Transport for London

Performance Information - Buses

QSI Statistics Explained

iBus Quality of Service Indicators

v2.0 09.12.2013

The purpose of this document is to assist Bus Operators in understanding the QSI measures and calculations that are applicable for High and Low Frequency routes.

This document replaces the ‘High Frequency Calculations Explained’ and ‘Low Frequency Calculations Explained’ published in 2002.

The document is part of a set describing the QSI processes under iBus which also includes ‘iBus Missing Data Mitigation’ for QSIs, ‘iBus Data Cleansing for QSIs’ and ‘iBus Data Aggregation for QSIs’.

Contents

1. Introduction

Background

1.1. Bus Service QSIs started in 1977 with a team of survey staff (Traffic Recorders) recording times of buses on routes as they departed from designated stops. Recordings were made on hand-held data terminals and were downloaded into a computer programme which analysed the service from the **passenger's point of view**. Routes were split into two categories:

- High frequency services with QSI emphasis of <u>regularity</u> of service.
- Low frequency services with QSI emphasis on <u>punctuality</u> of service.

1.2. The scale of surveys increased over the years to give more robust results as monitoring of route performance took on much more importance, particularly with the move to Quality Incentive Contracts starting in 2001/02.

1.3. QSIs have always been an evolving system and use of automatic vehicle location (AVL) technology via iBus has provided a way forward as the main method of QSI data collection. The larger quantity of data available allows for more robust monitoring of service quality with easier identification of recurrent problems to assist decisions in overcoming such deficiencies.

1.4. Roadside observers were replaced by data collected via iBus from April 2011. There followed a 'transition' period whereby iBus was initially used to collect data based on the legacy survey design with High Frequency routes moving to full iBus from April 2012 and Low Frequency routes from April 2013.

Route Frequency

1.5. Routes are categorised by frequency as High Frequency or Low Frequency services.

1.6. <u>High frequency services</u> are those with general weekday daytime frequencies of five buses per hour or more. High frequency routes account for over 80% of scheduled mileage. <u>Low frequency services</u> are those with service intervals of 15 minute or more during the daytime on weekdays.

1.7. A slightly different approach is taken for night routes where frequencies of at least four buses per hour on weekdays but higher frequencies at weekends are classified as high frequency. Other night routes are categorised as low frequency.

High Frequency Services

1.8. A passenger using a high frequency service is more inclined to turn up at a bus stop randomly and not to have consulted a timetable in order to catch a specific bus. It is important therefore to measure the *regularity* of the service, i.e. the interval (or headway) between buses. It is more important to the passenger that a bus turns up regularly even if there have been cuts in the number of buses running.

1.9. The key components when looking at the reliability of High Frequency services are:

1.9.1. Scheduled Waiting Time (SWT): the scheduled service interval between buses.

1.9.2. Actual Waiting Time (AWT): the observed service interval between buses.

1.9.3. Excess Waiting Time (EWT): the difference between the Actual Waiting Time (i.e. what the passenger experienced) and the Scheduled Waiting Time (what the service interval was expected to be).

1.9.4. Long Gaps (LG): gaps in service that are significantly larger than scheduled.

Low Frequency Services

1.10. A passenger using a low frequency service is assumed to have consulted a timetable in order to catch a specific bus. It is important therefore to measure the *punctuality* of the service, i.e. how late or early the bus was at a bus stop in relation to what the passenger expected.

1.11. The key components when looking at punctuality of Low Frequency services are:

1.11.1. On-time %: the percentage of expected buses observed as 'on time'.

1.11.2. Early %: the percentage of expected buses observed as 'early'.

1.11.3. Late %: the percentage of expected buses observed as 'late'.

1.11.4. Non Arrival %: the percentage of expected buses that were not observed or were observed outside of the 'early' or 'late' parameters.

QSI Calculations

1.12. The minimum element of QSI calculation is for one hour at one QSI point in one direction on one route. iBus stores the results of these 'hourly block' calculations, as described in this document, in the London Reporting Database (LRD).

1.13. The hourly block calculations are performed more than once. Firstly they are calculated as part of the daily 'staging' process whereby data collected from the buses is validated against the route schedules held in the LRD and secondly after the data cleansing processes which mitigate against corrupt or unrepresentative data have been performed. The document entitled 'iBus Data Cleansing for QSIs provides further information.

1.14. The hourly blocks can then be combined across time and locations to produce aggregated QSI results. The methodology used for this aggregation includes weighting factors and is explained in a separate document entitled ‘iBus Data Aggregation for QSIs’.

