CAV2 Cambridge Autonomous Bus Project

Service Level Definition (Cambridge Southern Busway)

Lessons from European deployments

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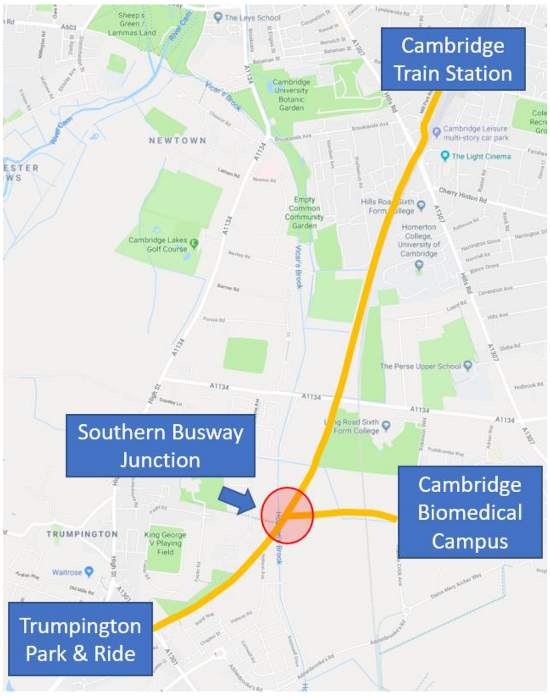
1) Introduction

This report summarises work undertaken t define the required level of service for th proposed Cambridge Autonomous Bus Servic (CABS), that will connect the Cambridg Biomedical Campus / Addenbrooke's Hospit (CBC) with the Cambridge Train Station (Statio and Trumpington Park and Ride (P&R)

Work has been done to assess the 'Weekda Night', 'Weekend Night' (Saturday Night 'Sunday' and 'Weekday' daytime service leve which might apply to operations on th Cambridge southern guided busway.

Two business case appraisals are presented. Th first for an out-of-hours autonomous vehic service on the busway (running only at nights ar on Sunday when no bus service current operates). The second details the case for a 24 hour 7 day a week service.



Cambridge Southern Guided Busway Map

2) Method

The assessment procedure includes the following steps:

- Estimate the passenger demand patterns at each node on the system (Addenbrooke's Site; Cambridge Station; Trumpington P&R)
- Propose a service frequency / capacity at each node which satisfies the predicted demand.
- Calculate the number of vehicles required to provide the proposed levels of service.
- Assess the operational consequences of running the required number of vehicles
- Assess the financial consequences of running the required number of vehicles

3) Demand Estimation

This study utilises estimates of passenger demand for public transport services on the busway, which were calculated in a study conducted by Arup (http://www.connectingcambridgeshire.co.uk/wp-content/uploads/2015/10/Cambridge-Autonomous-Vehicle-Study.pdf). The Arup methodology provided an estimate of demand based on job numbers and staffing patterns at Addenbrooke's site, current busway ridership and traveller data from the rail services at Cambridge Station. As autonomous vehicles (AVs) are still in the early stages of testing there is, as of yet, no pre-defined methodology for passenger demand forecasting. The method developed by Arup, for this study, was based on professional judgement and assumptions in the absence of an established evidence base. The assumptions made are particular to the area surrounding the guided busway between Trumpington and the Cambridge Station

The passenger demand estimates used in this report are summarised in the following table are reported in single passenger journeys:

LOCATION	Weekday (6:00am – 9:00pm)	Weekday Night (9:00pm – 6:00am)	Weekend Night (9:00pm – 6:00am)	Sunday (6:00am – Midnight)
Addenbrooke's CBC	2,839	393	142	306
Cambridge Train Station	1,495	150	217	500
Trumpington P&R	4,437	553	380	858
TOTAL	8,771	1,096	739	1,664

4) Service Frequency / Capacity

In order to determine the number of vehicles required to service the estimated passenger demand at each node in the network, a journey time analysis was conducted to establish the movement of the autonomous vehicles around the busway network. The exact journey time calculations will depend upon the final location of the AV stops at the P&R, Station and CBC (which are yet to be finalised) and will depend on the capability of the AV to operate on public roads. The journey times calculated in this study should therefore be treated as indicative journey times, which will be refined once stop locations are defined. Appendix A presents a preliminary Parking Zone Analysis at each of the nodes.

Appendix B describes the methodology by which the individual journey times between each of nodes in the network (serving the existing bus stops) were calculated. Journey times were derived using kinematic analysis, with a maximum vehicle velocity of 30 mph (48 km/h), an average acceleration rate of 0.8 m/s^2, an average deceleration rate of 1.2 m/s^2, using measured busway section lengths and identification of places where delays could occur in the network. Estimates of the slowest and fastest journeys between each of the nodes were calculated and are presented in the figure below.

Estimate of AV Journey Time between Busway Nodes

These journey times suggest that, to ensure optimal use of the vehicle fleet capacity, a 20-minute cycle should be employed for each AV from each node. This would enable an AV to depart any node, drop passengers at one of the other nodes, return to the original node and be ready to depart again on a 20-minute cycle; with sufficient time for boarding and alighting of passengers and allowing sufficient waiting time for the 10-15-seat vehicle to be adequately occupied.

Trumpington P&R to Cambridge Station – 20-minute Schedule

Location	Action	Time (Minutes)			
P&R	Depart at 0 minutes				
Busway	Departure P&R to Station - Travelling on Busway	min travel	5	max travel	7
Station	Boarding / Alighting / Waiting - Depart at 10 minutes	max stationary	5	min stationary	3
Busway	Departure Station to P&R - Travelling on Busway	min travel	6	max travel	8
P&R	Boarding / Alighting / Waiting - Depart at 20 minutes	max stationary	4	min stationary	2

Trumpington P&R to Cambridge Biomedical Campus – 20-minute Schedule

Location	Action	Time (Minutes)			
P&R	Depart at 0 minutes				
Busway	Departure P&R to CBC - Travelling on Busway	min travel	4	max travel	6
CBC	Boarding / Alighting / Waiting - Depart at 10 minutes	max stationary	6	min stationary	4
Busway	Departure CBC to P&R - Travelling on Busway	min travel	4.5	max travel	7
P&R	Boarding / Alighting / Waiting - Depart at 20 minutes	max stationary	5.5	min stationary	3

Cambridge Station to Cambridge Biomedical Campus – 20-minute Schedule

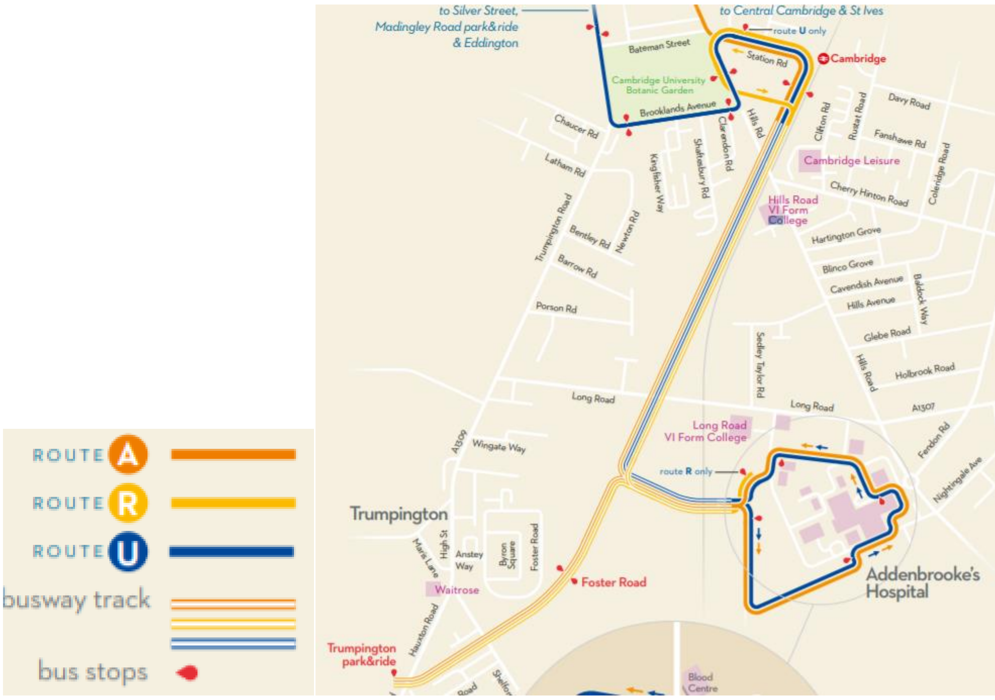
Location	Action	Time (Minutes)			
Station	Depart at 0 minutes				
Busway	Departure Station to CBC - Travelling on Busway	min travel	5	max travel	5.5
CBC	Boarding / Alighting / Waiting - Depart at 10 minutes	max stationary	5	min stationary	4.5
Busway	Departure CBC to Station - Travelling on Busway	min travel	5	max travel	6
Station	Boarding / Alighting / Waiting - Depart at 20 minutes	max stationary	5	min stationary	4

4a. Comparison of the Current Busway Public Transport Provision with the Proposed AV Pod Service

The goal of an AV transport network must be to provide a better public transport system in comparison to existing public transport services, with a higher frequency service and reduced waiting times for passengers. The southern section of the guided busway currently has three services which operate on weekdays and Saturdays.

- Route R [1] serves the P&R, CBC and Station. It runs only during peak-hours at an interval of 15 minutes. The northbound journey (P&R-CBC-Station) is timetabled to take 9 minutes and the southbound journey (Station-CBC-P&R) 13 minutes.
- Route A [1] also serves the P&R, CBC and Station, but incorporates a loop around the CBC. It runs throughout the day at an interval of 15 minutes. The northbound journey is timetabled to take 17 minutes and the southbound journey 15 minutes.
- Route U [2] serves only the Station and CBC. It runs throughout the day at an interval of ≈15 minutes. The northbound (CBC-Station) journey is timetabled to take 7-8 minutes and the southbound journey (Station-CBC) 5 minutes.

The route U bus service is operated by Whippet and a day rover ticket, with unlimited travel on Route U, costs £3. A single journey adult fare on Route U costs £2. The Route A and R services are operated by Stagecoach. A day rider ticket costs £4.50 and includes unlimited travel on Route A and R, a single journey ticket costs £2.80.



Map of Current Guided Busway Bus Services [3]

The combination of the three services results in an interval between buses of 5 to 10 minutes during peak periods and 15 minutes during off-peak periods, as the scheduled departure times of Routes A and U are very similar. During the night and on Sundays there is no service operating on the southern busway.

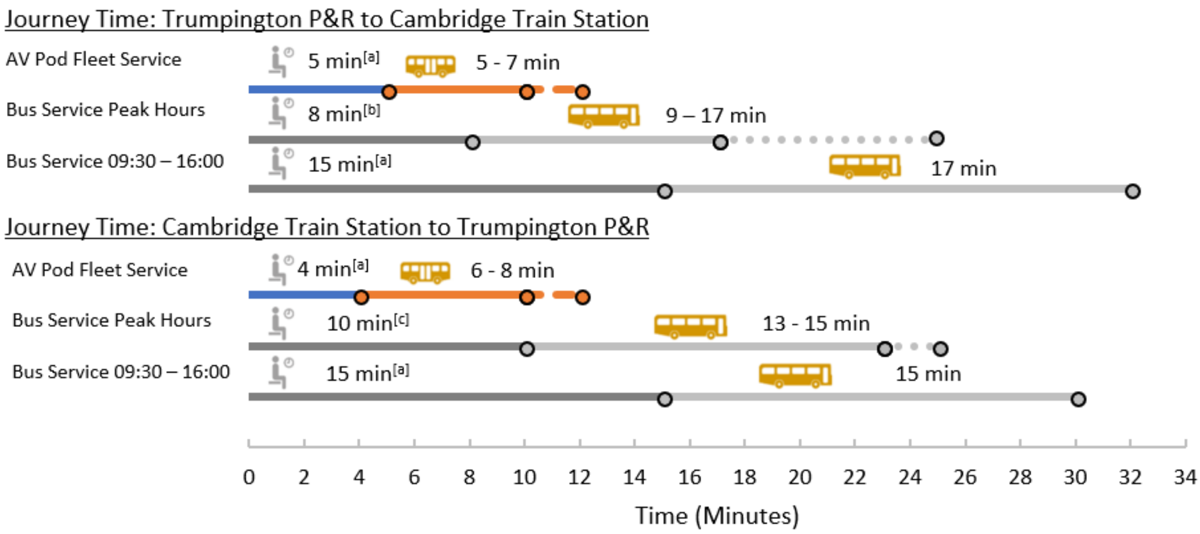
In order for the CABS to provide a superior service to the current bus service it is intended that the frequency of vehicles should be increased so the following parameter is proposed:

1) Maximum passenger waiting time at a node: 5 minutes

The goal of the southern busway AV network should be to deliver this level of service at all times of the day, i.e. not only during peak periods. With this parameter the AV network would offer a reliable high frequency service with reduced waiting times for passengers, especially in off-peak periods. As the journeys are from node to node, rather than following a scheduled route, the journey time between the Station and the Park and Ride would also be significantly reduced from (9-17 minutes for the current bus service to 5-8 minutes for the AV service).

The following figure presents a comparison of the level of service for journeys between the P&R and Station for:

- the current bus service during weekday off-peak daytime hours (09:30 – 16:00),
- the current bus service during 'peak weekday hours' (i.e. all operational hours outside of the off-peak hours)
- the level of service of an AV fleet with a maximum permissible waiting time of 5-minutes



[a] Maximum 'wait time' (defined as the interval between consecutive vehicle departures). Vehicle departure is at regular intervals.
[b] Median wait time as bus departure times are at irregular intervals. Wait times are between 7 - 30 mins in this period.
[c] Median wait time as bus departure times are at irregular intervals. Wait times are between 2 - 30 mins in this period.

The wait times presented here are the maximum possible length of time a passenger must wait before the departure of a vehicle. The total journey time, in reality, is therefore likely to be shorter. The figures for the current bus service are calculated from the combined timetable for the A, R and U routes (http://www.thebusway.info/pdfs/tt/ABNR.pdf) and the variance in journey times for the bus service, during peak hours, reflects the different paths taken by the respective bus routes.

A comparison of the estimated AV journey times for the other legs in the network (i.e. P&R - CBC and CBC - Station) with the current level of service offered by the bus fleet on these routes is presented in Appendix C.

4b. Concept of Operations

It is envisaged that as passengers arrive at each node station and book a space in an AV pod, they will receive the number of the pod to board.

Pods will depart each node at scheduled five-minute intervals either singularly (if there is insufficient demand for more than one pod) or in a group (where 5-minute demand is greater than the capacity of 1 pod). As highlighted above, this would allow sufficient time for passenger alighting / boarding and waiting. The waiting time enables a greater number of passengers to gather to travel on each pod, alleviating some of the risk that the 10-15-seat AV pods would be predominantly single occupancy, which could be the case if the pod were to leave shortly after the first passenger boards.

The maximum time a passenger would have to wait is 5 minutes (in the event of arriving just as a pod was departing).

The number of pods departing one node will need to be matched by a reciprocal number of pods departing the destination node, whether or not there is a passenger demand at the destination node (i.e. some pods may be required to travel empty). This is required to balance the number of pods across the network, ensuring that there are sufficient to meet the 5-minute demand at each node. It also ensures there are enough empty parking bays available in which the approaching pods can park.

4c. Passenger Demand Analysis

Using the Arup time period passenger demand figures, an estimate of the hourly distribution of passenger demand for each departure node and an estimate of the passenger split to each of the two destination nodes from each departure node, the average hourly passenger demand for each node-to-node leg in the network was calculated. This analysis was conducted for each of the four time-periods ('Weekday', 'Weekday Night', 'Weekend Night' and 'Sunday'). From these estimates of passenger demand, the required pod fleet size to meet the passenger demand in the network was established for each time period. This analysis is presented in detail in Appendix D.

4d. Passenger Demand Analysis: Weekday Night, Weekend Night and Sunday

For the proposed Weekday Night, Weekend Night and Sunday AV services, the analysis showed that a 12-pod fleet of either 10-seat or 15-seat pods would be sufficient to meet the average 5-minute passenger demand proposed in the network. A fleet of 12 pods was found to be the minimum number of AVs which can run a 5-minute scheduled service on this network.

10 Seat Pod	
12	**NUMBER OF VEHICLES REQUIRED TO MEET DEMAND**
4	REQURED NUMBER OF PODS AT THE STATION
4	REQURED NUMBER OF PODS AT THE CBC
4	REQURED NUMBER OF PODS AT THE P&R
720	Network Total Capacity (Passengers per hour)
40	10 Minute Passenger Capacity at Each Node

15 Seat Pod	
12	**NUMBER OF VEHICLES REQUIRED TO MEET DEMAND**
4	REQURED NUMBER OF PODS AT THE STATION
4	REQURED NUMBER OF PODS AT THE CBC
4	REQURED NUMBER OF PODS AT THE P&R
1080	Network Total Capacity (Passengers per hour)
60	10 Minute Passenger Capacity at Each Node

For each of the time periods, the calculated factor by which the estimated passenger demand could increase before a further pod would be required (to meet the maximum hourly passenger demand) suggests that there is a large reserve capacity, should the ARUP demand forecast prove and underestimate. The network could run with a fleet of 12 15-seat pods, even if the maximum hourly passenger demand were doubled (or in most cases tripled) for all node-to-node legs.

However, although the calculated percentage occupancy of the pods is low on the Weekday Night, Weekend Night and Sunday AV services, with only 12 pods, the whole fleet is likely to be in frequent operation (with little pod stationary time). An assessment of the charging requirements / strategy will need to be undertaken to understand if there is enough charging time available for the 12 pods to operate continuously. If not, the fleet size would need to be increased to enable downtime to be incorporated into the network operations for pod charging.

4e. Passenger Demand Analysis: Weekday

The estimated passenger demand in the Weekday period is considerably greater than the Weekday Night, Weekend Night and Sunday demand. This increased demand would necessitate a significantly larger pod fleet. Again, using an estimate of the hourly distribution of passenger demand for each departure node and an estimate of the passenger split to each of the two destination nodes from each departure node, the required number of pods to meet the 5-minute passenger demand during the weekday period from 06:00 to 21:00 was estimated. This analysis is presented in Appendix D.

10 Seat Pod	
36	NUMBER OF VEHICLES REQUIRED TO MEET DEMAND
10	REQURED NUMBER OF PODS AT STATION
10	REQURED NUMBER OF PODS AT CBC
16	REQURED NUMBER OF PODS AT P&R
2160	Network Total Capacity (Passengers per Hour)
100	10 minute Passenger Capacity at the Station
100	10 minute Passenger Capacity at the CBC
160	10 minute Passenger Capacity at the P&R

15 Seat Pod	
28	NUMBER OF VEHICLES REQUIRED TO MEET DEMAND
8	REQURED NUMBER OF PODS AT STATION
8	REQURED NUMBER OF PODS AT CBC
12	REQURED NUMBER OF PODS AT P&R
2520	Network Total Capacity (Passengers per Hour)
120	10 minute Passenger Capacity at the Station
120	10 minute Passenger Capacity at the CBC
180	10 minute Passenger Capacity at the P&R

This analysis suggests that a fleet of 36 10-seat pods or 28 15-seat pods is sufficient to meet the 'baseload' average passenger demand for Weekday operations. The number of pods in the proposed AV services are tailored to the calculated passenger demand at each of the departure points (i.e. as the P&R has the greatest passenger demand, a greater number of pods are required at that node).

4f. Level of Service 10-Minute Capacity

Appendix E presents an assessment of the 10-minute passenger capacity for each node-to-node leg with varying pod fleet sizes, and evaluates this capacity againt the estimated maximum 10-minute passenger demand on each leg in the network. The analysis highlights that the capacity of the proposed Weekday Night, Weekend Night and Sunday and AV services, with 4 pods operating on each of the three loops, would be sufficient to the meet the estimate of 10-minute passenger demand.

4g. Passenger Surge Demand Analysis

Rather than designing the AV network on the guided busway to meet the average passenger demand across the network, it may be desirable to ensure that the system is able to cope with a 'worst case' passenger demand scenario, providing enough pods at each node to have sufficient 'surge capacity' for the time when the maximum number of passengers wish to use the AV service within a 10-minute period. Such spikes in demand could be caused by the arrival of multiple trains at the Station or the end of a working shift for large numbers of staff at the CBC.

For this reason, a second service parameter is proposed:

2) Maximum waiting time at a node in the event of a surge in demand: 10 minutes

Whilst the average 'baseload' passenger demand in the Weekend and Weekday Evening periods can be met with a fleet of 12 pods, the number of passengers each departure node can cope with in a 10-minute period (the surge capacity) is perhaps rather low with this arrangement. With 12 10-seat pods the surge capacity is 40 passengers per 10 minutes at any one node, and with 12 15-seat pods the surge capacity is 60 passengers per ten minutes.

However, at Cambridge Station, 42 trains arrive after 21:00 on weekday nights, and the maximum number of trains arriving in a 10-minute window is 4. If, for example, 30 passengers from each of these 4 trains decided to use the pod service to travel between the Station and the P&R, this would result in a surge demand of 120 passengers, which the 12-pod network fleet (with 4 pods operating the Station to P&R loop) would not be able to transport within the proposed 10-minute maximum wait time.

Likewise, if a significant number of workers at the CBC finish at a set time and choose to use the AV busway service, then a 10-minute surge in demand could be significantly greater than the 10-minute capacity of the system. At the CBC this effect is likely to be somewhat dissipated by differences in walking journey times from points around the campus to the CBC departure node (see Appendix A2).

If a service parameter were to be set that stipulated AV system on the busway should be able to cope with a surge demand of 150 passengers in a 10-minute period, this would require that each departure node (Station, CBC, P&R) is able to dispatch either 15 10-seat pods or 10 15-seat pods within the 10-minute period. This could be delivered in two ways:

1) The whole surge capacity is provided by vehicles which are already waiting at the departure node. In which case, the required pod fleet would be between 30 – 45 vehicles depending on the number of seats in each pod.
2) A proportion of the surge capacity is delivered by a reserve of pods located at a point in the busway network from where they can be summoned to provide additional surge capacity within the 10-minute timeframe. This would require fewer pods to wait at the departure nodes and reduce the overall size of the pod fleet.

The analysis in Appendix A5 reveals that there could be sufficient space to locate between 3 and 5 pod waiting bays at the southern busway junction. The journey time analysis in Appendix B5 shows that from this point in the network the pods could reach any of the departure nodes in under 4 minutes, and hence contribute to meeting the surge demand criteria. Depending on the number of seats in the pods (10 or 15) this could contribute an extra capacity of between 30 to 75 passengers to meet the 10-minute surge demand.

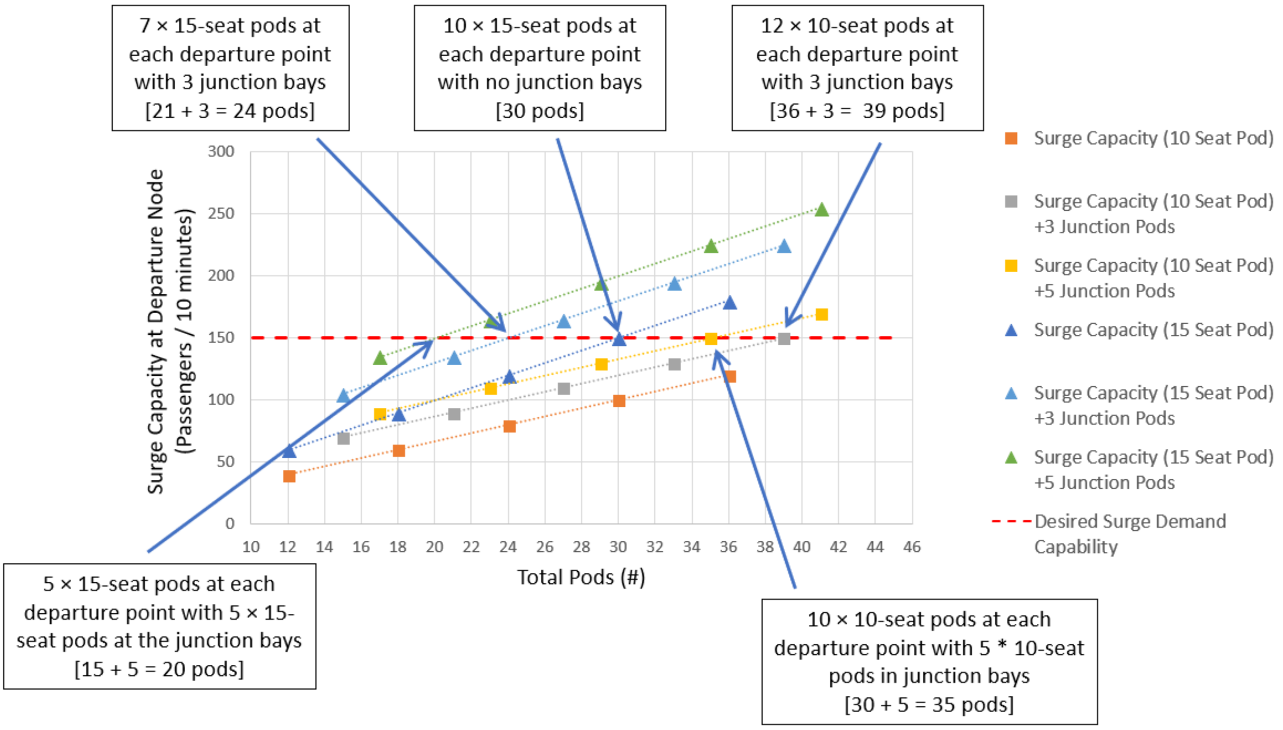
Estimate of AV Journey Time between the Central Junction and Departure Nodes

This demonstrates that a variety of pod fleet solutions for the out-of-hours service are available and the structure of the final fleet will depend on:

- The number of seats in each pod
- The specified 10-minute surge capacity
- The ability / inability to place pod waiting bays at the busway junction

The analysis shown in the figure below shows that there are several pod fleet configurations which would meet the surge criteria of transporting 150 passengers per 10 minutes. These fleets range from a 20 pod fleet, with

15-seat pods and the ability to station 5 vehicles at the central busway junction, to a fleet of 39 10-seat pods with the ability to station 3 pods at the junction.



