UTMC01

**Selected Vehicle Priority in the UTMC Environment (UTMC01)**
**(http://www.its.leeds.ac.uk/projects/spruce/)**

# WP2.1: Literature Review

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# Executive Summary

This review is one of the first outputs of the Department of Environment, Transport and the Regions (DETR) funded project UTMC-01 - Selected Vehicle Priority in the Urban Environment (SPRUCE). The purpose of the review is to establish the current state of the art in selective vehicle priority through a literature search and consultation with researchers and developers. The scope of the review is wide ranging and considers developments across the full range of applications for selective vehicle priority within urban traffic signal networks such as:

- bus priority;
- LRT priority;
- fire appliances;
- police vehicles; and
- ambulances.

# 1. Introduction

This review examines the core principles on which alternative systems of priority are based and considers how they influence the performance of the strategy in terms of the benefit afforded to priority vehicles and the disbenefit to other users.

Considerable work has already been carried out in the development of bus and tram priority within a variety of fixed time and dynamic urban traffic control strategies, for example:

- SPRINT (fixed time);
- SCOOT v3.1;
- MOVA (isolated intersection control)
- BLISS;
- BALANCE; and
- SPOT / UTOPIA

Within the UK, most recent experience has been obtained with SCOOT which grants priority to buses through green time extensions and stage recalls, coupled with a variety of possible compensation strategies. Priority is considered for an individual node only.

Priority to emergency vehicles is normally provided in UK systems through simple fixed green wave progression initiated manually from the fire station.

The research has examined the full range of systems developed within the UK and overseas, considering the impact of their different characteristics such as:

- the base UTC system which forms the vehicle for providing priority;
- rules applied to the application of extension, recalls and compensation mechanisms;
- the time horizon considered for modelling and granting priority; and
- effect of data transmission delays.

The review has sought out studies of the effect of traffic variables on the performance of priority systems such as congestion and the frequency of priority requests.

Experience of priority systems that are more advanced than those currently employed generally in the UK have been sought. Examples are priority systems that can discriminate between vehicle characteristics using data transmitted from “intelligent” in vehicle units. Greater sophistication has also been applied in some fire station green wave systems employing selective vehicle detection on the fire appliances.

The research review has also sought out developments that address the perceived demands of the UK market, which have been revealed in the parallel work package, WP3.0, the assessment of user needs. A particular area of interest has been currently unsatisfied areas of the market such as fixed time UTC systems.

Searches of relevant published literature have been made using on-line facilities linked to national and international databases, and UK library catalogues.

The review builds on previous work done in this area such as the ERTICO Collaborative Study on Public Transport Priority at Traffic Signals (Hounsell et al, 1996)

| KEYWORDS \ DATABASE | Transport CD-ROM | BIDS ISI | BIDS C/PO | UNCOVER |
|---|---|---|---|---|
| Selected Vehicle | 35 | - | 8 | 14 |
| Bus Priority | 264 | 7 | 32 | 9 |
| Emergency Vehicle Priority | 27 | - | - | - |
| Emergency Priority | 1 | - | - | - |
| LRT Priority | 7 | - | 2 | - |
| Tram Priority | 5 | - | - | - |
| Priority Strategies | 8 | - | 5 | - |
| Bus Priority Strategies | 1 | - | 2 | - |
| Transit System Priority | 1 | - | - | 1 |
| Public Priority | 3 | - | - | - |
| Selective Vehicle | 7 | - | - | - |
| Selective Vehicle Priority | 12 | - | - | - |
| SVD | 1 | - | - | - |
| Green Wave | 14 | - | - | - |
| Blue Wave | 1 | - | - | - |
| Public Transport Priority | 49 | - | - | - |
| Transit Vehicle Priority | 25 | - | - | - |

**Table 1: Results of keyword searches**

Use has been made of the TRANSPORT CD-ROM, the BIDS database and other bibliographic search tools which are available at ITS. Search parameters were defined to ensure that all relevant material has been uncovered, and to restrict the volume of material to be reviewed for manageable proportions. Abstracts of relevant publications have been examined and full copies of the most useful papers obtained and studied in detail. Table 1 gives the number of abstracts uncovered in each of the databases used for a variety of keywords.

Once the most important papers had been uncovered an attempt was made to obtain sufficient information about each scheme to enable the scheme architecture to be described in terms of the Logical Reference Model adopted by the UTMC programme (See Appendix A).

# 2. Selective Vehicle Priority Systems

## *2.1 Introduction*

The selective priority systems revealed by the literature search have been categorised under three headings. These are:

- Bus priority, where priority is only given to buses, usually travelling along with other traffic.
- Tram/trolley bus/guided bus priority, where priority is given to public transport vehicles which are constrained in their movements by tracks, overhead wires or a guideway and which often move along segregated carriageways. Sometimes these priority schemes are also integrated with bus priority schemes.
- Emergency vehicle priority, where priority is given to emergency vehicles when they attend emergencies. This is sometimes an adaption of a public transport priority scheme, with the emergency vehicle receiving a higher level of priority.

A specialist application which gives priority to slow moving convoys of vehicles has also been found in operation in Brisbane, Australia.

For each priority scheme reported on in this chapter, there is an Introduction section giving a brief description of the scheme. There is then a section describing how the priority is given by the signal control strategy. This is followed by a section describing the vehicle detection methods used by the scheme. Then there is a section on any benefits reported for the scheme. Finally, *where sufficient information is available*, there is also a table which maps the scheme architecture on to the Logical Reference Model adopted by the UTMC programme (See Appendix A).

## *2.2 Bus Priority*

### *2.2.1 Aalborg - Denmark*

#### *2.2.1.1 Introduction*

A bus priority system has recently been introduced in Aalborg in Denmark (Nør and Strand, 1998) with the aim of promoting the use of public transport and encouraging a transfer of motorists from private to public transport. Two bus routes have been given priority. Fifteen buses and twenty-seven sets of traffic signals have been equipped with the priority system.

#### *2.2.1.2 Control Strategy Description*

The control strategy is based around points along the bus route known as entry lines and report lines. As the bus moves along the route its position is continuously monitored. When the bus passes an point known as an entry line it transmits a priority request to the Traffic Priority Controller (TPC) at the downstream junction. This priority request is cancelled when the bus passes another point known as a report line. The position of the entry lines depends on how fast the bus normally drives on the road section in question. It is typically in the range of 50 to 250 metres from the traffic signal. The report line is usually placed at the traffic signal or immediately after it.

#### *2.2.1.3 Detection Methods*

The bus detection system is based around a Global Positioning System (GPS). Differential GPS is used to ensure high accuracy of the bus positions, with the differential reference station being installed at the garage of the bus operator. Each bus is equipped with a differential GPS unit which determines its location after combining signals received from the GPS satellites and the differential reference station. (See Section 3.4.2) The bus also has a tachometer which is used to help increase the precision in the determination of the position of the bus. It is claimed that by using the tachometer the error in the buses position can be less than 10 cm in the vicinity of the entry lines. The positioning system is combined with a computer and a data radio in a single unit called a Bus Unibox. Before a bus starts going along its route, the driver inputs details of the trip to the bus computer via a console in his cab. The bus computer contains information about each trip that the bus can make. This includes the bus route and the report lines and entry lines used to give the bus priority. This information can be downloaded to the bus via a radio link from a Central Unit in the bus garage. Report lines are used to define locations where the bus has to send a priority request to the signal controller. The bus computer uses the information from the position location system to discover when the bus has crossed an entry line. It then sends a priority request to a unit known as the Traffic Priority Controller (TPC) which is located alongside the local signal controller. The priority request is sent by radio to a base station antenna at the edge of Aalborg. From there it is passed by a serial line to the Radio Network Controller (RNC) at the bus garage. The priority request is then sent back to the base station and transmitted to the TPC. The TPC contains a data radio a CPU and I/O ports. It receives priority requests from the base station via the data radio and passes them on to the signal controller. It also logs the priority requests, which can be downloaded via the data radio and the RNC to the Central Unit at the bus garage.

#### *2.2.1.4 Benefits*

It is reported that bus journey times on the two equipped bus routes have been reduced. It has been possible to reduce the driving time in the timetables accordingly. Buses now also depart and arrive more punctually. A full assessment of the system should be completed by the end of 1998.

#### *2.2.1.5 Logical Reference Model Description*

| Node Type | Name | Sends to Node |
|---|---|---|
| A | None | |
| B1 | Base Station | B2<br>C2<br>E |
| B2 | Radio Network Controller | B1<br>B3 |
| B3 | Central Unit | B2 |
| C1 | Local Controller | C2<br>D |
| C2 | TPC | C1<br>B1 |
| D | Traffic Signals | |
| E | Bus Unibox | B1 |

### *2.2.2 BLISS / RAPID - Brisbane*

#### *2.2.2.1 Introduction*

Brisbane City Council has developed (Petersen, 1994, Miorandi and Campbell, 1997) an active bus priority system, now called the RAPID bus priority system, based around its own Urban Traffic and Control system known as BLISS (Brisbane Linked Intersection Signal System). The bus priority system has been giving priority at 14 sets of traffic signals in a trial of the system on Waterworks Road in Brisbane since it was installed in November 1996. The trial has been so successful that the system is being rolled out across the rest of the city. The system is also installed in Auckland, New Zealand.

BLISS is a PC based UTC system. The road network is divided up into regions, each under the control of a single PC. Each PC can co-ordinate up to 63 sets of traffic signals and is located near the intersections to reduce communications costs. The whole system is supervised by a system master, which is also a PC, providing effective control over all the signals within a city. Brisbane currently has 650 signalised intersections under the control of a single system master PC and 11 regional master PCs. The multi-user, multi-tasking UNIX operating system is used throughout, with the code being written in C. Each of the regional PCs communicates with local co-ordination modules via a modem and from there to the local intersection controllers. The local co-ordination modules talk to the intersection controllers using the SCATS protocol, as used by all intersection controllers manufactured for use in Australia, but other controllers with standard serial and parallel I/O interfaces could also be linked to BLISS.

The local co-ordination modules are also used to drive Bus Information Signs at bus stops, which give predicted arrival times for the next four buses due at the stop.

#### *2.2.2.2 Control Strategy Description*

BLISS uses a time of day, plan based approach. Signal timing plans are calculated off line, using TRANSYT, for different times of the day and for special shopping periods and special events. Current traffic parameters, such as volumes or occupancy are measured and recorded for all locations every five minutes and the appropriate plan selected according to predefined schedules. Operators can also use traffic surveillance cameras to monitor the network. In the event of unusual traffic conditions the operators can intervene and make changes to the signal timings. To assist them, BLISS continuously looks for abnormal congestion by comparing traffic volumes and occupancy levels against previously recorded average values for the particular time of day and day of the week. A special mode is also used during periods of very light traffic.

The local co-ordination module also forms the basis of the RAPID bus priority and passenger information system. The RAPID system operates independently of the traffic control system. However much of the same infrastructure is used. Thus RAPID is highly integrated into the BLISS system in Brisbane but can run alongside a competitive traffic system if BLISS is not used for traffic control.

