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Bus Journey Time Variability in Urban Areas

TECHNICAL REPORT

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1 Introduction

1. PBWSP with John Bates Services have been commissioned by the Department for Transport (DfT) to undertake a research study into the factors which influence bus journey time variability in urban areas. Our proposal for the project set out two key deliverables and an expected outcome.

2. This document, the Project Technical Report, is the first key deliverable and fulfils three main objectives of our study:

- It includes a summary of literature on the topic of bus journey time variability which is used to identify contributory factors;
- It provides a proposal for appropriate statistical tests and models to enable an assessment of bus journey travel time variability; and
- It includes a proposal for the methods of data collection to capture information about factors affecting bus journey travel time variability.

3. The first of these objectives is addressed in Section 2 where we consider a selection of academic papers to determine whether our proposals for identifying and quantifying variables affecting bus journey time variability, submitted to the Department in January 2013, are consistent with best practice and likely to deliver robust conclusions.

4. Within the proposal we suggest investigating the type of data collected to measure a range of variables which were apparently influencing bus journey time variability. Where there is evidence in the literature that these variables have been tested we will consider the data used in those studies. We also make some observations about collection methodology and propose how we would collect similar data.

5. One issue to address immediately is the distinction between *variability* and *reliability*. The reliability of bus services in the UK is conventionally measured for regulatory purposes by considering using two key metrics:

- the number of services run as opposed to the number of services scheduled; and
- the frequency with which those buses depart from nominated timing points within a period defined as 1 minute before and 5 minutes after the published timetable.

6. It is important to note that a *reliable* service may display *variability* which will not be captured in reliability reports. For example, a bus service with two timetable points,

“*a”* and “*b”*, being 08:20 and 08:40 may leave point “*a*” on Monday at 08:19 and leave at point “*b*” at 08:45 whereas on Tuesday it departed point “*a*” at 08:25 and departed point “*b*” at 08:39. In both cases, this would recorded as a reliable service by both the key reliability metrics – i.e. the bus was serving the route when it was advertised and it was never more than 1 minute early or 5 minutes late.

7. However, with a difference in journey time of 12 minutes on a notional 20 minute journey there is a high degree of journey time variability displayed.

8. This study is concerned with such variability which means that much of the published information about reliability cannot be used directly.

2 Variables to consider

9. The Literature Review carried out by the Department (DfT 2012) was predominantly UK-based. We have investigated more widely – but have attempted to restrict our search to recent publications which are of most relevance due to advances in data collection techniques – and our conclusion is that research in this area is very limited with pockets of activity principally in the United States, the Netherlands and Australia.

10. We conclude that much of the research activity is narrow in its scope of investigation, addressing specific issues regarding how to utilise secondary data to estimate models of journey travel time variability for general traffic or bus journey travel time variability.

11. The secondary datasets interrogated for this purpose do not include information about the cause of variability as there are no direct observations recorded whilst the buses were in service.

12. Due to the use of secondary data, none of the literature we have found has considered how to collect data specifically to address the relationship between supply side factors and bus journey time variability.

13. Whilst the data manipulation studies have demonstrated the richness of the data in various ways and the analysts have shown that the data can be used to develop models of a range of attributes associated with bus activity, including dwell times, headway variability and schedule adherence, there is no evidence that the data systematically explores the causes of bus journey travel time variability in the manner in which required for this study.

14. Having considered a number of publications in relation to the factors identified in our proposal as potentially affecting bus journey travel time variability, we have ranked these factors by their implied importance as shown in Table 1 below. We have considered how each item has been investigated in terms of its impact on bus journey time variability. From these investigations we have identified whether the data collection method employed can be incorporated into this study, and we report on this in the following sections and summarise the methods in Appendix A.

Table 1: Implied Importance of Factors Influencing Bus Journey Time Variability

Element	Implied Importance	Complexity of existing research with respect to journey time variability
General traffic	High	Simple relationships
Priority at junctions	High	Simple examinations for whole route / service; complex at specific junctions
Route length	High	Complex relationships for specific routes
Number of bus stops in route	High	Some investigation
Priority between junctions (segregated lanes)	Medium	Simple examination
Vehicle spacing policies	Medium	No substantial studies
Ticket type	Medium	Investigated within dwell time
Physical characteristics of the stops	Low	No substantial studies
Experience of drivers	Low	No substantial studies
Number of doors	Low	No substantial studies
Frequency of public transport use	Low	No substantial studies
Weather	Low	No substantial studies

2.1 High impact

2.1.1 General traffic

15. There is no dispute amongst the papers we have considered that general traffic conditions have a significant impact on bus journey time variability. Unfortunately, we have found very little in the research that directly aims to quantify or describe such general traffic conditions, and their variability, in tandem with the bus journey time variability.

16. Most of the papers use terms which imply what general traffic conditions prevail, such as “peak” and “off-peak” (see Mazloumi et al 2010), but do not quantify the traffic volumes or relate these to capacity.

17. Liu and Sinha (2007) presented a study which considered bus journey travel time variability on one bus route in a morning peak period in one direction within a traffic micro-simulation model. The traffic micro-simulation model represented a network including links on which buses and general traffic shared the carriageway as well as a link with a bus lane running alongside the general traffic lane.

18. However, the volume of general traffic was fixed in all the model runs. Liu and Sinha note that drivers’ routes and departure time choices were also kept fixed in all the model runs, with the result that bus journey travel time variability was mostly impacted by differences in total bus passenger volume and associated factors such as the dwell time at stops.

19. Model validation focussed on the bus travel times, with general traffic conditions calibrated to the “average” – which we have assumed to be average journey time between entry and exit point in the network as no evidence is presented.

20. The experiments designed by Liu and Sinha included increasing the general traffic volume by 5% and 10% - keeping all other assumptions the same. The conclusion of this test was:

> *“It was clear from the results… that increased congestion resulted in increases in both the average and the variability of bus journey times… Increased congestion also resulted in an increase in average headway.”*

21. Developing this work, Hollander (2007) improved the traffic micro-simulation model calibration such that it also produced bus travel times within the observed range of variability for buses and other vehicles for a particular study area, as opposed to merely reproducing the average travel time as the validation measure.

