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Data management and applications in a world-leading bus fleet

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ABSTRACT

Automatic Vehicle Location (AVL) Systems are being introduced increasingly in many major cities around the world to improve the efficiency of our road-based passenger transport systems. Satellite-based location and communication systems, particularly the Global Positioning System (GPS) have been the platform for AVL systems which are now supporting real-time passenger information (RTPI), fleet management and operations (FMOs) and public transport priorities (PTPs), to name three key applications. The process of real-time on-board bus location can result in a substantial database where the progress of the bus is stored typically on a second-by-second basis. This is necessary for the primary real-time applications such as those listed above (e.g. RTPI, FMO and PTP). In addition, it is clear that such data could have an array of 'secondary' purposes, including use off-line for improving scheduling efficiency and for automatic performance monitoring, thus reducing or removing the need for manual on-street surveys. This paper looks at these and other innovative uses of AVL data for public transport, taking the recent iBus system in London as a current example of a modern AVL/GPS application in a capital city. It describes the data architecture and management in iBus and then illustrates two further examples of secondary data use – dwell time estimation and bus performance analysis. The paper concludes with a discussion of some key data management issues, including data quantity and quality, before drawing conclusions.

1. Introduction

Automatic Vehicle Location (AVL) Systems are being introduced increasingly in many major cities around the world to improve the efficiency of our road-based passenger transport systems. Satellite-based location and communication systems, particularly the Global Positioning System (GPS) have been the platform for AVL systems which are now supporting real-time passenger information (RTPI), fleet management and operations (FMOs) and public transport priorities (PTPs), to name three key applications (Gardner et al., 2009).

With the increasing uses of AVL in public transport, it is apparent that a wide range of architectures are being employed in different cities across the globe. Taking an example of PTP, there are differences in the way priority need is assessed, the method of priority request and the means of implementation. The variations in the bus priority architectures are usually due to the evolutionary approach of improving a bus priority system in the existing infrastructures (rather than a revolutionary approach). These various architectures have been categorised and compared in earlier studies (e.g. Hounsell and Wall, 2002; Jones, 1998; Hounsell and Shrestha, 2005). Despite these differences in system architecture, the common feature of these systems is to provide real time bus location data.

The process of real-time on-board bus location can result in a substantial database where the progress of the bus is stored typically on a second-by-second basis. This is necessary for the primary applications such as those listed above (e.g. RTPI,

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FMO and PTP). In addition, it is clear that such data has an array of 'secondary' purposes, including use off-line for improving scheduling efficiency and for automatic performance monitoring, thus reducing or removing the need for manual on-street surveys.

The common thread across all operational systems of this type is the need for efficient data management systems, encompassing all the necessary elements of data collection, processing of the spatio-temporal information at high resolution, data transmission and so on – all according to the system architecture. In some examples this process may be 'driven' from the AVL centre or using roadside infrastructure, whilst in others substantial mobile on-bus data management is required. This paper provides both a summary of AVL systems and their data architectures in cities around the world and a more detailed look at data management issues in the 8000 strong London bus fleet – which has been equipped recently with a comprehensive management system known as iBus. The paper also allows comparisons to be made more generally, to see where best practice might be transferable across other systems with different characteristics.

2. AVL applications for public transport in international perspective

There are various examples of ITS applications around Europe. In these systems, buses are equipped with detection and communication technologies to locate their position in a network and to communicate with the AVL centre. Most of the recent systems are using GPS as the main locational technology for their AVL system. In these systems, the AVL centre is at the heart of the system, monitoring buses in the network and assessing their performance. Examples include: Aalborg's (Denmark) mobility centre (Jensen and Birk, 2007), Cardiff's system (Hill et al., 2001), Genoa's (Italy) SIMON system (UoS, 2002), Glasgow's (UK) BIAS (Bus Information and Signalling System) (Glasgow CC, 2009), Helsinki's (Finland) HeLMi (Helsinki Public Transport Signal Priority and Passenger Information) (Helsinki, 2003), Toulouse's (France) SITERE (UoS, 2002), London's iBus (Clarke et al., 2007), Sydney's (Australia) PTIPS (Public Transport Information and Priority System) (Mehaffey and Jarjees, 2001) and Auckland's (New Zealand) SP/RTPIS (Signal Pre-emption/Real Time Information System) (Vencatachellum, 2002). These centres collect locations of the buses in the network usually by polling in a pre-set interval of 10–30 s depending on the fleet size and radio capacity. In London's iBus system, in addition to polling, bus location information is also passed to the Control centre when departing from a bus stop.

The AVL centre processes the locational information collected and produces useful extracts for various applications such as Bus Priority, RTPI and Fleet Management. In the case of RTPI and Fleet management applications, the processed information is used directly, usually without further interaction with buses. However, in the case of bus priority traffic signals, buses will operate within a specified priority architecture. For example, in London, Cardiff and Helsinki, the lateness information is transmitted back to buses (from the AVL centre) so that they can pass the information to the traffic signal controller when requesting priority at a junction. Short range radio is then often used to request such priority. This way of requesting priority to the traffic signal locally is an example of decentralised architecture. In other cases such as Toulouse and Aalborg, the AVL centre directly passes information to the UTC centre without involving buses. This type of communication between the AVL centre and UTC centre is an example of a centralised architecture. In addition to these two main architectures, there are other variant architectures according to the location for decision making, etc. For example, Glasgow's case is slightly different in the sense that bus lateness relative to its schedule is calculated on board based on the daily schedule stored in the on-board computer unit (OBU) instead of at the AVL centre.