When a bus is detected at advance loops or at the stop line loops of an intersection then, if required, priority is activated at the current intersection. Priority calls may also be made to nearby downstream intersections if there are no intervening bus stops. For best results it has been found that the advance loops should be beyond the longest queue and at least 90m back from the stop line.

After the bus is detected a check is performed by the regional master computer to see if it qualifies for priority. If it does, then the regional master sends priority messages to the appropriate local controller units.

Each time a bus is detected the information received is stored in a database. This information is then used to automatically build up a bus schedule which is then used to help determine whether future buses should get priority. The data in the database stores the service number, the bus start time and the day type. There are 12 different day types, namely; Mon-Fri school in, Mon-Fri school out, Saturdays, Sundays and Public Holidays.

When a bus is detected at a loop, RAPID determines whether it is late when compared with the average recent progress of buses of the same service number, start time and day type. In the original system a bus qualified for priority if it was late by more than two minutes. In the system now being implemented a zero minute late threshold is to be used as experiments showed that this would not have a detrimental effect on other traffic.

The allowed interventions to try and ensure the bus gets a green signal at the junction include:
- starting a phase early
- extending a phase
- not skipping a phase because a bus is known to be approaching

The priority phase is cancelled if the bus is detected at the stop line and it has a green signal or if the bus is detected further downstream or after a timeout period has elapsed. If a phase is extended in the current cycle then it is shortened in the next cycle by the same amount. All interventions are recorded and stored in a database.

If there is a priority conflict at an intersection, a decision has to be made about which vehicle gets priority. For buses, this is determined by a priority level based on the number of passengers on the bus and the level of lateness. Normally the bus with the most passenger boardings gets the priority.

#### *2.2.2.3 Detection Methods*

The bus priority system uses an AVL system known as VID. The VID system locates any number of buses in real time at consistent locations. A VID tag is fitted to the underside of each bus. When the bus drives over a loop in the road, a message transmitted by the tag is picked up by the loop and decoded by the VID receiver in the traffic signal controller cabinet. The message is then relayed to the BLISS system using the existing communications infrastructure. Each tag on the bus is interfaced to its electronic ticketing machine (ETM). The message transmitted by the tag consists of a static part and a dynamic part. The dynamic part is provided by the ETM and consists of the service number, the scheduled start time and the passenger loading. The static part identifies the bus owner and the bus number.

#### *2.2.2.4 Benefits*

It was found that an intervention which extended a phase on the main road would save the bus around 20s. A similar intervention on a side road would save 90s. Interventions which start the phase early would save 7s. Initial trials however, have failed to produce statistically significant savings in travel times over the whole 7km length of road where the scheme has been piloted. In part this was due to the need to run buses to a schedule as so if they were early the drivers will stop at way points in order to get back on schedule. Refinements to the system are expected help define those areas where benefits can be shown to be statistically significant.

#### *2.2.2.5 Logical Reference Model Description*

| Node Type | Name | Sends to Node |
|---|---|---|
| A | | |
| B | BLISS System Master | |
| C1 | BLISS Regional Master | C2 |
| | | B |
| C2 | Local Controller | C1 |
| | | D1 |
| | | D5 |
| D1 | Traffic Signals | |
| D2 | Traffic Detectors | C2 |
| D3 | Push Button Detectors | C2 |
| D4 | VID Receivers | C2 |
| D5 | Bus Arrival Signs | |
| E | VID Tags | D4 |

### *2.2.3 CELTIC - Lyon, Toulouse*

#### *2.2.3.1 Introduction*

The CELTIC bus priority method was developed in the DRIVE II LLAMD project as part of the experiments in Lyon against a background of fixed time UTC.

#### *2.2.3.2 Control Strategy Description*

A conditional priority strategy was developed incorporating state estimation and optimisation at each intersection over a 50 second horizon, those tasks being performed each second (Farges and Henry, 1994). For private vehicles an estimation is required from loop sensors of the number of vehicles queuing while for each bus an estimate is made of the time to reach the stop line at free speed and the time to clear the queue in front of the bus. Various criteria are used for conditional priority including the minimisation of delay to public vehicles while minimising the difference this causes between the resulting stage change times and those of the background plan sequence.

#### *2.2.3.3 Detection Methods*

Loops were used to detect the buses, which travelled in reserved lanes. The loops were placed at both entrances and exits from links.

#### *2.2.3.4 Benefits*

This form of priority was tested initially using the SITRAB+ simulation model applied to a test network of three junctions representative of an axis in Lyon. The simulation included the modelling of the existing green wave control, several updated fixed time controls using TRANSYT plans with different weights for buses, an active bus priority strategy with a green wave and an active bus priority strategy with the zero-bus-weight TRANSYT plan. Site evaluation strategies were the zero-bus-weight TRANSYT plan and the active priority with this background plan. Field trials of the priority system were undertaken at two co-ordinated intersections in Toulouse, taking advantage of the experimental facilities of ZELT. Statistically significant reductions in public transport journey times of 11-14% were obtained during the field trials in Toulouse. There was very little difference in general traffic journey times. There was also a 19-29% reduction in the standard deviations of bus journey times for different O-D movements.

### *2.2.4 CGA system - France*

#### *2.2.4.1 Introduction*

A PT priority system developed by CGA in France (Laurens, 1994) uses a beacon based approach where the UTC system communicates with the PT vehicles prior to any stage change to see whether the stage change time should be advanced or retarded. Such a system has been used in Strasbourg since 1981, Nancy since 1982 and in five other French cities since then.

#### *2.2.4.2 Control Strategy Description*

When the bus is a long way away from an intersection, when it crosses a fixed point, it transmits a message to the central PT AVL computer requesting priority at the junction. The message contains the vehicle identifier and the phase it wants to use to cross the junction. This message is then relayed to the UTC computer where it is stored for later use. When the UTC computer has to make a decision regarding the next stage change it looks at the stored value to see if a bus is approaching. If there is a bus approaching it passes a message to the PT AVL computer requesting the current position of the bus. The PT AVL system then interrogates the bus and transmits its position back to the UTC computer. The UTC computer then uses the mean bus speed to estimate when the bus is due to cross the stopline. Then the usual extensions or recalls are used to give the bus priority across the junction if required. As soon as the bus has crossed the intersection it transmits a message to the PT AVL system which is relayed to the UTC computer allowing it to stop the green extension.

#### *2.2.4.3 Detection Methods*

An AVL system is used which allows two-way communication between each PT vehicle and a central computer. Location information can be obtained either on the initiative of the central computer or of the vehicle itself.

#### *2.2.4.4 Benefits*

Reductions in travel times of about 4%-5% over a whole run are claimed, assuming the frequency of buses is not much more than one every two or three signal cycles.

#### *2.2.4.5 Logical Reference Model Description*

| Node Type | Name | Sends to Node |
|---|---|---|
| A | PT AVL System | B<br>D2 |
| B | UTC System | C |
| C | Local Controller | D1 |
| D1 | Traffic Signals | |
| D2 | Antenna | A |
| D3 | Roadside Beacon | E |
| E | Transceiver | D2 |

### *2.2.5 MOVA - London and Winchester*

#### *2.2.5.1 Introduction*

MOVA (Vincent and Peirce, 1988) is a method of traffic signal control for isolated junctions. It analyses lane by lane detector data and controls signal timings to minimise delay and stops and if any approach becomes oversaturated it will also optimise capacity. The University of Southampton (1988) carried out a feasibility study to look at the incorporation of bus priority in MOVA. This resulted in bus priority features being added to MOVA, which underwent trials at three locations (Crabtree and Vincent, 1998) in 1995/6.

#### *2.2.5.2 Control Strategy Description*

When a priority vehicle has been detected extensions or recalls, subject to user defined constraints, are used to give the bus green at the intersection. Emergency vehicles can also receive priority, with their interventions being serviced before those of any other vehicle.

When a priority vehicle is detected then

- if the current stage caters for the vehicle then a pre-set extension can be provided which gives sufficient time for vehicle to reach the stopline under normal conditions,
- if the current stage does not cater for the vehicle then non-priority stages can be skipped or truncated to their minimum in order to run the priority stage as early as possible. Whether a stage can be skipped or truncated is set by the user. It is also possible to override a skip or truncation request depending upon whether the stage was skipped or truncated in the previous cycle and on the level of saturation on the link.

#### *2.2.5.3 Detection Methods*

Two detection methods were used during the trials. In the first two trials the buses were fitted with transponders and were detected when they passed over loops embedded in the road. It the third trial, in Winchester, inductive loops were still used but the buses were identified by their inductive footprint rather than via transponders.

#### *2.2.5.4 Benefits*

Three trials of the system have been carried out. The first two were in SW London, the third in Winchester. All the trials showed an overall reduction in bus journey times, of varying amounts according to each site’s characteristics.

#### *2.2.5.5 Logical Reference Model Description*

| Node Type | Name | Sends to Node |
|---|---|---|
| A | None | |
| B | None | |
| C1 | MOVA | C2 |
| C2 | Local Controller | D1 |
| D1 | Traffic Signals | |
| D2 | MOVA Loop | C2 |
| D3 | Bus Priority Loop | C2 |
| E | Transponder | D3 |

### *2.2.6 OPTICOM*

#### *2.2.6.1 Introduction*

The OPTICOM priority control system is used to give priority to selected vehicles at signal controlled intersections. It has been used to give priority to both emergency and transit vehicles. OPTICOM based systems have been implemented at over 40,000 intersections world wide, including systems in Bremerton - Washington, Charlotte - North Carolina, Puget Sound, Orlando - Florida, Phoenix - Arizona and Vicenza - Italy

#### *2.2.6.2 Control Strategy Description*

The priority system has been used in different ways at different locations.

In Charlotte, North Carolina (Jacobson, 1993), the OPTICOM system has been used when providing priority to an express bus route since 1985. Priority is provided on an intersection-by-intersection basis along the length of an express bus route. When the OPTICOM system is activated an emitter mounted on the front of the bus sends a frequency coded optical message to the detector mounted on the signal head. The emitters are manually switched on by the driver as the bus leaves the station. The detector then sends a signal to the phase selector in the roadside controller cabinet. The phase selector tells the signal controller to either extend the existing green light for the bus or shorten the existing red light. The green light extensions and red light reductions typically add 10-15 seconds to the green phase and reduce the red phase by the same amount. Once the bus has cleared the stopline the green phase ends. The detectors are only enabled at appropriate times of the day. This ensures that only inbound buses get priority during the AM peak and outbound buses during the PM peak. At other times of the day priority control is disabled in both directions. The system is used at 14 intersections on a six mile section of the ten mile long express bus route. The route is also used along with a Park-and-Ride lot.

Jacobson (1993) has reported on simulation studies using an AVI based system which included OPTICOM, in the Puget Sound region. Two signal control strategies were considered, an “HOV-Weighted OPAC” strategy and a “Lift” strategy but simulations were only able to be performed using the “Lift” strategy. The “Lift” strategy involved “lifting” (ignoring) all vehicle detections on approaches to all opposing phases for a period after the detection of an approaching HOV. In the simulation the priority vehicle detector was placed 1,300 feet from the intersection and the usual vehicle detectors on opposing arms were switched off for a period of 20 seconds. This allowed a rapid but safe change of phase to provide green time to the approaching HOV.