22. Hollander states:

> *The travel time data used here are based on travel time records generated by a system installed on several buses… [that] takes a note of the time when the bus arrives at each stop, and can therefore be used to generate a profile of the progress of the bus on each journey. Joining the records from multiple days forms the input required for travel time variability analysis (page 200).*

23. Hollander did not examine the underlying causes of variation within the dataset and restricted the calibration to measuring the goodness of fit between the observed and modelled travel time distribution. The purpose of the traffic microsimulation model was essentially to provide the demand model with different travel costs.

24. The common method of measuring variation in journey times for traffic is to consider the standard deviation of journey times or divide it by the mean journey time to produce the coefficient of variation [CV]. This method is recommended in the Department’s Transport Appraisal Guidance (DfT 2013).

25. We note an alternative method to determine the travel time variability within general traffic defined by Turochy and Smith (2002) who investigated the use of archived data as a resource to estimate a variability index. The variability index combined the normalised distributions of three variables calculated from historic traffic data – average speed, traffic volume and lane occupancy:

> *“The variability index (VI), founded in quality control theory, is easily calculated from an archival database… [and the VI] can*

be used by travellers to select departure times that exhibit relatively predictable travel times (periods of low variability).

26. The calculation of variability index is shown below:

$$VI = (S_{un})(S_{qn})(S_{hn})10^6$$

Where:
VI = variability index;
S_{un} = standard deviation of 'normalised' mean speed;
S_{qn} = standard deviation of 'normalised' hourly equivalent volume;
S_{hn} = standard deviation of 'normalised' [lane] occupancy; and
10^6 = a large constant to return a value greater than 1.

27. The 'normalisation' process was employed to remove the magnitude differences from the different datasets. For example, lane occupancy was expressed in percent terms between 0% and 100%, whereas speed is recorded in kilometres per hour and volume is an absolute figure. The normalisation process converts each observation in the dataset within each category to a figure between 0 and 1.

28. We conclude that investigating general traffic conditions is important and, given their variation over the course of the day (which should **not** be included in measures of variability), it is necessary to record it in reasonable detail, rather than simply recording the gross period of the day (e.g. peak vs. off-peak) in which bus journeys occur. We will continue to consider which metrics can be used to determine whether there is statistically significant variability of travel times within the general traffic, including those recommended by the DfT and those developed by Turochy and Smith, and consider these against bus journey travel time variability.

2.1.2 Junctions

29. Mazloumi et al (2010) identified signalised junctions as having a statistically significant impact on travel time variability. El-Geneidy et al (2002) also found that signal controlled junctions have an impact upon travel time variability.

30. Addressing the impact of signalised junctions requires some form of intervention by the traffic system managers – usually the local highway authority. Several options are available, including selected vehicle detection or simply biasing the traffic signals towards arms of the junction which have bus services.

31. Evidence of the scale of impact that managing junctions has on bus journey travel time variability is scarce, with much being location specific and no general papers on the topic being available. We will consider using Automatic Vehicle Location data, which we will discuss in more detail later, to determine the degree to which signal controlled junctions are contributing to bus journey travel time (and other traffic travel time variability) in our pilot study.

2.1.3 Route length and number of stops

32. It has been demonstrated for general traffic that while the standard deviation of travel time increases with journey distance, it increases less fast than the mean, so that the coefficient of variation [CV] (standard deviation divided by the mean) falls with increasing distance. This is in line with the relationship shown in DfT (2013). In terms of bus journey travel time variability, many authors have demonstrated that route length, which generally implies a higher number of stops, has a strong positive relationship with bus journey travel time variability. Mazloumi et al (2010) described a model for predicting bus journey travel time variability in which length of route (km) was an independent variable as were number of stops and number of signal controlled junctions. However, it is not clear from the work whether for buses the CV will rise or fall with distance.

33. Van Oort (2011) reports:

> *Shalaby et al. (2001) show that trip time variation not only depends on service trip time (or line length) itself, but is also affected by the number of stops made.*

34. The reason that these two factors have such an important impact on bus journey travel time variability is that a given event which may disturb a bus during its journey is more likely to occur the longer the bus is travelling, and the consequence of running late is that there are likely to be more passengers at the next stop, which in turn means a greater dwell time exacerbating the original delay. Recovering from this phenomenon requires an intervention by the driver or manager of the route.

35. We will use automatic vehicle location data to consider the relationship between route length and bus journey travel time variability.

2.2 Medium impact

2.2.1 Priority between junctions – segregated lanes

36. The extent of published research which presents statistically robust conclusions considering the relationship between infrastructure such as bus lanes and bus journey travel time variability is limited. Most of the material that has been published focuses on demonstrating the impact of a specific intervention and its contribution at that location on mean travel time rather than how the bus lane contributes to bus journey time variability along the route.

37. Hollander (2007) in his traffic micro-simulation experiment implemented a hypothetical bus lane to represent its impact on bus journey time variability. However, the scenario presented was artificial, as Hollander states:

> *"The length of the proposed new bus lane section is about 500 meters; it is suggested to construct it adjacent to, and not instead, the existing all-traffic lanes. It should be emphasized that this is only a conceptual scheme; we have not examined whether the physical right of way that would be needed for a bus lane along this section is actually available."*

38. Running the micro-simulation model to test the impact of the new priority measure resulted in:

> *"A lower Mean Travel Time in the new bus lane section, due to a reduced level of friction between buses and cars, is evident for the majority of the bus journeys" (page 229)*

39. A key issue was identified by the Scottish Executive (2000) in their study comparing "Greenways" – which include substantial investment in enforcement – with traditional bus lanes:

> *"In terms of the performance of Greenways relative to conventional lanes, where there are bus lanes in place, and no retail frontage, Greenways and conventional lanes perform equally well. Where bus lanes run along retail frontages, Greenways can be seen to perform better than conventional lanes. On sections where the physical layout does not permit bus lanes, the performance of Greenways is likely to be reduced. These findings suggest that enforcement is an influencing factor in the performance of bus lanes."*

40. This research project did not consider whether conventional bus lanes reduced variability, but did demonstrate that adherence to the scheduled timetable was improved when bus lanes were complemented by other measures.

41. We have not found any other systematic research into the impact of a bus lane on bus journey travel time variability. This presents a challenge in terms of this study in that the contribution which bus lanes may make to bus journey travel time variability does not appear to have been considered in isolation and their contribution to reducing mean travel time is generally measured alongside the impacts of other interventions.