Table 1 illustrates how AVL applications in public transport are spreading globally and the range of architectures employed. London's iBus system is similar to a number of other systems reviewed, apart from being very large in terms of the scale of implementation and range of applications. iBus in London therefore provides a good case study of data management in a large public transport fleet from which lessons can be learnt for other similar systems in Capital cities around the world.

3. iBus system

The iBus system in London (Fig. 1), is one of the world's largest integrated AVL systems. It is a comprehensive AVL system based on GPS and supporting technologies (e.g. dead reckoning, Kalman optimisation filter and map matching software) for

Table 1
Summary of ITS applications for public transport.

Place	System name	Communication technology	Data storage location	Data processing location	Bus priority request communication
Aalborg	–	GPRS, PMR Mobile Radio	AVL centre	AVL centre	AVL centre to signal
Auckland	SP/RTPIS	GPRS	AVL centre	AVL centre	AVL centre to UTC
Cardiff	–	VHF and UHF radio	AVL centre	AVL centre	Bus to Signal
Genoa	SIMON	UHF radio, Landline	AVL centre and Bus	AVL centre	AVL centre to UTC
Glasgow	BIAS	Two way Radio and Landline	AVL centre and Bus	Bus (lateness)	Bus to UTC
Helsinki	HeLMi	VHF radio	AVL centre	AVL centre	Bus to signal
London	iBus	GPRS	AVL centre and Bus	AVL centre (lateness) & Bus	Bus to Signal
Toulouse	SITERE	UHF Radio	AVL centre	AVL centre	AVL centre to UTC
Sydney	PTIPS	GPRS	AVL centre	AVL centre	AVL centre to UTC

bus location and the General Packet Radio System (GPRS) for data transfer (Clarke et al., 2007). The system has now been rolled out to every bus and garage in London – that is over 8000 buses and 90 garages. iBus keeps track of London's buses which send the location of each bus to the AVL centre about every 30 s. This bus location information is then passed onto: service controllers to better regulate services to make them more reliable; to the RTPI system to inform passengers; and to buses themselves for priority at traffic signals and data storage for post processing.

Fig. 1 (TfL, 2006) gives a simplified overview of iBus system components. Among these (Wong and Hounsell, 2010), three main components related to bus location data collection and storage are:

- an 'on-board unit (OBU)' mounted in each bus (Item L in Fig. 1);
- a 'data server' at individual bus garages (Item O);
- a central 'system server' located remotely (Item K), which holds the master records of bus routes, their timing points, operating frequencies, as well as information for specific applications, such as the locations of 'virtual' detectors for bus priority at traffic signals.

The OBU mounted in each bus is the key component collecting bus location data. It is a computer programmed to receive bus location as well as bus event information from various sources and store them in its memory. In terms of bus location, it receives information every second from a GPS receiver mounted on the roof (Item J) and the odometer and gyroscope. The System utilises this information along with optimisation and route/map matching algorithms to calculate the buses' location as accurately as possible. In addition to the bus location, the OBU also records activities of a bus along the route. For example, it records the opening/closing of doors with time-stamped information from the door sensors (Item G). The bus location information logged in the OBU is automatically uploaded to the data server at the bus garage when vehicles return to the depot using a Wireless Local Area Networking (WLAN). This WLAN uploads data to the Depot host servers with each OBU device and vehicle assigned a unique Media Access Control (MAC) address and Technical Vehicle Number (TVN) for data

