Bus Committee

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# UITP WORKING GROUP:
## Interaction of buses and signals at road crossings

# Deliverable 1

# Review of Bus Priority at Traffic Signals around the World


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## Executive Summary

### Introduction and scope

The UITP Working Group on the *Interaction of buses and signals at road crossings* was set up in 2008 and includes representation from Luxembourg, Cagliari, Sao Paulo, Montreal, Mexico, Bucharest, Geneve, Brussels and London. Phase 1 of the work, led by Transport for London (TfL) has involved a state-of-the art worldwide review of the topic, identification of lessons learnt from different cities/applications and developed recommendations for further work. In early 2009, TfL commissioned the Transportation Research Group (TRG) at the University of Southampton and the UK Transport Research Laboratory (TRL) to undertake Phase 1 of the work. The main focus of the work has been on bus priority at traffic signals.

### Key findings

A range of priority measures are adopted in many cities, including segregated facilities such as bus lanes and busways and priority facilities at traffic signals. Bus priority at traffic signals is the most relevant where opportunities for segregated systems are limited and/or where numerous traffic signals exist. With significant advances in detection, communication and data processing technologies in recent years, many different options are now available for bus priority at traffic signals.

The review presented in this report has confirmed that bus priority at traffic signals is being adopted increasingly around the world with applications ranging from small towns to big cities. The deployment of bus priority systems has been found to be very dependent on (i) the existing infrastructure, particularly the traffic signal control system, (ii) the characteristics of the bus operations and (iii) the policy and Institutional context in which both operate. As a result, a wide variation in priority architectures, technologies used and strategies deployed have been found, with insufficient impartial evidence to compare the cost effectiveness of alternative approaches. The benefits from bus priority have varied from place to place as result of various factors influencing the outcome. Nevertheless, all cities undertaking an economic appraisal of their bus priority systems have reported very good economic returns, with systems typically paying for themselves within 3-16 months, from the passenger and operator benefits gained.

A more detailed set of lessons learnt to date are included in Section 7 of the report.

### Recommendations for future research

The following areas for further research are presented for consideration at this stage:

- At present, the bus priority at traffic signals is mainly aimed at reducing bus delays as a result of the traffic signal timings. Ideally the combination of segregated priority and priority at traffic signals should give buses a relatively clear run along their route. With very few exceptions, this is not widely the case, due to varying degrees of traffic congestion. The normal operation of bus priority at traffic signals does not solve the congestion problem, which is often more severe for buses than the delays caused by signal aspects. Solving the congestion problem requires other measures, such as more bus-only roads/lanes, demand management, and/or strategies for **congestion management for buses**, requiring integrated segregation and real-time UTC strategies..

- Bus performance criteria adopted inevitably influence overall bus operations. For example, minimising bus journey times suggests the need for bus priority to all buses at all junctions, whereas optimising regularity implies the need for different priority actions for buses depending on their situation. Further research is therefore recommended to find out **current practices around the world and the rationale behind the chosen bus performance criteria**. This should also include the influence of the criteria on the implementation of bus priority systems and strategies.

- There is some evidence that the most applicable form of bus priority in a town/city could vary according to the city population, size of the bus fleet, and the numbers and characteristics of traffic signal controlled junctions. An analysis of these variables is recommended in Stage 2, with the aim of developing **guidelines for architectures and systems relating to city size**. This analysis would benefit from the largest possible sample size of example, which should be achieved following the final returns of completed questionnaires.

- It has been shown that investment in bus priority at traffic signals varies substantially between different cities and regions in the world. Greater understanding of the reasons for this variability, and barriers to deployment would be beneficial, not the least to identify examples of good practice. Work in Stage 2 is therefore recommended to **identify organisational/institutional issues which affect deployment**, including the effects of different transport policies.

# 1. Introduction

## 1.1 Preface

The UITP Working Group on the *Interaction of buses and signals at road crossings* was set up in 2008 and includes representation from Luxembourg, Cagliari, Sao Paulo, Montreal, Mexico, Bucharest, Geneve, Brussels and London. Phase 1 of the work, led by Transport for London (TfL) has involved a state-of-the art worldwide review of the topic, identification of lessons learnt from different cities/applications and developing recommendations for Work Stream Two. In early 2009, TfL commissioned the Transportation Research Group (TRG) at the University of Southampton and the UK Transport Research Laboratory (TRL) to undertake Phase 1 of the work ('Work Stream One'). The main focus of the work has been on bus priority at traffic signals.

This report presents the findings from Work Stream One. It has been produced in April 2009 to meet the deadline of the project. The timing of this report has necessitated that it is based mainly on the literature review undertaken along with limited information obtained from the questionnaires distributed. This included information from a desktop study of 22 cities and responses to a questionnaire survey from 7 cities, an 11% response rate.

## 1.2 Background

Buses are the predominant form of public transport in most towns and cities in many countries. In small/medium-sized towns and cities (e.g. up to around 1 million population), buses are often the only form of public transport (along with trams in some cases). With their large carrying capacity, buses make effective use of limited road space, and can therefore make a substantial contribution to reducing traffic congestion. However, buses themselves are often affected by congestion, leading to a decrease in speed and an increase in bus travel time variability and service irregularity. Giving priority to buses plays an important role to protect bus services from the effects of traffic congestion and to improve their speed and reliability.

A range of priority measures are adopted in many cities, including segregated facilities such as bus lanes and busways and priority facilities at traffic signals. Bus priority at traffic signals is the most relevant where opportunities for segregated systems are not available and/or where numerous traffic signals exist. With significant advances in detection, communication and data processing technologies in recent years, many different options are now available for this application. This report describes various options available for bus priority at traffic signals giving examples from various cities around the world including a more detailed case study of the largest such application in Europe – in London

## 1.3 Structure of this report

Following this introduction, this report presents a summary of bus priority methods (Section 2) and traffic signal control systems and strategies (Section 3). Section 4 then describes bus priority at traffic signals in terms of objectives, architectures, priority strategies and detection methods. Examples of bus priority at traffic signals in cities around the world are summarised in Section 5, followed by a more detailed case study of London. (London appears to be the largest system in Europe and substantial published information is available on its developments). Sections 7 and 8 then conclude the report with comparative analyses, lessons learnt and a summary, with recommendations for further work.

# 2. Bus priority methods

There are various ways of giving priority to buses which could be broadly categorised as: Physical measures, traffic signal priorities, and integrated measures. These measures are used according to the need and the feasibility to provide them and can include with-flow lanes, contra-flow bus lanes, bus only streets, priority at traffic signals and integrated measures such as queue-relocation and virtual bus lanes [1]. Examples of physical measures include with-flow lanes, contra-flow lanes, bus only streets and busways. Bus priority methods at traffic signals are examples of traffic signal priorities. Queue-relocation and virtual bus lanes are examples of integrated measures which combine traffic signal measures with physical measures where any of these systems alone is not effective.

## 2.1 Link based measures

Among link based measures, with-flow bus lanes are the most common form of priority. With-flow bus lanes are reserved traffic lanes, usually on the nearside, for the use of buses and may accommodate bicycles [1]. A with-flow bus lane enables buses to bypass traffic queues, usually approaching traffic signals. This will produce substantial time savings to buses and their passengers.

A contra-flow bus lane is a lane where buses are allowed to travel against the main direction of traffic flow. This enables buses to avoid unnecessary diversions, to maintain route patterns when new one-way streets are introduced, and to gain better access to business and shopping areas. These contra-flow bus lanes are usually introduced in area-wide one-way traffic systems, where the effect is to create a two-way road with 'buses only' allowed in one direction, and all other vehicles including buses, in the other [2].

Busways are substantial corridors or networks of bus-only sections of road constructed specifically for the exclusive use of buses. Busways are designed to segregate buses from general traffic that protect them from congestion. For reasons of economy and land requirement, automatically guided or tracked busways may be preferred over busways relying on manual steering [3]. Finally, some links/roads may be reserved for the exclusive use of buses and other priority vehicles.

## 2.2 Junction based measures

Junction based measures vary from an exemption for buses from turning restrictions applied to other vehicles to technology-led adaptive bus priority at traffic signals. Bus priority at traffic signals is an important form of bus priority measure in urban areas. Many forms of bus priority options available in signalised junctions can be grouped as 'passive' priority and 'active' priority. 'Passive' systems apply to those where signal timings are weighted, or re-optimised, to take account of streams of traffic containing significant bus flows. Even though no infrastructure is required for such systems, it is believed that these facilities are not widely used as the perceived benefits are modest at best.

In 'active' systems, bus priority is given by making the traffic signal responsive to the arrival of individual buses which are detected on the traffic signal approach. Most of the development work has been related to such 'active' systems, which provide greater benefits to buses than passive systems.

Signal measures combined with physical measures to reduce the effect of congestion and to give priority can be considered as integrated measures. These measures include 'queue relocation', incorporating with-flow bus lanes and 'pre-signals' [1].

The facilities available to give bus priority at signal controlled junctions are described in more detail in Section 4.

# 3. Traffic signal control systems and strategies

A variety of traffic signal control systems and associated strategies are operational in different cities around the world. These may be conveniently grouped into the following categories:

## 3.1 Isolated systems

Signal controlled junctions that are located and operated independently are known as isolated junctions. This form of control is selected when traffic arrivals at the junction are largely unaffected by any neighbouring traffic signals. These signals, which may still be linked to a Traffic Control Centre (e.g. for fault monitoring), are more common in suburban/rural areas where traffic signal density is lower or in smaller towns. An isolated system can be fixed time or vehicle actuated.

### 3.1.1 Fixed time/Cableless linking

With fixed time control, signal timings (‘plans’) are calculated off-line, and implemented using the traffic controller at the site. These plans use historic, based on measured traffic data to generate optimum plans that usually vary by time of day and day of week.

### 3.1.2 Vehicle actuated

Vehicle actuated (VA) systems rely on traffic detectors on junction approaches to detect vehicles, to allocate green times to different traffic movements according the traffic detected. With its traffic responsive capability, VA is the most common form of control for isolated junctions in the UK. In this system, a vehicle approaching a red, or amber, signal registers a demand for a green. This demand is stored in the controller, which serves allowed stages in cyclic order omitting any stages for which no demand has been received. Once a green signal is displayed, the duration may be extended by vehicles detected moving towards the signal. If vehicles continue to extend the green period and a demand exists for another stage, the green signal will be terminated on expiry of a preset maximum period. On expiry of the last extension and with no more vehicles detected, the controller will answer a demand for another stage. This description is UK-specific, but it is expected that similar systems exist elsewhere.

The UK VA system can give priority to buses detected on the approach by extending the current green period or by recalling the priority stage for the buses early. A ‘priority recall’ may be implemented by curtailing the non-priority stages to their minimum values. Non-priority stage curtailed to give priority may be compensated by increasing its normal maximum value by the compensation period. An inhibit facility can also be provided which prevents bus priority actions in consecutive signal cycles. This ensures that compensation can be given to non-priority stages.

**MOVA**

MOVA (Microprocessor Optimised Vehicle Actuation) is an advanced VA controller developed in the UK [4]. MOVA analyses lane-by-lane detector data and controls the signal timings to optimise delay and stops or capacity (if any approach becomes oversaturated). Approximately 600 junctions in the UK use MOVA and the installation rate is over 100 per year.

Bus priority can be implemented within MOVA [5] using Selective Vehicle Detectors (SVDs) to distinguish buses from most other vehicles. The system gives priority to the buses detected on the approach by extending the current green period or by demanding the priority stage for the buses. The priority stage demand may be implemented by truncating the non-priority stages to their minimum values (stage truncations) or by skipping all those stages en-route to the priority stage (stage skipping).

## 3.2 Co-ordinated systems

When signal controlled junctions are more closely spaced, and traffic interactions occur, co-ordinated control is often implemented. Operations at a junction are then influenced by operations at one or more neighbouring junctions, with all junctions then co-ordinated using an

Urban Traffic Control (UTC) system. UTC systems are implemented in most medium and large towns and cities around the world, particularly in central areas where junction density is highest. Co-ordinated UTC systems can be traffic responsive or fixed time.

### 3.2.1 Fixed time UTC

With fixed time control, signal timings ('plans') are calculated off-line, often using software such as TRANSYT, and implemented via the UTC system. These plans use historic, measured traffic data to generate optimum plans that usually vary by time of day and day of week. In other cases, real-time traffic data from strategic detectors in the network are used to select the most appropriate plan from a library.

SPRINT (Selective PRIority Network Technique) was developed in the UK to give priority to buses at traffic signals controlled by a fixed time UTC system [6]. The system gives priority to the buses detected on the approach by extending the current green period (an extension) or recalling the next green period earlier (a recall). Extensions get preference over recalls. The priority implementation is constrained by maximum cycle, maximum move from the base, target degree of saturations and inhibit period.

### 3.2.2 Traffic responsive UTC

Traffic responsive systems rely on traffic detectors on junction approaches to provide data that is used to calculate optimum signal settings in real time. The improved traffic performance that has been demonstrated with traffic responsive control has led to the development of a number of systems, such as SCOOT, SCATS, UTOPIA, PRODYN and BALANCE [7]. Nevertheless, full traffic responsive control carries a significant implementation and maintenance cost, so has not become widespread in all cities.

**SCOOT**

SCCOT (Split Cycle Offset Optimisation Technique) is an adaptive Urban Traffic Control (UTC) system that responds automatically to fluctuations in traffic flow obtained from the on-street detectors [8]. This is carried out by continuously adapting three key traffic control parameters - the amount of green for each approach (Split), the time between adjacent signals (Offset) and the time allowed for all approaches to a signalled intersection (Cycle time). The adaptation is aimed at minimising wasted green time at intersections and reducing stops and delays by synchronising adjacent sets of signals. The changes in signal timings are made such that they are small enough to avoid major disruptions in traffic flow, but are frequent enough to allow rapid response to changing traffic conditions.

Bus priority can be provided in SCOOT by extending the current stage for a bus to allow it clear the junction, or shortening intervening stages to return more quickly to the bus stage [9]. The amount of priority given to buses can be restricted depending on the saturation of the junction as modelled by SCOOT and the target degrees of saturation for extensions and recalls. These are the degrees of saturation to which the non-priority stages can be run in the case of a priority extension or recall respectively. Normally, the amount of priority is decided by the SCOOT optimiser at the UTC centre and communicated to the local traffic controller. However, in the case of priority extensions, there is a facility to decide it locally within the limit set by the central control. In recent developments, SCOOT also has facility to give different levels of priority to buses based on their performance against the predefined criteria. For example, no priority for buses running on time, moderate priority for late buses, high priority for very late buses. The recent version of SCOOT also has facility give priority by skipping non-bus stages.

**SCATS**

SCATS (Sydney Coordinated Adaptive Traffic System) is an urban traffic control (UTC) system originally developed for application in Sydney and other Australian cities [10]. SCATS primarily manages the dynamic (on-line, real-time) timing of signal phases at traffic signals, meaning that it tries to find the best phasing (i.e. cycle times, phase splits and offsets) for the current traffic situation (for individual intersections as well as for the whole network). This is based on the automatic plan selection from a library in response to the data derived from loop detectors or other road traffic sensors.

Public Vehicle priority in SCATS caters for both buses and trams. SCATS has a facility to provide three levels of priority:

- High –In the high priority mode the hurry call facility is used. i.e. the phase needed by the tram is called immediately, skipping other phases if necessary
- Medium – Flexible window – Phases can be shortened to allow the bus/tram phase to be brought in early. The bus/tram phase can occur at more than one place in the cycle.
- Low –takes its turn

Trams would normally be given high priority, the aim of which is to get the tram through without it stopping. Buses would normally expect to receive a medium level of priority.

**MOTION**

MOTION (method for the Optimization of Traffic Signals Online-Controlled Networks) has two components, MOTION central and MOTION local. The central function creates plans that can then be adjusted by the local element, where suitable detectors are installed. Buses can be given priority in the offset optimisation in MOTION central by limiting the range of options for optimising stage sequence, split and offset for private vehicles to those that provide a green time window for public transport vehicles at their expected arrival times.

MOTION provides the following means of PT-prioritisation [11]:

- at the network level: coordination of traffic lights can be forced to take into account predominantly the routes of important and frequently used PT-lines, offsets may be determined by using average travel times of PT along the respective links.
- at the intersection level: automatic generation of new signal timings by the network-optimization can be forced to treat splits and stage sequences in a PT oriented way. The degree of local PT-prioritization can dynamically be set to a more or less restrictive mode - according to an assessment of the current traffic situation by the network-model.

**UTOPIA/SPOT**

UTOPIA (Urban Traffic Optimisation by Integrated Automation)/SPOT (System for Priority and Optimisation of Traffic) is a hierarchical-decentralised traffic signal control strategy developed by Mizar Automazione in Italy. It is now used in several cities in Italy and also in the Netherlands, USA, Norway, Finland and Denmark. UTOPIA/SPOT aims to minimise the total time lost by private vehicles during their trips, subject to the constraint that public vehicles to be prioritised shall not be stopped at signalised intersections. This is carried out by optimising a cost function depending upon various elements including: vehicle delays and stops, delays to public transport; and deviation from the reference plan and previous signal settings. The optimisation is carried out at two levels: local and network. At the local level, the controller determines the signal settings by optimising a cost function adapted to the current intersection traffic situation. Optimisation is done on a ‘time horizon’ for the next 120 seconds and is repeated every three seconds. At the network level, optimisation is based on the cost function taking account of the state of neighbouring intersections to build dynamic signal co-ordination.

In UTOPIA/SPOT, bus priority is provided by shifting the ‘green window’ to match the estimated arrival time of a bus at the stop line. This method uses bus location information from well upstream of the junction and the signal timing is gradually adapted to match the relevant green stage occurrence to the predicted arrival time of the bus. This method has the potential advantage of a less abrupt impact on signal timings but its efficiency is more dependent on accurate journey time forecasting. Information on all vehicles is provided to the SPOT controllers by inductive loop vehicle detectors located just downstream of the previous junction.

**RHODES**

RHODES (Real-time, Hierarchical, Optimized, Distributed, and Effective System) responds to the natural stochastic behaviour of traffic, which refers to spatial and temporal variations and tries to optimize a given performance measure by setting timing plans in terms of phase durations for any given phase sequence. The RHODES architecture has three levels of hierarchy: Dynamic network loading model; network flow control model; and the intersection control model. At the network flow level, the APRES-NET model predicts the platoon arrivals while the REALBAND algorithm performs the optimization calculations [12]. The PREDICT algorithm predicts flow at the intersection level and the Controlled Optimization of Phases algorithm does the controlling to adjust splits.

RHODES incorporates bus priority using the BUSBAND algorithm [13] provided that the location of the buses and the passenger counts for each bus are known. The priority is provided to buses considering the number of bus passengers and on/behind bus schedule.

**SPRUCE**

SPRUCE stands for Selective PRiority in the UTMC Environment originally developed by Leeds City Council as a part of DfT's Urban Traffic Management and Control (UTMC) programme in UTMC01 project [14]. This system has been used to coordinate signals in Leeds for guided buses since 2002 and in Sheffield on trams since 2000. Deliverable 4 [15] of the project gives some details of the SPRUCE strategy as applied in Sheffield.

Priority is afforded by adjusting the start time of the fixed time plans with respect the difference between the bus/tram detection time and the ideal time in the cycle for the tram to arrive at the detection point. The fixed time plans are delayed or brought forward depending on whether the bus/tram is late or early. Junctions are linked such that the plan is delayed by the same amount for the next junction down, so that the bus/tram can get through there too. Sometimes the same LRT phase appears in several stages, in which case the most appropriate stage is run.

# 4. Bus priority at traffic signals

## 4.1 Priority types

Bus priority at traffic signals is an important form of bus priority measure in urban areas. Many forms of bus priority options available in signalised junctions can be grouped as passive priority and active priority. The categorisation mainly depends on the use of detection system to determine the presence of buses.

### 4.1.1 Passive priority

'Passive' systems apply to those where signal timings are weighted, or re-optimised, to take account of streams of traffic containing significant bus flows. This is a straightforward form of priority at traffic signals which gives more green time to the approach having higher bus flow than it would have done otherwise. The other approaches then share the remaining part of the cycle time. Even though no infrastructure is required for such systems, it is believed that these facilities are not widely used as the perceived benefits are modest at best.