The OPTICOM priority control system has been combined with another 3M product, the Integrated Fleet Operations (INFO) system in the Puget Sound region and in Orlando, Florida. Here it has been used to pinpoint the location of buses and determine if they are behind schedule. If they are running late the OPTICOM priority control system is activated and extensions or recalls provided as the bus moves through signalised intersections.

In Vicenza (Jellison, 1998) three strategies have been tried out, with five intersections and twenty-eight buses being equipped with the OPTICOM system. The three strategies are “queue jumping”, “express routing” and “far-side intersection”. The queue jumping strategy uses bus detection to trigger a signal in a lane which is used by general traffic for right turns only, but which buses can use for straight ahead movements. This lane has its own signal, which usually turns to green at the same time as the straight ahead movement.

But if a bus is detected then the right turn lane gets its green a few seconds ahead of the straight ahead movement. This allows the bus to move ahead of the queue of waiting traffic in the lane alongside. The express routing strategy sets up a green wave through a number of intersections for an approaching bus. The far-side intersection strategy is the usual provision of extensions or recalls at a signalised junction.

#### *2.2.6.3 Detection Methods*

The OPTICOM priority control system uses infrared based communications between buses and signalised intersections. The primary components of the system are an emitter on the bus and a detector at the intersection. When the emitter is activated it sends a data encoded optical message to the detector. In a stand-alone system the emitter is activated by the driver as the bus approaches the junction. The detector reads the message and sends an appropriate message to the intersection controller. The emitters can be received within a range of 750m down to 60m from the detector. The actual range used can be adjusted using software. The data sent is vehicle classification, vehicle priority level and vehicle identification. Ten vehicle classifications, multiple priority levels and 1000 specific vehicle ID’s per priority level are available.

Most of the European implementations of bus priority also link the activation of the emitter to bus doors. If the bus doors are open then the emitter is automatically switched off. This stops the emitter requesting priority while the bus is waiting at a bus stop.

The INFO system combines GPS technology with accurate digital mapping and is primarily used to provide both transit system operators and the general public with real-time information on schedule adherence. The GPS technology has been combined with a beacon location system in urban areas where satellite communications may be obscured. An on board unit on each bus lets the driver know whether the bus is running early or late and whether a green light advantage has been requested for the up coming intersection.

#### *2.2.6.4 Benefits*

Benefits in Charlotte include a four minute reduction in travel times and a more reliable and regular service. Ridership on the express bus route has doubled in the ten years since the service has been in operation and the numbers of runs made has increased from four runs in each direction to ten runs in the morning peak and nine runs in the evening peak.

In Phoenix, Arizona the OPTICOM system saved transit buses an average of up to 15s per intersection. Improvements in timetable adherence and increased ridership were also reported. There was a small increase (1.4%) in delay to other traffic.

In Vicenza, average weekly run times of buses were cut by nearly 24%, on a 12 minute journey, when the OPTICOM priority system was used.

#### *2.2.6.5 Logical Reference Model Description*

Here is the Logical Reference Model Description for an INFO system using OPTICOM priority.

| Node Type | Name | Sends to Node |
|---|---|---|
| A | Transit Centre | |
| B | None | |
| C | Local Controller | D1 |
| D1<br>D2<br>D3 | Traffic Signals<br>OPTICOM Receivers<br>Bus Information Signs | C |
| E1<br>E2 | OPTICOM Emitter<br>INFO System | D2<br>A<br>E1<br>D3 |

### *2.2.7 Portland*

#### *2.2.7.1 Introduction*

Two bus priority methods and two detection methods have been tested in a scheme on four intersections on a two mile section of the Powell Boulevard in the City of Portland, Oregon (Hunter-Zaworski, et. al., 1995). Seventy five buses were equipped with transmitters for the trial.

#### *2.2.7.2 Control Strategy Description*

Two control strategies were used. The first was a green extension-early green return strategy, which was used on three of the intersections. The second was a queue jumping strategy which was used at one other intersection.

The green extension - early green return strategy took green time from the cross-street green time. The overall cycle time remained the same. The technique was only applied at junctions where the bus stop was on the far side of the junction.

The queue jumping strategy was used at a junction where the bus stop was just before the signals and the bus stop was in a lane which was for right turning traffic and buses only. This lane had its own signal head and a System B detector in the lane was used to find out when a bus was at the bus stop. If the signals were red when the bus was at the stop then the bus would receive a short advance green allowing it to move in front of the queue of straight ahead traffic at the signals. The advance green would start at the same time that the normal green would have started if the bus had not been detected.

#### *2.2.7.3 Detection Methods*

Two bus detection methods were used, named system A and system B. System A used radio frequency activated tags with special RF readers installed along the roadside. For each link two readers were required. The first reader was placed at the roadside 122 to 183 m from the stop line and the second reader was at the traffic signals. When the bus passed the first detector it would initiate a priority call which would remain in place until the bus passed the second reader at the signals. A timeout was provided to cancel the priority call in case the second reader failed. The priority calls, and the start and end of the green times during the priority call period were all logged by the system A controller.

System B used a special transmitter on the bus, requiring a power supply, which was read through the standard vehicle loop detectors embedded in the road. Once again two detectors were used. The first to detect the bus, the second at the stop line to confirm the bus has passed through the intersection.

#### *2.2.7.4 Benefits*

The measured benefits were inconclusive due to problems with the field trials, however, bus travel times were reduced and there was no substantial increase in the delay to other vehicles.

### *2.2.8 PRODYN - Brussels, Pau and Toulouse*

#### *2.2.8.1 Introduction*

PRODYN is a real-time traffic control system developed by CERT/ONERA in France and implemented in three French cities. In the CITIES project, PRODYN was also implemented in Brussels. More recently a version of PRODYN specifically developed to provide priority to buses (QUARTET +, 1998) has been developed for implementation in Toulouse. PRODYN is based on state space modelling and estimation of queues, with signal control computations at each intersection performed on a 75 second rolling horizon every 5 secs. Co-ordination is ensured by the exchange of platoon forecasts from upstream to downstream intersections.

#### *2.2.8.2 Control Strategy Description*

Originally, PT priority in PRODYN was achieved in a non-optimal way by assuming a detected bus to be worth several private vehicles in the optimisation process. However, a new process for PT priority in PRODYN was developed in the DRIVE II CITIES project and tested through simulation (Henry and Farges, 1994). For each link, an estimation of priority vehicle state variables is performed at each sampling time using the values predicted at the previous sampling time and, for an internal link, the information received from the upstream intersection module. Predicted values are then modified according to actual bus detections. Optimisation criteria include a consideration of the weighted priority vehicle delay and the probability of the vehicle having left the link.

#### *2.2.8.3 Detection Methods*

The position of the bus is determined with a location system based on GPS and the vehicle's odometer.

#### *2.2.8.4 Benefits*

Evaluation of PT priority in PRODYN has been through the use of the SITRAB+ simulator applied to an isolated intersection, covering both segregated lane and mixed traffic situations, and to an axis network incorporating 3 signal controlled junctions.

### *2.2.9 SCOOT - Leeds, Leicester, London, Norwich, Southampton*

#### *2.2.9.1 Introduction*

SCOOT is a centralised system in which information from SCOOT detectors on traffic flows and occupancies at the upstream end of each link is transmitted from each junction to the SCOOT computer every second over standard telephone lines. SCOOT optimises network cycle times every 2½ to 5 minutes, offsets between nodes every cycle and green splits at each junction at every stage. These timings are implemented on-street with the philosophy of small but frequent stage changes to react to changing traffic conditions without compromising network traffic stability.

The DRIVE II project PROMPT developed an active bus priority system of stage extensions and recalls, based on previous work undertaken in the SELKENT study. PROMPT was initially evaluated off-line by TRL using a computer simulation. Trials were then taken in London under PROMPT and in Southampton under ROMANSE using transponders and an AVL system. The PROMPT software was incorporated into the SCOOT kernel in SCOOT version 3.1 which became available to users in 1996 (Bowen, 1997).

Another DRIVE II project, PRIMAVERA, also developed an active bus priority system using SCOOT. This was aimed specifically at giving priority on urban arterial roads and was developed and evaluated using both simulation and on-street trials for a site in Leeds (Fox et.al., 1995).

Bus priority systems have also been developed which provide extensions and recalls for buses, but which are not integrated into the SCOOT UTC system. When a bus is detected, the SCOOT system is overridden to give priority to the bus at the upcoming junction. All that SCOOT does in this case is attempt to ameliorate the delay such actions cause to other traffic once the bus has passed through the junction. Such systems have been tried in Bedford and Norwich (Cranshaw and Shaw, 1995)

#### *2.2.9.2 Control Strategy Description*

The approach of a bus can trigger a green extension or stage recall depending on the current stage. To limit the disbenefit to non-priority traffic, users can set target degrees of saturation for non-priority stages, which if likely to be exceeded will inhibit the granting of priority. Higher targets allow greater priority and more potential disruption to other road users. The duration of the extension is varied according to the journey time for the bus to pass the stop line, predicted by the traffic model.

While priority extensions and recalls are applied, the original SCOOT timings continue to operate in the background. On completion of the priority sequence, the timings are re-synchronised with the background plan using one of a range of user selectable strategies. The priority strategy contains no specific logic to compensate phases which are penalised when priority operates. However, the SCOOT split optimiser will work to redress any imbalance in queues remaining once priority ends.

For safety, a constraint is applied to the granting of recalls to ensure that no stages are skipped. For multi-stage junctions, this rule slows the introduction of the priority stage.

Priority for buses at mid block pedestrian facilities is not an option.

Variability of journey times and the presence of bus stops means that, typically, buses are detected within approximately 100 metres of the stop line. The priority strategy is local to the node under consideration as no reference is made to the imminent arrival of buses from upstream links or to co-ordination with downstream signals.

Communications delays (from street to centre to street) are typically 4 to 5 seconds which effectively shifts the detection point closer to the stop line and reduces the benefits from priority. A non centralised architecture is possible that places some logic for granting extensions within the outstation and giving an immediate response when granting extensions.

#### *2.2.9.3 Detection methods*

SCOOT/PROMPT priority has been applied with SVD using both transponders fitted to buses and various AVL systems.

An AVL system (BUSTRACKER) was part of the Southampton trial and formed part of a passenger information system. This system can use roadside beacons and the odometer on the bus to determine the location of the bus.

In DRIVE II project PRIMAVERA (Fox et. al. 1995) the buses were detected using Texas Instruments Registration and Identification System (TIRIS) tags. These are small transponders which are attached to the bus. To interrogate the tag, a reader sends out a 134.2 kHz radio signal to the transponder via an antenna (loop) embedded in the road. The signal carries enough energy to power up the battery free transponder. The transponder then returns a signal that carries the data it is storing over a time period of 20 milliseconds. This data is a unique, 64 bit, factory programmed identifier. The transmission technique used between the transponder and the reader is Frequency Shift Keying (FSK) using 134.2 kHz and 123.2 kHz. The loops have to be placed far enough away from the stop line to allow the signals to react to the presence of the bus, but not too far from the stop line, in order to provide an accurate prediction of the arrival time at the stop line. The loops were therefore often placed just downstream of the last bus stop before the stop line.

