A Feasibility Study to Explore the Potential for Running Autonomous Vehicle Trials in Cambridge Utilising the Unique Aspects of the Guided Busway

Contents

1. Introduction

Cambridge has a vibrant, expanding economy. The University, and the high-tech businesses and spin-offs which surround it, combine to make the city-region one of the UK's top growth hot-spots and one of the greatest entrepreneurial clusters outside Silicon Valley. This climate of economic success has created great pressure on the Local Authorities to provide more high quality residential and working space in and around the city. But, in a crowded space that already experiences acute congestion problems, this poses serious challenges for the city's transport planners. As a result, the County Council and its partners in the City Deal have begun to examine all possible options as they develop their future transport strategy for the city and its surrounding sub-region.

The options are many, because the future of public transport is likely to be very different from the traditions of its past. This is because rapid developments in the fields of clean vehicle technologies, mobile computing power, ubiquitous information systems, and personal communications all appear to be converging in a manner that could transform the way in which transport services are provided. One of the most dramatic possibilities created by this nexus is the introduction of autonomous vehicles; the City Deal is therefore beginning to consider the implications of introducing such vehicles as part of its future multi-modal public transport strategy.

There are three particular reasons why it is appropriate at this time to consider the possibility of autonomous transport systems. First, the notion of autonomous systems is a natural part of the wider concept of 'intelligent mobility' and it sits well alongside the other developments which are currently taking place under the Smart Cambridge initiative. Second, the Cambridge Guided Busway provides a well-defined segregated transport corridor within which an early demonstration of the technology could be launched. Using this asset would mean that public trials could be carried out within a relatively short space of time because the complications of constant inter-action with road-going traffic can be largely avoided.

Third, there is a significant amount of central government funding which is currently available to support the development and demonstration of autonomous vehicles. In recent years, the national Government has put a great deal of effort into promoting the UK as a hot-spot for clean vehicle technology and autonomous systems. In the latter case, the government's activity is co-ordinated through the newly-formed Office of Connected Cars and Autonomous Vehicles (C-CAV). Amongst a range of wider activities, this office promotes and administers a fund of around £200M which will be distributed over the next four years through a programme of national competitions. These competitions are currently being run at the rate of two per year; the first three rounds have already been completed, and the call for the next round (C-CAV 4) is anticipated during the Summer 2017.

Recognising the opportunity to take a lead in this exciting new field of transport provision, the City Deal Team commissioned the University of Cambridge to carry out a feasibility study to explore the potential for running autonomous vehicle trials in Cambridge. The brief for the study is reproduced in Appendix 1.

2. The Current State-of-the-Art

There has been a lot of work carried out in the field of intelligent transport and autonomous vehicles over the past decade. It is therefore important that any programme which is planned for Cambridge should be developed in the knowledge of what has been, and is being, done elsewhere.

A summary description of some of the systems which have been built and demonstrated, or are in plan, around the world is presented in Appendix 2. The systems described there might be collectively referred to as Low-Speed Autonomous Transport Systems (L-SATS). Beneath this generic title they fall, broadly, into two categories: those that follow pre-designated paths (referred to here as 'Fixed Path Systems'), and those that operate freely within a large designated pedestrian area (referred to here as 'Roaming Systems'). In each case, the vehicles may be larger (typically the size of a small mini-bus, with room for 10-12 people), or smaller (typically 2-4 seat vehicles, frequently referred to as 'driverless pods'). A generic description of these two different types is presented in the following sub-sections.

2.1 Fixed Path Systems

These systems began to appear in the early 2000's and several are now in operation around the world. They require segregated pathways and are, consequently, much more expensive to commission than the 'roaming systems' which require no special infrastructure. Examples of fixed path systems are the ULTRa System at Heathrow Terminal 5 (illustrated below), and the '2GetThere' system at Masdar City, UAE. Both of these systems are described further in Appendix 2.

2.2 Roaming Systems

These systems are more recent and are capable of navigating a route in open space without physical guidance. They can run without out any expensive, purpose-built, infrastructure and this makes them very attractive for the retro-fit of any first/last-mile requirements within an existing urban context. Examples of the larger 'mini-bus' type of vehicle which fit this category are the Easymile and Navya vehicles. The Navya vehicle is illustrated below; it can accommodate 12 passengers and is currently under trial at several different locations around the world.

An alternative to the ‘mini-bus’ type of vehicle is the much smaller, more agile, 2-4 seater ‘driverless pod’. This genre is exemplified by the RDM vehicle which is currently under development as part of the large UK Autodrive programme in Milton Keynes (illustrated below).

A high-level overview of the most well-known L-SATS systems currently being demonstrated around the world is presented in the following table.

System	Operational Location	Vehicle Capacity (Passengers)	System Peak Capacity (Pass/hour per direction)	Speed (km/hr)	Range (km)	Estimated System Cost (or cost/vehicle)
Fixed Path Systems						
- ULTRa	UK (Heathrow)	4/6	650	40	tbd	£30M
- 2GetThere	Abu-Dhabi	4	300	40	60	Unknown
- Park Shuttle	Netherlands	24 (12 seated)	480	40	100	Unknown
- Vectus	Korea	tbd	tbd	tbd	tbd	Unknown
-						
Roaming Systems						
- EasyMile	Multiple (Appendix 2)	12	n.a.	15	100	£180K/veh
- Navya	Multiple (Appendix 2)	11	n.a.	25	70	£180K/veh
- Oxbotica	UK (Milton Keynes)	2	n.a.	20	60	tbd
- Oxbotica/ Westfield	UK(Greenwich)	4	n.a.	tbd	tbd	tbd
- RDM	UK (Milton Keynes)	2,8	n.a.	20	60	tbd
- Ollie	Multiple (Appendix 2)	12	n.a.	tbd	tbd	tbd

3 Reasons for Developing a Cambridge Autonomous Vehicles Programme

There are a number of good reasons why it is timely to explore the use of autonomous vehicles in and around Cambridge.

- Cambridge suffers an acute congestion problem which demands radical action. No potentially 'game-changing' solution should be left unexplored.
- The UK government is a strong supporter of Connected and Autonomous Vehicle technology (CAV technology). Through the Office for Connected Cars and Autonomous Vehicles (C-CAV), the government has pledged more than £100M to support industrial research in this sphere over the next 5 years. This sum will be matched to industry contributions of a similar amount, taking the total funds available for the programme to £200M) This money will be distributed via a series of regular competitions which will be organised by InnovateUK between now and 2020.
- The County Council possesses an extremely valuable asset in the form of the Cambridge Guided Busway. This facility provides an ideal environment in which to explore the use of autonomous vehicles in a protected environment by making use of the busway's segregated corridor.
- The city has an unusually high complement of large campus sites (the Science & Business Parks, Addenbrooke's, Wellcome Genome Campus, Babraham, and the University's new West Site/North-West Cambridge developments). These sites are all highly successful and many have plans to expand, but each of them already suffers from a lack of on-site parking. Any future moves to reduce the number of private cars allowed on these sites would create an intra-site transport need which could be met by an L-SATS solution.
- The planned expansion of the Campuses is putting increasing pressure on the surrounding transport network, thus creating local off-site congestion and parking problems within the adjacent residential areas. Formal off-site parking solutions, with sustainable public transport links to the core of each site, would be an attractive solution for all.
- The University represents one of the world's leading technology research institutions. To maintain its international status, it needs to expand to match the development of its international peers. Making Cambridge an attractive place to live is essential to the University's ability to continue to attract world-class researchers. The development of world-class public transport system is a critical enabler for this.
- The argument for attracting world-class staff similarly applies to the large number of commercial/industrial organisations which have either grown up in Cambridge (e.g. ARM) or have chosen Cambridge as a location for one of their international research centres (e.g. Microsoft, AstraZeneca)

4 Pre-Programme Considerations

For a realistic programme to be developed in Cambridge, the following considerations should be taken into account.

4.1 The City Deal Perspectives

- How important is it to solve the current congestion problems?
- Could an exploratory project deliver a useful legacy in terms of meeting any of the city's immediate or future transport needs?
- In its legacy form, could such a project become an integral part of a more general multi-modal transport offering in future?
- What is the cost of ignoring this technology?

4.2 The University & Local Business Perspectives

- How important is it to solve the current congestion problems?
- What are the benefits which might accrue to the University and the local business community as a result of introducing autonomous vehicles in the city and its major campus sites?
- How willing are local businesses to engage with the Council to support and encourage new transport initiatives?
- What is the cost of ignoring this technology?

4.3 The Technology Risk

There is always a technology risk in setting out to accomplish something that is ground-breaking. But careful planning can contain that risk and there is plenty of evidence from the systems cited in Appendix 2 to suggest that some of the 'bleeding edge' risks have already been taken by others. A well-planned programme of visits and meetings to see and discuss those systems at first hand would be a wise move before finalising an action programme for Cambridge.

4.4 The Cost and Time Risk

The cost of implementing a working system will amount to far more than the simple cost of acquiring or developing suitable vehicles. Apart from the capital costs (vehicles, supporting systems, infrastructure modifications, etc) there will be significant staff costs associated with fleet operations (customer care, vehicle allocation and despatch, etc), safety and security, technical support, and repair and maintenance. There will also be further non-staff recurring costs such as electricity, publicity, insurance, etc. A summary of the headline cost items which must be considered is presented in the table below.

Cost Type	Comment
Capital Costs	
Purchase price per vehicle	Estimated £180K - £220K per vehicle for 'mini-bus' vehicles. £40-60K per vehicle for 'driverless pod' vehicles
Operations Centre	Space and office equipment for controlling vehicle operations including emergency interventions
Surveillance & control systems	Cameras, voice-systems, and sensors deployed around the operational theatre

Stabling & maintenance facility	Basic shelter, cleaning, and engineering facilities
Boarding/alighting points	Simple shelters plus space for turning and manoeuvring
Infrastructure additions	Segregated pathways – if required. This is to be avoided if at all possible due to the very high construction costs.
Infrastructure modifications	Lights, white-lines, signage, surface improvements, fencing, etc
Operating Costs	
Operator's costs (staff)	Office based staff within the Operations Centre
Security staff	Field based staff on the route
Fleet maintenance	Routine servicing, maintenance, and repair
Electricity	Electric vehicles
Data transmission costs	Rental costs for data services
Insurance	Operations insurance

In terms of the time risk, a suitable programme should be designed, implemented, and completed within a period of around 3 years. This timetable is important; the fast-moving pace of development in the L-SATS/CAV world means that anything more protracted would be overtaken by events elsewhere and the 'leadership ' element of the programme would be lost. This would compromise the ability to win supporting funds from the government's C-CAV programme. This also means that anything developed in this programme will need to have a legacy value that endures, despite the fact that other developments elsewhere will, inevitably, overtake anything which is specifically developed within this programme.

4.5 Physical and Legislative Barriers to Using the Guided Busway

As has been mentioned previously, the Guided Busway is a great asset to Cambridge's ambition to develop an L-SATS demonstration programme. There are, however, some potential barriers which must be fully understood before any commitments are made

4.5.1 Physical Barriers

The major barrier to use of the Guided Busway is the frequent and fast-moving buses. It might be impractical to run the L-SATS demonstration during the daily timetabled periods but, if an L-SATS demonstration and subsequent legacy service could be run daily between 2100 and 0600 and on Sundays, when bus services do not run, this conflict would be avoided. The potential demand for an L-SATS service operating during these periods is discussed in more detail in Section 5.2, but it is considered likely that a sufficient level of demand would exist to make this mode of operation viable.

In terms of other physical barriers, the Guided Busway incorporates a central drainage channel and a series of car traps. The width of the L-SATS vehicle (its 'track') will either have to be wide enough to straddle these features (like the bus does), or the busway will have to be modified to accommodate smaller vehicles. The latter is likely to be an expensive option – the cost of modifying the central drainage strip to accommodate narrower vehicles is estimated at £100,000 per km.

4.5.2 Legislative Barriers

Legislation and other legal requirements are important considerations and there are several different approaches which might be adopted. These include options to consider fixed route systems in the same light as rail systems, or to consider both fixed route and roaming systems in the same light as road-going vehicles.

The Heathrow ULTRa system falls under the Rail and Other Guided Systems (ROGS) legislation. Approval to operate must be obtained by means of assessment by a "competent person" as under

ROGS. This includes checks of: safety management systems, safety certificates, risk assessments and implementation of measures identified to mitigate risks.

The Cambridgeshire Guided Busway was originally intended to be under Her Majesty's Railway Inspectorate (HMRI) legislation, but this position changed in 2004. The Busway has, instead, been considered a private road by Cambridgeshire County Council under the Transport and Works act which gives it protection from 3rd parties carrying out works which would disrupt the infrastructure.. This suggests that the regulatory framework within which the L-SATS trials would take place on the Guided Busway section would need to be discussed and agreed with the Council.

There are sections of route, for instance on the town centre approach near the rail station, where buses leave the Guided Busway and use the road network. In this case, the L-SATS would need to abide by Department for Transport (DfT) legislation. Testing of automated vehicles on public roads is possible in the UK today, provided a test driver/operator/vehicle controller is present and takes responsibility for the safe operation of the vehicle; and that the vehicle can be used compatibly with road traffic law.

In 2015 the Government published a detailed review of existing legislation to establish the regulatory situation with regards to testing of automated vehicle technologies and their longer term introduction to the market. *The Pathway to Driverless Cars* review was published by the DfT in February 2015. It notes that "those wishing to conduct tests in the UK are not limited to the test track or certain geographical areas, do not need to obtain certificates or permits, and are not required to provide a surety bond (provided they have insurance arranged)".

One outcome of the DfT review was the development of *The Pathway to Driverless Cars: A Code of Practice for Testing*. This Code of Practice is non-statutory but has been developed to promote responsible testing. The Code is not intended to apply to tests carried out on private test tracks or other private areas (e.g. the Guideway) but it would need to be applied in areas of the L-SATS route which use the public highway. Therefore it is worth noting the guidelines for testers set out by the DfT:

- During testing of automated vehicles on public roads or in other public places, a suitably licenced and trained test driver or test operator should supervise the vehicle at all times and be ready and able to over-ride automated operation if necessary.
- Vehicles under test on public roads must obey all relevant road traffic laws.
- Testing organisations should:
    - ensure that test drivers and operators hold the appropriate driving licence and have received appropriate training even if testing a vehicle's ability to operate entirely in an automated mode

      conduct risk analysis of any proposed tests; be conscious of the effect of the use of such test vehicles on other road users; and manage the risk of adverse impacts on other road users.

      consider the need to engage with the relevant transport and highway authorities with responsibility for the areas in which the tests will be conducted.
- Automated vehicles under test should be fitted with a data recording device which is capable of capturing data from the sensor and control systems associated with the automated features as well as other information concerning the vehicle's movement.

