AUTOMATIC VEHICLE LOCATION AND BUS PRIORITY: THE LONDON SYSTEM

NICK HOUNSELL
Transportation Research Group
Department of Civil and Environmental Engineering
University of Southampton, SO17 1BJ, SOUTHAMPTON, UNITED KINGDOM

FRASER MCLEOD
Transportation Research Group
Department of Civil and Environmental Engineering
University of Southampton, SO17 1BJ, SOUTHAMPTON, UNITED KINGDOM

Abstract

This paper describes how automatic vehicle location (AVL) and urban traffic signal control (UTC) systems are being integrated in London to provide bus priority. Alternative architectures for integrating AVL and UTC systems for bus priority are discussed, with reference to operational systems in France, Italy and the United Kingdom. Summary results of a study illustrating the potential benefits of providing different levels of priority according to adherence to schedule are presented. The paper concludes with an outline of the implementation of AVL/UTC in London and the evaluation of it within the European Commission DGVII project INCOME.

INTRODUCTION

Improvement to public transport systems and services is seen by many city authorities as an important component of any strategy to tackle increasing congestion and pollution caused mainly by private traffic. Investment in modern light rapid transit (LRT) systems is growing, but in many countries, including the U.K., the bus remains the predominant form of public transport in most towns and cities. However, buses themselves are often affected by congestion, leading to operational problems for bus managers and to a deteriorating service for the public. New solutions are therefore being sought, taking advantage of the rapid advances in information technology and "Intelligent Transport Systems" (ITS). Automatic vehicle location (AVL) is one such application of ITS which is proving to offer substantial benefits to public transport operators and passengers.

This paper presents an increasingly important application of AVL - its use for bus priority at traffic signals - and focuses on current developments in London.

AUTOMATIC VEHICLE LOCATION

AVL systems have developed substantially over the past decade, particularly for commercial fleets, emergency/security vehicles and public transport operations. For public transport, AVL applications include fleet management (real-time vehicle scheduling and control), real-time passenger information at bus stops and (in a few cases) public transport priority. The key components of AVL systems for public transport are location, communications and central processing/control. Five functional components are often categorised:

(i) On-vehicle equipment, used to track the position of the vehicle in real-time and provide a variety of other on-bus functions. Tracking may be through odometer-based distance measuring relative to a pre-defined route, with roadside beacons often used for calibration, or through satellite-based global positioning systems (GPS).
(ii) Roadside equipment (beacons) for vehicle location and data transfer. These beacons may be active, sending a location code continuously, or dormant, where the location code is only transmitted to the bus on request. In the latter case both the vehicle and the beacon are fitted with a transmitter and receiver. Several methods of communication are used between the vehicle and the beacon, including infra-red, microwave, UHF or loop-based methods.
(iii) The control centre, where the location of the bus fleet is monitored in real-time and various manual and automatic functions take place to optimise management of the fleet. Data for other functions such as passenger information and bus priority requests are processed at the AVL centre.
(iv) Communications systems, for communications between the AVL centre and the vehicles, with each having a radio transmitter and receiver. Various public and private mobile radio services are available, with cellular radio and satellite services generating increasing interest.
(v) Bus stop equipment, "driven" by the AVL system, supplying information to passengers.

Beacon-based AVL systems have been most common for public transport applications in the U.K., although applications of satellite systems (GPS) is increasing, particularly for small bus fleets and/or where locational accuracy to within ~100m is sufficient. Where much better accuracy is required, differential GPS can be used, although the current cost of this system limits its application. Terrestrial radio-based systems such as the Securicor Datatrak system in the U.K. have not been generally taken up for public transport applications.

AVL specification clearly depends on the functions required. Key items are locational accuracy, polling frequency and communications reliability. In the U.K., polling frequency with many systems has been governed largely by the number of buses equipped and radio channel availability. Communications reliability is system and situation dependent; typical problems can be radio blackspots and the overriding of AVL with speech where a shared communications system is used.

Where AVL provides the location function for public transport priority at traffic signals within urban traffic control (UTC) systems, a strict specification is required if the priority system is to be efficient. For example, in the integrated UTC/AVL system in Turin (UTOPIA), the AVL system was specified primarily for priority applications, providing a ±5m locational accuracy and a 20 second polling cycle, which could become more frequent as a bus/tram approaches a junction (Di Taranto and Beccaria, 1995). The UTC system was also designed for this architecture, so that a "rolling horizon" control principle is also adopted for signal optimisation, incorporating updated information on bus/tram locations.