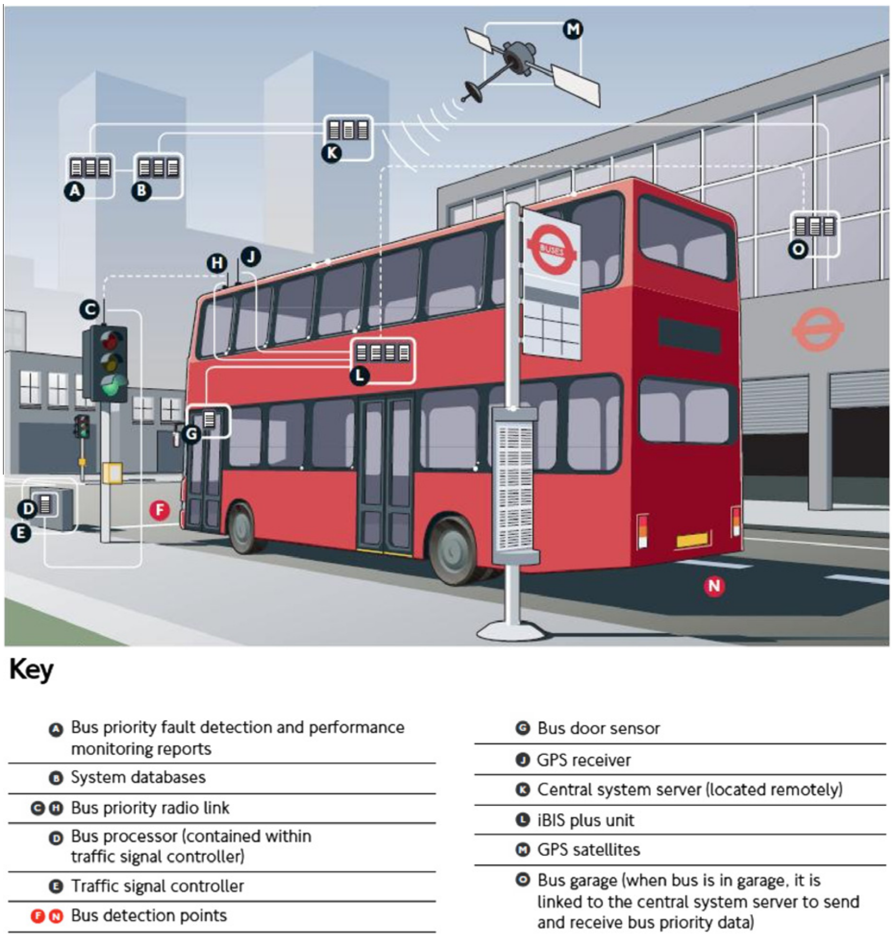

Fig. 1. iBus system in London (from TfL, 2006).

communications and identification purposes. The location and activities data is then forwarded from these servers to the TfL central server via wide area communications links for post processing, historical storage and management reporting.

In addition to bus location data collection, the OBU is also responsible for triggering bus priority at traffic signals. The OBU keeps a record of the priority-defined virtual detection points which are compared with the bus location to trigger priority at each equipped traffic signal. For this priority triggering purpose, the OBU is connected to a transmitter mounted on the roof of each vehicle (Item H); this sends Real-Time Information Group (RTIG)-compliant radio ‘telegrams’ to request bus priority from individual traffic signal ‘controllers’ (Item E) via their aerials (Item C).

When buses return to their depots at the end of each ‘block’ of trips, their OBUs are connected to the garage’s data server through the WLAN. This in turn, provides a link to the remote central system server for the purpose of downloading new route and/or detector locations into the OBUs, and to upload the individual bus location/event ‘log’ files. The log files are then consolidated centrally, to provide local databases for users, which are used for information storage, historical analysis, and management reporting.

The real time information received at the AVL centre in regular intervals is used for three core applications: bus fleet management, real time passenger information and bus priority at traffic signals.

3.1. Real-time passenger information

One of the main real time applications of the bus location data available from iBus is to provide real time information on bus service arrivals to passengers. London’s real time passenger information system, known as COUNTDOWN, was operated initially using roadside beacons located along the bus route. Although the system was successful, it only served part of the overall network. With the implementation of iBus, RTPI will be available at 2500 key bus stops in London by 2011 (TfL, 2010c). TfL also provide various other means for receiving this information, including: next-stop signage on board, text messaging and the internet (see Fig. 2).

3.2. Fleet management and operations (FMOs)

FMO is another real time application of the bus location information available from iBus. In addition to the TfL control centre, the real time location of buses is available to service controllers of respective operators’ garages. There is a provision to display the location of every bus against tabular representation and geographical maps, along with their performance relative to the scheduled frequency or headway for that route, e.g. whether each bus is ‘early’, ‘on-time’, or ‘late’ (as defined in the system). Such information available to the service controller allows him/her to take fleet management actions quickly in the case of disruption in the network.

3.3. Bus priority at traffic signals

Another application of iBus is to enhance London’s successful bus priority at traffic signal system. This replaces earlier infrastructure-based detection systems (Hounsell and Shrestha, 2005) used for bus priority at traffic signals. For example, in-road inductive loops or physical road-side beacons with associated vehicle transponders to identify buses on approach were used to trigger priority on the approaches of traffic signals to provide them with a green time extension or recall at the signal. However, these physical infrastructure-based ‘Selective Vehicle Detection’ (SVD) systems are becoming increasingly outdated, as they are relatively expensive to install and maintain, so are no longer being applied to London’s signal junctions (TfL, 2006).

With iBus, SVD is triggered through the use of ‘virtual’ detectors. These locations associated with each signal junction and defined in terms of a set of GPS longitude and latitude coordinates, are programmed onto the OBU of each bus. These bus detector locations are configured in the on-bus computer of iBus equipped buses and have no physical presence – hence their name as ‘virtual detectors’ (Hounsell et al., 2006). The predefined virtual detector coordinates are compared with the

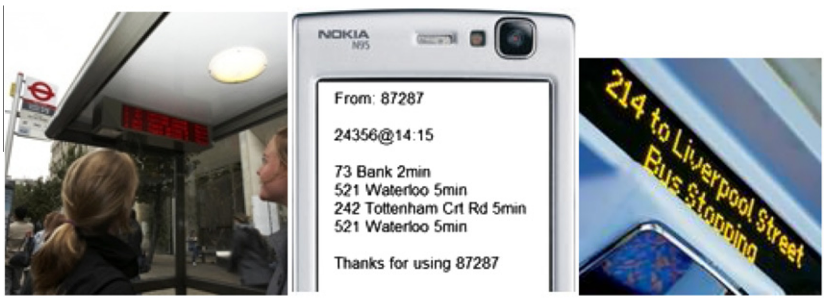

Fig. 2. Various channels of real time passenger information system in London (from TfL, 2010c).

location of the bus obtained from the on-bus navigation system to ascertain whether a bus has reached the detection position to trigger a priority request by transmitting a bus priority telegram to the traffic signal controller. Virtual detectors allow much more flexibility in terms of installation and repositioning. They may be used at new junction sites or to replace (or supplement) existing physical SVD detector locations, as they do not require road-side infrastructure changes. iBus is enabling bus priority at traffic signals to be introduced much more widely across London, because of the reduced infrastructure costs associated with 'virtual' bus detectors and improved system functionality/benefits. A simple representation of bus priority at traffic signals using iBus is shown in Fig. 3.