#### *2.2.9.4 Benefits*

Simulation studies in the PROMPT project (McLeod et.al., 1994) indicated that bus passenger delay savings of 20-30% could be achieved by using the new bus priority methods in SCOOT. In one simulated network, extensions were shown to reduce bus delay by 24%, without disrupting other traffic.

The simulation studies led to on-street trials in Southampton and London. Average bus delay savings of 5s per bus per junction were achieved.

Simulation studies in the PRIMAVERA project (Fox et.al., 1995) indicated that bus journey times would be reduced by up to 4% for buses equipped with transponders. The subsequent field trials showed a reduction of 8% in travel times for equipped buses but this was counterbalanced by a slight increase in journey times for other traffic.

#### 2.2.9.5 *Logical Reference Model Description*

| Node Type | Name | Sends to Node |
|---|---|---|
| A | None | |
| B | SCOOT | C |
| C | Local Controller | D1<br>B |
| D1 | Traffic Signals | |
| D2 | Bus Detection Receivers | C |
| D3 | Loop Detectors | C |
| E | Bus transponders | D2 |

### 2.2.10 *SPOT - Leeds*

#### 2.2.10.1 *Introduction*

A key component of the UTOPIA system developed by MIZAR Automazione in Turin (see Section 2.3.7) is the SPOT intelligent signal control processor. This processor implements the "intersection level" control function of the UTOPIA system. Each intersection equipped with SPOT aims to minimise a set of cost functions over a rolling horizon of two minutes and co-operates with the neighbouring intersections by exchanging information on the traffic observed and the control decided locally. The optimisation and communication process is updated every three seconds. Stage change times are limited only by stage order and minimum/maximum stage durations. Priority PT vehicles are handled in terms of vehicle arrival time predictions and are represented as weighted platoons of private vehicles.

#### 2.2.10.2 *Control Strategy Description*

In DRIVE II project PRIMAVERA, bus priority in SPOT was adapted to allow it to use bus arrival time predictions based on local selective detection via loops, rather than a continuous vehicle monitoring system as used in Torino. This priority technique was tried on a site in Leeds and evaluated using simulation modelling (NEMIS) and in field trials.

#### 2.2.10.3 *Detection Methods*

The TIRIS tags described in Section 2.2.9.3 were used. An advance prediction facility was also used. When a bus was detected approaching a junction this information was also passed to the next downstream junction to allow it to have advance warning of a likely bus arrival. This would allow the downstream controller more time to evaluate possible bus priority signal settings and thus minimise disruptions caused to other traffic.

#### 2.2.10.4 *Benefits*

A field trial of the enhanced SPOT system was carried out on the Dewsbury Road in Leeds (Fox et.al., 1995). This showed that bus travel times for those buses fitted with transponders were reduced by approximately 10% over a fixed time plan, and by 19% over the network under SPOT control without the bus priority component. Car travel times were unchanged.

#### *2.2.10.5 Logical Reference Model Description*

| Node Type | Name | Sends to Node |
|---|---|---|
| A | None | |
| B | UTC Centre | C1 |
| C1 | SPOT Unit | B<br>C2<br>C1 |
| C2 | Local Controller | C1<br>D1 |
| D1 | Traffic Signals | |
| D2 | TIRIS Detectors | D3 |
| D3 | Loop Detectors | C2 |
| E | Transponder | D2 |

### *2.2.11 SPRINT - London*

#### *2.2.11.1 Introduction*

The Selective Priority Network Technique (SPRINT) gives priority to buses at signals controlled by a fixed time UTC system (Hounsell et.al., 1997a). It has been developed within the INCOME project (Hounsell et. al., 1997b) and tested in a trial on the Uxbridge Road in London in 1996.

#### *2.2.11.2 Control Strategy Description*

When a bus is detected an algorithm is used to determine new signal timings which will let the bus through the next junction at the earliest possible time. This algorithm uses a traffic model for both the bus and the other traffic and it attempts to optimise the signal timings subject to a number of constraints. It uses extensions and recalls to achieve its aims.

The traffic signals are under fixed time control, so the state of the signals at any time should be known by the UTC computer. However, some junctions will have demand dependent stages so the actual state of the signals may be different from that expected. The state of the signals is therefore monitored by the UTC computer by examining data bits sent back from the street to confirm which stage is actually running.

The traffic and the buses in the network are modelled using some user supplied parameters.

For each link in the network the *traffic flow* and the *saturation flow* need to be supplied. Traffic flow is assumed to be uniform throughout the cycle. During effective green the traffic is assumed to discharge at the saturation flow. If a queue has not discharged by the end of green it remains for the following cycle. The bus model requires two parameters per link. The *priority extension* is defined as the minimum time the lights must remain green from the time the bus is detected during green for the bus to receive priority. The *priority minimum* defines the minimum time the lights must have been green for the bus to receive priority.

Various constraints are also used to ensure that the disbenefits to other traffic are not too great. For each junction the traffic engineer can decide

- whether both extensions and recalls are allowed or just extensions

- the maximum number of cycles that SPRINT can run timings different from the base plan
- the maximum time difference of a stage from the base plan
- the maximum levels of saturation allowed for each of extensions, recalls and recovery periods

A further constraint is that once SPRINT has performed a recall and returned to the base plan it is inhibited from implementing a further recall for that stage for one cycle.

Compensation is provided by adding compensatory green time to the same stage in the cycle following a recall.

Subject to these constraints SPRINT can make one of five decisions when a bus is detected:

- **No operation** - No action can be made which would give priority and satisfy the constraints.
- **Central extension** - An extension is requested by the central UTC computer.
- **Local extension** - An extension is provided to the bus by the controller on street, this is sometimes required, rather than using a central extension, to overcome transmission delays.
- **Stay** - No action is required to ensure the bus gets a green at the next junction, but make sure that any following buses do not change the signal timings to change this situation.
- **Recall** - Call a later stage to give the bus priority.

### *2.2.11.3 Detection Methods*

Buses are detected using a system based on loops in the road surface and transponders on the buses. The loops are usually positioned after any bus stop on the link.

### *2.2.11.4 Benefits*

A trial of the SPRINT system has been carried out on eight junctions of the Uxbridge Road in London. The trial section covered 3km and includes 11 bus stops. There were up to 40 buses an hour in each direction. The main benefits obtained were an average of 2.0 seconds reduction in delay per junction for buses on the main road links and 6.4 seconds reduction for buses on side road links. During the trial the proportion of actions requested by SPRINT were as follows: Green extensions (5%), Green recalls (25%), No priority required (67%), No priority available due to constraints (3%).

### *2.2.11.5 Logical Reference Model Description*

| Node Type | Name | Sends to Node |
|---|---|---|
| A | None | |
| B | UTC Computer | C |
| C | Local Controller | D1<br>B |
| D1 | Traffic Signals | |
| D2 | Loop Detectors | C |
| E | Transponder | D2 |

### *2.2.12 UTOPIA - Bologna*

#### *2.2.12.1 Introduction*

The UTOPIA Urban Traffic Control System developed by MIZAR Automazione has been adapted for use with a bus fleet monitoring system, based on GPS, in Bologna, Italy. A total of 170 intersections are controlled by the UTOPIA system.

#### *2.2.12.2 Control Strategy Description*

The basic operation of a UTOPIA system is described in see Section 2.3.7.

#### *2.2.12.3 Detection Methods*

Every twenty seconds the UTOPIA control centre receives data over an optical fibre link from the public bus company's (ATC) fleet management system. This management system tracks the location of the buses in Bologna by using GPS receivers on the buses.

#### *2.2.12.4 Benefits*

No details of the benefits of the system have been found.

## ***2.3 Light Rail / Tram / Trolley Bus / Guided Bus and Bus Priority***

### *2.3.1 BALANCE - Munich*

#### *2.3.1.1 Introduction*

BALANCE (Balancing Adaptive Network Control Method) is a traffic signal control method developed within the Munich COMFORT project (Friedrich et.al. 1995), forming part of the DRIVE II project LLAMD consortium. BALANCE (Toomey, et.al., 1997) represents an extension of the existing microscopic control programs (vehicle actuation) in Munich by a macroscopic control component that runs on an area computer and is based on economic modelling. The BALANCE philosophy involves a two-level control strategy, being (i) a decentralised operational level and (ii) a centralised tactical level, for junctions under UTC.

#### *2.3.1.2 Control Strategy Description*

Realisation of priority for PT vehicles at the operational level is through priority pre-emption (stage change), green time extension and special stages. A pre-determined priority level ranges from absolute priority (no delay, if there are no competing public transport vehicles) to no priority. At the tactical level, one of four priority levels is selected depending on the general traffic situation, and particularly the delay suffered by competing PT lines. BALANCE incorporates an objective function for optimisation based on a performance index, PI, which is composed of a linear combination of the criteria "delay suffered by persons using private traffic" and "delay suffered by persons using public transport vehicles". Optimisation can therefore be performed according to weight in the range 0-1 related to the influence given to each criterion.

#### *2.3.1.3 Detection Methods*

Buses and trams were detected using a system based on transponders.

#### *2.3.1.4 Benefits*

Evaluation of BALANCE was undertaken in LLAMD at one junction using microscopic simulation incorporating the actual detection and control methods existing on-street. Field trials were also carried out in Munich on a network where 21 junctions were equipped to provide priority. Journey time savings for public transport vehicles of 14% were recorded. Delays to both cars and trams were reduced following the introduction of BALANCE.

### *2.3.2 Los Angeles / Long Beach*

#### *2.3.2.1 Introduction*

The Los Angeles Light Rail system extends for 22 miles from downtown Los Angeles to downtown Long Beach. The LRT is able to receive priority at some intersections at certain times of the day.

#### *2.3.2.2 Control Strategy Description*

Full and partial priority options have been developed. The partial priority option is based on window stretching, which allows the green window provided for the LRT phase to be started earlier or finish later than normal. This extra green time is taken from the other phases, but there is a limit on the length of time that can be used. Full priority has no such limitations and the signal timings are adjusted to favour the LRT movement when the LRT is present.

#### *2.3.2.3 Detection Methods*

The LRT vehicles are detected using inductance loops in the segregated LRT tracks. An advance detector is used to trigger a priority request and a stopline detector is used to cancel it. The advance detector is usually placed after any stop, unless the stop is less than 200 feet from the target intersection. In this case the release of the LRT vehicle from the stop is co-ordinated with the signal phasing.

#### *2.3.2.4 Benefits*

No reports on the measured benefits of the system have been found.

### *2.3.3 SCATS - Melbourne*

#### *2.3.3.1 Introduction*

The Melbourne SCATS (Sydney Coordinated Adaptive Traffic System) system is an example of both passive and active PT priority in a centralised system. In Melbourne it controls 250 km of tram tracks and 180 sets of signals. SCATS adjusts signal plans based on traffic conditions at critical intersections. These critical intersections control co-ordination within subsystems and subsystems coordinate with other subsystems as traffic demands vary. Subsystems can include from one to ten intersections.