2. Expected and Observed Buses

Scheduled Buses (EB)

2.1. This is the number of scheduled (expected) bus departures at a location / hour.

2.2. For calculations covering multiple locations and/or hours the sum of the scheduled buses is used.

Excluded Buses (EB_E)

2.3. This is the number of scheduled (expected) bus departures marked as ‘excluded’ (i.e. not used for QSI calculations) at a location / hour. For one hour at one location either all buses will be excluded or all buses will be included (partial hours are not excluded). The Data Exclusion process is explained in the separate document entitled ‘iBus Data Cleansing for QSIs’.

Removed Buses (EB_R)

2.4. This applies only to Low Frequency routes.

2.5. This is the number of scheduled (expected) bus departures marked as ‘removed’ from the Linking Process (see Section 5) and arises where an “imputable” cause code has been assigned. Imputable cause codes and the Data Removal process are explained in the separate document entitled ‘iBus Missing Data Mitigation for QSIs’.

Expected Buses (EB_I)

2.6. For High Frequency routes this is defined as the sum of expected bus departures for non-excluded (i.e. included) hourly totals:

$$EB\_I = EB - EB\_E$$

2.7. For Low Frequency routes the formula also needs to take account of buses removed from the linking process:

$$EB\_I = EB - (EB\_E + EB\_R)$$

Observed Buses (OB)

2.8. This is the number of observed bus departures at a location / hour (ignoring any observed buses which have been coded as lost mileage).

2.9. For calculations covering multiple locations and/or hours the sum of the observed buses is used.

2.10. The sum of observed buses does not include those observed buses for hourly totals that have been marked as excluded.

Observed %

2.11. This is the volume of observed buses as a proportion of those expected. For a location / hour:

$$Observed\ \% = (OB / EB\_I) \times 100$$

2.12. This percentage can be over 100 and would occur if an Operator ran extra buses than indicated in the schedule.

2.13. For calculations covering multiple locations and/or hours:

$$Observed\ \% = (sum\ of\ OB / sum\ of\ EB\_I) \times 100$$

3. High Frequency Reliability Statistics

Scheduled Waiting Time (SWT)

3.1. SWT is defined as the time passengers would wait, on average, if the service ran exactly as scheduled during the period under calculation. This is equivalent to half the *scheduled* interval between buses.

3.2. For a particular route, direction and QSI point combination SWT is evaluated for each hour block (‘hourly total’). For any hour that contains **only** a first bus (either scheduled or observed) the SWT should not be calculated.

3.3. If the calculation results in zero divided by zero the result for SWT is set as zero. Any hour where this zero result occurs is not included when aggregating SWT.

3.4. The formula used to calculate hourly SWT (hSWT) is:

$$hSWT = \frac{\sum^{n} (SH_i \times SH_i)}{\sum^{n} (2 \times SH_i)}$$

SH	*The scheduled headway in minutes calculated as the difference between a scheduled departure of a bus and the scheduled departure of the preceding bus on the same route/direction at a QSI point. If a bus is the first bus the headway is set as zero.*
i	*The variable used to represent an individual headway.*
n	*The total number of headways within the hour block for the route, direction & QSI point combination being calculated.*
h	*Hourly.*

3.5. Example 1 shows the calculation of hSWT for Route A, Direction 1, QSI point X and hour beginning 09:00:

Example 1

Scheduled Time	Scheduled Headway (SHi)	Headway Squared (SHi x SHi)
08:45:00	*0*	
08:55:00	10	100
09:05:00	10	100
09:17:00	12	144
09:29:00	12	144
09:41:00	12	144
09:53:00	12	144
10:05:00	12	144

$$hSWT = \frac{100 + 144 + 144 + 144 + 144}{2 \times (10 + 12 + 12 + 12 + 12)} = \frac{676}{116} = 5.83$$

3.6. It is necessary to aggregate hSWT across time and/or locations to generate QSI results. The methodology used is detailed separately in the document entitled ‘QSI Aggregation in iBus’.

Actual Waiting Time (AWT)

3.7. AWT is defined as the time passengers wait, on average, during the period under calculation. This is equivalent to half the *observed* interval between buses.

3.8. For a particular route, direction and QSI point combination AWT is evaluated for each hour block. As with SWT, for any hour that contains **only** a first bus (either scheduled or observed) the AWT should not be calculated.