AVL systems applied for fleet management and/or for passenger information at bus stops need a less exacting specification for some functions (polling frequency, locational accuracy) than where they are applied for bus priority. Bus stop displays are typically provided to the nearest minute, whereas bus priority requires journey time prediction accuracy to a few seconds. U.K. examples here are the COUNTDOWN (Smith et al, 1994) and STOPWATCH (Wren, 1994) systems, in London and Southampton respectively, for real-time passenger information at bus stops, described later in this paper. Given the potential benefits of bus priority, both systems are now being used/enhanced for this purpose, as described later in this paper.

PUBLIC TRANSPORT PRIORITY AT TRAFFIC SIGNALS

Many systems have been developed throughout Europe for providing public transport vehicles with priority at traffic signals. In the UK significant developments and applications of bus priority have occurred in London. These have included both passive and active systems.

Passive bus priority has been applied both in fixed time UTC (TRANSYT) and in the SCOOT traffic responsive UTC system (Hunt et al, 1981). In fixed time systems, BUS TRANSYT can be used, where signal co-ordination is optimised taking account of the different performance of buses relative to general traffic. With SCOOT, facilities such as 'split weighting' and 'offset weighting' can be used to benefit specific traffic links where these contain high proportions of buses. Although requiring no infrastructure costs, benefits to buses are usually only limited with these facilities and interest has, therefore, centred more on active priority systems, where individual priority is given to detected buses, usually by extending or recalling the green phase for the bus.

Active priority at isolated junctions was first trialled in London in the 1970s and implementation has grown steadily since the large-scale trial conducted in the SELKENT area of London in 1987 (University of Southampton, 1987). This involved equipping 900 buses with transponders to activate priority at 56 junctions operating under the UK D-system of vehicle actuation. Average bus delay savings of 9 seconds per bus per junction, with very small disbenefits to general traffic, produced an economic payback period of one year, approximately. New priority facilities have now also been introduced into the MOVA strategy for isolated junction control.

Active priority at traffic signals operating under UTC is provided by the PROMPT and SPRINT systems in London.

PROMPT (Priority and Informatics in Public Transport) was an EC-funded collaborative project involving public transport applications in London, Gothenburg and Turin. In London, bus priority was developed and implemented in the SCOOT UTC system using the well-established bus transponder and loop technology operating there, with trials at 17 junctions in the Camden Town and Edgware Road SCOOT regions. The PROMPT development process and its evaluation in London has been described at the Second World Congress in Yokohama (Hounsell and Landles, 1995) and elsewhere (Hounsell, 1996a). In summary, the priority green extension, recall and resynchronisation facilities implemented automatically by SCOOT provided

(i) Average bus delay savings of 4 secs/bus/junction reaching an average of 8 seconds (70% saving) at lightly trafficked junctions. These savings were achieved with no significant disbenefits to general traffic.
(ii) Reductions in bus delay variability and operating costs.
(iii) An economic "return" of 72% of system costs in the first year (a 16 month payback period).

These results were achieved against a background of relatively high congestion, limited system tuning and relatively high installation costs which would be lower in most other London areas.

Despite the expansion of SCOOT in London, some 700 signalised junctions still operate under fixed time UTC. Active bus priority is equally necessary at these junctions and techniques developed could be of much wider interest elsewhere given the large number of cities around the world operating fixed time UTC systems. In London, the system developed for bus priority within fixed time UTC is called SPRINT (Hounsell et al, 1997b).

SPRINT has been designed to be compatible with PROMPT as far as possible; the principal differences are that SPRINT operates against a background of fixed time plans and has no knowledge of actual traffic conditions. This means that SPRINT cannot match the priority given to the actual traffic conditions, unlike SCOOT/PROMPT. It also means that facilities such as the "resynchronisation" to UTC plans, following a priority action, and the compensation to non-priority stages (where necessary) have to be fixed in a database, depending on TRANSYT traffic predictions for that time of day. With PROMPT, these activities can be undertaken automatically by SCOOT in response to actual traffic conditions.

SPRINT has been installed on a 3km section of the Uxbridge Road in West London, incorporating 8 signal controlled junctions. System evaluation is continuing.

AVL FOR PUBLIC TRANSPORT PRIORITY AT TRAFFIC SIGNALS

Most public transport priority systems at traffic signals have relied on transponders and inductive loops to detect buses/trams on the signal approach. Sometimes only one loop is used (e.g. as in the London/Southampton systems) as the installation of additional loops to monitor the buses approach, or to cancel priority when it has crossed the stopline has not been considered cost effective. However, the potential of AVL to track the progress of the bus/tram and to provide a locational capability for priority has been recognised for some time; the UTOPIA system in Turin (Di Taranto and Beccaria, 1995) is probably the first example of this application. AVL architectures now being used or developed for this purpose are now discussed.