#### *2.3.3.2 Control Strategy Description*

On detection of a tram approaching a junction, priority phases can be called to either clear the queue ahead of the tram or to provide a phase extension. Flexibility is provided allowing priority to be given or not depending on the time of day, tidal flow determination based on traffic flows or on how congested the intersection is.

#### *2.3.3.3 Detection Methods*

The trams are detected using two selective tram detectors on each approach. One detector loop is placed approximately 200m from the stopline, the other is at the stopline.

#### *2.3.3.4 Benefits*

Evaluation of the system on a small network of two parallel main routes and three crossing routes showed (in peak conditions) savings to trams of between 6% and 10%, with benefits to private cars between 1% and 7%. On the crossing routes, results for private vehicles varied between 41% of saving and 13% of disbenefit, depending on signal co-ordination and tram priority.

### *2.3.4 Sheffield*

#### *2.3.4.1 Introduction*

When Sheffield introduced its Supertram system it was decided that the maximum priority would be afforded the trams at signalised intersections. This has resulted in the development of a set of signal control techniques for use with the Supertram system (Saffer and Wright, 1994).

#### *2.3.4.2 Control Strategy Description*

LRT priority is given by using demand dependent stages. Each LRT phase only appears on demand. If the same LRT phase appears in several stages, the stage served is not defined and the most appropriate stage may run.

#### *2.3.4.3 Detection Methods*

A transponder and loop system is used to detect the trams. Up to four loop detectors are provided for each approach. The first loop a tram crosses is the *Prepare* detector. This may be used to initiate pre-emptive control actions at the junction prior to the arrival of the tram. The second loop is the *Demand* detector. This is mainly used to send the priority demand to the signal controller. The third loop is the *Stopline* detector which can be used to terminate phase extension or initiate a priority phase demand if the tram is stopped at the signals. The final loop is the *Exit* detector. This is normally used to curtail the intergreen early once the tram has left the junction.

#### *2.3.4.4 Benefits*

As the priority system was an integral part of the initial system design there is no way of seeing what the benefits of the selective priority system are as the Supertram system always operates with it in operation.

### *2.3.5 SPOT - Gothenburg*

#### *2.3.5.1 Introduction*

Development of PT priority in Gothenburg in the DRIVE II PROMPT project centred on the implementation of the new SPOT decentralised traffic controllers to provide traffic responsive signal control, incorporating public transport priority. Control had previously been fixed time, including the use of Automatic Updating of TRANSYT (AUT) where fixed time plans are regularly updated (e.g. every 15 mins) according to traffic conditions. In this kind of control PT priority is provided through heuristic techniques that do not take into account traffic congestion. Special stages are actuated as soon as possible when priority trams or buses are detected on the incoming links, 15-20 seconds prior to the stop line. The intersection then gets back into co-ordination.

Evaluation of the new control system in Gothenburg was undertaken off-line, using the HUTSIM simulator and through field trials. The test site adopted for experimentation is the OPAL network, that consists of eight critical intersections crossed by two main absolute priority tram routes (operating in reserved lanes) and several bus lines. All the intersections were equipped with SPOT units.

#### *2.3.5.2 Control Strategy Description*

An advanced priority system was designed in PROMPT that was based on the functional integration of the AUT and the KomFram AVL system. AUT provides the reference plans to be actuated by the SPOT units and KomFram provides the long term arrival time prediction of the priority vehicles at the intersections. The SPOT unit was enhanced to manage the public transport vehicle detection information provided and the special stages traditionally used in the site. An objective was for the new control system not to significantly compromise the provision of absolute priority for the city's trams while performing better traffic control.

#### *2.3.5.3 Detection Methods*

Short term predictions were provided by dedicated loops (priority request) connected to the traffic signal controller. Further loops were adopted for cancellation and back-up requests.

#### *2.3.5.4 Benefits*

The system was assessed using both simulation (with the HUTSIM model, Sane and Kosonen, 1995) and in field trials. Three junctions out of the eight were equipped to provide priority. Car journey times were reduced by 5% to 15%, but public transport journey times did not change.

### *2.3.6 Stuttgart*

#### *2.3.6.1 Introduction*

The light rail system in Stuttgart consists of 71 public transport lines covering 540km with 451 vehicles. Several real-time signal control strategies are used for giving priority to these light rail services and to buses (Nelson et.al., 1993).

#### *2.3.6.2 Control Strategy Description*

Three levels of priority can be granted. The first level, called “limited preferential treatment” allows green extensions when required. The second level allows both extensions and recalls, but there is a limit to the maximum red time allowed for opposing phases. The third level gives absolute priority without any red time constraints being imposed.

#### *2.3.6.3 Detection Methods*

Two detection methods have been used. The first uses inductance loops embedded in the road. When any vehicle passes over the loop its inductance profile is compared with profiles for different types of vehicle and it is identified appropriately. The second method uses infra-red beacons on the buses. When a bus is 40m away from the junction it sends out a “telegram” through the beacon to a detector at the junction to let the system know that it is approaching. When it gets closer to the junction a “change signals telegram” is sent and when it has passed through the junction a “cancel priority telegram” is sent so that priority is not given for longer than necessary.

#### *2.3.6.4 Benefits*

Delays to public transport vehicles have been reduced by 50%, with little extra delay to private vehicles, by using the limited preferential treatment priority level.

### *2.3.7 UTOPIA - Turin*

#### *2.3.7.1 Introduction*

The Urban Traffic Optimisation by Integrated Automation (UTOPIA) Urban Traffic Control system has been in operation in Turin since 1985 (Mauro and Di Taranto, 1989). UTOPIA is a fully traffic responsive UTC system designed with the twofold objective to (i) optimise private traffic control at the area level and, simultaneously (ii) provide weighted and absolute priority for selected public transport vehicles.

UTOPIA is based on a hierarchical and decentralised control concept. At the intersection level the SPOT traffic control units perform the decentralised control.

#### *2.3.7.2 Control Strategy Description*

This section contains a description of the basic concepts of the SPOT intersection controller which is a UTC unit designed to optimise the signal settings of a single intersection, an isolated small network of controlled intersections as well as a network supervised by a central system.

The control function which operates at the intersection level determines the signal settings to be applied to the traffic signals by optimising a suitable function according to the current intersection traffic situation. The optimisation is done on a 'time horizon' of the next 120 seconds and is repeated every three seconds. The resulting optimal signal settings are actually in operation only for three seconds. The closed loop control thus obtained can be viewed as an 'Open Loop Feedback Control' or as an application of a 'Rolling Horizon' concept.

In order to guarantee the optimality and the robustness of the control at the network level, the function optimised by the controller has been designed by adopting the 'strong interaction' concept: the function takes into account the state of the neighbour intersections, thus keeping a closed loop capability of building a dynamic signal co-ordination, and is constrained by limits given by the area level control (while remaining sensitive to traffic dependent criteria).

The function is defined by the sum of different weighted cost elements calculated on the whole optimisation horizon. The optimisation goal is:

$$\min_{\underline{c}} \sum_j w_j \; a_j(X)$$

subject to constraints such as:

$$\underline{c_{\min}} \leq \underline{c} \leq \underline{c_{\max}}$$
$$\underline{x_{k+1}} = f(\underline{u_k}, \underline{x_k}, \underline{c_k})$$

$w_j$ = weight of the cost element 'j'
$a_j$ = cost element 'j'
c = signal setting
x = intersection state defined on the whole optimisation horizon
u = intersection demand

The first condition represents constraints on the length of the stages.

The cost elements are:

1. Time lost by vehicles on the incoming links.
2. Stops on the incoming links. Stops are defined as vehicles which arrive at the stop line when queues are present.
3. Excess queuing on the incoming links (this term denotes queues exceeding safety thresholds which are proportional to the maximum capacity of the links).
4. Time lost on the outgoing links by vehicles leaving the intersection (these terms actuate the 'strong interaction' principle at the intersection level. They provide intersection control co-ordination and control stability at the area level).
5. Time lost by public transport vehicles to be given priority at the intersection.
6. Deviation from the reference plan provided by the central level (this element actuates 'strong interaction' with the area level and allows the degree of interaction between the two levels to be dynamically changed).
7. Deviation from the signal setting decided at the previous iteration (this element contributes to the smoothness of the area control)

Cost elements are evaluated on the whole horizon on the basis of traffic propagation rules which take into account the signal settings and the constraints on the minimum and maximum stage lengths. Different weights are allowed for different links and for different PT services (for providing absolute and lower level priority).

Traffic propagation at the intersection starts from the state estimate provided by the observer and makes use of all the defined traffic parameters. Input information required is as follows:

For the incoming links:

1. Traffic counts
2. Traffic forecasts provided by the neighbouring controllers (Forecasts correspond to vehicles which will leave the upstream intersections. An approximation is made assuming that the outgoing flows are uniform at intervals).
3. Forecasts concerning the arrival of the public transport vehicles to be given priority.

For the outgoing links:

4. The control strategies defined by the downstream controllers

Public transport vehicles are represented by equivalent vehicle platoons which appear as probability curves centred on the predicted arrival times. Curves becomes sharper as the vehicles approach the intersections and forecast variances decrease. The weight of the single vehicle depends on the level of priority requested. Weights can assume values within a suitable range defined on the basis of a sensitivity analysis of the cost function.

Currently, absolute priority vehicles correspond to four-five hundred equivalent vehicles and the weight of normal priority vehicles depends on the weight predefined for the corresponding services.

When no PT vehicle priority is requested the intersection controller provides the optimal traffic signal control according to the private traffic conditions only. The intersection controller is then able to satisfy priority requests even without any significant disturbance of private traffic through:

- Gradual adjustments of the traffic signal stages (in terms of duration and actuation time).
- Gradual adjustments of the synchronisation with the neighbouring controllers.
- Actuation of stages whose duration is as close as possible to the duration suitable for private traffic control (according to the weights introduced in the function optimised).

The intersection control performance depends on both the availability of PT vehicle arrival time forecasts updated in time according to the vehicle's progress, and the number of requests to be solved together. The experimentation performed demonstrated that the priority system was able to provide absolute priority to PT vehicles approaching the intersection once per cycle (in protected lanes) and simultaneously to optimise private traffic control.

Optional stages are included within the signal cycle during the horizon optimisation, whenever waiting or approaching public vehicles are forecast on suitable links.

Seeking the optimum strategy, for each horizon step the possible stage is reckoned according to the following algorithm:

#### First optimisation step (long horizon)

The optional stages are "skippable" if they don't improve the optimisation function cost which, at this level, takes into account strategy variation and bus priority costs only.

#### Second optimisation step (short horizon)

Select the stage following the previous step stage within the whole cycle (including all the optional stages)

- If the selected stage is not optional, it is the only possible following stage.
- If the selected stage is optional, the presence of queued vehicles and the presence of forecast approaching vehicles on the proper link are evaluated. If the evaluations show the stage is needed, it is the possible following stage else the test is repeated selecting the next stage within the whole cycle.

Approaching PT vehicle forecasts, in the form of probability distributions, can also be carried out according to information provided by special detectors installed on-road.

Two methods for bus priority are currently managed:

**Presence detection**

One stopped waiting vehicle is generated on the appropriate link while the loop is occupied.