3.9. As with SWT, if the calculation results in zero divided by zero the result for AWT is set as zero. Any hour where this zero result occurs is not included when aggregating AWT

3.10. The formula used to calculate hourly AWT (hAWT) is:

$$hAWT = \frac{\sum^{n} (OH_i \times OH_i)}{\sum^{n} (2 \times OH_i)}$$

OH	*The observed headway in minutes calculated as the difference between a observed departure of a bus and the observed departure of the preceding bus on the same route/direction at a QSI point. If a bus is the first bus the headway is set as zero.*
i	*The variable used to represent an individual headway.*
n	*The total number of headways within the hour block for the route, direction & QSI point combination being calculated.*
h	*Hourly.*

3.11. Example 1 shows the calculation of hAWT for Route A, Direction 1, QSI point X and hour beginning 09:00:

Example 2

Observed Time	Observed Headway (OHi)	Headway Squared (OHi x OHi)
08:47:00	*0*	
08:56:00	9	81
09:06:00	10	100
09:19:00	13	169
09:28:00	9	81
09:44:00	16	256
09:59:00	15	225
10:05:00	6	36

$$hAWT = \frac{100 + 169 + 81 + 256 + 225}{2 \times (10 + 13 + 9 + 16 + 15)} = \frac{831}{126} = 6.60$$

3.12. As with hSWT, it is necessary to aggregate hAWT across time and/or locations to generate QSI results. The methodology used is detailed separately in the document entitled 'QSI Aggregation in iBus'.

Excess Waiting Time (EWT)

3.13. The Excess Waiting Time (EWT) is the difference between the Actual Waiting Time (AWT) and the Scheduled Waiting Time (SWT).

3.14. EWT represents the amount of time that a passenger has had to wait in excess of the time that they should expect to wait based on the schedule. In order to calculate EWT for a particular route, direction, hour and QSI point combination the following calculation is performed:

$$hEWT = hAWT - hSWT$$

(where h='hourly')

3.15. If either hAWT or hSWT does not contain a result, or has been set as 0, then hEWT is not calculated for that hour.

3.16. Example 3 shows the calculation of EWT using the results from Examples 1 and 2 above:

Example 3

$$hEWT = 6.60 - 5.83 = 0.77$$

EWT Minimum Standard

3.17. This is the minimum standard that a route is expected to achieve for Excess Waiting Time. Bus Operators are incentivised to achieve an EWT figure that is less than the minimum standard.

3.18. The aggregation of the EWT Minimum Standard follows the same rules as defined for the SWT values.

Variance from EWT Minimum Standard (EWT_Var)

3.19. This is the difference between the EWT minimum standard and the EWT. In order to calculate the variance from EWT minimum standard for a particular route, direction, hour and QSI point combination the following formula is used:

$$hEWT\_Var = EWT\ minimum\ standard - hEWT$$

(where h='hourly')

3.20. It can be seen from this formula that if a route is performing better than its minimum standard then the variance will be positive. A negative variance indicates that a route is not meeting its minimum standard.

AWT / SWT Ratio

3.21. The AWT/SWT Ratio is the ratio between the Actual Waiting Time (AWT) and the Scheduled Waiting Time (SWT). A value of 1.0 indicates that the average waiting time is equal to the scheduled waiting time. Higher values indicate worsening performance.

3.22. In order to calculate the AWT/SWT ratio for a particular route, direction, hour and QSI point combination the following calculation is performed:

$$hAWT/SWT\ Ratio = hAWT\ /\ hSWT$$

(where h='hourly')

3.23. If either hAWT or hSWT does not contain a result, or has been set as 0, then the ratio is not calculated for that hour.

% Chance of Waiting > x Minutes

3.24. The chance of waiting calculation provides the percentage chance of a customer waiting longer than x minutes for a bus, where x is provided. The chance of waiting percentage value must be between 0 and 100 inclusive.

3.25. The chance of waiting is calculated by finding all headways that are larger than x for a unique combination of QSI point/route/direction/hour. Once identified, x should be subtracted from each of these headway values. The remaining time is then allocated to the hour in which it falls.

3.26. The result of this process is, for each hour, the amount of time that a customer would have to wait longer than x minutes. This amount of time is then divided by 60 (number of minutes in an hour) and expressed as a percentage.

3.27. Example 4 considers a chance of waiting > 10 minutes for a particular QSI Point/direction/route:

Example 4

Observed Time	Observed Headway
10:00:00	0
10:13:00	13
10:20:00	7
10:32:00	12
10:44:00	12
11:00:00	16

There are four headways that are greater than ten minutes as highlighted. For each one subtract ten minutes and sum the results:

$$\textit{Chance of waiting} > 10mins \quad = (13\text{-}10)+(12\text{-}10)+(12\text{-}10)+(16\text{-}10) / 60 \quad = 13/60 \quad =21.7\%$$

Long Gaps (LG)

3.28. The Long Gaps measure is used to identify gaps in a bus service that are significantly larger than scheduled. The measure shows the percentage occurrence of these gaps in a given time period.

3.29. Long Gaps uses the Chance of Waiting > x Minutes calculation. The x here is the SWT multiplied by four. The lowest value x can be is *ten*. If SWT × 4 evaluates to less than ten then x is set as ten. This is because it is expected that a customer would not perceive a gap between buses of less than ten minutes to be ‘long’.