AVL architectures for public transport priority

The use of AVL for public transport priority applications can take a variety of forms. Two categories of particular relevance to the U.K. are illustrated in Figures 1 and 2, termed Architecture A and Architecture B in the following descriptions.

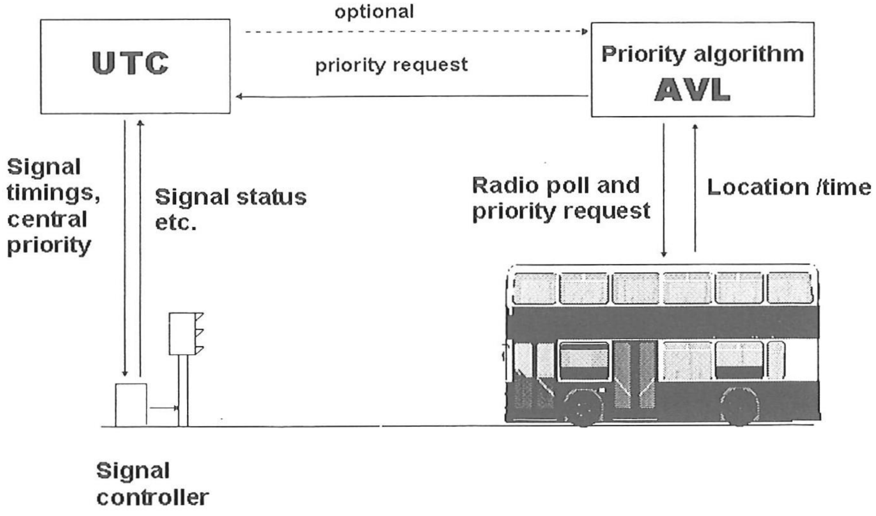

Figure 1 - Architecture A

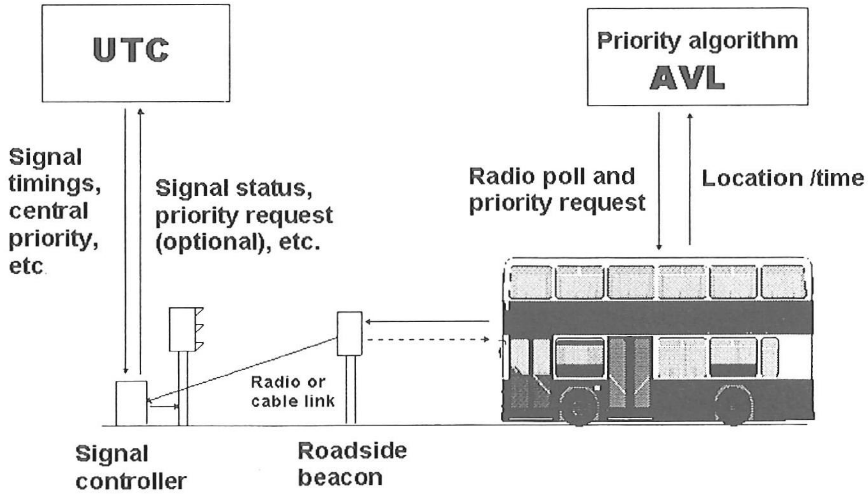

Figure 2 - Architecture B

Architecture A (Figure 1) involves the use of AVL for bus/tram location and the use of a priority algorithm in the AVL centre to determine the priority requirements for each bus/tram (e.g. according to its headway or adherence to schedule). A priority request is then passed from the AVL system to UTC defining the priority level requested at that time/location for that bus/tram. The UTC system determines how this priority request is best activated, often taking account of all traffic at the junction. Where UTC is under centralised control, signal timings are re-optimised centrally to incorporate the priority request and transmitted to the local signal controller for implementation. This type of system is currently under trial in Southampton where the SCOOT centralised traffic responsive UTC system is operational which incorporates bus priority developed in the recent European project PROMPT (Hounsell et al, 1996b). Where UTC is wholly or partly decentralised (e.g. UTOPIA) the priority request is transmitted to the local controller for de-centralised optimisation. This system is operational in Turin.

In Turin, UTOPIA uses a "rolling horizon" technique to predict bus/tram arrival times at the downstream signal, from as far as 120 seconds upstream of the junction. In this way, the green "window" for the bus/tram, defined by the start and end of the relevant green stage, can be adjusted gradually to be aligned with the approaching bus/tram, which would be located typically four or five times during its approach using the AVL system. Bus delay savings of up to 97% have been recorded for this technique, with little impact on other traffic (Hounsell et al, 1996a).