### 4.1.2 Active Priority

In 'active' priority, bus priority is given by making the traffic signal responsive to the arrival of each bus detected on the approach. Most of the development work has been related to such 'active' systems, which is technologically advance and is efficient in giving priority to particular group of buses. Buses can be given active priority implementing different strategies depending on the policy objectives and the availability of the infrastructure to support the implementation. Bus priority "strategies" refer, here, to the various ways in which the bus priority methods above can be used to benefit buses. The following strategies have been identified:

- **Priority to all buses**

All buses are eligible for priority irrespective of whether they are late or not. This strategy has been called the "maximum speed" strategy, in the PRISCILLA project, as the aim is to increase the running speed of all buses. However, it should be noted that where bus flows are high, priority to a large number of buses can delay other buses, and so maximum speed is not necessarily achieved. This is one of the simplest strategies to implement, as the only information required about an individual bus is its expected arrival time at the traffic signal. The strength of this strategy can be varied by specifying the level of priority to be awarded (e.g. full priority, traffic signal extensions only, or priority constrained by traffic considerations). It is possible that full priority to all buses can lead to unacceptable delays to general traffic, particularly where bus flows are high and the priority leads to a large number of traffic signal recalls being introduced. Disbenefits to general traffic can be reduced by:

- Constraining/disabling traffic signal recalls at junctions where general traffic flow levels are high or where traffic degree of saturation levels are high
- Applying full priority only where bus flows are at low or medium levels

- **Differential/conditional bus priority**

Priority can be targeted to the buses fulfilling pre-defined criteria designed to serve particular policy objectives. One common strategy is 'priority to late buses only'. Buses that are behind schedule receive priority; buses that are on time or early do not receive priority. The PRISCILLA study indicated this priority strategy to be superior to giving priority to all buses, since it provides a good balance between travel time savings and passenger waiting time savings and reduces the impact on general traffic. A similar strategy can be used for buses operated under headway control, i.e. giving priority on the basis of their headway. Such a strategy aims to improve bus regularity rather than bus punctuality. PRISCILLA study indicated that this strategy is to be preferred where buses operate to a high service frequency (e.g. an average headway of 12 minutes or less), where passengers tend to arrive at bus stops randomly. From a practical viewpoint it should be noted that this strategy is more difficult to implement than the strategies above, due to the requirement of knowing what the time gaps between buses are. An AVL system is a prerequisite for obtaining headway data in real-time.

### 4.1.2 Integrated Priority

Integrated measures combine both physical and signal measures (e.g. with-flow bus lanes with the signalling measures). Queue relocation and pre-signals techniques are some the examples of integrated measures utilising physical as well as signal measures to give preferential treatment to buses.

**Queue relocation**

Queue relocation (also known as traffic metering) is one such measure in which the flow of traffic is controlled at upstream junctions by adjusting signal timings to reduce capacity, so that this junction becomes more critical than the one downstream [2]. The downstream junction is the main junction whereas the upstream junction is the metered junction. Along with this, the bus lane running up to the upstream stop line enables buses to by-pass the relocated traffic queue.

**Pre-signals**

Pre-signals can be used at a junction to create a bus advance area (Figure 4.1) and in a link to create virtual bus lane [16]. At a signalised junction, a pre-signal can be used to create bus advance area that enables buses to by-pass queues of general traffic (held by pre-signal) and to undertake manoeuvres to make turns ahead of other traffic.

*Figure 4.1: Bus advance area using pre-signals (from [16])*

In a congested link with insufficient width to provide a physical bus lane, a pre-signal can be used to hold general traffic upstream of this narrow section. This allows buses on the bus lane to by-pass the queue and rejoin the main traffic stream ahead of other traffic.

## 4.2 Bus detection and location methods

The first requirement for bus priority at traffic signals is a means of bus location/detection that identifies a bus on the approach of a traffic signal. The following general categories summarise the options for this process:

### 4.2.1 Methods where only the infrastructure is equipped

These methods provide bus detection with no need for on-bus equipment. One example is ‘Signature processing’ loops which can identify buses based on the shape of the detection output characteristics. This technique, which may only be applicable where buses are a consistent and distinct vehicle category, can be a cost effective option where all detected buses are eligible for priority and have similar physical characteristics

### 4.2.2 Methods where only the bus is equipped

These methods allow buses to be located solely (or primarily) from equipment on board the bus. The main example here is the Global Positioning System (GPS) which provides ‘continuous’ vehicle positioning to an accuracy of typically 5-10metres. Appropriate on-board software can then locate the bus relative to the traffic signals. Bus location on a fixed route can also be estimated using an odometer; however, potential cumulative errors make this approach rarely used in its own right.

#### 4.2.3 Methods where the infrastructure and the bus are equipped

These methods detect buses on the basis of communication between on-bus equipment and the related field infrastructure. A common example is 'loop and transponder' which involves equipping buses with a transponder that communicates with an inductive loop placed upstream of a traffic signal. This provides reliable detection (of equipped buses only) at specific locations. Systems may either be de-centralised or part of a centralised Automatic Vehicle Location (AVL) system. Other AVL-based methods include continuous on-board bus location using the bus odometer and roadside beacons, with locations being regularly 'polled' by the AVL centre using radio communications.

These different detection methods are based on the detection technology implemented. Among various bus detection/location technologies implemented, common types of detection/location technology used are: loops/transponders, beacons, optical detection and GPS.

- **Loops/transponders**: One or more bus detectors installed at optimum locations for bus priority, subject to site constraints (e.g. bus stops). When the loop detects a bus fitted with a relevant transponder a priority request is sent to the downstream traffic signal controller. A priority request is then sent via the cable connecting the loop with the controller.
- **Beacons**: As for loops/transponders, but using above-ground beacons placed on the approach to a junction. A variant of this technology, an optical beacon mounted on the traffic signal post, is extensively used in the USA to detect buses at junctions.
- **GPS**: Satellite-based technology in which buses are detected at the points programmed into the on-board computer (also known as 'virtual loops'). Passage across each such loop, according to the GPS-predicted location of a bus, triggers a communication from the bus to the roadside or AVL centre. This technology requires radio communication between bus and the downstream signal controller or AVL centre to request priority.

### 4.3 Control Strategies for Bus Priority

#### 4.3.1 Extension and Recall Methods

These methods refer to the extension of green time, should a bus be detected on a signal approach towards the end of green, or the recall of the green signal should the signal be on red. These methods are commonly used where detection is relatively close to the junction (e.g. up to 150metres), and are implemented with constraints (maximum extension time, minimum green time for non-priority stage(s), etc).

#### 4.3.2 Rolling Horizon Methods

These methods use bus location information further upstream from the junction (e.g. up to a 120 second bus journey time in UTOPIA) and use gradual adaptation of the relevant green stage occurrence and duration to match the predicted arrival time of the bus. This has the advantage of a less abrupt impact on signal timings, which could compromise efficient signal co-ordination, but is more dependent on accurate journey time forecasting (which naturally deteriorates the further the bus is from the junction).

#### 4.3.3 Stage Re-ordering

The two categories of bus priority strategy described above are normally implemented without affecting the normal stage/phase structure. An alternative, and stronger form of priority often used in tram priority systems, is to allocate a specific stage to the bus/tram when it is detected. This stage is then inserted into the sequence at the next opportunity. This can mean effectively 'skipping' or delaying other stages, and may allow a repeated green of a bus/tram stage, if the bus/tram is detected in the inter-green period immediately after a bus/tram stage has just terminated.

#### 4.3.4 Stage skipping:

This allows one or more traffic stages to be omitted from the normal stage sequence when a bus is detected, so that the bus stage can be recalled as quickly as possible. Pedestrian stages may also be skipped, although this is often not allowed for safety reasons.

#### 4.3.5 Green wave

This refers to an interventionist priority system where a special plan is initiated in the UTC system to provide a sequence of green signals for the selected priority vehicle(s). This is often implemented for emergency vehicles (particularly ambulances and fire appliances) responding to emergency calls. The long green periods which often result (and long red periods to some traffic streams) can be justified by the importance of the vehicle and the infrequency of the event; such action can seldom be justified for public transport.

### 4.4 Priority architectures

Bus priority at traffic signals can be achieved with an increasingly large range of system architectures. At its simplest, local roadside bus detection can provide local bus priority, through the local signal controller(s) itself or through communications with the UTC system. At the other extreme, there can be full integration with one or two way communication between the bus, AVL centre, UTC centre and the local signal controller when giving priority to buses. A wide range of variants exist between these extremes. Some of these communication links may be one way or two-way and some may not be used depending on the way of working of the priority system i.e. the priority architecture.

#### 4.4.1 Priority request communication

Once the priority requirement is determined, the request needs to be sent to the traffic controller for its implementation. The traffic signal then changes its timings in favour of the approaching bus. Broadly, there are 2 ways of requesting priority for the approaching bus at a traffic signal. The control centre may send the priority request directly to UTC for processing onward implementation at the traffic signal controller or priority may be requested via the bus onwards to the local traffic controller. These two methods of requesting priority are sometimes also categorised as centralised and decentralised communication systems [17] as discussed below.

**Centralised (AVL-UTC)**

In this method, the AVL centre (determining the priority requirement) directly passes requests to the UTC system to give priority to an approaching bus at a particular traffic signal. The UTC then calculates the possibility of implementing changes in the stage. This information about changes in signal timing is then transmitted to the local controller to implement. The local controller where the bus is approaching will change the traffic signal to favour the bus, depending on the UTC instruction. Since this method involves communication between two centre (AVL centre and UTC), it is also known as Centralised communications. Since priority is requested directly from the AVL centre to UTC, this architecture does not need on-street infrastructure for bus detection to activate a priority request. This reduces infrastructure as well as the communication costs as there is no communication of priority information needed from the centre to each bus.

**Decentralised (AVL-Bus-signal)**

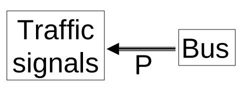
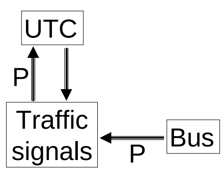
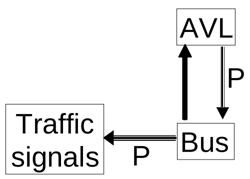
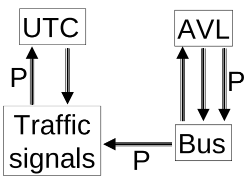
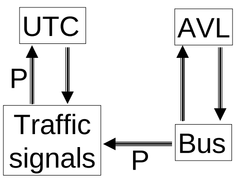
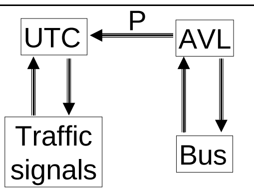
In this method, the AVL centre sends the priority request to a bus approaching a traffic signal after determination of its priority requirements. The bus then communicates to the traffic signal just before approaching the traffic signal for priority implementation. This type of communication architecture was trialled first in London and is adopted generally in recent systems in the UK. Such a method of requesting priority in conjunction with a GPS based AVL system is used in places such as Cardiff [18] and Leicester [19].

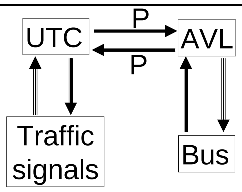
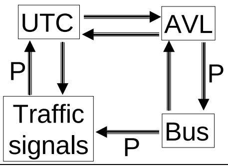
The main advantage of a decentralised system is the accuracy in estimation of bus arrival time at the signal. Since the priority is requested when a bus is detected on the approach, its location is precisely known and hence its estimated arrival time can be more accurately calculated. In this process, any local effects on a link affecting journey time of a bus, before the detection point, are reduced and hence the wastage of the priority given. Furthermore, this system can also be implemented at isolated signal-controlled junctions so that same priority architecture can be implemented in coordinated as well as isolated junctions. However, this type of system requiring a detection system to activate priority and communication links to transmit priority requests from the bus to the signal, can make it relatively more expensive compared to the centralised alternative.

### 4.4.4 System category/examples

A review of bus priority techniques and applications at traffic signals in Europe carried out within European funded PRISCILLA project [20] showed that AVL is in widespread use in different forms, with a range of system architectures/designs. Diversity appears to be prevalent, rather than harmonised design, as evident from the examples in Table 4.1.

*Table 4.1 - Examples of System Architectures*

| Category | Architecture (P = priority request) | Examples/ Cities | Priority options | |
|---|---|---|---|---|
| | | | Centralised | Decentralised |
| 1 |   | Examples in many European cities | | √ |
| 2 |   | Examples in many European cities | √ | √ |
| 3 |   | Aalborg<br>Helsinki | | √ |
| 4 |   | London | √ | √ |
| 5 |   | Zurich | √ | |
| 6 |   | Southampton<br>Toulouse<br>Turin<br>Cardiff<br>Gothenburg | √<br>√<br>√<br>√<br>√ | <br><br>√<br><br>√ |

| | | | | |
|---|---|---|---|---|
| 7 |  | CGA | √ | |
| 8 |  | Genoa | √ | √ |

These can be summarised as follows:

- ***Category 1.*** This architecture involves bus priority at isolated junctions, without the use of AVL or UTC. Buses are typically detected using transponders, tags, or through entering an infra-red detection zone.

- ***Category 2.*** This architecture is as Category 1, except that the traffic signals and the priority provided operate under UTC.

- ***Category 3.*** This involves the use of AVL to determine bus-specific priority levels, which are then transmitted from the bus to each traffic signal controller on the route. With no UTC involved, signal control is isolated/decentralised.

- ***Category 4.*** This architecture is similar to category 3, except that the traffic signals are under UTC. There is no communication between AVL and UTC, so bus-specific priority requests are routed from the AVL centre to UTC via the bus and traffic signal controllers.
- ***Category 5.*** With this architecture, used in Zurich, Switzerland, AVL is used predominantly for fleet management. Buses and trams are given ‘absolute’ priority using loop detection and maintain schedule through operational efficiency and through the implementation of strong traffic/demand management measures, including public transport segregation where necessary. In this case, only ‘fixed’ timetables are needed, as buses and trams nearly always run on schedule.

- ***Category 6.*** This involves one-way communication of bus location and priority requirements from an AVL centre directly to UTC. AVL becomes the primary source of bus location upstream of signalised junctions for priority purposes, therefore requiring a higher locational accuracy (e.g. within 5-10 metres) than typically required for other AVL applications. This removes the need for transponder/tag/loop detection (although some hybrid systems are maintained). Most systems provide locational information according to the radio polling cycle (e.g. at 20-30 second intervals), which may not be ideal for bus priority purposes.

- ***Category 7.*** Common in many French Cities*,* involving centralised UTC/AVL integration; UTC plays an active role in informing AVL of each proposed signal stage change at each junction, and requesting the location of any approaching buses or trams which should influence the stage change time (i. e. where priority is needed).

- ***Category 8****.* This architecture illustrates the highest level of two-way communication between the system components. In the example in Genoa, Italy, buses are allocated a priority level by the AVL centre and transmit this directly to the traffic signals for implementation subject to UTC commands. At a higher level, strategic data is transferred between the AVL and UTC centres, and the ‘global’ situation in the network, or on the bus route can influence whether priority is permitted or not.

## 4.5 Priority objectives

In more advanced forms of bus priority at traffic signals, each approaching bus can be continuously monitored and different levels of priority can be given according to requirements (e.g. lateness). The monitoring of locations of buses is carried out continuously using an Automatic Vehicle Location (AVL) system. This facilitates implementation of a priority strategy to target particular group of buses (e.g. late buses). The priority strategy alters the number of buses eligible for priority (depending on the lateness criteria) and the amount of priority they can get (depending on the priority level assigned). This changes the outcome of the bus priority in terms of bus delay savings, regularity benefits, impacts on other traffic and total economic benefits. Hence, a priority strategy can be implemented targeting one of the following objectives.

### 4.5.1 Bus journey time savings

Bus priority traffic signals can be targeted to improve journey time of buses through a junction. Shorter journey time could give competitive edge to buses in comparison to general traffic and encourage modal change. If this is the only criteria, then giving maximum levels of priority to all buses will give the best results.

### 4.5.2 Bus regularity/punctuality

Bus regularity and punctuality are the main factors in passenger perception of bus service performance. Punctuality is the measure showing the percentages of buses on time taking account of the accepted tolerance. This is used in low frequency timetabled services. Regularity is the measure showing the variation in headways (the interval between consecutive buses travelling on a route) in comparison to the scheduled headway. This is used in high frequency headway-based services. These measures affect passenger waiting times at bus stops. Targeting late buses or the buses with higher headways will give the best results if this is the only criteria.

### 4.5.3 Total economic benefit

Total economic benefit is another potential objective function for bus priority at traffic signals. This is calculated on the basis of the performance of buses and all other traffic at a junction, including the effects of passengers waiting for buses. This criterion takes account of general traffic in addition to the benefits to the buses when calculating total economic benefits.

# 5. Examples of bus priority at traffic signals in the World

## 5.1 Aalborg, Denmark

Aalborg is the fourth largest city in Denmark. The Municipality of Aalborg has a population of some 194,149. It is also the trade, cultural and educational centre of northern Jutland. Bus priority at traffic signals in Aalborg started within a comprehensive project called JUPITER (Joint Urban Project In Transport Energy Reduction) in 1993-1996 [23]. It has included providing bus priority at 15 intersections on the CITYBUS line. The system covers bus routes 10 and 11 which use some of the busiest approach roads in Aalborg. The positioning system was based on GPS and the data transmission used a radio system between the bus computer and the traffic signal controller [24]. The bus priority system has reduced the average delay at a junction for a bus by a reported 5.8 seconds and the occurrence of a bus waiting at the signals for more than a traffic cycle by 71%.

More recently, Aalborg Municipality have carried out a project for bus-telematics during 2002-2006 partly granted by EU's Vivaldi project under the CIVITAS frame programme [25] . Within this project, the municipality implemented a traffic signal priority (TSP) system based on real-time information from the Automatic Vehicle Location system (AVL) installed in the buses. In this system, all buses transmit GPS position and timestamp to the central AVL-server via wireless GPRS (General Packet Radio Service). The AVL-server holds a comprehensive view of all buses on the routes and whether they are on schedule. If a bus is delayed, the AVL-server can request priority to the next following traffic light on the route, in order to avoid additional delay, or if possible to recover. To request signal priority for a bus, the bus shall meet individually criteria, which in advance are specified by the traffic manager of the line in question. When these criteria are met, the AVL-server transmits a priority request via wireless radio LMR (Land Mobile Radio) to the next following traffic light on the route.

The signal controller receiving a priority request, at a certain degree depending on the traffic flow, performs the necessary adaptation of its signalling cycle and gives priority to the bus. The adaptation can take place either by shortening the red-light time or extending the green-light time for the link with the bus. When buses with crossing directions in the same traffic light can obtain simultaneous priority request, the AVL-server decides – on the basis of the specified criteria - the direction in which the priority request shall be effective. The criteria of priority request may include: day of week, time of day and the importance of the bus route. The traffic light may accept or reject a priority request based on the signalling state and the traffic volume in crossing directions

In Aalborg, ITS applications in the public transport are operated by a mobility centre where the central server and database is the interface between the buses, the intersections with bus priority and the public transport terminal (Figure 5.1). The mobility centre initiates bus priority when a bus is delayed and sets up information in the RTPI depending on the actual distance to the RTPI-sign. Totally, 249 busses in the public transport plan are now fitted with bus computers and they are connected to the mobility centre that operates the RTPI. There are around the city 46 signs with RTPI placed at the new public transport terminal and the most important bus stops in Aalborg.

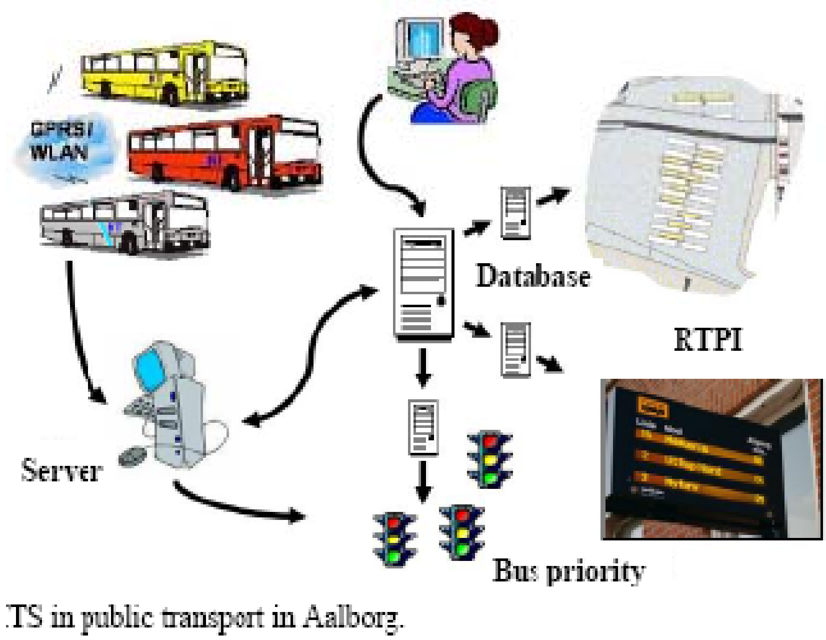



*Figure 5.1: ITS application in Public transport in Aalborg (from [26])*

More recently, as a part of an ITS in public transport project, the number of intersections with bus priority has increased to 51. A study of the bus priority impacts made in a corridor with 8 signalised intersections all fitted with bus priority showed that the buses on an average saved up to 4% of total travel time [26]. In the trial only buses delayed more than 3 minutes were actually given priority. Based on the study a rough estimate of the impact of the entire bus priority system is a daily travel time savings of 15-20 minutes at each of the 51 signals with bus priority or a total of approximately 15 hours saved per day [26].