3.30. Long gaps are calculated for each unique combination of hour/route/direction/QSI Point. It is therefore necessary to use the SWT value for the same combination.

3.31. Example 5 shows the Long Gaps calculation where 4×SWT is greater than ten minutes. Thus it is necessary to calculate the Chance of Waiting greater than 4 × SWT.

Example 5

Scheduled Time	Scheduled Headway	Observed Time	Observed Headway
10:00	-	10:00:00	-
10:10	10	10:15:00	15
10:20	10	10:20:00	5
10:32	12	10:45:00	25
10:44	12	10:49:00	4
10:56	12	10:58:00	9

The first stage is to calculate the hSWT for 10:00-11:00 using the methodology in Example 1. This gives an hSWT of 5.64mins. Thus Long Gaps in this example is the chance of waiting more than 22.56mins (4 x SWT).

There is one headway that is greater than 22.6 minutes:

$$\text{Long Gaps} = (25 - 22.6) / 60 = 2.4 / 60 = 4.0\%$$

Long Gaps Benchmark

3.32. This is the value that defines the percentage Long Gaps benchmark that a route is expected to achieve. Operators should aim to achieve a long gaps percentage below that of the benchmark.

Variance from Long Gaps Benchmark (LG Var)

3.33. This value measures the difference between the Long Gaps benchmark and the Long Gaps %. In order to calculate the variance from the Long Gaps benchmark for a particular route, direction, hour and QSI point combination the following formula is used.

$$hLG\_Var = LG\ benchmark - hLG$$

(where h='hourly')

Maximum Gap

3.34. This measure gives the maximum observed headway at a location or locations over a chosen period of time.

3.35. The 'maximum gap' can be calculated by simply looking for the maximum headway.

4. Low Frequency Reliability Statistics

Overview

4.1. Low Frequency punctuality statistics are derived from the outcome of the 'LINKING' process. There are two types of linking; 'LINKING BY TIME' (see Section 5 for details) and 'LINKING BY TRIP' (See Section 6 for details).

4.2. For punctuality statistics the outcome of the 'LINKING BY TIME' process is used.

4.3. Linking provides four categories of bus arrivals: On-Time, Late, Early and Non-Arrival. The proportion of the total expected buses that fall into each of these categories can be calculated and are expressed as percentages.

4.4. The sum of On-Time %, Early %, Late % and Non-Arrival% for a unique combination of QSI point/route/direction/hour must always equal 100%. Thus the value of any single category cannot exceed 100%.

On-Time % (OT%)

4.5. For a particular route, direction and QSI point combination On-Time % is evaluated for each hour block ('hourly total').

4.6. The formula used to calculate On-Time % is:

$$OT\,\% = (\text{Sum of buses time linked as 'on time'} / EB\_I) \times 100$$

4.7. Example 1 calculates the On-Time % for a specific route/direction/ QSI point for the 10:00 hour:

Example 1

Bus	Scheduled Time	Observed Time	Linking Status
1	10:05	10:10:00	On Time
2	10:25	10:31:00	Late
3	10:45	10:44:00	On Time
4	10:59	11:08:00	Late
5	11:25	11:26:00	On Time

It should be noted that in this example there are 4 expected buses. This is because it is the scheduled time of a bus that is used to determine the time period and not the observed time.

On-Time % = (Sum of buses linked 'on-time' / EB_I]) * 100 = (2 / 4) * 100 = 50.0%

Late % (L%)

4.8. For a particular route, direction and QSI point combination Late % is evaluated for each hour block ('hourly total').

4.9. The formula used to calculate Late % is common to that used for On-Time % and again it is not possible for this value to exceed 100%:

$$L\ \% = (\text{Sum of buses time linked as 'late'} / EB\_I) \times 100$$

4.10. In 'Example 1' above, the Late % is 50.0%.

Early % (E%)

4.11. For a particular route, direction and QSI point combination Early % is evaluated for each hour block ('hourly total').

4.12. The formula used to calculate Early % is common to that used for On-Time % and again it is not possible for this value to exceed 100%:

$$E\% = (\text{Sum of buses time linked as 'early'} / EB\_I) \times 100$$

4.13. In 'Example 1' above, the Early % is 0.0%.

Non-Arrival % (NA%)

4.14. For a particular route, direction and QSI point combination Non-Arrival % is evaluated for each hour block ('hourly total').

