this, two aspects have been examined, demand for the route and the cost of the service.

**Route Demand**

- From data obtained, there is no conclusive evidence that there is demand for the study route discussed in this document. For any service to be successful a clear demand is required, the conclusions from the data suggest linking BVP to BHI would serve few customers. While there is the potential of the service inducing demand, this would only be speculation and cannot be used as a factor for investment at this time and without further investigation.
- The areas that the route links are relatively affluent compared to the West Midlands region. This affluence suggests that ticket fare prices are less of a consideration when choosing between a public transport service or private vehicle. In support of this conclusion is the pricing data of uber rides between BVP and BHI, showing the minimum cost to be significantly higher than the public transport alternative. This is compounded by the suggestion that the same affluence allows customers to live lives with more complex travel needs that are not easily catered to by public transport. CAM services may be able to address this complexity but at a high cost.
- Direct survey feedback from workers at BVP and residents of the West Midlands showed positive attitudes around the novelty of a CAM service, mixed with concerns over safety of the system. However, a leading detractor from the service along the study route is not fulfilling their journey needs. This supports the conclusion that this specific route has low demand, which could be improved by allowing for more flexible routing and destinations.

**Cost of Service**

- To setup a CAM service currently involves significantly higher investment and significantly higher ongoing maintenance costs. Traditional public transport options can leverage existing depot, maintenance and operational centres. New facilities can be erected for a reasonable investment as much of the equipment and designs have standardised over a long period of time. The novel requirements of CAM vehicles, and the support staff required to operate them safely, leads to the higher investment requirements. These costs may reduce overtime as CAM specific technologies become more available and affordable. However, this is not guaranteed and will likely only occur in conjunction with scale of CAM service deployments.
- CAM services can offer unique benefits over traditional public transport offering. Obvious cost saving for not requiring a driver for the vehicle is one area, but also greater options for dynamic routing systems allowing the service to serve a great number of customers. However, these capabilities come with additional costs either in the form of service centre staff or additional infrastructure, both to ensure the safe operation of the CAM vehicle. Today, the cost of implementation of these would negate the advantage a CAM service offers and would not provide good value for money.
- Scaling the service can allow it to become more cost competitive with traditional public transport services. An assessment of the service scaled to 120 vehicles over a selection of similar routes, showed the initial investment and maintenance cost being spread over the larger fleet. This resulted in more favourable per person costs and narrowing the advantage of traditional public transport. However, traditional services still maintain a cost advantage, especially with larger capacity vehicles. Again, it is likely that advancements in CAM technologies will continue to improve the cost competitiveness but is not guaranteed. Further assessment would be advised, to assess broader impact on the investment profile of scaling commercial CAM services, in particular where we can see benefits in reduction in congestion compounding an improvement on sustainability elements such as Air Quality and Carbon Emissions.

# Key Findings

## *Key Findings*

*The table overleaf acts as a pivotal reference point for the outcome of this project, summarising identified gaps and the specific challenges relating to the feasibility of installing a CAM service between Blythe Valley Park and Birmingham International Rail Station. This table can be referenced specifically in relation to this study route but should also be considered a reference point for understanding the challenges across equivalent public transport routes, providing valuable direction for where time and focus should be spent by both government and industry to progress public, shared CAM solutions.*

This feasibility study has taken an ambitious, comprehensive approach to exploring the feasibility of introducing a CAM mass transit service into the West Midlands. The study looked at a specific route that is currently not expected to be commercially viable via existing mobility business models.

Over-coming the primary reasons for increasingly more travellers abandoning or ignoring road-based public transport must be the starting point for any future CAM service. Simply the absence of an on-board driver whilst everything else in terms of the user experience remains the same (congestion; inconvenience; unreliability) should not be expected to illicit any increased level of adoption.