At present, virtual detectors for priority are only being located where physical detection would have been located. However research (Hounsell et al., 2004) has shown that bus delay savings can sometimes be improved by increasing the number of virtual detectors on a traffic signal approach and thus monitoring the buses progress more closely. For example, a detector upstream of a bus stop and/or at the junction exit can be particularly beneficial in the right circumstances.

In addition to the flexibility of virtual detectors to trigger priority at traffic signals, iBus also provides bus performance information relative to other buses serving the route or relative to the timetable the bus is on. With iBus, the control centre has the information of all the buses serving the network. It uses such information to calculate the headway of a bus (relative to other buses on the same route) or the earliness/lateness of the bus relative to the predefined timetable. Such information is available in real time. This provides an opportunity to implement 'differential priority' at traffic signals – a strategy where priority is given according to the individual needs of buses, e.g. depending on differing thresholds of regularity or punctuality. This form of priority helps to reduce the impact on other traffic, and leads to more regular and improved journey times for buses overall.

4. Data architecture and post processing applications

In addition to the real time applications described above, iBus stores historic second-by-second information of all the buses in the network. This data is then post-processed for monitoring and reporting purposes, including such data as average route journey times (Hardy, 2009). Fig. 4 shows two distinct paths of iBus data applications: real time applications and post-processing applications.

Looking now at the post-processing applications, these are largely driven by user requirements relative to the information available. So, for example, the bus event log files and databases provide a vast repository of operational information collected by London's buses, including vehicles' real-time GPS locations and messages of their interactions with traffic signals, as well as trip journeys times, relative headways, and average speeds on route. Key examples of the current and forthcoming uses of this data include; (i) average route journey times (Hardy, 2009) and (ii) automatic performance monitoring, particularly for bus punctuality and regularity statistics which have previously relied on manual surveys on-street.

Looking to the future, it is clear that the quantity and detail of the information recorded in the bus log files and central databases lends itself to a variety of other applications, including: improved bus service monitoring, enhanced operational reporting/scheduling, enriched spatio-temporal analysis, dwell time estimation, emission estimation and bus priority surveys. Some of these applications are now described and others are discussed in more detail.

4.1. Improved bus service monitoring

TfL produces a quarterly service performance report (TfL, 2010b) on high-frequency services (representing services with 5 or more buses per hour). This has been based on manual on-street data collection typically at a set of five or six pre-set points

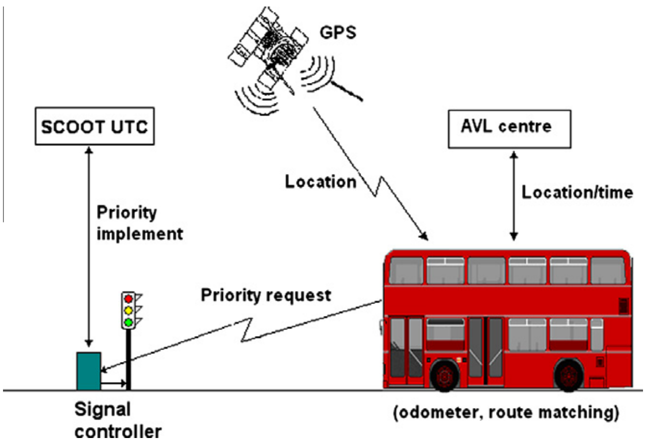

Fig. 3. Simple representation of bus priority at traffic signals using iBus.

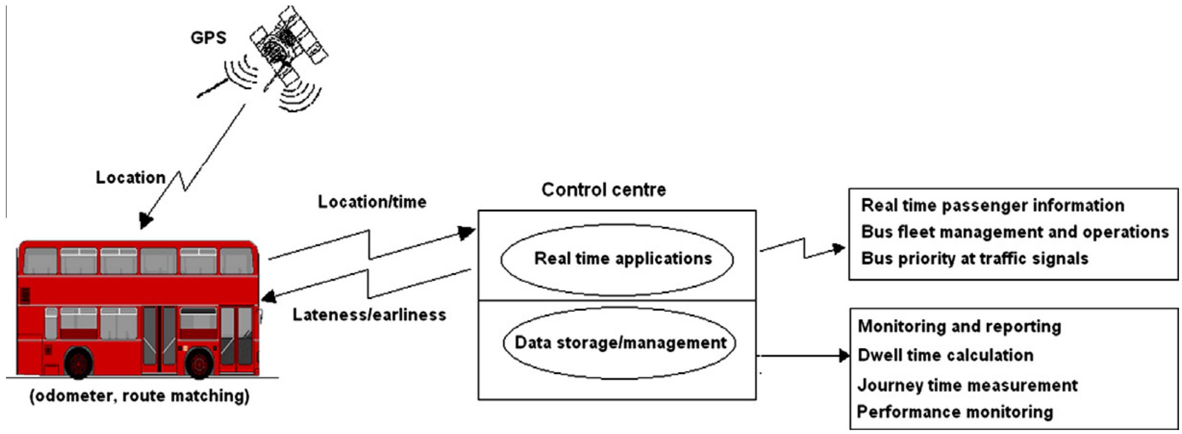

Fig. 4. Simple representation of logical data flow in iBus.