In the U.K., the SCOOT UTC system uses upstream traffic detection for signal optimisation but does not incorporate prediction other than the time predicted for detected traffic to reach the stopline. Bus priority has therefore been developed assuming useful detection is restricted to the approach link, so that, even with AVL, only data for buses up to about 30 seconds from the junction would be used for priority. In addition, detection is restricted to locations downstream of any bus stops on a link, because of the often high and variable bus stop dwell times which make journey time prediction too imprecise. (This is less of a problem in some European cities (e.g. Turin) which operate automatic ticketing.) The U.K. approach with Architecture A has the advantage of being less dependent on journey time prediction accuracy, but has the disadvantage of requiring more abrupt changes to signal timings to provide effective priority because of the greater proximity of detection to the junction.

A variant of Architecture A concerns possible communication from UTC to AVL, shown by the dashed line in Figure 1. A system developed by CGA in France uses this approach, where UTC communicates to AVL just before each proposed stage change, to determine whether any bus is near the junction concerned and therefore whether the stage change time should be advanced/retarded. In the following description of this approach (taken from Laurens (1994)) the term AVMCS (Automatic Vehicle Monitoring and Control System) describes the integrated system incorporating AVL.

When the vehicle crosses a fixed point situated before the intersection, at a sufficient distance to cover all the maximum timings of the intersection, it transmits spontaneously to the AVMCS central computer a message indicating that it requests priority (depending on its position as regards the schedule), indicating its identification and the traffic phase it will use to cross the intersection. This message is relayed to the UTCS computer which stores it in a table corresponding to this intersection for later use. When the UTCS detects that the timing of this intersection is near a decision point (end of green or end of the minimum red) for a given phase, it looks in the table for this phase to see if there is an approaching bus. If so, it transmits to the AVMCS computer a request to know the present position of this bus. The AVMCS computer interrogates immediately the corresponding bus and transmits to the UTCS computer the present position of the bus. The UTCS computer uses the mean bus speed corresponding to the present situation to compute the arrival time of the bus at the intersection.

The centralised solution described here has advantages of reduced cost, compared to decentralised systems needing on-street infrastructure, and of potential improved operational efficiency, as bus locational information is only requested when and where required. The CGA system was operational in 7 French cities by 1994.

Decentralised AVL/UTC Communications

Architecture B (Figure 2) again involves the calculation of individual bus/tram priority requirements at the AVL centre, based on AVL information. However, priority requirements are then returned to each individual bus with the radio polling message, rather than to the UTC centre. Priority requests are then transmitted either directly from the bus to the downstream traffic signal (e.g. by short range radio) or, as currently proposed for London, transmission is via a roadside beacon sited at the normal detection point, with cable or radio communications from the beacon to the traffic signal controller.

Key reasons for adopting this architecture in London are that:

(i) The precise locational requirements for bus priority are provided by the beacon rather than AVL, which was not designed for this purpose.
(ii) Potential complexities in establishing direct AVL/UTC communications in the short term.
(iii) The capability for "local" priority is required, as this provides higher benefits than the central priority necessary in Architecture A. "Local" priority is where the intersection controller provides immediate priority for the approaching bus, to avoid the ~3-5 secs of communication delay which occurs with the centralised system. (This delay can significantly reduce the benefits of bus priority where detection is relatively close to the stopline (e.g. 30-80m) as typical in London.)
(iv) Priority at isolated junctions is required, which is not possible with Architecture A.

A further non-AVL technique for bus priority involves decentralisation of intelligence to the bus and/or to the roadside (e.g. beacons and/or signal controllers), where priority decisions are made according to the status of the bus (adherence to schedule, etc.) A system such as this, using differential GPS for location and short range radio communications to request priority, is currently being developed in the U.K. in Maidstone.

AVL AND SELECTIVE PRIORITY: THE LONDON EXAMPLE

The provision of selective priority in London, following Architecture B above, requires substantial investment in hardware, communications and software. Feasibility studies have therefore been undertaken to evaluate various aspects of system implementation as described in the following section.

Feasibility study

A feasibility study, undertaken by TRG for London Transport Buses (University of Southampton, 1996) has shown that selecting buses for priority according to their headway (relative to the scheduled/average frequency) could have the following benefits:

(i) Improved service regularity, providing reduced average waiting time for passengers and operating savings for the operator. A sample analysis of waiting times for one service at seven bus stops is shown in Table 1. This revealed an average waiting time of 7.6 minutes, of which 2.8 minutes

(37%) was "excess" waiting time due to irregularity in bus arrivals. The problem of bunching and irregularity is further illustrated in Figure 3, which is based on a bus headway distribution recorded in inner London. Selective priority clearly has plenty to work on here!