If it is not possible to station pods at the southern busway junction, then the fleet would need a minimum of 10 15-seat pods at each of the departure nodes (fleet = 30 pods) or a minimum of 15 10-seat pods at each departure node (fleet = 45 pods). If a 15-seat pod is employed on the network, the ability to station 5 pods at the junction reduces the required fleet size by 10 vehicles.

5. Financial Appraisal

It is clear from the analysis in earlier sections that the greater vehicle capacity of 15-seats enables the proposed service to run with a significantly smaller vehicle fleet. As shown in Appendix D, the 15-seat pod service also reduces the number of required journeys, the amount of time pods would remain stationary and the number of times the pod would travel empty. As a result, the following financial appraisal is calculated on the basis of employing 15-seat autonomous pods. Further background to the calculations can be found in Appendix F.

<u>**Assumed Costs**</u>

- 15-Seat Passenger Pod: £100,000 per vehicle
- Infrastructure Side Systems (CCTV network, etc): £500,000
- Minor Works (Busway modification, Vehicle stabling sheds, etc): £1,000,000

5a. Financial Appraisal of Out-of-Hours AV Service, for Different Pod Fleets and Levels of Service

Number of 15-Seat Pods	12	15	17	24	27	29	36	39	41
Cost of Vehicle	£100,000	£100,000	£100,000	£100,000	£100,000	£100,000	£100,000	£100,000	£100,000
Total Cost of Vehicles	£1,200,000	£1,500,000	£1,700,000	£2,400,000	£2,700,000	£2,900,000	£3,600,000	£3,900,000	£4,100,000
Station Capacity per 10 mins	60	60	60	120	120	120	180	180	180
10 min Surge Capacity at any departure point	60	105	135	120	165	195	180	225	255
Number of Pods at each departure point	4	4	4	8	8	8	12	12	12
Number of Junction waiting bays	0	3	5	0	3	5	0	3	5
Infrastructure	£500,000	£500,000	£500,000	£500,000	£500,000	£500,000	£500,000	£500,000	£500,000
Busway Modifications / Stabling etc	£1,000,000	£1,000,000	£1,000,000	£1,000,000	£1,000,000	£1,000,000	£1,000,000	£1,000,000	£1,000,000
Capital and Interest Repayments (10 year 3% bond) on vehicles, infrastrucutre and minor works	**£362,857**	**£403,175**	**£430,053**	**£524,127**	**£564,445**	**£591,323**	**£685,397**	**£725,715**	**£752,593**
Fuel (Electricity) Costs	**£55,000**	**£55,000**	**£55,000**	**£55,000**	**£55,000**	**£55,000**	**£55,000**	**£55,000**	**£55,000**
Staff Costs	**£460,000**	**£460,000**	**£460,000**	**£460,000**	**£460,000**	**£460,000**	**£460,000**	**£460,000**	**£460,000**
Vehicle Maintainance	**£12,000**	**£15,000**	**£17,000**	**£24,000**	**£27,000**	**£29,000**	**£36,000**	**£39,000**	**£41,000**
Insurance	**£18,000**	**£22,500**	**£25,500**	**£36,000**	**£40,500**	**£43,500**	**£54,000**	**£58,500**	**£61,500**
TOTAL COST p.a.	**£907,857**	**£955,675**	**£987,553**	**£1,099,127**	**£1,146,945**	**£1,178,823**	**£1,290,397**	**£1,338,215**	**£1,370,093**

In this table the cost of the vehicles, AV infrastructure and the cost of the minor works on the busway (in the range £2.7 M to £5.6 M depending on the level of service required) are financed via a Local Government Bond at 3% over 10 years. The annual repayment on these figures would be in the range of £360,000 to £750,000.

The total expenditure of running the out-of-hours (Weekday Night, Weekend Night and Sunday) Cambridge Autonomous Bus Service would be in the order of £900,000 to £1.4 M per annum.

5b. Estimate of Annual Income from Out-of-Hours Operation:

Total Weekly Out of Hours Journeys:	7883							
Single Fare per Trip	£1.00	£1.50	£2.00	£2.50	£3.00	£3.50	£4.50	£5.00
Weekly Income	£7,000	£11,000	£15,000	£19,000	£23,000	£27,000	£35,000	£39,000
Annual Income	**£364,000**	**£572,000**	**£780,000**	**£988,000**	**£1,196,000**	**£1,404,000**	**£1,820,000**	**£2,028,000**

Depending on the level of service required (related to the desired provision of surge capacity at each node in the network) a fare in excess of £3 per trip is likely to be required for the out-of-hours service to break-even, balancing income against expenditure during out-of-hours service operation. It is possible thought, that advertising within the pods / sponsoring of pods by local businesses could negate any shortfall were the fare price set a little lower than £3.

5c. Financial Appraisal of a 24-Hour AV Service, for Different Pod Fleets and Levels of Service

Number of 15-Seat Pods	28	31	33	36	39	41
Cost of Vehicle	£100,000	£100,000	£100,000	£100,000	£100,000	£100,000
Total Cost of Vehicles	£2,800,000	£3,100,000	£3,300,000	£3,600,000	£3,900,000	£4,100,000
Number of Pods at Station	8	8	8	12	12	12
Number of Pods at CBC	8	8	8	12	12	12
Number of Pods at P&R	12	12	12	12	12	12
Number of Pods at Junction Waiting Bays	0	3	5	0	3	5
Station and CBC Capacity per 10 minutes	120	120	120	180	180	180
P&R Capacity per 10 minutes	180	180	180	180	180	180
10 min Surge Capacity at Station and CBC	120	165	195	180	225	255
10 minute Surge Capacity at P&R	180	225	255	180	225	255
Infrastructure	£500,000	£500,000	£500,000	£500,000	£500,000	£500,000
Busway Modifications / Stabling etc	£1,000,000	£1,000,000	£1,000,000	£1,000,000	£1,000,000	£1,000,000
Capital and Interest Repayments (3% bond)	**£577,884**	**£618,202**	**£645,080**	**£685,397**	**£725,715**	**£752,593**
Fuel (Electricity) Costs	**£190,000**	**£190,000**	**£190,000**	**£190,000**	**£190,000**	**£190,000**
Staff Costs	**£1,450,000**	**£1,450,000**	**£1,450,000**	**£1,450,000**	**£1,450,000**	**£1,450,000**
Vehicle Maintainance (£2,0000 per pod)	**£56,000**	**£62,000**	**£66,000**	**£72,000**	**£78,000**	**£82,000**
Insurance (£1,500 per pod)	**£42,000**	**£46,500**	**£49,500**	**£54,000**	**£58,500**	**£61,500**
TOTAL COST p.a.	**£2,315,884**	**£2,366,702**	**£2,400,580**	**£2,451,397**	**£2,502,215**	**£2,536,093**

Using the 15-Seat pod fleet calculated in Section 4c as a starting point, the table above shows the total per annum cost of running a 24-hour autonomous pod service, capable of meeting the baseload passenger demand in the network for all hours of the day. The larger pod fleets in these scenarios would enable the service to meet larger surge demands within the network.

The main factor behind the projected rise in cost of the 24-hour service in comparison to the out of hours service is the increase in staff costs. This cost is detailed in Appendix F.

The total annual expenditure of running a 24-hr Cambridge Autonomous Bus Service would be in the range of £2.3 M to £2.6 M. However, it should be noted that larger pod fleets could be required to meet the desired surge capacity at each departure node in the network.

5d. Estimate of Annual Income from 24-hour Operation:

Total Weekly 24-Hour Journeys:	60,509							
Single Fare per Trip	£1.00	£1.50	£2.00	£2.50	£3.00	£3.50	£4.50	£5.00
Weekly Income	£60,000	£90,000	£121,000	£151,000	£181,000	£211,000	£272,000	£302,000
Annual Income	**£3,120,000**	**£4,680,000**	**£6,292,000**	**£7,852,000**	**£9,412,000**	**£10,972,000**	**£14,144,000**	**£15,704,000**

The addition of 52,626 additional weekly journeys during the weekday hours (8771 × 6, Mon-Sat) at £2 a fare generates an additional annual fare income of £5,473,104.

Charging a fare of between £1.50 and £2.50 per single journey (throughout the day) could generate a profit of between £2.1 M and £5.5 M per year. Therefore, providing a 24-hour autonomous pod service on the Cambridge guided busway would improve the level of service over the existing bus fleet and deliver a very positive business case. The pod service would reduce passenger waiting times at the CBC, Station and Trumpington Park and Ride, significantly reduce the journey time between the P&R and the Station and generate a significant profit.

6. Impact on traffic flows

The Cambridge Biomedical Campus (CBC) is a major destination and generator of travel demand, with around 17,250 staff currently working on-site and 14,500 visitors per day. The CBC is a major asset in the development of the UK's life science research, teaching and healthcare industries. It contributes to Greater Cambridge's position as one of the UK's most successful Cities in terms of economic indicators, such as productivity and knowledge-based jobs. The Campus is currently in a period of exceptional sustained growth and development, as is the whole Greater Cambridge area. Current tenants on the site include Addenbrookes Hospital and Glaxo Smith Kline. AstraZeneca will shortly move into its new corporate headquarters and global research centre at CBC, Royal Papworth Hospital and the life-science company Abcam will also be relocating to CBC in the near future. Further growth is anticipated to 2031.

Access to and from CBC by highway during peak hours is challenging, due to congestion on the highway network surrounding the site. Buses access the site from Cambridge City Centre, Cambridge Rail Station and Trumpington Park and Ride along the CGB which provides segregated, traffic free access for buses as well as cyclists and pedestrians. Within the site, cycle and pedestrian infrastructure is inconsistent and car and cycle parking is nearing or at capacity.

A person total of 28,475 vehicular trips, 4,779 cycle trips, 4,313 bus trips and 3,820 pedestrian trips are made to the site each day. Most originate from within the Greater Cambridge Region, however some come from further afield.

The level of near-term and long-term growth will lead to significantly increased travel demand from patients, visitors and employees. Significant growth on the CBC site will continue up until at least 2031. The level of staff on-site is expected to increase by 16% above 2022 levels, with a 31% growth in patient and visitor levels. This will give rise to an increase in demand of 10,600-person trips per day to the site. The interrelationship between the construction of schemes and the phasing of on-site developments indicated that there would be two periods with specific constraints on the network; prior to 2020 and from 2026. In line with the Cambridge Access Study, a target to reduce the level of highway traffic to the site by 10%-15% based on 2011 levels has been adopted, which poses significant challenges for the site going forward.

The Draft Local Plan for Cambridge and South Cambridgeshire predicts that, by 2031, the population of Cambridge will be 21% greater than it was in 2011 and that there will also be a 25% growth in Cambridge jobs.

The County Council's aspirations are that city centre traffic levels in 2031 will be no greater, and preferably lower, than 2011 traffic levels… a significant mode shift from car use. The Campus expects to contribute in an appropriate manner to delivering these aspirations, with all partners playing their part. This will require a major and concerted effort.

The autonomous bus deployment is aimed at staff and visitors who are currently driving onto the site as public transport is unavailable either for their journey into the campus or out. The deployment will enable modal shift away from the private vehicle and will be one of the measures that help to alleviate congestion on the highway network. Previous research in 2015 shows;

Staff	
Car (Single Occupancy)	2308
Car (Multi Occupancy)	801
Visitors	
Car (Single Occupancy)	5064
Car (Multi Occupancy)	7462

To estimate the impact on traffic flows we have split the project into two phases - – Phase 1 pilot deployment of 6 vehicles and phase 2 deployment of 12 vehicles and then used the ARUP model to estimate demand.

No of Vehicles	**Weekday** (6:00am – 9:00pm)	**Weekday Night** (9:00pm – 6:00am)	**Weekend Night** (9:00pm – 6:00am)	**Sunday** (6:00am – Midnight)
6 (Phase 1)	0	648	369	832
12 (Phase 2)	8,771	1,096	739	1,664

Our assumptions is that users of the service would most likely have previously used single occupancy cars because of the unsocial hours of their shifts and are less likely to cycle (approx. 10%).

From the model we anticipate the impact on traffic flows will be to remove this number of car journeys:

No of Vehicles	**Weekday** (6:00am – 9:00pm)	**Weekday Night** (9:00pm – 6:00am)	**Weekend Night** (9:00pm – 6:00am)	**Sunday** (6:00am – Midnight)
6 (Phase 1)	0	583	332	749
12 (Phase 2)	7849	996	665	1498

Based on the current daily vehicular trips of 28.475 we anticipate that the initial pilot would remove approx. 2-3% of the vehicular traffic, however for a full deployment of vehicles to include daily journeys it would potentially remove approx. 25% however the majority of this would potentially be displaced from current bus services and so an estimate of between 5%-10% additional modal shift has been calculated.

7. Economic Impact

The Cambridgeshire and Peterborough Independent Economic Review panel have delivered an interim report on the Cambridgeshire and Peterborough economy. Based on the preliminary analysis, it seems that Cambridge and South Cambridgeshire will be unable to maintain their present growth given current infrastructure and housing plans, unless something radical is done to tackle congestion, house prices and skills.

Our analysis shows that the initial proposed will not bring direct economic benefit although the experience of other deployments most notably Sion has shown an up-lift in visitors which bring economic benefits. However a full deployment would bring economic benefit particularly as part of planned wider infrastructure improvements such as the Cambridge South Station and CAM the mayors proposed rapid mass transit scheme. Quantifying that benefit is difficult at present due to the uncertainty of other large schemes but the proposals for the shuttle will be included in future economic models.

8. Deployments Comparisons

'ParkShuttle'- Rivium (Netherlands) – 2getthere

Date of Visit: 9th January 2018

Contact: Dennis Mica (dennis@2getthere.eu)

Location: Capelle aan den IJssel, near Rotterdam, Netherlands.

Developer: 2getthere, a Dutch firm which designs, develops, manufactures and markets automated transit networks for personal and group transportation (https://www.2getthere.eu)

Operator: ConneXXion, a large public transport company in the Netherlands (https://www.connexxion.nl).

Stakeholders: Metropolitan Region Rotterdam The Hague (MRDH) contributes €600,000 per year to operation of the system [1]. The city of Capelle aan den IJssel and De Verkeersonderming made a financial contribution to delivery of the system [1].

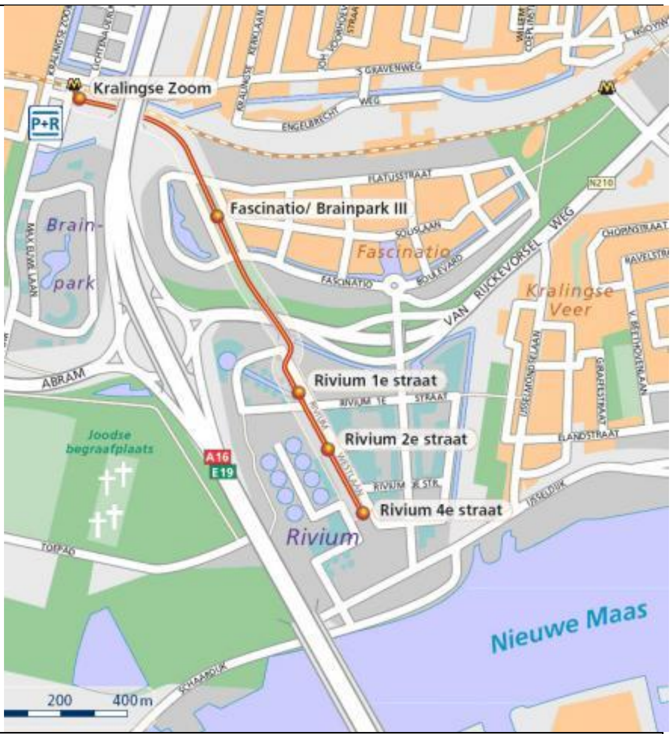
Vehicles: Six 2nd generation GRT (Group Rapid Transit) vehicles built and maintained by Spijkstaal (http://www.spijkstaal.nl/grt-parkshuttle-en) with the interior and exterior designed by Duvedec (http://www.duvedec.com/en/services/concept/research/parkshuttle/).

Vehicle Specifications:

L / W / H	6.0 m / 2.1 m / 2.75 m [2]	
Capacity	20 (12 seated, 8 standing) or 25 (8 seated, 17 standing) [3]	Allows for wheelchair access [3]
Weight Empty	3,500 kg [2]	Van Sterkenburg et. al give an operational mass of 4650 kg [4]
Load Capacity	2,000 kg [2]	
Max. Speed	40 km/h [2]	Max. Speed in Operation ≈ 30 km/h [4]
Range	75 km [5]	
Drive	Electric	
Motor	Rated power 23 kW [4]	Leroy-Somer TRA 240 asynchronous induction motor [4]
Inverter	Curtis 1238 [4]	
Transmission	A gear with fixed transmission ratio and a differential [4]	
Battery	52 kWh [4]	42 (620Ah) lead-acid traction cells in series [4]
Charging	Up to 6 hrs [5]	
Vehicle Communication	- Information can be conveyed to passengers through a user console and voice module - A camera system enables real-time display of the vehicle interior [3]	
Safety Systems	- An array of short and long-range sensors which scan the area in front of the vehicle and decelerate or stop the vehicle when an unknown object is detected - Bumper sensors bring the vehicle to an immediate stop in the event of an impact - The vehicles have both internal and external vehicle emergency stop buttons [3] - Stopped vehicles can only be restarted by system controllers	

ParkShuttle Route: The ParkShuttle connects Kralingse Zoom Metro Station to the Rivium Business Park along a 1.8 km track featuring 5 stations and serves two business parks (Brainpark III and Rivium) along with a residential area (Fascinatio). The track is for the sole use of the autonomous Parkshuttle vehicles and is closed to other traffic modes.

The system functions as a horizontal elevator. Passengers call a vehicle by pushing a button on a request console found at each station and upon boarding the vehicle select a destination station by pressing a button inside the vehicle. After all passengers have boarded, the vehicle automatically drives to each of the selected destinations. The service provides approximately 2,500 passengers trips each weekday.



Rivium ParkShuttle Map [6]

During peak-hours all six available vehicles run at a scheduled 2.5 minute interval, which ensures optimal use of the vehicle fleet capacity. During off-peak hours an on-demand service operates to maximise passenger service, with a maximum wait time for a vehicle of 6 minutes.

The Rivium ParkShuttle is currently the only autonomous system (i.e. operating without a safety driver or steward) which transports passengers on a pathway that features 'at grade' intersections with traffic and pedestrians [7]. The operation of vehicles and crossings is controlled by 2getthere's dedicated supervisory control system.

History: The decision to test a GRT system at the site was taken in 1995 and a pilot project was conducted between February 1999 and November 2001. After a successful pilot, Phase II of the project began in 2005, with the track extended to 1.8 km, made dual-lane (except for a bridge and a tunnel) and expanded to provide a service to 5 stations. The three Phase I vehicles were replaced with six 2nd generation vehicles which doubled the passenger per vehicle capacity, from 10 to 20 passengers.

Rational for Deployment: The ParkShuttle project was designed to provide

- a better public transport service (higher frequency / reduced waiting-times / greater reliability) when compared to existing shuttle bus services
- more cost-effective operation (reduced labour cost without drivers, which in the Netherlands has been estimated to be 50 to 70% of the operational costs [8, 9])

- environmental benefits (employing electric vehicles, zero tailpipe emission and reduced noise)
- a more attractive public transport alternative for car drivers.

A recent passenger survey suggests that the current ParkShuttle service compares favourably to the regular bus service to Rivium, with respondents valuing its reliability, hours of operation (from 06:00 to 21:00), shorter waiting times and better travel information [8, 10].

Future: A measure of the success of the system is the recent decision to upgrade and expand its operation. In a world first, a proposed €8.5 million project will aim to deliver a vehicle with the capability for level 4 autonomy, in order to operate an autonomous system on public roads, in mixed traffic, by 2020 [11]. From 2019, the vehicle fleet will be upgraded to 3rd generation shuttle vehicles, which will be lighter, air-conditioned and bi-directional (removing the necessity for turning loops at the ends of the track) [10]. From 2020 the service will be extended to provide a link to a water bus service near the Rotterdam Schaardijk, which will require the vehicles to operate on public roads [12]. This new connection is expected to increase passenger numbers by 20% [12].

Operation Specifications:

Route Length	1800 m [5]	
Design	2.5m wide asphalt track which is closed to other modes of transport	
Lanes	Primarily Bi-Directional Dual-Lane	Single-Lane at the A16 tunnel and the N210 bridge
Number of Stations	5	• **Kralingse Zoom Station:** − 2 boarding berths (Southbound) and 2 separate alighting berths (Northbound) − Turning Loop • **Fascinatio (Residential) / Brainpark III (Business Park) Station:** − 1 boarding / alighting berth on each station platform (North & Southbound platforms) • **Rivium 1e Straat Station (Business Park Rivium):** − 2 boarding / alighting berths on each station platform (North & Southbound platforms) • **Rivium 2e Straat Station (Business Park Rivium):** − 1 boarding / alighting berth on each station platform (North & Southbound platforms) • **Rivium 4e Straat Station (Business Park Rivium):** − 2 boarding / alighting berths on the station platform (Northbound) − Turning Loop
Traffic Crossings	6	− 3 at grade (i.e. the road and the ParkShuttle route intersection is at the same height) − A tunnel under A16 − A bridge over Fascinatio Boulevard − A bridge over the N210
Pedestrian Crossings	5	− All at grade
Peak Capacity	500 passengers / hr [5]	
Patronage	≈ 2500 passengers / day [5]	
Journey Time	≈ 8 minutes	Journey from Kralingse Zoom to Rivium 4e Straat
Journey Average Speed	≈ 13.5 km/h	1.8 km in 8 minutes (see reference [4] for a second by second profile)
Service Frequency	2.5 minute schedule (peak) / on-demand (off-peak) [5] The operator can also select a 5-minute interval [5]	06:00-07:30 – every 6 mins 07:30-09:30 – every 2.5 mins (if defective vehicle 3-4 mins) 09:30-16:30 – every 6 mins 16:30-18:30 – every 2.5 mins (if defective vehicle 3-4 mins) 18:30-21:00 – every 6 mins [13]
Time of Operation	15 hours per day [13], Monday to Friday	06:00 – 21:00 weekdays [14]

Number of Vehicles	6	6 operational in peak hours / 3 in off-peak (alternate charging) [5]
Vehicle Request	Push-Button at each station	
Cost of Ride	OV Chip Card flat rate €0.55 [15] per ride plus a basic rate where required.	A basic rate of €0.90 (2018) is applied at the start of a journey on public transport. If a further journey begins within 35 minutes of 'checking-out' of a previous journey it is considered the same trip [16]
Entry Control	OV Chip Card readers, policed by ticket inspectors [17]	A traveller must 'check-in' and 'check-out' for each individual journey using the OV card. Failure to check-in risks a fine. In practice the service was free until 2011, due to the lack of ticket sales, ticket machines and supervisory staff [17]
Supervisory Control System	Transit Operations Monitoring and Supervision (TOMS) [18]	A single operator is on duty during operational hours, supported by a maintenance engineer during office hours [14]
Certification (Phase II)	TNO – FMECA method	Safety and suitability of the system demonstrated by TNO through qualitative analysis and external testing [18]
Vehicle Navigation	Free Ranging On Grid (FROG)	– A map of the operational area is stored in the on-board computer in each vehicle from which the vehicle can plan its route between station stops – Accuracy of the vehicle path is maintained through calibration of vehicle position to a series of magnets embedded in the road surface – Positioning accuracy is better than 3cm
Years Active	13 [19]	Since 2005
Vehicle km driven	200,000+ per vehicle [19]	
Total Passengers	6,000,000+ [12]	
Vehicle Storage	Garage at Kralingse Zoom	Overnight storage, maintenance and vehicle charging
Contingency Plan	Replacement Bus Service	In the case of system failure, a replacement bus service operates

Cost Estimates: Some limited cost estimates for the ParkShuttle are available from on-line sources:

Phase I Pilot:
http://faculty.washington.edu/jbs/itrans/parkshut.htm suggests the following as costs of Phase I ParkShuttle pilot project:

ParkShuttle system (including 3 vehicles): $1.5 million (≈ €1.4 million at 1999 rate)
Infrastructure: $1.0 million (≈ €0.9 million at 1999 rate)
Test phases: $1.0 million (≈ €0.9 million at 1999 rate)

Giving a total pilot project cost of $3.5 million (≈ €3.3 million at 1999 rate)

Phase II:
https://www.polisnetwork.eu/publicdocuments/download/128/document/21582_policynotesWG4_1.indd_low.pdf suggests the following as costs of constructing a similar system to the ParkShuttle Phase II project at 2008 prices.

