

Bus Priority at Traffic Signals— Evaluating Strategy Options

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Abstract

This article compares different strategy options for providing bus priority at traffic signals. The different strategies considered vary in the strength of the priority awarded and in the selection of the buses that are to receive priority. The strategies include so-called differential priority, where buses receive individual priority treatment according to some criterion such as lateness, and nondifferential priority, where all buses are treated in the same way.

The strategies are compared using a simulation model, SPLIT, that has been developed and validated by the authors. The article describes some of the modelling issues that are involved in simulating bus priority systems and how they have been treated within the SPLIT model.

Introduction

Bus transit priority at traffic signals has been used in many cities worldwide and is becoming increasingly accepted as a way in which bus operations can be improved, complementing other measures such as bus lanes and automated ticketing arrangements. One of the reasons why the use of bus priority at traffic signals is widespread is that it can be applied almost anywhere, as there is no need for additional road space for buses or for buses to be segregated from general traffic. Example applications of bus priority at traffic signals include London, Tokyo,

Melbourne, and Portland, Oregon. The state-of-the-art in bus priority applications in Europe was reviewed by Hounsell and Wall (2002).

This article describes research undertaken in a European Union funded project, PRISCILLA, investigating the performance of different bus priority strategies. These strategies differed from one another in terms of the strength of the priority actions taken and in the selection of which buses to give priority to. The form of priority where different buses are awarded different levels of priority, usually according to a bus lateness criterion, is known as *differential priority*.

The majority of reported bus priority applications tend to be implemented on a single bus corridor or on a small number of bus corridors. One of the objectives of this research was to widen the application to consider bus priority over a citywide bus network. The city used here was Southampton in the United Kingdom.

The research was based on the bus priority facilities available within the SCOOT traffic signal control system, as developed by the Transportation Research Laboratory (TRL) in the United Kingdom (Bretherton et al. 1996). Updated details of these facilities are reported at the website: <http://www.scoot-utc.com/SCOOTFacilities/busprior.htm>. The basic priority actions that can be taken under this control system are to give an approaching bus extra green time to get through the junction or to recall the required signal phase sooner than would be done otherwise. Since these priority actions are fundamental to the majority of bus priority control systems, the results presented here will be of general interest and application.

Assessment of different bus priority strategies was undertaken using a simulation model, Selective Priority to Late buses Implemented at Traffic signals (SPLIT), that has been designed and developed by the authors since 1996 (McLeod 1998). This article includes details of some features of this model, including the modelling of buses, passengers, nonpriority traffic, and how they interact with each other.

The network used was based on the City of Southampton in the United Kingdom. The article describes the network topology, bus services modelled, routes taken, and numbers of traffic signals encountered. Results and conclusions from the simulation runs of the different bus priority strategies are described.

The Bus Priority System

The research presented here was based upon the bus priority facilities available within the SCOOT traffic signal control system (Bretherton et al. 1996). This

section provides a brief description of these facilities and gives details of the priority strategies considered.

Priority Levels

Different levels of priority can be awarded to different buses, typically according to the lateness of the individual bus. Each priority level is defined by parameters that specify the traffic degree of saturation conditions under which the bus is allowed to receive either:

1. a signal *extension*, where the bus is detected on a green signal aspect, which is maintained until the bus passes by, or
2. a signal *recall*, where the bus is detected on a red signal aspect, whose length is reduced so that the desired green signal aspect comes around quicker.

These degree of saturation parameters can be used to constrain the bus priority actions, where desired, to ensure that delays to nonpriority traffic streams are acceptable. Clearly, the definition of “acceptable” here is a question of policy and will depend on a number of political factors.

Four different priority levels were considered in this research (Table 1).

Table 1. Priority Levels

| Priority Level | Priority Description |
|-----------------------|---|
| 0 | No priority |
| 1 | Signal extensions only (no recalls) |
| 2 | Extensions and recalls (constrained: degree of saturation of nonpriority traffic stream not allowed to exceed 95% as a result of any bus priority action) |
| 3 | Extensions and recalls (unconstrained) |

Priority Strategies

A number of different priority strategies were considered, varying both in the level of priority awarded and in the buses that receive the priority. The priority strategies are described below.

Priority strategy P0—No Priority.

None of the buses in the network are given priority. This is the base case against which the other priority strategies are compared.