2.2.2 Vehicle management policies

42. While bus drivers will seek to maintain the schedule of the published timetable, their first priority is the safety and comfort of their passengers and therefore operators will have supervisory and management staff (route managers) available to make decisions on how best to respond to service perturbations.

43. These route managers will be guided by the scheduling policy of the operator. This will cover both the routing and timing of services in the first instance and the layover

which is provided between journeys, which should, in normal circumstances, allow for late running.

44. Where services do become delayed beyond acceptable limits, operators will take actions to return the service to as close to its schedule as possible. Van Oort (2011) summarises several strategies which can be implemented including:

> *"Skipping stops;*
> *Deadheading (or let down only);*
> *Headway control; and*
> *Short turning."*

45. Essentially, each of these interventions can impact upon bus journey travel time variability as a particular vehicle is taken out of "normal" service in an attempt to recover lost time due to delays earlier in its route. For data collection purposes, this means that a particular bus may not appear on the later parts of its route.

46. To allow for this factor we will collect this information by interview with the relevant commercial and operational management staff.

2.2.3 Passenger number and ticket types

47. Passenger numbers, activity – which includes attributes such as how orderly the queue is, how readily passengers have their fare to hand and whether passengers are impeded by luggage – and ticketing arrangements have all been shown by several authors to have a statistically significant impact on bus journey travel time and bus journey travel time variability.

48. The assessment of factors that might influence passenger demand or their choice of ticket type is outside the scope of this project: however, it is important to collect information regarding the volume of demand and the boarding process as these clearly are important factors influencing journey time and potentially bus journey travel time variability.

49. Several authors, including Kimpel and Strathman (2004), Patnaik et al (2004) and Dueker et al (2004) considered the use of automatic passenger counter or APC technology as a means of obtaining data about the number of boarders and using it as a component data set for their consideration of scheduling, arrival times and dwell times.

50. The advantages of automatic passenger counters are reported by Dueker et al (2004) as reducing the need to have labour intensive data collection on the vehicles

themselves, but the limitation of the technology is that it does not record passenger activity, passenger / driver interaction or ticket arrangements.

51. Whilst we would suggest collecting passenger numbers using automated systems which are fixed to the doors of buses, these are not common in the UK. We recognise that operators do record passengers using driver operated ticket machines, but these are often not set up to capture stop by stop data. Therefore, manual observations will be required to provide appropriate data.

2.3 Low impact

2.3.1 Bus driver and vehicle characteristics

52. We have found very little evidence that driver behaviour has been observed in sufficient detail to determine its impact on bus journey travel time variability. El-Geneidy et al (2011) included the experience of the driver expressed in the number of years as an explanatory variable in their research and concluded that an increase in the number of years reduced travel time and journey time variability. However, there is no body of evidence that demonstrates that years of experience is directly related to competence or behaviour of the driver and, given the limited impact, we will not capture this data.

53. The vehicle characteristics were only recorded in terms of whether buses had powered lifts which facilitated wheel chair access, as opposed to smaller, and often manual, ramps. The number of observations across the datasets examined of a lift being used is relatively small although its impact is significant. For the purpose of this study though, buses used on local bus services do not have lifts and therefore, the impact of this factor will not be considered.

54. Another significant vehicle characteristic is the number of doorways on each bus and whether these are all used for both boarding and alighting or just boarding or alighting. However, most operators outside of London have single doorway (with double doors) vehicles so the impact of this factor may not be possible to isolate. Operators in London, by contrast have vehicles with a doorway at the front near the driver and one in the middle of the vehicle. When articulated buses are used, three doorways are typically provided, one at the front, one in the middle and one at the rear.

55. Another factor considered in the literature is the amount of space passengers have to enter and leave the bus and to circulate within. This can vary substantially, depending on local circumstances, practices, legislation and the age of vehicles. This

factor will have a lesser impact in current operations than historically would be the case due to changes in operating vehicle design, primarily due to Disability Discrimination Act legislation which has required buses to have easy access and space for wheel chairs to manoeuvre.

56. Other variables about vehicle characteristics do not appear to have been considered in the literature we have interrogated.

57. We propose to include vehicle characteristics relating to the number of doorways and the use of doors for alighting and boarding as explanatory variables but not to record other vehicle characteristics or any driver characteristics.

2.3.2 Weather

58. The impact of weather conditions was considered by a number of authors and ultimately shown to have little discernible impact on increasing travel time variability. It is generally agreed that rainfall reduces capacity within the network for all traffic and increases demand – both for car use and bus use – leading to heavily congested conditions. Once a network is heavily congested, the mean travel times are observed to be larger than uncongested networks, but the variability is often reduced, that is all journeys are consistently taking a long time.

59. We propose that weather is recorded during the pilot study, but do not suggest that substantial effort is made to obtain precise weather data – such as rainfall volume or visibility. Bearing in mind that the ultimate objective is to provide a technique to determine the impact of schemes that can be implemented, and no scheme can control the weather, the only influence in the study that needs to be considered is how to adjust our data to account for the weather.

2.3.3 Seasons

60. The impact of the seasonal differences in demand has not been considered in research we have reviewed. Whilst in some locations this has an impact on services, it is anticipated that operators modify their timetables to accommodate additional demand and different types of passenger.

2.4 Incidents

61. Although incidents, such as road traffic collisions or road works were recognised as having an impact on bus journey travel time variability there is very little research which reports the statistical significance of these variables. The main limitation on data is that the events are relatively rare, randomly distributed within the network and relatively short term – most incidents are cleared within an hour and most road works

are completed within a period of a few weeks – which is unlikely to yield representative data.

62. Those events that are longer and have a greater impact on bus services – such as imposing diversionary routes – are outside the scope of the project, as the study focus is for schemes that will be implemented and have a lifespan of several years. Furthermore, long term events usually involve revisions to the timetable to reflect anticipated changes in journey times.

63. Incidents are therefore unlikely to form a substantial part of the investigation, though their occurrence will be recorded.

2.5 Other factors

64. We have reviewed all the variables that have been included in the research papers that we have had access to and concluded that there are no significant oversights or omissions from the data which we propose to collect.

65. There are some variables which are not consistent with those that we have proposed, but generally, these are due to limitations of the data which has been made available to the respective researchers. For example, peak period is used as an explanatory variable in a number of papers as representative of different traffic volumes and trip purposes.