## 5.2 Brighton and Hove, UK

Brighton and Hove city is on the south coast of England and has a population of around 248,000. Brighton & Hove city council is responsible for transport facilities within the city. The majority of the road network within the city is restricted to 30mph speed limit. Congestion levels are usually high with a great increase in the summer months and during holiday periods. The city has a comprehensive local bus network run by a private operator. The routes are either council funded or commercial services. The key feature of bus service delivery is a very successful and long-standing informal Quality Bus Partnership between the local authority and the bus operator.

Brighton and Hove has a GPS-based bus priority and real time passenger information system (Figure 5.2). The system provides priority to buses at 8 SCOOT controlled signalised junctions. Priority is given to the buses by extending the current green or by recalling the next green period quickly. Priority is limited to late buses only. It is reported that the bus priority system has improved punctuality and reduced journey time of the buses.

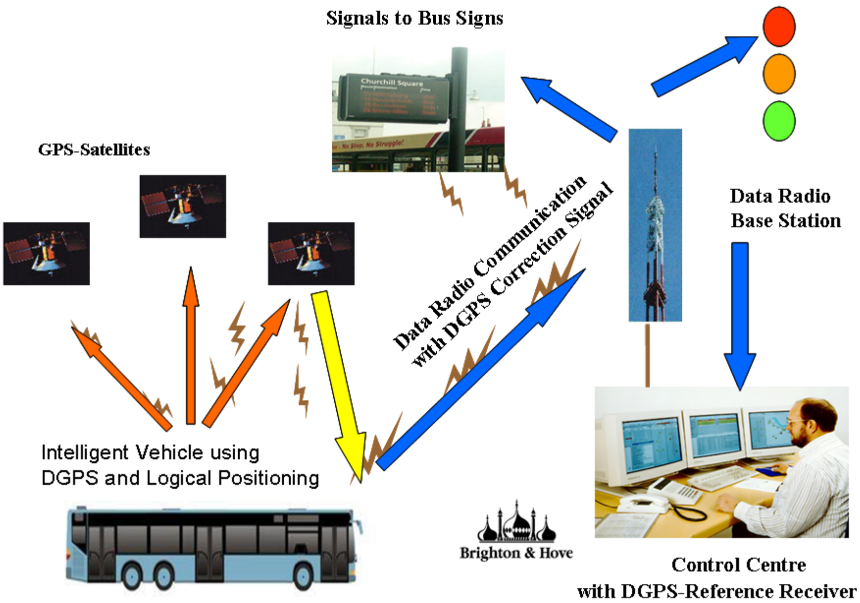



*Figure 5.2: Brighton's bus priority system [27]*

## 5.3 Cardiff, UK

Cardiff is the capital city of Wales with a population of 315,000 inhabitants. It installed the largest GPS based bus priority and real time passenger information system in the UK in 1999/2000 [28]. The system concentrated in the northern corridor of the city included 191 buses and 46 signalised junctions. The junctions were controlled under the SCOOT UTC system where bus priority was provided by the method of extensions and recalls. The system architecture illustrated in Figure 5.3 has a GPS-based AVL system to locate buses within a specified locational accuracy of 5 metres.

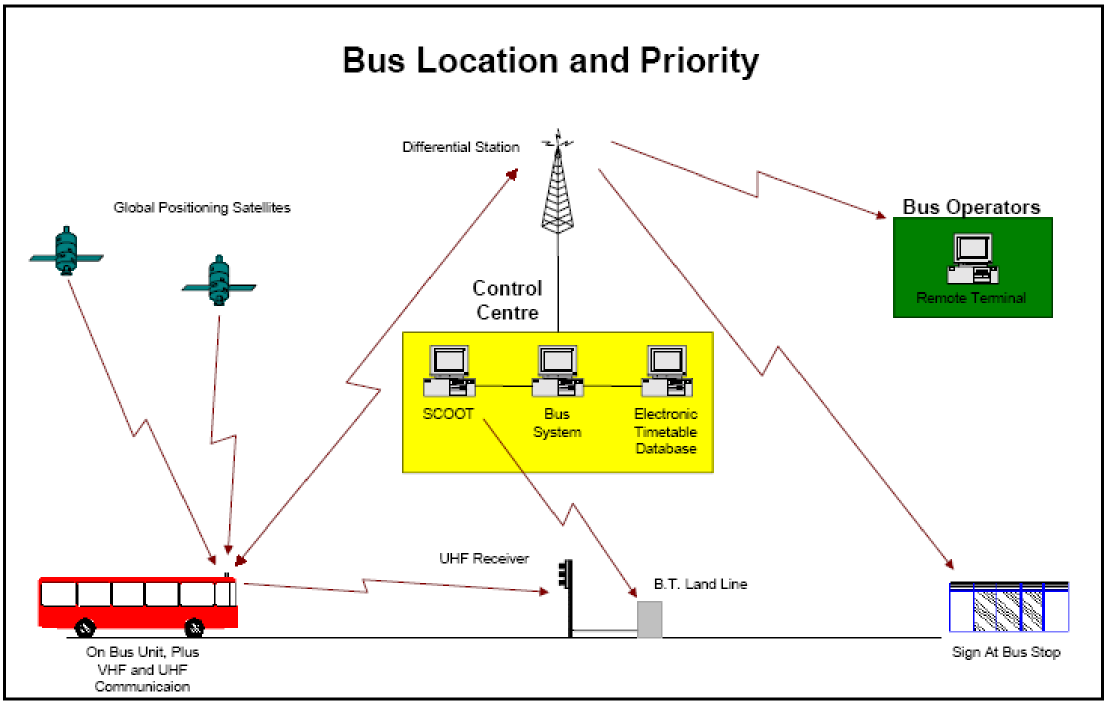



*Figure 5.3: Bus location and priority system in Cardiff (from [18])*

In the system, bus priority is triggered when a bus is detected within a predefined virtual detector zone stored in the on-board computer. A bus is then given priority with a pre-determined priority level taking account of its lateness. The lateness calculation is carried out in the control centre on the basis of bus locations obtained by regular polling of all buses at a pre-set slot. The system also has the potential to implement different priority levels according to lateness and passenger loading (through an interface with the ticket machine). Preliminary results showed bus journey time savings of 3-4% for average weekdays, including 11% in the peak period [28].

### 5.4 Genoa, Italy

Genoa (650,000 inhabitants) is a port city in northern Italy. The municipality is responsible for managing private and public transport in an integrated way, using telematics technologies. The Urban Traffic Control (UTC) system in Genoa is known as SIGMA which is currently based on a three-level architecture: control centre, six area controllers and 113 multifunction units (MFU) located at intersections. The AVM (Automatic Vehicle Monitoring) bus system (called SIMON), covers 500 buses circulating all over the Genoa city area; it is based on: GPS equipment (on bus) to calculate real-time positioning and a UHF radio link between the buses and the bus control centre [29]. The bus priority system in Genoa started in 1992 was further enhanced under different EU funded projects such as EUROSCOPE (1996-1998), URBAN – ZENIT and PRISCILLA (1998-2000). Within these projects, more than 84 junctions were equipped for bus priority. With the exclusion of some special cases with very high critical conditions, earlier results from the priority system showed a reduction of bus travelling times in the range 7 to 10%.

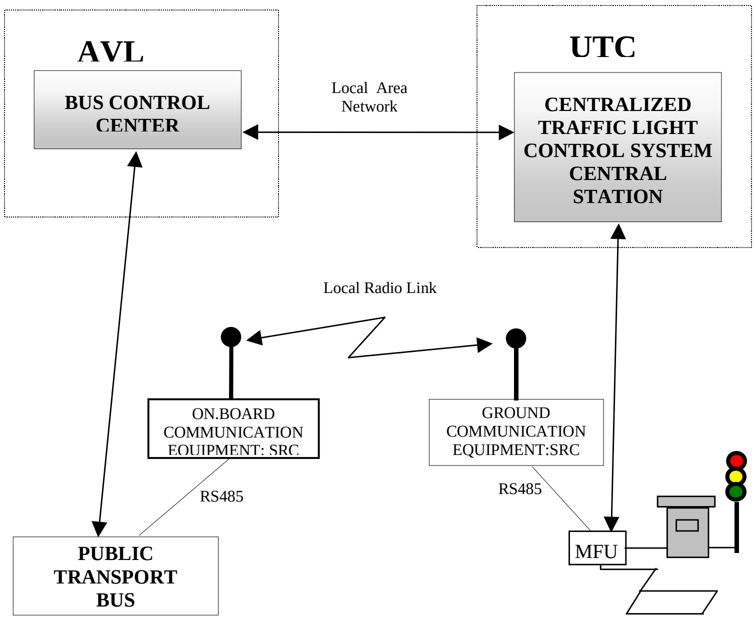



*Figure 5.4: The PRISCILLA system in Genoa (from [29])*

The bus priority system in Genoa consists of following parts: AVM, UTC and data transmission. The AVM system SIMON monitors all the equipped buses by a continuous radio link with a polling interval of 30 seconds. On the basis of the information received from the field, the AVM system decides whether a bus needs to be assigned with priority and passes it to the UTC. Once a bus arrives at the traffic signal, it gives priority on the basis of the information received from the centre. The priority implementation is based on the priority system algorithm (applied on the SIGMA System) which makes changes to the traffic light phase plan to help buses at junction crossings [29]. The local level MFU's collects bus priority requests (a bus starts sending priority requests from 300 metres and the MFU waits till the bus is near the junction to select the highest level request amongst all which are received.. For selecting a request, MFU has an algorithm using the junction typical parameters such as the lateness of the bus, importance of the bus route, time band and/or direction of bus and the optimisations. These optimisations aim to advance or delay the priority action to fit well with the green phases already foreseen. After the bus passage (and however within a programmable timeout) the MFU restarts the traffic signal plan stopped (earlier) and proportionally adjusts the subsequent phases, to re-synchronisation with nearby junctions. During this phase the MFU does not keep new priority requests.

## 5.5 Geneva, Switzerland

The traffic light priorities management system (TPG) for public transport in the canton of Geneva is one of the features implemented in 2006. The management of the traffic light priorities is de-centralised: the vehicle communicates directly with the traffic light receptor without interface of a centralised system. The release of the signal is determined according to the position of the vehicle. The traffic light receptor belongs to the mobility state service. As often as possible, the vehicle gets the absolute priority in order to drive through the crossroad without stopping.

At the end of 2008, Geneva had 263 adaptive crossroads with the PT priority system. All crossroads of the tramways lines are equipped with priority, and approximately 75% for the bus lines. Each of the 420 vehicles of the network of Geneva is equipped with the management system for traffic light priority.

The administrator of the traffic lights manages a database containing all the calls of the traffic lights of the network. The calls are scheduled according to the distance between the vehicle and the next stop. When the vehicle is on the line, according to its position (GPS and odometer) and the distance value of the next stop, the onboard system delivers the appropriate message. Then it is communicated to the on-board radio and finally transmitted to the ground analogue receptor. If a stop is close to a traffic light, a message sent at the time of the locking of doors is used to indicate to the controller of the crossroads the end of the passengers boarding. An example of this process is shown in Figure 5.5.

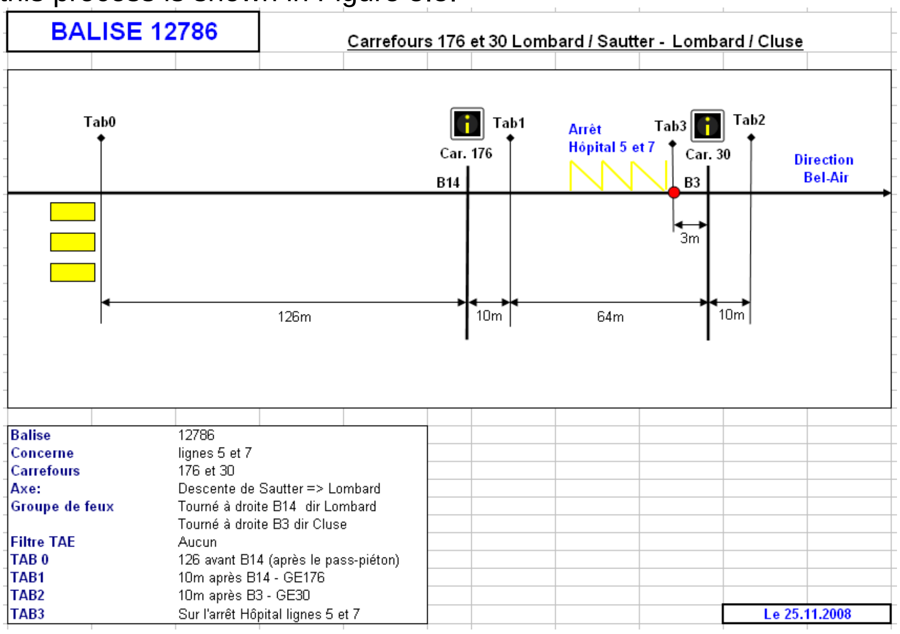



*Figure 5.5: An example of bus priority process in Geneva*

In the figure, the first message is sent after the crosswalk, the second after the first traffic light, one on the locking of the door and the last one indicates the passage of the bus and ends the priority.

Operational data is collected from every vehicle every day using 'wifi' connection. These data are easily displayed graphically to identify any problem or to support request to the State to obtain improvement of the priority at signals. More analysis can be carried out by the administrator of traffic lights using a hand device which allows displaying and analyzing of the message generated by vehicles. The problem analysis can determine the cause of the problem, if any, such as: data, on-board hardware or on-road receptor.

## 5.6 Glasgow, UK

Glasgow is the third most populous city in the United Kingdom with nearly 600,000 residents. Bus priority at traffic signals in Glasgow is based on the Bus Information and Signalling System (BIAS). The system shown in Figure 5.6 comprises mainly: a satellite based Global Positioning System (GPS) for locating buses; and an Urban Traffic Control (SCOOT) system to provide priority to buses through the City's traffic signals. The system tracks the movement of 500 buses over eight key bus routes. If a bus slips behind schedule the system registers the information with the Traffic Control Centre which then gives bus priority at 241 remotely controlled traffic lights [30].

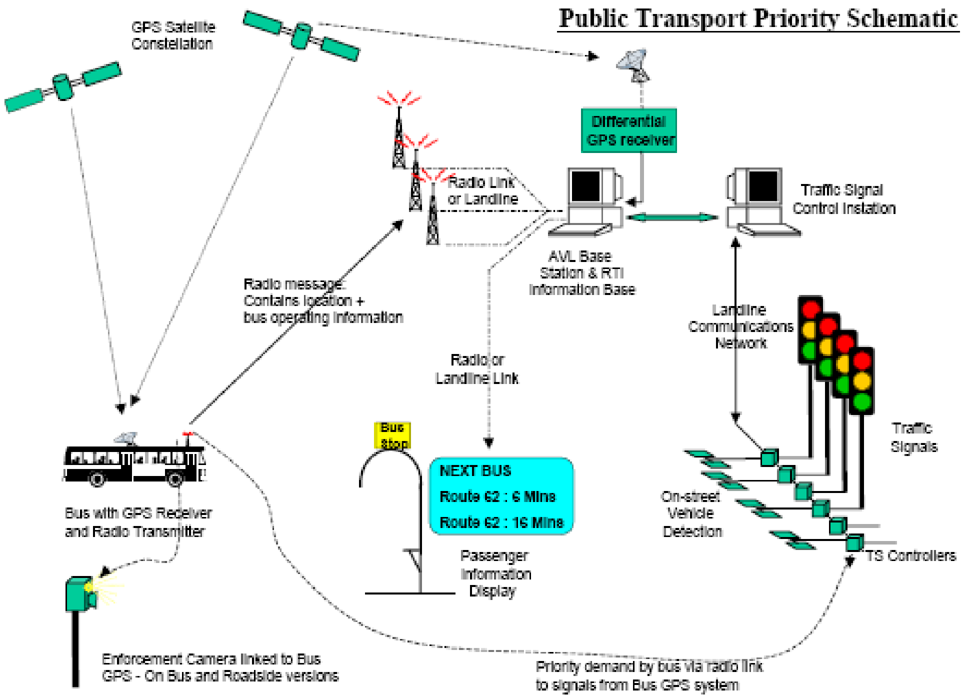



*Figure 5.6: Glasgow's Bus Information and Signalling System (BIAS) (from [31])*

Each BIAS equipped bus will have an on-board computer unit (OBU) which interfaces to the bus's ticket machine, vehicle odometer, and a GPS receiver. The on-board computer holds the daily schedule for the bus and compares its actual position on the road with that expected. The Traffic Control Centre tracks the location of buses throughout the network using onboard Global Positioning System (GPS) technology, roadside sensors and two-way radio systems. Based on immediate assessments of traffic volumes, the centre then makes adjustments to signal phasing to clear free-moving bus corridors and keep services on schedule [30]. The UTC System then optimises the traffic signal timings to ensure that the transition back to normal conditions is as smooth as possible.

The real-time bus priority application is reported to have reduced the variability between journey times for buses travelling through the corridors considerably. There are also reports of greater passenger satisfaction and increased usage [30].

## 5.7 Gothenburg, Sweden

The city of Gothenburg is located on the west coast of Sweden. The city is the second largest city in the country with close to 500,000 inhabitants. Some 25% of the 1.64 million trips made per day are by public services. Most cities in Scandinavia have installed bus/tram priority within fixed time UTC. Priority is provided using heuristic techniques that do not take traffic congestion into account. Special stages are actuated as soon as possible when priority vehicles are detected on the incoming links, typically 15-20 seconds prior to the stop line. The intersection then gets back into co-ordination.

Trials in Gothenburg first compared the benefits of introducing adaptive UTC (SPOT) over existing fixed time control. Travel time improvements of 5%-10% were achieved for general traffic, according to time of day. Comparisons of adaptive UTC incorporating bus/tram priority with fixed time control (no priority), indicated reductions in public transport travel times of 13%-15% [29]. However, there was no significant improvement for public transport when priority was offered both with adaptive UTC and with fixed time control. This occurred because an 'absolute priority' strategy was implemented in the latter case, whereas adaptive control incorporated an overall optimisation which did not guarantee absolute priority to buses and trams.

## 5.8 Helsinki, Finland

Helsinki accommodates one-tenth of the inhabitants (approximately 546,200) of Finland. The public transport telematic system in Helsinki called HeLMi (Helsinki Public Transport Signal Priority and Passenger Information) was launched in 1999. HeLMi provides several public transport telematic functions such as real time passenger information, bus and tram priority at traffic signals and schedule monitoring. The HeLMi system is one of the most sophisticated and is based almost solely on wireless communication [32]. The system configuration of HeLMi is shown in Figure 5.7.

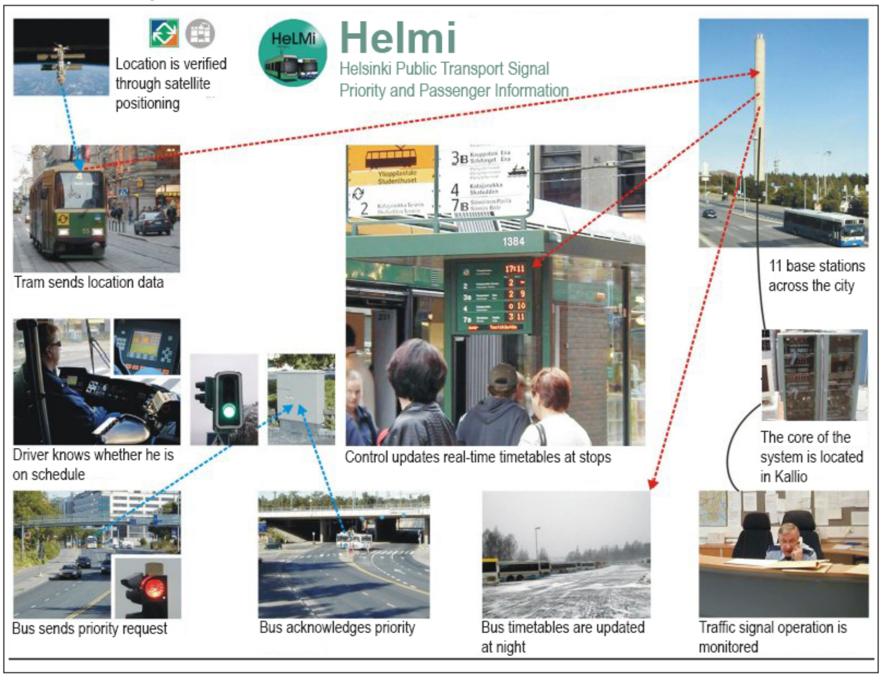



*Figure 5.7: System Configuration of Helsinki's bus priority system (HeLMi) (from [33])*

In the system, the location of a bus is determined in three steps:

- GPS-satellite navigation plots the bus roughly on the right bus stop window (a section of the route before and after the bus stop)
- Bus door opening at the bus stop locates the bus exactly on the right position along the route.