- Manufacturers providing vehicles, and other organisations supplying parts for testing will need to ensure that all prototype automated controllers and other vehicle systems have appropriate levels of security built into them to manage any risk of unauthorised access.
- It is expected that automated driving systems will rely on the interaction and correct operation of several computers and electronic control modules. It will be important that: software levels and revisions running on each vehicle to be tested are clearly documented and recorded and all software and revisions have been subjected to extensive and well documented testing.
- Testing is likely to involve the processing of personal data. For example, if data is collected and analysed about the behaviour or location of individuals in the vehicle, such as test drivers, operators and assistants, and those individuals can be identified, this will amount to the processing of personal data under the Data Protection Act 1998. The project team must therefore ensure that the data protection legislation is complied with, including the requirements that the personal data is used fairly and lawfully, kept securely and for no longer than necessary.

The DfT also recommends that testing organisations should consider the benefits of developing a public relations and media communications strategy in order to educate the public regarding the potential benefits of automated vehicles. This would: explain the general nature of the tests to be undertaken; explain the implications for other road users, if any, and what steps are being taken to mitigate any risks; provide reassurance and address any concerns. It is recommended that a communications strategy be implemented for the AV trials in Cambridge.

In summary, it is considered that the legislative framework in the UK does not provide any serious barrier to the development of an L-SATS programme in Cambridge.

4.6 Commercial Models

There are several different operating models and commercial partnerships which could be explored:

1) An L-SATS system provider could own and operate the system, re-couping their costs through fare income and advertising. Advertising income would be secured by the L-SATS supplier/operator. By way of example, the Heathrow pods are supplied and operated by ULTra PRT, the client is BAA, and the pods are sometimes liveried with adverts. The illustration below shows branding for the Royal Horticultural Society.

2) An L-SATS system provider could partner with a local public transport company such as Stagecoach, Whippet, or Abellio. The vehicle livery could represent the public transport provider, and this would reinforce the perception that the local public transport network is truly integrated. But the loss of advertising income might leave a hole on the financial equation which would need to be plugged by the Local Authority.
3) The L-SATS system could be owned and operated by a public transport operator, with or without sponsorship advertising.
4) The L-SATS system could be owned and managed by Cambridgeshire County Council with, or without, sponsorship advertising livery. In the latter case, this would be similar to the London cable car (owned/operated by TfL, sponsored by Emirates).

4.7 Future Mass Transit Developments (AVRT)

The concern over congestion and its impact on the future growth of the city has prompted a range of different proposals for new, or alternative, transport solutions. One of those under current study is Affordable Very Rapid Transit (AVRT), a low-cost rapid transit concept which is the subject of a separate report currently in draft at the time of writing.

The AVRT system comprises a fleet of very rapid 40-seater vehicles which run on segregated pathways around, and under, the city's central zone providing a mass transit-like service which is tailored to the needs of a small city.

The proposed route layout is shown, stylistically, in the figure below. A characteristic of AVRT is that it has a relatively small number of interchanges which are separated by several kilometres in each case. (This is an intrinsic part of the formula for bringing the costs down to affordable levels). As a result, a complementary 'last-mile' service is required for travel from the interchange at which a traveller alights to the point of final destination. This 'last-mile' requirement is particularly important in the central zone marked on the image below.

There are several possibilities for providing a convenient and efficient last-mile public transport service, but there is a clear potential for introducing a ‘roaming’ L-SATS system which can operate at will within the city centre area. Such a system could provide an ideal solution if promoted in parallel with walking and cycling, and a formal consideration of this need should be part of any autonomous vehicle programme which the city might embark upon.

5 The 'Reference Programme'

This section proposes an outline programme of work which the City Deal authorities might consider as a 'Reference Programme'. The initial definition of this programme was developed during the early stages of this study and, prior to completion of the study, it was submitted in collaboration with RDM Automotive and the Wellcome Foundation for funding within the most recent round of C-CAV competitions (C-CAV3). The submission was successful and £250,000 was awarded to fund a much more detailed Feasibility Study for taking this work forward. The expanded resources provided by these funds should be used to create a more detailed plan, and to generate interest amongst the University, local businesses and other influential institutions. The matched-funding requirement for a subsequent full-blown demonstration programme will likely run into several millions of pounds, so the enthusiastic support of industry is a pre-requisite for success.

The Reference Programme is outlined in Section 5.3. It has been shaped by the following primary requirements:

1. It must be clearly focussed on exploring systems which have the potential to solve real-world problems.
2. It must keep the technical and commercial risk profiles within acceptable bounds.
3. On completion, the programme should deliver a tangible and lasting benefit for the city and its different communities (citizens, businesses, universities, etc). The ambitions for the legacy benefit must be defined with care. They must not be set so high that the technical risks become unacceptable, but they must be ambitious enough to create real benefit for the City. Importantly, the legacy must be delivered within a reasonable timescale.

These three requirements are expanded on below.

5.1 <u>Legacy Benefit - Cambridge's Transport and Mobility Needs</u>

There are a number of different scenarios in which CAV's might provide part of the solution to the City's transport problems. These are summarised in the following table. The Reference Programme should be directly related to one or more of these scenarios.

Location	Service Type	Scenario Description	Potential Solution
Major Campus Sites	**1**	**'Commuter Surge':** The arrival and departures of daily commuters/visitors generates acute on-site congestion and parking problems. It also causes traffic congestion and delays on the surrounding public roads.	Large AV's to provide fixed-route transport links to off-site transport nodes and parking sites.
	2 (a & b)	**Intra-Site Movements: M**ovements within the campus boundaries by employees and visitors. Includes both passenger movements and deliveries/ facilities management/administrative services movements.	**a)** Large AV's to provide fixed-route services (timetabled or on-demand). **b)** Small AV's to provide 'random services' (i.e. flexible,

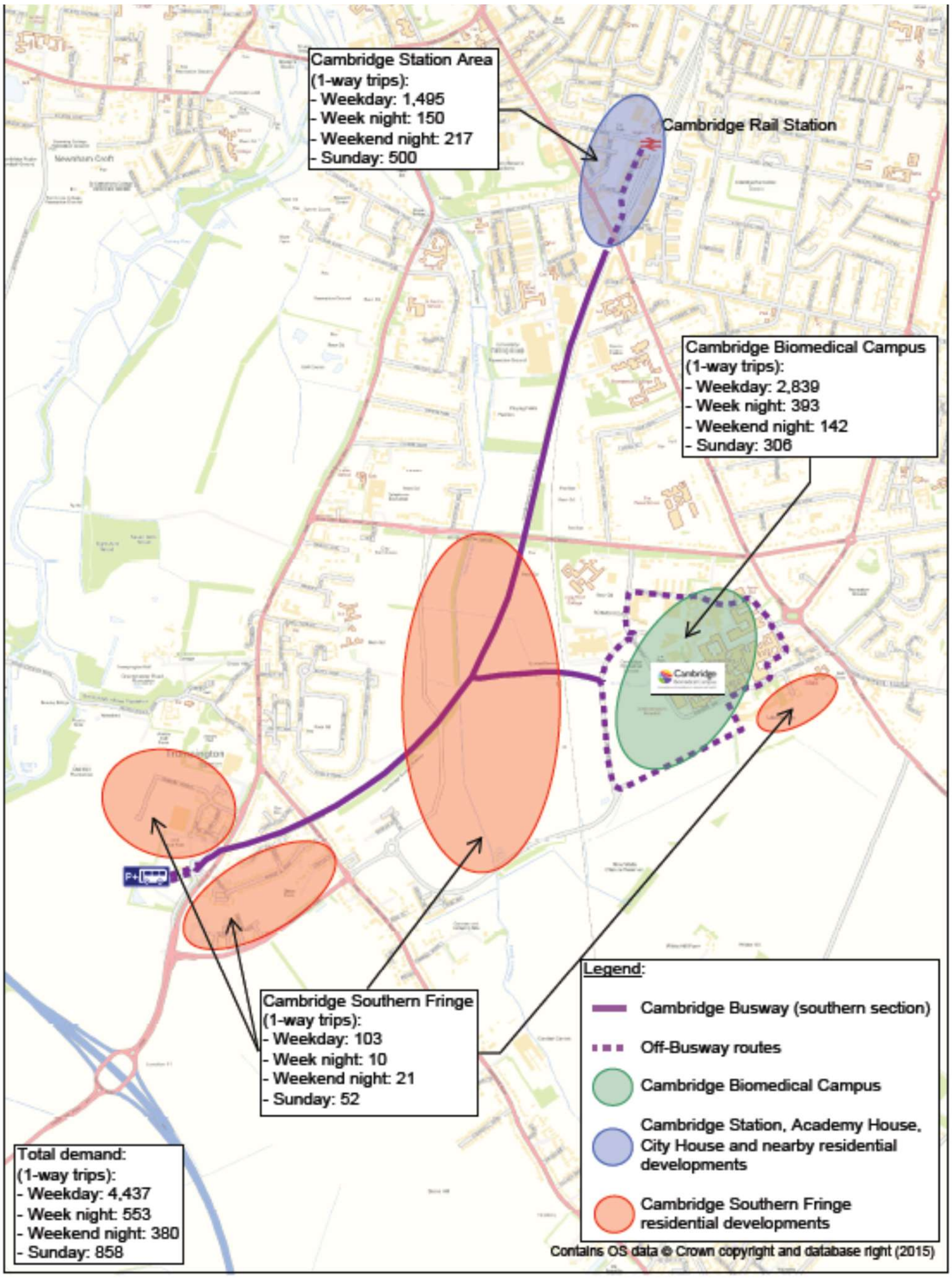
			on-demand, 'anywhere-to-anywhere' services)
Wide areas of public realm within the city limits	**3 (a & b)**	**First/last miles services:** Some of the solutions being proposed for the relief of city-wide congestion include the restriction of private and commercial vehicles from quite large areas within the city limits. The proposals for AVRT, for example, come with a rider that car/commercial vehicle restrictions should be applied to a large area of the city within a ring of AVRT links. For such proposals to be acceptable, an affordable and effective first/last mile transport service must be provided within the proposed restricted zones.	**a)** Large AV's to provide fixed-route services (either timetabled or on-demand) **b)** Small AV's to provide flexible, on-demand, 'anywhere-to-anywhere' services within the defined zone.
Small areas of public realm within the city limits (e.g. the city centre)	4	**Random, Short-distance Movements:** This is a special sub-set of case 3(b) above. In the case of the city-centre zone, private vehicles are already largely excluded, but buses and taxis are allowed unrestricted access. A strategy to remove these vehicles from this zone (e.g. AVRT) would need to be coupled with the provision of alternative transport options for current users.	Small AV's to provide flexible, on-demand, 'anywhere-to-anywhere' services within the defined zone (illustrated in the figure at Section 4.7 above).

5.2 Limiting the Technical & Commercial Risks

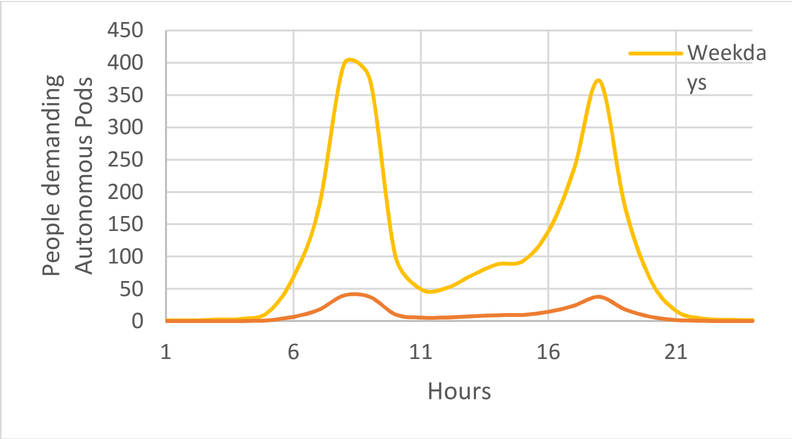
The following tactics are recommended to minimise technical and commercial risks.

Technical risks: Make use of the Cambridge Guided Busway. The busway provides Cambridge with a big advantage over most other locations when it comes to creating a test environment for L-SATS/CAV development work. This asset provides a protected corridor within which autonomous vehicles can be segregated from other traffic whilst, at the same time, allowing sufficient access to members of the public for building public trust in their operation.

Commercial risks: Make sure the demonstration system has a positive business case. A preliminary assessment suggests that an out-of-hours service on the southern part of the busway in the area shown on the map below could generate an initial demand of up to about 550 trips during regular 'weekday night' hours. This represents a period when the normal bus services are not running (between 9:00pm at night and 6:00am next morning on weekdays and Saturdays and all day on Sunday). The background to this analysis, with an assessment of future growth possibilities, is described in Appendix 3. With a flat-rate fare in the range £1 - £2 per single trip, the fare box would comfortably exceed the system operating costs, thus allowing the capital costs to be repaid over a reasonable period of time.



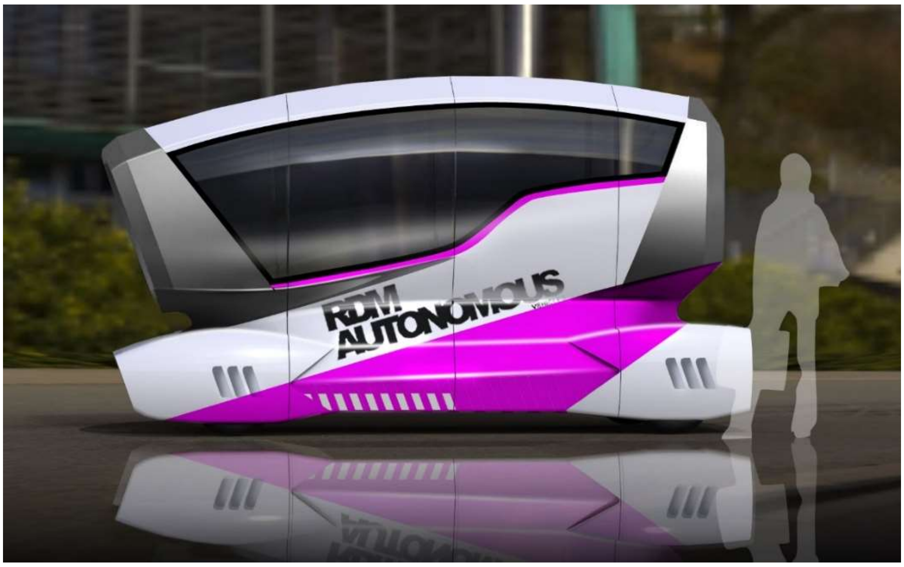
Similar business case assessments suggest that positive cases can be made for both large and small L-SATS running Service Types 2(a) & 2(b) operations on the large campus sites (see table in Section 5.1 above). A preliminary business assessment for the larger sites (West Site/Addenbrooke's) suggests that a fleet of some 50-80 small 'driverless pods' operating in combination with around 5-10 'mini-bus' CAV's might even be privately financed as a campus-based sustainable transport solution. The methodology used to make this assessment is explained in Appendix 4.The diagram below, taken from that appendix, suggests the levels of ridership which might be attracted during different times of day during the working week and at the weekends.