4.15. The formula used to calculate Non-Arrival % is common to that used for On-Time % and again it is not possible for this value to exceed 100%:

$$NA\ \% = (\text{Sum of buses time linked as 'non arrival'} / EB\_I) \times 100$$

4.16. In 'Example 1' above the Non-Arrival % is 0.0%.

Linked % (Lk%)

4.17. Linked % is sum of buses linked as on-time, late or early.

4.18. In 'Example 1' above the Linked % is 100.0%.

Aggregation

4.19. It is necessary to aggregate punctuality statistics across time and/or locations to generate QSI results. The methodology used is detailed separately in the document entitled 'iBus Data Aggregation for QSIs'.

On-Time Minimum Standard

4.20. This is the minimum standard that a route is expected to achieve for percentage on-time. Bus Operators are incentivised to achieve an on-time figure that is more than the minimum standard.

4.21. The aggregation of the On-Time Minimum Standard follows the same rules as defined for the on-time values.

Variance from On-Time Minimum Standard (OT_Var)

4.22. This is the difference between the On-Time minimum standard and the On-Time %. In order to calculate the variance from On-Time minimum standard for a particular route, direction, hour and QSI point combination the following formula is used:

$$hOT\_Var = hOT\,\% - On\text{-}Time\ Minimum\ Standard$$

(where h='hourly')

4.23. It can be seen from this formula that if a route is performing better than its minimum standard then the variance will be positive. A negative variance indicates that a route is not meeting its minimum standard.

Early Benchmark

4.24. This value defines the level of early running that a route is expected to achieve. Operators should aim to achieve an early running percentage below that of the benchmark.

Variance from Early Benchmark (E_Var)

4.25. This value measures the difference between the Early benchmark and the Early %. In order to calculate the variance from the Early benchmark for a particular route, direction, hour and QSI point combination the following formula is used.

$$hE\_Var = Early\ benchmark - hE\,\%$$

(where h='hourly')

5. Linking by Time (Low Frequency)

5.1. Observed Low Frequency buses are "linked" to an appropriate scheduled time in a pre-determined sequence designed to portray punctuality as it would be *experienced by the passenger.* A bus will be linked to the nearest available scheduled bus [as '**on time**'] wherever possible. Otherwise, it will be linked '**late**' in preference to '**early**'. Only if none of these categories can be met is the bus treated as a '**non-arrival**' for QSI purposes.

5.2. Linking is performed by working through each scheduled bus at each QSI point and attempting to fit it to an observed bus. Each rule below is worked through for every scheduled bus at the QSI point before moving on to the next rule. Linking is a one-to-one process: no scheduled bus can be linked to two observed buses and vice-versa. Although linking is in principle a continuous process (for 24hr routes there is no start and end of recordings to be linked), for processing reasons it is necessary to consider a limited range of times when linking. Under iBus, each service day's recordings are considered for linking and are treated in isolation. Therefore a scheduled bus and an observed bus on different days will not be considered for linking.

5.3. The following criteria are used when determining whether to 'link' a trip;

5.3.1. Look for buses that are 'on-time', i.e. the observed bus that is nearest the scheduled time. For a bus to be counted as 'on-time' it must be less than 2.5 minutes early and up to 5 minutes late.

5.3.2. If more than one bus fits these criteria, always use the bus that is after the scheduled time rather than before.

5.3.3. If two or more buses are observed between the scheduled time and ≤ 5 minutes late, use the bus that has the lowest time difference to the schedule.

5.3.4. Where no buses are observed between the scheduled time and ≤ 5 minutes late but there is more than one bus < 2.5 minutes early use the bus that has the lowest time difference to the schedule.

5.3.5. If no "on time" bus was found look for a bus considered as being late. Late is defined as > 5 minutes to 15 Minutes late.

5.3.6. If more than one bus fits the criteria in 5), use the bus that has the lowest time difference to the schedule.

5.3.7. If no "on time" or "late" bus was found look for a bus considered as being early. Early is defined as 8 minutes to 2.5 Minutes early.

5.3.8. If more than one bus fits the criteria in 7) use the bus that has the lowest time difference to the schedule.

5.3.9. Any other scheduled bus that cannot be linked using the rules defined in 4.1.1 – 4.1.8 above is marked as a non arrival.

5.4. If two or more observed buses have an identical time (hh:mm:ss are exactly the same) then pick the first one in the sequence (can be arbitrarily ordered) to be counted for the linking status in question. From a customer's point of view the choice is irrelevant however in some exceptional circumstances it may affect the linking of other buses.

5.5. One can imagine all linkings as represented by lines between scheduled and observed buses. Using this method an important rule can be described: <u>links must not cross one another</u>.