Capital: 6 Vehicles: €1.6 million (at €270k per vehicle)
Infrastructure: €3.6 million (guideway construction: including a guidance system using magnet; a depot for vehicle storage, maintenance and charging; and a control centre)

This study estimates yearly operational costs to be €650k – including electricity and communication costs and 3 staff per day for operations and maintenance (5-day, 16 hour/day week).

Phase III Upgrade and Expansion:
https://www.2getthere.eu/first-autonomous-system/ 2getthere suggest the upgrade and expansion of the ParkShuttle system for 2020 requires an €8.5 million investment. No clear costing of this figure is provided although the figure likely contains the purchase of six 3rd generation vehicles, the creation of a new station on the waterfront, some extension and modification of the ParkShuttle pathway and preparation of the surrounding roads and junctions for the addition of autonomous vehicles on these public roads.

ParkShuttle Incidents:

- December 6th 2005 – A collision between two empty ParkShuttle vehicles. Communication was lost between the central computer and one of the vehicles on track, causing it to stop on the bridge, a single lane portion of the track. Operator human error caused the vehicle to be manually released despite the presence of a vehicle in front and the system was restarted. The two vehicles collided even though the obstacle detection system did take effect on both vehicles, as collision avoidance had been calculated for a single vehicle approaching a stationary object not two moving vehicles approaching each other. The error in the software was corrected, the communications system improved and both vehicles were repaired.
- February 8th 2006 – A fire started overnight in the vehicle parking area, likely due to a short circuit, which destroyed one vehicle and damaged another.
- April 3rd 2007 – The navigation systems provider FROG declared bankruptcy. The firm was promptly re-founded in a smaller form. FROG AGV Systems was subsequently purchased by Oceaneering International in 2014.
- April to December 2011 – The Parkshuttle system was out of service for a number of months due to construction of a parking garage at the Kralingse Zoom station. A replacement bus service was operated in its place.

Notes from the Visit:
The existing system functions well as part of the city's transport infrastructure providing a reliable and robust service for commuters to the business parks. The system seems to run with a minimal level of supervision from controllers, as the operations are monitored by a single operator who also has the available time for cleaning the vehicles and for individual ticket sales.

The main cause for intervention of the controller is related to vehicles perceiving obstructions on the track (leaves, plastic bags, animals) and such issues can primarily be resolved from the control centre at the Kralingse Zoom Station. There is, however, need for a scooter in the parking garage to provide a means of transport for the operator to quickly resolve issues on the track which cannot not be remedied from the control centre. The operator reported some issues with cyclists illegally using the track and local youths interfering with operations (deliberately stopping vehicles at junctions). An external speaker system on the vehicles has been used to deter such actions and the number of such incidents has reduced over time.

Whist the ParkShuttle was described by the operator and 2getthere as a profitable part of ConneXXion transport infrastructure, it's profitability is dependent on a yearly contribution (€600k per year [1]) to operations from the Metropolitan Region Rotterdam The Hague (MRDH). The passenger demand is mainly limited to transporting passengers arriving from the Kralingse Zoom Metro Station to and from the business parks. With a reported 2,500 passenger trips per day (650,000 trips per year) the opportunity for profitability under the current ticketing system seems limited. The proportion of the ticket price for each journey that is received by the ParkShuttle was unclear. A flat rate of €0.55 seems to be paid directly to the ParkShuttle, whilst a basic rate of €0.90 (applied at the start of each journey) is distributed across providers in the city's transport network.

Ticketing is policed by occasional inspection teams entering the ParkShuttle. Due to the complete lack of entrance barriers and the small number of staff, there seems significant scope for 'fare-dodging'. It was unclear the extent to which ticket inspectors prevent people from using the service without a valid ticket.

The 1st generation vehicles used in the pilot project received a special waiver under the Public Transport Law to have the ParkShuttle operate as a public transport system. The newly constructed pathway was declared a private road meaning the vehicles did not have to meet the legislation for vehicles on public roads. Liability was arranged in line with a 'normal' bus system. The 2nd generation ParkShuttle system was part of the CyberCars / CyberMove programs. A TNO developed Failure Modes, Effects and Criticality Analysis (FMECA) method was applied to provide proof of the safety of the 2nd generation vehicles to provide public transport in Rivium [18].

Conclusions:
The project has nearly 20 years of practical experience in running an automated public transport system. The ParkShuttle has successfully established the feasibility of the autonomous system over a long time scale and shown that such a system can be successfully integrated into existing transport infrastructure as a last mile solution. The project has demonstrated passengers' acceptance of automated shuttle vehicles.

The Rivium project has several similarities to the proposed autonomous vehicle trials in Cambridge on the southern section of the guided busway in that it operates on a pathway segregated from other modes of transport, with vehicles travelling at significantly above walking pace to deliver a meaningful transport service. The proof of concept that ParkShuttle offers provides strong evidence of the technological feasibility of implementing an automated public transport system on the busway, with the advantage for such trials in Cambridge that the existing busway removes the substantial cost of pathway construction from the initial infrastructure costs.

The applicability of the Rivium ParkShuttle business model to the Cambridge proposal is less strong. The ParkShuttle system appears to be limited by passenger demand for its service. The relatively low level of patronage on the ParkShuttle means that at the current ticket price (€1.45 per journey) the system must be financially supported by MRDH to remain viable.

As the scheme is designed for passengers to continue their journey from the Kralingse Zoom Metro to the business parks, a vast majority of the tickets will be purchased as a connected journey rather than as a single fare. Under this ticketing policy, with 650,000 trips per year, if less than 50% of the basic €0.90 rate for each trip is paid to the ParkShuttle (i.e. the fare received by Parkshuttle is less than €1) then the ParkShuttle system would not break even with the estimated yearly operational costs of €650k [20].

A recent report by the MRDH suggests ridership figures on the ParkShuttle of 300,000 passengers per year [21] (≈1,100 passengers per day [12]). It is not clear whether the MRDH figures refer to single or return journeys, however a smaller ridership would make it impossible for the ParkShuttle to operate without the significant financial contribution from the local government. At the current passenger demand and ticket price there does not seem to be a compelling business case for running the ParkShuttle based purely on the economics as transport provision.

The passenger demand for such a service in Cambridge would likely be significantly greater than found at Rivium (especially if the automated service were to operate in peak-hours) given the large number of potential commuters around the proposed busway stations at the Cambridge Biomedical Campus, the Cambridge Train Station and the Trumpington Park and Ride. The ParkShuttle project does however demonstrate the need for careful consideration of the project funding and the ticket pricing strategy to negate the necessity for significant financial support.

The Rivium project does however have tangible value as a demonstration of concept. With the planned Phase III expansion due to deliver autonomous public transport on public roads in mixed traffic by 2020 the Rivium ParkShuttle will continue to be a world leader. The expected global growth in demand for automated public transport systems which can deliver low emission, low noise, cost-effective, high-frequency, reliable transport solutions mean the cost of MRDH’s early investment in the industry (which has supported the development of Dutch businesses in the field) is likely to be significantly outweighed by the future benefits to the local economy of having local firms which are market leaders in the delivery of automated transit networks.

ParkShuttle Rivium System Photographs:

ParkShuttle Control Centre at Kralingse Zoom Station

Rivium ParkShuttle Request Console

Station Boarding Platform at Kralingse Zoom Station

ParkShuttle Rivium 4e Straat Station (2 boarding / alighting berths)

ParkShuttle Vehicle Traversing the Bridge over the N210

Rivium ParkShuttle at Grade Crossing with Traffic and Pedestrians

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'Stimulate' – Berlin (Germany) – Berliner Verkehrsbetriebe (BVG)

Date of Visit: 8th June 2018

Attendees: Daniel Clarke (Cambridgeshire City Council), Andy Williams (AstraZeneca) and David Wyatt (University of Cambridge)

Contact: Johannes Jähne (johannes.jaehne@bvg.de)

Location: Campus Charité Mitte and Campus Virchow-Klinikum, Wedding District of Berlin [1]

Project Partners:

- **Berliner Verkehrsbetriebe (BVG):** Is the main public transport company in Berlin, managing the underground, tram, bus and ferry networks in the City (but not the S-Bahn urban rail system) [2].

- **Charité – Universitätsmedizin Berlin:** One of the largest university hospitals in Europe and one of the largest employers in Berlin with 13,370 staff (17,500 including subsidiaries https://www.charite.de/en/).

- **das Land Berlin (the state of Berlin)**

Charité provided the road and charging infrastructure, whilst BVG is responsible for the autonomous operation of the vehicles [1].

Technology Partners:

EasyMile (http://www.easymile.com/), a joint venture between the Liger Group (a French vehicle manufacturer) and Robosoft (a high-tech company specialising in service robotics) [3].

Navya (https://navya.tech/en/) [1].

Background:

The 36-month "Stimulate" project is funded by the Federal Ministry for the Department for the Environment, Transport and Climate Protection (https://www.bmu.de/en/), who are contributing approximately 3.2 million Euros to the total project budget of 4.1 million euros [4] (the remainder of the budget is from the state of Berlin, the Charité and the BVG [5])

The pilot project was announced in August 2017 [1]

The duration of the project is 36 months [1] (May 2017 to April 2020).

The project arranged testing in three phases [6]:

> Phase I November 2017 – January 2018 (accompanied driving without passengers)
> Phase II February 2018 – October 2018 (accompanied driving with passengers)
> Phase III November 2018 – April 2020 (autonomous operation)

Until October 2018, an attendant will be required within each vehicle, who has the ability to stop the vehicle at any time. In the first quarter of 2019, it is planned that the vehicle will be able to operate autonomously, without the requirement of an accompanying attendant.

Vehicles:

A total of four shuttles have been purchased for the pilot project, two EasyMile EZ10 and two Navya Autonom vehicles [4].

Vehicle Specifications: Navya

L / W / H	4.75 m / 2.05 m / 2.55 m [7]	Clearance 0.20 m [8]
Capacity	15 (11 seated, 4 standing) [7]	Allows for wheelchair access [7]
Weight Empty	2,400 kg [7] (GVW 3,450 kg [8])	
Load Capacity	1,050 kg [8]	
Max. Speed	45 km/h [7]	Max speed in the Berlin project is 12 km/h
Range	The shuttle can operate for 8 to 10 hours. Navya list average autonomy as 9hrs [8]	Depends on use of AC, heating and the number of people
Maximum Slope	12 %	
Turning Radius	< 4.5 m	Bidirectional drive
Heating / Cooling	Heating central regulation (3.4 kW) [8]	Automatic regulation cooling 2 * 4.6 kW (warm counties) [8]
Drive	Electric	2 drive wheels [9]
Motor	15 kW nominal (25 kW peak) [8]	

Battery	33 kWh [8]	Battery pack LiFePO4 [8]
Charging	6 to 8 hours [7]	Induction / Plug [9]
Vehicle Communication	- The project currently has no remote observation	
Safety Systems	- 2 stereo-vision cameras located in the lower area of the windscreen to monitor the road and detect traffic lights and signs [7] - 6 LiDAR sensors as core elements of the vehicle. They scan the vehicle surroundings in a radius of 360° (2 sensors) and 180° (4 sensors) from 50 to 100 m [7] - Two emergency stop buttons [7] - There is a safety attendant on board who can stop the vehicle at any time [7]	

Navya AUTONOM Detection and Navigation Technology [10]

Vehicle Specifications: EasyMile

L / W / H	3.928 m / 1.986 m / 2.75 m [11]	Wheelbase 2.800 m [14]
Capacity	10 (6 seated, 4 standing) [3]	Access ramp for wheelchair access [14]
Weight Empty	1,800 kg [12]	
Load Capacity	1,000 kg [13] (GVW 2,750 kg [11])	
Max. Speed	40 km/h [14] (Limited to 20 km/h [13])	Max speed in the Berlin project 11-12 km/h
Range	Autonomy up to 14 hrs [14]	Autonomy depends on use of AC, heating and the number of people (37-50 miles a day [17])

Maximum Slope	15% [12]	
Turning Radius	4.5 m [15]	Bidirectional drive
Heating / Cooling	Air-Conditioning	
Drive	Electric (asynchronous) [14]	Single gear
Motor	10 kW [16]	
Battery	2 batteries with a total of 19.2 kWh [12]	Battery pack Lithium-ion LiFePO4 [14]
Charging	8 - 10 hours [12]	Plug 230V 16A [14]
Vehicle Communication	- The project currently has no remote observation	
Safety Systems	- Localisation and Navigation Using Data Fusion - 3G/4G GPS tracking system [12] - Visual guidance system (Cameras) [3] - LIDAR collision detection system [3] - SLAM technology (Simultaneous Localisation And Mapping) [3]	- Decision-making Safety Chain - 3 × emergency stop buttons [14] - Safety control units [14] - Obstacle detection lasers [14] - Braking system and failsafe parking brake [14] - Onboard safety attendant

EasyMile EZ10 Detection and Navigation Technology [13]

Operation Specifications:

Three defined test loop routes, with fixed stops, have been created at two campus sites [4].

- A 1.2 km long route at Campus Charité Mitte, with 9 stops (approx. 16 mins [5])
- A 0.8 km route at Campus Virchow-Klinikum, with 8 stops
- And a 1.5 km route at Campus Virchow-Klinikum, with 9 stops

The Campus Charité Mitte and Campus Virchow-Klinikum locations (covering 268,207 m² and 137,964 m² respectively [18]) offer ideal test sites that provide a sufficiently large test area that is separate from public roads, but which incorporates interaction with pedestrians, cyclists and ambulances [19].

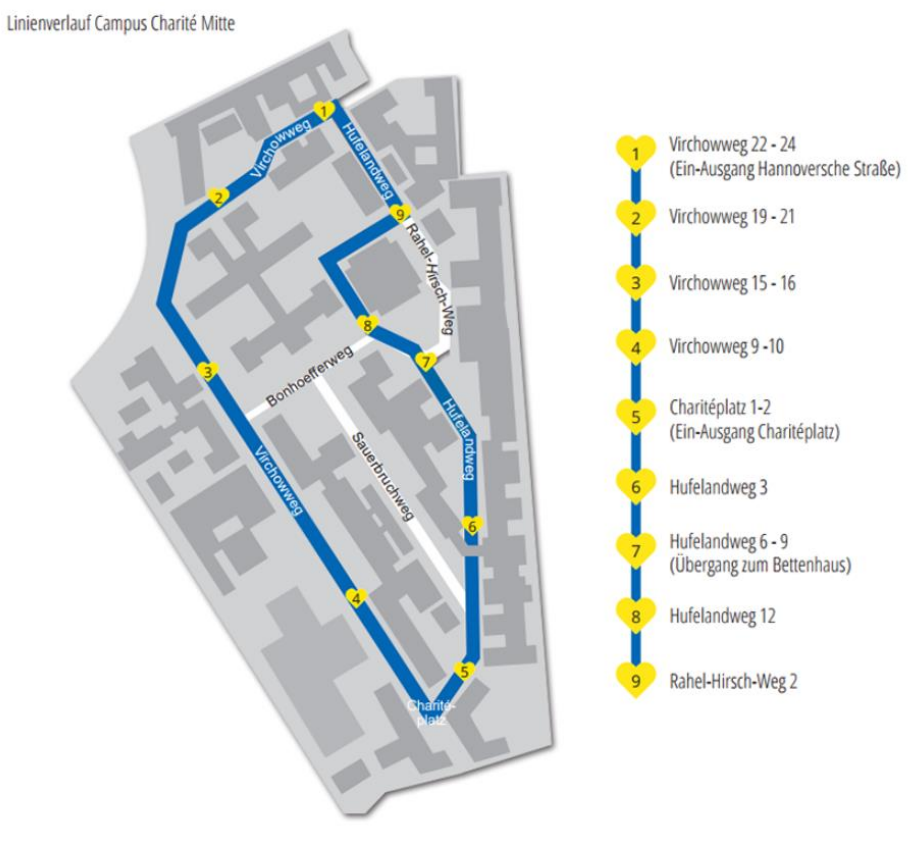
Testing began at the Campus Charité Mitte site at the end of January 2018, employing the two EasyMile vehicles. The initial phase of testing prepared the vehicles and trained the attendants to operate the route [20]. Since March 2018 testing has been conducted at Charité Mitte with the vehicles transporting passengers [5].

Operation at the Campus Virchow-Klinikum began in the middle of April 2018 using the Navya vehicles [1].

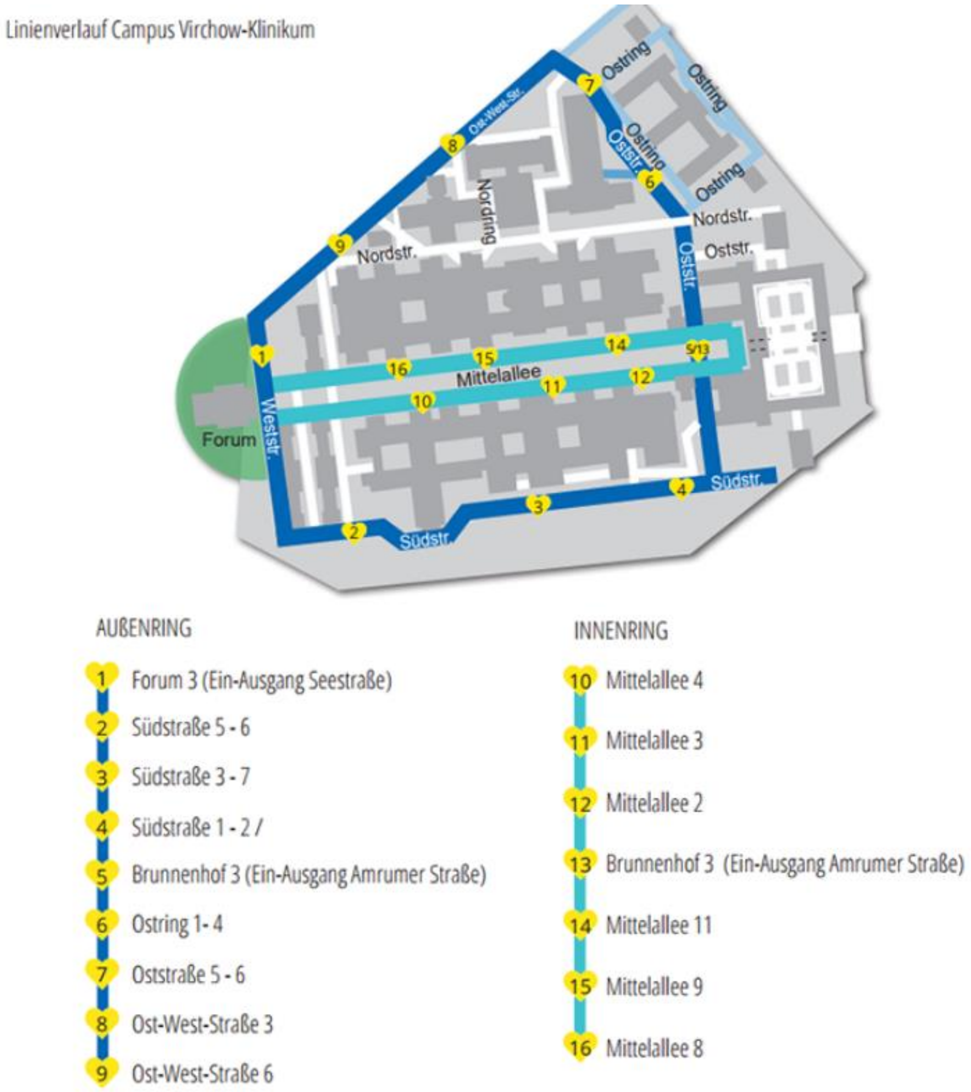
The autonomous vehicles are restricted to a top speed of 11-12 km/h at both sites

Operational hours are from 09:00 to 16:00, Monday to Friday [4]

The service is currently operated free of charge to passengers [4]



Route Campus Charité Mitte (EasyMile) [21]



Routes Campus Virchow-Klinikum (Navya) [21]

Rational for Deployment:

The aim of the project is to test areas of application and the acceptance of autonomous driving in a realistic environment, to uncover potential for improvement and to make a contribution to climate and environmental protection [18].

BVG hopes that the testing will provide important insights into the potential of the technology as a possible supplement to other forms of public transport [21].

The state of Berlin, together with the Charité and its Institute of Medical Sociology and Rehabilitation Sciences, will examine the acceptance and other practical aspects of using autonomous buses [21].

Cost Estimates:

The goal of the project is to test the application and acceptance of an autonomous last mile bus service, there is no requirement to recoup any of the project cost. Passengers are able to use the vehicles free of charge at both test sites during the operational hours of the service.

The four autonomous vehicles have been purchased for the project at a cost of approximately €250,000 per vehicle. Further to the vehicle costs there are additional expenses including the cost of service contracts, the training of vehicle operators and the initial commissioning of the route (recording of the route to allow the vehicle to locate itself and move along the recorded trajectory [3]).

Quotes:

Michael Müller, Governing Mayor of Berlin [4]:
"We have set ourselves the goal of making Berlin one of the leading smart cities. Our national companies and research institutions play an important role in this. The project by BVG and Charité is a perfect model example of this: With innovative technology, we are jointly designing a promising mobility offer that will benefit the people of our city."

Svenja Schulze, Federal Environment Minister [4]:
"We want to explore whether this approach can move more people to switch to public transport and thus relieve the burden on the environment. It is also about the question of how far passengers accept autonomous driving in order to learn from it for the further use of such vehicles.

Prof. Dr. med. Karl Max Einhäupl, Chairman of the Charité [4]
"Both our CampusCharité Mitte and our Campus Virchow-Klinikum behave like small microcosms in which patients, visitors, employees and students move. We hope that the project will enable us to expand existing transport services for them in the future and make their everyday lives easier."

Dr. Henrik Haenecke, BVG [4]
"With projects such as Stimulate, we are further expanding our expertise to offer even more attractive public transport with new technologies."

Notes from the Visit:

During the visit we observed the EasyMile vehicles in operation at the Campus Charité Mitte. We were not able to view operation of the Navya vehicles as no service was running at the Campus Virchow-Klinikum site on the day of our visit due to a technical issue with those vehicles.

Travelling in the EasyMile vehicle, on the Campus Charité Mitte test loop, the vehicle exhibited a smooth acceleration and braking profile, resulting in a very comfortable ride for the passengers (who are not restrained by seatbelts). The vehicle was able to interact with other transport modes using the same test area, for example recognising and slowing down (without stopping) as a group of cyclists overtook in close proximity to the vehicle. The 11 to 12 km/h maximum speed of the vehicle (determined by the vehicle manufactures as part of the initial route set up) felt adequately fast to offer a worthwhile alternative to walking. A demonstration of the autonomous emergency stop facility of the vehicle revealed that whilst the emergency brake is aggressive it was not so aggressive as to cause significant discomfort to passengers within the vehicle. The vehicle is currently programmed to stop at each of the stops on the route (in “metro mode”) regardless of passenger demand for the vehicle at each stop. In future (though not part of this project) it is envisaged that an on-demand service would be operated.

Commissioning of the test route at the Campus Charité Mitte took place in January 2018 and required the vehicle to be driven very slowly (≈1 mph) around the test loop in order for the vehicle to identify and map significant reference points on the route using the two on-board cameras and LIDAR sensors. These reference points enable the vehicle to locate itself on the route and travel along the recorded trajectory. BVG report they have had some issues during testing at Charité Mitte as the result of losing GPS signal. Loss of GPS signal causes the vehicle to stop as the vehicle is unable to locate itself on the route.

An attendant is required on-board the vehicle at all times to manually permit the vehicle to proceed both at junctions and after emergency stops (a button must be pressed once it is confirmed safe to proceed). The attendant is also required to manually steer the vehicle around obstacles blocking the recorded vehicle path (by means of an adapted games console controller) and to ensure safe operation of the vehicle, including deployment of an access ramp. The access ramp requires a very flat surface in order to be successfully deployed, this required careful siting of the stops on the route. The project employs 11 trained attendants across the sites along with a manager to organise operations and to act as the face of the project (N.B. there are 3 trained attendants per vehicle and attendants are trained to drive both the Navya and the EasyMile).

Testing two different autonomous vehicles has enabled some early comparison to be drawn between the vehicles from the two manufacturers:

- It was noted that the EasyMile vehicle could not be used to operate the Campus Virchow-Klinikum routes because the routes are too narrow for the EasyMile sensors. For this reason, the Navya vehicles were chosen to operate at this site.
- The EasyMile vehicle offers only plug in charging, whereas the Navya has both plug in and induction charging. In future BVG envisage induction charging will be the preference for this technology.
- Both the EasyMile and Navya vehicles comfortably manage the daily demand of operating the services. Covering approximately 25km, the vehicles are left with a 40-45% battery state of charge at the end of daily operation (N.B. Minimum SOC for the project is 20%).
- A strength of the EasyMile vehicle is that during manual operation (where the attendant takes control of the vehicle) the sensor safety system remains in operation, preventing the attendant from being able to drive the vehicle into an obstacle. Conversely for the Navya vehicle, whilst in manual driving mode all collision avoidance systems are disabled.

The project does not employ fleet management software, therefore neither the Navya or EasyMile vehicles are controlled or observed remotely. The project is looking into potential operating systems.

Since the end of March 2018 at Campus Charité Mitte and since May 2018 at Campus Virchow-Klinikum a total of approximately 2,000 passengers have ridden on the autonomous vehicles.