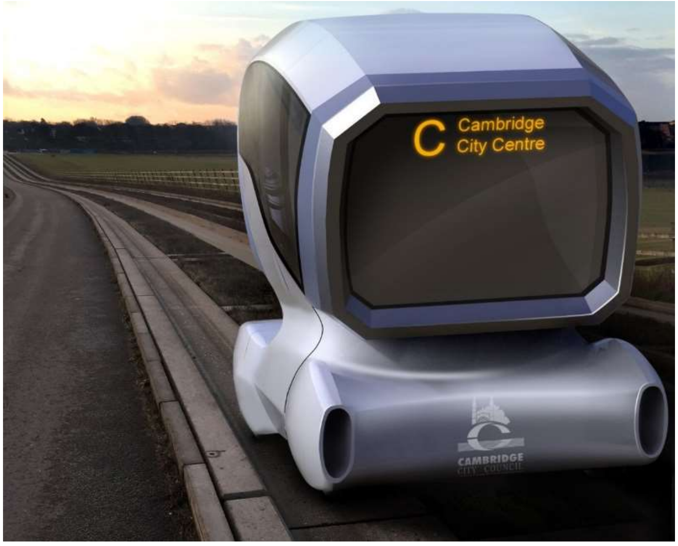


5.3 <u>Setting the Ambition – Programme Definition</u>

A programme which could strike the right balance between minimising the risks and maximising the beneficial legacy is described below. It is referred to as the 'Reference Programme' and comprises the following elements:

1. A 'baseline programme' designed to explore fixed route L-SATS operations of Types 1 and 3(a) as described in the table in Section 5.1. This programme would require the use of large, 12-15 passenger capacity, vehicles of the type shown in the illustrations below.





The southern length of the Cambridge Guided Busway could be used as the proving ground for a functioning out-of-hours, fixed-route, public transport service which would serve the area between Addenbrooke's site, Cambridge central railway station, and the Trumpington Park and Ride site. To demonstrate the ability of the large AV to integrate seamlessly with the city's conventional transport services (bus, train) the vehicle should be required to operate in both 'fixed route' and 'roaming' modes. Specifically, the vehicle should be required to demonstrate its ability to leave the busway and travel short distances in un-segregated space within the following three zones:

- on the Addenbrooke's site
- in the vicinity of the Cambridge central railway station
- in the vicinity of the Trumpington Park & Ride site.

Some special arrangements may need to be made to facilitate these off-busway excursions, especially during the early stages of programme development.

The technical development elements of the baseline programme could probably be delivered using only two or three vehicles, but a fully functional public transport demonstration would probably require a fleet of between 8 – 10 vehicles to provide the levels of service which would be needed to give confidence of commercial viability in the longer term.

2. A 'complementary programme' in which the use of small, roaming, AV's should also demonstrated. This recommendation is driven by the recognition that Services of Type 2, 3, & 4 will represent important elements of Cambridge's future transport requirements. This part of the programme would probably best be explored in the context of a Type 2(b) service operating on one of the large campus sites. West Cambridge would be a good venue, given its open layout and relatively light usage.

3. The programme should include an element for the exploration and development of the ticketing systems which will be required if AV's become an integral part of the City's public transport offering. Revenue protection and interoperability with other modes of transport (buses and trains) are obvious examples of where some creative thought is required.

6 Conclusions and Recommendations

The development of autonomous vehicle technology is being pursued in many locations around the world. The UK's ambition to be at the forefront of these developments has been heavily underlined by the government which has made significant funds available to support industrial research through the Office of Connected Cars and Autonomous Vehicles (C-CAV). These funds have already begun to flow and will continue to be distributed over the next four years via a series of matched-fund competitions. Cambridge, with its acute congestion problems, stands to gain significant benefits from the deployment of autonomous vehicle technologies and, provided it can secure a good measure of industrial support, the City Deal Team is well placed to take advantage of the C-CAV programme of competitions.

The presence of the guided busway provides Cambridge with a unique test infrastructure for the demonstration of short-range public transport services using fixed-route Low Speed Autonomous Transport Systems (L-SATS). The presence of a number of very large campus sites also provides Cambridge with ideal infrastructure for the demonstration of 'roaming' L-SATS services. The combination of these two forms of infrastructure makes Cambridge a very attractive location in which to stage a major demonstration of L-SATS technologies and, in the process, create a lasting benefit for the city.

An outline 'Reference Programme' has been proposed. Based on this programme, and working in collaboration with Wellcome Trust and RDM Automotive, funding of £250,000 has already been secured from C-CAV to produce fully-detailed plans for an L-SATS exploration programme that could be delivered in Cambridge. This background sets the context for the following recommendations:

- The County Council should actively pursue the development of a comprehensive L-SATS demonstration programme as defined in Section 5.3.
- The funds already secured from C-CAV should be used for three primary purposes:
    - To organise, and learn from, study visits to other L-SATS projects which are currently in progress around the world (see Appendix 2)
    - To fully develop the details of the L-SATS demonstration programme for Cambridge
    - To engage local businesses and raise the local financial support which will be necessary for the implementation of the defined programme.

The resulting programme could be match-funded through the C-CAV programme, or it could be fully funded by local businesses and other influential organisations. The fully-funded model brings with it a valuable degree of freedom to define and control the programme; the C-CAV route brings with it a valuable contribution of government funds. In either case, a consortium of interested parties will need to be formed around a strong statement of common interest, and substantial financial commitments will need to be made. The County Council should act as the broker for bringing the necessary consortium together.

Appendix 1

The Brief – A Feasibility Study to Explore the Potential for Running Autonomous Vehicle Trials in Cambridge Utilising the Unique Aspects of the Guided Busway

Background

Connected and autonomous vehicles incorporate a range of different technologies, facilitating the safe, efficient movement of people and goods, helping to improve mobility and productivity, and offer an alternative to driving.

Vehicles with increasing levels of automation will use information from on-board sensors and systems so they can understand their global position and local environment. This will allow them to operate with little or no human input (ie be driverless) for some, or all, of the journey.

The UK is one of the best countries for car makers and others to develop and test these technologies because of our:

- permissive regulations
- thriving automotive sector
- excellent research base and innovation infrastructure

The Government is investing heavily in autonomous and connected vehicle research and has launched 4 trials in UK cities, Greenwich, Bristol, Coventry and Milton Keynes. A further round of funding has been announced and Government will be making grants totalling up to £100m for studies and other work under a CCAV (Connected and Autonomous Vehicles) funding programme. Interested parties can 'bid' for this money later in the year. There is potential for Cambridge to do so, however some preparatory investigative work needs to be undertaken first

The opportunity is for the Greater Cambridge area to participate in future transport innovation centred on driverless vehicles for business and leisure travel – supporting out of hours working, evening leisure activities and future-facing "on demand" transport services not reliant on individual car ownership.

The University of Cambridge are already leading a piece of work looking at the potential for autonomous vehicles to provide rapid transport on the western orbital of the city. This work also encompasses investigating whether autonomous rapid transit could provide transport solutions linking up various University campuses and the bio-medical campus.

Key outputs

The report will:

- Examine the suitability of using the Guided Busway to run autonomous vehicles, identifying any legislative or physical barriers which will need to be addressed, and where possible outlining potential solutions.
- Identify the most suitable section of the busway to use based on the strongest use case and suitability of infrastructure. Other options outside of the busway may also

be identified for consideration, setting out how this would add to the current transport mix.

- Identify opportunities and unique characteristics of the proposed test beds which can support bids into Government/Investors. This may also include some analysis on how any project in Cambridge could support the UK's wider vision as a centre for autonomous vehicles
- A preliminary investigation of the commercial use cases for autonomous vehicles in Cambridge, including where possible estimations of demand.
- A preliminary view of possible operator models for any service.
- Identify opportunities to partner with other cities and benefit from knowledge transfer from other projects, including re-use of Milton Keynes pod design if feasible.
- Identify possible commercial partners such as Astra Zeneca, GSK, Wellcome etc., and the role they could play in delivering the vision
- A preliminary investigation into funding options for the delivery of a project (Government funding, Private finance, ESIF etc)

Appendix 2

Low-Speed Autonomous Transport Systems (L-SATS)

This appendix summarises a number of L-SATS schemes which are currently operating, or being planned, around the world.

2.1 Heathrow Airport Terminal 5

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

Introduction: May 2011

Cost: £30 million

Function: Transports business car park users between Business Car Park Terminal 5 and the Terminal 5 building.

Cost to passenger: £5 per pod if travelling from the hotel. Otherwise cost is included in cost of parking.

Operation: The capacity of the Heathrow pod system is 164 vehicles per hour per direction – equivalent to a maximum of 656 passengers per hour per direction. The system is controlled on a synchronous basis with no vehicle being dispatched without a time slot allocated to it on the guideway. It runs up to a maximum speed of 25 miles per hour (40 kilometres per hour). Headway between pods is 6 seconds minimum and a fixed block detection system (AVP) is built into the track to ensure this safe distance is maintained.

Infrastructure: 21 vehicles connecting three stations. Each vehicle has four seats and enough room for accompanying luggage. 3.8km of guideway. The guideway consists of a concrete plank running surface on a steel structure. It is fixed to concrete block foundations.

Power: There are no emissions at the point of use. The system uses lead acid batteries which are charged each time a vehicle enters the station.

Other features: There is a central control centre for monitoring of the pods by trained operators in the event that anything goes wrong. A "snow and ice" vehicle is available which operates when snow and ice are expected and keeps the guideway clear by applying low concentrations of de-icer.

2.2 Masdar City, Abu Dhabi

This system, supplied by Netherlands based company '2GetThere**'**, has been in operation since 2010. At the time of writing, it has delivered 2 million passenger journeys and completed nearly 1 million vehicle km without any accidents.

Introduction: November 2010

Cost: Unknown

Function: Transport people from the North Car Park at Masdar City to phase 1a of the Masdar Institute of Science and Technology.

Cost to passenger: Free. As residents of the city cannot park their cars at their apartments, the system is provided free as compensation by the developer. Through branding the operational costs can be covered (partially).

Operation: The system is operational 7 days a week, 18 hours per day (06:00-24:00) requiring a staff of six operators, three engineers and an Operations Manager to perform operations. The system can carry up to 300 passengers per hour per direction. The headway is five seconds minimum. Separation of the vehicles is ensured through radio based communications and the vehicles' obstacle detection system.

Infrastructure: Each vehicle has four seats and enough room for accompanying luggage. The vehicles operate on a completely flat track, according to virtual routes. The position of the vehicle is verified relative to external reference points (magnets embedded in the road surface).

Power: There are no emissions at the point of use. The system uses lithium ion batteries which provide a 60+km range. Recharging is done when demands allows either at the berths or in the dedicated charging rooms at the operations facility.

2.3 Business Park Rivium, Capelle aan den Ijssel, Netherlands

Originally piloted in a demonstration which started in 1999, the ParkShuttle was the first autonomous system in the world to carry passengers without a driver on a pathway at grade through barrier-protected intersections with other traffic. Six second-generation vehicles were commissioned in 2006 and it is planned to significantly extend the network by late 2018.

Supplier: 2getthere (based in Utrecht, the Netherlands)

Introduction: November 2008

Cost: Unknown

Function: The ParkShuttle connects business park Rivium and the residential area Fascinatio (both located in the city of Capelle aan den Ijssel) as well as business park Brainpark III (located in the city of Rotterdam) with the metro and bus station Kralingse Zoom (located in the city of Rotterdam)

Cost to passenger: Unknown

Operation: The system operates on schedule in peak hours, with all six vehicles available for transportation. In off peak hours the vehicles alternate charging, with the vehicles remaining in service operating on-demand. Distribution over the track is such that the waiting time for passengers at each stop is minimized. The system is operational on weekdays, from 06:00 in the morning until 21:00 at night. A single operator is on duty during operational hours, supported by a small maintenance engineer during ‘office-hours’. Each Friday (when demand is typically lower) one of the vehicles is serviced. The capacity is theoretically 480 passengers per hour per direction, based on 20 passenger occupancy.

Infrastructure: The vehicles operate on a completely flat track, according to virtual routes. The position of the vehicle is verified relative to external referenc e points (magnets embedded in the road surface).

Power: Vehicles are powered by Lead-Acid batteries (Track-air) providing a range of approximately 75 kilometres. Recharging is done overnight and with vehicles alternating during midday, ensuring all vehicles are operational during the morning and afternoon peak hours. Recharging is an automatic process conducted in the maintenance facility.

2.4 Suncheon Wetlands SkyCube, South Korea

This system, based on a design concept which originated in Sweden**,** has been in operation on a 5km elevated track in Suncheon Wetlands since 2013.

Supplier: Vectus Ltd.

Introduction: September 2013

Cost: Unknown

Function: Connects Suncheon's 'Dream Bridge' with the Suncheon Bay Ecological Park

Cost to passenger: Tickets cost 5,000 won (£2.85)

Operation: The system is rail based. All vehicles are controlled via a distributed control system with a typical headway of 4-5 seconds.

Infrastructure: The guideway is a concrete pillar and beam construction with typical spans of 30m (50m over the main river).

Power: Elimination of all emissions (at the point of use) from transportation into the eco-park (currently served by cars and buses) which is an environmentally sensitive area. The system is rail based and vehicles are powered by a current collection system installed along the guideway.

2.5 EasyMile

Easymile, an electric vehicle producer founded in 2104, specialises in providing both software powering autonomous vehicles and last mile smart mobility solutions. The company's headquarters are in Toulouse, France with offices in Singapore and Denver (USA). It also operates through value added resellers, notably in Japan and the Middle East. EasyMile has developed the EZ10, a driverless bus which is operated entirely autonomously and does not even have a steering wheel.