**Single approaching vehicle detector**

Every time a variation on-off is received from the loop, one approaching vehicle forecast is produced on the appropriate link (the detected vehicle delay is selectable).

Following vehicles will pile up at the stop line until the beginning of the favourable optional stage. During the optional stage, queued vehicles are released at the rate of one vehicle per step.

In DRIVE II project PRIMAVERA and additional bus priority strategy was developed for use with SPOT / UTOPIA. This was called the bus stop protection strategy. When a bus stops is close to an intersection it is quite possible for a queue of traffic from the intersection to block access to the bus stop. This can cause problems for bus priority systems. First the bus has to stop in the queue and then it has to stop again when the queue starts moving and it can access the stop. As well as increasing the delay to the bus this can also make stopline arrival time forecasts uncertain, inhibiting successful signal priority at the intersection. To overcome this problem a strategy was developed to clear the queue from the bus stop as a bus approached. In the SPOT cost function a penalty was added if the queue was predicted to exceed a given length on the approach of a bus.

#### *2.3.7.3 Detection Methods*

The location of public transport vehicles is obtained from the SIS AVM system. This deals with several objectives intended to benefit the public transport company, the bus drivers and the passengers. They are:

- operating service monitoring and regularization
- data/voice message exchange between the fleet and the control centre
- central operator assistance in emergency situations
- passenger and driver safety
- service data acquisition for planning purposes
- user information

The AVM system has a hierarchical, decentralised and modular structure. Each vehicle is equipped with advanced devices which perform autonomous functions such as vehicle location, user counting, equipment diagnostics and data exchange with the operational centre. Vehicles are connected via radio to a central system which collects all data transmitted by the vehicles, provides the drivers with suitable representations of the current service condition, undertakes actions to maintain service regularity automatically, supports the drivers for recovering service emergency situations and maintains up-to-date statistical and historical information about the service operated.

Vehicle location is performed completely on-board without the help of roadside infrastructures (beacons, markers or other equipment).

For the localisation purpose, each vehicle is provided with the following on-board equipment:
- media reader (for driver identification and static route information loading)
- odometer (for route estimation)
- open/close door sensors

The technique adopted for the automatic location is based on the statistical correlation of the following available information:

- distance travelled by the vehicle, which is determined by filtering the odometer output and estimating on-line the ratio between wheel turns and metres travelled;
- bus stop recognition, which is performed by comparing the route description, open/close door sensor output and current possible vehicle position;
- route description, which is provided by the driver by inserting a particular memory support into the media reader, or by the central system, via radio communication.

Route description consists of:
- length of the depot-service links;
- sequence of stops along the route starting from one of the terminals (chosen as the reference terminal);
- average and variation of the distance between subsequent stops;
- points where the vehicle enters and exits the route.

The route description is prepared for each 'service' and 'turn' (where 'turn' is a sequence of trips which have to be performed on the 'service' by a single vehicle), as provided by the schedules. The driver is responsible for the transmission of the information to the vehicle equipment.

Vehicle position is defined in terms of:
- metres travelled by the vehicle from the reference terminal;
- time spent within the current route section, a section being a stretch of route which contains the single stop (stop section) or which comprises two subsequent stops (free section).

The technique adopted allows vehicle location with a standard deviation of less than five metres. This result was a target for the system design: high accuracy in vehicle location is required for obtaining selective traffic signal priority.

When the vehicle is not 'sure' of its position (because of on-board equipment faults or if large deviations occurred along the route) it declares itself as 'lost' and starts a 'back-up' procedure which looks for the correct location in the shortest feasible time.

#### *2.3.7.4 Benefits*

In the PRIMAVERA project, simulation studies indicated that the use of the usual SPOT bus priority strategy along with the bus stop protection strategy would result in a reduction of bus journey times of between 15 and 25% when compared with fixed time operation on an arterial road in Torino.

#### *2.3.7.5 Logical Reference Model Description*

| Node Type | Name | Sends to Node |
|---|---|---|
| A | SIS AVM | B |
| B | UTOPIA | C |
| C1 | SPOT Unit | C2<br>B |
| C2 | Local Controller | C1<br>D1 |
| D1 | Traffic Signals | |
| D2 | Loop Detector | C2 |
| D3 | On-Street Antenna | A |
| E | Transceiver | D3 |

### *2.3.8 VS-PLUS - Duisburg*

#### *2.3.8.1 Introduction*

Trams in the German city of Duisburg are given priority at signals (Lange and Lenzen, 1997) using a system based on roadside beacons and infrared communications.

#### *2.3.8.2 Control Strategy Description*

When the tram reaches certain positions it sends a message to the signal controller which is then able to calculate an optimal intervention which gives priority to the tram and minimises the resulting loss in green time to other traffic. The signals at each intersection are controlled using a system called VS-PLUS.

#### *2.3.8.3 Detection Methods*

Roadside beacons exchange radio data telegrams with passing trams using infrared communication. When the travel time to the junction is estimated as being between 15s and 25s the tram sends a message to the signal controller.

#### *2.3.8.4 Benefits*

No descriptions of the benefits of the system have been found.

### *2.3.9 Zurich*

#### *2.3.9.1 Introduction*

Zurich has a highly successful integrated transport system which enjoys high levels of patronage. A priority system for public transport vehicles has been developed with the aim of reducing their delay to zero. (See e.g. Bishop, 1994)

#### *2.3.9.2 Control Strategy Description*

On detection of a public transport vehicle the local controllers ensure that the vehicle will receive a green light at the upcoming intersection. The detection information is also passed to adjacent intersections so that local optimisation can be performed and to a central computer where more strategic decisions are made, based on optimisation of the whole network.

Gating is also used to keep public transport routes free of congestion.

#### *2.3.9.3 Detection Methods*

The detection system uses loops embedded in the road and transponders on the buses and trams. There are three detectors on each arm of a junction. These are placed at 300m, 150m and 0m from the stopline. The transponders send a coded message to the loops as they pass over them. The message contains the route identifier, whether the vehicle is running late or not and the length of the vehicle.

#### *2.3.9.4 Benefits*

It is claimed that zero waiting time for public transport is achieved at about 90% of signalised intersections.

High annual trip rates of 490 per person are also reported. This compares with 131 for Manchester, 250 for Stuttgart and 290 for London.

Swiss politicians regularly use the public transport system in Zurich, not just at election times.

## *2.4 Emergency Vehicle Priority*

### *2.4.1 BLISS - Brisbane*

#### *2.4.1.1 Introduction*

The BLISS system in Brisbane has already been described in Section 2.2.2. As well as being capable of providing priority to buses it can also give priority to emergency vehicles.

#### *2.4.1.2 Control Strategy Description*

The original BLISS system gave priority to emergency vehicles without using any vehicle detection information. In an emergency a control button in the fire or ambulance station was pressed to initiate special timing plans for signals along a selected route. These plans guaranteed a pre-determined window of green at each intersection along the route. Up to ten intersections could be specified with a given starting delay and green window time. The routes are pre-determined and each has an associated button to press to activate the emergency plan. The introduction of the VID detection system used in the Bus Priority Scheme provided the potential for the emergency vehicle priority strategy to be enhanced. Emergency vehicles could fitted with the VID tags and vehicle detector loops and a VID receiver installed at each emergency centre. These would allow the special priority plans to be automatically initiated when the emergency vehicle left the emergency centre. The route identifier for the emergency could also stored in the VID tag using a driver interface unit. The emergency vehicles would also get priority over buses at any intersection where conflicts with the bus priority system might occur. Currently this scheme is only partially implemented. Emergency vehicles have been fitted with the VID tags and are monitored using the same graphical displays as used for the RAPID bus priority system. No priority is currently being given for these vehicles.

#### *2.4.1.3 Detection Methods*

The same detection system as used for the buses is used, except that a higher priority level and different data is passed between the VID tag and the VID receiver.

#### *2.4.1.4 Benefits*

No measured benefits of the system were presented.

### *2.4.2 Milwaukee*

#### *2.4.2.1 Introduction*

An OPTICOM based emergency vehicle signal pre-emption system has been developed and implemented (Fornal, C.J. and Hanbali, R.M., 1996) in the City of Milwaukee. Several operational constraints were encountered and overcome. These included integration with the operation of a lift bridge adjacent to one of the priority intersections, high pedestrian flows at priority intersections and the need for a short contra-flow traversal when fire engines need to attend emergencies north of the fire station.

#### *2.4.2.2 Control Strategy Description*

When a lift bridge in Milwaukee is in the raised position a special set of signal plans are automatically initiated. Integration of an emergency vehicle priority system with the operation of the lift bridge was provided by allowing the bridge operation to have pre-emption priority over the OPTICOM emergency vehicle pre-emption priority.

The exit to a fire station in Milwaukee was onto a one-way street. This could mean that a long diversion would be required to attend emergencies in the direction opposite to the direction of the one-way flow. To overcome this a pre-emption strategy was developed to clear the one way street of traffic when a fire engine left the fire station, allowing it to traverse the one-way section against the normal flow. A hardwired connection was made between the fire station and the intersection controller to allow this to happen. On receiving an emergency call requiring a trip in the appropriate direction, pre-emption was used to hold back traffic at the intersection that fed vehicles into the one-way section. All the pedestrian signals at that intersection also showed a “Don’t Walk” display to prevent conflicts with pedestrians.

#### *2.4.2.3 Detection Methods*

OPTICOM emitters and detectors were used (See Section 2.2.6.3).

#### *2.4.2.4 Benefits*

No measured benefits of the system were presented.

### *2.4.3 OPTICOM - Houston, Vicenza*

#### *2.4.3.1 Introduction*

An OPTICOM based emergency response system has been demonstrated and evaluated by the Fire Department in Houston, Texas. Twenty two intersections were equipped with the system, to service emergency vehicle requests from two fire stations.

The OPTICOM based public transport priority system implemented in Vicenza and described in Section 2.2.6 has also been adopted for use by the fire, police and ambulance services in the city. OPTICOM based systems emergency vehicle priority systems have also been implemented in other Italian cities and also in Utrecht and Nijmegen in the Netherlands and in Teeside and London in the UK.

#### *2.4.3.2 Control Strategy Description*

The same priority method as used for public transport is used, except that the emergency vehicles have a higher level of priority. This ensures that the emergency vehicle will always get priority at a junction even if it opposes a priority request from a public transport vehicle.

#### *2.4.3.3 Detection Methods*

The same OPTICOM beacons and detectors as for the Public Transport priority system are used. There is one major difference however. The minimum distance from the junction that vehicles are detected by the OPTICOM system can be a function of the vehicle class. For fast moving emergency vehicles this distance is set to a value of about 500m to allow a smooth and safe transition to green. For buses, the distance is much closer to the stop line and varies according to the intersection layout.

#### *2.4.3.4 Benefits*

In Houston, emergency drivers felt that the new system reduced stress, reduced the likelihood of accidents at junctions and reduced delay. Emergency response times were also reduced.

The priority system has only been installed at two intersections in Vicenza and the beacons attached to two fire engines. However, during the first three months of the trial the equipped fire engines have been able to go through 41 signals that would have been set at red if they were not equipped with the OPTICOM system. The main benefit of the system is seen as being improved safety when crossing junctions with a green rather than having to force their way through a red.