Table 1 - Headway statistics (bus route 15, central London)

Bus stop	Average	Standard deviation	Maximum	Sample size	Excess wait	Average wait
1	8:59	7:08	27:00	81	2:50	7:19
2	9:06	8:36	47:00	79	4:04	8:37
3	10:48	9:04	29:00	71	2:36	7:41
4	9:32	7:33	31:00	75	3:00	7:46
5	8:47	8:22	38:00	80	3:59	8:23
6	8:48	5:22	30:00	83	1:38	6:02
7	10:35	7:53	39:00	68	2:56	8:14

Key to Table 1
All times are expressed in minutes and seconds (mm:ss).
Excess wait = variance of headway / (2 * average headway)
Average wait = average headway/2 + excess wait

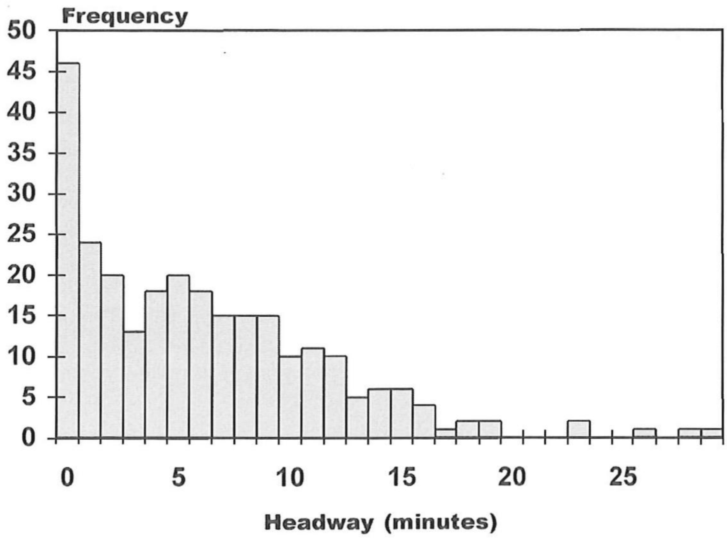

Figure 3 - Example headway distribution (Bus route 18, Edgware Road)

(ii) Targeting buses with higher than average passenger loading, which is expected for those buses with a higher than average headway (from the preceding bus). Analysis of bus occupancy data at the same seven stops as in (i) showed that the average occupancy for the 50% of buses with the highest headways was some 25% higher than the average occupancy for all buses. Buses constituting the top 25% of headways had an average occupancy some 46% higher than that for all buses.

(iii) The provision of a higher level of priority without significantly affecting general traffic, because of the reduced number of priority actions.

(iv) Less disruption to general traffic, again because of the reduced number of priority actions.

Figure 4 illustrates points (iii) and (iv) through relationships between delay reductions/increases for buses and general traffic due to priority and the level of bus flow. Figure 4 has been compiled from a variety of results from London studies. Figure 4 shows how green extensions (line A) provide constant benefits to buses with no disbenefit to other traffic. However, the benefits to buses of green recalls decrease with increasing bus flow (lines B and C) partly due to the increasing disbenefits to general traffic (lines D and E) caused by the priority system.

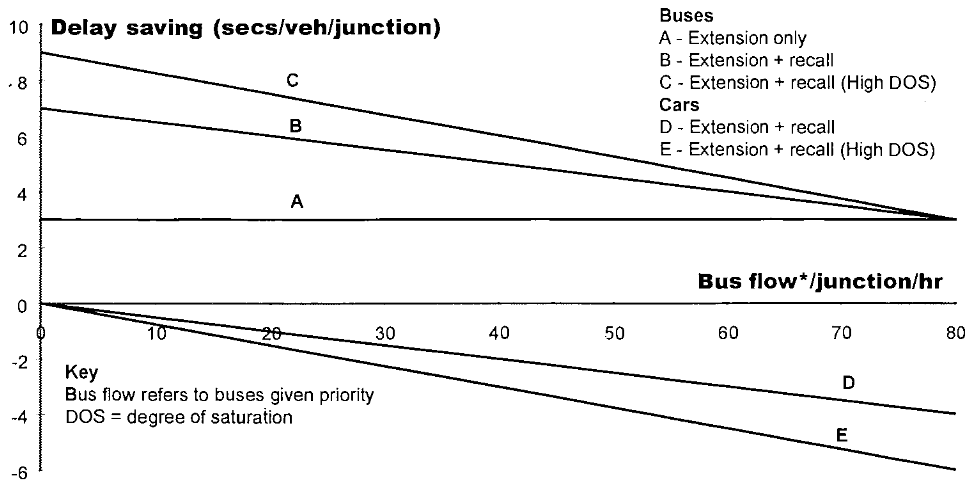

Figure 4 - Relationships for delay savings

The main disadvantage of selective priority concerns passengers on those buses not awarded priority, who lose journey time (and associated) benefits they would otherwise gain if priority was awarded to all buses.