5.6. The status 'Linked' is evaluated from the link status of buses:

Criteria Trip is:	**Status**	**Scheduled Time is:**
<2.5 mins early to ≤5 minutes late	On time	Linked
>5 mins late to ≤15 minutes late	Late	Linked
≥2.5 mins early and ≤8 mins early	Early	Linked
>15 minutes late	Non Arrival	Not Linked
>8 minutes early	Non Arrival	Not Linked
Missing buses	Non Arrival	Not Linked

Example 1 – Simple Linking

5.7. Here is part of a bus service that broadly matches the schedule with no missing trips.

Bus	Scheduled Time	Observed Time
1	10:05	10:10:00
2	10:25	10:31:00
3	10:45	10:44:00
4	11:05	11:00:00
5	11:25	11:26:00

5.7.1. First **rule 1** is applied, namely marking which buses are 'on time':

Bus	Scheduled Time	Observed Time	Linking Status
1	10:05	10:10:00	On Time
2	10:25	10:31:00	
3	10:45	10:44:00	On Time
4	11:05	11:00:00	
5	11:25	11:26:00	On Time

Note that bus 1 is on time as the boundary is ≤5 minutes late.

5.7.2. Next **rule 2** is applied, adding any buses which can be classed as ‘late’:

Bus	Scheduled Time	Observed Time	Linking Status
1	10:05	10:10:00	On Time
2	10:25	10:31:00	Late
3	10:45	10:44:00	On Time
4	11:05	11:00:00	
5	11:25	11:26:00	On Time

5.7.3. Next **rule 3** is applied, adding any buses which can be classed as ‘early’:

Bus	Scheduled Time	Observed Time	Linking Status
1	10:05	10:10:00	On Time
2	10:25	10:31:00	Late
3	10:45	10:44:00	On Time
4	11:05	11:00:00	Early
5	11:25	11:26:00	On Time

5.7.4. All scheduled times now have a link status now, so the operation is complete.

Example 2 – A non-linked bus

5.8. This example shows a service irregularity of sufficient extent (in this case early running) to cause a bus to not be linked.

Bus	Scheduled Time	Observed Time
1	15:53	15:59:00
2	16:09	16:00:00
3	16:24	16:12:00
4	16:39	16:26:00
5	16:54	16:50:00
6	17:09	16:52:00
7	17:24	17:07:00
8	17:39	17:29:00
9	17:54	17:45:00
10	18:09	17:56:00

5.8.1. Since linking will not always be directly horizontal some extra columns are introduced. The code on the right hand side is a way of identifying particular observed buses, just as the number is used to identify scheduled buses.

Bus	Scheduled Time	Linking Status	Linked with
1	15:53		
2	16:09		
3	16:24		
4	16:39		
5	16:54		
6	17:09		
7	17:24		
8	17:39		
9	17:54		
10	18:09		

Code	Observed Time
A	15:59:00
B	16:00:00
C	16:12:00
D	16:26:00
E	16:50:00
F	16:52:00
G	17:07:00
H	17:29:00
I	17:45:00
J	17:56:00

5.8.2. Rule 1: On time

Bus	Scheduled Time	Linking Status	Linked with
1	15:53		
2	16:09	On Time	C
3	16:24	On Time	D
4	16:39		
5	16:54	On Time	F
6	17:09	On Time	G
7	17:24		
8	17:39		
9	17:54	On Time	J
10	18:09		

Code	Observed Time
A	15:59:00
B	16:00:00
C	16:12:00
D	16:26:00
E	16:50:00
F	16:52:00
G	17:07:00
H	17:29:00
I	17:45:00
J	17:56:00

Note that scheduled bus 2 is linked with observed bus C, and this causes the rest of the results to appear out of step.

5.8.3. Rule 2: Late

Bus	Scheduled Time	Linking Status	Linked with
1	15:53	Late	A
2	16:09	On Time	C
3	16:24	On Time	D
4	16:39	Late	E
5	16:54	On Time	F
6	17:09	On Time	G
7	17:24	Late	H
8	17:39	Late	I
9	17:54	On Time	J
10	18:09		

Code	Observed Time
A	15:59:00
B	16:00:00
C	16:12:00
D	16:26:00
E	16:50:00
F	16:52:00
G	17:07:00
H	17:29:00
I	17:45:00
J	17:56:00

5.8.4. Rule 3: Early

5.8.5. No trips are classified as early, so the final table is:

Bus	Scheduled Time	Linking Status	Linked with	Code	Observed Time
1	15:53	Late	A	A	15:59:00
2	16:09	On Time	C	B	16:00:00
3	16:24	On Time	D	C	16:12:00
4	16:39	Late	E	D	16:26:00
5	16:54	On Time	F	E	16:50:00
6	17:09	On Time	G	F	16:52:00
7	17:24	Late	H	G	17:07:00
8	17:39	Late	I	H	17:29:00
9	17:54	On Time	J	I	17:45:00
10	18:09	Non Arrival		J	17:56:00

Example 3 – Late over early

5.9. This example shows the requirement for late to be valued over early, which comes out automatically if the rules are applied in sequence.