Priority Strategy P1—Extensions Only.

All buses in the network are awarded traffic signal extensions, where required, but traffic signal recalls are not awarded to any bus. This is a moderate form of priority that, from previous experience, has little or no negative effect on nonpriority traffic.

Priority Strategy P2—Priority to Late Buses Only.

Buses that are late receive the highest priority level, while buses that are on time or early do not receive any priority.

Priority Strategy P3—Hybrid of P1 and P2.

In this strategy buses that are late receive full priority while other buses are eligible for a traffic signal extension only. This may be justifiable because extensions provide substantial delay savings to the small proportion of buses (~10%) for which an extension is appropriate.

Priority Strategy P4—Full Priority.

The highest level of priority is awarded to all buses. This is the most extreme, strongest priority strategy possible and the most likely to have a negative effect on nonpriority traffic.

Central or Local Control

Traffic signal extensions can be controlled by the central SCOOT computer or by the local traffic signal controller. The main advantage of local control is that a faster response to buses can be achieved than through central control, which incurs delays due to transmission lags between the local traffic signal controller and the central SCOOT computer. A fast response is particularly important for the awarding of a traffic signal extension, as it has a direct influence on the “window of

opportunity” for gaining an extension. The effect of a transmission lag of x seconds is equivalent, in effect, to detecting the bus x seconds closer to the stopline. In practice, central control is often preferred, however, as it is easier to set up and maintain.

Restricting Recalls

Previous experience of bus priority applications in London (Hounsell et al. 1996) found that traffic signal recalls can sometimes have a damaging effect on nonpriority traffic. This is particularly true when the nonpriority traffic flow is high, as can happen when the priority bus turns into a busy main road from a side road. One of the reasons for this negative effect is the resulting loss of good traffic signal coordination on the main road. Bearing this in mind, it seems sensible to restrict traffic signal recalls to junctions where the total volume of nonpriority traffic, summed over all of the nonpriority traffic arms, is below some specified limit. For the purposes of this research, a limit of 1,500 vehicles/hour was specified and simulation runs with and without this restriction in place were made to investigate the effects.

Simulation Network Details

The bus priority system was modelled using a simulation model, SPLIT, developed by the authors since 1996. Details of the model and its validation are provided by McLeod (1998). The following sections provide information about some of the modelling aspects of the research, including modelling of the buses, passengers, other traffic, and their interactions.

Bus Network

The bus network used was based on the City of Southampton, United Kingdom. Southampton has a population of around 215,000 but with a travel to work area population of approximately 500,000. It is a regional center with the port as the main industry. Southampton is constrained by the sea to the south and two rivers that dissect the City. As with most cities throughout the world, the City council's policies limit the use of private transport within the highly developed area and promote the use of public transport.

The modelled network consisted of six bus services operating on overlapping routes. These bus services run between the city center to the south and Southampton Airport and the University of Southampton at the northern end of the City. Details of these bus services are shown in Table 2.

Table 2. Bus Services in Southampton SPLIT Network

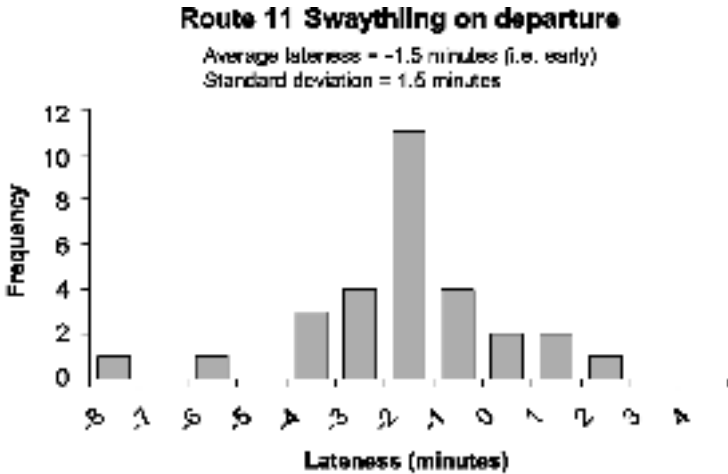
| Route No. | No. of Bus Stops | Bus Frequency | Route Length | Average No. of Users | No. of Traffic Signals |
|-----------|------------------|---------------|--------------|----------------------|------------------------|
| | | (bus/hr) | (km) | (passenger/bus) | |
| 101 | 30 | 3 | 7.7 | 30 | 12 |
| 11 | 31 | 3 | 8.1 | 21 | 16 |
| 13 | 29 | 3 | 8.1 | 21 | 17 |
| 20 | 30 | 2 | 8.8 | 36 | 14 |
| 102 | 21 | 2 | 8.8 | 18 | 9 |
| 103 | 10 | 2 | 4.8 | 9 | 4 |