Of the many scenarios considered in the feasibility study, three were carried forward for an economic evaluation of benefits, as illustrated in Table 2. Results here are related to a particular bus route (the Edgware Road) where bus priority in SCOOT has already been evaluated. These results are based on (a) delay impacts summarised in Figure 4, (b) the relationship between bus occupancy and headway implied in (ii) above and (c) an assumed relationship between bus delay savings and regularity savings, when selective priority is implemented.

Table 2 - Summary of economic benefits: Edgware Road

	Economic Benefit (£K/annum/junction)		
Case	**Priority buses**	**Cars**	**All vehicles**
1	18	0	18
2	26	-26	0
3	36	-26	10

Case 1 refers to the current strategy where all buses are eligible for priority extensions only. This is a moderate level of priority but causes no disbenefit to general traffic. Case 2 considered the selection of 25% of buses with the highest headways for high priority. This provided greater aggregate benefits for buses, with a similar aggregate disbenefit to general traffic due to the use of a high priority strategy causing some traffic disturbances.

The most promising strategy (Case 3) involved allocating priority extensions to all buses, with additional high priority to 25% of buses with the highest headways. Compared to the existing situation (Case 1) this strategy provided higher overall bus benefits (by 100%), with some disbenefit to non-priority traffic, giving a slightly poorer overall performance. However, by providing greater benefits for buses and a bigger difference between bus and car impacts, Case 3 would benefit public transport operations and be more likely to encourage modal change.

These promising findings have led to the development and production (University of Southampton, 1997) of a functional specification for a headway-based selective priority algorithm for implementation and evaluation in INCOME, a collaborative project sponsored by DGVII of the European Commission (Hounsell et al, 1997a). The features of this algorithm are described in the following section.

Headway algorithm

A bus priority algorithm, based on bus headways, was developed to investigate the effect of selective priority. The algorithm was incorporated into a simulation model to assess the impact of selective priority on passenger waiting and travel times. The operating framework envisaged for implementing the headway algorithm in practice is as follows:

Bus routes are divided into user-defined sections, each section having similar bus operating characteristics. The priority requirement for each bus is determined at the start of each section (known as the priority calculation point (PCP)) according to its adherence to schedule (for timetabled services) or to its actual headway relative to the scheduled headway. One of up to four priority level requests (PLR) is transmitted to the bus at each polling occurrence. This PLR will then be communicated to each roadside beacon positioned for bus priority (using new on-bus equipment/communications) and transferred immediately to the signal controller of the next downstream junction, possibly using radio (LAN) communications. The signal controller will then interpret the PLR locally, or via UTC, and carry out the appropriate priority action. The system is illustrated in Figure 5, while initial options for PLRs are given below Table 3.

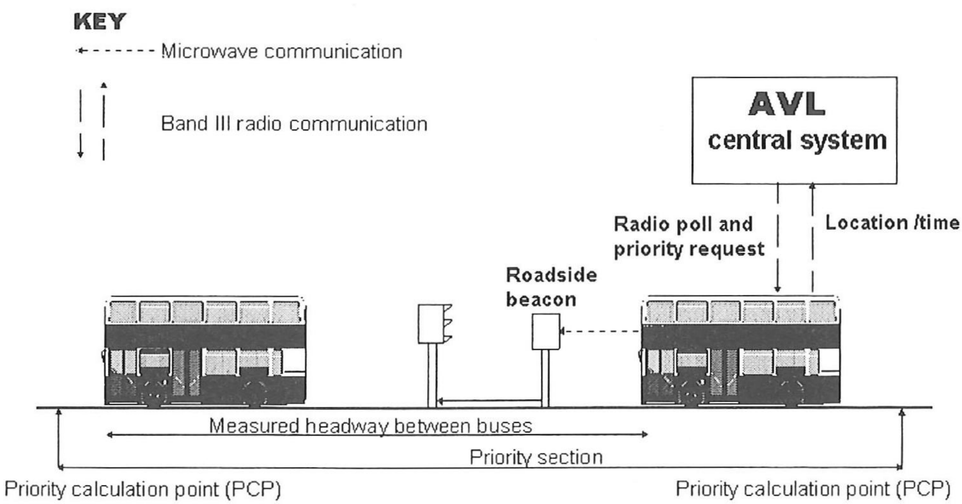

Figure 5 - Priority system architecture

The headway algorithm was developed to provide different levels of priority according to the size of the bus headway relative to the expected average headway. Both the ratio of and the difference between bus headway and expected headway were considered as measures of 'lateness' of a bus :