Whilst the vehicles are able to operate on the two routes with an attendant, there is (as of the time of our visit) no arrangement for how the vehicle will be insured for autonomous operation. There was some scepticism about whether the project would be in a position to realise the autonomous ambition of phase III by the November 2018 target.

Conclusions:

The Berlin ‘Stimulate’ project is in the early phases of testing an autonomous bus service and is as a result it is still reliant on having an attendant on-board the vehicles. The project is intended as a demonstration of concept with the aim of building experience with the new technology and answering questions about the operation of autonomous shuttles in public areas. The operators do not envisage the autonomous shuttles replacing existing bus services in the near future but are investigating the possibility of using such systems for first and last mile services.

This BVG project will help facilitate the progression toward the deployment of autonomous shuttles in public spaces. The chosen test routes offer a realistic vision of how such technologies could be usefully deployed in the future, and as the project continues, the development work and findings from the project should be very useful for future autonomous shuttle ventures in other locations.

An interesting aspect of the Berlin project is its ability to compare two rival shuttles. As the project continues the appraisal of the relative strengths and weaknesses of the Navya and EasyMile shuttles, should help inform the future development of autonomous vehicles and help in clarifying where each of the vehicles would be best deployed.

Photographs:

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APPENDIX A – Parking Zone Analysis

Preliminary study investigating Parking Zone feasibility at:

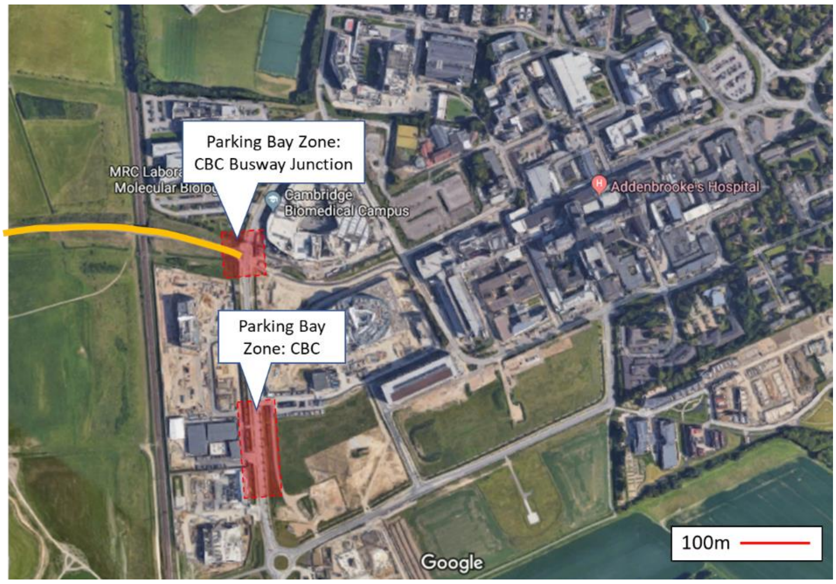
- Cambridge Biomedical Campus
- Cambridge Train Station
- Trumpington Park & Ride
- Southern Busway Junction

A1. Assumptions

Vehicle Length: 5.5 meters
Vehicle Width: 2.6 meters (In line with the Cambridge guided busway guidewheel settings)
Parking Bay Length: 6.0 meters
Parking Bay Width: 4.1 meters (with a 1.5m wide access for passenger boarding / alighting)
Minimum Turning Circle (Kerb-to-kerb) = 12 meters

The parking zone design at each of the nodes will be specific to the final location chosen. These locations are yet to be determined and will require further analysis to be undertaken to evaluate the availability and cost of the necessary land and the total development cost for each parking zone. The final design will also be dependent on factors such as; the final vehicle specs (length, width, turning circle, etc), whether the vehicle is bi-directional, whether the vehicle can operate on public roads, the precision of movement of the autonomous vehicle, and the required design specifications for a passenger waiting / boarding /alighting area at each parking bay. As a result, the analysis in this appendix presents a preliminary study into the feasibility of parking zones at each of the nodes on the busway along with the potential for vehicle waiting bays at the southern busway junction.

A2. Cambridge Biomedical Campus – Addenbrooke's Hospital (CBC)

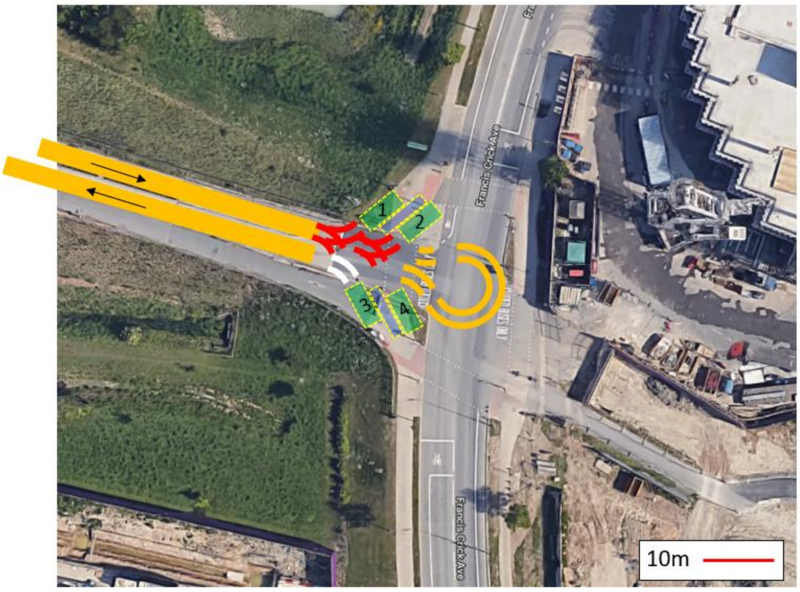


The highlighted areas show possible locations for vehicle parking bays in the CBC. The final parking bay locations will be dependent on the availability of land and whether the vehicle is able to manoeuvre autonomously on public roads.

The following figure details the walking time across the CBC to the end of the busway in minutes. The figure is constructed with an assumed walking pace of 5 km/h and takes no account of path design (i.e. in reality buildings will hinder pedestrians from taking the direct route which will increase the journey time). Where workers on the campus are contracted to specific shift hours, the scale of the site will likely diffuse the possible (on the hour) passenger surge demand as workers will have different walking journey times.

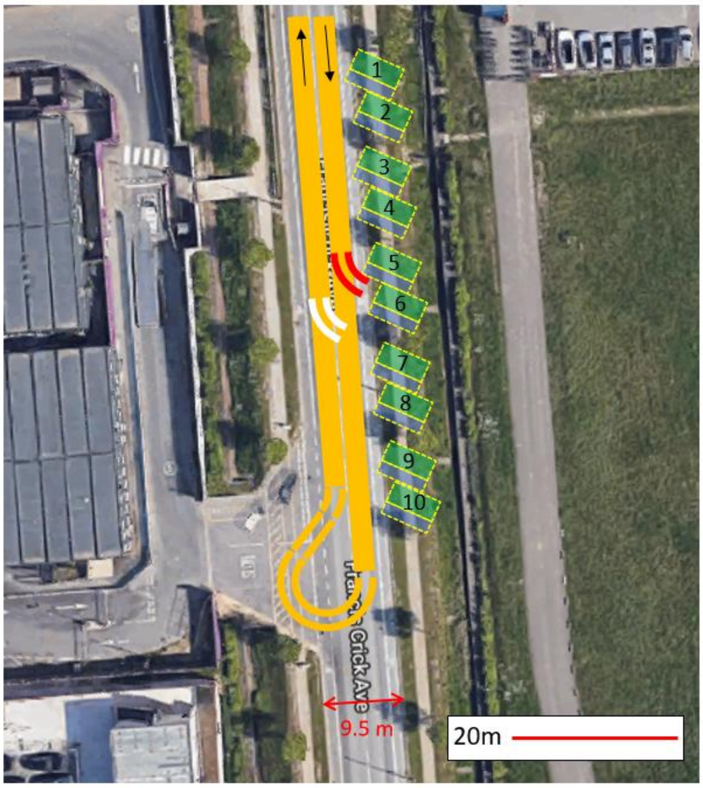
A2a. Parking Bay Design - CBC Busway Junction

If the autonomous vehicle is unable to operate on the public road at the CBC, parking bays will need to be constructed at the end of the existing busway. At the junction, the path to the side of the busway has sufficient space to allow four 6m by 2.6m parking bays with a shared 1.5m wide vehicle embarking and disembarking area. If the vehicle is bi-directional it can access the bays to either side of the busway without entering the public road. If the vehicle is not bi-directional there is sufficient room for turning if the turning circle is no more than 12m. Construction of the parking bays would however necessitate redesign of the existing pathway, including the repositioning of pedestrian signals.

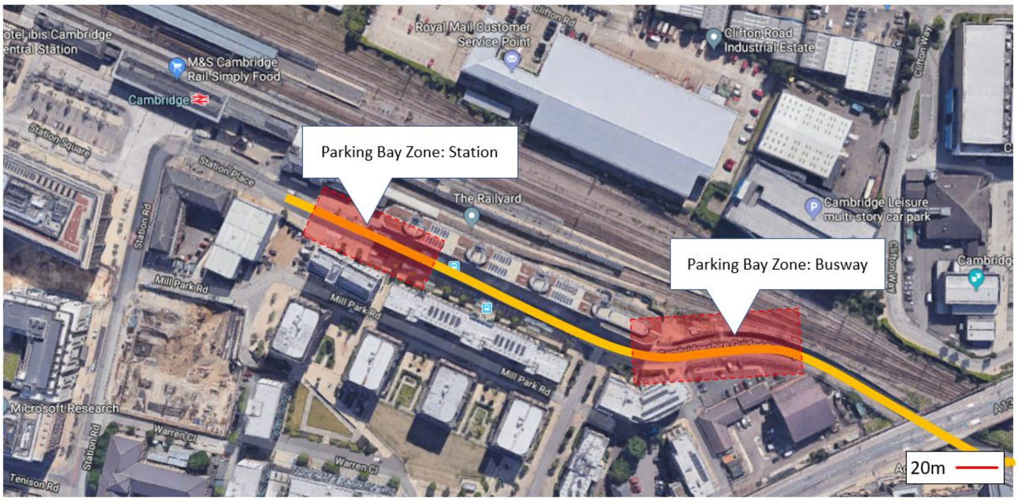


A2b. **Parking Bay Design - Cambridge Biomedical Campus (CBC)**

If the autonomous vehicle is able to operate on the public road the width of the verge area to the side of the existing road would be sufficient for parking bays and loading areas to be built. This design would ensure that parked vehicles do not block cycle lanes during operating hours. If the vehicles are bi-directional they can directly enter and exit the parking bays. If the vehicles cannot be driven both forwards and backwards, the vehicle would have to reverse out of the parking bay and either perform a 3-point-turn or the design must incorporate a turning loop (as shown in the figure).



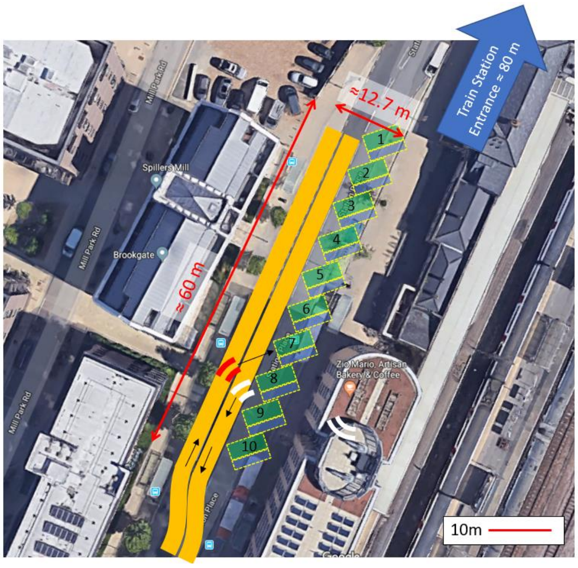
A3. Cambridge Train Station



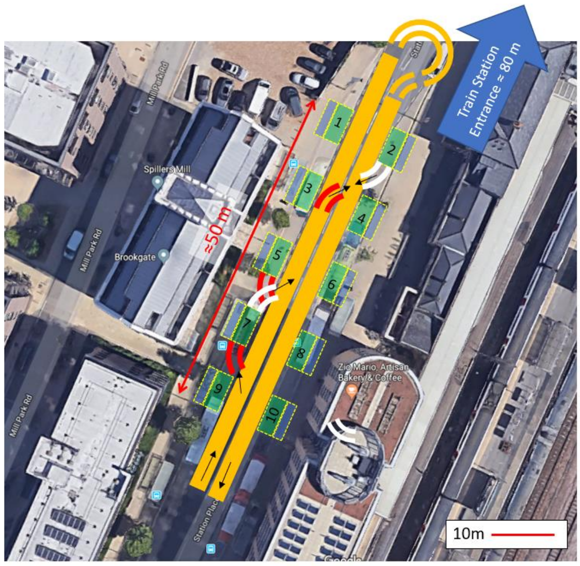
As noted with the CBC design, the final parking bay location is dependent on the ability of the vehicle to manoeuvre on public roads (e.g. Station Place) and the availability of the required space.

A3a. Cambridge Train Station

The width of Station Place (≈12.7 m) would allow angled parking bays with loading areas to be constructed on one side of the road (Figure a), with two lanes for the vehicles to enter and exit the parking zone. This design would be dependent on the road (Station Place) being closed to public traffic during the hours of autonomous vehicle operation (as the vehicles do not drive in the designated lanes in the parking zone). The design also requires the vehicles to have bi-directional drive. The vehicles would then able to enter and depart each of the bays without performing a turning manoeuvre.



a) Design for Bi-directional Vehicles



b) Turning Loop Design

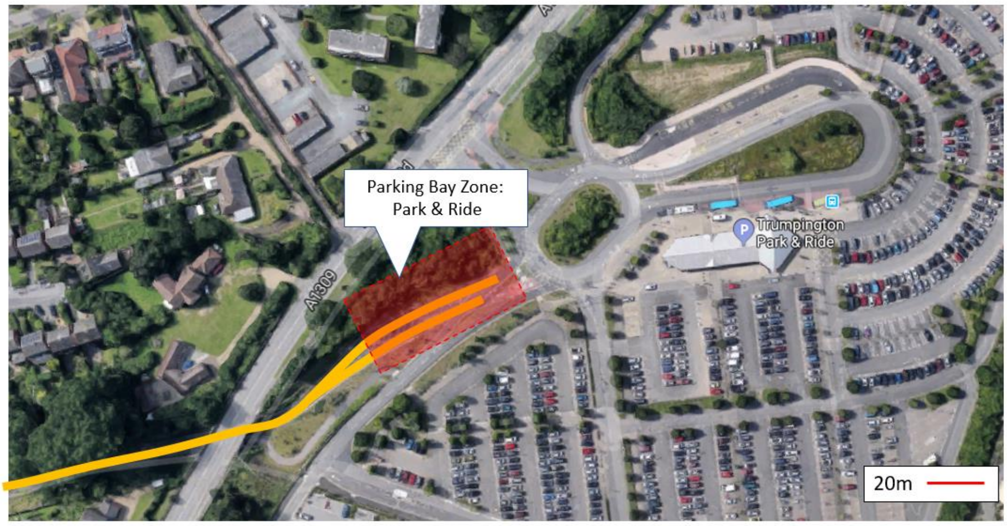
If Station Place cannot be closed to other modes of transport during the operating hours, the designated lanes could be used by siting the parking zones in the existing bus parking bays. Parking bays could be constructed on either one side of the road or both. Figure b shows a parking arrangement where both sides of the road have parking bays. Vehicles in this arrangement are able to depart forward out of each bay, obviating the requirement for the vehicles to be bi-directional. The vehicles would be able to return in the other direction using a turning loop.

A3b. **Cambridge Train Station Busway Zone**

Positioning the bays at the end of the busway would mean the autonomous vehicles would not need the capability to interact with other traffic on Station Place (primarily buses). The road at this location is potentially too narrow for both parking bays and two lanes. The available space narrows further towards busway (under Hills Road Bridge) preventing the addition of further parking bays. The problem of the narrow space could be alleviated by using a single access lane and traffic light to control vehicles entering the parking zone, although this would likely increase journey times. To minimise the area required for parking bays, this design means it would only be possible to exit each bay in one direction which would be determined by the bi-directional design of vehicle.

A4. **Trumpington Park and Ride**

The final location of the autonomous vehicle parking bays at the Trumpington Park and Ride is also dependent on the capability of the vehicles to manoeuvre on public roads, as the roundabout at the Park and Ride is used by public vehicles to access the parking areas.

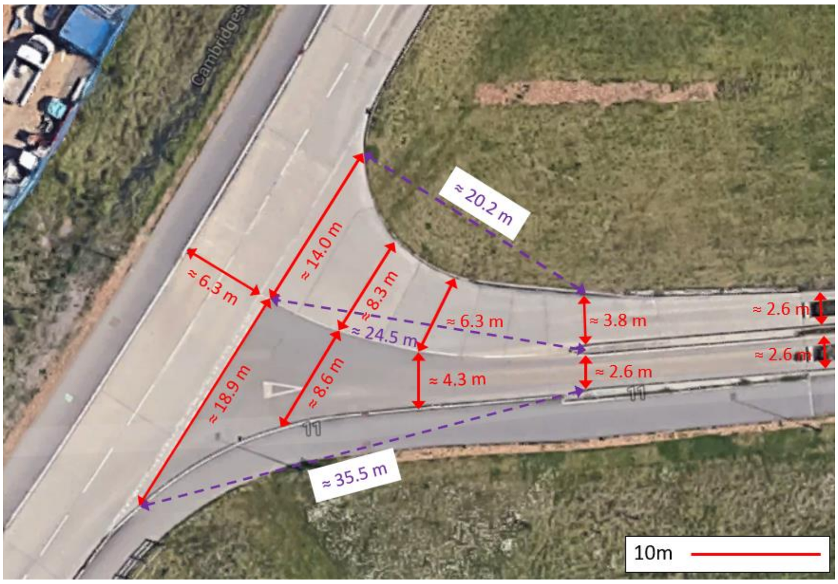


The width of the verge area to the side of the busway at the Park and Ride is sufficient for parking bays and loading areas to be built, although some significant landscaping may be required to adjust current banking and remove current vegetation.

Locating the parking bays before the roundabout would prevent the autonomous vehicles from having to travel on public roads. With this design, if the vehicles are bi-directional they can directly enter and exit the parking bays, without requiring turning manoeuvres.

A5. **Southern Busway Junction Hub**

The size of the tarmacked area at the junction on the southern busway offers the possibility to create a number of waiting bays. The creation of waiting bays would be of benefit to the network as vehicles parked at this point could quickly be deployed to the Train Station, CBC and P&R and add extra capacity to meet surge demand across the network. The figure below presents the dimensions of the Southern Busway Junction



As autonomous vehicles are capable of following a very precise path, the vehicles on the busway could be directed through the junction leaving a potential parking area of approximately 100m^2 (shaded red). Provided that it is permissible to redesign the pedestrian / cycle pathway at the junction, this area could accommodate 3 to 5 waiting bays.

3-Bay Design

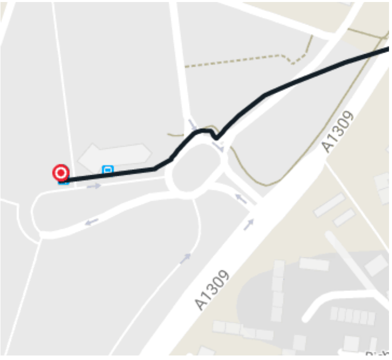
5-Bay Design

APPENDIX B – Journey Time Analysis

The following is an estimation of journey times, for an autonomous vehicle, between each of the nodes on the southern section of the Cambridgeshire Guided Busway.

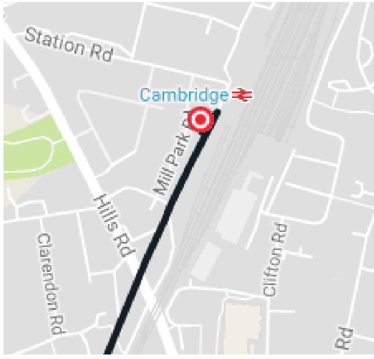
The journey time is calculated between existing stops on the busway which are currently served by Stagecoach Buses on Routes A and R. The stops are:

- Trumpington, The Busway Trumpington Park-and-Ride
- Addenbrooke's, Francis Crick Avenue (Cambridge Biomedical Campus)
- Cambridge, The Busway Railway Station (Stop 9)



Trumpington Park-and-Ride

Addenbrooke's / CBC



Railway Station (Stop 9)

To access each of these stops the current bus service leaves the guided busway and joins public roads. Depending on the capability of the autonomous vehicle to interact with traffic on public roads, the location of the stops for the Cambridge Autonomous Bus Service may be different to the stops on the existing Stagecoach bus service. The times calculated in this work therefore provide only an indicative journey time for the level of service analysis. Once the final position of the stops is determined a more accurate appraisal of journey times can be conducted and utilised to optimise the service.

B1. Journey Time Calculation Assumptions:

Vehicle Maximum Speed: 30 mph (48 km/h)
Average Acceleration: 0.8 m/s^2 *
Average Deceleration: 1.2 m/s^2 *
* The vehicle acceleration and deceleration values are derived from a real-world bus velocity dataset

B2. Journey Time Variation Trumpington P&R to the Cambridge Train Station

The distance from the P&R to the Station is the longest journey (leg) between two busway nodes. The difference between the respective P&R-Station and Station-P&R journey lengths is due to the location of the bus stops. The P&R stop is accessed by a one-way loop, whilst at the train station, an extra ≈150m loop was added into the Station-P&R journey, which the vehicle follows to return to the P&R.

Start	Destination	Distance (m)		Estimated Journey Time (m:ss)	Average Speed (km/h)
P&R	Station	3745	FAST	4:57	45.5
P&R	Station	3745	SLOW	6:43	33.5
Station	P&R	3975	FAST	5:40	42.1
Station	P&R	3975	SLOW	7:36	31.4

The variance between the fast and slow journey times is the result of different assumptions about delay times within the busway network. For the P&R to Station leg the possible points of delay are:

From	To	Delay Type	Stationary Delay Time (s)		Description
			Fast	Slow	
P&R	Station	Roundabout	0	5	Give way at P&R roundabout
		Traffic Light	0	45	P&R Busway single lane section - Traffic Light
		Station	0	20	Busway station
		Traffic Light	0	0	At grade junction with Hobson Avenue (Pod priority)
			0	70	Total Stationary Delay Time (s)
Station	P&R	Right Turn	1	5	Turning loop at Cambridge Station
		Left Turn	1	5	Turning loop at Cambridge Station
		Traffic Light	0	0	At grade junction with Hobson Avenue (Pod priority)
		Station	0	20	Busway station
		Traffic Light	0	45	P&R Busway single section - Traffic Light
		Roundabout	0	5	Give way at P&R roundabout
			2	80	Total Stationary Delay Time (s)

N.B. The delay time listed is only the stationary time. The remaining time difference between the slow and the fast time is the result of the vehicle breaking to / accelerating from a stationary position.

B3. Journey Time Variation Trumpington P&R to the Cambridge Biomedical Campus (CBC)

The P&R to CBC leg of the southern busway network has the shortest distance journey between two nodes. The primary difference in the P&R-CBC and CBC-P&R distance is use of the roundabout at the junction of Francis Crick Ave and Robinson Way as a turning loop for the vehicles, which adds ≈290m to the length of the CBC-P&R leg. The 80m difference at the P&R, between the inbound and outbound journey to/from the stop, on the one-way loop also increases the length CBC-P&R leg relative to the P&R-CBC leg.

Start	Destination	Distance (m)		Estimated Journey Time (m:ss)	Average Speed (km/h)
P&R	CBC	2155	FAST	3:41	35.2
P&R	CBC	2155	SLOW	5:47	22.4
CBC	P&R	2510	FAST	4:14	35.6
CBC	P&R	2510	SLOW	6:50	22.0

The variance between the fast and slow journey times is the result of different assumptions about delay times within the busway network. For the P&R to CBC leg the possible points of delay are:

From	To	Delay Type	Stationary Delay Time (s) Fast	Slow	Description
P&R	CBC	Roundabout	0	5	Give way at P&R roundabout
		Traffic Light	0	45	P&R Busway single Section - Traffic Light
		Station	0	20	Busway Station
		Traffic Light	0	0	At grade junction with Hobson Avenue (pod priority)
		Right Turn	1	20	Guided Busway central junction
		Traffic Light	1	15	CBC Traffic Lights - Busway exit to Francis Crick Ave
			2	105	Total Stationary Delay Time (s)
CBC	P&R	Roundabout	1	15	CBC turning loop
		Traffic Light	1	15	CBC Traffic Lights - Francis Crick Ave to Busway exit
		Left Turn	0	20	Guided Busway central junction
		Traffic Light	0	0	At grade junction with Hobson Avenue (pod priority)
		Station	0	20	Busway Station
		Traffic Light	0	45	P&R Busway single section - Traffic Light
		Roundabout	0	5	Give way at P&R Roundabout
			2	120	Total Stationary Delay Time (s)

B4. Journey Time Variation Cambridge Station to the Cambridge Biomedical Campus

As in Appendix B2 and B3, the difference in the length of the Station-CBC and CBC-Station legs relates to the length of the respective turning loops at the Station and at the CBC.