Key: No. of users = total number of boarding passengers

Bus Punctuality

Bus punctuality, or lateness, was an important consideration, as it affected which buses received priority under the differential bus priority strategies (P2 and P3). Bus lateness was calculated for each bus whenever the bus departed from a bus stop and was defined to be the difference between the actual departure time and the scheduled departure time. Bus entry times onto the network were varied in the simulation runs to give a range of different starting conditions for buses, in terms of their lateness at the start of the route. An example frequency distribution of bus lateness near the start of one of the routes being modelled is shown in Figure 1. This frequency distribution was based on a sample of five day's data collection.

Figure 1. Frequency Distribution of Lateness



Bus Passengers

Passenger arrivals at bus stops in the Southampton network were obtained from on-street surveys and were used to validate the simulation model. For high frequency bus services (10-minute frequency or more), it was found that passengers tended to arrive at random. For lower frequency services, there was a tendency for passengers to time their arrival time according to the scheduled arrival time of the bus. This tendency was most marked at the lowest frequency service considered here (30-minute frequency).

Traffic Congestion

Bus travel times along a route vary from day to day according to a number of factors, including traffic congestion. Clearly traffic congestion will have a significant effect on bus punctuality and on any bus priority control strategy that tries to maintain buses running to schedule. Although, vehicles are not explicitly modelled within SPLIT, the effects of varying levels of traffic congestion were approximated by varying the amount of junction delay incurred at traffic signals by buses. Typical junction delays were obtained through collection of data from the traffic signal control system, SCOOT, operating in Southampton.

Results and Evaluation

The different bus priority strategies were compared through a series of simulation runs. The strategies were compared in terms of their effects on:

- bus travel cost saving (euro/hour); this was totalled over the whole bus network modelled (15 buses/hour) and reflects the effect on bus journey times through the network;
- passenger waiting cost saving (euro/hour); this was totalled over all waiting passengers (~340 passengers per hour) and reflects the regularity of the bus service and how long passengers have to wait at bus stops;
- disbenefit to nonpriority traffic (euro/hour); this was totalled over all of the nonpriority traffic flows modelled; these varied from link to link with an average nonpriority traffic flow of 1,000 vehicles/hour approximately; this measure took into account any negative impact of the priority system on nonpriority traffic;
- overall cost saving (euro/hour); that is, the aggregate of the above cost savings less the disbenefit to nonpriority traffic.

Costs for the whole network, in terms of euro/hour, were chosen as performance measures to allow a direct comparison between the different aspects of performance, namely the effects on bus journey times, passengers waiting times and delay to nonpriority traffic. Costs per bus, per passenger or per vehicle are not shown here but can be readily derived by dividing by the appropriate numbers of buses, passengers, and vehicles as stated above.

Results from the different priority strategies are compared in Figure 2.

Figure 2. Effect of Priority Strategy



Comparison Strategies

Effect on Bus Travel Time

As one might expect, bus travel time savings increase as the priority strength is increased and as more buses receive priority.

The largest saving is seen for strategy P4, where the highest level of priority was given to all buses.

Effect on Passenger Waiting Times

The largest passenger waiting time saving is found for the differential priority strategy (P2), where only late buses receive priority.

A smaller waiting time saving was found for strategy P3, where late buses received full priority and other buses were eligible to receive a traffic signal extension.

Where all buses were treated identically (i.e., nondifferential priority), the effects on passenger waiting time were negligible or worse).

In the case of strategy P4, where all buses received the highest level of priority, a negative effect on passenger waiting time was found. The reason for this was that some buses in the model were ahead of schedule and were still given

priority under this scenario. In practice, it is likely that there would be some form of bus fleet control, separate from the bus priority system, to avoid buses running ahead of schedule. This result would not generally be expected.