Having started by defining the parameters against which public transport must improve (Safety, Reliability, Affordability, Accessibility), the study undertook a systematic and detailed analysis of user requirements and operational demands across:

- User trust safety and acceptance
- System safety
- Infrastructure
- Reliability
- Access for everyone
- Economics

Within this scope the following conclusions have been established:

1. A Connected and Automated Mobility service implemented in the medium-term i.e. by 2030 is not at this time feasible on the high-speed route the study was undertaken on

The inability to offer any level of priority or segregation to a service on this route

| Ch | Pillar | Focus | "Needs to be True" Statement *(Bar that must be met)* | Gap-Statements ("Where we are today") that need to be overcome to realise feasibility | RAG |
|---|---|---|---|---|---|
| 1 | | | An automated service should be perceived, and experienced, as being as safe, or safer than a traditional public transport service | **Evidence collected through this study indicates significant concerns exist among the general public relating primarily to the safety of CAM services.** The need for gradual introduction, education and development alongside target users *and* the communities that services will run through will be crucial to ensure the best chance of successful implementation. Although evidence suggests that sentiment improves following engagement with the technology, the universal adoption and acceptance of new solutions cannot be assumed. | Amber |
| | | | | **The length, speed and relative complexity of this study route is not expected to ease perceptions of safety.** Although commercial examples of driverless, rubber-on-tarmac, shared public transport systems do exist – they are in controlled environments over short routes travelling at a maximum speed of 40 km/h. Ensuring riders feel, and are, safe over longer distances remains a crucial area for development, but indications suggest solutions can and will be developed | Amber |
| 2 & 3 | | | The vehicle/service must be capable to operate within the static, dynamic, and environmental conditions of the route with risk as low as reasonably practicable. | **The AV's considered in this study are unable to join the motorway safely at the peak traffic densities/ speeds on the M42 due to reduced traffic spacing on carriageway and vehicle top-speeds** (note: the consortium are unaware of any CAM system that publicly claims such level of performance). The feasibility study has considered solutions of: on-slip-lane becoming an additional lane and installing V2X radar detector technology and connected vehicle capability to support the vehicle. Given the additional investment this item is Amber, turning to Red if further work identifies these solutions unfeasible. | Amber |
| | | | | **The AV's considered cannot operate through unmanaged junctions**. There are currently fourteen junctions on the route of which only five are signalised. Solution for all signal information to be available digitally would be required via the installation of connected traffic lights/signals to all junctions, crossings, and ramp meters. Red as most junctions on the route are not currently signalised and would require infrastructure and/ or operational changes. | Red |
| | | | | **If sufficient connectivity were to become unavailable, one of the vehicle systems in this study would perform a minimum risk manoeuvre** (and come to a safe stop). This would not be acceptable or safe in a live traffic lane on the motorway (including its impacts on the existing dynamic hard shoulder). More understanding around the safety implications of MRMs on the SRN is needed. Red, as sufficient connectivity to avoid un-necessary MRM's would require investment and the implications of MRM's on the SRN needs to be better understood. | Red |
| | | | | **It's unclear if existing connectivity provision along the route is sufficient (C-ITS)**. Amber as a robust assessment of this would be required to determine required bandwidth (and signal strength) in relation to number of potential users. A more detailed (resource intensive) mapping of connectivity resilience across the route is needed, with a cross reference to vehicle capability and safety implications to establish if further cellular V2X would be required. | Amber |
| | | | | **For the conceptual vehicle specification to operate along the proposed route a minimum infrastructure cost in excess of £7m estimated** (estimate solely for information purposes)**.** Amber at feasibility stage as further work would be needed to firm up exact costs (including whole life cycle costs) and its relationship to a wider business case for the service. | Amber |
| 4 | | | An automated bus service should be as, or more, resilient, robust, and reliable as traditional public bus options. | **There is yet to be a sufficient body of evidence to suggest future CAM systems will be capable of operating to the same level of robustness in the study ODD as a manually driven service**. This is particularly in relation to atmospheric conditions, where although there is significant levels of research and development, no equivalent commercial services running at motorway speeds are yet able to demonstrate automated control systems that can reliably meet human driven capability. Future CAM-based public transport services should be expected to need to meet higher levels of up-time (resilience) than private "robo-taxi" use cases due to the foundational role they play in communities. | Amber |
| | | | | **Without the ability to provide a segregated lane to provide journey time reliability, there would remain limited benefit / incentive to those who currently have access to a private car.** The direct route proposed within the study would improve journey times against current public transport options between the two locations, however, for those currently relying on private car, the service would be stuck in congestion around peak commute times, offering little benefit. | Red |
| 5 | | | An automated service must be as, or more, available and accessible as current public transport options | **A service that seeks to deliver an end-to-end trunk route with limited / no flexibility is unlikely to maximise potential ridership.** To maximise access for future users, services should be considered as being required to have a degree of flexibility, primarily at the start and end of routes. This flexibility will however increase complexity significantly but will better mirror the nature of the private car. | Amber |
| | | | | **Providing accessibility (e.g. level-access) by design will be imperative to minimise operational conflict and issue.** Future users should be able to access vehicles without need for delay, specific personal technology or additional human assistance. Automated vehicle technology within road-based public transport systems cannot be expected to operate effectively without supporting operational infrastructure / solutions, adding cost to address issues traditionally managed by human drivers. | Amber |
| 6 | | | The economic case for investment must work for commissioners, suppliers, operators and future users | **Demand for this study route was not found to be sufficient to cover projected operational costs against any of the operational models considered.** Revenues were modelled using reasonable public transport fares, in line with municipality expectations that services must be affordable and not exclude on any grounds, including income / relative wealth. When modelled against manually driven services, a service of this scale would not be expected to be the most cost-effective solution to deliver desired outcomes. | Red |