An OPTICOM implementation in St. Pauls, Minnesota, has reduced accidents involving emergency vehicles at junctions by 70%. In Denver, Colorado travel times for firetrucks have been reduced by between 14% and 23%.

### *2.4.4 RESPONSE - Ottawa*

#### *2.4.4.1 Introduction*

An emergency vehicle signal pre-emption system, called RESPONSE (Thompson and Nicholls, 1997), based on GPS units on emergency vehicles has been developed and installed in Ottawa, Canada.

#### *2.4.4.2 Control Strategy Description*

The location of emergency vehicles (fire, police, ambulance) is determined using a GPS unit on each vehicle. This is used to estimate the time of arrival at each signalised intersection. The traffic control system is able to use this information to automatically pre-empt the local signal controller to provide right-of-way. Manual pre-emption is also possible by issuance of a command through the central communications.

#### *2.4.4.3 Detection Methods*

A GPS unit is fitted to each emergency vehicle. This communicates with the centralised traffic control system via a portable cellphone/modem. A dedicated channel was used for the once per second communications required. As well as the usual GPS information about the position, speed and heading of the vehicle, additional information has to be supplied. This includes a unique identifier for each vehicle, whether the vehicle is to make a left or a right turn at the upcoming intersection, the current state of the emergency flashing lights and an indication of whether the vehicle was parked at its destination. A special communications server was produced to handle the messages being received from the emergency vehicles before passing appropriate messages on to the traffic control system. A graphical interface allows the emergency vehicle information to be displayed on a digital map. All data collected by the system is logged for possible future playback.

#### *2.4.4.4 Benefits*

No quantified benefits have been presented.

#### *2.4.4.5 Logical Reference Model Description*

| Node Type | Name | Sends to Node |
|---|---|---|
| A | None | |
| B1<br>B2 | UTC System<br>Communications Server | C<br>B1 |
| C | Local Controller | D |
| D | Traffic Signals | |
| E | GPS Unit | B2 |

## *2.5 Other Selective Vehicle Priority Applications*

### *2.5.1 Long Vehicles and slow moving convoys - BLISS Brisbane*

The BLISS system described in Section 2.2.2 has two further features that might be classified as Selective Vehicle Priority applications. The first involves long slow moving vehicles. These vehicles sometimes arrive at junctions where they would require longer than the minimum green time to cross the junctions. Therefore it was proposed that they should be fitted with VID tags and have the intersection temporarily extend the minimum green time on their detection. The other application involves the introduction of special timing plans for slow moving convoys of vehicles. Examples cited include 100 charter buses attending a convention, or 400 motor cyclists en-route through Brisbane for a charity appeal, or visits by high profile international dignitaries.

# 3. Selective Vehicle Detection Methods

## *3.1 Introduction*

Three main families of vehicle detection methods have been identified.

- **point detection systems**: vehicles are equipped with "electronic registration plates" or "tags", which send a message including the vehicle identification to a specialised loop detector able to read this message when the vehicle crosses it; in this case, we get a precise location at a given time.
- **area detection systems**: an infrared, radar or radio frequency emitter is mounted on the vehicle, and the messages are received by a beacon when the vehicle occupies the area covered by this beacon; messages can include complementary information such as bus stop departure time, ahead/behind of schedule signal and turning signal; reception quality may depend upon meteorological conditions.
- **integrated priority systems**: in this case, PT management is entrusted to an Automated Vehicle Monitoring (AVM) system, which collects all bus positions and communicates with the Traffic Control Centre in order to manage the priority actions. These systems also use Automatic Vehicle Localisation (AVL) systems, with different possible localisation techniques. Usually PT vehicles either use on-board positioning systems (odometry, GPS, GLONASS), which enable them to send their position either in a quasi continuous way (e.g. every 20 seconds) to the PT Control Centre, or only when they pass predetermined locations. Localisation beacons placed along the route enable the drift of odometry based localisation systems to be cancelled.

## *3.2 Loops and Transponders*

| Scheme | Tag Data | Location | Tag Cost | Loop & Reader Cost |
|---|---|---|---|---|
| BLISS<br>Bus Priority | Bus Owner<br>Bus Number<br>Service Number<br>Scheduled Start<br>Passenger Load | >90m from stopline and stopline loops | £25 | £3,500 + loop |
| Portland - A | Bus ID | Roadside, 122 -183 m from stopline and at stopline | £25 | £20,000 |
| Portland - B | Bus ID | at bus stop before stopline and at stopline | £50 | £12,000 |
| SCOOT - Leeds<br>SPOT - Leeds | Bus ID | between bus stop and stopline | £25 | £2,000 |
| Zurich | Vehicle ID | Up to 4 per arm, 200m - intersection | £185 | £10,000 |

In Stuttgart and Winchester systems have been developed which identify public transport vehicles from the signature they make when passing over inductive loops. Such systems can only say whether a vehicle is of a chosen type.

Elsewhere transponder based systems are common. As well as being able to identify a vehicle as being of a given type, the transponder can pass extra information to the control system to allow more selective priority to be given.

### *3.3 Beacons*

Information on typical costs of the OPTICOM infra-red beacon system are given below.

| Scheme | Data | Activation | Tag Cost | Reader Cost |
|---|---|---|---|---|
| OPTICOM | Vehicle Class<br>Priority Level<br>Vehicle ID | Manual or Automatic | £600 | £3000 |

### *3.4 Vehicle Monitoring Systems*

#### *3.4.1 Odometers*

An odometer measures the distance travelled by a vehicle. As public transport vehicles follow fixed routes, the odometer can therefore be used to provide a vehicle location system. This is usually achieved by linking the odometer outputs to a radio transceiver system which allows the odometer unit to be polled at regular intervals by a centrally located monitoring system. The odometer measures the number of wheel turns made. This alone does not usually provide a very accurate measure of distance travelled, therefore an odometer based approach is often supplemented with other information to allow more accurate determination of the vehicle's position. This can include sensors to monitor when the doors open and close at public transport stops, which are at precisely defined locations. Odometer based approaches have been shown to give positional accuracies of better than 5 metres.

#### *3.4.2 GPS and GLONASS*

The Global Positioning System (GPS) has been developed by the US Department of Defence. Twenty four Earth orbiting GPS satellites and a system of ground based tracking stations are used to provide a system which can let anyone equipped with a GPS receiver determine their position (latitude, longitude and altitude) and velocity and the current time. The tracking stations are able to determine highly accurate orbits of the GPS satellites, which they transmit up to the satellites. Highly accurate clocks are also maintained on each GPS satellite, with any required corrections also being made via signals transmitted from the ground stations. The GPS satellites then transmit their position and the transmission time every thirty seconds. A GPS receiver can pick up the signals being transmitted by the GPS satellites. The GPS receiver can calculate how far away a GPS satellite is by comparing the transmission time with the time on its own clock. When the receiver is receiving information from four GPS satellites it is able to determine its own position and an accurate time (which negates the need for a highly accurate clock in the GPS receiver). The orbits of the GPS satellites have been chosen so that there should be between five and eight GPS satellites visible from any point on the Earth's surface at any given time.

The US Department of Defence does not want everyone to be able to determine their position to the highest accuracy possible. It therefore uses cryptographic methods to encode some of the information being supplied by the system. This has the effect of degrading the accuracy of the calculated positions. When working to its full potential (Precise Positioning Service) the system can estimate positions to within less than 20m. The degraded service (Standard Positioning Service) only gives positions accurate to about 100m. For applications such as public transport priority, which require greater accuracy, is possible to use a technique called Differential Correction. Here a ground station whose position is know with absolute accuracy is equipped with a GPS receiver. It compares the position being given by the GPS receiver with its known position and then uses this information to correct the positions of other GPS receivers via a radio link. It is possible to get positions with an accuracy of less than 1m using this technique. This technique costs more however, as a ground station with a radio transmitter has to be provided and the GPS receivers have to be capable of receiving the additional signals from the ground station and integrating this new information with the position data received from the GPS satellites.

GPS based systems have started to be used to track vehicle fleets. Both public transport and emergency vehicle applications have been developed.

The former U.S.S.R developed a similar system to GPS called GLONASS (Global Navigation Satellite System). This system could also be used for selective vehicle tracking but no applications have been discovered by this review. Studies have been performed (Mistra, 1995) on the integrated use of GPS with GLONASS to reduce the errors in the estimates of the positions. These show that such an approach can significantly reduce these errors. The use of GLONASS for position fixing has not yet become widespread in the western world. Only recently have GLONASS receivers become readily available commercially. A further problem is that a full constellation of 24 GLONASS satellites is not currently available. Of the 22 satellites which were in operation by 1996, many have failed and there are now only about 14 alive, and no new launches are planned.

## 4. Conclusions

Details have been obtained on more than twenty different Selective Vehicle Priority systems that have been developed and implemented in many schemes around the world. These have been used to give priority for buses, trams/light rail and emergency vehicles (see Figure 1).

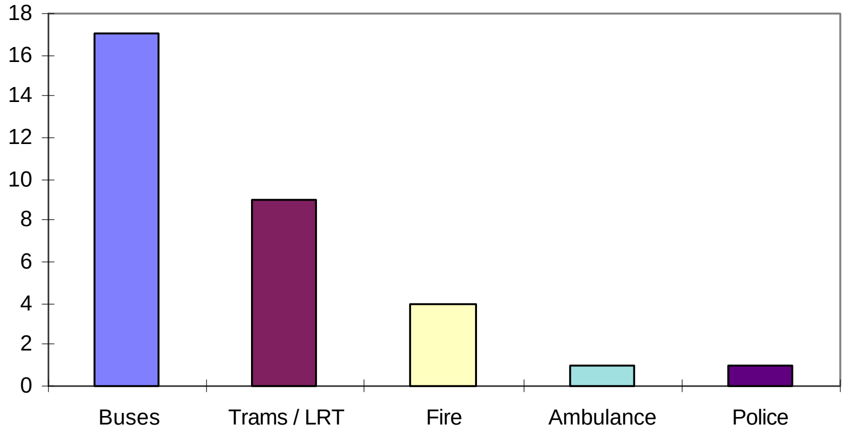

**Figure 1: Selective priority given to different vehicles**

Systems which can give priority to buses are the most common. Very little has been found on priority systems for emergency vehicles, particularly ambulances and police vehicles.

Very few of the selective priority systems developed did more than provide an opportunity for intervention by the local controller on detection of a vehicle requiring priority. Notable exceptions are the UTOPIA system in Torino (Mauro and Di Taranto, 1989) and PRODYN in Toulouse (Henry and Farges, 1994). In both of these adaptive Urban Traffic Control (UTC) systems Automatic Vehicle Location (AVL) is used to continuously track public transport vehicles. Predictions of delay to the public transport vehicles is used when optimising the signal settings.