- The bus location along the route is based on the odometer counting the accurate distance of the bus from the preceding bus stop

Each bus is polled by the central equipment every tenth second. So the central computer has continuously the data of the exact position of each bus along the route. Traffic Signal Priority is based on the request of the approaching bus sent via radio modem direct to the next junction [32]. The first message is sent 150-250 metres before the junction. According to the stage of the signal cycle that the message is received, the signal controller either calls or extends the green for buses. In complex junctions, even a special bus stage can be called during the signal sequence. The second message is sent just after the stop line as an indication that the bus has passed signals and the green for bus can be terminated. The signal priority is not given to buses which are ahead their time-table.

The system's effects have been studied particularly on tram line 4 and bus line 23 [34]. Benefits remained minor on the tram line due to previously existing signal priorities. On bus line 23, travel times fell by 11 percent and traffic light delays by 48 percent while an improvement of 20 percent was seen in regularity and 58 percent in punctuality. Passenger volume increased by 11 percent as a result of the system and one bus could be cut from the route thanks to reduced travel time.

## 5.9 London, UK

London is the capital city of United Kingdom and most populous city in the European Union with a population of 7,556,900. London has been the leading city in the UK for the development and implementation of bus priority at traffic signals. Systems were first implemented in the 1970's at isolated junctions controlled under the UK 'D-system' Vehicle Actuated (VA) control. Bus detection involved self-contained transponders mounted on the underside of buses, with data transfer to an inductive loop bus detector in the road surface typically 70-100m upstream of the junction. Priority was granted to all buses through a green time extension or a green time recall, with (optional) compensation facilities included for non-priority stages: These allowed an additional time for a non-priority stage following its truncation due to a priority call, and/or disallowed priority actions in consecutive cycles (the 'inhibit' facility). Successful early trials led to a larger implementation at 50 junctions in the SELKENT area of south east London [35], and to wider implementation.

London has been involved in two major EC- funded projects concerning bus priority at traffic signals. The first of these, PROMPT [36], involved the development and evaluation of bus priority in the SCOOT UTC system. (Of some 4000 signal installations in place at that time, nearly 50% operated under isolated VA control, while the remainder operated under UTC. Approximately 50% of these were under fixed time control (e.g. TRANSYT plans), while the remainder were under traffic responsive SCOOT control. Priority strategies include green extensions and recalls with benefits dependent on the 'spare green time' available at the junction which can be re-allocated to detected buses. The amount of spare green depends on the difference between the actual degree of saturation (DOS) on the non-priority stage(s), which is estimated by SCOOT in real time, and target DOS values set by the operator according to policy (e.g. the higher the target DOS, the higher the priority for buses, but the greater the potential disbenefit for non-priority traffic).

Recently, London is implementing a GPS-based Automatic Vehicle Location (AVL) system for bus fleet management, real time passenger information and bus priority at traffic signals. The system is known as iBus [37] and will cover 3200 traffic signals and 8000 buses [38]. 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 Figure 5.8.

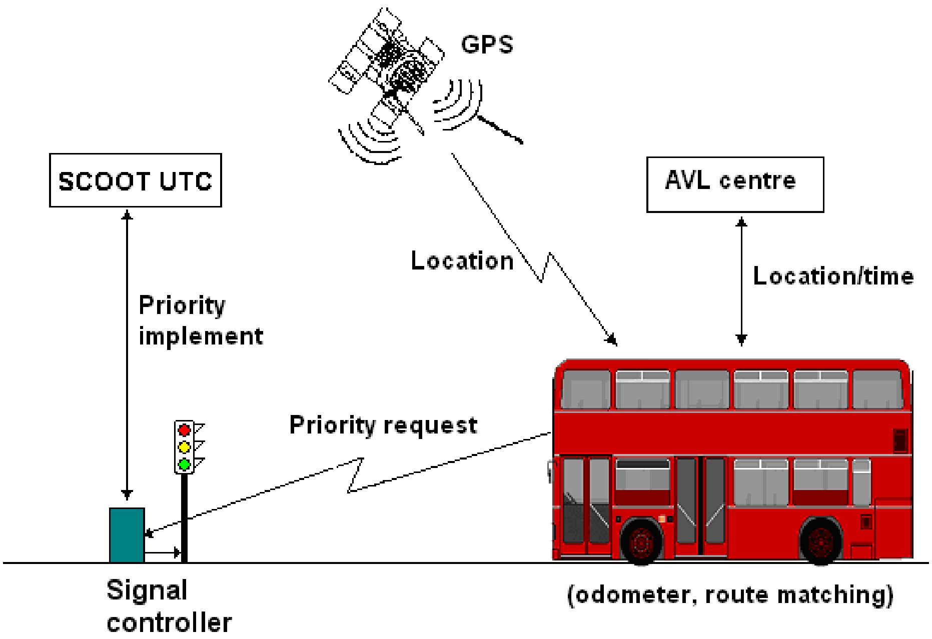



*Figure 5.8: Simple representation of bus priority at traffic signals using iBus*

Implementation of iBUS has provided the opportunity to implement more innovative bus priority methods in London. Various research and development activities are being carried out by the Transportation Research Group (TRG) at the University of Southampton and the Transport Research Laboratory (TRL) to exploit the opportunity provided. A detailed case study of bus priority at traffic signals developments in London is carried out in Section 6.

## 5.10 Malmo, Sweden

Malmö is Sweden's third largest city with a population of 276,000. The city is in the southernmost part of the country just 15km away from Copenhagen. Within the CIVITAS SMILE project, a bus priority system at traffic signals was implemented at over 40 intersections. The computer on the bus that manages the destination sign calls the traffic lights, asking for priority.

The objectives were to introduce bus priority at 42 traffic lights and to improve the attractiveness of public transport in Malmö by reducing bus headway from 10 minutes to 7.5 minutes without increasing the number of buses. By 2004 all city buses and some regional buses were equipped with GPS and computers that communicate with traffic lights, so measures were then only needed to install equipment in the traffic lights in order to establish a priority system. The system was launched and evaluated by Lund University during 2008. Expected results include an increase in use across the system of ~2% due to shorter travel times and improved punctuality [39].

## 5.11 Nantes, France

Nantes is the sixth largest city in France with 600,000 inhabitants. Public transport in the city comprises: 42 km tramway; 7 km busway lines; 55 bus lines and 3 boat shuttles. These services provide around 467,000 trips per day. Buses belong to the city's transport authority (Nantes Metropole) and are run by SEMITAN which is a mixed public/private company. The priority facilities available for the buses in the city include 31 km of bus lanes, 1 bus-only street and priority at traffic signals.

Bus priority at traffic signals uses Loop and Transponder technology to detect buses for priority purposes. Traffic signals give priority to all those detected buses in the form of green extension. At present, only a few signals are equipped for priority purposes and hence the benefits are localised. However, there is a plan to equip 5 major bus lines soon with the bus priority system.

## 5.12 Prague, Czech Republic

Prague is the capital of the Czech Republic. The City of Prague covers a total area of 496 square kilometres and has 1,225,000 inhabitants. Prague is a municipality and a self-governing territorial unit administered by the self-governing and state authorities. One of the biggest problems is the very fast increasing number of private cars, which more than doubled since 1990. In the City of Prague, public transport is based on subway (54.9 km), trams (554.1 km) and buses (2101.8 km). These facilities serve around 1200 million passengers per year. The public transport operation (including buses) is operated and controlled by The Prague Public Transport Company owned by the City of Prague. The priority facilities available for buses include around 10 km of bus lane, 5 km sharing tram lane and priority at traffic signals.

Within the framework of the 'Trendsetter' project, more adaptive signal control with a bus priority system was implemented in Prague to provide a faster and smoother flow of bus traffic by the removal of time losses at intersections. The main objective of the measure was to give priority to public buses over private cars when crossing intersections equipped with traffic lights. The measure included active detection system facilitates to give priority to buses when passing through the crossroads and is based on a radio communication between the vehicle and signal timing controller. An infra-red beacon located in front of the crossroads is used to localise vehicles [40]. The priority system is linked to timetables of particular lines thus facilitating the assess real time location of the bus against the timetable to determine the time difference. Based on the time difference, an appropriate level of priority is allocated to the bus. Buses ahead of the schedule do not receive priority at the traffic signals [41].

The new signal system that gives buses priority has made the bus service faster, smoother, much more reliable and predictable. Both the speed of the buses and the number of trips with public transport has increased [41]. Initially, the system was installed in eleven buses serving four selected bus lines. Since the measure was very successful, the number of junctions with bus priority system has been increased to 65 junctions and 352 buses are now equipped for gaining priority at these traffic signals.

## 5.13 Southampton, UK

Southampton (215,000 inhabitants) is a city located on the south coast of England, but with a travel to work area population of approximately 500,000. The Southampton Urban Traffic Control system controls all 120 junction signals (majority of them SCOOT-controlled) and 50 pedestrian crossing signals in the city. Bus priority was implemented initially in Southampton using "footprint" detection at a number of SCOOT-controlled junctions. The applications were successful in providing bus delay savings averaging some 8 secs/bus/junction, although the high level of priority implemented caused small disbenefits to private traffic.

Public transport priority based on AVL for bus location was successfully tested in a trial corridor, with the priority functions of green time extensions and recalls being developed in a parallel EC funded project (PROMPT). The algorithm for the provision of bus priority (developed in PROMPT) was provided by Siemens Traffic Controls and was operational on the Southampton UTC system. It provided "equal" facilities to all buses with "conflicts" at junctions being resolved on a "first come first served" basis, subject to green extensions being allocated before recalls because of the greater benefits available to individual buses from this facility.

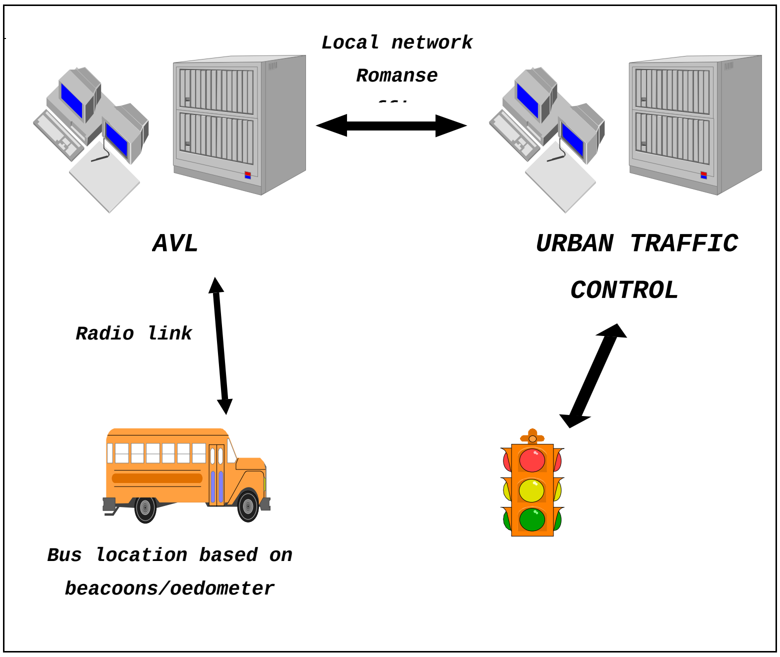



*Figure 5.9: Configuration of Southampton's bus priority system (from [29])*

In the beacon-based bus location system, an on-board computer picked up signals from a series of roadside beacons as the bus moved along its route. The computer combined this with the information from the odometer to locate the position of the bus accurately along a defined route [29]. The bus transmitted the known position to the Southampton ROMANSE traffic information centre every 15 seconds. Based on this locational information, a request was sent to the Urban Traffic Control Computer to give priority to an approaching bus at a traffic signal. The system in Southampton is currently being upgraded to use GPS for bus location.

## 5.14 Stockholm, Sweden

The City of Stockholm covers an area of 187 square kilometres and has a population of 0.74 million. The city has a very well functioning and safe public transport system. More adaptive signal control in a bus priority system was experimented in Stockholm within the EU funded Trendsetter project. The aim was to move on to a more integrated environment for efficient urban traffic management. The Urban Traffic Control (UTC) system in Stockholm aims at minimising the total time lost by private vehicles and their emissions during their trips within the controlled area, subject to the constraint that public vehicles for which weighted priority has been requested shall not be delayed at intersections with traffic lights. This increases the reliability and attractiveness of the bus service and reduces queuing and pollution.

Stockholm had a bus priority system prior to Trendsetter. However, on heavily trafficked streets and during peak hours, this was not enough. In Trendsetter, Stockholm tested another bus priority system (SPOT/UTOPIA, first developed in Turin) that is more adaptive to the actual and current traffic situation. The system has been installed at eleven intersections on the island of Kungsholmen, a part of Stockholm's inner city. The new system is adaptive, which means that it "learns" as it is used. Also, although this system gives buses priority, it does not forget the cars. The tasks within Trendsetter included [42]:

- installation of more adaptive traffic signals at eleven intersections
- substitution and renewal of some current traffic control equipment
- installation of necessary technical equipment, including inductive detectors that count the number of vehicles at intersections
- introduction of a dynamic bus priority-weighing scheme (IT-based) with links to the Road Traffic Management Centre and the Public Transport Management Centre

The results showed approximately 5 percent higher traffic flow, an average 10 percent shorter driving time for cars in the area, an average 10 percent shorter driving time for buses; and 10-20 percent shorter waiting time for cyclist and pedestrians [42].

## 5.15 Stuttgart, Germany

Stuttgart is a large city in south-west Germany with one of the most extensive and well used street tram systems anywhere in Europe. The city is the capital of the region Baden-Wirttemberg with a population of 550,000. The city and the whole region are characterized by high car ownership- 560 cars per 1,000 inhabitants. Stuttgarter Strassenbahnen (SSB), the Stuttgart public transport operator, operates a modern 77-mile light rail and tramway network and a 266-mile bus network that carries some 170 million passengers annually. While the expansion of light rail since the 1980s has helped to increase the attractiveness of the Stuttgart rail network, the bus network became less and less attractive. Delays longer than five to 10 minutes due to congested roads became a regular occurrence on some of the SSB bus lines.

Since 1996, SSB, in cooperation with the city of Stuttgart, has developed a new program to revitalize the bus network. The most significant city centre bus line (Line 42) with 31,000 passengers daily was tackled first; other lines have followed. Various measures implemented included: the creation of 1.1 miles of bus lanes (8 percent of the whole line length) has speeded up bus operations on Line 42 by enabling buses to run independently of other traffic. The most significant innovation on Line 42 has been priority at traffic lights. The system operates with an infrared technique to detect the vehicle's location; a Global Positioning System serves as a backup. A battery-powered infrared beacon communicates with the infrared-vehicle-reading-system IRIS (Infrared-Information System) of a passing bus [43]. It tells after how many meters radio signals have to be transmitted from the bus to the computer-controlled traffic light in order to get a green light. The system records each bus for prioritization until the bus has passed the traffic light. This barely interferes with other traffic.

In the model Line 42, 34 traffic lights were equipped with the radio beacon system. Considering the whole SSB bus network, 26 percent of all traffic lights have been upgraded, giving buses priority over general traffic and pedestrians. The various measures called for an investment of $4 million, of which 85 percent was met by public subsidies. From the operator's point of view, the increased travel speed from 9 to 10.1 miles per hour had additional benefits [43]. One bus per line could be reduced, for savings of $250,000 annually. Finally, the upgraded bus line has attracted up to 10 percent more passengers, showing the success of the Stuttgart bus acceleration program.

## 5.16 Suceava, Romania

Suceava City is in the north-eastern part of Romania, 450km from Bucharest, and has been the capital of Suceava County since 1388. The municipality of Suceava, with a surface area of 52.1km² has 118,500 inhabitants in the town and suburban areas. Bus priority measures were implemented in Suceava that include giving priority to buses at crowded junctions. The focus was set to improve bus operation by installing new traffic lights functioning in "green way" system utilising the bus location information obtained through GPS. This was part of a CIVITAS project with objective to make public transport more attractive with range of improvements including implementation of special traffic priority for buses, especially at peak hours. The project was expected to bring a significant boost to local public transport and reduce the traffic congestion in the city centre by increasing the number of public transport users with a view to decrease by 12% the number of car journeys. The project also aimed to increase public transport passengers by 10 -12% by reducing waiting time and shortening duration of travel [44].

## 5.17 Tallinn, Estonia

The City of Tallinn is the capital of Estonia. It is also the largest city in Estonia with 400,000 inhabitants. The number of private cars has been increasing rapidly and the public transport network has not developed at the same pace as the private modes and faces huge competition.

Between 1990 and 2000 public transport use fell from 250 to 94 million and the modal share of the public transport in Tallinn decreased from 77% to 31%.

A public transport priority system was implemented in Tallinn within EU funded CIVITAS SMILE project. This was aimed to establish a priority system for buses in order to increase the modal share of collective passenger transport. The measures included priority signals for public transport together with a stop directly before the signals.

The installation of equipment for priority system included 110 Tallinn Bus Company's (TAK) buses and 59 Tallinn Tram and Trolleybus Company's (TTTK) trolleybuses. The number of intersections equipped has grown from 26 to 30. The priority system is managing today the traffic of 7 bus and 3 trolleybus routes.

Survey results show an improvement in speed for trolleybuses on SMILE routes of 2 km/h in the evening peak hour in 2008 compared with 2005. Car speed on same route has decreased by 11.2 km/h compared to 2005 [45]. The previous steady decline in the modal share of public transport (passenger km) has been halted - retaining the modal share at the 2007 level.

## 5.18 Toulouse, France

Toulouse is located in the south-west of France. There are about 400,000 inhabitants in the city making it 4th highest populated city in France after Paris, Marseille and Lyon. The updated version of the Urban Traffic Control system CAPITOUL was installed in July 1999. Presently, there are 380 of the 490 traffic lights intersections controlled by the system. The Bus Fleet Management System called SITERE was installed in 1998 at the same time that the UTC system CAPITOUL II was actually in progress. In 2000, it covered about 160 buses circulating especially on the city centre lanes. The entire bus fleet (that includes about 430 buses) will shortly be equipped with: GPS equipment and odometer to calculate real time positioning and a UHF radio to link buses with the Bus Control Centre.

The city of Toulouse has implemented a system based on a centralised architecture, corresponding to the Toulouse context and the local operators requirements. The system has been developed within the CENTAUR project (1997-1999) in order to test and demonstrate the integration of this kind of system in the new UTC system of Toulouse. In this system architecture, the bus does not request priority directly to the traffic light controller; rather, it communicates with the SITERE system which sends, if needed, directly a priority request to the CAPITOUL system [29]. The bus priority action treatment is managed by the centralised system, through the application of centralised micro-regulation actions integrated in the macro-regulation traffic management strategies.

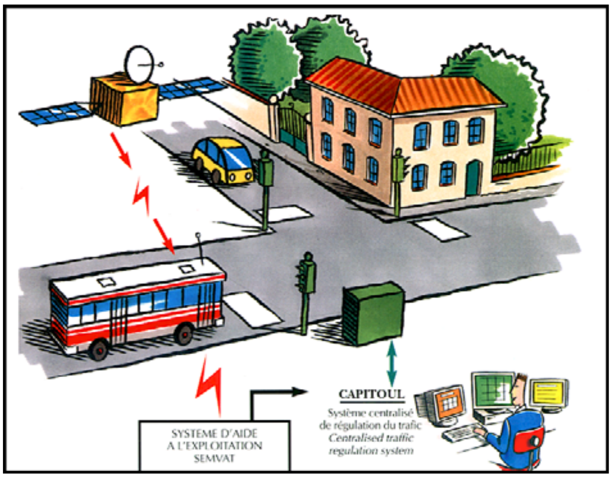



*Figure 5.10: Toulouse bus priority system architecture*

In this system, buses are monitored at 5-8 regulation points defined at strategic situations of each bus lane. When a bus passes a regulation point the time is recorded and transmitted to the AVL system using the radio channel. The communication between the bus and the SITERE system relies on a radio protocol pooling messages every 20 seconds. This information is used to calculate delay/advance at the centralised SITERE system level. The information could be used to request bus priority at the traffic lights level if a bus is considered as delayed. When a bus, considered as delayed, enters one of its lanes associated virtual areas, a specific message is immediately sent to the SITERE AVL system. The system manages the information (in relation with the overall bus priority strategy) and transmits bus priority requests to the CAPITOUL system. If the overall traffic plan applied on the associated traffic lights controller allows bus priority, the system will give bus priority. Experiments in 1999 showed an average decrease of the bus travel time of about 5% and up to 24% during the most congestion peak periods. An overall improvement of the bus travel time regularity that could be associated to an improvement of the bus regularity was also recorded.