Start	Destination	Distance (m)		Estimated Journey Time (m:ss)	Average Speed (km/h)
Station	CBC	3030	FAST	4:59	36.5
Station	CBC	3030	SLOW	5:21	34.0
CBC	Station	3185	FAST	5:02	38.0
CBC	Station	3185	SLOW	5:49	32.8

The variance between the fast and slow journey times is the result of different assumptions about delay times within the busway network. For the P&R to CBC leg the possible points of delay are:

From	To	Delay Type	Stationary Delay Time (s) Fast	Slow	Description
Station	CBC	Right Turn	1	5	Turning Loop at Cambridge Station
		Left Turn	1	5	Turning Loop at Cambridge Station
		Traffic Light	1	15	CBC - Busway exit onto Francis Crick Ave
			3	25	Total Stationary Delay Time (s)
CBC	Station	Roundabout	1	15	CBC Turning Loop
		Traffic Light	1	15	CBC - Francis Crick Ave onto Busway
		Right Turn	1	20	Guided Busway Central Junction

	3	50	Total Stationary Delay Time (s)

B5. Journey Time Variation Busway Central Junction to Trumpington Park and Ride, Cambridge Station and the Cambridge Biomedical Campus.

The junction at the centre of the southern busway (Appendix A5) is wide enough that it may be able to accommodate a parking bay area for a number of vehicles. The benefit of centrally located parking bays within the network is that pods can quickly be called to any of the nodes in the network and as such can be utilized to meet surge demands at any point in the network.

Location of Junction Hub

Proposal for 3-Bay Parking Area at the Junction

The following table shows the calculated journey times from the junction parking area to each of the node stops. Each of the times includes a ≈15s allowance for the vehicles to leave the parking bay. At each location a vehicle from the Junction hub could be summoned and depart within 5 minutes.

Start	Destination	Distance (m)		Estimated Journey Time (m:ss)	Average Speed (km/h)
Junction	P&R	1635	FAST	2:31	25.5
Junction	P&R	1635	SLOW	3:47	20.7
Junction	Station	2315	FAST	3:19	41.9
Junction	Station	2315	SLOW	3:29	39.9
Junction	CBC	735	FAST	1:44	38.9
Junction	CBC	735	SLOW	2:08	25.9

The variance between the fast and slow journey times is the result of different assumptions about delay times within the busway network.

The Junction – Station leg, is the longest, however the only source of delay is the possibility of having to give way to vehicles already on the bus way as the vehicle joins the network.

The Junction – P&R leg has the greatest potential delay however the traffic light which controls entry to the 550m section of single busway could potential be programmed to give priority to vehicles from the junction hub, in order to meet surge demand criteria.

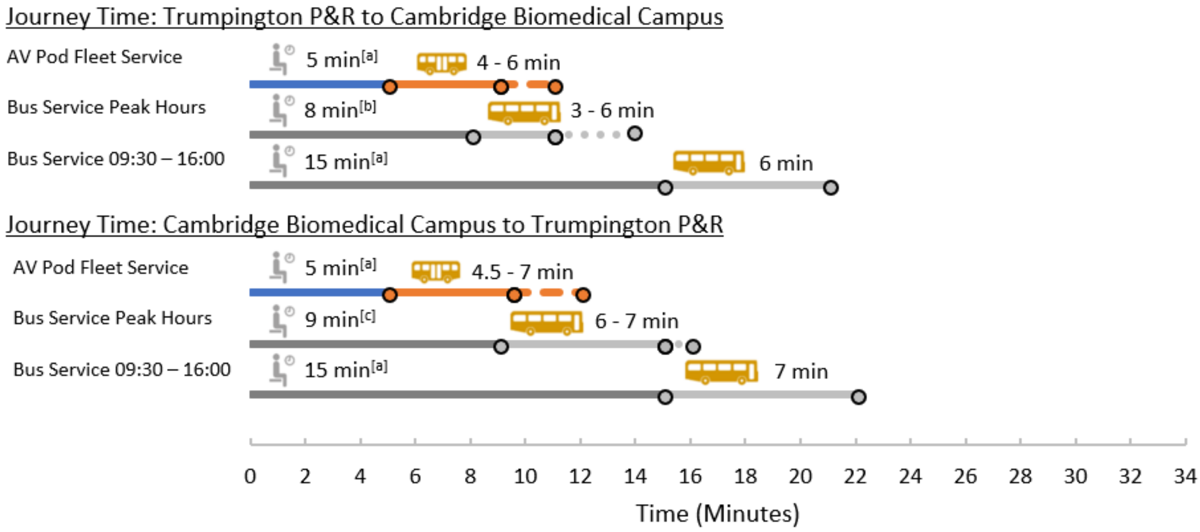
The possible points of delay for the Junction – P&R, Junction – Station, Junction – CBC legs are shown below.

From	To	Delay Type	Stationary Delay Time (s) Fast	Stationary Delay Time (s) Slow	Description
Junction	P&R	Left Turn	0	10	Turn onto Busway at Junction Hub
		Traffic Light	0	0	At grade junction with Hobson Avenue (Pod priority)
		Station	0	0	Busway station (assumed does not stop from Junction Hub)
		Traffic Light	0	45	P&R Busway single section - Traffic Light
		Roundabout	0	5	Give way at P&R roundabout
			0	60	Total Stationary Delay Time (s)
Junction	Station	Right Turn	0	10	Turn onto Busway at Junction Hub
			0	10	Total Stationary Delay Time (s)
Junction	CBC	Right Turn	0	10	Turn onto Busway at Junction Hub
		Traffic Light	1	15	CBC - Busway exit onto Francis Crick Ave
			1	25	Total Stationary Delay Time (s)

APPENDIX C – Level of Service Comparison AV Pods vs Current Bus Fleet

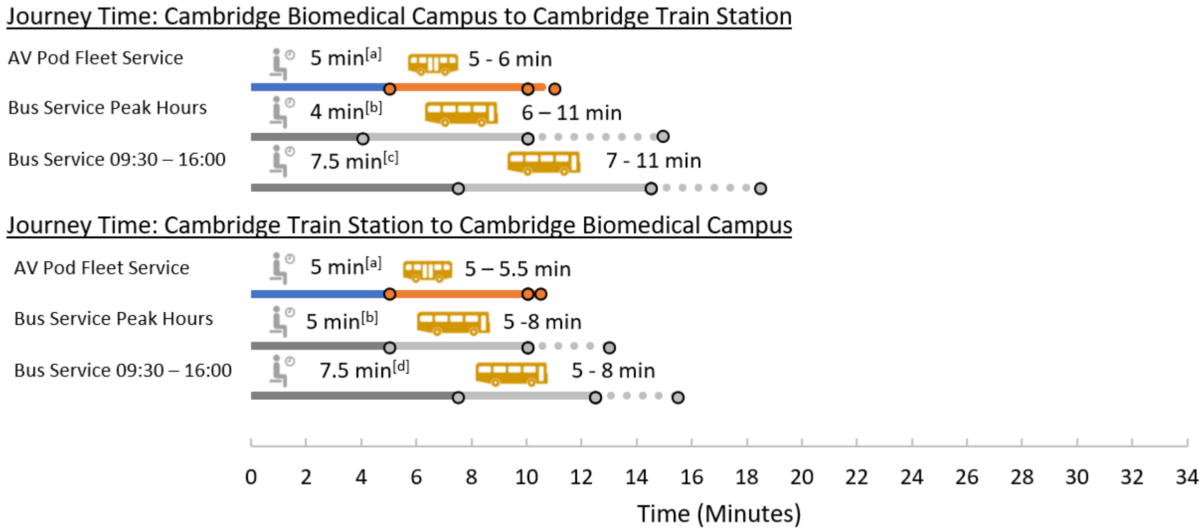
The following is a representation of the level of service (total passenger journey time) on the southern section of the Cambridgeshire Guided Busway, comparing the existing bus service to the service which could be offered by an AV pod fleet. Description of the current bus service is provided on pages 3 and 4 of this report. It should be noted that whilst the Route R bus service serves the same bus stop in the CBC (Francis Crick Avenue) employed in the AV journey time analysis, the Route A and Route U services do not follow the same path, and the journey times for these routes are calculated (from the timetables) to and from the Addenbrooke's Outpatients Stop and Cambridge Biomedical Campus Rosie Hospital Stop respectively. The journey times on the Route A and Route U services are therefore slightly longer than would be the case if they followed the same path as used by the Route R service.

C1. Level of Service between the Trumpington Park & Ride and Cambridge Biomedical Campus



[a] Maximum 'wait time' (defined as the interval between consecutive vehicle departures). Vehicle departure is at regular intervals.
[b] Median wait time as bus departure times are at irregular intervals. Wait times are between 7 - 30 mins in this period.
[c] Median wait time as bus departure times are at irregular intervals. Wait times are between 2 - 30 mins in this period.

C2. Level of Service between the Cambridge Train Station and Cambridge Biomedical Campus



[a] Maximum wait time. Vehicle departure is at regular intervals.
[b] Median wait time as bus departure times are at irregular intervals. Wait times are between 1 - 30 mins in this period.
[c] Median wait time as bus departure times are at irregular intervals. Wait times are between 5 - 10 mins in this period.
[d] Median wait time as bus departure times are at irregular intervals. Wait times are between 4 - 11 mins in this period.

APPENDIX D – Passenger Demand Analysis

D1. Weekday Night Passenger Demand Analysis

To calculate an estimate of the hourly passenger demand for each node to node leg, the Arup demand calculations for each time period were used. The Arup passenger demand values for each time period were multiplied by an estimate of the hourly passenger trip journey distribution over the time period, to give an estimate of the passenger demand in each hour. This hourly estimate was then multiplied by an estimate of the split of those single journeys to each of the possible destination nodes. For example, in the Weekday Night example below, it is assumed the passengers are equally likely to want to go to the station and the CBC from the P&R .

ARUP – Demand Calculations from the Feasibility Study

LOCATION	POPULATION	Weekday	Weekday Night	Weekend Night	Sunday
		6:00 - 21:00	21:00 - 6:00	21:00 - 6:00	6:00 - 00:00
Southern Fringe (Residential)	9053	103	10	21	52
Cambridge Station	10267	1495	150	217	500
Trumpington Park & Ride	876	4437	553	380	858
Addenbrooke's CBC	18638	2839	393	142	306
TOTALS		8874	1106	760	1716
TOTALS (Excluding the fringe)		8771	1096	739	1664

Estimate of Hourly Passenger Demand (P&R to CBC and Station – WEEKDAY NIGHT)

Number of Passengers Per Hour

			Single Journeys	Estimate		Estimate	
			553				
		Dist	P&R	to CBC		to STATION	
21:00	22:00	25%	138	69	50%	69	50%
22:00	23:00	20%	111	55	50%	55	50%
23:00	00:00	10%	55	28	50%	28	50%
00:00	01:00	5%	28	14	50%	14	50%
01:00	02:00	3%	17	8	50%	8	50%
02:00	03:00	3%	17	8	50%	8	50%
03:00	04:00	3%	17	8	50%	8	50%
04:00	05:00	6%	33	17	50%	17	50%
05:00	06:00	25%	138	69	50%	69	50%
		100%	TRUE	277		277	
		MAX	138	69		69	

Estimate of hourly journey distribution

Estimate of the % split to each destination

The figure below presents estimates of the hourly passenger demand from each of the three nodes.

Estimate of Hourly Passenger Demand - WEEKDAY NIGHT

Arup demand forecast

Number of Passengers Per Hour

			Single Journeys	Estimate		Estimate	
			553				
		Dist	P&R	to CBC		to STATION	
21:00	22:00	25%	138	69	50%	69	50%
22:00	23:00	20%	111	55	50%	55	50%
23:00	00:00	10%	55	28	50%	28	50%
00:00	01:00	5%	28	14	50%	14	50%
01:00	02:00	3%	17	8	50%	8	50%
02:00	03:00	3%	17	8	50%	8	50%
03:00	04:00	3%	17	8	50%	8	50%
04:00	05:00	6%	33	17	50%	17	50%
05:00	06:00	25%	138	69	50%	69	50%
		100%	TRUE	277		277	
		MAX	138	69		69	

			Single Journeys	Estimate		Estimate	
			393				
		Dist	CBC	to P&R		to STATION	
21:00	22:00	25%	98	84	85%	15	15%
22:00	23:00	20%	79	67	85%	12	15%
23:00	00:00	15%	59	53	90%	6	10%
00:00	01:00	5%	20	20	100%	0	0%
01:00	02:00	5%	20	20	100%	0	0%
02:00	03:00	5%	20	20	100%	0	0%
03:00	04:00	5%	20	20	100%	0	0%
04:00	05:00	5%	20	18	90%	2	10%
05:00	06:00	15%	59	53	90%	6	10%
		100%	TRUE	353		40	
			98	84		15	

			Single Journeys	Estimate		Estimate			
			150						
		Dist	STATION	to CBC		to P&R		TOTAL	
21:00	22:00	30%	45	4	10%	40	90%	281	passengers / hour
22:00	23:00	30%	45	4	10%	40	90%	234	passengers / hour
23:00	00:00	21%	32	3	10%	29	90%	146	passengers / hour
00:00	01:00	13%	19	2	10%	17	90%	66	passengers / hour
01:00	02:00	2%	3	0	10%	3	90%	39	passengers / hour
02:00	03:00	0%	0	0	10%	0	90%	36	passengers / hour
03:00	04:00	0%	0	0	10%	0	90%	36	passengers / hour
04:00	05:00	0%	0	0	90%	0	10%	53	passengers / hour
05:00	06:00	4%	6	6	90%	1	10%	204	passengers / hour
		100%	TRUE	20		130			
			45	6		40			

Estimate of maximum hourly passenger demand P&R to CBC during a weekday night

Hourly Passenger Demand in the Network

To estimate the 5-minute passenger demand the hourly figure was divided by 12.

Estimate of Passenger Demand per 5 Minutes - WEEKDAY NIGHT

Average number of passengers every 5 minutes

Number of passengers every 5 minute interval

			553						393						150				
			P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
21:00	22:00		138	5.8	/ 5 min	5.8	/ 5 min		98	7.0	/ 5 min	1.2	/ 5 min		45	0.4	/ 5 min	3.4	/ 5 min
22:00	23:00		111	4.6	/ 5 min	4.6	/ 5 min		79	5.6	/ 5 min	1.0	/ 5 min		45	0.4	/ 5 min	3.4	/ 5 min
23:00	00:00		55	2.3	/ 5 min	2.3	/ 5 min		59	4.4	/ 5 min	0.5	/ 5 min		32	0.3	/ 5 min	2.4	/ 5 min
00:00	01:00		28	1.2	/ 5 min	1.2	/ 5 min		20	1.6	/ 5 min	0.0	/ 5 min		19	0.2	/ 5 min	1.4	/ 5 min
01:00	02:00		17	0.7	/ 5 min	0.7	/ 5 min		20	1.6	/ 5 min	0.0	/ 5 min		3	0.0	/ 5 min	0.2	/ 5 min
02:00	03:00		17	0.7	/ 5 min	0.7	/ 5 min		20	1.6	/ 5 min	0.0	/ 5 min		0	0.0	/ 5 min	0.0	/ 5 min
03:00	04:00		17	0.7	/ 5 min	0.7	/ 5 min		20	1.6	/ 5 min	0.0	/ 5 min		0	0.0	/ 5 min	0.0	/ 5 min
04:00	05:00		33	1.4	/ 5 min	1.4	/ 5 min		20	1.5	/ 5 min	0.2	/ 5 min		0	0.0	/ 5 min	0.0	/ 5 min
05:00	06:00		138	5.8	/ 5 min	5.8	/ 5 min		59	4.4	/ 5 min	0.5	/ 5 min		6	0.5	/ 5 min	0.1	/ 5 min

To estimate the required number of AV pods to meet the average 5-minute passenger demand, the 5-minute demand value was divided by the number of seats (10 or 15) and rounded up to the nearest integer value.

Number of 10-seat pods required per 5 minutes - WEEKDAY NIGHT

Estimate of number of pods required to transport the average number of passengers every 5 minutes

Number of 10 seater vehicles every 5 minute interval

10 Seats

			553						393						150				
			P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
21:00	22:00		138	1	/ 5 min	1	/ 5 min		98	1	/ 5 min	1	/ 5 min		45	1	/ 5 min	1	/ 5 min
22:00	23:00		111	1	/ 5 min	1	/ 5 min		79	1	/ 5 min	1	/ 5 min		45	1	/ 5 min	1	/ 5 min
23:00	00:00		55	1	/ 5 min	1	/ 5 min		59	1	/ 5 min	1	/ 5 min		32	1	/ 5 min	1	/ 5 min
00:00	01:00		28	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	0	/ 5 min		19	1	/ 5 min	1	/ 5 min
01:00	02:00		17	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	0	/ 5 min		3	1	/ 5 min	1	/ 5 min
02:00	03:00		17	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	0	/ 5 min		0	0	/ 5 min	0	/ 5 min
03:00	04:00		17	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	0	/ 5 min		0	0	/ 5 min	0	/ 5 min
04:00	05:00		33	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	1	/ 5 min		0	0	/ 5 min	0	/ 5 min
05:00	06:00		138	1	/ 5 min	1	/ 5 min		59	1	/ 5 min	1	/ 5 min		6	1	/ 5 min	1	/ 5 min

Number of 15-seat pods required per 5 minutes - WEEKDAY NIGHT

Number of 15 seater vehicles every 5 minute interval

15 Seats

			553						393						150				
			P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
21:00	22:00		138	1	/ 5 min	1	/ 5 min		98	1	/ 5 min	1	/ 5 min		45	1	/ 5 min	1	/ 5 min
22:00	23:00		111	1	/ 5 min	1	/ 5 min		79	1	/ 5 min	1	/ 5 min		45	1	/ 5 min	1	/ 5 min
23:00	00:00		55	1	/ 5 min	1	/ 5 min		59	1	/ 5 min	1	/ 5 min		32	1	/ 5 min	1	/ 5 min
00:00	01:00		28	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	0	/ 5 min		19	1	/ 5 min	1	/ 5 min
01:00	02:00		17	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	0	/ 5 min		3	1	/ 5 min	1	/ 5 min
02:00	03:00		17	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	0	/ 5 min		0	0	/ 5 min	0	/ 5 min
03:00	04:00		17	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	0	/ 5 min		0	0	/ 5 min	0	/ 5 min
04:00	05:00		33	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	1	/ 5 min		0	0	/ 5 min	0	/ 5 min
05:00	06:00		138	1	/ 5 min	1	/ 5 min		59	1	/ 5 min	1	/ 5 min		6	1	/ 5 min	1	/ 5 min

For the Weekday Night, this analysis suggests that one pod per departure node for each destination node is sufficient to meet the maximum 5-minute passenger demand over the time period (both for 10 and 15-seat pods). Therefore, for each departure node (P&R, CBC and Station) two pods depart every 5-minutes, one to each of the two possible destination nodes.

When a pod departs a node, it takes 10 minutes (the total of journey time plus alighting, boarding and wait time), before the pod can again depart a node (see 20-minute schedule page 3). Therefore, in order to run a 5-minute schedule continuously, it is necessary to have four pods at each node, two for each destination, setting off at 5-minute intervals (see next figure). As four pods are required at each of the three departure points, a fleet of 12 pods is required to meet the Weekday Night passenger demand, this is irrespective of whether they are 10- or 15-seat AVs.

The below figure presents an operational diagram describing the movement of pods in the network for a 12 pod fleet:

Operation Diagram - Network Capacity with 10-seat pods - WEEKDAY NIGHT

Pod #1 departs the P&R for the Station at 00:00 – it travels to the Station – the passengers alight – and new passengers board – and it then departs the Station to return to the P&R at 00:10, from where the cycle continues

Departure time

10 Seats | Colour = Starting Destination | 12 Pod Service

Departure Point and Destination

	P&R - S	S - P&R	P&R - CBC	CBC - P&R	CBC - S	S - CBC
0	1	5	3	9	11	7
5	2	6	4	10	12	8
10	5	1	9	3	7	11
15	6	2	10	4	8	12
20	1	5	3	9	11	7
25	2	6	4	10	12	8
30	5	1	9	3	7	11
35	6	2	10	4	8	12
40	1	5	3	9	11	7
45	2	6	4	10	12	8
50	5	1	9	3	7	11
55	6	2	10	4	8	12
	120	120	120	120	120	120

Total Network Capacity passengers / hour

	Capacity Passengers per hour
720	Network Total Capacity Passengers per hour
40	Capacity at Station (Passengers per 10 minutes) for both destinations
15	Pod Service (3 Pods at Junction waiting Area)
70	10 minute Surge Demand Capacity at Station

Capacity (passengers / hour) for each leg in the network

Surge demand capacity at each departure point

Surge demand capacity at each departure point with extra pods from the junction waiting bays

Increasing the size of the AV from 10 to 15-seats, increases the passenger capacity per hour for each of the node to node legs from 120 passengers per hour to 180 passengers per hour, and increases the total busway network capacity from 720 to 1080 passengers per hour, for the 12-pod service.

Operation Diagram - Network Capacity with 15-seat pods - WEEKDAY NIGHT

15 Seats | 12 Pod Service

	P&R - S	S - P&R	P&R - CBC	CBC - P&R	CBC - S	S -CBC
0	1	5	3	9	11	7
5	2	6	4	10	12	8
10	5	1	9	3	7	11
15	6	2	10	4	8	12
20	1	5	3	9	11	7
25	2	6	4	10	12	8
30	5	1	9	3	7	11
35	6	2	10	4	8	12
40	1	5	3	9	11	7
45	2	6	4	10	12	8
50	5	1	9	3	7	11
55	6	2	10	4	8	12
	180	180	180	180	180	180

	Capacity Passengers per hour
1080	Total Capacity Passengers per hour
60	Capacity at Station (Passengers per 10 minutes) for both destinations
15	Pod Service (3 Pods at Junction waiting Area)
105	10 minute Surge Demand Capacity at Station

Increased pod seating (to 15 seats from 10) = increase in network capacity

To evaluate the estimated occupancy of the pods the estimated passenger demand was compared to the capacity of the network with 10- and 15-seat AVs.

Estimate of Pod Occupancy (12 Pod Fleet) - WEEKDAY NIGHT

		553						393						150				
		P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
21:00	22:00	138	5.8	/ 5 min	5.8	/ 5 min		98	7.0	/ 5 min	1.2	/ 5 min		45	0.4	/ 5 min	3.4	/ 5 min
22:00	23:00	111	4.6	/ 5 min	4.6	/ 5 min		79	5.6	/ 5 min	1.0	/ 5 min		45	0.4	/ 5 min	3.4	/ 5 min
23:00	00:00	55	2.3	/ 5 min	2.3	/ 5 min		59	4.4	/ 5 min	0.5	/ 5 min		32	0.3	/ 5 min	2.4	/ 5 min
00:00	01:00	28	1.2	/ 5 min	1.2	/ 5 min		20	1.6	/ 5 min	0.0	/ 5 min		19	0.2	/ 5 min	1.4	/ 5 min
01:00	02:00	17	0.7	/ 5 min	0.7	/ 5 min		20	1.6	/ 5 min	0.0	/ 5 min		3	0.0	/ 5 min	0.2	/ 5 min
02:00	03:00	17	0.7	/ 5 min	0.7	/ 5 min		20	1.6	/ 5 min	0.0	/ 5 min		0	0.0	/ 5 min	0.0	/ 5 min
03:00	04:00	17	0.7	/ 5 min	0.7	/ 5 min		20	1.6	/ 5 min	0.0	/ 5 min		0	0.0	/ 5 min	0.0	/ 5 min
04:00	05:00	33	1.4	/ 5 min	1.4	/ 5 min		20	1.5	/ 5 min	0.2	/ 5 min		0	0.0	/ 5 min	0.0	/ 5 min
05:00	06:00	138	5.8	/ 5 min	5.8	/ 5 min		59	4.4	/ 5 min	0.5	/ 5 min		6	0.5	/ 5 min	0.1	/ 5 min

Occupancy 10-Seat

		P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
	Dist	Passengers	10 Seat	15 Seat	10 Seat	15 Seat	Dist	Passengers	10 Seat	15 Seat	10 Seat	15 Seat	Dist	Passengers	10 Seat	15 Seat	10 Seat	15 Seat
	25%	138	57.6%	38.4%	57.6%	38.4%	25%	98	69.6%	46.4%	12.3%	8.2%	30%	45	3.7%	2.5%	33.5%	22.3%
	20%	111	46.1%	30.7%	46.1%	30.7%	20%	79	55.7%	37.1%	9.8%	6.6%	30%	45	3.7%	2.5%	33.5%	22.3%
	10%	55	23.0%	15.4%	23.0%	15.4%	15%	59	44.2%	29.5%	4.9%	3.3%	21%	32	2.7%	1.8%	23.9%	16.0%
	5%	28	11.5%	7.7%	11.5%	7.7%	5%	20	16.4%	10.9%	0.0%	0.0%	13%	19	1.6%	1.1%	14.4%	9.6%
	3%	17	6.9%	4.6%	6.9%	4.6%	5%	20	16.4%	10.9%	0.0%	0.0%	2%	3	0.3%	0.2%	2.4%	1.6%
	3%	17	6.9%	4.6%	6.9%	4.6%	5%	20	16.4%	10.9%	0.0%	0.0%	0%	0	0.0%	0.0%	0.0%	0.0%
	3%	17	6.9%	4.6%	6.9%	4.6%	5%	20	16.4%	10.9%	0.0%	0.0%	0%	0	0.0%	0.0%	0.0%	0.0%
	6%	33	13.8%	9.2%	13.8%	9.2%	5%	20	14.7%	9.8%	1.6%	1.1%	0%	0	0.0%	0.0%	0.0%	0.0%
	25%	138	57.6%	38.4%	57.6%	38.4%	15%	59	44.2%	29.5%	4.9%	3.3%	4%	6	4.8%	3.2%	0.5%	0.4%
		MAX % OCCUPANCY	57.6%	38.4%	57.6%	38.4%		MAX	69.6%	46.4%	12.3%	8.2%		MAX	4.8%	3.2%	33.5%	22.3%
		FACTOR INCREASE TO NECESSITATE A FURTHER POD	**1.7**	**2.6**	**1.7**	**2.6**			**1.4**	**2.2**	**8.1**	**12.2**			**20.9**	**31.3**	**3.0**	**4.5**

Factor by which the estimated passenger demand could increase before a further pod would be required to meet the maximum hourly passenger demand.