5.9.1. Rule 1: On time

Bus	Scheduled Time	Linking Status	Linked with	Code	Observed Time
1	10:05			A	10:11:10
2	10:25	On Time	B	B	10:23:32
3	10:45			C	10:39:06
4	11:05			D	10:58:21
5	11:25	On Time	E	E	11:28:42
6	11:45	On Time	F	F	11:47:00
7	12:05			G	11:56:27
8	12:25	On Time	H	H	12:26:05
9	12:45	On Time	I	I	12:45:29

5.9.2. Rule 2: Late

Bus	Scheduled Time	Linking Status	Linked with	Code	Observed Time
1	10:05	Late	A	A	10:11:10
2	10:25	On Time	B	B	10:23:32
3	10:45	Late	D	C	10:39:06
4	11:05			D	10:58:21
5	11:25	On Time	E	E	11:28:42
6	11:45	On Time	F	F	11:47:00
7	12:05			G	11:56:27
8	12:25	On Time	H	H	12:26:05
9	12:45	On Time	I	I	12:45:29

It would have been theoretically possible to assign trip 3 to C as an early trip, and thus trip 4 as another early trip with D. However, late is preferable to two early, and this preference is achieved automatically by following the rules in turn.

5.9.3. Rule 3: Early

5.9.4. No trips are classified as early, so the final table is:

Bus	Scheduled Time	Linking Status	Linked with	Code	Observed Time
1	10:05	Late	A	A	10:11:10
2	10:25	On Time	B	B	10:23:32
3	10:45	Late	D	C	10:39:06
4	11:05	Non Arrival		D	10:58:21
5	11:25	On Time	E	E	11:28:42
6	11:45	On Time	F	F	11:47:00
7	12:05	Non Arrival		G	11:56:27
8	12:25	On Time	H	H	12:26:05
9	12:45	On Time	I	I	12:45:29

Example 4 – On time after schedule over on time before schedule

5.10. This example shows the requirement for an on time bus running later than the scheduled time to be valued over an on time bus running earlier than the scheduled time.

Bus	Scheduled Time	Linking Status	Linked with	Code	Observed Time
1	10:05			A	10:06:00
2	10:20			B	10:24:00
3	10:35			C	10:49:30
4	10:50			D	10:51:00
5	11:05			E	11:10:00

5.10.1. After applying the on-time rule, one bus is left which is classed as Late.

Bus	Scheduled Time	Linking Status	Linked with
1	10:05	On time	A
2	10:20	On time	B
3	10:35	Late	C
4	10:50	On time	D
5	11:05	On time	E

Code	Observed Time
A	10:06:00
B	10:24:00
C	10:49:30
D	10:51:00
E	11:10:00

Here bus 4 is linked with D, not C. Although C is closer to the scheduled time than D, the on-time criteria require that buses after the scheduled time are taken in preference to those before. It is for this reason that D is selected in preference to C.

Example 5 – Non-crossing of link lines

5.11. This example demonstrates the restriction regarding the ‘crossing’ of link lines.

Bus	Scheduled Time	Linking Status	Linked with
1	10:35	Non arrival	
2	10:49	On time	A

Code	Observed Time
A	10:49:00
B	10:50:00

The linking rules link 2 to A and 1 to nothing - 1 cannot be linked to B (despite being ≤ 15 minutes late) as linking rules do not allow a crossing of link lines.

Example 6 – Linking across hours

5.12. This example shows a scheduled bus in one hour being linked with an observed bus in a different hour and demonstrates the rule that says the linking status (and all other punctuality statistics) are counted in the hour of the scheduled bus rather than the observed bus.

Bus	Scheduled Time	Linking Status	Linked with
1	12:00:00	On time	A
2	12:20:00	Late	C
3	12:40:00	Late	D
4	13:00:00	On time	E
5	13:20:00	Not linked	

Code	Observed Time
A	12:02:00
B	12:05:00
C	12:30:00
D	12:53:00
E	12:59:00

The percentage of buses linked for 13:00 – 14:00 is 50%. This is because the link status of the bus scheduled at 13:00 is counted in the hour 13:00 – 14:00 despite the linked observed bus being in the previous hour. % On Time is also 50% for 13:00 – 14:00.

6. Linking By Trip (Low Frequency)

6.1. Scheduled Low Frequency buses are “linked” to the corresponding observed bus by matching the trip number of the buses. If an observed bus cannot be found with the same trip number then the scheduled bus will be flagged as not-linked. This linking process is used to help diagnose aspects of the operational performance of the service. It is not necessarily representative of the customer’s experience and is therefore not used for reporting reliability statistics.