## 5.19 Turin, Italy

Turin is a major city in northern Italy with a population of 910,437 (June 2008). Turin has an advanced traffic responsive UTC system (UTOPIA/SPOT) in which public transport priority formed an integral part of the system design. The city has a total of some 1400 trams and buses operated by the local transit company (ATM) and included within the Automatic Vehicle Monitoring (AVM) system. Most of the traffic signals are controlled by the UTC subsystem, which can provide priority to selected vehicles according to requirements received from the AVM. These are based on 'adherence to schedule' and 'headway variability', with highest levels of priority also being provided to vehicles in protected lanes.

During the 1990's, this system was subsumed within a larger IRTE (Integrated Road Transport Environment) known as 5T, developed within a series of collaborative EC-funded projects (e.g. QUARTET, QUARTET+). Public transport management was implemented by means of the SIS (Service Information System), whose basic task was to control the transport system's capacity as a function of demand and its regular and timely performance in relation to travel time and other data. The public transport priority system was based on the beacon-based AVL technology, with radio communications (polling) between PT vehicles and the control centre holding the priority algorithm. Priority is given to buses/trams by gradually adjusting the 'green window' at the signals to match the predicted arrival time of the bus/tram based on the location information received from up to 120 seconds upstream of the junction [29].

Particularly high benefits have been reported for the Turin system, although it is noted that these apply to the combined effects of improved UTC and priority. An EC-funded CPC study [7] on public transport priority reported:

- Average PT journey time savings of 19% and junction delay savings of 97%.
- Average increase in delay to general traffic of up to 2%.
- A decrease in the 'irregularity index' (the deviation of actual headways from nominal ones) of 11%.

Further trials in the INCOME project [46] reported average tram delay savings of around 10 seconds per junction, with a journey time reduction of around 5 minutes (12%) for the entire service.

## 5.20 Vienna, Austria

Vienna is the capital city of Austria and has a population of approximately 1.6 million people. The public transport facility in the city comprises rail, underground, tram and buses. Among these, underground, tram and buses are operated by Wiener Linien – a city owned company. The bus operation in the city is in public ownership and is regulated. The bus network consists of 54 high frequency routes (5 or more buses per hour) and 29 low frequency routes (less than 5 buses per hour).

The bus priority facilities in the city includes 23.3 km of bus lanes, 1.3 km of bus only streets and 185 traffic signals with bus priority facilities. At these traffic signals with bus priority facilities, all buses detected on the approach are given priority. The priority is given by extending the present green time or by recalling the next green time early. The system employs a short range radio to request priority by a bus to the controller. The decision on whether to give priority to the bus or not is taken by the traffic signal controller. In addition to the bus priority facilities, the city also has extensive tram priority facilities covering more than 500 traffic signals. The benefits obtained from the priority at traffic signals are mainly in terms of punctuality and regularity improvements.

### 5.21 York, UK

The City of York is in the northern part of the United Kingdom and has a population of around 193,000. The main form of public transport in York is bus which is run by private operator. The bus network within the city consists of 9 high frequency routes (5 or more buses per hour) and 22 low frequency routes (less than 5 buses per hour).

Priority to buses is given in the form of bus lanes, bus gates and bus priority at traffic signals. Bus priority facilities at traffic signals are installed at 25 traffic signals (out of 75 signals) covering 15 bus routes. The system employs GPS to detect buses on the approaches to traffic signals and a short range radio to request priority by a bus to the controller. In this system, priority is given to late buses only. However, priority is given to all Park and Ride buses regardless of their lateness.

### 5.22 Zurich, Switzerland

The City of Zurich in Switzerland has a population of some 0.55 million inhabitants. It has developed and implemented a very strong policy of support for road-based public transport (trams and buses), based on the objectives of: promoting a change from the car to public, environmentally-friendly transport and channelling motor traffic, creating quieter conditions in residential areas. The strong support for local public transport has been consolidated in a series of referendums and public campaigns in Zurich since the 1970’s. This mandate has led to the application of imaginative urban traffic management and modern information technology to benefit public transport in three main ways:

- The use of individual routes, separate bus lanes and parking controls to create unhindered travel between junctions.
- Maximum preference for buses and trams at signalised junctions, with the aim of ensuring ‘waiting time zero’ for public transport.
- The introduction of a tram and bus operation control system based on AVL, to optimise fleet management, aiming for maximum adherence to timetable.

Zurich has implemented a fully centralised traffic signal operating system which controls 7 areas within the city, each in a duplex system and with about 60 traffic signals. The operating system involves some 14 process computers, 2 central co-ordination computers and over 3000 detectors in the road surface permit completely dynamic signal program switching [29]. Full tram and bus priority is implemented at traffic signals throughout Zurich. In addition, ‘access control’ is implemented using traffic signals to meter traffic into any area of the city which would otherwise become overcrowded. These facilities, together with a goal of keeping pedestrian waiting times as short as possible, have produced conditions for private traffic which have encouraged a modal change towards public transport; around 42% of trips in Zurich are by local public transport.

The operation control system enables the Traffic Manager to talk to every driver and to every passenger whether at a stop or in the bus/tram. This is most valuable whenever there is any disruption to normal service. A comparison of ideal and actual performance is displayed continuously to operators and drivers leading to considerable improvements in regularity. The following points summarise some key characteristics of bus/tram priority in Zurich [47]:

- Strong commitment and investment in public transport with proven citizens approval
- Centralised control of planning, design and operations, with knowledge and system developments remaining under the control of the Zurich Authority.
- Full priority to all buses and trams to maximise operational speeds. Regularity maintained by operational efficiency, driver information/action and efficient 'incident' management. A link between AVL and UTC considered unnecessary.
- Use of buried loops at optimum locations to provide detection/priority.
- Passengers expect, and appear to usually receive, a punctual, fast service. The operator talks to passengers on buses/trams and/or at stops should there be a disruption. Real time displays considered unnecessary.

## 5.23 Japan

The bus plays the major role to service the public in many areas of Japan, especially local areas. The bus is also served as a feeder mode for transit passengers in metropolitan areas. Priority is given to the buses with the Public Transportation Priority System (PTPS) which is one of the advanced technology systems of the Japanese Urban Traffic Control system known as the Universal Traffic Management Systems (UTMS). PTPS helps buses by providing a priority through the exclusive bus lane, the traffic signal pre-emption and the warning to a vehicle which is illegally running in the exclusive bus lane. Currently, more than a half of prefectures in Japan are operating PTPS (UTMS, 2004). The PTPS can serve not only along multiple lanes arterials but also along two-lane arterials [48].

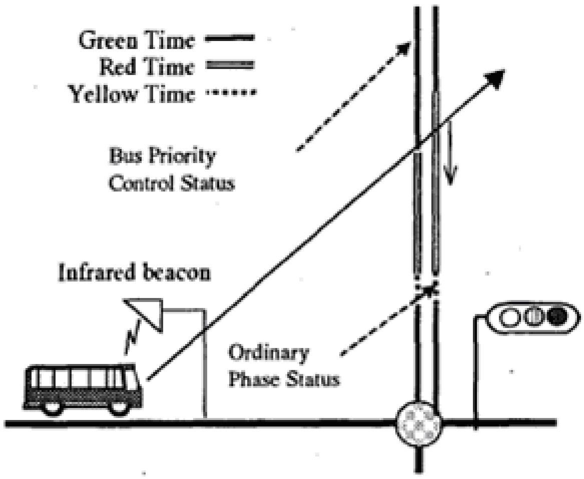



*Figure 5.11: PTPS bus priority system at isolated junction (from [49])*

PTPS uses infra-red beacons as the key detection infrastructure. They perform two-way communication with travelling vehicles based on highly directional infra-red technology and have a vehicle detecting capability. Buses are detected using Infra-red overhead detection and the smooth passage is given through a row of signals. The system predicts the time of the bus arrival on each intersection and helps the bus to pass each intersection by lengthening green time or shortening red time. Bus priority has been implemented in both isolated as well as co-ordinated junctions. A trial in Kawasaki City concluded that the system reduces about 5 % of the travel time [49].

## 5.24 Auckland, New Zealand

Auckland City is the city in the North Island of New Zealand. Auckland City is the most populous city in the country, with a population of 438,100. Auckland City is working with the Auckland Regional Transport Authority (ARTA) and the city's bus operators to install technology that will improve passenger transport and ultimately get more people catching buses. Signal pre-emption is a GPS-based technology that enables buses to communicate their position to the city's traffic signals system. Since introducing the system in 2003, Auckland City has fitted 734 buses with GPS, installed over 204 on-street passenger information displays, and equipped 174 intersections for signal pre-emption [50]. The total contract cost was $6.9m over the three stage implementation period. Operating costs are jointly funded by Auckland City, ARTA and the bus operators.

Various measures are being considered to give priority to buses in the city including bus priority at traffic signals. For this purpose, buses are equipped with on-board Global Positioning System (GPS) equipment to detect their position on the bus route. At the beginning of each trip, the bus driver enters the route number and departure time into the on-bus ticketing machine. As the bus travels along its route, predicted arrival times are communicated to the electronic display signs at bus stops. This information is relayed as the bus passes set points along the route, using information from the GPS system. If a bus approaches an intersection fitted with signal pre-emption, the system can request traffic signal priority for the bus:

- if the signals are green but about to turn red, the green phase can be extended by up to 10 seconds
- if the signals are red, the green phase can be brought forward by 10 seconds.

The system is also used to monitor passenger transport services for use by Auckland City, ARTA and the bus companies. Research undertaken indicates a saving to passengers of approximately 11 seconds per intersection, or in the case of The Link service, about eight minutes per circuit (the average Link circuit takes an hour).

### 5.25 Brisbane, Australia

Brisbane is Australia's third largest city with a population of 1.6 million and the state capital of Queensland. Brisbane City Council is responsible for all traffic management within the city including responsibility for 650 sets of traffic signals. The Council has developed a computerised traffic control system called BLISS (Brisbane’s Linked Intersection Signal System) that provides optimum signal settings, automatic traffic counting and priority for buses and emergency vehicles at signals. The active bus priority system giving priority to buses at traffic signals is known as RAPID (Real-time Advanced Priority and Information Delivery), which operates within BLISS [51].

The Vehicle Identification (VID) system involves the installation of specialised receiver equipment in the traffic signal controller cabinets and the fitting of identification transmitters (tags) to selected vehicles including buses. As a vehicle passes over the detection loops, the identification receiver decodes a message from the vehicle’s tag and sends to the controller as shown in Figure 5.12 [29].

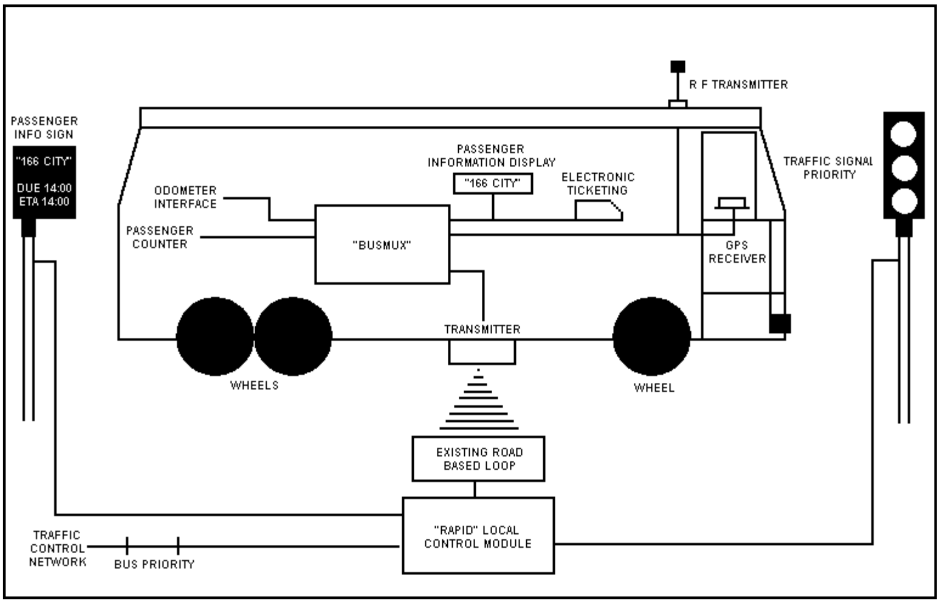



*Figure 5.12: Woking of Brisbane's RAPID bus priority system*

When a bus is detected, BLISS determines how late it is by comparing its progress to previous journeys. If the bus is late and qualifies for priority (an intervention), a message is sent to the field processor inside the relevant signal controller cabinet stating which bus to give priority to and which phase it requires. Interventions are implemented by starting a phase early and extending a phase.

An on-street survey was carried out from October 1996 to March 1997 along Waterworks Road, a major arterial route into the city [52]. The survey included 205 buses and 14 sets of signals on the route. The survey showed that there was an average of 111 interventions per weekday, mainly in the peak period. There was no statistically significant reduction in bus travel times due to a number of reasons including:

- Too few interventions due to 2 minute lateness criteria
- Constraints on timing changes for interventions were too restrictive
- System response to bus detection's were too slow
- Buses slowed down by downstream congestion
- Loops not placed far enough back from the stop-line.

Overall, the survey showed that the bus priority system was working well, enhancing bus services and encouraging a greater use of public transport. The scheme was to be extended to another 4 major arterial routes with the whole bus fleet being tagged.

## 5.26 Sydney, Australia

Sydney is the most populous city in Australia, with a metropolitan area population of approximately 4.34 million. Bus services in Sydney are provided under contract to the government by both private and government operators. Sydney has significant lengths of bus lanes, high occupancy vehicle lanes and numerous B signals (with a short pre-start phase for buses). Most traffic signals are connected to the SCATS system developed by the Roads & Traffic Authority (RTA) of New South Wales. Bus priority at traffic signals is based on Public Transport Information and Priority System (PTIPS) developed by the RTA [53]. The purpose of PTIPS is to facilitate a smooth movement of public transport vehicles by providing them with priority at signalised intersections. PTIPS generates priority requests for public transport vehicles in the following manner:

- Determining the arrival time of the vehicle at the next intersection(s);
- Generating requests for "green windows" at these intersections;

- Specifying the required “green window” – phase extension or early recall, start-time and duration; and
- Resolving conflicts between different priority requests.

Priority is given only to the buses that are running late. This priority is provided by applying a "dwell" to the signals to extend the current phase until the bus passes. The location technology used is GPS on the bus, and the bus is connected to RTA's PTIPS control centre by GPRS. Buses send their actual position to the PTIPS control centre which is then compared with the planned position according to the bus timetable. If buses are running more than say 2 minutes late a request for priority is sent from the PTIPS control centre to SCATS, and then SCATS determines whether to grant the priority request or not.

Trials of PTIPS on the Sydney Airport Express Bus Service in 2001 were undertaken with PTIPS using a GPS-based bus detection. Buses were equipped with a GPS receiver and a GSM (Global System for Mobile telecommunications) modem, including a Vehicle Tracking System (VTS) software package that displayed the locations of tracked buses on a map to an accuracy of 10 metres. The trials indicated that PTIPS reduced both mean travel times (up to 21%) and variability of travel time (up to 49%) for buses [54].

## 5.27 Portland, USA

Portland is situated approximately 70 miles from the Pacific Ocean on the West Coast. It has a population of 503,000 within its city limits but 1.7 million within the metro area. Portland's mass transit system is one of the most extensive and advanced in the U.S. The transit system includes buses and the MAX, an urban light rail line, as well as a downtown transit mall and Fareless Square, the downtown free-ride zone. The city of Portland and the Tri-County Metropolitan Transportation District of Oregon (Tri-Met) work together to provide bus service in the Portland metropolitan area. Recently, city and TriMet have implemented a bus priority project that included 8 corridors, 250 junctions and 650 buses in its first phase [55]. The goals of the project were: to reduce operating costs and improve reliability of schedules through reduced variability; to provide priority to emergency vehicle (fire), and to increase the people throughput through intersections.

The system is decentralized based on 3M’s ‘Opticom’ technology which uses Encoded Infrared Communication technology. The system is integrated with AVL system. Conditional priority based on four criteria: 1) Door closed, 2) on route, 3) 30 seconds or more late, and 4) within city of Portland as defined by a geometric polygon. All equipped buses know their location and lateness status. When a bus is late, it activates its ‘Opticom’ emitter and requests priority at the downstream traffic signal. The intersection receives the priority call and gives priority by extending the green period or truncating red period (Figure 5.13). As the bus passes the intersection detector, the priority call is dropped and the controller returns to normal operation. Recovery is not needed because the signals are never out of coordination. The system does not provide priority to a bus request in the cycle following a cycle in which priority was requested. The system allows 7-10 seconds extension which changes by intersection. If signals are too close together, no bus priority is given.

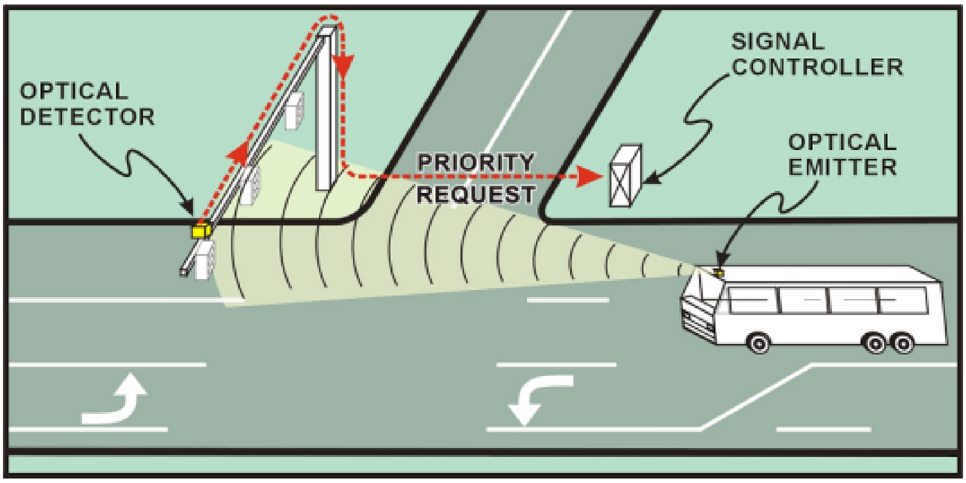


*Figure 5.13: Illustration of bus priority working in Portland*

Portland also has some queue jump facilities (pre-signalling) at junctions where a bus lane is in a right turn only lane. The queue jump gives a six seconds advance to buses to jump the queue. TSP is integrated with emergency vehicle pre-emption but is restricted to fire trucks only, not regular police vehicles or ambulances. The scheme increased reliability and reduced recovery time needed to ensure on-time departure of buses.

## 5.28 King County, USA

King County, located on Puget Sound in Washington State, is 13th most populous county in the USA with more than 1.8 million people. King County Metro is responsible for providing bus, vanpool, and para-transit services to the county. One of the 10 largest bus systems in the nation, Metro operates 220 bus routes throughout the county, with nearly 10,000 bus stops and 126 park-and-ride facilities connecting riders with those routes.

Traffic Signal Priority (TSP) has been deployed along three corridors that required 28 intersections and 1,400 buses to be equipped [55]. The TSP system does not request priority based on schedule adherence conditionality but there are many traffic-related conditions: phase state, emergency pre-emption, route/trip and call frequency. Future technology will request priority based on conditions such as lateness and/or ridership.

Buses equipped with programmable passive RF tags are detected by wayside readers with RF antennas that are located 500 to 1,000 feet upstream as shown in Figure 5.14. The detection is then communicated to the intersection Transit Priority Request Generator (TPRG) located in the controller cabinet. It generates priority requests to the controller for eligible buses (based on an eligibility table). Priority is provided by green extension and red truncation, without shortening any minimum clearance intervals, skipping phases, or breaking coordination. Phase insertion also exists at four queue jumps using loop and/or video for detection.