For the Weekday Night this analysis reveals that for a 15-seat AV the Arup estimated passenger demand could double without the need for a further pod. The capacity of the network with twelve 15-seat pods is significantly greater than the expected passenger demand.

D2. Weekend (Saturday) Night Passenger Demand Analysis

The same analysis was undertaken for each of the defined time periods.

Estimate of Hourly Passenger Demand - WEEKEND NIGHT

			Single Journeys		Estimate		Estimate		Single Journeys		Estimate		Estimate		Single Journeys		Estimate		Estimate		
			380						142						217						
		Dist	P&R	to CBC		to STATION		Dist	CBC	to P&R		to STATION		Dist	STATION	to CBC		to P&R		TOTAL	
21:00	22:00	25%	95	48	50%	48	50%	25%	36	30	85%	5	15%	30%	65	6	10%	58	90%	195	passengers / hour
22:00	23:00	20%	76	38	50%	38	50%	20%	28	24	85%	4	15%	30%	65	6	10%	58	90%	169	passengers / hour
23:00	0:00	10%	38	19	50%	19	50%	15%	21	19	90%	2	10%	21%	46	5	10%	42	90%	105	passengers / hour
0:00	1:00	5%	19	10	50%	10	50%	5%	7	7	100%	0	0%	13%	28	3	10%	25	90%	54	passengers / hour
1:00	2:00	3%	11	6	50%	6	50%	5%	7	7	100%	0	0%	2%	5	0	10%	4	90%	23	passengers / hour
2:00	3:00	3%	11	6	50%	6	50%	5%	7	7	100%	0	0%	0%	0	0	10%	0	90%	19	passengers / hour
3:00	4:00	3%	11	6	50%	6	50%	5%	7	7	100%	0	0%	0%	0	0	10%	0	90%	19	passengers / hour
4:00	5:00	6%	23	11	50%	11	50%	5%	7	6	90%	1	10%	0%	0	0	90%	0	10%	30	passengers / hour
5:00	6:00	25%	95	48	50%	48	50%	15%	21	19	90%	2	10%	4%	9	8	90%	1	10%	126	passengers / hour
		100%	TRUE	190		190		100%	TRUE	127		15		100%	TRUE	29		188			
		MAX	95	48		48			36	30		5			65	8		58			

Once again, the Arup passenger demand value over the time period, for each node (P&R, CBC and Station) was multiplied by an estimate of the passenger trip journey distribution over each of the hours in the time period. This hourly estimate of passenger demand was then multiplied by an estimate of the split of those single journeys to each of the possible destination nodes.

Each of the average 5-minute passenger demand values calculated for the Weekend Night are less than the capacity of one 10-seat pod.

Estimate of Passenger Demand per 5 minutes - WEEKEND NIGHT

Number of passengers every 5 minute interval																			
			380						142						217				
			P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
21:00	22:00		95	4.0	/ 5 min	4.0	/ 5 min		36	2.5	/ 5 min	0.4	/ 5 min		65	0.5	/ 5 min	4.8	/ 5 min
22:00	23:00		76	3.2	/ 5 min	3.2	/ 5 min		28	2.0	/ 5 min	0.4	/ 5 min		65	0.5	/ 5 min	4.8	/ 5 min
23:00	0:00		38	1.6	/ 5 min	1.6	/ 5 min		21	1.6	/ 5 min	0.2	/ 5 min		46	0.4	/ 5 min	3.5	/ 5 min
0:00	1:00		19	0.8	/ 5 min	0.8	/ 5 min		7	0.6	/ 5 min	0.0	/ 5 min		28	0.2	/ 5 min	2.1	/ 5 min
1:00	2:00		11	0.5	/ 5 min	0.5	/ 5 min		7	0.6	/ 5 min	0.0	/ 5 min		5	0.0	/ 5 min	0.3	/ 5 min
2:00	3:00		11	0.5	/ 5 min	0.5	/ 5 min		7	0.6	/ 5 min	0.0	/ 5 min		0	0.0	/ 5 min	0.0	/ 5 min
3:00	4:00		11	0.5	/ 5 min	0.5	/ 5 min		7	0.6	/ 5 min	0.0	/ 5 min		0	0.0	/ 5 min	0.0	/ 5 min
4:00	5:00		23	1.0	/ 5 min	1.0	/ 5 min		7	0.5	/ 5 min	0.1	/ 5 min		0	0.0	/ 5 min	0.0	/ 5 min
5:00	6:00		95	4.0	/ 5 min	4.0	/ 5 min		21	1.6	/ 5 min	0.2	/ 5 min		9	0.7	/ 5 min	0.1	/ 5 min

Number of 10-seat pods required per 5 minutes - WEEKEND NIGHT

Number of 10 seater vehicles every 5 minute interval																			
10	Seats																		
			380						142						217				
			P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
21:00	22:00		95	1	/ 5 min	1	/ 5 min		36	1	/ 5 min	1	/ 5 min		65	1	/ 5 min	1	/ 5 min
22:00	23:00		76	1	/ 5 min	1	/ 5 min		28	1	/ 5 min	1	/ 5 min		65	1	/ 5 min	1	/ 5 min
23:00	0:00		38	1	/ 5 min	1	/ 5 min		21	1	/ 5 min	1	/ 5 min		46	1	/ 5 min	1	/ 5 min
0:00	1:00		19	1	/ 5 min	1	/ 5 min		7	1	/ 5 min	0	/ 5 min		28	1	/ 5 min	1	/ 5 min
1:00	2:00		11	1	/ 5 min	1	/ 5 min		7	1	/ 5 min	0	/ 5 min		5	1	/ 5 min	1	/ 5 min
2:00	3:00		11	1	/ 5 min	1	/ 5 min		7	1	/ 5 min	0	/ 5 min		0	0	/ 5 min	0	/ 5 min
3:00	4:00		11	1	/ 5 min	1	/ 5 min		7	1	/ 5 min	0	/ 5 min		0	0	/ 5 min	0	/ 5 min
4:00	5:00		23	1	/ 5 min	1	/ 5 min		7	1	/ 5 min	1	/ 5 min		0	0	/ 5 min	0	/ 5 min
5:00	6:00		95	1	/ 5 min	1	/ 5 min		21	1	/ 5 min	1	/ 5 min		9	1	/ 5 min	1	/ 5 min

Number of 15-seat pods required per 5 minutes - WEEKEND NIGHT

Number of 15 seater vehicles every 5 minute interval																			
15	Seats																		
			380						142						217				
			P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
21:00	22:00		95	1	/ 5 min	1	/ 5 min		36	1	/ 5 min	1	/ 5 min		65	1	/ 5 min	1	/ 5 min
22:00	23:00		76	1	/ 5 min	1	/ 5 min		28	1	/ 5 min	1	/ 5 min		65	1	/ 5 min	1	/ 5 min
23:00	0:00		38	1	/ 5 min	1	/ 5 min		21	1	/ 5 min	1	/ 5 min		46	1	/ 5 min	1	/ 5 min
0:00	1:00		19	1	/ 5 min	1	/ 5 min		7	1	/ 5 min	0	/ 5 min		28	1	/ 5 min	1	/ 5 min
1:00	2:00		11	1	/ 5 min	1	/ 5 min		7	1	/ 5 min	0	/ 5 min		5	1	/ 5 min	1	/ 5 min
2:00	3:00		11	1	/ 5 min	1	/ 5 min		7	1	/ 5 min	0	/ 5 min		0	0	/ 5 min	0	/ 5 min
3:00	4:00		11	1	/ 5 min	1	/ 5 min		7	1	/ 5 min	0	/ 5 min		0	0	/ 5 min	0	/ 5 min
4:00	5:00		23	1	/ 5 min	1	/ 5 min		7	1	/ 5 min	1	/ 5 min		0	0	/ 5 min	0	/ 5 min
5:00	6:00		95	1	/ 5 min	1	/ 5 min		21	1	/ 5 min	1	/ 5 min		9	1	/ 5 min	1	/ 5 min

Like the Weekday Night, this analysis of the Weekend Night passenger demand suggests that one pod per departure node for each destination node is sufficient to meet the maximum 5-minute passenger demand over the time period (both for 10- and 15-seat pods). A fleet of 12 pods is therefore sufficient to meet the expected weekend night passenger demand.

Estimate of Pod Occupancy (12 Pod Fleet) - WEEKEND NIGHT

		380						142						217				
		P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
21:00	22:00	95	4.0	/ 5 min	4.0	/ 5 min		36	2.5	/ 5 min	0.4	/ 5 min		65	0.5	/ 5 min	4.8	/ 5 min
22:00	23:00	76	3.2	/ 5 min	3.2	/ 5 min		28	2.0	/ 5 min	0.4	/ 5 min		65	0.5	/ 5 min	4.8	/ 5 min
23:00	00:00	38	1.6	/ 5 min	1.6	/ 5 min		21	1.6	/ 5 min	0.2	/ 5 min		46	0.4	/ 5 min	3.5	/ 5 min
00:00	01:00	19	0.8	/ 5 min	0.8	/ 5 min		7	0.6	/ 5 min	0.0	/ 5 min		28	0.2	/ 5 min	2.1	/ 5 min
01:00	02:00	11	0.5	/ 5 min	0.5	/ 5 min		7	0.6	/ 5 min	0.0	/ 5 min		5	0.0	/ 5 min	0.3	/ 5 min
02:00	03:00	11	0.5	/ 5 min	0.5	/ 5 min		7	0.6	/ 5 min	0.0	/ 5 min		0	0.0	/ 5 min	0.0	/ 5 min
03:00	04:00	11	0.5	/ 5 min	0.5	/ 5 min		7	0.6	/ 5 min	0.0	/ 5 min		0	0.0	/ 5 min	0.0	/ 5 min
04:00	05:00	23	1.0	/ 5 min	1.0	/ 5 min		7	0.5	/ 5 min	0.1	/ 5 min		0	0.0	/ 5 min	0.0	/ 5 min
05:00	06:00	95	4.0	/ 5 min	4.0	/ 5 min		21	1.6	/ 5 min	0.2	/ 5 min		9	0.7	/ 5 min	0.1	/ 5 min

	P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
Dist	Passengers	10 Seat	15 Seat	10 Seat	15 Seat	Dist	Passengers	10 Seat	15 Seat	10 Seat	15 Seat	Dist	Passengers	10 Seat	15 Seat	10 Seat	15 Seat
25%	95	39.6%	26.4%	39.6%	26.4%	25%	36	25.1%	16.8%	4.4%	3.0%	30%	65	5.4%	3.6%	48.5%	32.3%
20%	76	31.7%	21.1%	31.7%	21.1%	20%	28	20.1%	13.4%	3.6%	2.4%	30%	65	5.4%	3.6%	48.5%	32.3%
10%	38	15.8%	10.6%	15.8%	10.6%	15%	21	16.0%	10.7%	1.8%	1.2%	21%	46	3.8%	2.6%	34.6%	23.1%
5%	19	7.9%	5.3%	7.9%	5.3%	5%	7	5.9%	3.9%	0.0%	0.0%	13%	28	2.3%	1.5%	20.8%	13.9%
3%	11	4.8%	3.2%	4.8%	3.2%	5%	7	5.9%	3.9%	0.0%	0.0%	2%	5	0.4%	0.3%	3.5%	2.3%
3%	11	4.8%	3.2%	4.8%	3.2%	5%	7	5.9%	3.9%	0.0%	0.0%	0%	0	0.0%	0.0%	0.0%	0.0%
3%	11	4.8%	3.2%	4.8%	3.2%	5%	7	5.9%	3.9%	0.0%	0.0%	0%	0	0.0%	0.0%	0.0%	0.0%
6%	23	9.5%	6.3%	9.5%	6.3%	5%	7	5.3%	3.6%	0.6%	0.4%	0%	0	0.0%	0.0%	0.0%	0.0%
25%	95	39.6%	26.4%	39.6%	26.4%	15%	21	16.0%	10.7%	1.8%	1.2%	4%	9	6.9%	4.6%	0.8%	0.5%
	MAX % OCCUPANCY	39.6%	26.4%	39.6%	26.4%		MAX	25.1%	16.8%	4.4%	3.0%		MAX	6.9%	4.6%	48.5%	32.3%
	FACTOR INCREASE TO NECESSITATE A FURTHER POD	**2.5**	**3.8**	**2.5**	**3.8**			**4.0**	**6.0**	**22.5**	**33.8**			**14.4**	**21.7**	**2.1**	**3.1**

For the Weekend Night this analysis reveals that for a 15-seat AV the Arup estimated passenger demand could triple without the need for a further pod. The capacity of the network with twelve 15-seat pods is significantly greater than the expected passenger demand.

D3. Sunday Passenger Demand Analysis

The AV service on Sundays is proposed to operate over 24 hours, the assumption has been made however, that the demand for the service between midnight and 6am on the Monday morning is zero. An estimate of the hourly number passenger journeys on each leg of the network was made using the Arup demand figures and an estimate of the distributions hourly distribution of journeys and the split to each destination node from each departure node.

Estimate of Hourly Passenger Demand - SUNDAY

Number of Passengers Per Hour												Check Trains									
			Single Journeys		Estimate		Estimate		Single Journeys		Estimate		Estimate		Single Journeys		Estimate		Estimate		
			858						306						500						
		Dist	P&R	to CBC		to STATION		Dist	CBC	to P&R		to STATION		Dist	STATION	to CBC		to P&R		TOTAL	
6:00	7:00	2%	17	9	50%	9	50%	3%	9	8	90%	1	10%	2%	10	8	80%	2	20%	36	passengers / hour
7:00	8:00	2%	17	9	50%	9	50%	7%	21	19	90%	2	10%	6%	30	24	80%	6	20%	69	passengers / hour
8:00	9:00	8%	69	34	50%	34	50%	5%	15	14	90%	2	10%	7%	35	28	80%	7	20%	119	passengers / hour
9:00	10:00	8%	69	34	50%	34	50%	5%	15	14	90%	2	10%	6%	30	24	80%	6	20%	114	passengers / hour
10:00	11:00	8%	69	34	50%	34	50%	5%	15	14	90%	2	10%	4%	20	14	70%	6	30%	104	passengers / hour
11:00	12:00	8%	69	34	50%	34	50%	5%	15	14	90%	2	10%	4%	20	13	65%	7	35%	104	passengers / hour
12:00	13:00	8%	69	34	50%	34	50%	5%	15	14	90%	2	10%	4%	20	12	60%	8	40%	104	passengers / hour
13:00	14:00	8%	69	34	50%	34	50%	5%	15	14	90%	2	10%	3%	15	8	55%	7	45%	99	passengers / hour
14:00	15:00	8%	69	34	50%	34	50%	5%	15	14	90%	2	10%	3%	15	8	50%	8	50%	99	passengers / hour
15:00	16:00	8%	69	34	50%	34	50%	7%	21	19	90%	2	10%	5%	25	6	25%	19	75%	115	passengers / hour
16:00	17:00	7%	60	30	50%	30	50%	9%	28	25	90%	3	10%	8%	40	4	10%	36	90%	128	passengers / hour
17:00	18:00	7%	60	30	50%	30	50%	11%	34	30	90%	3	10%	11%	55	6	10%	50	90%	149	passengers / hour
18:00	19:00	7%	60	30	50%	30	50%	9%	28	25	90%	3	10%	14%	70	7	10%	63	90%	158	passengers / hour
19:00	20:00	4%	34	17	50%	17	50%	7%	21	19	90%	2	10%	9%	45	9	20%	36	80%	101	passengers / hour
20:00	21:00	3%	26	13	50%	13	50%	3%	9	8	90%	1	10%	5%	25	5	20%	20	80%	60	passengers / hour
21:00	22:00	2%	17	9	50%	9	50%	3%	9	8	90%	1	10%	4%	20	4	20%	16	80%	46	passengers / hour
22:00	23:00	1%	9	4	50%	4	50%	3%	9	8	90%	1	10%	3%	15	3	20%	12	80%	33	passengers / hour
23:00	0:00	1%	9	4	50%	4	50%	3%	9	8	90%	1	10%	2%	10	2	20%	8	80%	28	passengers / hour
		100%	TRUE	429		429		100%	TRUE	275		31		100%	TRUE	185		316		158	
		MAX	69	34		34			34	30		3			70	28		63			

Estimate of Passenger Demand per 5 minutes - SUNDAY

Number of passengers every 5 minute interval

			858						306						500				
			P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
6:00	7:00		17	0.7	/ 5 min	0.7	/ 5 min		9	0.7	/ 5 min	0.1	/ 5 min		10	0.7	/ 5 min	0.2	/ 5 min
7:00	8:00		17	0.7	/ 5 min	0.7	/ 5 min		21	1.6	/ 5 min	0.2	/ 5 min		30	2.0	/ 5 min	0.5	/ 5 min
8:00	9:00		69	2.9	/ 5 min	2.9	/ 5 min		15	1.1	/ 5 min	0.1	/ 5 min		35	2.3	/ 5 min	0.6	/ 5 min
9:00	10:00		69	2.9	/ 5 min	2.9	/ 5 min		15	1.1	/ 5 min	0.1	/ 5 min		30	2.0	/ 5 min	0.5	/ 5 min
10:00	11:00		69	2.9	/ 5 min	2.9	/ 5 min		15	1.1	/ 5 min	0.1	/ 5 min		20	1.2	/ 5 min	0.5	/ 5 min
11:00	12:00		69	2.9	/ 5 min	2.9	/ 5 min		15	1.1	/ 5 min	0.1	/ 5 min		20	1.1	/ 5 min	0.6	/ 5 min
12:00	13:00		69	2.9	/ 5 min	2.9	/ 5 min		15	1.1	/ 5 min	0.1	/ 5 min		20	1.0	/ 5 min	0.7	/ 5 min
13:00	14:00		69	2.9	/ 5 min	2.9	/ 5 min		15	1.1	/ 5 min	0.1	/ 5 min		15	0.7	/ 5 min	0.6	/ 5 min
14:00	15:00		69	2.9	/ 5 min	2.9	/ 5 min		15	1.1	/ 5 min	0.1	/ 5 min		15	0.6	/ 5 min	0.6	/ 5 min
15:00	16:00		69	2.9	/ 5 min	2.9	/ 5 min		21	1.6	/ 5 min	0.2	/ 5 min		25	0.5	/ 5 min	1.6	/ 5 min
16:00	17:00		60	2.5	/ 5 min	2.5	/ 5 min		28	2.1	/ 5 min	0.2	/ 5 min		40	0.3	/ 5 min	3.0	/ 5 min
17:00	18:00		60	2.5	/ 5 min	2.5	/ 5 min		34	2.5	/ 5 min	0.3	/ 5 min		55	0.5	/ 5 min	4.1	/ 5 min
18:00	19:00		60	2.5	/ 5 min	2.5	/ 5 min		28	2.1	/ 5 min	0.2	/ 5 min		70	0.6	/ 5 min	5.3	/ 5 min
19:00	20:00		34	1.4	/ 5 min	1.4	/ 5 min		21	1.6	/ 5 min	0.2	/ 5 min		45	0.8	/ 5 min	3.0	/ 5 min
20:00	21:00		26	1.1	/ 5 min	1.1	/ 5 min		9	0.7	/ 5 min	0.1	/ 5 min		25	0.4	/ 5 min	1.7	/ 5 min
21:00	22:00		17	0.7	/ 5 min	0.7	/ 5 min		9	0.7	/ 5 min	0.1	/ 5 min		20	0.3	/ 5 min	1.3	/ 5 min
22:00	23:00		9	0.4	/ 5 min	0.4	/ 5 min		9	0.7	/ 5 min	0.1	/ 5 min		15	0.3	/ 5 min	1.0	/ 5 min
23:00	0:00		9	0.4	/ 5 min	0.4	/ 5 min		9	0.7	/ 5 min	0.1	/ 5 min		10	0.2	/ 5 min	0.7	/ 5 min

All calculated 5-minute demand values for the Sunday service are less than capacity of a 10-seat pod.

Number of 10-seat Pods Required per 5 minutes - SUNDAY

Number of 10 seater vehicles every 5 minute interval

10 Seats

			858						306						500				
			P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
06:00	07:00		17	1	/ 5 min	1	/ 5 min		9	1	/ 5 min	1	/ 5 min		10	1	/ 5 min	1	/ 5 min
07:00	08:00		17	1	/ 5 min	1	/ 5 min		21	1	/ 5 min	1	/ 5 min		30	1	/ 5 min	1	/ 5 min
08:00	09:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		35	1	/ 5 min	1	/ 5 min
09:00	10:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		30	1	/ 5 min	1	/ 5 min
10:00	11:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	1	/ 5 min
11:00	12:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	1	/ 5 min
12:00	13:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	1	/ 5 min
13:00	14:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min
14:00	15:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min
15:00	16:00		69	1	/ 5 min	1	/ 5 min		21	1	/ 5 min	1	/ 5 min		25	1	/ 5 min	1	/ 5 min
16:00	17:00		60	1	/ 5 min	1	/ 5 min		28	1	/ 5 min	1	/ 5 min		40	1	/ 5 min	1	/ 5 min
17:00	18:00		60	1	/ 5 min	1	/ 5 min		34	1	/ 5 min	1	/ 5 min		55	1	/ 5 min	1	/ 5 min
18:00	19:00		60	1	/ 5 min	1	/ 5 min		28	1	/ 5 min	1	/ 5 min		70	1	/ 5 min	1	/ 5 min
19:00	20:00		34	1	/ 5 min	1	/ 5 min		21	1	/ 5 min	1	/ 5 min		45	1	/ 5 min	1	/ 5 min
20:00	21:00		26	1	/ 5 min	1	/ 5 min		9	1	/ 5 min	1	/ 5 min		25	1	/ 5 min	1	/ 5 min
21:00	22:00		17	1	/ 5 min	1	/ 5 min		9	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	1	/ 5 min
22:00	23:00		9	1	/ 5 min	1	/ 5 min		9	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min
23:00	00:00		9	1	/ 5 min	1	/ 5 min		9	1	/ 5 min	1	/ 5 min		10	1	/ 5 min	1	/ 5 min

Number of 15-seat Pods Required per 5 minutes - SUNDAY

Number of 15 seater vehicles every 5 minute interval

15 Seats

			858						306						500				
			P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
06:00	07:00		17	1	/ 5 min	1	/ 5 min		9	1	/ 5 min	1	/ 5 min		10	1	/ 5 min	1	/ 5 min
07:00	08:00		17	1	/ 5 min	1	/ 5 min		21	1	/ 5 min	1	/ 5 min		30	1	/ 5 min	1	/ 5 min
08:00	09:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		35	1	/ 5 min	1	/ 5 min
09:00	10:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		30	1	/ 5 min	1	/ 5 min
10:00	11:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	1	/ 5 min
11:00	12:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	1	/ 5 min
12:00	13:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	1	/ 5 min
13:00	14:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min
14:00	15:00		69	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min
15:00	16:00		69	1	/ 5 min	1	/ 5 min		21	1	/ 5 min	1	/ 5 min		25	1	/ 5 min	1	/ 5 min
16:00	17:00		60	1	/ 5 min	1	/ 5 min		28	1	/ 5 min	1	/ 5 min		40	1	/ 5 min	1	/ 5 min
17:00	18:00		60	1	/ 5 min	1	/ 5 min		34	1	/ 5 min	1	/ 5 min		55	1	/ 5 min	1	/ 5 min
18:00	19:00		60	1	/ 5 min	1	/ 5 min		28	1	/ 5 min	1	/ 5 min		70	1	/ 5 min	1	/ 5 min
19:00	20:00		34	1	/ 5 min	1	/ 5 min		21	1	/ 5 min	1	/ 5 min		45	1	/ 5 min	1	/ 5 min
20:00	21:00		26	1	/ 5 min	1	/ 5 min		9	1	/ 5 min	1	/ 5 min		25	1	/ 5 min	1	/ 5 min
21:00	22:00		17	1	/ 5 min	1	/ 5 min		9	1	/ 5 min	1	/ 5 min		20	1	/ 5 min	1	/ 5 min
22:00	23:00		9	1	/ 5 min	1	/ 5 min		9	1	/ 5 min	1	/ 5 min		15	1	/ 5 min	1	/ 5 min
23:00	00:00		9	1	/ 5 min	1	/ 5 min		9	1	/ 5 min	1	/ 5 min		10	1	/ 5 min	1	/ 5 min