Together with public transport company Kolumbus and Forus PRT, EasyMile will start a pilot project at the Forus PRT business park in Stavanger, Norway. The pilot project (to be started in early 2017) aims to provide a transport service within the business park and to also test the EZ10's operation and technology in the challenging conditions. The project will roll out in phases and the goal is to eventually transport people around the whole business park. If the pilot goes well, it could lead to the implementation of an additional four EZ10S into service at the business park.

In Germany , Deutsche Bahn announced that it has been running an autonomous bus project in Leipzig since October 2016, with the EZ10 driverless shuttle by EasyMile. The EZ10 transports DB's employees along a 1.6km route at the Schenker site on a daily basis so as to gather user feedback and test the vehicle operation and technology under real life conditions.

In the USA, First Transit, one of the nation's largest private-sector providers of mobility solutions has introduced its first AV passenger shuttle. First Transit, in partnership with EasyMile, will pilot the AV passenger shuttle at the Bishop Ranch Office Park in San Ramon, California. The shuttle will connect tenants to multiple transit options including bus, bike and car-sharing services. It will run a fixed route stopping at designated stops within the office park. A pilot service will begin with two vehicles, each with a customer service agent on-board for passenger questions and information. The AV passenger shuttle is designed to travel short distances using pre-programmed routes. Each passenger shuttle is equipped with a sensor and intelligent vehicle system to detect obstacles and avoid collisions. The pilot launched in December 2016.

EasyMile is also running trials in:

- Lausanne – as part of the CityMobile2 project on the Swiss Federal Institute of Technology campus (55 hectares; 13,000 students)
- Dubai – on the Mohammed bin Rashid Boulevard.
- Singapore – in the Waterfront Gardens

2.6 Navya

Navya was one of the first companies to introduce a 'roaming' autonomous vehicle and is currently running a number of trials/demonstrations including:

- Sion, Switzerland - where POSTBUS, Switzerland's public transport company, is currently operating two vehicles offering a service to Sion's residents and visitors.
- Singapore (One North) – where an early model vehicle has been under trial for more than a year at the National University of Singapore (NUS)
- Perth, Australia – where a vehicle is operating on an esplanade path along the coast
- UK (Heathrow) – where the vehicle was recently demonstrated on a short-term basis

2.7 Olli (Local Motors/IBM)

In 2016, Local Motors unveiled an autonomous, electric-powered bus. The vehicle was initially named the "Berlino" from the Urban Mobility Challenge: Berlin 2030. Now re-named "Olli", the vehicle is manufactured in Chandler, Arizona using additive manufacturing techniques, including 3D Printing. It has IBM Watson technology installed to provide a personalized experience for riders.

The vehicle is still undergoing development, but was demonstrated live in mid-2016 to an online audience on Facebook at a media event in National Harbor. MD, USA. The company has not announced pricing yet.

2.8 LUTZ Pathfinder

The LUTZ Pathfinder project was originally proposed by the UK Automotive Council and became the fore-runner of the UK's three driverless car projects. It was carried out in Milton Keynes by the Transport Systems Catapult during the period 2013-2016. Very specific in its objectives, the project set out to explore the credibility of developing a small, low-speed autonomous vehicle which could operate safely in pedestrianized space. The project concluded successfully in late 2016 with the demonstration of a purpose-built vehicle ('The Genie') operating in public space under the control of the Oxbotica 'Selenium' system which had been developed at the University of Oxford.

2.9 Greenwich Gateway Project (Westfield/ULTRa)

Thames Gateway is one of the three UK Driverless Car projects which were launched in 2015 following the commissioning of the LUTZ Pathfinder project. Currently underway in Greenwich, south-east London, the plan is to take the Ultra type of vehicle (as operated at Heathrow) and develop the concept from a fixed-path solution into a fully roaming solution.

This project is being undertaken by a consortium of partners which includes TRL, Westfield, and Oxbotica. The Oxbotica 'Selenium' automatic control system (ACS) is being used to control the new vehicles which will be built by Westfield. Trials in the public realm are imminent at the time of writing.

2.10 UK Autodrive

UK Autodrive is the largest and most ambitious of the three UK Driverless Car projects launched in 2015 following the commissioning of the LUTZ Pathfinder project. Currently underway in Milton Keynes, its objective is to demonstrate the credibility of operating a roaming fleet of 40 driverless pods as a 'last-mile' public transport service in the large pedestrianized spaces in Central Milton Keynes. The vehicles and the ACS system are being developed by RDM Automotive. Trials in the public realm are imminent at the time of writing.

Appendix 3

Estimation of Demand – the Arup approach

3.1 Introduction

AVs are still in the early stages of testing and there is no established method for demand forecasting. In this appendix, a simple approach has been adopted based on assumptions which are particular to Cambridge and the characteristics of the area surrounding the Guided Busway between Trumpington and Cambridge rail station. The methodology described here was developed by Arup and is based on professional judgement and assumptions in the absence of an established evidence base.

3.2 Behavioural Factors

One aspect of demand forecasting is the behavioural parameters relating to the perception of a transportation mode and the willingness to choose that over the alternatives. There is established research and methodology for existing modes but no solid evidence base yet for AVs.

Human factors that could potentially affect the demand for autonomous vehicles are listed below. All factors could potentially be beneficial or detrimental to the demand for autonomous vehicles. As with any new technology, there is expected to be a period of trial where the users get accustomed to using it.

- Safety: One of the fundamental design concepts for autonomous vehicles is to remove the human error factor and replace this with reliable technology, which could lead to increased safety. However, the lack of a ‘driver’ can also be perceived as less safe and render AVs less attractive to passengers. This is a factor in the continued employment of drivers on London Underground trains, instead of using driverless trains. The Docklands Light Railway is driverless but each train has an operative on board.

- Technology and novelty: AVs are the latest technological trend in the field of transportation. This could attract users who highly value innovation and have a preference to use state of the art services.

- Convenience and availability: If an AV system could provide an easy, cheap and convenient on-demand service then it could be a preferred alternative to scheduled public transport. For maximum convenience, the pods would be door-to-door, however this may not be possible with the current trial on the Guided Busway. This would reduce the attractiveness of travel by AV at night.

- Autonomy: AVs offer the privacy of a car and the ability for passengers to use their time whilst travelling. This could induce increased demand for AVs vis-à-vis private cars, although some people may not want to give up the experience of driving. Additionally, people who cannot drive could experience the use of a private vehicle.

In summary, the factors affecting demand forecasting that are related to human behaviour are innately derived from the perception of the AVs and what the experience entails. As a result, they could affect the demand either way and there is so far no established methodology for accurate predictions.

3.3 Mode Split and Trip Generation

In order to consider potential demand, the mode splits for journeys to work in Cambridge in comparison with London, the rest of the East of England and England and Wales have been reviewed. They are shown in fig 3.1. These data sets are derived from the 2011 census and are for those who are travelling to work (not including those unemployed or working from home). The graphs show that the percentage of people travelling to work by bicycle and on foot is much higher in Cambridge compared with London, the rest of the East of England and the average for England and Wales. The percentage of people driving to work in Cambridge is low and on a par with London.

The proportion of households without a car is high in Cambridge in comparison with the rest of the East of England, and England and Wales, although London still shows the highest percentage of households without a car. Car ownership of one car per household is higher in Cambridge than London, the rest of the East of England and England and Wales (Fig 3.2) but is similarly low to London for the percentage of two-car households, three-car households and four or more-car households.

More recent work on trip generation, mode shares and travel plan monitoring data for the Cambridge Biomedical Campus (adjacent to the section of Guided Busway intended for the AV trials) demonstrates a slightly lower mode share for car and a much higher mode share for bus (Table 3.1). This could mean that the demand for door-to-door journeys is not as high as in other parts of Cambridge – people would be willing to use AVs even if they remained on a fixed route (much like a bus).

Figure 3.1 Journey to work data (Source: 2011 census)

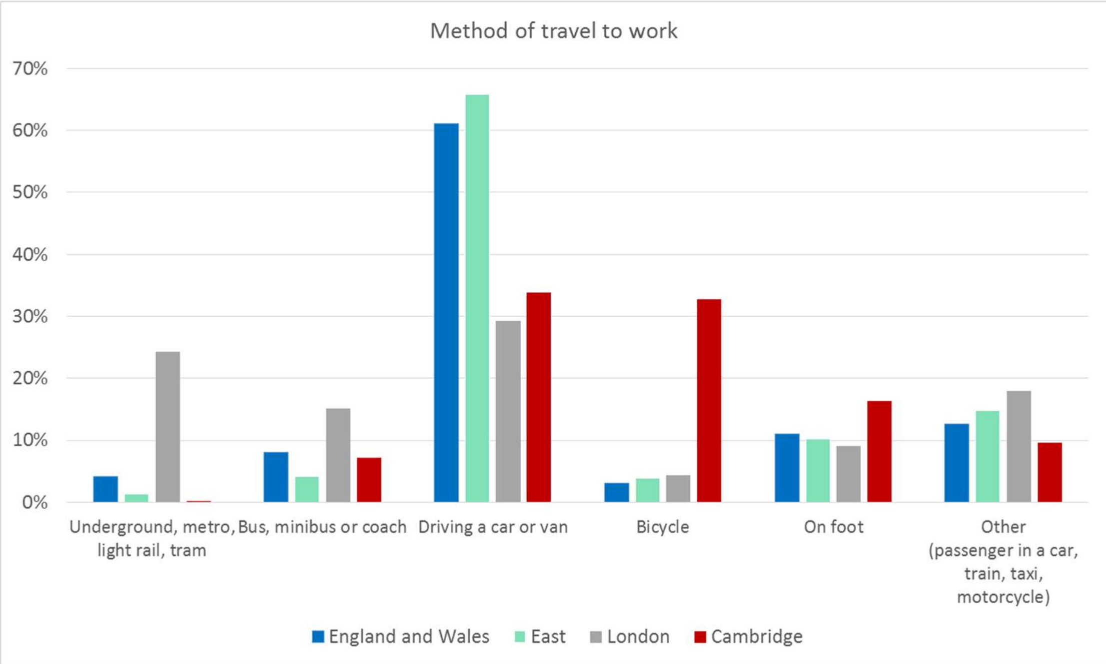
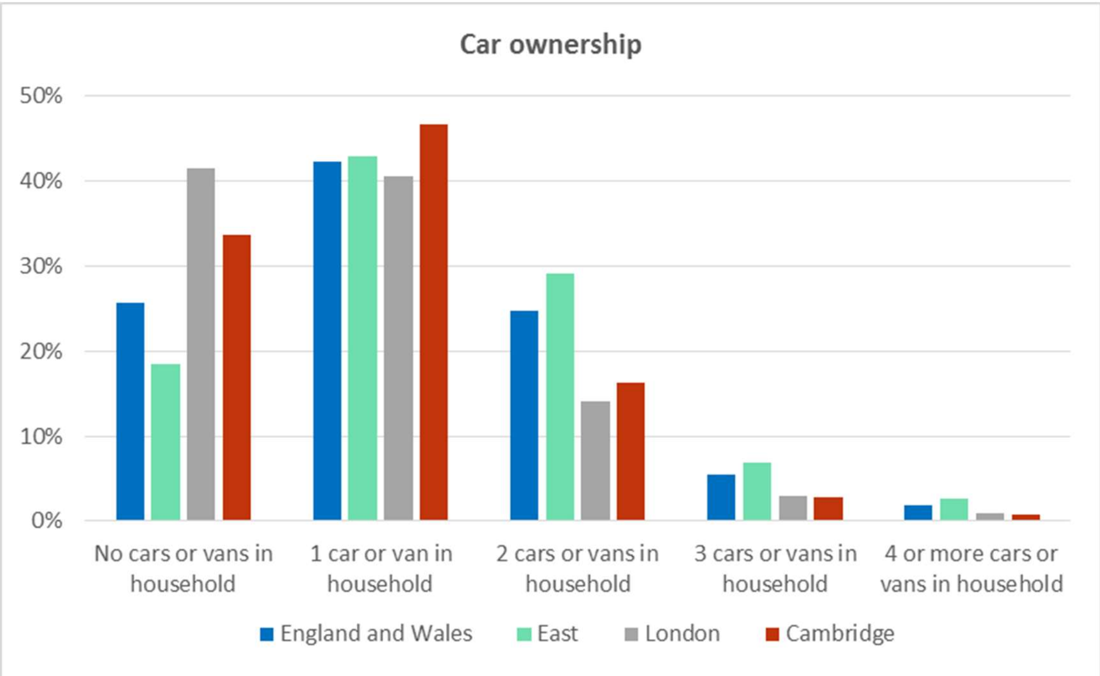


Figure 1.2 Car ownership per household (2011 census)



We have used the mode share information from Addenbrooke's hospital and the AstraZeneca development (both in the CBC) to inform potential demand scenarios for the AV system, where no site-specific information was available.

Table 3.1 Mode shares 2013 and 2014 for Cambridge Biomedical Campus

Mode	Addenbrooke's Hospital Travel Survey 2013	Project Laureate (AstraZeneca new HQ in CBC) Transport Statement 2014
Cycle	31%	34%
Motorcycle	2%	2%
Car single occupancy	28%	27%
Shared car	6%	6%
Bus	27%	26%
Walk	6%	5%
Total	100%	100%

3.4 The Scenarios

Due to the absence of established data, we have developed a series of eight scenarios in order to formulate a potential demand methodology for AVs on the Guided Busway. Table 3.2 sets out the demand scenarios.

Table 3.2 Demand scenarios

Baseline scenarios	Estimated induced scenarios
1 - Weekday	5 - Weekday
2 - Week night (estimated)	6 - Week night
3 - Weekend night (estimated)	7 - Weekend night
4 - Sunday (estimated)	8 - Sunday

Scenario 1 is the 'baseline' weekday scenario derived by generating trips based on the population at each development and estimating existing and future usage of the Busway. Travel plans, census data and other data sources are used in the calculation of demand for this scenario.

Scenarios 2-4 are estimations of what current demand for bus services would be along the Busway if bus service timetables were extended to run through evenings and weekends. Broad assumptions are made based on people's travel patterns and choices during these times. These scenarios are the estimated baseline figures, whether buses or autonomous vehicles (AVs) run along the Busway.

Scenarios 5-8 account for any induced demand due to the introduction of a service using AVs. An expansion factor (which varies by location) is applied to each demand value in Scenarios 1-4 to obtain a corresponding value for the induced demand scenarios. This takes account of new demand specifically because the service provided is by means of AVs (as opposed to a bus service) which may attract additional users.