Most of the priority schemes are based on a handful of possible interventions. These are:

- **extensions**, where a green is extended to allow the priority vehicle through the junction,
- **recalls**, where a stage giving green to the priority vehicle is brought in early,
- **queue jumping**, where a special stage which gives priority vehicles a chance to start ahead of other traffic is triggered,
- **queue management**, where queues of traffic are cleared to allow the priority vehicle a clear run through a junction,
- **triggering green waves**, where a progression through a series of junctions is triggered by the arrival of a priority vehicle.

Many of these interventions are made directly by the local controllers on the street and no attempt is made to compensate non priority vehicles for the extra delay incurred by the passage of the priority vehicle. More recent schemes however attempt to make some compensatory actions. These usually result in lost green time being returned to stages where it has been cut, in the cycle following the passage of the vehicle.

Schemes have also been developed to be selective about giving priority in congested conditions. Priority is not given if it would cause any arms of the junction to become oversaturated, resulting in queues that would not be cleared. Limits can also be placed on how often priority requests are allowed, to avoid continual shortening of opposing phases.

The detection of priority vehicles uses many different technologies (see Figure 2).

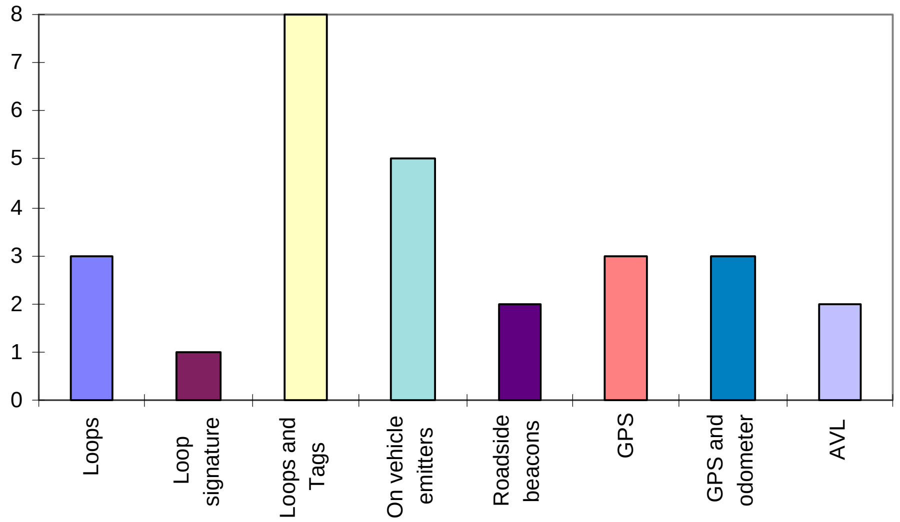

**Figure 2: Vehicle Detection Technologies**

Some of the methods are only able to provide the information that a priority vehicle has been detected, whilst others are able to also provide extra information about the priority vehicle which can be used to make priority requests more selective. The most common use of this information is to determine whether a public transport vehicle is adhering to its schedule and only give it priority if it is running late. Conflicts, where public transport vehicles on opposing stages both request priority at the same time, can also be resolved by giving first priority to the vehicle with the most passengers or the vehicle which is most behind schedule.

It is also common to have a combined public transport and emergency vehicle priority system, where emergency vehicles get a higher level of priority than public transport vehicles. In this case there is a need to discriminate between the two different classes of vehicle.

One final method, which is not really a priority method but which uses the same technology, is used where a public transport stop is close to a junction. A special signal at the stop is used to provide advance notice of an upcoming green signal at the junction so that the public transport vehicle can leave the stop and be sure it will not be held up as it passes through the junction. This means that the public transport vehicle only waits at the stop, where it can pick up passengers, rather than at the signals where it cannot. Such a method has been used in both Sheffield, UK and Long Beach, California.

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## 6. Abbreviations

| | |
|---|---|
| AUT | Automatic Update of TRANSYT |
| AVI | Automatic Vehicle Identification |
| AVL | Automatic Vehicle Localisation |
| AVM | Automatic Vehicle Monitoring |
| BLISS | Brisbane Linked Intersection Signal System |
| BALANCE | Balancing Adaptive Network Control Method |
| DETR | Department of the Environment, Transport and the Regions |
| ETM | Electronic Ticketing Machine |
| GLONASS | GLObal NAvigation Satellite System |
| GPS | Global Positioning System |
| HUTSIM | Helsinki University of Technology Simulator |
| LRT | Light Rail Transit |
| MOVA | Microprocessor Optimised Vehicle Activation |
| PRIMAVERA | Priority Management for Vehicle Efficiency Environment and Road Safety on Arterials (a DRIVE II project) |
| PROMPT | PRiority and InfOrMatics in Public Transport (a DRIVE II project) |
| PT | Public Transport |
| RNC | Radio Network Controller |
| SCATS | Sydney Co-ordinated Adaptive Traffic System |
| SCOOT | Split, Cycle and Offset Optimisation Technique |
| SPOT | System for Priority and Optimisation of Traffic (Sistema per la Priorità e lìOttimizzazione del Traffic) |
| SPRINT | Selective Priority Network Technique |
| SPRUCE | Selected Vehicle Priority in the Urban Environment |

| | |
|---|---|
| SVD | Selective Vehicle Detection |
| TPC | Traffic Priority Controller |
| TRANSYT | Traffic Network Study Tool |
| UNIX | Not an acronym at all! In the authors' words, "A weak pun on Multics". An interactive time-sharing operating system invented in 1969 by Ken Thompson and Dennis Ritchie. |
| UTC | Urban Traffic Control |
| UTMC | Urban Traffic Management and Control |
| UTOPIA | Urban Traffic Optimisation by Integrated Automation |
| VID | Vehicle Identification |

## Appendix A - Logical Reference Model

Here a UTMC system is described by a series of interconnected nodes as given in Table 2 and depicted in Figure 3.

| Node Type | Description |
|---|---|
| A | Fixed gateways to external systems including other UTMC systems |
| B | UTMC management centres - instations |
| C | UTMC outstations |
| D | UTMC controlled units and detectors (on street) |
| E | Mobile units - In vehicle systems |

**Table 2: UTMC Node Types**

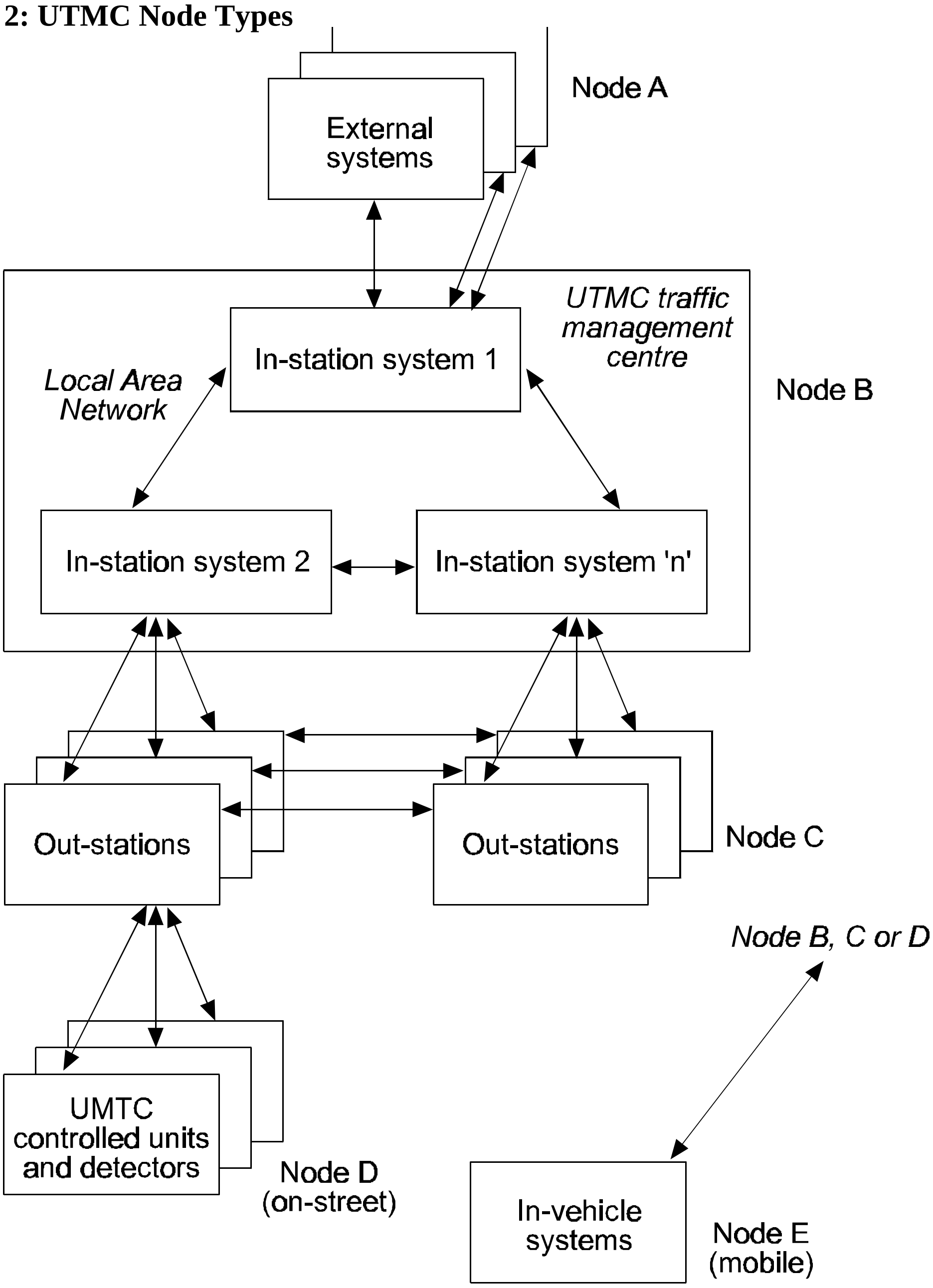

**Figure 3: UTMC Logical Reference Model**

The components are defined as follows (taken from TS001-Part 1, DETR, 1997):

***External system***: Systems that are not formally part of an individual UTMC system, but may exchange information with the UTMC system. An external system has no direct contact with UTMC outstations.

***Instation***: Collection of UTMC components and applications based in an indoor environment. Will often be regularly manned. While conceptually there must be only one Node B (UTMC management centre) in a UTMC system TS 001 allows for Node B to be distributed over a Local Area Network (LAN), or Wide Area Network. Node B may be physically distributed in several locations, but shall act as a single logical node.

***Outstation***: UTMC components and applications based in the field. Outstations will not normally be manned. Nodes C may be capable of acting autonomously taking higher level control decisions. Nodes C may be permanent or temporary installations. Nodes C, outstations, are not simply equipment under control (Node D). They are on-street equipment with local processing power and data storage.

***UTMC Controlled Units and Detectors***: Equipment which cannot act autonomously. Nodes D may be permanent or temporary installations.

***In-vehicle Systems***: Nodes E may range from simple units to sophisticated units with local processing power.

The following restrictions on configuration shall apply:

a) there may be zero or more Nodes A;
b) there shall be one and only one Node B;
c) there may be zero or more Nodes C;
d) there may be zero or more Nodes D;
e) there may be zero or more Nodes E; and
f) there shall be at least one Node D or Node E in a UTMC system.