3 Review of statistical techniques

3.1 Metrics to Describe Journey Time Variability

66. Van Oort (2011) suggests:

> *"Given the stochastic nature of public transport operations, statistical measures such as standard deviation or percentiles are logical indicators."*

67. Hollander (2007) offers:

> *"Travel time variability is most commonly measured as the standard deviation of travel times (namely, of the set of travel time measurements that exhibit travel time variability as defined in the respective study)."*

68. In comparing different situations where mean values of travel time may be substantially different, the standard measure is the coefficient of variation [CV]. As discussed above, this is the recommended measure for urban travel time variability in general traffic (DfT 2013). Essentially, the CV indicates a journey becomes more reliable as the value tends towards 0.

69. This is the measure of variability which we propose to adopt in this study of bus journey travel time variability.

3.2 Statistical tests and definition of a transferable model

70. To establish the relationship between CV and the variables discussed in Section 2 we will collect journey time data and record incidents and characteristics of journeys during a pilot survey, which itself is discussed in more detail in Section 4.5 below.

71. We will test each variable against the calculated CV to determine whether there is a statistically robust relationship between CV and individual variables and then repeat the analysis by combining different variables using multivariate regression.

72. To undertake the statistical analysis of the dataset which we anticipate collecting we will utilise a specialist software package called R (http://www.r-project.org/).

73. Below we describe a worked example to demonstrate how the model will be estimated. For consistency we will maintain the notation used by Liu and Sinha (2007):

route:	*is a fixed set of road links and bus stops which are served by a set of bus vehicles (service) according to some schedule described by its frequency and the start of the first service*
service:	*the set of bus vehicles which run along the fixed bus route*
section:	*part of a route between two consecutive bus stops*
x	*sample measurements*
σ_x	*standard deviation of the sample {x}*
μ_x	*mean of the sample {x}*
i	*index for a bus route*
s	*index for a bus stop*
n	*index for a bus trip or vehicle*
m	*index for the mth day of observation*
$D_{i,n,s,m}$	*actual departure time on route i of trip n from stop s on day m*
$T_{i,n,m}$	*journey time of bus trip n on day m along route i*

74. We will begin with a single route (X37). Suppose this starts at bus stop 0 with scheduled departure time 08:01:00 for the 5th vehicle of the day. However, this is subject to delay on day 1, so we write $D_{X37,5,0,1}$ = 08:01:12 as the actual departure time on day 1. We record the vehicle travel time between stops 0 and 1 as $T_{in,s=1,m}$ and the dwell time $L_{in,s=1,m}$ which in our example are 13 minutes 31 seconds and 45 seconds respectively. The time to depart stop 1 will therefore be: $D_{in0m} + T_{in1m} + L_{in1m}$, or 08:15:28. More generally this is expressed as:

$$D_{insm} = D_{in(s-1)m} + T_{insm} + L_{insm}$$

75. Each of these “time” quantities is potentially random and can vary from day to day (m). Among other effects, we would expect the T variables to vary with general traffic conditions and characteristics on the link (i.e. the highway section between successive bus stops), and the L variables to vary with the number of boarders and alighters, as well as the ticketing arrangements. The dwell time may also be affected, for some stops, by timetabling requirements – i.e. buses may be “held” until the scheduled departure time.

76. These considerations suggest that at the least travel times T between stops and dwell times L at each stop need to be measured, separately for each vehicle, for a considerable number of days.

77. The same essential logic can be used to calculate appropriate journey times for analysis from the survey observations. For example, by combining running times and dwell times for adjacent stops, we can calculate the in-vehicle time between any pair of stops on any day and hence the day-to-day distribution of in-vehicle times.

78. This is similar to the approach used by Hyder et al (2007) which underpins WebTAG Unit 3.5.7. Hyder et al (2007) adopted a method of which allowed observations on successive links – defined as starting and ending at a timing point – to be combined into a journey with the arrival time at each timing point being recorded on a number of days. This in turn permitted the calculation of the distribution of journey times for the set of all possible point-to-point journeys.

79. For our worked example service, we generate a synthetic set of observations for three consecutive days for a route with 6 stops as shown in Table 2 below.

Table 2: Synthetic Journey Time Data

Journey Number	From Stop	To Stop	Average Total Travel Time (Stop Departure to Stop Departure) μ_x	SD Travel Time σ_x	Coefficient of Variation (CV)
1	0	1	00:12:31	00:01:25	0.1130
2	0	2	00:24:49	00:04:19	0.1742
3	0	3	00:36:58	00:05:00	0.1354
4	0	4	00:49:21	00:06:22	0.1289
5	0	5	01:08:47	00:15:55	0.2313
6	0	6	01:21:00	00:16:45	0.2068
7	1	2	00:10:18	00:02:55	0.2838
8	1	3	00:22:27	00:03:40	0.1633
9	1	4	00:34:50	00:05:07	0.1470
10	1	5	00:54:16	00:15:00	0.2763
11	1	6	01:06:29	00:15:47	0.2374
12	2	3	00:09:24	00:01:01	0.1078
13	2	4	00:21:47	00:02:40	0.1221
14	2	5	00:41:13	00:12:57	0.3144
15	2	6	00:53:25	00:13:38	0.2552
16	3	4	00:10:08	00:01:39	0.1626
17	3	5	00:29:34	00:11:57	0.4040
18	3	6	00:41:46	00:12:37	0.3021
19	4	5	00:17:41	00:10:18	0.5826
20	4	6	00:29:54	00:10:58	0.3670
21	5	6	00:11:13	00:01:05	0.0961

Where: x = 3

80. As noted in the table, the route is made up of numerous journeys – as defined by stop to stop observations. Each of these journeys has a CV value assigned to it which is the ratio of standard deviation to the mean.