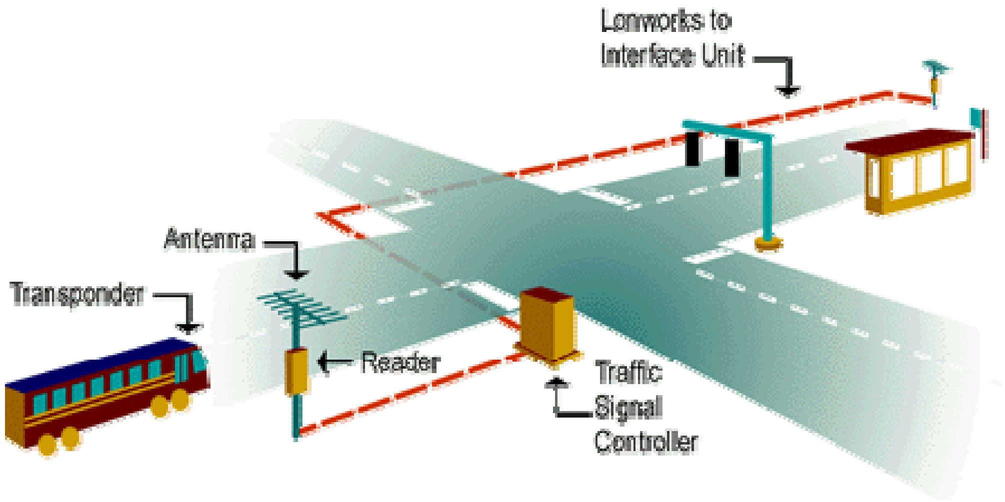



*Figure 5.14: Illustration of bus priority system in King County (from [56])*

The goals for the TSP program were: to increase the amount of “green time” at intersections for selected bus trips; to decrease average travel time; to decrease variation in travel time; to reduce signal-related delay, and to minimize impact on general traffic. The evaluation studies were conducted for two corridors. Key benefits identified from the two studies were [55]:

- 25-34% reduction of average intersection delay for eligible buses
- 14-24% reduction of stops at intersections
- 35-40% reduction in trip travel time variability
- 5.5-8% reduction in travel time along the corridors during peak hour

There have been no complaints regarding normal operations and the side street delay was minimal.

## 5.29 Los Angeles, USA

Los Angeles, on the south-western coast of the USA, has a population of 3.5 million (14 million for Greater Los Angeles). Los Angeles Department of Transportation (LADOT) and Metropolitan transportation Authority (MTA) worked together to provide traffic signal priority (TSP) with a policy to move people not vehicles. Within the partnership, 9 BRT corridors with 654 intersections and 283 buses were equipped for TSP. Priority is based on headway management. The traffic control system tracks the location of buses (each with unique ID) along the BRT corridors and compares passage times to the defined table of headways for that road segment which resides in traffic servers. Priority is only granted to buses whose headway since the previous bus is equal or greater than the defined headway.

Buses with transponders on them are detected by detector loops and communicated to the controller using cable. The controller communicates to the central system which initiates all phase changes. The local controller can only time phases and can be used for backup. Priority is given by recalling early green, green extension and phase hold. Priority is then not permitted for one or two cycles (set by LADOT). Evaluation carried out showed 19 to 25% reduction in travel times [55]. 1/3 of savings is due to TSP; and 2/3 of time savings is due to headway based service fewer stops, and shorter dwell times. Ridership of Metro Rapid lines increased 4% - 40% depending on the line. Impact on non-priority traffic was typically 1 second/vehicle/junction.

# 6. Bus priority at traffic signals: Detailed Case Study of London

## 6.1 Background

Methods for implementing bus priority at traffic signals have been available in London since the 1970's. Most of the development work has been related to 'active' systems, where priority is provided for individually detected buses in various ways including: inductive loops, beacons; and satellite based GPS (Global Positioning System) system. The priority strategies adopted in London are related to the type of signal control facilities available and local preference. For example:

- At isolated junctions, vehicle actuated control predominates.
- For junctions co-ordinated within the traffic responsive UTC system (e.g. SCOOT in the UK), extensive priority facilities are available [9].
- For junctions co-ordinated within fixed-time UTC systems, the SPRINT system has been developed in London [6].

The development of bus priority facilities adopted in these different types of signal control facilities in London are discussed in the following sections.

## 6.2 Bus Priority in VA

Bus priority at VA junctions started in London in the 1970's with the first major evaluation trial occurring in the SELKENT area of London in 1987-88 [35]. The success of the trial led to the expansion of bus priority at 300 more VA controlled junctions in the outer areas of London. The SELKENT bus priority scheme involved installation of bus detectors at some 56 signal controlled junctions and equipping 900 buses with transponders to activate the system. Most of the detectors were sited at 70m upstream of the stop-line from the consideration of journey time variability and enough warning time.

The system was capable of giving priority to the buses detected on the approach by extending the current green period or by recalling the priority stage for the buses early. The priority recall could be implemented by curtailing the non-priority stages to their minimum values. Stage skipping was not allowed in this system, unless there was no demand for the stage. Any non-priority stage curtailed to give priority to buses could be compensated by increasing its normal maximum value by a compensation period. An inhibit facility was also provided at some sites with high bus flows, to prevent bus priority occurring in consecutive signal cycles, which could disrupt non-priority signal stages significantly.

Field trials undertaken at 10 junctions showed that the average flow weighted bus delay savings was 8.6 sec/bus (29%), 8.3 sec/bus (31%) and 13.7 sec/bus (35%) for morning peak, off-peak and evening peak periods respectively. The overall, bus delay savings was 9 sec/bus (32%) and the reduction in standard deviation (variability) was 4 sec/bus. The trial demonstrated that bus priority at VA controlled junctions can give significant benefits to buses. The average bus delay saving of 9 sec/bus/junction was somewhat higher than typically achieved at co-ordinated systems in London, where the needs of network stability can constrain the amount of bus priority given.

Bus priority is also available within the more advanced MOVA traffic control system for isolated junctions.(Microprocessor Optimised Vehicle Actuation) [5]. MOVA analyses lane-by-lane detector data and controls the signal timings to optimise delay and stops or capacity (if any approach becomes oversaturated). The system gives priority to the buses detected on the approach by extending the current green period or by demanding the priority stage for the buses. The priority stage demand may be implemented by truncating the non-priority stages to their minimum values (stage truncations) or by skipping all those stages on route to the priority stage (stage skipping).

Implementation and trials of bus priority in MOVA have been limited. A trial carried out at Harlington in London showed only modest benefits, after taking account of the disbenefits recorded. The trial highlighted the fact that it is difficult to get bus priority benefits in certain junctions where bus stops are close to traffic signals and there are conflicting bus flows competing with each other for priority. A trial in Winchester in South Hampshire showed bus delay savings of 5 seconds overall that represented a 26% reduction in bus delays. The trials demonstrated that bus priority at MOVA controlled junctions is capable of giving worthwhile benefits to buses.

### 6.3 Bus Priority Development in SCOOT

SCOOT (Split Cycle Offset Optimisation Technique) is a leading traffic responsive Urban Traffic Control (UTC) system. It is installed in most cities in the UK and many around the world. SCOOT has a number of facilities that can be used to provide priority to buses. 'Passive' priority, which does not differentiate between vehicles, can be given to links or routes using split and offset weightings. As all vehicles on the weighted link receive a similar benefit, the level of priority that can be given is limited. 'Active' priority can be given to individual buses: extensions to prevent a bus being stopped at the start of red and recalls to start the bus green earlier than normal. In addition, in some situations, intermediate stages between the current stage and the bus stage can be skipped.

The benefit to buses gained through providing SCOOT priority without stage skipping varies considerably, and is dependent on the scope for increasing or decreasing the lengths of signal stages. At junctions where the non-priority stages are already at or close to their minimum length, there is little scope for providing priority through recalls. Assuming that stages are not running close to their minimum length, the benefits of priority are then very dependent on the traffic conditions. Reductions in delay as high as 50% are achieved when the degree of saturation is low. Whereas, at high degrees of saturation the reduction in delay is of the order of 5 - 10%.

In extensive trials in London reduction of delay of around 3-5 seconds per bus per junction are typical [57]. The increase in delay to general traffic is similarly dependent on the degree of saturation. At low degrees of saturation the increase is small and insignificant, whereas at high degrees of saturation the increase in delay to general traffic can be large. The disruptive effect of providing priority by recalls is much greater than by extensions. Giving recalls to buses on a side road can be particularly detrimental as it reduces the green time as well as disrupting the coordination along the main road. The number of buses being given priority is also an important factor, particularly at higher degrees of saturation. Benefit per bus decreases as bus flow increases, due to competing/conflicting priority calls, but total passenger benefit remains substantial at bus flows as high as 120 buses/hr/junction.

Active priority requires that SCOOT be informed of a bus's presence either by selective vehicle detectors, i.e. using bus loops and transponders on buses, or by an automatic vehicle location (AVL) system. Bus management and information systems such as IBUS which make use of GPS technology to track buses through the network can also be used to provide bus priority in SCOOT. One big advantage of such systems is that they can provide detection of buses without the need for the installation of additional street hardware. This means that there is little cost in providing additional detection points.

SCOOT has recently been enhanced to take advantage of the information that these systems can provide. In particular, the bus priority logic in SCOOT has been enhanced to allow for multiple detection points on the approaches to traffic signals, including a cancel detector when the bus passes through the junction. Another advantage is that they can provide information on a bus's adherence to schedule which provides the option of giving different levels of priority to buses, according to how late they are. Differential priority is particularly useful in improving the regularity of high frequency bus services which run on the headway principle.

All these techniques are controlled by user set parameters to prevent the priority causing undesired extra delay to other vehicles. These different techniques are described in more detail in the following sections.

### 6.3.1 Bus detection

The SCOOT kernel software allows for buses to be detected either by selective vehicle detectors, i.e. using bus loops and transponders on buses, or by an automatic vehicle location (AVL) system. Bus loops, or AVL systems where bus detection points can be specified, have an advantage as they can be placed in optimum positions. The best location for detection will usually be a compromise between the need for detection as far upstream as possible and the need for accurate journey time prediction. Prior to recent developments (see cancel detection and Long Journey Time sections below) bus detectors needed to be located downstream of any bus stop, as SCOOT does not attempt to model the time spent at bus stops. Depending on site conditions, a location giving a bus journey time of 10 to 15 seconds to the stop line is recommended.

### 6.3.2 Modelling

Buses are modelled by SCOOT as queuing with other vehicles [58]. This allows buses to be given priority even though other vehicles may delay them. The effect of bus lanes can also be modelled, including those which end before the stop line.

### 6.3.3 Priority

Signal timings are optimised to benefit the buses, by extending a current green signal (an extension) or causing succeeding stages to occur early (a recall) or by stage skipping. Extensions can be awarded centrally, or the signal controller can be programmed to implement extensions locally on street (a local extension). For example, for the three stage junction illustrated in Figure 6.1, if a bus is detected towards the end of Stage "1" (which is a green period on Link "A") it will receive an extension (i.e. Stage 1 is extended) as shown in Figure 6.2. If the bus is detected during a red period it will receive a recall (i.e. stage 2 and stage 3 are shortened so that stage 1 starts earlier) as shown in Figure 6.3. It may also benefit from stage skipping, when stage 3 is one that may be skipped. Figure 6.4 shows the result, where stage 2 has been shortened and stage 3 completely omitted from this cycle.

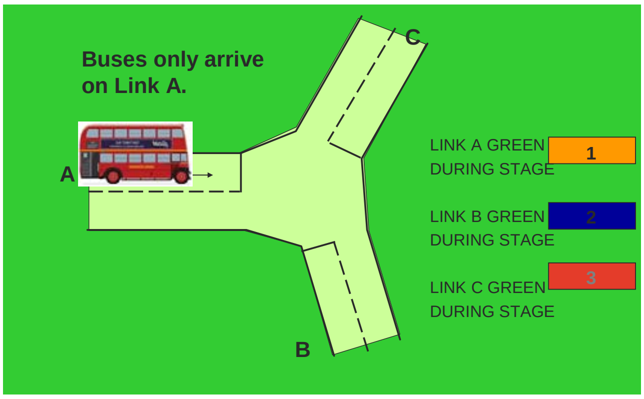



*Figure 6.1: An example of three stage junction*

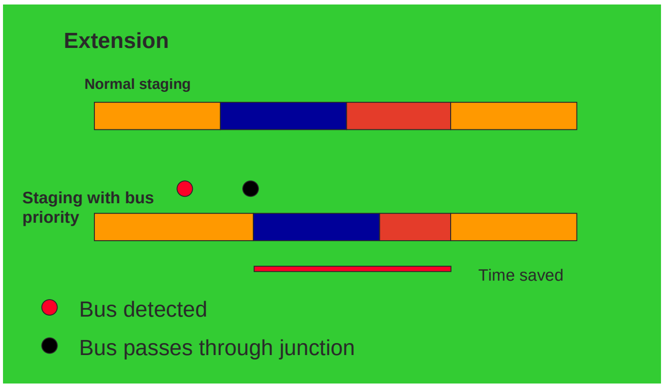



*Figure 6.2: An example of priority extension*

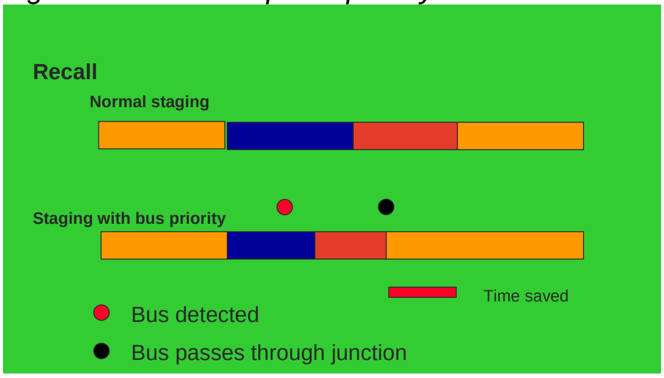



*Figure 6.3: An example of priority recall*

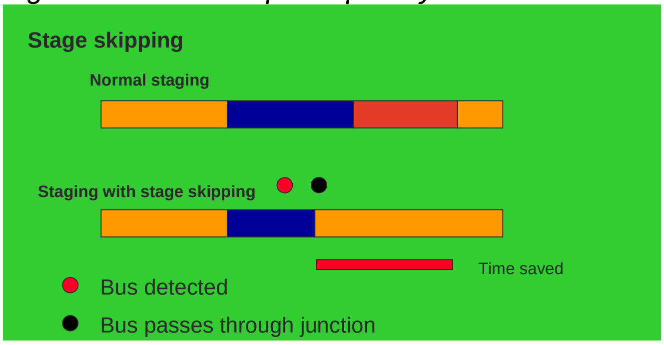



*Figure 6.4: An example of stage skipping*

### 6.3.4 Local extension

Extensions awarded in the local controller on-street can be advantageous, as they eliminate 3 to 5 seconds transmission delay between outstation and instation. (Currently in the London UTC system the transmission lag is ~5 seconds).That allows the system to grant extensions to buses that arrive in the last few seconds of green. The feature is especially important where link lengths are short, or where bus stops are located near to the stop line. SCOOT is still in control as it sends a bit each second to permit local extensions only when the saturation of the junction is sufficiently low. Techniques for programming the signal controller have been developed and implemented in London.

### 6.3.5 Recovery

Once the bus has passed through the signals, a period of recovery occurs to bring the timings back into line with the normal SCOOT optimisation.

### 6.3.6 Stage skipping

In many countries, including the United Kingdom, stage skipping is not common practice and its implications on safety need to be carefully considered. Of particular interest is the potential effect on regular users of a junction who become familiar with the normal operation, particularly when they should receive a green at the next stage change. When a stage is skipped, this normal order is interrupted. Users anticipating their green could be caught out when the bus stage, rather than their expected stage, is given green. No adverse effects were observed in the trials in London where great care was taken with the implementation. It is recommended that the principles used in the trials should be adhered to:

- Main road stages should not be skipped
- Pedestrian stages should not be skipped – a possible exception is where the pedestrian phase being skipped occurs more than once per cycle.

When stage skipping is to be introduced at a junction the stage order should be reviewed, as it may be desirable to re-order the normal stage sequence. This is especially likely at junctions where it is not permitted to skip a particular stage.

The benefits of stage skipping are in addition to those obtained through extensions and recalls. When restrictions are at their minimum level, stage skipping gives good benefits in the range 2.5 to 6 seconds per bus per junction, depending on the junction and flow conditions. Typically where the skipped roads are not too busy, the extra saving in delay, due to stage skipping, averages about 4 seconds per bus. At junctions where the links being skipped are busy, the benefit may be as low as 1 second per bus even if the skipping is uninhibited. This low benefit is due to an increase in queues of general traffic delaying buses.

On average there is a small increase of about 1 second per vehicle in the delay to general traffic when stages are skipped. The main disbenefit is to traffic on the side road being skipped. In some cases of low side road flows, there is an overall benefit to general traffic, since extra green is given to the busier main road. At junctions where the links whose green is skipped are busy, it is necessary to use the stage skipping saturation parameter to avoid large increases in delay to general traffic.

### 6.3.7 Restrictions on priority

One of the main advantages of providing priority through SCOOT is that the extent of priority given to buses can be controlled. Extensions and recalls can be restricted depending on the saturation of the junction as modelled by SCOOT. This is managed by specifying target degrees of saturation for both extensions and recalls. Non-priority stages can be run to these target saturation values, in the case of a priority extension or recall respectively. Normally the target saturation limits are set so that the junction is not allowed to become over saturated, although some degree of over saturation may be allowed to service an extension. This means that bus priority will be most effective at junctions that have spare capacity. Stage skipping has extra controls to limit the frequency of skips in addition to those that prevent skipping of a stage whose degree of saturation is over a user set level.

### 6.3.8 Cancel Detection

In order for SCOOT to provide priority to buses it is necessary for them to be detected some way before the stop line. SCOOT then models the bus travelling down the link and crossing the stop line using the configured journey time from the detector to the stop line, the modelled traffic queues on the link and the colour of the traffic signals. In practice, because of the variability of the actual behaviour of the bus and the queuing traffic, the modelling cannot be assumed to be perfect. When giving priority to buses by providing extensions, therefore it is prudent to allow extra green time to ensure that the bus has crossed the stop line. The amount of this extra green time is determined by the value of the input data parameter BVARY. The setting of the BVARY parameter is currently something of a dilemma. A high value for BVARY would ensure that all buses given an extension would pass through on green but would provide unnecessarily long green times on many occasions resulting in higher delays to traffic on opposing stages. A low value of BVARY may lead to some buses not getting through on the green.

The introduction of a cancel detector should help to overcome this dilemma. The cancel detector will allow an extension to be terminated when a detection is received indicating that the bus has crossed the stop line (in the case of local extensions), or is close to crossing the stop line (in the case of central extensions). It will therefore be possible to set a high value for BVARY which reduces the chance of a bus being given an extension but in fact being stopped by the lights. Once the indication that the bus has reached the cancel detector is received then the stage will be terminated. This will help to reduce the unnecessary extra green time given to buses and so reduce disruption to other traffic.

#### 6.3.9 Long Journey Time

The original SCOOT bus priority logic was based on the assumption of *immediate implementation*, i.e. that for maximum efficiency bus priority should be given as soon as a bus is detected, subject to constraints such as BAUTH (maximum extension allowed) and BESAT (degree of saturation constraint). So if a bus is detected during green, an extension may be granted, which is implemented by extending the current green. Conversely, if a bus is detected during red, a recall is implemented as soon as possible, with stages being shortened and run in succession until a stage is reached which is green to the bus. Then, the stage remains green until the bus has left the link. For shorter journey times, the assumption is valid and results in bus priority being given as soon as possible for a bus. For longer journey times, however, the assumption may not be valid, and can result in very long greens or priority not being given.

The original logic also made the assumption that when a bus is detected in red a recall will always be beneficial. No check was made as to when the green would start, and it is possible that the recall would cause the green to start earlier than is required. The assumption is reasonable for the situation with short journey times, as there will be at most a few seconds of wasted green. For longer journey times, the original logic could result in a large amount of wasted green time.

The SCOOT logic has now been modified so that it will operate satisfactorily with long journey times. This has been accomplished by introducing a system of *delayed implementation*. This means that, if the bus is too far away, it will delay the preparation of the extension or recall until it is at the correct stage in the cycle for the logic to operate correctly, and so that the extension or recall will be implemented when it can be used by the bus, thus avoiding wasted green time. The optimisation is delayed until the commencement of the period when the current logic is designed to operate correctly. This period amounts to a red period and a green period finishing when the bus clears the stop line, i.e. up to about one cycle.