6.2. Linking is performed by working through each scheduled bus at each bus stop in turn and attempting to fit it to an observed bus. Linking is a one-to-one process: no scheduled bus can be linked to two observed buses and vice-versa.

6.3. Initially, identify an observed bus that has the same trip number as the scheduled bus. If no observed bus has the same trip number then the scheduled bus should be marked as ‘Not Linked’. If more than one observed bus has the same trip number, always use the bus that has the lowest time difference to the scheduled bus. If the observed buses with the same trip number are either side of the scheduled bus (or equidistant from it), use the later bus. If two or more buses with the same trip number have an identical time (hh:mm:ss are exactly the same) then arbitrarily pick one to be counted for the linking status in question.

6.4. Once the correct observed bus has been identified, the comparison of scheduled and actual times allows the linking status to be derived. This is done according to the rules in the table below:

Criteria Trip is:	**Status**	**Scheduled Time is:**
<2.5 mins early to ≤5 minutes late	On time	Linked
>5 mins late to ≤120 minutes late	Late	Linked
≥2.5 mins early and ≤60 mins early	Early	Linked
>120 minutes late	Non Arrival	Not Linked
>60 minutes early	Non Arrival	Not Linked
Missing buses	Non Arrival	Not Linked

Example 1 – Simple Linking

6.5. Here the both quantity of observed trips and the observed trips numbers match the scheduled trips.

Trip	Scheduled Time
1	10:05
2	10:25
3	10:45
4	11:05
5	11:25

Trip	Observed Time
1	10:10:00
2	10:31:00
3	10:44:00
4	11:00:00
5	11:26:00

6.5.1. The table below shows the linking statuses for the above trips.

Trip	Scheduled Time	Linking Status
1	10:05	On Time
2	10:25	Late
3	10:45	On Time
4	11:05	Early
5	11:25	On Time

Trip	Observed Time
1	10:10:00
2	10:31:00
3	10:44:00
4	11:00:00
5	11:26:00

Example 2 – A non-linked bus

6.6. This shows a service where the quantity of observed trips does not equal the scheduled trip. It also shows a variation of trip numbers.

Trip	Scheduled Time
1	15:53
2	16:09
3	16:24
4	16:39
5	16:54
6	17:09
7	17:24
8	17:39
9	17:54
10	18:09

Trip	Observed Time
1	15:54:00
2	18:09:00
3	18:25:00
4	16:26:00
5	16:50:00
6	16:52:00
8	17:07:00
10	17:09:00
12	17:45:00

6.6.1. As it is only possible to link scheduled trips for which there is an observed trip with a corresponding number, it can be seen that the *maximum* possible quantity of linked buses in this example is 8. This is because the scheduled trips 7 and 9 do not have a corresponding observed trip number. This is before considering that some of these trip might fall outside of the early and late boundaries as per trip 3.

6.6.2. The table below shows the linking statuses for the above trips.

Trip	Scheduled Time	Linking Status
1	15:53	On time
2	16:09	Late
3	16:24	Not Linked
4	16:39	Early
5	16:54	Early
6	17:09	Early
7	17:24	Not Linked
8	17:39	Early
9	17:54	Not Linked
10	18:09	Early

Trip	Observed Time
1	15:54:00
2	18:09:00
3	18:25:00
4	16:26:00
5	16:50:00
6	16:52:00
8	17:07:00
10	17:09:00
12	17:45:00

Example 3 – Duplicate matching trip numbers

6.7. This example shows more than one bus that has a trip number that matches that of a scheduled trip.

Trip	Scheduled Time
1	15:53
2	16:09
3	16:24
4	16:39
5	16:54
6	17:09
7	17:24
8	17:39
9	17:54
10	18:09

Trip	Observed Time
1	15:59:00
2	16:00:00
3	16:21:00
3	16:26:00
5	16:50:00
6	16:52:00
7	17:07:00
8	17:29:00
9	17:45:00
10	17:56:00

6.7.1. It can be seen that there are two observed trips with the number 3. In this case the scheduled trip 3 will be linked to the observed trip 3 whose observed time is closest to that of the scheduled trip.

Trip	Scheduled Time	Linking Status
1	15:53	Late
2	16:09	Early
3	16:24	On Time
4	16:39	Not linked
5	16:54	Early
6	17:09	Early
7	17:24	Early
8	17:39	Early
9	17:54	Early
10	18:09	Early

Trip	Observed Time
1	15:59:00
2	16:00:00
3	16:21:00
3	16:26:00
5	16:50:00
6	16:52:00
7	17:07:00
8	17:29:00
9	17:45:00
10	17:56:00