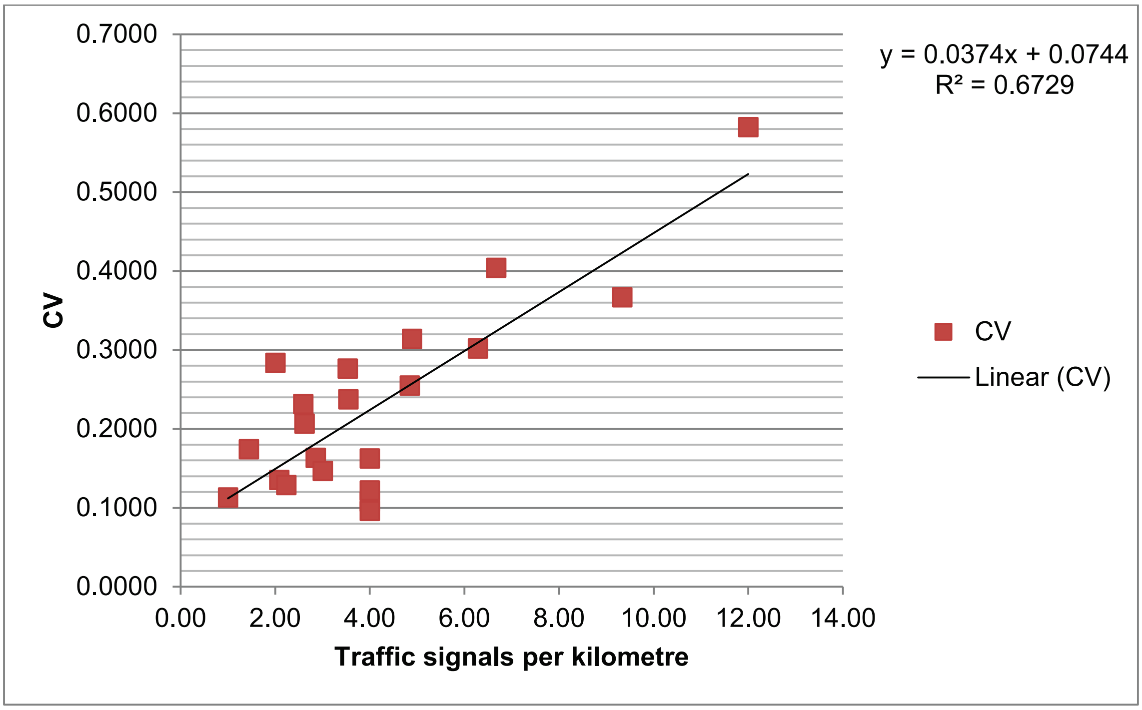
81. For each of these journeys, we can also record other variables, such as the number of traffic signals as shown in Table 3 below.

Table 3: Route Characteristics

Stop	Distance from previous stop (m)	Traffic signals from previous stop	Distance from origin (m)	Traffic Signals Encountered	Density of Traffic Signals / km
0	0	0	0	0	0.0000
1	5000	5	5000	5	1.0000
2	4000	8	9000	13	1.4444
3	3000	12	12000	25	2.0833
4	1000	4	13000	29	2.2308
5	500	6	13500	35	2.5926
6	250	1	13750	36	2.6182

82. We can now plot the CV value against the density of traffic signals and estimate the relationship between the two sets of data, as shown in Figure 1.

Figure 1: CV against traffic signal density



83. As Figure 1 is based on fabricated data with a very small sample size, the relationship, although in the correct direction, is not statistically significant.

84. By progressing the statistical analysis of each variable an outcome will be the identification of candidate combinations of variables such that a model to forecast CV values for different scenarios will be developed. In this case, the relationship is:

$$CV = 0.0374x + 0.0744$$

Where x = number of traffic signals per kilometre

3.3 Forecasting with the model

85. Once a model has been developed it is possible to employ it to determine how interventions might impact upon the travel time variability. Using our worked example, and accepting that it is statistically unreliable, we can employ the relationship to estimate the value of the current standard deviation of journeys on a route and the value of a "post" intervention standard deviation of journey times – assuming that the mean remains constant – which in itself is a notable assumption.

86. So using the 21 journeys of Table 2 and the relationship estimated in Figure 1 we can reproduce a before estimate of the standard deviation that would be expected for each journey in the "current" situation – along the route described in Table 3.

87. We can then "intervene" in the network, in this case by reducing the number of traffic signals to ¼ of the existing number. This intervention means we can apply our model to determine a new CV value which in turn provides a new standard deviation of journey times.

88. This progression from the base to forecast scenario is shown in Table 4 below.

Table 4: Forecasting with the travel time variability model

Journey	Obs. mean	Modelled CV	Modelled SD	Obs. Density of signals /km	Proposed density of signals /km	Forecast CV	Forecast SD	Reduction in SD
1	00:12:31	0.1118	00:01:24	1.0000	0.250	0.0837	00:01:03	-25%
2	00:24:49	0.1284	00:03:11	1.4444	0.361	0.0879	00:02:11	-32%
3	00:36:58	0.1523	00:05:38	2.0833	0.521	0.0939	00:03:28	-38%
4	00:49:21	0.1578	00:07:47	2.2308	0.558	0.0952	00:04:42	-40%
5	01:08:47	0.1713	00:11:47	2.5926	0.648	0.0986	00:06:47	-42%
6	01:21:00	0.1723	00:13:57	2.6182	0.655	0.0989	00:08:00	-43%
7	00:10:18	0.1492	00:01:32	2.0000	0.500	0.0931	00:00:58	-38%
8	00:22:27	0.1812	00:04:04	2.8571	0.714	0.1011	00:02:16	-44%
9	00:34:50	0.1865	00:06:30	3.0000	0.750	0.1024	00:03:34	-45%
10	00:54:16	0.2063	00:11:12	3.5294	0.882	0.1074	00:05:50	-48%
11	01:06:29	0.2068	00:13:45	3.5429	0.886	0.1075	00:07:09	-48%
12	00:09:24	0.2239	00:02:06	4.0000	1.000	0.1118	00:01:03	-50%
13	00:21:47	0.2239	00:04:53	4.0000	1.000	0.1118	00:02:26	-50%
14	00:41:13	0.2571	00:10:36	4.8889	1.222	0.1201	00:04:57	-53%
15	00:53:25	0.2554	00:13:39	4.8421	1.211	0.1196	00:06:24	-53%
16	00:10:08	0.2239	00:02:16	4.0000	1.000	0.1118	00:01:08	-50%
17	00:29:34	0.3236	00:09:34	6.6667	1.667	0.1367	00:04:02	-58%
18	00:41:46	0.3094	00:12:55	6.2857	1.571	0.1331	00:05:34	-57%
19	00:17:41	0.5229	00:09:15	12.0000	3.000	0.1865	00:03:18	-64%
20	00:29:54	0.4233	00:12:39	9.3333	2.333	0.1616	00:04:50	-62%
21	00:11:13	0.2239	00:02:31	4.0000	1.000	0.1118	00:01:15	-50%

89. As Table 4 shows, the application of this simple model demonstrates that the CV may be employed to estimate the change in travel time variability experienced due to changes to the variables which influence variability.