Estimate of Pod Occupancy (12 Pod Fleet) - SUNDAY

	P&R	to CBC		to STATION			CBC	to P&R		to STATION			STATION	to CBC		to P&R	
Dist	Passengers	10 Seat	15 Seat	10 Seat	15 Seat	Dist	Passengers	10 Seat	15 Seat	10 Seat	15 Seat	Dist	Passengers	10 Seat	15 Seat	10 Seat	15 Seat
2%	17	7.2%	4.8%	7.2%	4.8%	3%	9	6.9%	4.6%	0.8%	0.5%	2%	10	6.7%	4.4%	1.7%	1.1%
2%	17	7.2%	4.8%	7.2%	4.8%	7%	21	16.1%	10.7%	1.8%	1.2%	6%	30	20.0%	13.3%	5.0%	3.3%
8%	69	28.6%	19.1%	28.6%	19.1%	5%	15	11.5%	7.7%	1.3%	0.9%	7%	35	23.3%	15.6%	5.8%	3.9%
8%	69	28.6%	19.1%	28.6%	19.1%	5%	15	11.5%	7.7%	1.3%	0.9%	6%	30	20.0%	13.3%	5.0%	3.3%
8%	69	28.6%	19.1%	28.6%	19.1%	5%	15	11.5%	7.7%	1.3%	0.9%	4%	20	11.7%	7.8%	5.0%	3.3%
8%	69	28.6%	19.1%	28.6%	19.1%	5%	15	11.5%	7.7%	1.3%	0.9%	4%	20	10.8%	7.2%	5.8%	3.9%
8%	69	28.6%	19.1%	28.6%	19.1%	5%	15	11.5%	7.7%	1.3%	0.9%	4%	20	10.0%	6.7%	6.7%	4.4%
8%	69	28.6%	19.1%	28.6%	19.1%	5%	15	11.5%	7.7%	1.3%	0.9%	3%	15	6.9%	4.6%	5.6%	3.8%
8%	69	28.6%	19.1%	28.6%	19.1%	5%	15	11.5%	7.7%	1.3%	0.9%	3%	15	6.3%	4.2%	6.3%	4.2%
8%	69	28.6%	19.1%	28.6%	19.1%	7%	21	16.1%	10.7%	1.8%	1.2%	5%	25	5.2%	3.5%	15.6%	10.4%
7%	60	25.0%	16.7%	25.0%	16.7%	9%	28	20.7%	13.8%	2.3%	1.5%	8%	40	3.3%	2.2%	30.0%	20.0%
7%	60	25.0%	16.7%	25.0%	16.7%	11%	34	25.2%	16.8%	2.8%	1.9%	11%	55	4.6%	3.1%	41.3%	27.5%
7%	60	25.0%	16.7%	25.0%	16.7%	9%	28	20.7%	13.8%	2.3%	1.5%	14%	70	5.8%	3.9%	52.5%	35.0%
4%	34	14.3%	9.5%	14.3%	9.5%	7%	21	16.1%	10.7%	1.8%	1.2%	9%	45	7.5%	5.0%	30.0%	20.0%
3%	26	10.7%	7.2%	10.7%	7.2%	3%	9	6.9%	4.6%	0.8%	0.5%	5%	25	4.2%	2.8%	16.7%	11.1%
2%	17	7.2%	4.8%	7.2%	4.8%	3%	9	6.9%	4.6%	0.8%	0.5%	4%	20	3.3%	2.2%	13.3%	8.9%
1%	9	3.6%	2.4%	3.6%	2.4%	3%	9	6.9%	4.6%	0.8%	0.5%	3%	15	2.5%	1.7%	10.0%	6.7%
1%	9	3.6%	2.4%	3.6%	2.4%	3%	9	6.9%	4.6%	0.8%	0.5%	2%	10	1.7%	1.1%	6.7%	4.4%
	MAX % OCCUPANCY	28.6%	19.1%	28.6%	19.1%		MAX	25.2%	16.8%	2.8%	1.9%		MAX	23.3%	15.6%	52.5%	35.0%
	FACTOR INCREASE TO NECESSITATE A FURTHER POD	3.5	5.2	3.5	5.2			4.0	5.9	35.7	53.5			4.3	6.4	1.9	2.9

In common with the Weekend Night and Weekday Night this analysis shows that the Arup estimated passenger demand could approximately triple, in the case of a 15-seat pod, and double in the case of a 10-seat pod, without the need for addition of a further pod. The capacity of the network with twelve 15-seat pods is, again, significantly greater than the expected passenger demand.

D4. Weekday Passenger Demand Analysis

The same 5-minute passenger demand analysis was undertaken using the Arup estimate of the Weekday passenger demand. As the Weekday incorporates the peak hours of travel, the passenger demand for the service will be considerably higher than the off-peak period, which necessitates a much larger fleet of AV pods. For example, there is an estimated requirement to move 444 passengers between the P&R and CBC between 07:00 and 08:00.

Estimate of Hourly Passenger Demand - WEEKDAY

Number of Passengers Per Hour												Check Trains									
			Single Journeys		Estimate		Estimate		Single Journeys		Estimate		Estimate		Single Journeys		Estimate		Estimate		
			4437						2839						1495						
		Dist	P&R	to CBC		to STATION		Dist	CBC	to P&R		to STATION		Dist	STATION	to CBC		to P&R		TOTAL	
6:00	7:00	8%	355	177	50%	177	50%	5%	142	128	90%	14	10%	5%	75	60	80%	15	20%	572	passengers / hour
7:00	8:00	20%	887	444	50%	444	50%	5%	142	128	90%	14	10%	7%	105	84	80%	21	20%	1134	passengers / hour
8:00	9:00	16%	710	355	50%	355	50%	5%	142	128	90%	14	10%	9%	135	108	80%	27	20%	986	passengers / hour
9:00	10:00	10%	444	222	50%	222	50%	3%	85	77	90%	9	10%	7%	105	84	80%	21	20%	634	passengers / hour
10:00	11:00	5%	222	111	50%	111	50%	3%	85	77	90%	9	10%	3%	45	31	70%	13	30%	352	passengers / hour
11:00	12:00	5%	222	111	50%	111	50%	3%	85	77	90%	9	10%	3%	45	29	65%	16	35%	352	passengers / hour
12:00	13:00	4%	177	89	50%	89	50%	3%	85	77	90%	9	10%	3%	45	27	60%	18	40%	308	passengers / hour
13:00	14:00	3%	133	67	50%	67	50%	3%	85	77	90%	9	10%	3%	45	25	55%	20	45%	263	passengers / hour
14:00	15:00	4%	177	89	50%	89	50%	5%	142	128	90%	14	10%	3%	45	22	50%	22	50%	364	passengers / hour
15:00	16:00	5%	222	111	50%	111	50%	8%	227	204	90%	23	10%	5%	75	19	25%	56	75%	524	passengers / hour
16:00	17:00	5%	222	111	50%	111	50%	14%	397	358	90%	40	10%	8%	120	12	10%	108	90%	739	passengers / hour
17:00	18:00	5%	222	111	50%	111	50%	17%	483	434	90%	48	10%	13%	194	19	10%	175	90%	899	passengers / hour
18:00	19:00	4%	177	89	50%	89	50%	14%	397	358	90%	40	10%	17%	254	25	10%	229	90%	829	passengers / hour
19:00	20:00	3%	133	67	50%	67	50%	7%	199	179	90%	20	10%	9%	135	27	20%	108	80%	466	passengers / hour
20:00	21:00	3%	133	67	50%	67	50%	5%	142	128	90%	14	10%	5%	75	15	20%	60	80%	350	passengers / hour
		100%	TRUE	2219		2219		100%	TRUE	2555		284		100%	TRUE	587		908			
		MAX	887	444		444			483	434		48			254	108		229			

Estimate of Passenger Demand per 5 minutes - WEEKDAY

Number of passengers every 5 minute interval

		4437					2839					1495				
		P&R	to CBC		to STATION		CBC	to P&R		to STATION		STATION	to CBC		to P&R	
06:00	07:00	355	14.8	/ 5 min	14.8	/ 5 min	142	10.6	/ 5 min	1.2	/ 5 min	75	5.0	/ 5 min	1.2	/ 5 min
07:00	08:00	887	37.0	/ 5 min	37.0	/ 5 min	142	10.6	/ 5 min	1.2	/ 5 min	105	7.0	/ 5 min	1.7	/ 5 min
08:00	09:00	710	29.6	/ 5 min	29.6	/ 5 min	142	10.6	/ 5 min	1.2	/ 5 min	135	9.0	/ 5 min	2.2	/ 5 min
09:00	10:00	444	18.5	/ 5 min	18.5	/ 5 min	85	6.4	/ 5 min	0.7	/ 5 min	105	7.0	/ 5 min	1.7	/ 5 min
10:00	11:00	222	9.2	/ 5 min	9.2	/ 5 min	85	6.4	/ 5 min	0.7	/ 5 min	45	2.6	/ 5 min	1.1	/ 5 min
11:00	12:00	222	9.2	/ 5 min	9.2	/ 5 min	85	6.4	/ 5 min	0.7	/ 5 min	45	2.4	/ 5 min	1.3	/ 5 min
12:00	13:00	177	7.4	/ 5 min	7.4	/ 5 min	85	6.4	/ 5 min	0.7	/ 5 min	45	2.2	/ 5 min	1.5	/ 5 min
13:00	14:00	133	5.5	/ 5 min	5.5	/ 5 min	85	6.4	/ 5 min	0.7	/ 5 min	45	2.1	/ 5 min	1.7	/ 5 min
14:00	15:00	177	7.4	/ 5 min	7.4	/ 5 min	142	10.6	/ 5 min	1.2	/ 5 min	45	1.9	/ 5 min	1.9	/ 5 min
15:00	16:00	222	9.2	/ 5 min	9.2	/ 5 min	227	17.0	/ 5 min	1.9	/ 5 min	75	1.6	/ 5 min	4.7	/ 5 min
16:00	17:00	222	9.2	/ 5 min	9.2	/ 5 min	397	29.8	/ 5 min	3.3	/ 5 min	120	1.0	/ 5 min	9.0	/ 5 min
17:00	18:00	222	9.2	/ 5 min	9.2	/ 5 min	483	36.2	/ 5 min	4.0	/ 5 min	194	1.6	/ 5 min	14.6	/ 5 min
18:00	19:00	177	7.4	/ 5 min	7.4	/ 5 min	397	29.8	/ 5 min	3.3	/ 5 min	254	2.1	/ 5 min	19.1	/ 5 min
19:00	20:00	133	5.5	/ 5 min	5.5	/ 5 min	199	14.9	/ 5 min	1.7	/ 5 min	135	2.2	/ 5 min	9.0	/ 5 min
20:00	21:00	133	5.5	/ 5 min	5.5	/ 5 min	142	10.6	/ 5 min	1.2	/ 5 min	75	1.2	/ 5 min	5.0	/ 5 min

Number of 10-seat Pods Required per 5 Minutes - WEEKDAY

4 pods (10 seat) are required to depart at each five minute interval in the morning rush hour to meet passenger demand.

Number of 10 seater vehicles every 5 minute interval

10 Seats

		4437					2839					1495				
		P&R	to CBC		to STATION		CBC	to P&R		to STATION		STATION	to CBC		to P&R	
6:00	7:00	355	2	/ 5 min	2	/ 5 min	142	2	/ 5 min	1	/ 5 min	75	1	/ 5 min	1	/ 5 min
7:00	8:00	887	4	/ 5 min	4	/ 5 min	142	2	/ 5 min	1	/ 5 min	105	1	/ 5 min	1	/ 5 min
8:00	9:00	710	3	/ 5 min	3	/ 5 min	142	2	/ 5 min	1	/ 5 min	135	1	/ 5 min	1	/ 5 min
9:00	10:00	444	2	/ 5 min	2	/ 5 min	85	1	/ 5 min	1	/ 5 min	105	1	/ 5 min	1	/ 5 min
10:00	11:00	222	1	/ 5 min	1	/ 5 min	85	1	/ 5 min	1	/ 5 min	45	1	/ 5 min	1	/ 5 min
11:00	12:00	222	1	/ 5 min	1	/ 5 min	85	1	/ 5 min	1	/ 5 min	45	1	/ 5 min	1	/ 5 min
12:00	13:00	177	1	/ 5 min	1	/ 5 min	85	1	/ 5 min	1	/ 5 min	45	1	/ 5 min	1	/ 5 min
13:00	14:00	133	1	/ 5 min	1	/ 5 min	85	1	/ 5 min	1	/ 5 min	45	1	/ 5 min	1	/ 5 min
14:00	15:00	177	1	/ 5 min	1	/ 5 min	142	2	/ 5 min	1	/ 5 min	45	1	/ 5 min	1	/ 5 min
15:00	16:00	222	1	/ 5 min	1	/ 5 min	227	2	/ 5 min	1	/ 5 min	75	1	/ 5 min	1	/ 5 min
16:00	17:00	222	1	/ 5 min	1	/ 5 min	397	3	/ 5 min	1	/ 5 min	120	1	/ 5 min	1	/ 5 min
17:00	18:00	222	1	/ 5 min	1	/ 5 min	483	4	/ 5 min	1	/ 5 min	194	1	/ 5 min	2	/ 5 min
18:00	19:00	177	1	/ 5 min	1	/ 5 min	397	3	/ 5 min	1	/ 5 min	254	1	/ 5 min	2	/ 5 min
19:00	20:00	133	1	/ 5 min	1	/ 5 min	199	2	/ 5 min	1	/ 5 min	135	1	/ 5 min	1	/ 5 min
20:00	21:00	133	1	/ 5 min	1	/ 5 min	142	2	/ 5 min	1	/ 5 min	75	1	/ 5 min	1	/ 5 min

4 pods (10 seat) per 5 minutes are required to depart the CBC to the P&R between 17:00 and 18:00, whilst only 1 pod (10 seat) is required from the P&R to the CBC at the same time. In this case 3 empty pods also would need to be sent from the P&R to the CBC to balance the number of pods.

Number of 15-Seat Pods Required per 5 Minutes - WEEKDAY

Number of 15 seater vehicles every 5 minute interval

15 Seats

		4437					2839					1495				
		P&R	to CBC		to STATION		CBC	to P&R		to STATION		STATION	to CBC		to P&R	
6:00	7:00	355	1	/ 5 min	1	/ 5 min	142	1	/ 5 min	1	/ 5 min	75	1	/ 5 min	1	/ 5 min
7:00	8:00	887	3	/ 5 min	3	/ 5 min	142	1	/ 5 min	1	/ 5 min	105	1	/ 5 min	1	/ 5 min
8:00	9:00	710	2	/ 5 min	2	/ 5 min	142	1	/ 5 min	1	/ 5 min	135	1	/ 5 min	1	/ 5 min
9:00	10:00	444	2	/ 5 min	2	/ 5 min	85	1	/ 5 min	1	/ 5 min	105	1	/ 5 min	1	/ 5 min
10:00	11:00	222	1	/ 5 min	1	/ 5 min	85	1	/ 5 min	1	/ 5 min	45	1	/ 5 min	1	/ 5 min
11:00	12:00	222	1	/ 5 min	1	/ 5 min	85	1	/ 5 min	1	/ 5 min	45	1	/ 5 min	1	/ 5 min
12:00	13:00	177	1	/ 5 min	1	/ 5 min	85	1	/ 5 min	1	/ 5 min	45	1	/ 5 min	1	/ 5 min
13:00	14:00	133	1	/ 5 min	1	/ 5 min	85	1	/ 5 min	1	/ 5 min	45	1	/ 5 min	1	/ 5 min
14:00	15:00	177	1	/ 5 min	1	/ 5 min	142	1	/ 5 min	1	/ 5 min	45	1	/ 5 min	1	/ 5 min
15:00	16:00	222	1	/ 5 min	1	/ 5 min	227	2	/ 5 min	1	/ 5 min	75	1	/ 5 min	1	/ 5 min
16:00	17:00	222	1	/ 5 min	1	/ 5 min	397	2	/ 5 min	1	/ 5 min	120	1	/ 5 min	1	/ 5 min
17:00	18:00	222	1	/ 5 min	1	/ 5 min	483	3	/ 5 min	1	/ 5 min	194	1	/ 5 min	1	/ 5 min
18:00	19:00	177	1	/ 5 min	1	/ 5 min	397	2	/ 5 min	1	/ 5 min	254	1	/ 5 min	2	/ 5 min
19:00	20:00	133	1	/ 5 min	1	/ 5 min	199	1	/ 5 min	1	/ 5 min	135	1	/ 5 min	1	/ 5 min
20:00	21:00	133	1	/ 5 min	1	/ 5 min	142	1	/ 5 min	1	/ 5 min	75	1	/ 5 min	1	/ 5 min

The maximum estimate of 5-minute demand for the Weekday time period is 37 passengers on the P&R to CBC and P&R to Station legs between 07:00 and 8:00. To transport this number of passengers every 5-minutes would require either 4 10-seat pods or 3 15-seat pods. Analysis of the pod occupancy below, shows that during peak periods of demand the expected occupancy of the pods would be, for a number of the node-to-node legs, greater than 90% with a 10-seat pods and greater than 80% with a 15-seat pod. In the off-peak periods the estimated pod occupancy is in the range of 10 to 20%.

Estimate of Pod Occupancy (36 Pod Fleet – 10 Seat AV, 28 Pod Fleet – 15 Seat AV) - WEEKDAY

Occupancy 10-Seat / 15-Seat

If all pods run each time

			P&R	to CBC		to STATION	
06:00	07:00	Dist	Passengers	10 Seat	15 Seat	10 Seat	15 Seat
07:00	08:00	8%	355	37.0%	32.9%	37.0%	32.9%
08:00	09:00	20%	887	92.4%	82.2%	92.4%	82.2%
09:00	10:00	16%	710	74.0%	65.7%	74.0%	65.7%
10:00	11:00	10%	444	46.2%	41.1%	46.2%	41.1%
11:00	12:00	5%	222	23.1%	20.5%	23.1%	20.5%
12:00	13:00	5%	222	23.1%	20.5%	23.1%	20.5%
13:00	14:00	4%	177	18.5%	16.4%	18.5%	16.4%
14:00	15:00	3%	133	13.9%	12.3%	13.9%	12.3%
15:00	16:00	4%	177	18.5%	16.4%	18.5%	16.4%
16:00	17:00	5%	222	23.1%	20.5%	23.1%	20.5%
17:00	18:00	5%	222	23.1%	20.5%	23.1%	20.5%
18:00	19:00	5%	222	23.1%	20.5%	23.1%	20.5%
19:00	20:00	4%	177	18.5%	16.4%	18.5%	16.4%
20:00	21:00	3%	133	13.9%	12.3%	13.9%	12.3%
		3%	133	13.9%	12.3%	13.9%	12.3%
			MAX % OCCUPANC'	92.4%	82.2%	92.4%	82.2%
			FACTOR INCREASE TO NECESSITATE A FURTHER POD	1.1	1.2	1.1	1.2

			CBC	to P&R		to STATION	
06:00	07:00	Dist	Passengers	10 Seat	15 Seat	10 Seat	15 Seat
07:00	08:00	5%	142	26.6%	23.7%	11.8%	7.9%
08:00	09:00	5%	142	26.6%	23.7%	11.8%	7.9%
09:00	10:00	5%	142	26.6%	23.7%	11.8%	7.9%
10:00	11:00	3%	85	16.0%	14.2%	7.1%	4.7%
11:00	12:00	3%	85	16.0%	14.2%	7.1%	4.7%
12:00	13:00	3%	85	16.0%	14.2%	7.1%	4.7%
13:00	14:00	3%	85	16.0%	14.2%	7.1%	4.7%
14:00	15:00	3%	85	16.0%	14.2%	7.1%	4.7%
15:00	16:00	5%	142	26.6%	23.7%	11.8%	7.9%
16:00	17:00	8%	227	42.6%	37.9%	18.9%	12.6%
17:00	18:00	14%	397	74.5%	66.2%	33.1%	22.1%
18:00	19:00	17%	483	90.5%	80.4%	40.2%	26.8%
19:00	20:00	14%	397	74.5%	66.2%	33.1%	22.1%
20:00	21:00	7%	199	37.3%	33.1%	16.6%	11.0%
		5%	142	26.6%	23.7%	11.8%	7.9%
			MAX	90.5%	80.4%	40.2%	26.8%
				1.1	1.2	2.5	3.7

			STATION	to CBC		to P&R	
06:00	07:00	Dist	Passengers	10 Seat	15 Seat	10 Seat	15 Seat
07:00	08:00	5%	75	49.8%	33.2%	6.2%	4.2%
08:00	09:00	7%	105	69.8%	46.5%	8.7%	5.8%
09:00	10:00	9%	135	89.7%	59.8%	11.2%	7.5%
10:00	11:00	7%	105	69.8%	46.5%	8.7%	5.8%
11:00	12:00	3%	45	26.2%	17.4%	5.6%	3.7%
12:00	13:00	3%	45	24.3%	16.2%	6.5%	4.4%
13:00	14:00	3%	45	22.4%	15.0%	7.5%	5.0%
14:00	15:00	3%	45	20.6%	13.7%	8.4%	5.6%
15:00	16:00	3%	45	18.7%	12.5%	9.3%	6.2%
16:00	17:00	5%	75	15.6%	10.4%	23.4%	15.6%
17:00	18:00	8%	120	10.0%	6.6%	44.9%	29.9%
18:00	19:00	13%	194	16.2%	10.8%	72.9%	48.6%
19:00	20:00	17%	254	21.2%	14.1%	95.3%	63.5%
20:00	21:00	9%	135	22.4%	15.0%	44.9%	29.9%
		5%	75	12.5%	8.3%	24.9%	16.6%
			MAX	89.7%	59.8%	95.3%	63.5%
				1.1	1.7	1.0	1.6

From the estimate of the required number of 10-seat pods per 5 minutes, the following figure presents a calculation of the necessary size of pod fleet to transport the average passenger demand.

Estimate of Required Fleet Size (10 seat Pod), Pod Travelling Empty % and Stationary % - WEEKDAY

Number of possible pod journeys where the pod remained stationary due to greater capacity than passenger demand.

Empty journeys required to balance pod numbers. For example – 4 pods required P&R to S, 2 pods S to P&R – number of pods must balance – 2 extra S to P&R pods sent empty each 10 minutes

8 pods required each 10 mins to meet demand (P&R - S) between 7:00 and 8:00, but between 6:00 and 7:00 only 4 pods are required. Therefore 4 pods are not required between 6 and 7 ((8-4)*(60/10)) = 24 journeys not required, so the vehicle remains stationary

For 10 minute - 10 Seats

		P&R - S	S - P&R	DIFF	P&R - CBC	CBC - P&R	DIFF	CBC - S	S -CBC	DIFF	CALCULATION OF STATIONARY POD %						TRAVELLING EMPTY CALC		
6:00	7:00	4	2	2	4	4	0	2	2	0	24	24	24	24	0	0	12	0	0
7:00	8:00	8	2	6	8	4	4	2	2	0	0	0	0	0	0	0	36	24	0
8:00	9:00	6	2	4	6	4	2	2	2	0	12	12	12	12	0	0	24	12	0
9:00	10:00	4	2	2	4	2	2	2	2	0	24	24	24	24	0	0	12	12	0
10:00	11:00	2	2	0	2	2	0	2	2	0	36	36	36	36	0	0	0	0	0
11:00	12:00	2	2	0	2	2	0	2	2	0	36	36	36	36	0	0	0	0	0
12:00	13:00	2	2	0	2	2	0	2	2	0	36	36	36	36	0	0	0	0	0
13:00	14:00	2	2	0	2	2	0	2	2	0	36	36	36	36	0	0	0	0	0
14:00	15:00	2	2	0	2	4	2	2	2	0	36	36	24	24	0	0	0	12	0
15:00	16:00	2	2	0	2	4	2	2	2	0	36	36	24	24	0	0	0	12	0
16:00	17:00	2	2	0	2	6	4	2	2	0	36	36	12	12	0	0	0	24	0
17:00	18:00	2	4	2	2	8	6	2	2	0	24	24	0	0	0	0	12	36	0
18:00	19:00	2	4	2	2	6	4	2	2	0	24	24	12	12	0	0	12	24	0
19:00	20:00	2	2	0	2	4	2	2	2	0	36	36	24	24	0	0	0	12	0
20:00	21:00	2	2	0	2	4	2	2	2	0	36	36	24	24	0	0	0	12	0
	MAX	8	4	6	8	8	6	2	2	0	432	432	324	324	0	0	108	180	0

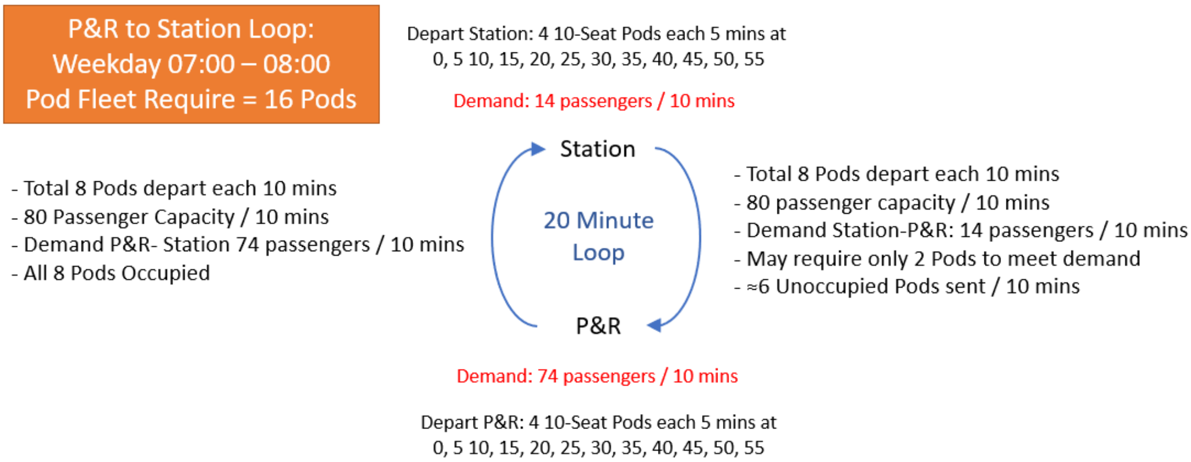
	36	**NUMBER OF VEHICLES REQUIRED TO MEET DEMAND**					
	10	REQURED PARKING BAYS AT STATION	8	P&R		2	CBC
	10	REQURED PARKING BAYS AT CBC			8 P&R	2	S
	16	REQURED PARKING BAYS AT P&R	4	S	8 CBC		
TRUE	3240	Total Possible Pod Movements	46.7%	Pods Stationary			
	288	Pod travelling empty	8.9%	Pod Travelling Empty			
	1512	Pod Waiting	44.4%	Pod Travelling with Passengers			

To meet the baseload weekday passenger demand a fleet of 36 10-seat pods are required

46.7% of possible journey are not required to be made, 8.9% of pod journeys have no passengers, 44.4% of possible pod journeys transport passengers

The required fleet size to deliver the weekday baseload passenger demand in the network, and meet the stipulated maximum passenger waiting time of 5 minutes, is 36 pods.