3.4 Methodology

The method used to calculate potential demand along the Cambridge Busway can be summarised as:

1. Trip generators along the Busway were identified (Section 3.5). This mainly consists of the residential developments of the Cambridge Southern Fringe, the R&D centres and hospitals of the Cambridge Biomedical Campus, Cambridge rail station, and the existing patronage on Guided Busway services A and R from Trumpington Park and Ride; and
2. Two sets of reduction factors were developed to calculate the subset of this population that may use services on the Busway, namely:

   a. Time factors: People travelling to locations adjacent to the Busway during different times (Section 3.6); and

   b. Mode share: People choosing to travel along the Busway using AVs or bus services (Section 3.7). An expansion factor is applied to account for induced demand, assuming more people will use AVs due to the convenience and innovative nature of the services (as per Scenarios 5-8).

3.5 Total Population

Total 'population' is calculated for each development so that the number of one-way trips for each scenario could then be calculated. The key assumptions used are set out in the following sections, divided by land use. One-way trips are used to avoid the double counting of trips. This is owing to the nature of travel on the Busway, primarily because Cambridge rail station is both a significant trip attractor and trip distributor throughout a typical day. Where two-way trips were provided in the data sources used, these were divided by two to estimate one-way trips.

3.5.1 Residential

- 2.54 persons per household in Cambridge (2011 census).
- According to the Cambridge Southern Fringe growth site guide (November 2016) 5,673 homes are planned.

3.5.2 CBC

- Hospitals:
    - One one-way visitor trip associated with inpatients for both hospitals i.e. each patient is assumed to receive one visitor per day.

- Addenbrooke's: 2,625 one-way employee trips, 1,500 outpatients (one one-way trip each), 1,000 inpatient beds.
- Papworth: 310 beds (assumed all beds are for inpatients so aforementioned visitor trips apply), 2,000 employees.

- AstraZeneca (R&D), Forum, Capella, Bellatrix: bus mode share given in relevant planning documents:
  - AstraZeneca: 25.00%.
  - The Forum: 18.60%.
  - Capella: 25.37%.
  - Bellatrix: 25.00%.
- Laboratory of Molecular Biology (LMB): assume 25% based on other comparable developments in the CBC.
- Abcam: As per AstraZeneca (R&D).
- AstraZeneca (administrative functions): assume 50%. This is high to account for the assumed high proportion of trips between the administration and R&D facilities, as well as commuters using the Trumpington Park and Ride to Academy House or City House.

3.5.3 Cambridge Rail Station and Surrounding Area

- ORR statistics: 5,477,106 yearly entries/exits (i.e. two-way trips).
- The total entries/exits is divided by 52 to estimate weekly entries/exits, and then by two to obtain the number of weekly passengers entering OR exiting the station. Assume 16% of weekly trips occur each weekday (then 12% Saturday, 8% Sunday).
- AstraZeneca (administrative functions): 1,000 staff from January 2017 at Academy House and City House.

3.5.4 Trumpington Park and Ride

- Existing patronage on routes A and R has been estimated based on information from AstraZeneca and Addenbrooke's hospital.
  - Route A: 3,218 one-way trips per week
  - Route R: 1,700 one-way trips per week.

3.6 Trips to Locations Along the Busway

This first set of factors is used to calculate the number of people travelling to/from locations adjacent to the Cambridge Busway section between Trumpington Park and Ride and Cambridge rail station. These are total trips that do not account for the chosen mode.

3.6.1 Scenarios 1 and 5

The total population is multiplied by 1.00 for these two scenarios because all of the trip origins and destinations analysed as part of this study are located adjacent to the Busway. This assumes that, regardless of the type of development, all trips are made to/from somewhere that is directly accessible from the Busway. It also assumes that 100% of the population chooses to travel on a typical weekday.

3.6.2 Scenarios 2-4 and 6-8

As a conservative estimate it was assumed that, on weekdays, 10% of the population may want to travel to a location adjacent to the Busway outside of the current hours of operation (Scenarios 2 and 6). Therefore, a factor of 0.10 was applied to the total population of each development for Scenarios 2 and 6 i.e. the ones that represent demand on weekday nights. There are some exceptions to the use of this factor, and these are outlined in the following section. For Scenarios 3 and 7, 20% was used, and 50% was used for Scenarios 4 and 8 (for CBC locations, 5% was used for these four scenarios).

3.6.3 Exceptions

Factors used for AstraZeneca's administration facilities near Cambridge rail station are assumed to be the same as the corresponding ones for the R&D facility at the CBC as staff members travel between the two facilities for meetings.

Due to the differing nature of trips to hospitals versus trips to R&D facilities, separate factors have been used for Addenbrooke's and Papworth hospitals as opposed to the biomedical research facilities at the CBC. This is in order to represent the likely higher proportion of hospital visitors compared with the biomedical facilities when the Busway is not in operation i.e. at night and on Sundays. The factors used for both hospitals are as follows:

- Scenario 2: 0.10.
- Scenario 3: 0.10.
- Scenario 4: 0.20.

3.7 Trips on the Busway

This second set of factors accounts for demand for trips on the Busway using the existing services when in operation (Scenario 1), when the services could be extended to run (Scenarios 2-4), and assuming additional demand if AVs were introduced (Scenarios 5-8). The bus mode share is used for the relevant development site.

A reduction factor is applied depending on the location of the residential development. As all of the sites analysed in this study are adjacent to the Busway, it is assumed that 50% of all bus journeys would take place on services that travel on the Busway. This factor could be raised or lowered depending on an agreed assumption of demand along the Busway. We have assumed 50% as a conservative estimation, as there are more bus services than those using the Guided Busway.

For Trumpington Park and Ride, the bus mode share is 100% for scenarios 1-4. This has been uplifted in scenarios 5-8 assuming additional demand if AVs were introduced due to the attraction of the innovation.

3.7.1 Residential

- From the 2011 census, the bus mode share in Cambridge was estimated to be 3.93%.

3.7.2 Cambridge Rail Station

- Due to the lack of data for the onward mode share of rail passengers at Cambridge rail station, it is assumed that 10% of rail passengers would travel to/from the station via the Busway. This is a conservative estimate, with consideration given to the high cycling mode share in Cambridge, the large number of other buses serving the station and the proximity of Cambridge city centre to the station.

3.7.3 CBC

- Hospitals:
    - The Addenbrooke's hospital travel plan assumes an 11% and 27% bus mode share for patients and staff respectively.
    - These values were also used for the calculation of factors for Papworth hospital.
- The bus mode share in Cambridge travel to work data for 2011 was only 3.93%, but the observed mode share for the CBC is much higher. This is reflected in the AstraZeneca (R&D), Forum, Capella and Bellatrix bus mode shares given in the relevant planning documents:
    - AZ: 25.00%.
    - Forum: 18.60%.
    - Capella: 25.37%.
    - Bellatrix: 25.00%.
- LMB: assume 25% based on other comparable developments in the CBC.
- Abcam: As per AstraZeneca (R&D).
- AstraZeneca (admin): assume 50%. This is high to account for the assumed high proportion of trips between the administration and R&D facilities, as well as commuters using the Trumpington P&R to Academy House or City House.

3.7.4 Summary

The above methodology is applicable to the baseline scenarios (Scenarios 1-4).

An uplift factor is applied to each of these to get the corresponding factors for Scenarios 5-8 (induced demand). These factors vary by location, as follows:

- Station area: 1.1
- CBC: 1.3 (assuming highest uplift in demand for AVs as people shift for using their cars to using the AV pods)
- Southern Fringe: 1.2
- Trumpington Park and Ride: 1.2

3.8 Demand Calculations

To calculate the demand for each development and scenario, the total population is multiplied by the appropriate location and Busway factors as defined in previous sections.

Figure 3.2 - Busway demand calculation process

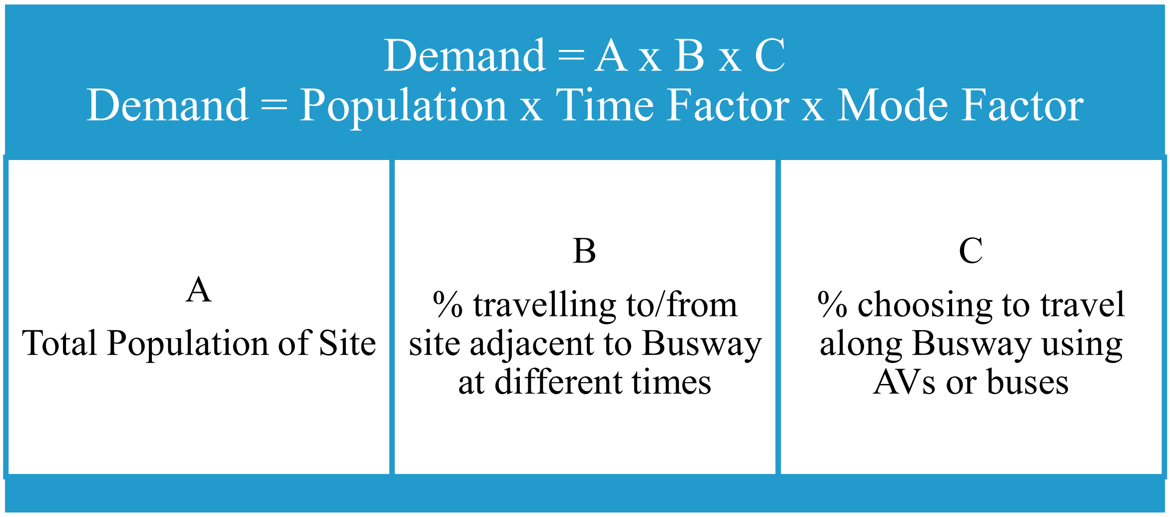


Table 3.3 and Table 3.4 show the demand calculated, using the method outline in Figure 3.2, for services on the Busway.

Location	Population	Scenario 1		Scenario 5		Scenario 2		Scenario 6	
		Time factor	Mode factor	Time factor	Mode factor	Time factor	Mode factor	Time factor	Mode factor
Cambridge S Fringe	9,053	4,379	86	4,379	103	438	9	438	10
Station	10,267	10,267	1,359	10,267	1,495	1,027	136	1,027	150
Trumpington P&R	876	876	876	876	1,052	88	88	88	105
CBC	18,638	18,638	2,184	18,638	2,839	1,864	218	1,864	284
Total	38,834	34,160	4,505	34,160	5,489	3,416	451	3,416	549

Table 3.3 – Baseline and induced demand for weekday (Scenarios 1 and 5) and week night (Scenarios 2 and 6)

Location	Population	Scenario 3		Scenario 7		Scenario 4		Scenario 8	
		Time factor	Mode factor	Time factor	Mode factor	Time factor	Mode factor	Time factor	Mode factor
Cambridge S Fringe	9,053	876	17	876	21	2,189	43	2,189	52
Station	10,267	1,903	197	1,903	217	4,684	455	4,684	500
Trumpington P&R	876	175	175	175	210	438	438	438	472
CBC	18,638	1,304	151	1,304	197	2,047	235	2,047	306
Total	38,834	4,258	540	4,258	644	9,358	1,171	9,358	1,330

Table 3.4 – Baseline and induced demand for weekend night (Scenarios 3 and 7) and Sunday (Scenarios 4 and 8)

Appendix 4

Estimation of Demand – the University of Cambridge Approach

In this appendix, demand forecasts are made for fleets of 'roaming' L-SATS vehicles operating on three major campus sites (Addenbrooke's, West Site, and North West Cambridge). The demand forecasts are made using an approach which was developed at the University of Cambridge. These forecasts are then used to estimate the business case for L-SATS operations at the various campus sites.

The first step in building the business case is to estimate the levels of potential ridership. This may be done by carrying out the following sequence of operations:

1) **Trip generation** – forecast the general patterns of demand within the chosen geographic area by identifying the daily activity levels within different zones of journey origins and journey destinations (e.g. for different times of day, identify the numbers of people occupying residential zones, retail zones, industrial zones, etc).

2) **Trip distribution** – forecast the connections between the various trip origins and trip destinations within the defined geographic area.

3) **Modal split analysis** – for each particular journey pair, forecast the distribution of choice regarding the preferred mode of travel (e.g. bus, cycling, walking, or L-SATS)

The Addenbrooke's site has been selected to illustrate the analysis but the same methodology was followed for all the campus sites.

The area of Addenbrooke's Site is illustrated in Figure 4.3. The figure shows current and future developments, on site access and circulation.

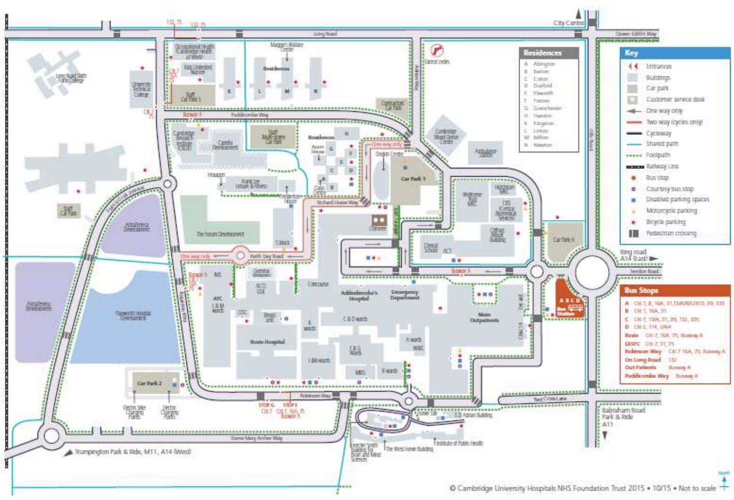


Figure 4.3: Addenbrooke' Site Map – not to scale (Cambridge University Hospital NHS Foundation Trust)

1.1 Trip Generation

The first stage was to estimate the number of trips made in the Addenbrooke's Site. Three type of journeys were considered in this study. Category A includes trips generated from workers, Category B trips generated from visitors for business purposes (including outpatient appointments) and Category C includes trips generated from people who visit the site for leisure purposes. Access to reliable information about number of residents, number of workers, students, outpatient appointments, etc. was essential to calculate the number of trips generated. Sources of data were the University of Cambridge Estate Management and Cambridge University Hospitals NHS Foundation Trust. Our assumptions include 15,000 working population by 2020, 1,000 bed spaces for students and key workers' accommodation and about 3,000 visitors per day, of which 2,900 are visitors for business purposes. The remaining are visitors for leisure purposes. The number of generated trips were also combined with daily trips distribution data from the Department for Transport for creating daily profiles.

Figure 4.4 shows the trips generated in Addenbrooke's by journey purpose through a typical weekday. Category C journeys are multiplied by a factor of 100 to be visibly comparable with the other categories. There are significantly more Category A trips than Category B and C trips.