90. The fixed mean assumption expressed in paragraph 85 has been made due to the very small dataset used to provide an example. With a larger dataset it would be possible to identify how the mean changes with different route variables such that it would be possible to forecast a new mean journey time value as well as the new CV value.

91. Furthermore, Hyder et al (2007) identified that to calculate the standard deviation for multi-link journeys, such as those described in Table 2, simply adding each individual value is along the route. We will consider using the method recommended in Hyder et al to account for route section to route section correlation which essentially quantifies the coefficient of correlation and applies it within each journey.

4 Review of options for primary data collection

4.1 Bus journey time data – alternative data collection methods

92. We have reviewed the options available for gathering the data required for the statistical analysis and have concluded that direct observation is the only practical option that will provide the full range of data required. We have summarised in Appendix A how we propose collecting each item of data.

93. Secondary datasets which could assist in understanding the bus operations do exist. These include the automatic vehicle location data, branded locally as “Travel+”, and the timetable registered with the Traffic Commissioner, which is available as electronic data from the Traveline National Data Set (previously the National Public Transport Data Repository (NPTDR).

94. Of these datasets, the automatic vehicle location data is the most promising as it provides information similar to that recorded by global positioning systems – a global grid reference for location alongside a timestamp. This allows the data to be interrogated to provide actual rather than scheduled journey time information based on interpolating between location and time.

95. However, there are two access considerations which have an impact on whether this data can be used more generally. Firstly, much of this data is owned and controlled by operators and is typically regarded as commercially sensitive. While it is perfectly reasonable to assume that access could be arranged, it would be subject to negotiation on a case by case basis. Secondly, the operators may not retain records at a sufficient level of granularity for an appropriate period of time. Live bus tracking data has a very short useful life for an operator and as such there is little incentive to retain records of journey times for extended periods. Once the operator has reviewed the data and reacted to any apparent issues there is no reason to retain the information.

96. Therefore, the pilot study needs to demonstrate that data can be collected without the need to rely on access to data owned and controlled by bus operators.

97. Outside of access issues, automatic vehicle location data is also limited in that it does not record the cause of any delay or disruption, simply that a delay has occurred happened and the location where it occurred. Whilst some disruptions can be inferred from the data – such as dwell times at bus stops or delay at junctions – information such as the number of boarding passengers or whether the bus was “let out into the traffic” is not recorded.

98. For the purposes of this study, we will need to identify these variables within our data in order to quantify their significance. Ultimately, it may be proved that data about these variables can be successfully inferred from global positioning system location data, and that if automatic vehicle location data captures the same information, it will be an appropriate secondary data source.

99. The Traveline National Data Set is timetable data, so is not directly relevant to the study as it does not have any information on the actual variation of specific journeys.

100. Data obtained by Traffic Commissioners is limited to the definition of reliability which it employs – that 95% of buses run within 1 minute before and 5 minutes after the published timetable. This data, for reasons explained in paragraph 6, is inadequate for this study.

101. Therefore, for bus data for the purposes of the pilot study needs to be collected by direct observation.

102. Ultimately, we may demonstrate that some variables do not require data collected by direct observation as the statistical analysis will demonstrate a lack of significance in their contribution to variability. These will be documented in our final report and removed from the suggested list of variables to consider.

103. If the statistical analysis does demonstrate that the variables which require primary observation may be excluded from future data collection it is entirely possible that the bus journey time variability may be modelled using secondary data available from the through automatic vehicle location datasets.

4.2 Other traffic journey time data – alternative data collection methods

104. For non-bus traffic, an appropriate primary data collection method is described in DfT (1997) which essentially requires timed runs of the subject route. These could be completed using modern global positioning system devices.

105. For the purposes of the pilot study we do not require information about the causes of variability for general traffic – those that disrupt the bus service will be identified by the enumerators on the buses. Therefore, primary data collection is much simpler – requiring a driver with a global positioning system device to traverse the route.

106. We suggest that data is collected, subject to the budget being made available, during the survey period to provide a dataset for general traffic which correspondents to the bus journey time dataset.

107. An alternative source of journey time data is that derived from satellite navigation system providers. One such source is Trafficmaster data which is available through the DfT itself.

108. The Trafficmaster data is gathered from two sources, by in vehicle devices operating in a similar manner to global positioning devices and road side detectors observing traffic speeds. The data is used in satellite navigation devices and by vehicle fleet managers to plan routes. This dataset shares a number of characteristics with other satellite navigation datasets, which could provide an alternative should Trafficmaster not be available for a specific site.

109. We have undertaken a preliminary assessment of one of the Trafficmaster datasets which has information summarised by quarter hour period based on the number of observations in that period for each link in a network. Whilst it is possible to identify the average journey travel time and standard deviation of journey time – and therefore the coefficient of variation – the observations tend to be from a small number of vehicles.

110. For example, on a section of the route which has been identified for the pilot study in October 2012 the number of observations during the month by period is shown in Table 5 below.

Table 5: General traffic journey time observations in Saltford

	Morning Peak (07:00 to 09:59)	Inter Peak (10:00 to 15:59)	Afternoon Peak (16:00 to 18:59)	Off Peak (19:00 to 06:59)	Total
Monday	43	76	26	22	167
Tuesday	43	99	33	39	214
Wednesday	37	96	36	36	205
Thursday	40	76	27	27	170
Friday	36	92	21	34	183
Saturday	18	57	16	14	105
Sunday	12	30	9	12	63
Total	229	526	168	184	1107

Note: data is from link 3435473 which is 98 metres in length, runs towards Bristol and situation immediately outside "The Crown" public house.

111. As Table 5 shows there were 1,107 observations recorded during October 2012 with the greatest number of observations falling on weekdays.

112. Further analysis of the data, to consider the variability between periods of the day is shown in Table 6 below.

Table 6: Average journey times (seconds) by day and period

	Morning Peak (07:00 to 09:59)	Inter Peak (10:00 to 15:59)	Afternoon Peak (16:00 to 18:59)	Off Peak (19:00 to 06:59)	Average
Monday	12.4	13.1	15.5	10.2	12.9
Tuesday	13.5	15.7	16.4	9.0	14.0
Wednesday	14.3	16.2	17.8	12.8	15.5
Thursday	15.0	12.0	17.4	8.7	13.1
Friday	26.3	19.2	19.3	8.7	18.5
Saturday	31.8	16.7	17.2	8.8	18.4
Sunday	8.0	9.6	20.5	7.7	10.6
Average	16.9	15.1	17.5	9.7	14.9

Note: data is from link 34335473 for October 2012.