- the ratio, R = *actual headway / expected headway*
- the difference, D = *actual headway - expected headway*

The level of priority assigned to a bus would then be determined by comparing its ratio R (or D if differences were to be used) with pre-set threshold values R_1, R_2, R_3 :

If	$R \geq R_3$	then	*priority level* = 3
else if	$R \geq R_2$	then	*priority level* = 2
else if	$R \geq R_1$	then	*priority level* = 1
else			*priority level* = 0

where $R_3 \geq R_2 \geq R_1$

The bus headway is defined to be the time gap between 'equivalent' buses. Equivalent buses could be defined as buses having the same service number or, where bus routes overlap on certain parts of the network, then the definition could be broadened on those parts of the network where different bus services numbers effectively serve the same passengers.

The features of the simulation model developed are described in the following subsections.

Network

The network used was a simple, linear one, based on the Uxbridge Road in West London. It contained 29 bus stops and 14 signalised junctions.

Buses

Realistic bus flows, starting headways and occupancies were used in the simulation derived from survey data. Four different bus routes were modelled, displaying a range of different headway and stopping characteristics and overlapping on parts of the route.

Passengers

Boarding and alighting passengers at bus stops were modelled in order to measure passenger waiting and travel times. Survey data was used to determine typical boarding and alighting numbers at each bus stop. These were then translated into boarding and alighting rates by dividing by the expected average bus headway. The number of boarding and alighting passengers were then calculated as:

*no. boarders = boarding rate * bus headway*
*no. alighters = alighting rate * bus headway*

These calculations were based on the assumptions that

- arrival of passengers at bus stops can be modelled by a uniform random distribution
- buses with greater than average headway will tend to carry greater than average number of passengers

The first assumption seems reasonable although will clearly not hold at certain times of day when there may be a surge in demand (e.g. school, factory closing times etc.). The second assumption seems, intuitively, to be valid and has been supported by survey data as shown in Figure 6 where the number of boarding passengers is plotted against bus headway for one particular bus route in London.

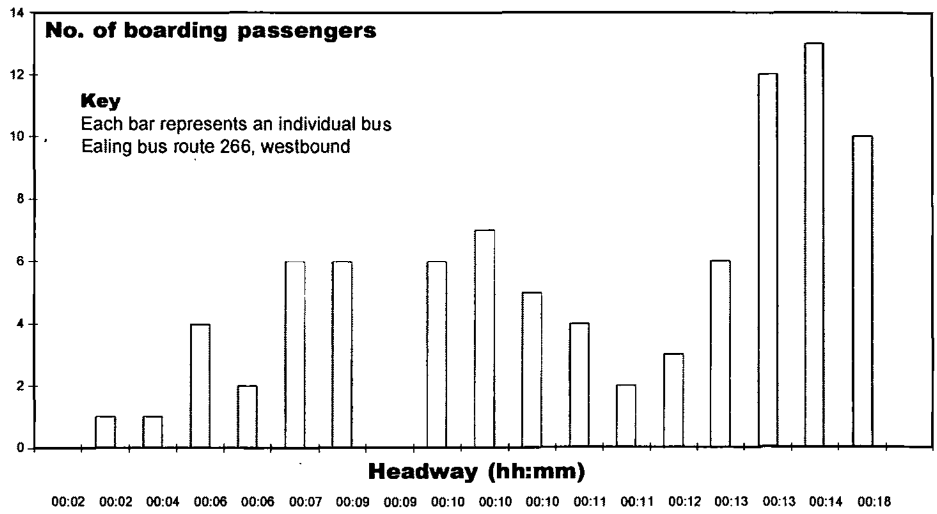

Figure 6 - No. of boarding passengers v bus headway

Bus stops
York (1993) derived relationships between bus dwell time and numbers of boarding and alighting passengers for different bus types (one-person operated (OPO), two-door etc.). These relationships also considered different types of fare-paying passengers (e.g. those with bus passes, whether or not they required change) but, for simplicity, the model here did not include this level of detail. The formula used for calculating bus stop dwell time used for OPO, 2-door buses was:

*dwell time = max (6.44+1.42*no. of alighters, 8.26+4*no. of boarders)*
where max (x, y) means the larger value of x and y

Traffic Signals
The time taken for each bus to progress through a traffic signal was determined from the priority level assigned to the bus according to its headway. Average journey times through signals were assumed rather than attempting to explicitly model any UTC system.

Typical results from the simulation are shown in Table 3, which illustrates how:

- Strategies A and B, where all buses are eligible for priority, provide travel time savings only. Strategy B produces predicted disbenefits for general traffic (and overall) due to the large number of priority recalls which produce some loss of signal co-ordination efficiency.
- Strategies C and D produce travel time and waiting time benefits with highest benefits to buses and overall. These strategies, which reflect different alternatives for selective priority based on bus headway, also provide the greatest differential in impacts between buses and general traffic and should therefore produce greatest modal change (which was not considered in the analysis).