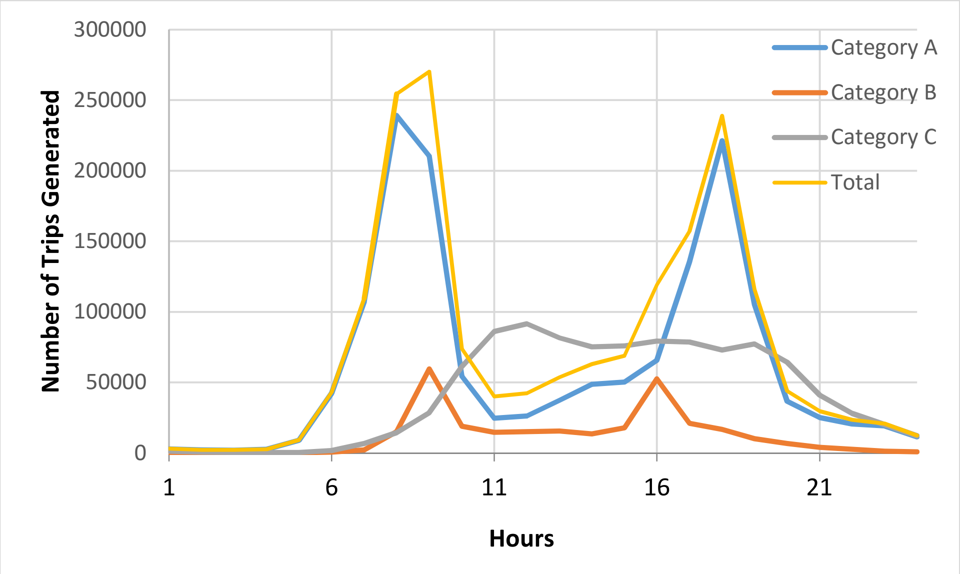


Figure 4.4: Trips Generated in Addenbrooke's by type of journey through a typical weekday (Category C is multiplied by a factor of 100)

1.2 Trip Distribution

Then, the area of interest was divided into five main zones for distributing the trips between zones and identifying the traffic flows. Figure 4.5 shows the zoning of the Addenbrooke's Site together with an example to show the process. In particular, Zone A is the destination for 3750 Category A trips. Of which, 15% (563 trips), 15% (563 trips), 10% (375 trips), 25% (938 trips) and 35% (1313 trips) originate from zone A, B, C, D, and E respectively. Zones A-D refer to areas within the site. Zone E was introduced for a mass transit transport system which has been recently proposed to facilitate access to the site. Although the matching of origins with destinations was performed rather qualitatively, the analysis was based on the following factors: (i) number of job positions in each zone, (ii) existence of medical or other community buildings in each zone, (iii) any transport links including availability of parking places and other forms of public transport.

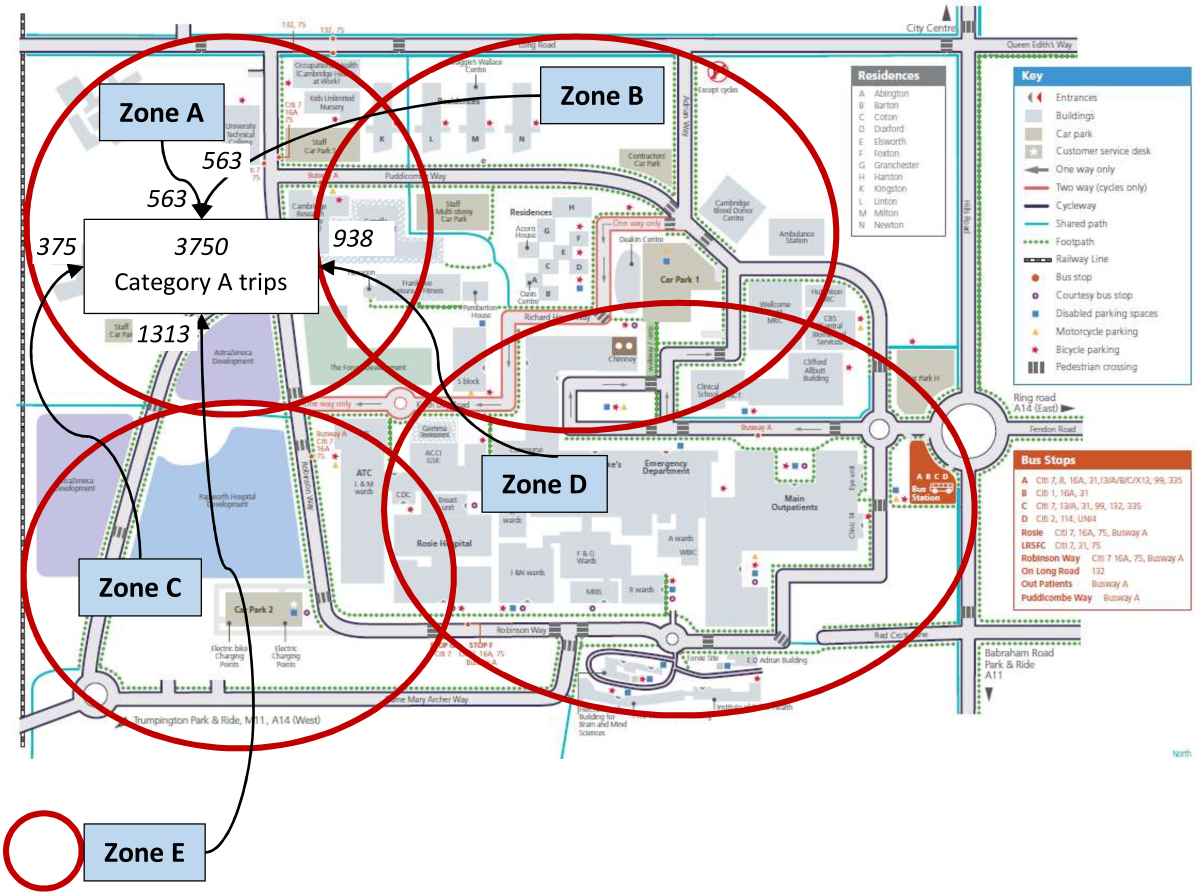


Figure 4.5: Zoning of Addenbrooke's Site together with an example for matching the origins and destinations for 3750 Category A trips

1.3 Modal Split

Afterwards, the modal split analysis was performed to calculate the number of trips that use autonomous pods instead of walking, cycling or taking the bus. The process is based on the concept of utility function which allows the comparison of mode choices based on various modal features. The utility function is shown below; where u_k is the utility function of travel mode k, X_i the variables measuring modal attributes, and a_i the weighting factor for each variable. Three main features were chosen to assess the mode choices. These are the Travelling Time, Waiting Time and Price whose weighting factor was chosen as -0.16, -0.30 and -0.54 respectively; using the Analytical Hierarchy Process (AHP) technique. The negative signs are due to the negative impact of each variable.

$$u_k = a_1X_1 + a_2X_2 + a_3X_3$$

The following example describes the process to compute the proportion of pod-trips (trips performed by autonomous pods) from the total 375 journeys starting from Zone C and ending to Zone A shown in Figure 4.5. TABLE 4.5 shows the four mode choices together with the variables measuring their modal attributes. The travelling time was calculated based on the average distance of the journey and the speed of each travel mode. In particular, an average speed of 2.2mph, 9.6mph, 20mph and 12.4mph was assumed for walking, cycling, taking the bus, or using an autonomous pod respectively. Any additional time required like waiting at the bus stop, waiting for an autonomous pod, embarking/ disembarking, etc. were included in the waiting time variable. The ticket price to use an autonomous pod was set to £2 per person. The utility function was exploited to quantify the degree of gain from each travel mode and based on that, the possibility $p(k)$ to use the travel mode k was computed as it is given by the following equation. The results indicate that there is 17% possibility to use an autonomous instead of the other mode choices. This corresponds to 64 pod trips.

$$p(k) = \frac{e^{u_k}}{\sum e^{u_k}}$$

TABLE 4.5: Modal split analysis example

Travel Mode	Travelling Time (minutes)	Waiting Time (minutes)	Price (£)	U_k	p (k)
Walk	21	0	0	-3.4	0.07
Cycle	5	1	0	-1.1	0.73
Bus	2	15	3	-6.4	0.03
Pods	4	3	2	-2.6	0.17

Additionally, the possibility to choose an autonomous pod for intra-site movements is influenced by the primary travel mode of each traveller. People arriving to the site by car/ bus would not probably shift to another mode of transport, if a car park/ bus stop is available in their destination zone. Data about the primary modal choice for journeys to Addenbrooke's for workers and visitors were obtained from the Cambridge University Hospitals NHS Foundation Trust. Indeed, the amount of pod-trips was reduced from 64 to 17 pod-trips after taking into consideration the primary travel mode of each traveller.

Overall, the levels of demand for a possible autonomous taxi service for the Addenbrooke's Site are shown in Figure 4.6 for weekdays and weekends separately. The number of people demanding autonomous pods during the weekends is significantly lower than the weekdays. Mainly because there are less Category A trips for workers traveling to their jobs. It could be noticed from the figure that more than 400 people would be demanding an autonomous pod during the morning peak hours. This corresponds to 295 trips per hour; assuming 1.5, 1.0 and 1.5 ridership ratio for Category A, Category B, and Category C journeys respectively. Based on the peak demand of trips and the average time required per trip, the size of the required fleet was found to be 43 autonomous pods.

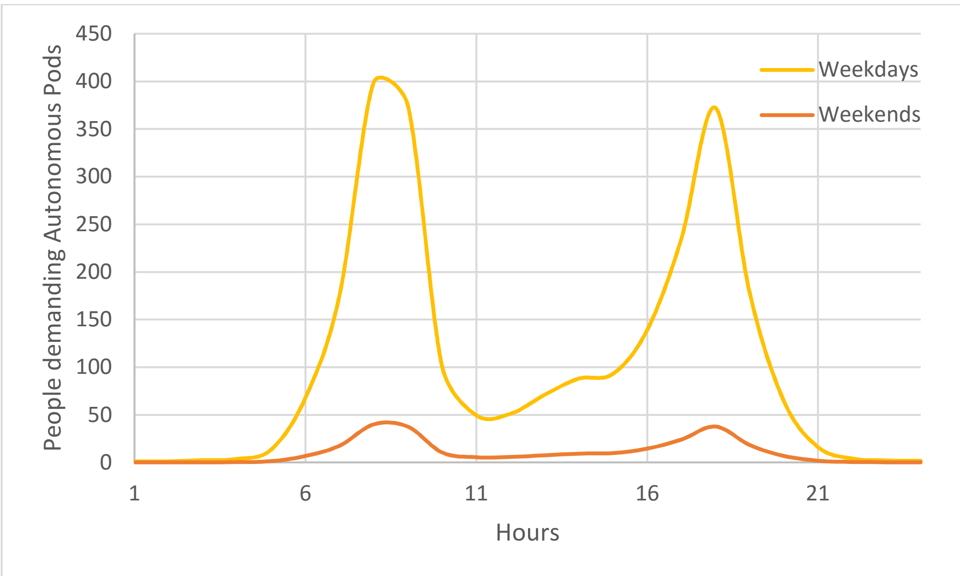


Figure 4.6: People demanding autonomous pods through a typical weekday day

1.4 Business Case Analysis

In this section, a business case analysis is presented to explore the financial viability of the proposed autonomous taxi service. The assumptions used for the cost model are shown in TABLE 4.6. It should be noted, in particular, that a purchase price of £8,000 per pod was adopted. This was taken to represent the price of each vehicle once a mature production standard has been reached. Under similar expectations, the cost of providing the required charging infrastructure was set to £3,000 per pod.

TABLE 4.6: Assumptions for cost model

Cost Variables	**£**	**Details**
Capital Costs		
Autonomous pods	8,000	
Charging Infrastructure	3,000	per pod
Operating Costs		
Per mile driven	0.02	0.2kWh/mile X £0.10/kWh
Maintenance	3,000	per pod per year
Staff wages	26,000	A person for every 5 pods

1.5Addenbrooke's Site

A balance sheet for the first 10 years of operation is presented in TABLE 4.7. Looking at the figures, a £1,357,836 turnover is possible for the first year of operation. The total cost figure for the same period, including capital and operating costs, is restricted lower at £847,758. Hence, the financial analysis revealed that an autonomous taxi service for the Addenbrooke's site is financial feasible with positive net profit even from the first year of operation.

TABLE 4.7: Balance Sheet of the proposed autonomous taxi service for 10 years of operation

Year	1	2	3	4	5	6	7	8	9	10
Growth rate	0	5	10	15	15	10	5	3	3	2
Number of pods	43	45	49	56	65	71	75	77	79	81
Income										
Annual Trips	475,499	499,274	549,201	631,581	726,318	798,950	838,897	864,064	889,986	907,786
Peak trips per hour	295	310	341	392	451	496	521	536	552	563
Annual Income	*1,356,836*	*1,424,678*	*1,567,146*	*1,802,218*	*2,072,551*	*2,279,806*	*2,393,796*	*2,465,610*	*2,539,578*	*2,590,370*
Costs										
Capital cost										
Pods	344,000	16,000	32,000	56,000	72,000	48,000	32,000	16,000	16,000	16,000
Infrastructure	21,500	1,000	2,000	3,500	4,500	3,000	2,000	1,000	1,000	1,000
Charging infrastructure	107,500	5,000	10,000	17,500	22,500	15,000	10,000	5,000	5,000	5,000
Operating cost										
Electricity costs	10,758	11,296	12,426	14,289	16,433	18,076	18,980	19,549	20,136	20,538
Maintenance costs	129,000	135,000	147,000	168,000	195,000	213,000	225,000	231,000	237,000	243,000
Staff Costs	234,000	234,000	260,000	312,000	338,000	390,000	390,000	416,000	416,000	442,000
Totals	*846,758*	*402,296*	*463,426*	*571,289*	*648,433*	*687,076*	*677,980*	*688,549*	*695,136*	*727,538*
Total										
Total per year	**510,078**	**1,022,382**	**1,103,721**	**1,230,929**	**1,424,118**	**1,592,730**	**1,715,816**	**1,777,061**	**1,844,442**	**1,862,831**
Net profit	***510,078***	***1,532,461***	***2,636,181***	***3,867,110***	***5,291,228***	***6,883,957***	***8,599,773***	***10,376,834***	***12,221,277***	***14,084,108***

Figure 4.7 shows the expected number of peak trips per hour for various ticket prices. As it was expected, the number of peak trips per hour is reduced when the ticket price increases. The use of autonomous pods is less desirable among the other mode choices according to the modal split process. In contrast, the number of peak trips per hour increases when the ticket price is lower. TABLE 4.8 shows the results of the sensitivity analysis.