#### 6.3.10 Predictive priority

The development to allow multiple detection points, cancel detectors and long journey times should make it possible to give higher levels of priority to buses. By detecting the bus earlier, possibly before the bus stop, the number of times that an extension can be given will be increased. Earlier detection might also increase the benefit due to a recall. There will be some inefficiency introduced due to the increased variability in journey time which needs to include any bus stop dwell time. As long as the variability in the bus stop dwell time is not too high this should be mitigated by the addition of a second downstream detector and a cancel detector. The method of initial detection of the bus before the bus stop has been termed ‘predictive priority’.

Whilst predictive bus priority has the potential for improving bus priority it will however need to be introduced carefully if delay to non-priority traffic is to be kept in check. It may require that maximum extension (BAUTH) is set lower than is the current practise. Though BAUTH may be set to its maximum value of 30 seconds, in practise it is unlikely that the green period will be extended by more than the value (BJYT – TL) where TL is the transmission lag. Where the bus detector is downstream of the bus stop and BJYT is a low value the length of the extension is small and the disruption to the signal settings and delay to non-priority traffic is low. When an upstream detector is used then the BJYT will be high and there will be the possibility of long extensions. These long greens could potentially be very disruptive and cause a large increase in delay to other traffic on opposing approaches or, in the case of a short downstream link, cause exit blocking. One way of overcoming this would be to set a lower value for BAUTH. An alternative approach in some situations might be to set a lower value for BESAT (the saturation above which an extension would not be permitted).

The benefits of the predictive priority and cancel detection logic in SCOOT have not yet been evaluated. Modelling work by the University of Southampton [61] showed the potential for predictive priority. They concluded that the main advantages of using upstream detection are that:

- central extensions can be used without compromising the benefits achievable
- extensions will tend to dominate over recalls, which implies greater benefits and less disruption to general traffic.

The modelling also showed that the use of an exit detector to cancel priority after the bus has crossed the traffic signal stop line can be effective at reducing delays to traffic on non-priority stages. Exit detection is most useful when it has been necessary to use a high value for the SCOOT parameter *busvary* to account for a high variation in bus journey times between the detection point and the stop line, perhaps due to an intervening bus stop.

The simulation results showed that a secondary detector, just downstream of the bus stop, in addition to a primary bus detector upstream of the bus stop, can increase bus delay savings. The main advantage of the secondary detector is to provide a further green extension for a bus that might otherwise miss the originally awarded extension due to spending a longer than average amount of time at the bus stop. The secondary detector is of most benefit where local extensions can be implemented. Where central extensions are used, the benefit of using a secondary detector is much reduced, however, a small benefit may still be obtained due to the secondary detector being able to provide priority recalls where required.

Bus benefits were maximised by using all three detector positions (upstream, downstream and exit), along with using an increased value for the maximum allowable extension (*bauth*). However, non-priority traffic tended to suffer under this detector arrangement, so for the bus priority scenarios they modelled this was not optimal overall.

The study also showed that bus priority benefits are optimal when the dwell time parameters (mean and standard deviation) used to estimate the bus arrival time at the stop line are accurate. Any estimation error here tended to reduce bus priority benefits. A method for improving bus dwell time estimation by collecting dwell time data using bus detectors placed on either side of the bus stop was suggested. The dwell time data collected could be used for estimation of dwell time parameters offline (using historical data) or online (using instantaneous data). It might also be possible to improve dwell time estimation by detecting and/or estimating numbers of waiting passengers at the bus stop. Evaluation of these new facilities is currently being carried out by TRL under contract to the TfL Bus Priority team using the SCOOT-VISSIM micro-simulation system. Field trials are planned for later in the year.

#### 6.3.11 Differential Priority

The introduction of AVL systems such as iBUS allow a bus's location to be compared against a schedule, and in this way priority can be differentiated by a bus's adherence to schedule. 'Differential priority' refers to providing priority on the basis of criteria other than vehicle class alone, such as adherence to schedule. If a 'degree of lateness factor' can be determined and provided to SCOOT, SCOOT is then able to provide different levels of priority according to how late a bus is. It can also be used to provide different levels of priority to buses on different routes. The advantages of this approach are:

- by providing priority to late buses only and hence to fewer buses, a higher level of priority may be given and the disbenefit to other traffic reduced

- greater improvement in the regularisation of the service and hence the waiting time of passengers will be reduced

SCOOT has facility to specify different priority levels for buses detected on a link according to a priority level associated with the individual vehicle. To enable this, SCOOT must receive a priority level together with other information about the detection of a bus. This priority level (or bus importance factor) is then used to determine what priority can be given for the bus. Bus priority levels are permitted in the range 0 to 6. The mechanism for determining the priority level for a given bus detection is located outside SCOOT. SCOOT receives the priority level, but does not know how this was produced. For an AVL system, the priority level may depend on the behaviour of the bus relative to a headway or timetable. For a selective vehicle detector (SVD) system, there may be no information available about the identity of the bus, so a fixed priority level could be defined for all buses detected on a certain link, or on a specific detector.

SCOOT can provide priority by either extending the current green signal (an extension) or causing succeeding stages to occur early (a recall). The level of priority that can be given is governed by the parameters *bus link extension saturation* and *bus link recall saturation*. These determine the amount by which a stage can be lengthened or shortened to achieve priority. In some situations, as described above it can also skip stages. Priority levels (bus importance factor) are configured by the user, as in the following example in Table 1:

*Table 6.1: An example of priority levels configuration in SCOOT*

| bus importance factor (0-6) | bus link extension saturation (%) | bus link recall saturation (%) | Allow stage skipping |
|---|---|---|---|
| 0 | 0 | 0 | No |
| 1 | 110 | 0 | No |
| 2 | 110 | 95 | No |
| 3 | 130 | 110 | No |
| 4 | 130 | 110 | No |
| 5 | 200 | 130 | No |
| 6 | 200 | 200 | Yes |

This table can be specified separately for each link. A value of 0% is used to indicate that the particular mode, extension or recall, is not permitted for a bus of that priority level. A value of 200% or higher is used to indicate that the extension or recall is unlimited by a target saturation

Extensive simulation testing has been carried out to investigate the effects of providing differential priority. The study considered both bus services that run according to a fixed timetable and bus services that run according to a fixed headway (normally high frequency services). Some of the main findings were:

- For both fixed headway and timetable services, the highest average reductions in journey time are given by strategies that provide priority to all buses. In general, the more buses that received priority the higher the average reduction in journey time.
- For both fixed headway and timetable services, in general, by using differential priority the increase in delay to other vehicles is minimised. The increase in delay to other vehicles is greatest at the highest flow level.
- For fixed headway services there is no improvement to regularisation (standard deviation of headway) for non-differential priority strategies.
- In terms of improvements in regularisation and reduction in passenger wait time the most beneficial strategies are the ones where priority is provided to late buses only.

- For timetable services, non-differential strategies do provide good improvements to regularisation. However, the differential priority strategies provided the highest benefits.

## 6.4 SPRINT: Bus Priority in Fixed Time UTC in London

SPRINT (Selective PRIority Network Technique) gives priority to buses at traffic signals controlled by a fixed time UTC system. The SPRINT system has been developed in London, using similar principles to those described above for SCOOT but within a fixed-time environment [6]. The system gives priority to the buses detected on the approach by extending the current green period (an extension) or recalling the next green period earlier (a recall). Priority can be given to buses in terms of extensions or recalls or both. The extension may be awarded locally or centrally in the UTC computer. Extensions get preference over recalls. The priority implementation is constrained by maximum cycle, maximum move from the base, target degree of saturations and inhibit period. The 'maximum cycle' limits the number of cycles for which SPRINT can run signal timings other than those of the base plan. The 'maximum move' from base is a limit on the move of a stage time from the base value which can be imposed. Target degree of saturation for extension, recall and recovery can be set so that non-priority traffic may not be disadvantaged too much. However, without traffic detection, the real-time impacts of bus priority are not known, so implementing an efficient recovery process is more difficult. Inhibition is imposed to implement a further recall to the same UTC stage for one cycle.

A Field trial was undertaken during a 6 week period between late October and early December 1996 at 8 junctions on the Uxbridge Road in West London, operating under fixed time UTC (at the time). The trial demonstrated that there is potential for small but worthwhile benefits (2 sec/junction) from SPRINT. Furthermore, the trial also highlighted the difficulty in getting statistically significant results (bus delay savings) in the field when there are so many factors affecting the outcome.

## 6.5 Developments of AVL system use in bus priority at traffic signals

To support bus priority in these different traffic signal facilities discussed above, London has continuously updated its bus priority system to keep up with this pace of change in the area of detection/location techniques, traffic signal systems and communication systems. For example, the bus transponder/loop-antenna technology used for Selective Vehicle Detection (SVD) has been gradually replaced in recent years with the use of roadside beacons, using technology derived from the COUNTDOWN system for passenger information at bus stops. The beacon-based AVL system solved some of the drawbacks of loop detectors (e.g. vulnerability of the loop to damage), but is still a rigid system with costly installation, maintenance and repositioning (if needed).

The use of AVL system generated opportunities for implementing flexible bus-specific priority strategies according to performance. One such method is differential priority where different levels of priority can be given to the buses depending on the priority requirements of individual buses. These concepts have been implemented in London, for example, using the architecture illustrated in Figure 6.5.

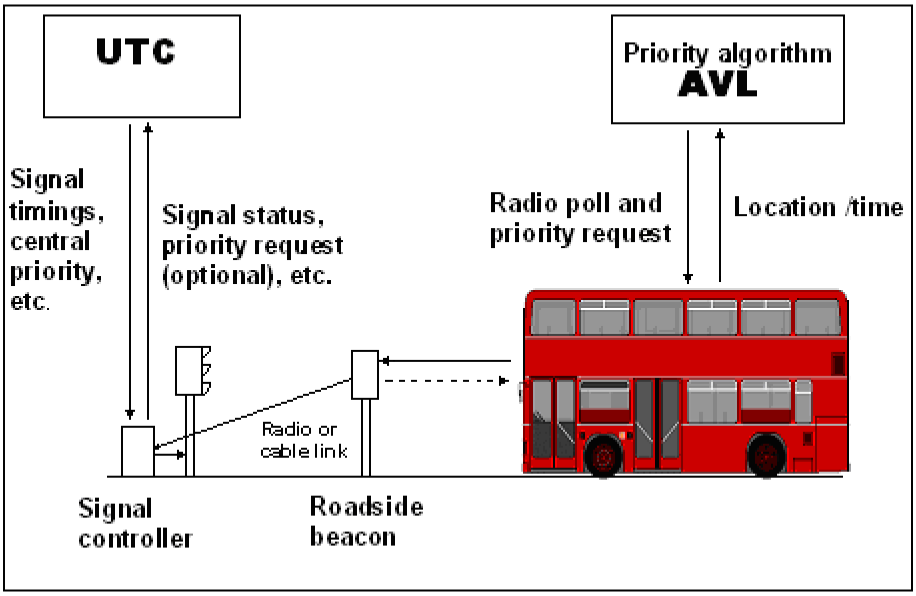


*Figure 6.5: Bus priority architecture used in London*

In this case, priority requirements are determined at the AVL centre and transmitted to each bus through the normal polling cycle. This request is then transmitted from each bus to the downstream traffic signals via a roadside beacon, with the actual priority awarded being controlled by the traffic control system (e.g. SCOOT). Trials have illustrated that worthwhile improvements in regularity can be achieved [59], which translate to reduced excess waiting time for passengers at bus stops. Further advantages of differential priority are that (i) buses selected tend to have higher passenger loadings and (ii) fewer priority calls mean that higher priority levels can be implemented and/or there is less disruption to other traffic.

With the availability more flexible satellite-based AVL system, Transport for London (TfL) has recently procured a modern AVL system for fleet management, passenger information and bus priority. The new system is known as iBUS and is based on GPS and supporting technologies for bus location. The implementation of this system is in progress in London at this stage.

### 6.5.1 iBus system

iBus system (Figure 6.6), currently being implemented in London is one of the world's largest integrated AVL systems. This is a comprehensive AVL system based on GPS and supporting technologies for bus location and General Packet Radio System (GPRS) for data transfer [60]. The £117m project has a plan to roll out the new iBus system to every bus and garage in London - that is over 8,000 buses and 90 garages. iBus keeps track of London's buses to allow bus controllers to better regulate services to make them more reliable. The bus data radio uses GPRS to send the location of the bus about every 30 seconds to a central computer system. This system passes on the bus location information to service controllers who maintain the bus performance.

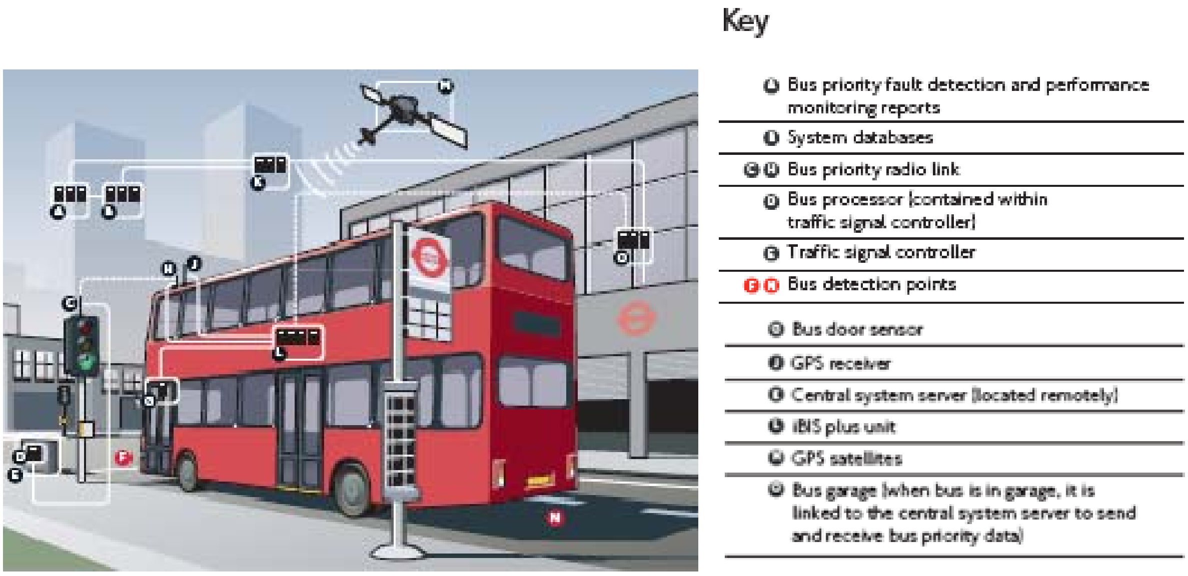



*Figure 6.6: iBus system in London (from [60])*

For bus priority at traffic signals applications, bus detector locations are configured in the on-bus computer of iBus equipped buses. These detectors are also known as “virtual detectors” as they have no physical presence. The predefined virtual detector coordinates are compared with the location of the bus obtained from the on-bus navigation system to trigger a priority request. A simple representation of bus priority at traffic signals using iBUS is given in Figure 6.7.

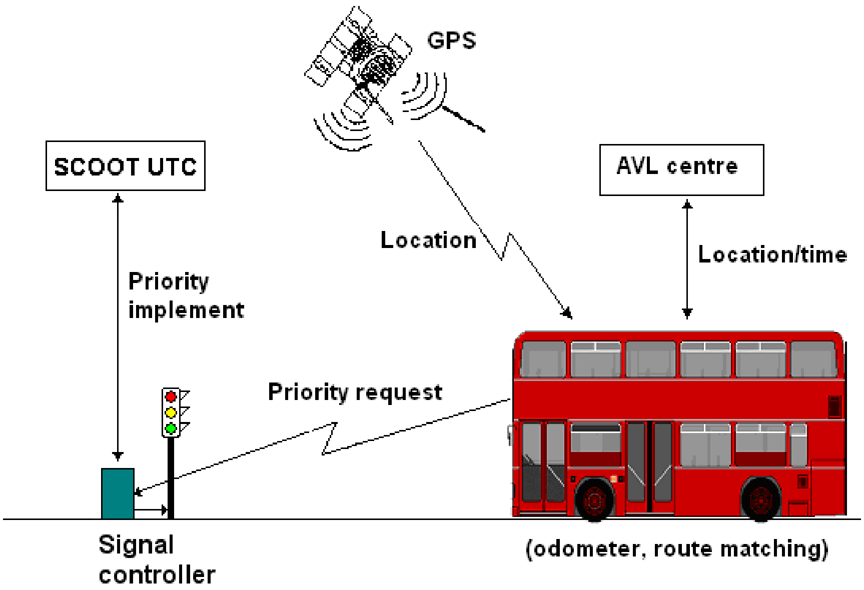



*Figure 6.7: Simple representation of bus priority at traffic signals using iBus*

In this priority architecture, each bus receives its location every second from its onboard GPS unit and is continuously monitored by the control centre. The monitoring is done by polling buses in 30-60 second intervals in addition to the information of arrival time at a bus stop that each bus sends when departing from a bus stop. The control centre uses the location information to update locations of the buses in its system and to calculate the headway and the headway deviation of the bus (that may be used to give differential priority to the buses). When a bus arrives near a traffic signal, the bus is detected at a predefined virtual detector location on the approach and the priority is triggered.

Once the signal controller receives the request for the bus priority, the priority is implemented mainly in two ways: extensions and recalls (within the constraint of the amount of priority time available). 'Extensions' is the method where the present green time is extended, if it is expected that the bus detected would otherwise just miss the present green period. 'Recalls' is the method where the green time is recalled more quickly if the bus is detected in the red period and is expected to arrive at the stop line before the start of the next green period. Facilities to compensate traffic on non-priority stages are also usually provided according to the type of signal control (e.g. SCOOT).

One of the main advantages of this system is that it eliminates the need of on-street hardware for detecting buses and requesting priority. Hence the incremental costs of installing bus priority at signals and the placing of additional detection points are much lower. The system also provides facilities to allocate up to four detection points to each bus movement at an individual junction. This provision of more than one virtual detection points opens up the opportunity for detecting buses for different purposes. For example, additional detection can be used as an extra detector (called a secondary detector here) at the downstream of the normal detector (called a detector here) to review the priority triggered by the primary detector. This will help slower buses to obtain an additional extension, which may not otherwise reach the stop line before the end of present green time. This is particularly the case when buses are detected upstream of bus stop where dwell time can vary considerably, affecting the bus journey time to the stop line. Furthermore, the extra detector can be used as a cancel detector placed near the stop line to curtail (cancel) a priority action once the bus has passed through the signals. Timely cancellation of bus priority removes the safety margin currently in use to protect buses from journey time variations. The cancellation of such time reduces the extra delay to side road traffic and improves junction efficiency. In addition, a cancel detector can also be used to ensure that more buses will clear the junction in the extended green period (by increasing the safety margin) than previously, where some slower buses may have missed the green.

Earlier research [61] showed that more bus priority benefits can be obtained when both of these detection options are implemented in addition to the normal detector. The simulation results showed that this arrangement is particularly beneficial where the bus stop is close to the traffic signals (<50m), where the bus priority benefits from detection downstream of the stop are likely to be low. In such situations, a secondary detector downstream of the bus stop updates the priority requirement once the bus has left the stop, and an exit detector close to the stop line terminates priority when it has achieved its purpose. A typical layout of these various detectors is shown in Figure 6.8.

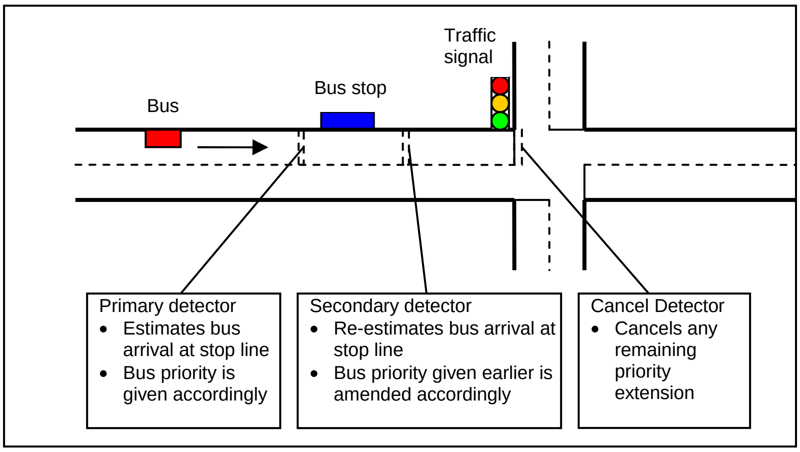



*Figure 6.8: A typical layout of detectors for multiple detection*

# 7. Comparative analysis and Lessons learned

## 7.1 Comparative analysis

The review has shown that bus priority at traffic signals is implemented widely around the world, in small towns as well as big metropolitan cities. Table 7.1 illustrates this variability of implementation from the reviews and questionnaire completions reviewed to date. It should be noted here that all the tables given in this section are based mainly on the literature review, and so individual data items are relevant to the year of their publication.