Safe

Reliable

Affordable

Accessible

User Focus

Vehicle/System Focus

# Additional Tables of Contents

# Figures

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# Glossary of terms

ACS ........ Autonomous Control Systems
ADAS ........ Advanced Driver Assistance Systems
ADS ........ Automated Driving Systems
ASB ........ Anti-Social Behaviour
AV ........ Automated Vehicle
BBP ........ Birmingham Business Park
BHI ........ Birmingham International rail station
BHX ........ Birmingham Airport
BVP ........ Blythe Valley Park
CAM ........ Connected and Automated Mobility
CAPEX ........ Capital Expenditure
CAV ........ Connected and Automated Vehicle
CAVForth ........ A CAM pilot deployment operating between Fife and Edinburgh
CIA ........ Confidentiality, Integrity, Availability
C-ITS ........ Cooperative Intelligent Transport Systems
DfC ........ Digital for Customer
DfT ........ Department for Transport
DMRB ........ Design Manual for Roads and Bridges
EV ........ Electric Vehicle
GDPR ........ General Data Protection Regulation
HGV ........ Heavy Goods Vehicle
HS2 ........ High Speed 2
JLR ........ Jaguar Land Rover
LA ........ Local Authority
LGV ........ Light Goods Vehicle
LSOA ........ Lower Super Output Area
MFM ........ Midlands Future Mobility
MND ........ Mobile Network Data
MODDEST ........ Minimum Operational Design Domain Environment Specification Tool
MRM ........ Minimum Risk Manoeuvre
MSOA ........ Middle Super Output Area
NEC ........ National Exhibition Centre
NH ........ National Highways
ODD ........ Operational Design Domain
OEM ........ Original Equipment Manufacturer
ONS ........ Office of National Statistics
OPEX ........ Operational Expense
PAVE ........ Partners for Automated Vehicle Education
PPP ........ Public-Private Partnerships
PRISM ........ Policy Responsive Integrated Strategic Model
PT ........ Public Transport
PVD ........ Probe Vehicle Data
PVH ........ Passengers per Vehicle Hour
RAG ........ Red - Amber - Green
RSU ........ Roadside Units
SCALE ........ Solihull and Coventry Autonomous Link Evolution
SDL ........ Scenario Description Language
SDV ........ Self Driving Vehicles
SMBC ........ Solihull Metropolitan Borough Council
SPSD ........ Safety Pool Scenario Database
spv ........ seconds per vehicle
SRN ........ Strategic Road Network
STPA ........ Systems Theoretical Process Analysis
TfWM ........ Transport for West Midlands
TM4CAD ........ Traffic Management for Connected and Automated Driving
TOD ........ Target Operational Domain
vpm ........ vehicles per minute
WMCA ........ West Midlands Combined Authority
WMG ........ Warwick Manufacturing Group, Warwick Manufacturing Group
WP ........ Work Package