along a route (TfL, 2010a). The availability of bus journey times throughout a route allows these reports to now be produced automatically using data available in the system. Potentially though, the system contains many more location points which record times, allowing many more timing points to be defined, thereby significantly increasing the sample size for measurements to be taken along a route for the monitoring of average and 'excess' passenger waiting times at bus stops. The 'excess waiting time' is the difference between the actual waiting time of passengers at bus stops and the average waiting time based on the scheduled headway. This excess waiting time for the passengers is the key performance criterion adopted in the UK for buses operating headway-based services (DfT, 2005; TfL, 2007). The 'excess waiting time' of the passengers is calculated as follows (TRG, 1997):

$$Excess\ waiting\ time = Actual\ average\ waiting\ time - Scheduled\ average\ waiting\ time$$

where

$$Actual\ average\ waiting\ time = \frac{\sum_i Actual\ headway_i^2}{2 \times \sum_i Actual\ headway_i}$$

$$Scheduled\ average\ waiting\ time = \frac{\sum_i Scheduled\ headway_i^2}{2 \times \sum_i Scheduled\ headway_i}$$

where $Actual\ headway_i$ and $Scheduled\ headway_i$ are time headways for bus i.

The excess waiting time thus calculated is valid for high frequency services where passengers tend to arrive randomly without knowing the arrival time of the buses. The excess waiting time (EWT) is the extra waiting time borne by passengers over and above the waiting time that might be expected if all the buses on the route ran on time. It reflects the regularity of the service. This is identified as the most important factor for quality of a bus service and its importance is reflected in DfT's Webtag (DfT, 2011) by valuing non-working time ('commuting' and 'other') spent waiting for public transport as two and a half times the 'commuting' and 'other' values.

4.2. Enhanced operational reporting/scheduling

Historically, TfL has only given passengers an indication of the scheduled journey times e.g. between two given points for a particular service, although actual journey times can vary according to level of traffic congestion and the time of day. Given that iBus holds the second-by-second timing of each vehicle, the iBus data may now be used to calculate actual journey time performance or the 'run' times between two pre-determined timing points, e.g. between two bus stops. On a simplistic level, this may be grouped by different time-of-day periods (i.e. morning peak, evening peak, and two inter-peaks) to provide passengers with improved journey time reporting, as well as an indication of their variability – see Fig. 5.

Fig. 5 shows the actual weekday average, maximum and minimum journey times (compared to scheduled) between two bus stops on a given London bus route (No. 198) in June 2010. The scheduled journey time between stops for the service is set at 1 min, while the average actual time varies from 0.91 to 1.12 min, depending on the time of day (it is principally a shopping service), with a maximum and minimum of 0.68 and 1.50 min respectively. Taken across the entire route of 48 bus stops, this data may be used to improve the run time of vehicles for scheduling purposes, including their variation with the time of day. A similar analysis can be performed for other days of the week, or to analyse journey times for other time periods (e.g. the night-time service). The run times could also be analysed over a longer period of time to review the service performance of a certain route for operational review purposes. This information can be used to help improve bus schedules,

Day Type	Time Period	No Of Trips over Month	Avg Sched Run Time	Max Sched Runtime	Min Sched Runtime	Avg Actual Runtime	Max Actual Run Time	Min Actual Run Time	Avg Actual-Sched Diff (%)	Max Actual-Sched Diff (%)	Min Actual-Sched Diff (%)	Std Dev (Time Period)
Mon-Fri	0500-0700	144	1.0	1.0	1.0	0.906	1.467	0.683	-9.41%	46.67%	-31.67%	0.173
	0700-1000	268	1.0	1.0	1.0	1.077	1.467	0.683	7.67%	46.67%	-31.67%	0.198
	1000-1300	242	1.0	1.0	1.0	1.111	1.500	0.683	11.13%	50.00%	-31.67%	0.201
	1300-1600	241	1.0	1.0	1.0	1.121	1.500	0.683	12.07%	50.00%	-31.67%	0.206
	1600-1900	245	1.0	1.0	1.0	1.085	1.500	0.700	8.48%	50.00%	-30.00%	0.202
	1900-2200	218	1.0	1.0	1.0	1.006	1.483	0.683	0.57%	48.33%	-31.67%	0.194
	Overall	**1,358**	**1.0**	**1.0**	**1.0**	**1.050**	**1.500**	**0.683**	**5.02%**	**50.00%**	**-31.67%**	

(Source for Raw Data: Transport for London, 2010)

Fig. 5. Bus journey time performance by different time-of-day periods (illustrative).

and allow operators to submit more realist schedules for future operations. Where bus services are tendered out to private operators, as is the case in London (where bus operators typically perform against a 5-year Quality Incentive Contract), this last point is of paramount importance, as operators are rewarded for bus reliability or their adherence to the contracted headway (for high-frequency services) or timetable (for low-frequency services), and it is therefore necessary to have adequate benchmarks for comparison purposes.

4.3. Spatio-temporal analysis

The provision of historic second-by-second GPS location information from each bus allows for the complex spatio-temporal analysis of bus services, including vehicle and driver locations. For example, from time-to-time, it may be necessary to view the performance of individual vehicles. Fig. 6 shows the simplified Northbound and Southbound journeys undertaken by one vehicle on a route north of Central London during 1 weekday in September 2009. On one of the Southbound routes, it can be seen that the driver needed to take a detour around Mornington Crescent Station, which can be used for audit checking (e.g. where operators incur lost mileage), driver and vehicle performance monitoring, and for providing supporting evidence to the emergency services.