*Table 7.1: Examples of cities and bus priority at traffic signals facility*

| City | Country | Population | No. of signal junctions providing bus priority | No. of buses equipped for bus priority |
|---|---|---|---|---|
| Aalborg | Denmark | 194149 | 51 | 249 |
| Brighton | UK | 248000 | 8 | |
| Cardiff | UK | 315000 | 46 | 191 |
| Genoa | Italy | 650000 | 84 | 500 |
| Geneva | Switzerland | 187000 | 263 | 420 |
| Glasgow | UK | 600000 | 241 | 500 |
| London | UK | 7556900 | 3200 | 8000 |
| Malmo | Sweden | 276000 | 42 | |
| Prague | Czech republic | 1225000 | 65 | 352 |
| Stuttgart | Germany | 550000 | 34 | |
| Tallinn | Estonia | 400000 | 30 | 169 |
| Toulouse | France | 400000 | | 160 |
| Vienna | Austria | 1600000 | 185 | |
| York | UK | 193000 | 25 | |
| Zurich | Switzerland | 550000 | 60 | |
| Auckland | New Zealand | 438100 | 174 | 734 |
| Brisbane | Australia | 1600000 | 11 | 205 |
| Portland | USA | 503000 | 250 | 650 |
| King County | USA | 1800000 | 28 | 1400 |
| Los Angeles | USA | 3500000 | 654 | 283 |

Table 7.1 shows that London's bus priority at traffic signals system is the biggest among the cities reviewed in this report. Among these cities, provision of priority facilities ranged from a few isolated junctions to many coordinated junctions controlled under various urban traffic control (UTC) systems such as SCOOT, UTOPIA, SCATS, etc. The systems also varied in terms of the technology used and the priority architectures used. The main characteristics of various these systems are given in the tables below.

*Table 7.2: Detection technologies used in different cities*

| City | Bus detection technology |
|---|---|
| Aalborg | GPS supplemented by Odometer |
| Brighton | GPS |
| Cardiff | GPS |
| Genoa | GPS |
| Geneva | GPS supplemented by Odometer |
| Glasgow | GPS |
| Gothenburg | Loop and transponder |
| Helsinki | GPS |
| London | GPS supplemented by Odometer and map matching |
| Malmo | GPS |
| Nantes | Loop and transponder |
| Prague | Beacon |
| Southampton | Beacon |
| Stockholm | GPS |
| Stuttgart | Beacon and GPS |
| Suceava | GPS |
| Tallinn | Not known |
| Toulouse | GPS supplemented by Odometer |
| Turin | Beacon |
| York | GPS |
| Zurich | Loop and transponder |
| Japan | Infra-red beacon |
| Auckland | GPS |
| Brisbane | Loop |
| Sydney | GPS |
| Portland | Beacon (Opticom) |
| King County | RF tags |
| Los Angeles | Loop and transponder |

Table 7.2 shows that GPS detection is used for bus priority purposes in most cities, particularly in European countries. Beacon based detection is still popular in some cities (mainly in Japan and USA). An earlier study found that approximately two-thirds of US cities use optical beacon detection [55].

*Table 7.3: Priority request communication*

| City | Priority request communication |
|---|---|
| Aalborg | Centralised |
| Cardiff | DeCentralised |
| Genoa | Decentralised |
| Geneva | Decentralised |
| Glasgow | Centralised |
| Helsinki | Decentralised |
| London | Decentralised |
| Malmo | Decentralised |
| Nantes | Decentralised |
| Prague | Decentralised |
| Southampton | Centralised |
| Stuttgart | Decentralised |
| Toulouse | Centralised |
| Turin | Centralised |
| Vienna | Decentralised |
| York | Decentralised |
| Zurich | Decentralised |
| Japan | Decentralised |
| Auckland | Centralised |
| Brisbane | Decentralised |
| Portland | Decentralised |
| King County | Decentralised |
| Los Angeles | Decentralised |

Table 7.3 shows that in most of the cities, the priority request is communicated directly from each bus to the traffic signals (decentralised method) although there are a number of cities which have adopted a centralised architecture.

*Table 7.4: Examples of traffic signal control systems used*

| City | Traffic signal control systems with bus priority facility |
|---|---|
| Brighton | SCOOT UTC |
| Cardiff | SCOOT UTC |
| Genoa | SIGMA UTC |
| Glasgow | SCOOT UTC |
| Gothenburg | SPOT UTC |
| London | SCOOT UTC, VA |
| Southampton | SCOOT UTC |
| Prague | MOTION |
| Stockholm | UTOPIA/SPOT UTC |
| Toulouse | CAPITOUL UTC |
| Turin | UTOPIA/SPOT UTC |
| York | VA, Fixed Time UTC |
| Japan | Universal Traffic Management Systems (UTMS) |
| Brisbane | Brisbane’s Linked Intersection Signal System (BLISS) |
| Sydney | Sydney Coordinated Adaptive Traffic System (SCATS) |

*Table 7.4 gives examples of the variety of traffic control systems used in different cities providing bus priority at traffic signals. Within Europe, SCOOT is widespread in the UK and UTOPIA/SPOT is used in a number of countries, particularly Italy and Sweden. Many other European countries use their nationality preferred traffic control systems, with functionality added for bus priority.*

*Table 7.5: Reported benefits from bus priority at traffic signals*

| City | Priority benefits and impacts | | | | |
|---|---|---|---|---|---|
| | **Delay savings** | **Travel time** | **Variability** | **Patronage** | **General traffic** |
| Aalborg | 5.8 sec/bus/jun | 4% reduction in average | | | |
| Brighton | | Reduced | Reduced | | |
| Cardiff | | 3-4% reduction | Improved schedule adherence | | 1-2% increase |
| Genoa | | 7-10% reduction | | | |
| Glasgow | | | Reduced considerably | Increased | |
| Gothenburg | | 13-15% decrease | | | 5-10% savings |
| Helsinki | | 11% reduction | | 11% increase | |
| London | 9 sec/bus/jun at isolated and 3-5 sec/bus/jun at SCOOT junctions | | | | |
| Malmo | | | Headway reduced from 10 min to 7.5 min. | | |
| Prague | | 2% reduction | | | |
| Southampton | 9.5 sec/jun | | | | Increased 3.8 sec/jun |
| Stockholm | | 10% savings | | | |
| Stuttgart | | Speed increased from 9 to 10.1 miles/hr | | 10% increase | |
| Suceava | | | | 10-12% increase | |
| Tallinn | | Speed increase by 2km/hr | | | |
| Toulouse | | 5-24% decrease | | | |
| Turin | | 12% reduction | | | |
| Zurich | | | | 42% increase | |
| Japan | | 5% reduction | | | |
| Auckland | 11 sec/bus/jun | | | | |
| Sydney | | up to 21% reduction | Up to 49% reduction | | |
| Portland | | | Improved reliability | | Very little effect |
| King County | 25-34% | reduced by 5.5-8% | Reduced by 35-40% | | Minimal effect |
| Los Angeles | | reduced by 6-8% | | Increased by 1-13% | Typically 1 sec/veh/jun |

Table 7.5 summarises the reported benefits of bus priority for a range of cities reviewed. This shows some variation in the criteria used to report benefits and also some degree of variability in the levels of benefit reported between different cities. It should be noted that these benefits are often affected by the policy adopted rather than the capability of the system. For example, for

SCOOT in London, the policy is to provide bus priority with minimal impact on other traffic. Given the high levels of bus flow and congestion in London, this means that priority has had to be constrained.

## 7.2 Lessons learned

Based on the review and the comparative analysis of various bus priority projects, following lessons could be leaned:

*Philosophy:*
Transport is about the movement of people and goods, not just the movement of vehicles. Optimising the movement of people in cities requires systems which attempt to minimise the delay to people. Most of the 'Standard' traffic control systems seek to minimise vehicle delays. This is the wrong target…but, rather than a formal 'people movement' optimisation, most systems have developed pragmatically in this direction by incorporating bus priority.

*Bus priority measures:*
Bus priority can be provided through physical segregation and this is usually the best method for reducing the effects of traffic congestion, provided bus lanes (etc) can be provided as continuously as possible. This leaves delay caused by the cyclic nature of traffic signals (e.g. delays due to the red signal). With traffic signals increasing in numbers in most cities, and road space often restricted (especially in urban areas), then delays to buses due to traffic signals can accumulate to significant quantities along a bus route.

*Bus priority at traffic signals:*
Priority can be given to the buses at traffic signals by providing more the green time for the link with higher bus flow without knowing the presence of a bus, also known as 'passive' bus priority. However, more efficient method is 'Active' bus priority at traffic signals, where a bus approaching each traffic signal is given priority. This form of priority is implemented in small towns to large metropolitan cities across the world. Priority can be given to the buses at a number of co-ordinated signals as well as at a few isolated junctions. The signal measures can also be combined with physical measures to reduce effect of congestion. Queue relocation and pre-signals techniques are used in cities including London and Auckland.

*Bus priority architectures:*
Bus priority at traffic signals can be achieved with an increasingly large range of system architectures often depending on the types of traffic control and bus operation systems implemented and their level of integration. There is no 'best' system architecture to be recommended. The choice for any individual city will depend upon a number of factors, including: the infrastructure already in place; the resources for installing and maintaining the system; and the level of functionality and, thereby, complexity of the system desired. Within this, the most common method of requesting bus priority is decentralised communication method where a bus directly communicated to the traffic signal (with or without the input from AVL centre) (see Table 7.2).

*Detection/location technologies:*
Various detection/location technologies are implemented for bus priority at traffic signals (see Table 7.1). The technologies vary from loop and transponder detection (Brisbane) to GPS detection (London). Most large bus fleets in Europe are being equipped with GPS-based Automatic Vehicle Location (AVL), often primarily for fleet management and real-time passenger information systems. With the right specification for location accuracy, this can also be used for bus priority at traffic signals. This includes providing advanced method such as 'differential' priority to improve bus service regularity/punctuality, should that be necessary.

*Bus priority strategies:*

With the growing use of AVL (Automatic Vehicle Location) systems, bus priority could be given to all buses or some of the buses depending on the aim of the scheme. If the aim is to reduce overall bus delay savings, priority to all buses is the best. However, many of the systems reviewed seem to be giving priority to late buses only. Such method is better in improving punctuality/regularity, however, not well as 'priority to all buses' when considering travel time savings.

*Bus priority benefits:*
Reported priority benefits from bus priority at traffic signals vary in terms of the measure and the value (see Table 7.4). In terms of delay savings, typical values are between 3 and 10 secs/bus/junction depending on the application and other traffic characteristics. For example, without the co-ordination requirement, benefits from priority at isolated junctions tend to be more than that from co-ordinated junctions. The evidence from across Europe is that bus priority at traffic signals can provide worthwhile benefits in bus delay savings, with systems typically repaying their investment in 3-16 months. This can be achieved with insignificant disbenefits to non-priority traffic if the right control strategies are used. Alternatively strategies can he used to provide higher benefits to buses, accepting also higher disbenefits to other traffic in the hope that some modal change will occur.

*Implementation issue:*
Where buses are mixed with general traffic bus priority at traffic signals has to be applied carefully, not the least because buses are often mixed in various traffic streams which could suffer if strong, uncompensated priority is given to another stream. This is particularly the case where there are high bus flows at busy junctions. This can reduce the benefits, as in London, where consideration of all traffic has always been important. In this regard, traffic responsive UTC systems can be particularly beneficial for control because they have a real-time estimate of the traffic state, which may/should influence the amount of priority given. The systems may also be able to re-synchronise/recover in an optimum way following a bus priority activity, in a way that fixed time systems cannot.

*Research and developments:*
In continuous advancement to the field of bus priority at traffic signals, London has currently implementing GPS based iBus system. The flexibility of the system is expected to enable deployment of more advanced priority methods using techniques currently being researched including: long journey time, predictive priority, differential priority. Such extensive bus priority research and developments literature has not been found for other cities.

*Institutional issue:*
Where bus operations are regulated, as in London, it is easier to require bus priority implementation as a component of the Quality of Service. This seems to be more difficult with de-regulated/privatised operations, where the instant financial return on investment in ITS applications is not so clear/ attractive.

# 8. Summary and future research

## 8.1 Summary

Buses are the predominant form of public transport in most towns and cities in many countries, including the U.K. With their large carrying capacity, buses make effective use of limited road space, and can therefore make a substantial contribution to reducing traffic congestion. However, buses themselves are often affected by congestion, leading to a decrease in speed and an increase in bus travel time variability and service irregularity. Giving priority to buses plays an important role to protect bus services from the effects of traffic congestion and to improve their speed and reliability.

A range of priority measures are adopted in many cities, including segregated facilities such as bus lanes and busways and priority facilities at traffic signals. Bus priority at traffic signals is the most relevant where opportunities for segregated systems are limited and/or where numerous traffic signals exist. With significant advances in detection, communication and data processing technologies in recent years, many different options are now available for bus priority at traffic signals.

This review has shown that the concept of bus priority at traffic signals is adopted across the world from small towns to big cities. The deployment of bus priority systems has been found to be very dependent on the existing infrastructure particularly the type of traffic signal control system and the Organisational/Institutional Structure in the city within which traffic signals and buses are operated. As a result, a wide variation in priority architectures, technologies used and priority strategies employed have been found in the review. The benefits from bus priority also varied from place to place as a result of this situation. Nevertheless, all cities undertaking an economic appraisal of their bus priority systems have reported very good economic returns, with systems typically paying for themselves within 3-16 months, from the passenger and operator benefits measured.

## 8.2 Recommendations for future research

The timing of this report has necessitated that the current findings and recommendations are based mainly on the literature review undertaken along with limited information obtained from the questionnaires distributed. On this basis, the following further recommendations are presented for consideration.

At present, the bus priority at traffic signals is mainly aimed at reducing bus delays as a result of the traffic signal timings. Ideally the combination of segregated and priority at traffic signal should give buses a relatively clear run along their route. With very few exceptions, this is not widely the case, due to varying degrees of traffic congestion. The normal operation of bus priority at traffic signals does not solve the congestion problem, which is often more severe for buses than the delays caused by signal aspects. Solving the congestion problem requires other measures, such as more bus-only roads/lanes, demand management, and/or strategies for **congestion management for buses**, requiring integrated segregation and real-time UTC strategies. This is recommended as a **prime area for further research**.

As pointed out earlier, the bus performance criteria implemented influences overall bus operations. For example, minimising bus journey times suggests the need for bus priority to all buses at all junctions, whereas optimising regularity implies the need for different priority actions for buses depending on their situation. Further research is therefore recommended to find out **current practices around the world and the rationale behind the chosen bus performance criteria**. This should also include the influence of the criteria on the implementation of bus priority system.

There is some evidence that the most applicable form of bus priority in a town/city could vary according to the city population, size of the bus fleet, numbers and characteristics of traffic signal controlled junctions. An analysis of these variables is recommended in Stage 2, with the aim of developing guidelines for architectures and systems relating to city size. This analysis would benefit from the largest possible sample size of example, which should be achieved following the final returns of completed questionnaires.

It has been shown that investment in bus priority at traffic signals varies substantially between different cities and regions in the world. Greater understanding of the reasons for this variability, and barriers to deployment would be beneficial, also to identify examples of good practice. Work in Stage 2 is therefore recommended to **identify organisational/institutional issues which affect deployment**, including the effects of different transport policies.

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# Appendix – A: Bus priority questionnaire

## UITP study of bus priority using traffic signals

**Thank you for agreeing to take part in this study**.

This questionnaire is in support of a UITP Working Group looking into the latest developments in the use of traffic signals for bus priority. The Group is led by Transport for London (TfL) with the help of the Transportation Research Group (TRG) at the University of Southampton, the Transport Research Laboratory (TRL) and other Working Group members. The main aim of the work is to identify best practice for implementing bus priority using traffic signals and opportunities for new applications; The experience of cities that have implemented bus priority using traffic signals is most important. Information is being gathered through this questionnaire survey and a review of available published materials. Case studies of the cities providing information of their systems or making published material available will feature in the final report.

If you have any questions regarding the questionnaire or the study in general, please contact Dr. Nick Hounsell (nbh@soton.ac.uk). **A response by March 2nd would be much appreciated.**

| | |
|---|---|
| Date (dd/mm/yyyy): | / /2009 |
| Organisation's Name:<br>Address: | |
| Contact person's Name<br>Position:<br>Phone:<br>Email: | |

## Section 1: Background

**City** (Country, approx. population)

**General traffic**
Please describe the traffic situation (average speeds in the city, congestion, etc.). A web-site reference would be most helpful.

**Public transport**
Please summarise public transport (PT) provision (rail, metro, LRT, bus, etc. – with lengths of each system if possible). How is PT controlled and operated and by whom? A web-site reference would be most helpful.

## Section 2: Bus operation

**Ownership:**
(e.g. Private/Public/Regulated/deregulated)

**Type of operation**
No. of high frequency routes (5 or more buses per hour)

No. of low frequency routes (less than 5 buses per hour)

**Physical bus priority facilities** (Approx. lengths (or numbers) of other bus priority facilities)

| Bus lane | Busways | Bus only streets | Others (please specify) |
|---|---|---|---|
| | | | |

## Section 3: junctions controlled by traffic signals

| | Fixed time Isolated | Vehicle actuated Isolated | Fixed time Co-ordinated | Traffic responsive Co-ordinated |
|---|---|---|---|---|
| Total nos. of junctions | | | | |
| System | | | | |
| Supplier | | | | |
| Nos. with bus priority facility | | | | |

*(NB: System - e.g. SCOOT, SPOT, etc.; Supplier - e.g. Siemens, Peek, etc.)*

## Section 4: Traffic signals with bus priority

**4.1 Implementation details** (Please summarise when bus priority was implemented and the scale of current provision – numbers of buses, bus routes and signals with bus priority. An indication of typical costs would also be useful

**4.2 Bus priority strategy** (Please tick **all** priority strategies used)

- ☐ Priority to all buses
- ☐ Priority to late buses only (or buses with higher headway than scheduled)
- ☐ Other condition (different priority levels according to another criteria (please specify)
- ☐ Others (please specify)

**4.3 Bus location/detection technology used** (Please tick **all** detection technology)

| Loop | Beacon | GPS | 'Opticom' | Others (please specify) |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ ………………………… |

**4.4 Priority methods** (Please tick **all** the priority methods used)

- ☐ Green extension
- ☐ Green recall
- ☐ 'Rolling horizon'
- ☐ Stage re-ordering
- ☐ Stage insertion/skipping
- ☐ Compensation and recovery
- ☐ Others (please specify)

**4.5 Communication link** (Please tick **only one** method use for priority **request)**

- ☐ Bus to traffic signals
- ☐ Bus AVL centre to UTC centre
- ☐ Bus AVL centre to bus and then bus to traffic signals
- ☐ Others (please specify)

**4.6 Communication technology** (Please tick/cross **all** communication technologies used)

| | Short range radio | Long range mobile radio | GPRS | Others (please specify) |
|---|---|---|---|---|
| Link (From & To) (e.g. bus to signal) | ☐ | ☐ | ☐ | ☐ |

**4.7 Location where bus priority decision is made**

| AVL centre | On-bus computer | At traffic signals | At UTC Centre | Other (please specify) |
|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ ……………… |

**4.8 Other priority facilities using traffic signals** (e.g. Emergency vehicle pre-emption, queue relocation, congestion management for buses, tram priority etc.)

**4. 9 System monitoring** (systems available to monitor bus priority operations/impacts?)

UNIVERSITY OF Southampton
School of Civil Engineering and the Environment

## Section 5: Benefits/results

**5.1 Signal controlled junctions with bus priority**

| | |
|---|---|
| Benefits to buses. e.g.<br>- delay savings<br>- journey time savings<br>- punctuality/regularity | |
| Impacts on other traffic | |
| Impacts on other road users, if known | |
| Overall public response, if known | |

**5.2 Publications available** (Please attach publications (reports, papers) if electronic version available, or advise of web-site)

**5.3 Lessons learned** (What do you think are the main lessons learned from the implementation of bus priority using traffic signals in your city?)

**5.4 Future plans** (Please comment on any future plans for upgrading/implementing bus priority facilities)

**5.5 Any other comments**

**Thank you very much for taking part!**

Please email this completed form to me (nbh@soton.ac.uk) by **2nd March 2009.**