Maximum net profit could be achieved for a £3 ticket price. This corresponds to £747,000 and £5,885,000 positive net profit on the first and fifth year of business.

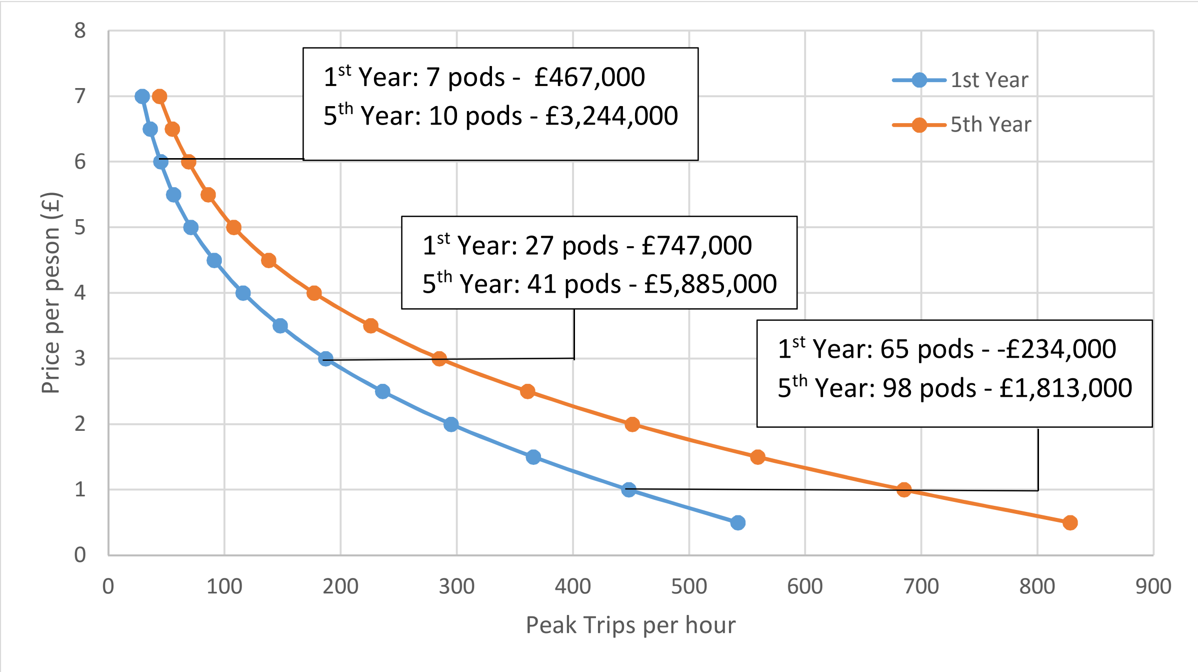


Figure 4.7: Addenbrooke's Site – Peak Trips per hour relative to ticket price

TABLE 4.8: Addenbrooke's Site – Financial Analysis Results

Price (£ per person)	1st Year			5th Year		
	Peak trips per hour	Number of Pods	Net Profit (£k)	Peak trips per hour	Number of Pods	Net Profit (£k)
0.5	542	78	-905	828	119	-1565
1	448	65	-234	685	98	1813
1.5	366	53	220	559	80	4036
2	295	43	510	451	65	5291
2.5	236	34	688	361	52	5853
3	187	27	747	285	41	5885
3.5	148	22	744	226	33	5675
4	116	17	714	177	26	5208
4.5	91	13	671	138	20	4741
5	71	11	576	108	16	4111
5.5	56	9	524	86	13	3644
6	45	7	467	69	10	3244
6.5	36	6	390	55	8	2742
7	29	5	352	44	7	2372

1.6West Cambridge

The levels of demand for a possible autonomous taxi service in the West Cambridge site (Fig 4.7) were then estimated in conjunction with a financial appraisal of the scheme. The same methodology applied for the Addenbrooke's Site was followed for this area as well, but representative figures for the new area were employed. In particular, the study assumed 15,000 workers, 750 visitors for business purposes and 800 visitors for leisure purposes per day. As expected, fewer visitors for business purposes were considered for the West Cambridge site in comparison to the Addenbrooke's Site. In contrast, the number of visitors for leisure purposes is larger for the case of West Cambridge where the sport facilities might be an attraction for students and workers of the area.

The number of pod-trips relative to ticket price is shown in Figure 4.9. Maximum positive net profit could be achieved for a £2.5 ticket price. The net profit of an autonomous taxi service in the site of West Cambridge was estimated at £1,074,000 for the first year and £7,871,000 for the fifth year of business. The number of required pods for such a scheme would be 27 and 41 for the first and fifth year respectively.

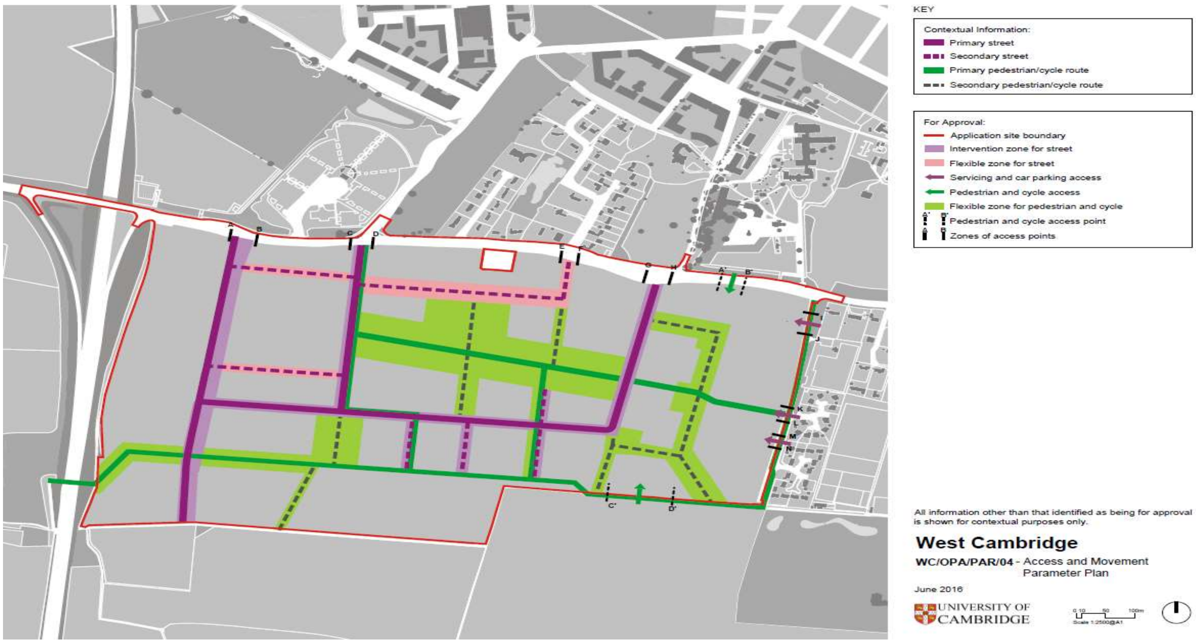


Figure 4.8: West Cambridge Site Map

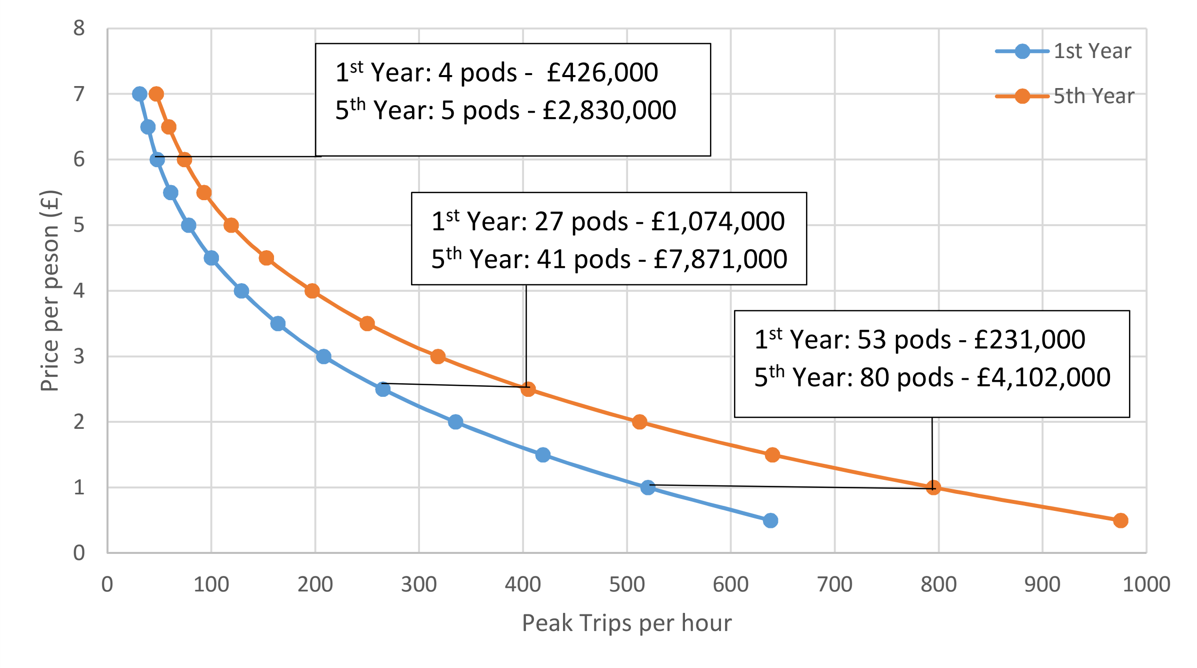


Figure 4.9: West Cambridge site – Peak Trips per hour relative to ticket price

TABLE 4.9: West Cambridge - Financial Analysis Results

Price (£ per person)	1st Year			5th Year		
	Peak trips per hour	Number of Pods	Net Profit (£k)	Peak trips per hour	Number of Pods	Net Profit (£k)
0.5	638	64	-468	975	98	341
1	520	53	231	795	80	4102
1.5	419	42	702	640	64	6391
2	335	34	967	512	52	7543
2.5	265	27	1074	405	41	7871
3	208	21	1094	318	32	7736
3.5	164	17	1046	250	25	7264
4	129	13	984	197	20	6636
4.5	100	11	859	153	16	5827
5	78	8	778	119	12	5113
5.5	61	7	656	93	10	4392
6	48	5	600	74	8	3802
6.5	39	4	521	59	6	3227
7	31	4	426	47	5	2830

1.7 North West Cambridge

This site is shown in Fig 4.9. For the purposes of this analysis, it was assumed that the site has a working population of 4,500 people, and a residential population of 7,000 people. 4,000 visitors per day for both business and leisure purposes were assumed. The increased number of visitors is justified by the large number of residential population and in-site facilities like school, hotel, convenience stores, etc.

The number of peak trips per hour relative to ticket price is shown in Figure 4.11 Maximum positive net profit could be achieved for a £2.50 ticket price. The net profit of an autonomous taxi service in the site of North West Cambridge was estimated at £308,000 for the first year and £2,241,000 for the fifth year of business. The number of required pods for such a scheme would be 7 and 11 for the first and fifth year respectively.