113. The analysis of the data in Table 6 suggests that the most variable period is the morning peak (07:00 to 09:59) with a range during the working week of 13.81 seconds within the working week.

114. Table 7 considers the CV by period by day of the week from the data we have to hand to determine when the most variable periods of the week are.

Table 7: Standard deviation of journey times by day and period

	Morning Peak (07:00 to 09:59)	Inter Peak (10:00 to 15:59)	Afternoon Peak (16:00 to 18:59)	Off Peak (19:00 to 06:59)	Average
Monday	2.25	1.99	3.60	2.70	1.24
Tuesday	2.76	2.69	3.44	1.67	1.48
Wednesday	3.79	2.04	3.54	3.09	1.41
Thursday	2.95	1.64	3.78	1.89	1.19
Friday	10.96	2.29	5.20	1.59	2.48
Saturday	20.96	2.59	5.52	2.63	3.80
Sunday	2.55	1.89	15.00	2.49	2.22
Average	2.25	1.99	3.60	2.70	1.24

Note: data is from link 34335473 for weekdays in October 2012.

115. The figures from Table 6 and Table 7 provide the CV values which are shown in Table 8 below.

Table 8: Coefficient of variation [CV] of journey times by day and period

	Morning Peak (07:00 to 09:59)	Inter Peak (10:00 to 15:59)	Afternoon Peak (16:00 to 18:59)	Off Peak (19:00 to 06:59)	Average
Monday	0.181	0.152	0.232	0.263	0.096
Tuesday	0.204	0.171	0.210	0.187	0.106
Wednesday	0.264	0.126	0.199	0.242	0.091
Thursday	0.196	0.137	0.217	0.217	0.091
Friday	0.418	0.119	0.269	0.182	0.134
Saturday	0.659	0.155	0.321	0.300	0.207
Sunday	0.319	0.198	0.731	0.324	0.209
Average	0.181	0.152	0.232	0.263	0.096

Note: data is from link 34335473 for weekdays in October 2012.

116. As Table 8 shows there are some periods of the week when the journey times are extremely variable, such as Saturday mornings and Sunday afternoons. It is likely that these results are due to outliers in the data or events that are not common during the week. The inter peak period is the most stable period over the whole week with CV values consistently between 0.1 and 0.2. The weekday morning and afternoon peaks are similar to one another in terms of variability – with Friday morning standing out as an extreme value.

117. Overall, this simple analysis does highlight the weakness of the Trafficmaster data in that the reasons for these variations cannot be identified from the data. It may be a recurring event, such as refuge collection, or a series of unique events that in combination caused variation in the journey travel times.

118. However, as discussed above, as we do not require information about the cause of journey time variability for general traffic the Trafficmaster data is considered to be an adequate dataset as it does allow a comparison between conditions for general traffic and the bus journey time variability.

4.3 Pilot study sites available

119. We have reviewed potential sites for the pilot study within the parameters of:

- Having an active and relevant – defined as a physical infrastructure scheme – Local Sustainable Transport Fund (LSTF) bid currently in progress; and
- Being located within an urban area with a population of more than 100,000 but not within a conurbation.

120. From our review of the information available about these schemes, including discussions with the DfT, we have concluded there are two potential locations which can be explored further, Bristol and Bournemouth.

4.3.1 Bristol

121. As part of the Greater Bristol Bus Network (GBBN) strategy a range of schemes are being proposed to improve bus service reliability in the city and its environs. Included in this package are a number of measures to:

- Improve bus punctuality in the North Fringe; and
- Introduce bus priority measures along the A4.

122. Both of these elements of the GBBN strategy fulfil the requirement of including physical measures, as both propose modifications to existing signal controlled junctions, the implementation of bus lanes, changes to bus stop infrastructure and the introduction of selected vehicle detection transponders to buses.

4.3.2 Bournemouth

123. Within the "South East Dorset Sustainable Travel Package – The Three Towns Corridor" there are proposals to introduce new sections of dedicated bus lanes, targeted in areas where buses currently experience delays caused by queuing traffic.

124. The packages also involves enhancements to existing bus lanes, at identified locations where there are opportunities to provide additional benefits. In addition, the proposed measures will be complemented with changes to junction control strategies.

125. The effectiveness of all bus lanes along the corridor will be enhanced through increased enforcement in order to maximize the benefits of journey time savings. As part of this activity, existing loading and parking restrictions will be reviewed and amended.

4.3.3 Summary of locations

126. Of the two potential sites, both offer limited opportunity to obtain "before" data about variability within the network ahead of improvements being implemented. We will work with the scheme promoters to precisely identify the schemes and make further proposals with regard to their suitability once these discussions have concluded.

4.4 Review of existing data at the pilot sites

4.4.1 Bus operations

127. The latest annual bus statistics from the Department of Transport (2011-2012) show that an increasing number of buses are equipped with Automatic Vehicle Location devices, with the percentage for England (outside London) standing at 73%.

128. For both Bristol and Bournemouth we are aware that this data is now routinely collected by bus operators. We have not had direct access to the data collected but anticipate it will provide the following information in sufficient detail for our study:

- Vehicle location;
- Vehicle speed;
- Dwell times at bus stops;
- Waiting times at junctions associated with transient delay – i.e. the delay built into the system at traffic signals;
- Waiting times at junctions associated with over-capacity delay – i.e. the delay caused by traffic in excess of capacity;
- Duration of delays by individual vehicle;
- Frequency of delay at specific locations, or proximate locations, within a period (peak hour, peak period, day, week);
- Headway between buses on the same highway section, but not necessarily the same service.

129. We have not approached the operators yet to secure access to this data and will need to confirm our specific requirements with them and arrangements to obtain the data during the pilot survey period.

4.4.2 Bus passengers

130. Published data available in both locations is not sufficiently detailed. We are aware that the operators collate data on passenger numbers in categories for their commercial and statutory reporting purposes, but these records are not consistent with the needs of this study.

131. As discussed above the requirements of this study extend beyond data collected by passenger ticket type by each driver during a shift: they need to include information about the transaction duration and information about the number of passengers alighting.