Effect on Delay to Nonpriority Traffic

There is a negative effect on nonpriority traffic that tends to increase the more priority is given to buses. It should be explained, however, that this effect is built into the SPLIT simulation model based on measurements taken in field trials in London (Hounsell et al. 1996). Explicit modelling of traffic and their interaction with the bus priority actions taken at traffic signals is not undertaken in SPLIT.

Overall Effect

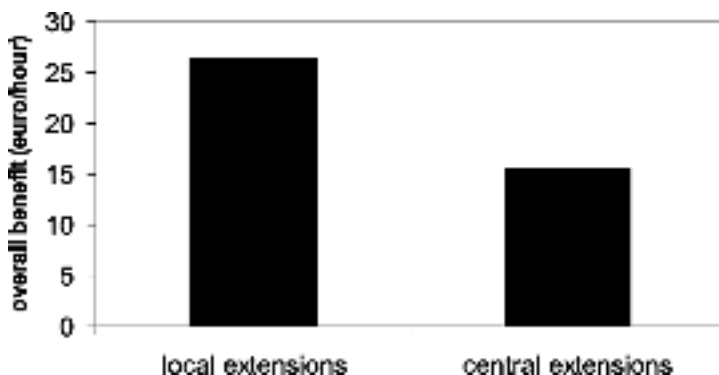
Two differential priority strategies, P2 and P3, gave the best overall results, as they had positive effects on both bus travel time and passenger waiting time and only a relatively small negative effect on nonpriority traffic.

The full priority strategy, P3, did not perform so well overall here, as bus travel time benefits were cancelled out by negative effects on passenger waiting time and disbenefits to nonpriority traffic.

Central or Local Extensions

The results of implementing traffic signal extensions either locally or centrally are compared in Figure 3. The priority strategy used here was to award extensions only (strategy P1). It can be seen that the overall benefit, taking both buses and

Figure 3. Comparison of Central and Local Traffic Signal Extensions



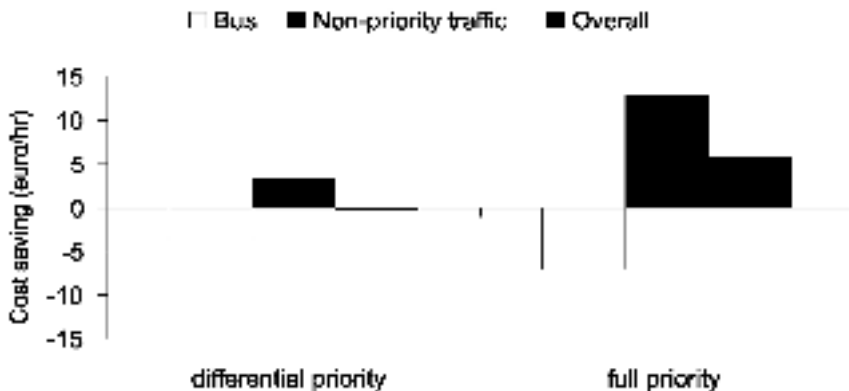
general traffic into account, increased from around 15 euros/hour to 25 euros/hour, as a result of moving from central control to local control.

Restricting Recalls

The effect of restricting traffic signal recalls to those junctions where the total nonpriority traffic flow was less than 1,500 vehicles/hour is shown in Figure 4 for two different priority strategies: differential priority strategy (P2) and full priority strategy (P3). With this restriction in place, the number of recalls awarded was reduced by about 20 percent. It can be seen from Figure 4 that restricting traffic signal recalls has:

- reduced the benefits to buses,
- increased benefits to nonpriority traffic,
- for the differential priority strategy, these results have cancelled each other, and
- for the full priority strategy, there has been a small net overall benefit here, although, this result is specific to the relative bus and nonpriority traffic flows used in this simulation run, as described earlier.

Figure 4. Restricting Number of Traffic Signal Recalls



It is desirable to implement traffic signal extensions locally, at the traffic signal controller, rather than via the central control computer, as the opportunities for buses gaining traffic signal extensions are increased. This is due to the avoidance of the transmission lag associated with the communication between the traffic signal controller and the central computer operating the bus priority system. Anticipated benefits to bus passengers were confirmed by the simulation runs. Provision of local traffic signal extensions requires special conditioning of traffic signal controllers. This additional work could act as a barrier to implementation of local extensions and the preference of using central extensions in SCOOT.

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