For the P&R to Station loop in the network, the maximum 5-minute passenger demand is 4 pods (from the P&R to Station between 07:00 and 08:00), therefore 8 pods are required every 10 minutes. The passenger demand for pods on the Station to P&R leg at this time would need only 1 pod every 5 minutes (2 per 10 minutes), however, as this leg is part of the P&R-Station loop, when the demand on the P&R to Station leg requires 8 pods, 8 pods must also be in operation on the Station-P&R leg. This is required to ensure the pod passenger capacity on the loop is sufficient to meet demand at both the P&R and Station throughout the hour. As the maximum passenger demand at a node in the loop requires 8 pods per 10 minutes (from the P&R), and the loop takes 20 minutes to complete (see page 3), a 16 pod fleet is required (8 pods at each node).

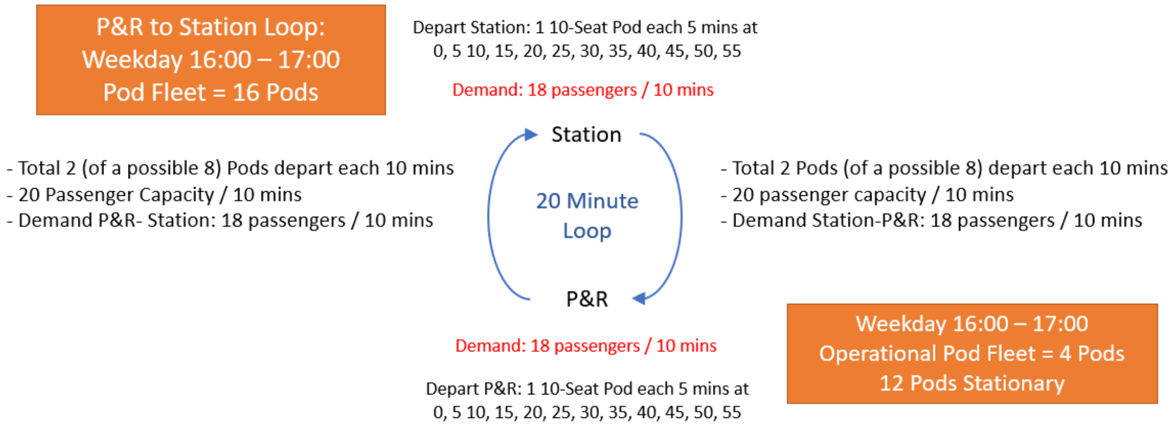


The requirement to keep the number of pods at each node in balance means that, at this time (07:00 – 08:00), a number of the pods from the Station to the P&R (3 of the 4 pods sent per 5 mins) are likely to travel unoccupied. This will occur at any time where there is a large disparity in passenger demand between the two nodes on the loop.

Outside peak weekday travel hours, the required number of pods to meet passenger demand is significantly reduced. In this instance it is only necessary to send out the minimum number of pods that meet the maximum passenger demand at any node in the loop in any particular hour.

In the previous example, the maximum 5-minute passenger demand on the P&R to Station loop dictated a required fleet size of 16 pods for the Weekday time period on this loop, with 4 pods departing every 5 minutes. Between 16:00 and 17:00 on the same loop, the demand at both nodes drops to 9 passengers every 5-minutes, which would require only 1 pod to depart each node every 5 minutes. Rather than running all available pods (4 pods per 5 minutes) the service can be run with 1 pod per 5 minutes to deliver the required capacity, whilst the other 3 pods remain stationary at their respective nodes.

When the passenger demand increases then the stationary pods can be brought back into service, with the same number departing both nodes to keep the number of pods at each node in balance.
The pod stationary time can be used to manage charging of the pods to ensure that all the AV pods are available for peak passenger demand periods.



The analysis suggests the P&R to CBC loop also requires a fleet of 16 pods, whilst the Station to CBC loop requires 4 pods, resulting in a fleet total of 36 pods for all three loops. Of the possible 3240 daily trips, the pods remain stationary 1512 times (46.7%) travel empty 288 times (8.9%), and therefore travel with passengers 1440 times (44.4%).

Repeating the same analysis with a larger capacity 15-seat pod decreases the required fleet size to 28 pods, with 12 required to meet the passenger demand on the P&R to Station loop, 12 required for the P&R to CBC loop and 4 required for the CBC to Station Loop.

Estimate of Required Fleet Size (15 seat Pod), Pod Travelling Empty % and Stationary % - WEEKDAY

6 pods required each 10 mins to meet demand (P&R - S) between 7:00 and 8:00, but between 6:00 and 7:00 only 2 pods are required. Therefore 4 pods are not required between 6 and 7 ((6-2)*(60/10)) = 24 journeys not required, where the vehicle remains stationary

For 10 minutes - 15 Seats

		P&R - S	S - P&R	DIFF	P&R - CBC	CBC - P&R	DIFF	CBC - S	S - CBC	DIFF	CALCULATION OF STATIONARY POD %						TRAVELLING EMPTY CALC		
6:00	7:00	2	2	0	2	2	0	2	2	0	24	24	24	24	0	0	0	0	0
7:00	8:00	6	2	4	6	2	4	2	2	0	0	0	0	0	0	0	24	24	0
8:00	9:00	4	2	2	4	2	2	2	2	0	12	12	12	12	0	0	12	12	0
9:00	10:00	4	2	2	4	2	2	2	2	0	12	12	12	12	0	0	12	12	0
10:00	11:00	2	2	0	2	2	0	2	2	0	24	24	24	24	0	0	0	0	0
11:00	12:00	2	2	0	2	2	0	2	2	0	24	24	24	24	0	0	0	0	0
12:00	13:00	2	2	0	2	2	0	2	2	0	24	24	24	24	0	0	0	0	0
13:00	14:00	2	2	0	2	2	0	2	2	0	24	24	24	24	0	0	0	0	0
14:00	15:00	2	2	0	2	2	0	2	2	0	24	24	24	24	0	0	0	0	0
15:00	16:00	2	2	0	2	4	2	2	2	0	24	24	12	12	0	0	0	12	0
16:00	17:00	2	2	0	2	4	2	2	2	0	24	24	12	12	0	0	0	12	0
17:00	18:00	2	2	0	2	6	4	2	2	0	24	24	0	0	0	0	0	24	0
18:00	19:00	2	4	2	2	4	2	2	2	0	12	12	12	12	0	0	12	12	0
19:00	20:00	2	2	0	2	2	0	2	2	0	24	24	24	24	0	0	0	0	0
20:00	21:00	2	2	0	2	2	0	2	2	0	24	24	24	24	0	0	0	0	0
	MAX	6	4	4	6	6	4	2	2	0	300	300	252	252	0	0	60	108	0

	28	NUMBER OF VEHICLES REQUIRED TO MEET DEMAND
	8	REQURED PARKING BAYS AT STATION
	8	REQURED PARKING BAYS AT CBC
	12	REQURED PARKING BAYS AT P&R
TRUE	2520	Total Possible Pod Movements
	168	Pod travelling empty
	1104	Pod Waiting

43.8%	Pods Stationary
6.7%	Pod Travelling Empty
49.5%	Pod Travelling with Passengers

To meet the baseload weekday passenger demand a fleet of 28 15-seat pods are required (8 less than required with 10 seat pods.

Employing a 15 seat pod rather than 10 seat, reduces both the stationary % and the % of journeys travelled empty

Of the possible 2520 daily trips, the pods remain stationary 1104 times (43.8%) travel empty 168 times (6.7%), and therefore travel with passengers 1248 times (49.5%). The decrease in the number of pod movements from 1800 per day with a 10-seat pod to 1272 per day with a 15-seat pod should reduce the operational cost of the electricity required per day, but this saving is somewhat depended upon the respective weights of the 10- and 15-seat pods.

APPENDIX E – Assessment of Estimated Node-to-Node Leg Maximum 10 Minute Passenger Demand against 10 Minute Passenger Capacity Under Different Pod Scenarios

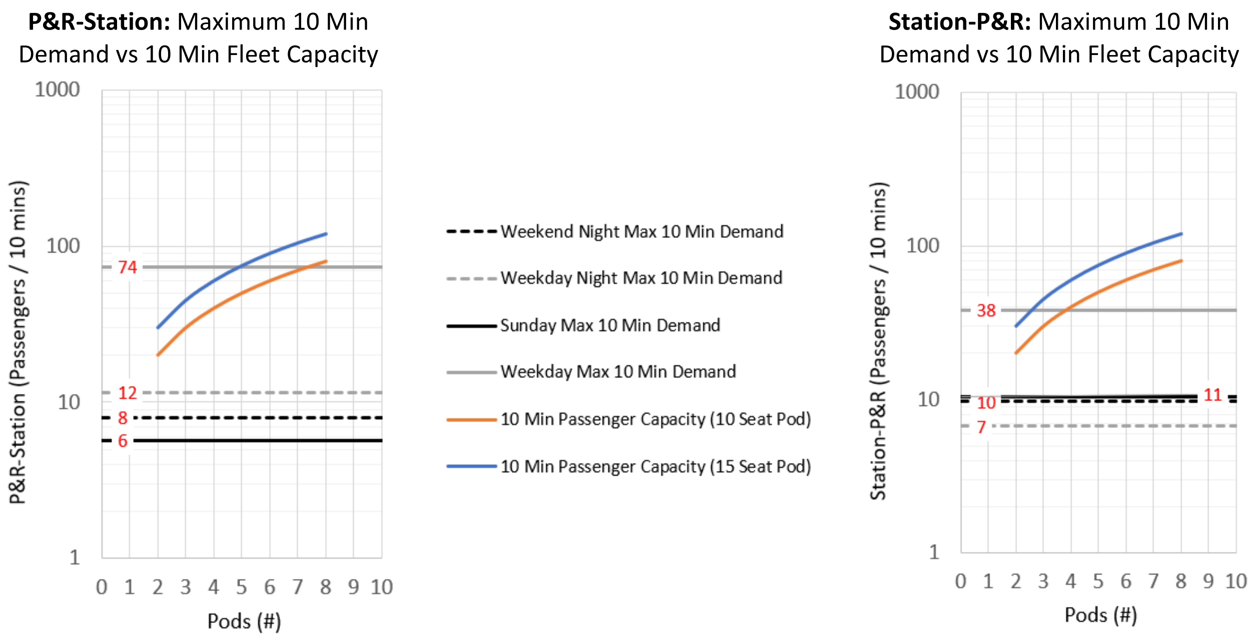
The following analysis evaluates the 10-minute capacity of the AV pod service, for each node-to-node leg in the proposed AV pod network, under different pod scenarios. These scenarios describe the number of pods stationed at each departure node for each node-to-node leg, with a range from 2 to 8 pods. The capacity estimates under the different scenarios are compared to the maximum estimate of 10-minute passenger demand on each leg, derived from the Arup demand estimates.

The 10-minute capacity for each leg is equal to: the number of pods on the node-to-node leg × the capacity of the pod (10- or 15-seat).

Pod Scenario (# of Pods for each node-to-node leg)	2*	4	6	8
Number of Pods on each Node-to-Node Loop	4	8	12	16
10 min Capacity – 10-seat Pod	20	40	60	80
10 min Capacity – 15-seat Pod	30	60	90	120

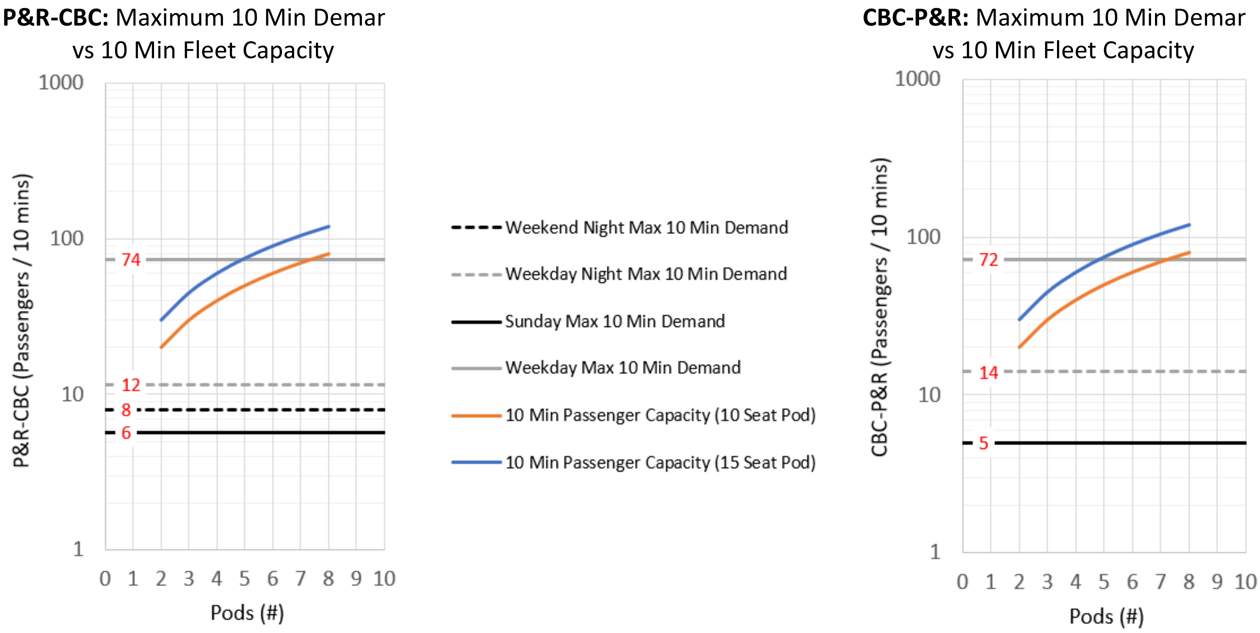
* min 2 pods required at each node for 5-minute schedule

E1. Trumpington P&R to the Cambridge Train Station Loop



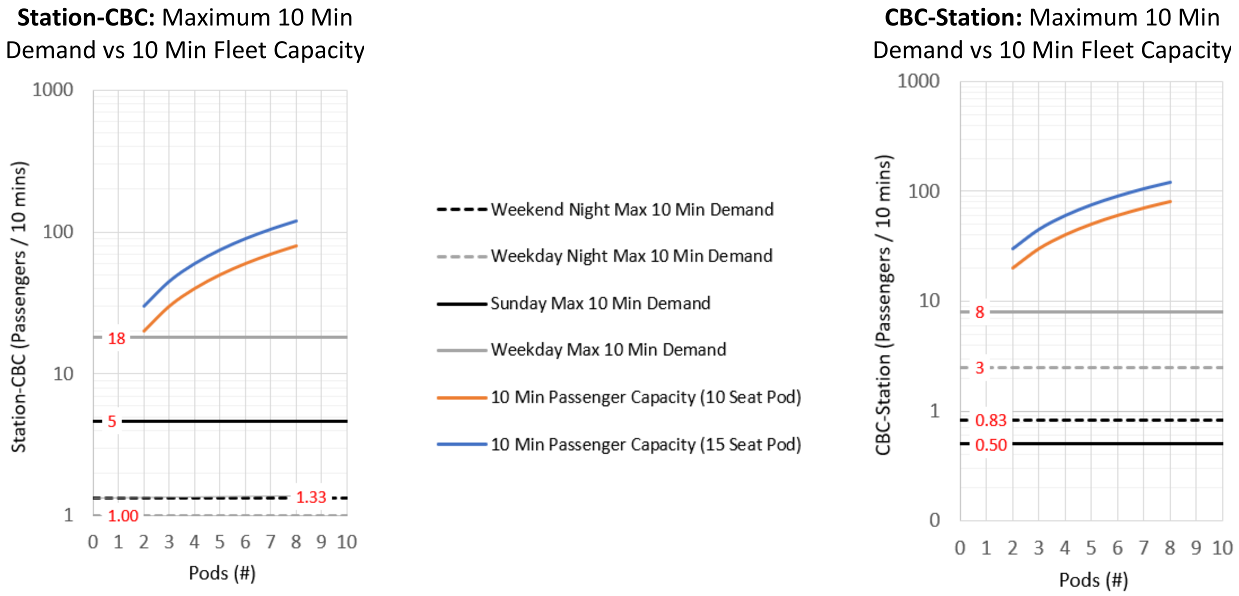
The figures show the maximum 10-minute passenger demand on the P&R to Station and Station to P&R node-to-node legs in the network and compare these values to the 10-minute capacity on the legs with a range of pod fleet sizes in operation. For both legs, the maximum 10-minute passenger demand for the Weekend Night, Sunday and Weekday night figures are well below the 10-minute capacity of the leg when 2 pods depart every 10 minutes (at a 5-minute interval). Therefore, a fleet of 4 pods on the P&R to Station loop in the network could comfortably meet the passenger demand for these time periods. For the Weekday time period the maximum demand of 74 passengers per 10 minutes on the P&R to Station leg, can be catered for with a fleet of 8 10-seat pods on the leg (16 10-seat pods total on the P&R to Station loop) or 6 15-seat pods (12 15-seat pods on the loop). Whereas, for the Station to P&R leg, where the maximum 10-minute demand is only 38 passengers, either 4 10-seat or 4 15-seat pods (8 in total on the P&R to Station loop) would meet the demand.

E2. Trumpington P&R to the Cambridge Biomedical Campus



The results for the P&R to CBC and CBC to P&R legs are similar to the P&R to Station Loop legs, with the Weekend Night, Sunday and Weekday night demand well below the 10-minute capacity of the leg with 4 pods operating the P&R to CBC loop. The maximum 10-minute demand in the Weekday period requires a pod fleet of 16 10-seat or 12 16-seat pods on the P&R to CBC loop.

E3. Cambridge Station to the Cambridge Biomedical Campus



The maximum 10-minute demand for all time periods on the CBC to Station loop could be satisfied with a fleet of 4 pods operating the loop.

APPENDIX F – Breakdown of Estimated Annual Costs

F1. Out-of-Hours Operations

Fuel (Electricity) Costs – £55,000 p.a.

- Weekly passenger journeys provided (1,096×5) + (739) + (1664) = 7,883
- Total distance travelled per week (9,298) + (1,860) + (4,018) = 15,176 km
- Total distance travelled per year (483,506) + (96,701) + (208,915) = 789,122 km
- Average energy consumption of pods = 0.7 kW/km
- Annual energy consumption = 552,386 kW @ 12.5p/kWh = £55,000 (approx.)

Estimate of the distance travelled by pods during Weekday Evening operations with 15-seat pods.

Leg	P&R - Station	Station - P&R	P&R - CBC	CBC - P&R	CBC - Station	Station - CBC
Journey Length (km)	3.7	4	2.2	2.5	3.0	3.2
Max Number of Daily Journeys	108	108	108	108	108	108
Pod Stationary (no Journey)	0	0	0	0	24	24
Distance Travelled per Day (km)	404	404	233	271	254	267
Total Fleet Distance Travelled per Day					1,860 km	
Total Fleet Distance Travelled per Week					9,298 km	
Total Fleet Distance Travelled per Year					483,506 km	

Estimate of the distance travelled by pods during Weekend Evening operations with 15-seat pods.

Leg	P&R - Station	Station - P&R	P&R - CBC	CBC - P&R	CBC - Station	Station - CBC
Journey Length (km)	3.7	4	2.2	2.5	3.0	3.2
Max Number of Daily Journeys	108	108	108	108	108	108
Pod Stationary (no Journey)	0	0	0	0	24	24
Distance Travelled per Day (km)	404	404	233	271	254	267
Total Fleet Distance Travelled per Day					1,860 km	
Total Fleet Distance Travelled per Week					1,860 km	
Total Fleet Distance Travelled per Year					96,701 km	

Estimate of the distance travelled by pods during Sunday operations with 15-seat pods.

Leg	P&R - Station	Station - P&R	P&R - CBC	CBC - P&R	CBC - Station	Station - CBC
Journey Length (km)	3.7	4	2.2	2.5	3.0	3.2
Max Number of Daily Journeys	216	216	216	216	216	216
Pod Stationary (no Journey)	0	0	0	0	0	0
Distance Travelled per Day (km)	809	859	465	542	654	688
Total Fleet Distance Travelled per Day					4,018 km	
Total Fleet Distance Travelled per Week					4,018 km	
Total Fleet Distance Travelled per Year					208,915 km	

Staff Costs (1 shift per night plus 2 shifts on Sunday = 8 shifts per week) – £460,000 p.a.

- Operations Manager: 1 @ £50,000 p.a.
- Office Support (Office Services, Customer Services): 1 @ £25,000 p.a.
- Control Room Staff (Safety Supervisors): 5 @ 35,000 p.a. = £175,000 p.a.
- Customer Support Staff (at Stations): 4 @ £30,000 p.a. = £120,000 p.a.
- Security Staff: 3 @ £30,000 p.a. = £90,000 p.a
- Maintenance Staff: 2 (assumed to be provided by the Operator at the Operator's expense)

Vehicle Maintenance Costs - £35,000 (for 35 Pod Fleet)

- Disposable and replacement parts per vehicle (tyres included): £1,000 p.a.

Insurance - £52,500 (for 35 Pod Fleet)

- Estimated at £1,500 per vehicle

Stabling and Maintenance Facilities

- Minor buildings provided for with the original capital provision
- Tools and equipment assumed to be provided by the Operator at the Operator's expense

F2. 24-Hour Operations

Fuel (Electricity) Costs – £190,000 p.a.

- Weekly passenger journeys provided (1,096×5) + (739) + (1664) + (8,771*6) = 60,509
- Total distance travelled per week (9,298) + (1,860) + (4,018) + (25,890) = 41,066 km
- Total distance travelled per year (483,506) + (96,701) + (208,915) + (1,346,286) = 2,135,432 km
- Average energy consumption of pods = 0.7 kW/km
- Annual energy consumption = 1,494,802 kW @ 12.5p/kWh = £190,000 (approx.)

Estimate of the distance travelled by pods during Weekday operations with 15-seat pods.

Leg	P&R - Station	Station- P&R	P&R – CBC	CBC – P&R	CBC – Station	Station - CBC
Journey Length (km)	3.7	4	2.2	2.5	3.0	3.2
Max Number of Daily Journeys	540	540	540	540	180	180
Pod Stationary (no Journey)	300	300	252	252	0	0
Distance Travelled per Day (km)	899	945	621	723	545	573
Total Fleet Distance Travelled per Day					4,315 km	
Total Fleet Distance Travelled per Week					25,890 km	
Total Fleet Distance Travelled per Year					1,346,286 km	

Staff Costs (3 shift per day for some staff) – £1,450,000 p.a.

- Operations Manager: 1 @ £50,000 p.a.
- Office Support (Office Services, Customer Services): 2 @ £25,000 p.a. = £100,000 p.a.
- Control Room Staff (Safety Supervisors – 3 shifts per day): 18 @ 35,000 p.a. = £630,000 p.a.
- Customer Support Staff (at Stations – 3 shifts per day): 12 @ £30,000 p.a. = £360,000 p.a.
- Security Staff (3 shifts per day): 12 @ £30,000 p.a. = £360,000 p.a
- Maintenance Staff (2 shifts per day): 6 (assumed to be provided by the Operator at the Operator's expense)

Vehicle Maintenance Costs - £70,000 (for 35 Pod Fleet)

- Disposable and replacement parts per vehicle (tyres included): £2,000 p.a.

Insurance - £52,500 (for 35 Pod Fleet)

- Estimated at £1,500 per vehicle

Stabling and Maintenance Facilities

- Minor buildings provided for with the original capital provision
- Tools and equipment assumed to be provided by the Operator at the Operator's expense

REFERENCES

[1] http://www.thebusway.info/pdfs/tt/ABNR.pdf
[2] http://www.thebusway.info/pdfs/tt/U.pdf
[3] http://www.thebusway.info/pdfs/maps/trumpington.pdf