4.4. Dwell time estimation

The ability to derive typical dwell times at bus stops from the iBus data has a variety of uses. For example, the dwell time profiles could help TfL to optimise the location of vehicle detectors in providing bus priority through iBus, and provide guidance values to systems like SCOOT or Countdown to improve their performance. Dwell times are also useful generally in public transport operations, traffic management and micro-simulation modelling, by providing an improved understanding of the expected delay of vehicles at bus stops and therefore their impact on other traffic, and help predict more effectively the overall link journey times for both buses and other vehicles.

Previous research on dwell times in London (York, 1993) is now largely outdated, due to major changes to the vehicle fleet composition, passenger demand, and road traffic conditions. While other countries have conducted more recent research, these have involved operations on a smaller scale, used different definitions of dwell times, or relied on Automatic Passenger Counter technologies in their estimates, which have yet to be applicable to London.

Extracting the dwell time-related data from the iBus databases is not necessarily automatic or straightforward. The database records are not relational so it is not easy to associate when a vehicle has entered the capture zone of a bus stop, and determine when its doors opened and closed, and other associated vehicle stationary times. These three types of events are independently recorded in the bus log files, and logic must be written to associate these records based on their sequence or relative timings. The data required needed to be derived using new computer algorithms, via timestamps of when vehicles recorded these events, as stored in these files.

Among over 35 different record types stored within the bus log file, there are four which may be used individually or collectively to derive dwell time. These are:

1. vehicle halt events (either a halt 'beginning' or a halt 'end');
2. bus stop zone events (either vehicle 'enters' or 'exits' the capture zone of a bus stop, which is typically defined as 30 or 50 m before and after the site of the bus stop 'flag' or pole);
3. door events (when the doors have either 'opened' or 'closed');
4. detailed GPS second-by-second location, with associated vehicle speed (from the odometer pulses).

Middleware programs have been developed in C++ by the Authors of this paper to convert the raw bus log file data into more meaningful forms, by capturing and comparing the recorded timestamps of when vehicles entered and exited the bus

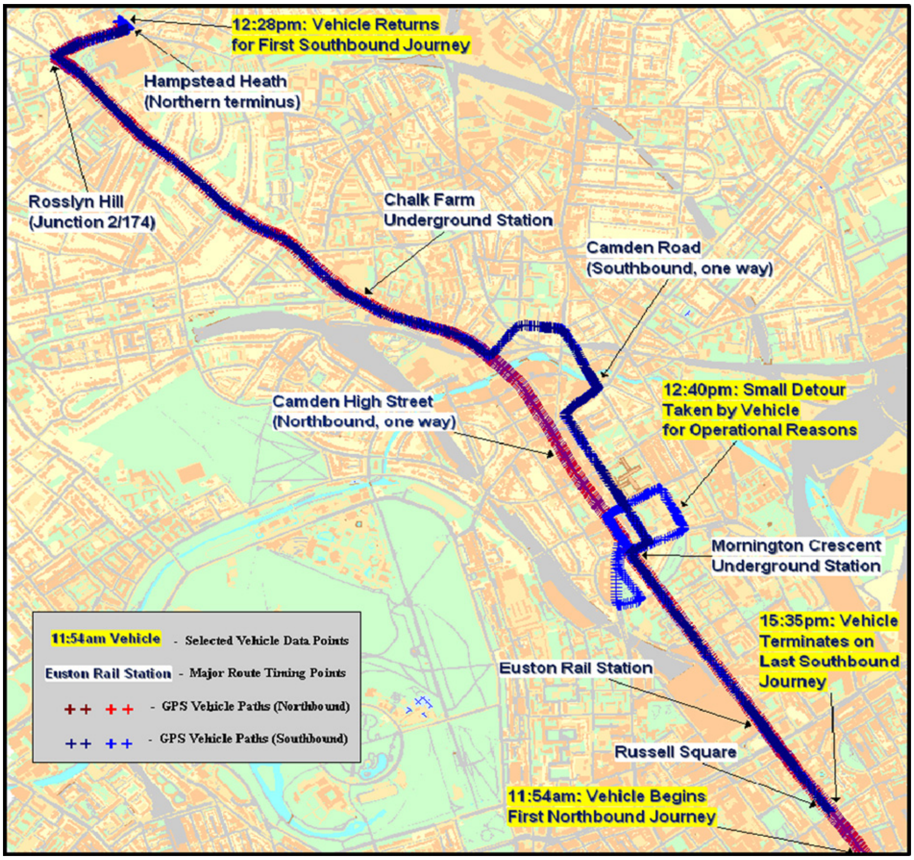

Fig. 6. Mapping of a journey undertaken by a bus.

stop capture zones, halted, opened and closed doors, and/or when the speed remained at zero, and using these to derive the bus stop dwell time durations – see Fig. 7 below.

There are many different definitions of what constitutes bus stop dwell times, for example York (1993), DfT (2006), and Robinson (2009). In addition to the time taken for passengers to board and alight (which is included within the door open and close times), dwell time may also be defined to include other associated vehicle 'dead' times (York, 1993), for example when the bus remains stationary while waiting to re-join the traffic flow. These various definitions of dwell may be derived using one or more combinations of the different bus log file events, since these provide the necessary information to calculate the range of stationary or dead time durations at a bus stop.