4.4.3 Physical characteristics of routes

132. In both locations the general approach to obtaining data about physical characteristics of routes is to obtain basic information through third party mapping or digital imagery and validate this with on-site observations.

133. We will complement this information by liaising with the local highway authority to obtain information about traffic regulation orders controlling parking and bus lane

operation. The content of the TROs will be validated against on-street signing and lining to verify that records are up to date and correct.

4.4.4 Non-bus service characteristics

134. We have started the process of securing Trafficmaster data for Bristol which will be used to determine the travel times of traffic using the same parts of the network for the same periods as the pilot bus routes. We will need to determine the time lag between the pilot study and the Trafficmaster data becoming available.

135. The degree of integration between buses and general traffic will be recorded by combining information about bus lanes and other priority measures from the local highway authority with information observed by the enumerators collecting along route observations as well as those on the buses themselves.

136. Turning movements at key junctions will be obtained from count information held by the local highway authority. If none is available, which will be identified once the pilot location has been agreed, we will estimate the value of undertaking traffic surveys and make these costs known to the Department.

137. As discussed above, given that weather and climatic conditions have been shown to have very little impact on journey time variability, we will only record information by observation and will not be seeking to use third party data.

4.5 Primary data collection during the pilot study

4.5.1 Bus operations

138. We propose to collect data which records the “reasons” for delays and disruptions. As noted above, Automatic Vehicle Location data collects basic information about the duration of a delay or the location where a bus service was disrupted, but does not provide the additional data to explain the events at or around the vehicle. Key within this dataset are observations on the time taken for buses to return to cruise speed after servicing bus stops or negotiating obstructions within bus lanes or junctions.

4.5.2 Bus passenger information

139. We propose to collect data using enumerators on the buses regarding the passengers which will include:

- Number of tickets sold on-vehicle and complexity of transactions;
- Number of cashless boardings;
- Proportion of passengers with difficulty “stepping on / stepping off” the bus; and
- Number of passengers alighting and boarding at each individual bus stop.

4.6 Data “Cleaning”

4.6.1 Bus operations

140. The data collected for bus operations will be cleaned prior to being processed. The cleaning process will use a series of logic tests to ensure it is appropriate for use in statistical analysis. The logic tests will include, but may not be limited to, the following:

- Are the surveys on the correct routes?
- Are records of journeys complete?
- Do the data progress in the correct direction and increase incrementally?
- Do journey times fall within sensible thresholds?
- Have the enumerator observations recorded all items of data required?
- Are the enumerator records consistent – by time and direction – with the automatically collected data?

141. These simple checks will verify that the data is usable in statistical analysis.

4.6.2 Bus passenger information

142. We propose to validated the data collected using enumerators on the buses regarding the passengers with a series of logic checks including, but not limited to:

- Was the number of tickets sold reasonable?
- Was the number of cashless boardings reasonable?
- Do the volume of boarders and alighters across the route match?

143. These validation tests will verify the data is fit to be used in analysis.

4.6.3 General traffic data

144. The Trafficmaster data will be cleaned by the provider prior to be issued for further analysis. We will undertake a filtering process to limit the dataset we use to those routes on which the buses run and for the periods in which we have collected data.

5 Summary and Proposal

5.1 Summary of literature

145. The body of literature we have reviewed addresses a number of issues that contribute to bus journey time variability but none of the papers present a systematic approach to isolating all of the contributory factors which have been identified. Most of the papers focus on particular issues and generalise other variables, such as the volume of traffic for example, which is generalised to "peak" or "off peak."

146. Therefore, we conclude that there is no substantial body of work which can be considered best practice in the area of bus journey time variability estimation.

5.2 Proposal for pilot study

147. We propose that Bristol and Bournemouth are both approached to confirm that their proposed schemes are adequate to allow sufficient data to be collected for the study.

148. The pilot study should be undertaken in accordance with the methodology articulated in the project proposal. Our data collection proposals are summarised in Appendix A.

6 Selected Reading

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Appendix A Data Collection Proposals

General Element	Specific item	Collection technique	Units
General traffic	Volume	Traffic data from local highway authority	Vehicles per hour; Volume to capacity ratio
	Speed	Data from traffic master	Average kilometres per hour
	Travel time variability	Data from Trafficmaster	Range of observed values of kilometres per hour
Priority at junctions	Junction type	Digital mapping and on-site observation	
	Junction capacity	Available models	Ratio of flow to capacity in peak hour
Route length		Digital mapping	Kilometres
Number of bus stops in route (planned)		TNDS data, on-site investigation and confirmation with operator	Number
Number of bus stops in route (used)		On board observation	Number
Priority between junctions (segregated lanes)	Location and length of bus lanes	On-site observation, traffic regulation order and digital mapping	Kilometres
	Hours of operation	Traffic regulation orders	Hours per day
	Violations	Local highway authority records	Number
Vehicle spacing policies	Operator strategy	Liaison with the operator	Description
Ticket type	Proportion of different tickets used in general	Liaison with the operator	Reported ratio
	Proportion of different tickets used in pilot	On bus observation (split between cash / non-cash only)	Observed ratio
Physical characteristics of the stops	Arrangements for boarding and alighting	On-site observations	Check list of common items
Experience of drivers		Requested from driver	Years

Number of doors		On board observation	Number
Weather		On board observation	Description
Bus vehicle location	Minute by minute location of buses in service	Automatic vehicle location	Ordnance survey grid reference
Vehicle speed	Minute by minute estimate of bus speed whilst in service	Automatic vehicle location	Kilometres per hour
Dwell times at bus stops	Time spent slowing, stopped and moving away from bus stops	Automatic vehicle location	Seconds
Waiting times at junctions	Time spent at junctions	Automatic vehicle location	Seconds
Waiting times on links	Time spent in queues	Automatic vehicle location where speeds is below a threshold of 5 mph	Seconds
Frequency of delay at specific locations	Consistent points where the bus in service is delayed	Automatic vehicle location	Number
Causes of delay	Categorisation of the how the delay was caused	On-board observation	Description
Proportion of passengers with difficulty "stepping on / stepping off" the bus		On board observation	Number
Number of passengers alighting and boarding at particular bus stops		Driver operated ticket machine and on-board observation	Number

Note:

The data collection approach will be finalised once the pilot site has been confirmed.