Table 3 - Typical simulation results to support the headway regularisation algorithm using selective bus priority

Strategy	Percentage of buses in each priority level				Savings - bus passengers (£/hr)			Savings - general traffic (£/hr)	Savings - all vehicles (£/hr)
	0	1	2	3	Trave l Time	Waiting Time	Overall		
A	0	100	0	0	34	0	34	0	34
B	0	0	100	0	58	0	58	-121	-63
C	58	0	0	42	56	33	89	-50	39
D	0	0	64	36	62	21	83	-43	40

Key to Table 3

Priority level 0 = No priority

Priority level 1 = Lowest level (green extensions only)

Priority level 2 = Intermediate level (green extensions and recalls, constrained according to degree of saturation on non-priority stage)

Priority level 3 = Highest level (as priority level 2 but less constrained)

CONCLUSIONS

Automatic vehicle location (AVL) is playing an increasingly important role in public transport operations, providing support for real-time management and control and the platform for other important functions such as passenger information systems and bus priority. There appears to be no single preferred architecture for AVL and its applications at present: solutions are being chosen according to the particular circumstances of the city, its traffic and its bus services. In London, a cost-effective approach is being taken which builds on the existing and expanding AVL infrastructure without compromising the strict requirements for effective bus priority. It will be interesting to see if the very promising benefits of AVL-based selective priority predicted by simulation are borne out by on-street evaluation in London in 1998/1999.

From an overall traffic management viewpoint, potential integration of AVL with urban traffic control (UTC) offers some exciting opportunities beyond the individual junction priority techniques outlined in this paper. AVL provides a rich source of network journey time data which could be valuable to UTC for a variety of congestion management functions. These functions in UTC systems such as SCOOT have been developed for general applications ("congestion effects", gating, etc.) but the opportunity is now being taken in projects such as INCOME to adapt strategies such as these to benefit buses: congestion information identified via AVL could be communicated to UTC for implementation of appropriate remedial strategies; in the other direction, incidents and/or congestion detected via UTC could be passed to AVL to alert the bus operator of potential impacts on bus services. These are just two examples within a number of opportunities for beneficial integration.

REFERENCES

Di Taranto, C. and G. Beccaria (1995). UTOPIA - Implementation in Europe: Consolidated Results for Bus Priority. **Workshop on East-West Co-operation in Road Traffic Operations**, Prague, October 1995.

Hounsell, N.B. and Landles, J.R. (1995) Public transport priority at traffic signals in London: progress, performance and opportunities. **Second World Congress on Intelligent Transport Systems,** Yokohama, November 1995

Hounsell, N.B. et al (1996a). Bus priority in London: Building on PROMPT. **Proceedings of the Third World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems,** Orlando, U.S.A., October 1996.

Hounsell, N.B. et al (1996b). Public Transport Priority at Traffic Signals: Results of a European Collaborative Study. **Proceedings of the Third World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems,** Orlando, USA, October 1996.

Hounsell, N.B. et al (1997a). Intelligent Systems for Priority at Traffic Signals in London: The INCOME Project. **Fourth World Congress on Intelligent Transport Systems**, Berlin, Germany, October 1997.

Hounsell, N.B. et al (1997b). SPRINT: Active bus priority in fixed time urban traffic control in London. **PTRC European Transport Forum**, *Brunel University, September 1997*

Hunt, P.B. et al (1981). SCOOT: A Traffic Responsive Method for Co-ordinating Signals. **Transport and Road Research Laboratory Report LR 1014**, Crowthorne.

Laurens, B. (1994) Experiences in Public Transport Priority at Intersections; Centralised Versus Decentralised Approach. **Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems**, Paris, Nov/Dec, 1994.

Smith, R. et al (1994). London Transport Buses: ATT in Action and the London COUNTDOWN Route 18 Project. **Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems,** Paris, Nov/Dec, 1994.

University of Southampton (1996). AVL/Bus Priority Feasibility Study. **Final Report to London Transport Buses**

University of Southampton (1997). Bus Priority at Signals: AVL/BP Headway Algorithm. **Final Report to London Transport Buses**

Wren, A. (1994) ROMANSE: Information Dissemination. **Proceedings of the First World Congress on Applications of Transport Telematics and Intelligent Vehicle-Highway Systems**, Paris, Nov/Dec, 1994.

York, I.O. (1993) Factors affecting bus-stop times. **TRL Project Report 2,** T1/25.