4.5. Bus performance analysis for bus priority

The provision of bus priority at traffic signals with iBus requires buses to identify when they are at the relevant virtual detection point (VDP) and to send a telegram to each 'bus processor' located within each traffic signal controller cabinet on street. The telegram contains various items of data including punctuality information of the bus which the bus has received from the control centre. This telegram information, which is used to request priority, is also stored in the bus processor unit. The punctuality information is categorised into sixteen different groups such as 'within 1 min of the expected time', and '2 min late'. This level of information is provided to give different levels of priority to the buses depending on their punctuality situation. However, such information can also be used to analyse the performance of the buses in terms of their punctuality along the route.

To carry out such analysis, a survey was carried out in February 2010 by collecting bus processor data from 10 northbound and nine southbound junctions on a bus route in North London. The bus processor data included: Site ID, Date, Time, Input priority, Output priority, Output action, Vehicle number, Movement number, Trigger point and Schedule deviation value. An example frequency distribution showing the punctuality of southbound buses at three different locations (the start, middle and end of the route) is shown in Fig. 8.

Fig. 8 shows that the profile is flatter towards the end point of the route in comparison to the start. This illustrates how bus punctuality deteriorates along the route (as expected). The average percentages of buses in different punctuality

Record ID	Date	Time	Speed [km/h]	Longitude	Latitude	Shortname							
EVENTS RELATED TO BUS STOP DWELL TIMES:													
Bus Stop Zone Event:							Event Type	Geo Index	Schedule Dev				
31	15/09/2009	14:54:16	29	-604450	185589149	StopZone	1	272	32767	*Vehicle Inside Stop Zone*			
31	15/09/2009	14:55:36	21	-607653	185590915	StopZone	2	272	32767	*Vehicle Outside Stop Zone*	*Calculated Duration: 1 minute 20 seconds*		
Halt Event:							Event Type	Schedule Dev					
21	15/09/2009	14:54:27	0	-606186	185590054	Halt	1	32767	*Vehicle Halt Began*				
21	15/09/2009	14:55:18	11	-606458	185590323	Halt	2	32767	*Vehicle Halt Ended*		*Calculated Duration: 51 seconds*		
Door Event:							Event Type	Schedule Dev					
41	15/09/2009	14:54:27	0	-606186	185590054	Door	1	32767	*Door Released*				
41	15/09/2009	14:54:32	0	-606186	185590054	Door	2	32767	*Door Closed*		*Calculated Duration: 5 seconds*		
GPS Event:													
82	15/09/2009	14:54:24	4	-606186	185590054	DetGPS	)						
82	15/09/2009	14:54:25	0	-606186	185590054	DetGPS	) *Speed Reduced to Zero in GPS Record*						
82	15/09/2009	14:55:14	0	-606165	185590060	DetGPS	)						
82	15/09/2009	14:55:15	1	-606167	185590073	DetGPS	) *Speed Increased from Zero in GPS Record*				*Calculated Duration: 49 seconds*		
OTHER USEFUL EVENTS (BUS PRIORITY EXAMPLES):													
Traffic Signal Priority Message Event:							Task	Junct ID	Movement	Telegram		Acknowledgement	
84	15/09/2009	14:55:15	0	-606165	185590060	RTIGTSP	0	9	4	1091004C2500F080FF0F00007080000C0		0	*Priority Requested*
84	15/09/2009	14:55:15	1	-606167	185590073	RTIGTSP	1	9	4	107091004C2500		1	*Acknowledged*
Virtual Detection Point Event (Coordinates-Based Action):							Trigger Index	Trig Long.	Trig Lat.	Capture Zone	Point Type	Sub Type	
103	15/09/2009	14:55:16	1	-606167	185590073	GeoAct	28485	-606662	185590080	20	GEOPOINT	SVD_Detect	*SVD Triggered Record*

Note: Only data shaded (in green and yellow) are from the bus "log" file. Data shaded in green (dark shade) are "header" items; those in yellow (light shade) are record specific items.
All other text has been added manually to aid reading and interpretation. (Some of the data has also been edited or formatted for this purpose.)
Some data items are NOT shown here for simplicity. (E.g. "navigation state", "driving direction", "coordinate quality", "number of satellites" and "odometer reading" for the "header".)
GPS longitude and latitudes in log files are in milliseconds, and must be divided by 3,600,000 to obtain "normal" GPS coordinates in decimal degrees.
Records are shown separated here for illustration. In practice, records are stacked one on top of another (in record ID and time order) - there can be tens of thousands of records for one afternoon.
In addition, the individual data items are concatenated with each other in one continuous text record (i.e. not split into cells, as shown here).

Fig. 7. Processed iBus data for estimating dwell time information.

categories taking account of all the junctions in the northbound and southbound directions included in this study are given in Table 2.

The table shows that in average 37% of buses were more than 1 min early and 42% were more than 1 min late. There were 21% of buses within 1 min of the expected time. This punctuality information could be used to ascertain the percentages of buses getting different levels of priority depending on the priority logic, or to design a priority logic within given punctuality constraints. Table 3 provides an example of a possible logic for 'differential' bus priority of this sort.