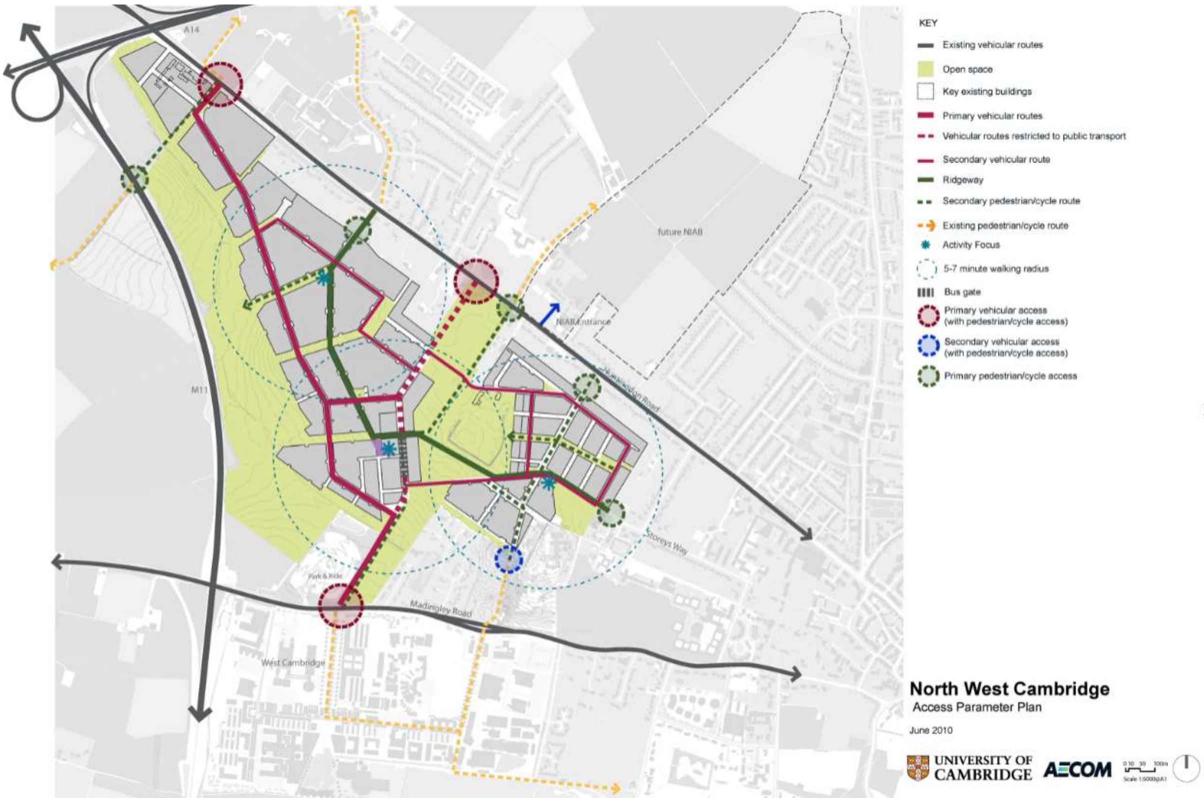


Figure 4.10: North West Cambridge Site Map

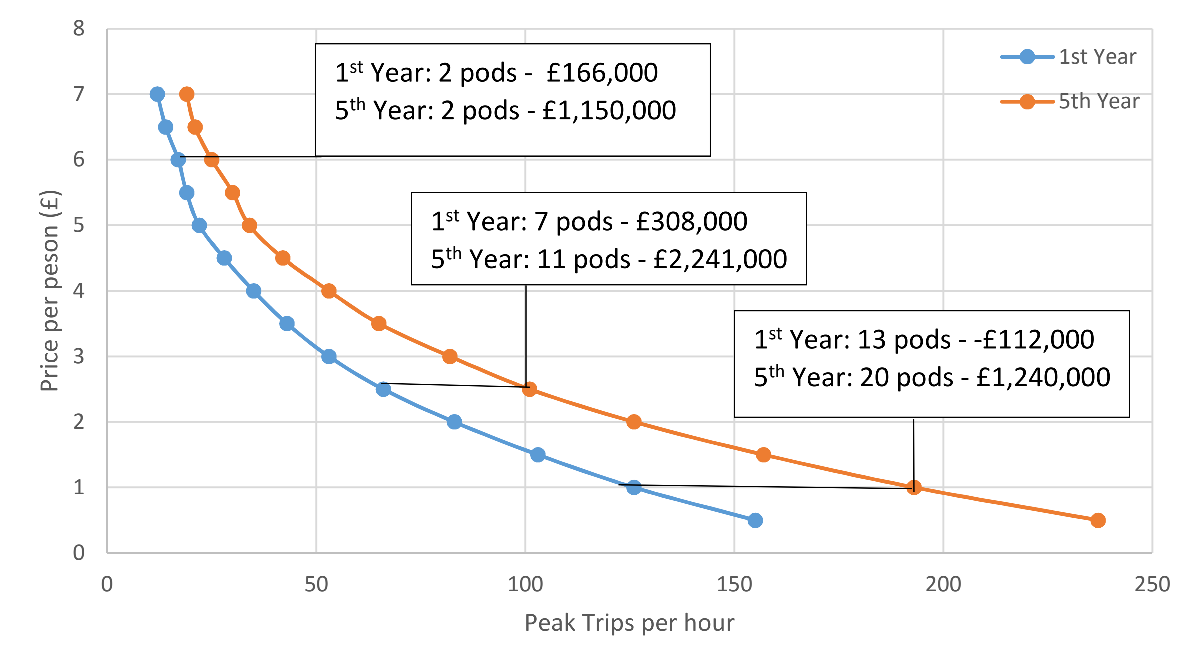


Figure 4.11: North West Cambridge site – Peak Trips per hour relative to ticket price

TABLE 4.10: North West Cambridge – Financial Analysis Results

Price (£ per person)	1st Year			5th Year		
	Peak trips per hour	Number of Pods	Net Profit (£k)	Peak trips per hour	Number of Pods	Net Profit (£k)
0.5	155	16	-112	237	24	181
1	126	13	93	193	20	1240
1.5	103	11	198	157	16	1820
2	83	9	282	126	13	2175
2.5	66	7	308	101	11	2241
3	53	6	307	82	9	2217
3.5	43	5	315	65	7	2146
4	35	4	298	53	6	2008
4.5	28	3	274	42	5	1832
5	22	3	233	34	4	1602
5.5	19	2	229	30	3	1513
6	17	2	205	25	3	1370
6.5	14	2	181	21	3	1227
7	12	2	166	19	2	1150

1.8References

[1] J. Kenworthy and F. Laube, “An International Sourcebook of Automobile Dependence in Cities,” Colorado, 2000.

[2] World Health Organisation, “The World Report on Road Traffic Injury Prevention,” 2004.

[3] International Energy Agency, “World Energy Outlook 2008,” 2008.

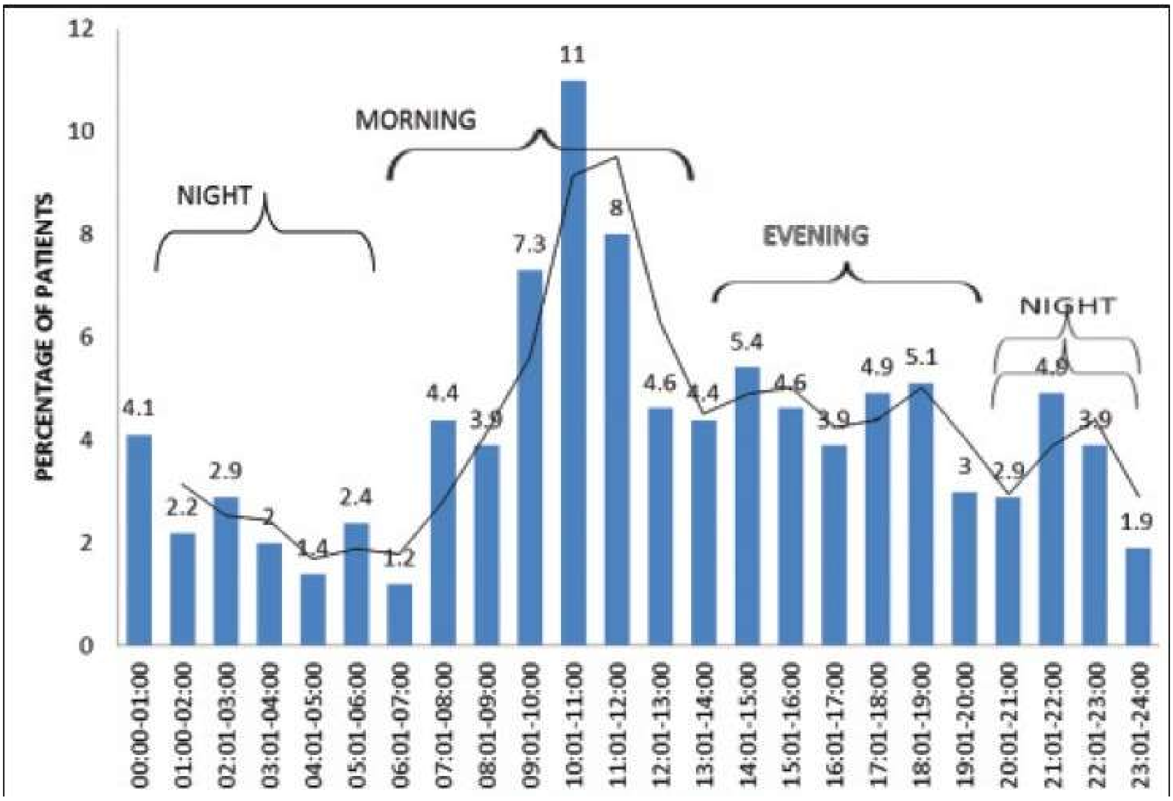
[4] UN-Habitat, *State of the World’s Cities 2008/2009 - Harmonious Cities*. UN-Habitat, 2008.

[5] W. Mitchell, C. Borroni-Bird, and L. Burns, *Reinventing the automobile: Personal urban mobility for the 21st century*. Massachusetts Institute of Technology Press, 2010.

Appendix 5

Estimation of Demand – Comparison Between the University of Cambridge Approach and the Arup Approach

A brief exercise was conducted to 'sense check' the results generated by the two different approaches to demand estimation. In this exercise, the following traffic distribution pattern was used for workers and visitors of the Addenbrooke's campus. (This follows the arrival time pattern for patients in the emergency department). For the weekends, a 0.3 factor was applied to the number of trips generated on weekdays



The UoC method implicitly includes the effect of pricing, so several calculations were carried out to compare the UoC results against a benchmark price for the bus (£3)

- Mode choice assumptions:
  - Price:
    - Bus: £3
    - L-SATS: £2, £3
  - Travelling speed
    - Bus: 50mph
    - Pod: 25mph
  - Waiting time:
    - Bus: 15 minutes
    - Pod: 5 minutes

The numbers of trips generated is summarised in the table below. It can be seen that the UoC method produces results which are generally compatible with the Arup method and that the UoC results are price sensitive in a manner that appears to be rational. Given the levels of uncertainty associated with each approach, the degree of agreement between the two was taken to provide a reasonable degree of confidence in using either method.

Ticket price	Weekday	Week night	Weekend night	Sunday	Total per week
£3	2389	655	197	846	18,652
£2	3232	895	269	1156	25,292
ARUP	3629	447	323	733	25,065

Using the UoC results, the exercise was then extended to develop a financial assessment of the case for running a fleet of 9 vehicles.

- Operating Model Assumptions

£3 per person

Annual trips: [(2389+655)X5 + (2389+197) + (846)] X 52 weeks= 969,904

Maximum people demanding pods per hour: 341 people

Maximum trips per hour: 341 people / 10-seat vehicle = 35 pod-trips per hour

Average time per trip: 9 minutes (including 5 minutes waiting time)

Number of 10-seat pods (including 50% safety margin): 9 vehicles

- Cost model assumptions

Cost of pods	32,000
Infrastructure cost per pod	2,000
Number of pods per charger	1
Cost of chargers	10,000
Electric consumption of pods	0.20
Price per kWh	0.10
Maintenance cost per pod	12,000
Pods per staff	1
Staff wages	26,000
Price per passenger	3.00

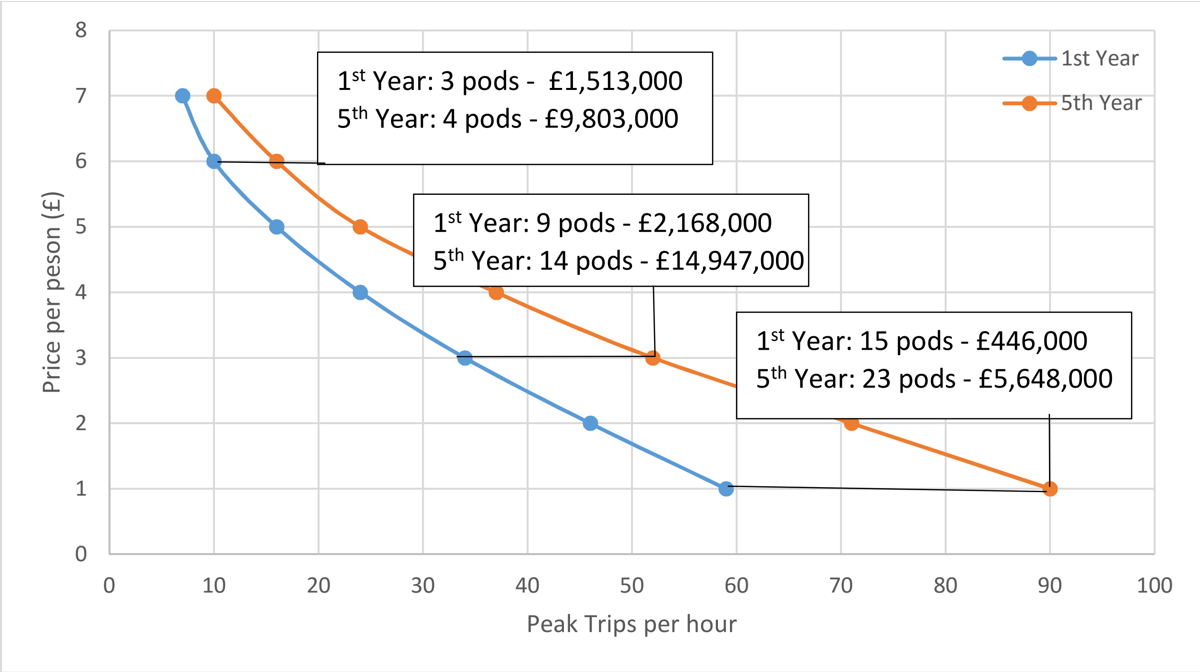
- Balance sheet

Year	1	2	3	4	5	6	7	8	9	10
Growth rate	0	5	10	15	15	10	5	3	3	2
Number of pods	9	9	10	12	13	15	15	16	16	17
Income										
Annual Trips	97,588	102,468	112,715	129,622	149,065	163,972	172,170	177,335	182,655	186,308
Peak trips per hour	34	36	39	45	52	57	60	62	64	65
Annual Income	*2,927,652*	*3,074,035*	*3,381,438*	*3,888,654*	*4,471,952*	*4,919,147*	*5,165,104*	*5,320,057*	*5,479,659*	*5,589,252*
Costs										
Capital cost										
Pods	288,000	0	32,000	64,000	32,000	64,000	0	32,000	0	32,000
Infrastructure	18,000	0	2,000	4,000	2,000	4,000	0	2,000	0	2,000
Charging infrastructure	90,000	0	10,000	20,000	10,000	20,000	0	10,000	0	10,000
Operating cost										
Electricity costs	3,251	3,413	3,755	4,318	4,966	5,462	5,735	5,908	6,085	6,206
Maintenance costs	108,000	108,000	120,000	144,000	156,000	180,000	180,000	192,000	192,000	204,000
Staff Costs	234,000	234,000	260,000	312,000	338,000	390,000	390,000	416,000	416,000	442,000
Totals	*741,251*	*345,413*	*427,755*	*548,318*	*542,966*	*663,462*	*575,735*	*657,908*	*614,085*	*696,206*
Total										
Total per year	**2,186,401**	**2,728,621**	**2,953,683**	**3,340,336**	**3,928,986**	**4,255,685**	**4,589,369**	**4,662,150**	**4,865,574**	**4,893,046**
Net profit	***2,186,401***	***4,915,022***	***7,868,705***	***11,209,041***	***15,138,027***	***19,393,712***	***23,983,081***	***28,645,231***	***33,510,805***	***38,403,851***

- Various ticket prices

Ticket price	Weekday	Week night	Weekend night	Sunday	Max per hour
1	4120	1155	346	1491	589
2	3232	895	269	1156	462
3	2389	655	197	846	341
4	1673	455	137	588	239
5	1120	303	91	391	160
6	726	195	59	252	104
7	460	124	37	160	66
ARUP	3629	447	323	733	

Price (£ per person)	1st Year			5th Year		
	Peak trips per hour	Number of Pods	Net Profit (£k)	Peak trips per hour	Number of Pods	Net Profit (£k)
1	59	15	446	90	23	5648
2	46	12	1642	71	18	12349
3	34	9	2168	52	14	14947
4	24	6	2217	37	10	14538
5	16	4	1937	24	7	12393
6	10	3	1513	16	4	9803
7	7	2	1137	10	3	7299



1st Year
5th Year
1st Year: 3 pods - £1,513,000
5th Year: 4 pods - £9,803,000
1st Year: 9 pods - £2,168,000
5th Year: 14 pods - £14,947,000
1st Year: 15 pods - £446,000
5th Year: 23 pods - £5,648,000
Price per peson (£)
Peak Trips per hour
0
1
2
3
4
5
6
7
8
0
10
20
30
40
50
60
70
80
90
100