If the priority logic given in Table 3 is implemented, based on Table 2 and 11% of buses (buses more than 7 min late) will get the highest priority (level 3). Similarly, 22% of buses will get level 2 priority and 31% will get level 1 priority. The percentage of buses not getting priority (early by more than 1 min) is 34%. In addition, information given in Table 2 could be

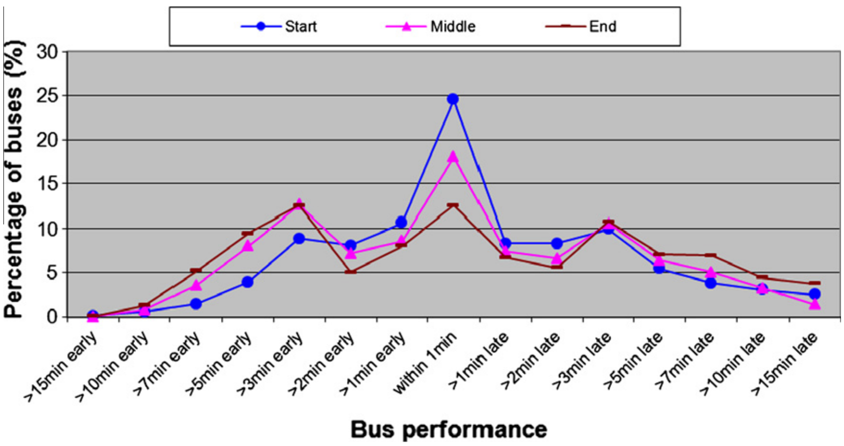

Fig. 8. Punctuality of buses at different locations along a route.

Table 2
Average punctuality percentages of buses along a route.

Punctuality	Northbound	Southbound	Average
>15 min early	0.31	0.14	0.23
>10 min early	1.01	0.71	0.86
>7 min early	3.46	3.00	3.23
>5 min early	6.04	5.51	5.77
>3 min early	11.00	9.02	10.01
>2 min early	7.83	7.02	7.42
>1 min early	9.55	9.43	9.49
Within 1 min of time	20.44	21.50	20.97
>1 min late	9.03	10.55	9.79
>2 min late	6.64	7.32	6.98
>3 min late	9.02	9.58	9.30
>5 min late	5.05	5.18	5.12
>7 min late	4.61	4.57	4.59
>10 min late	3.18	3.48	3.33
>15 min late	2.83	2.99	2.91

Table 3
Example of initial priority logic for differential priority in iBus.

Criteria	Priority level
Early by more than 1 min	0
Up to late by 2 min	1
Late by more than 2 min	2
Late by more than 7 min	3

used to design the priority logic to remain within a constraint. For example, if it is decided that highest level priority should not be given to more than 10% buses, then the criteria for such level should be late by more than 10 min (based on Table 2).

5. Discussion

Although there are clearly many potential benefits/applications of iBus data, there are also many issues, including:

5.1. Data aggregation and management

The System provides a vast repository of AVL and fleet operations data collected by London buses, including vehicles' real-time GPS locations and (by calculation) their journeys times and headways. AVL-based systems such as iBus can almost provide too much data, and one of the challenges for bus operators and local transit authorities users is getting to grips with the structure and quality of the data captured, how to store it (and for how long), and to understand where the information is good enough to justify further research and development, and that can provide tangible benefits to users and bus operators.

5.2. Data consistency

There is typically a 2 day lag between when files are recorded by vehicles, to when they are uploaded into the local data servers at bus garages and transferred to the central reporting databases, although this process can sometimes take up to a week, and longer in extreme cases. TfL have conducted a great deal of work to improve the quality of data in the System, but it should be recognised that, like many AVL systems, there will always be incidences when the bus log file data fails to capture, for example when there is a fault in the logging or communications equipment of a vehicle, which causes the record capture or file transfer process to break down. Nevertheless, the post-processing data coming from iBus is considerably more comprehensive than that collected previously using on-street, sample survey methods.

5.3. Selection of timing points

A key issue is the determination of where the start (or end) point for a measurement is. Most timing points are taken from bus stops, and iBus defines several records which define bus stop events, as discussed previously. For Quality of Service (QSI) and/or journey time measurement, the number of timing points chosen can be key, and depends on where they are located on a route. While an increase in timing points will provide a larger sample, it is known from previous operational experience that for example, bus punctuality and regularity often deteriorates from the start of a journey towards its end, so the selection of representative timing points for QSI measurements will be important.

5.4. System and data integration

iBus is a proprietary system, and the issue of integrating its data with other systems is not necessarily straightforward. The use of iBus data needs to be considered more strategically if, for example, we are to derive benefits of encouraging the transfer of information (and therefore passengers) to and from other modes. To this end, it is helpful that major transport providers such as TfL are clear on their information management strategy, to describe the data they hold, how they relate to each other, how it may be used, and what information could be make available to other institutions, for example to third-party system developers and research organisations. In longer term, the development of industry standards for importing and exporting such public transit-related information, similar to the work performed by the Real-time passenger information group, will also be beneficial.

6. Conclusions

The use of AVL systems to improve public transport performance through various real time applications is growing. In addition to the real time applications, these systems also provide a rich source of bus location and performance data available for various post-processing applications. Those described in this paper include: improved bus service monitoring, enhanced operational reporting/scheduling, enriched spatio-temporal analysis, dwell time estimation and bus priority surveys. The use of such data reduces the manual data collection resources and has the potential to provide much more detailed information that is not possible to collect from manual surveys. However, as well as providing opportunities, this vast amount of data also presents challenges for data storage and processing requirements, as a platform for subsequent interpretation and analysis.

The examples presented in this paper have come from London – a capital city with an extensive bus network and a state-of-the-art AVL system that uses satellites-based location technology. However, this technology is widely available for towns and cities across the world, even where bus fleets are much smaller than London, and efficient data management will remain a key requisite for successful systems to support the quest for sustainable city transport.

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