NEW STRATEGY OPTIONS FOR BUS PRIORITY AT TRAFFIC SIGNALS IN LONDON

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1. INTRODUCTION

Providing fast, frequent and reliable bus services is a key requirement for sustainable transport operations in many cities. As a part of achieving this goal, many cities and bus operators are implementing Automatic Vehicle Location (AVL) systems to support comprehensive public transport management, real time passenger information and bus priority at traffic signals. In London, Transport for London (TfL) has recently procured a GPS (Global Positioning System) based AVL system known as iBUS for this purpose. For bus priority at traffic signals, iBUS uses detector locations configured in the on-bus computer (known as "virtual detectors") to detect buses. In addition to this flexibility for detecting buses, iBUS also has the facility to monitor buses continuously from the control centre to assess their locations. This provides a real opportunity for Tfl to implement more targeted priority to buses. In this context, current research being carried out by the Transportation Research Group (TRG) for TfL is exploring different priority strategies.

Differential priority is a common term used to describe the strategy where different levels of priority are given to buses at traffic signals according to their need. Differential priority can allow a higher level of priority to be given to some buses (e.g. those which are late) and a lower level or no priority to others. The objective of this form of differential priority is generally to produce improved punctuality for low frequency time-tabled services, or improved regularity for higher frequency, headway-based services. Although this type of strategy can help make buses more punctual and reduce passenger waiting time, it gives lower journey time savings compared to the strategy giving priority to all buses. Clearly passengers waiting for a bus gain from improved punctuality, whilst those on board benefit from reduced journey times.

Implementation of a priority strategy depends on the policy objective of the respective authority. Unless the policy is only concentrated on improving passenger waiting time, a strategy giving a more balanced benefit in terms of passenger waiting time as well as the journey time savings could be more appropriate. Furthermore, a more enhanced priority strategy such as taking account also of the headway of the bus behind could be beneficial. The impact of such a strategy may also be influenced by the bus location on its route. For example, punctuality/reliability of an individual route may be of less importance in the location where many services converge (e.g. near a city centre). This paper will report on the progress and results of research into these options being undertaken by TRG for the TfL Bus Priority Team (BPT) to review how differential priority operates in iBUS and what might be the best priority strategy deployed to get the best outcome. This paper collates earlier results from TRG as well as presenting recent analytical results to derive more efficient priority strategies for iBUS.

2. DIFFERENTIAL PRIORITY

Differential priority is the term used here to describe the method of giving different levels of priority to buses at traffic signals according to their adherence to frequency. Differential priority can be used to give a higher level of priority to late buses and a lower level or no priority to the buses which are early or on time. It has earlier been shown that selecting buses for priority according to their headway (relative to the scheduled headway), in the case of headway-based services, can be better than providing priority for all buses. Benefits include (Hounsell et al, 1999); improved service regularity, which reduces passenger waiting times; targeting buses with a higher occupancy, because late buses typically have to pick up more passengers; the possible provision of a higher level of priority and less disruption to general traffic, because fewer buses are awarded priority.

Differential priority is reported to be implemented in many European cities including Cardiff (Hill, 2000), Leicester (Gillam et al, 2000), Twente (Witbreul, 2004) and Eidenhoven (Furth, 2000). Most of these systems are understood to have implemented a simple form of differential priority -giving priority to late buses only. Buses on time or early do not get priority in these systems. The trial in Eidenhoven (Netherlands), demonstrated that differential priority (termed as conditional priority in the literature) giving priority to late buses only at traffic signals is an effective and practical strategy for improving service regularity (Furth, 2000). However, as anticipated, the study found lower bus delay savings from differential priority in comparison to priority to all buses. This shows that priority to late buses only should be the strategy when the prime concern is bus regularity and not bus delay savings. This also highlights that different priority strategies could be implemented to achieve different scheme objectives. These objectives could be: to obtain maximum bus delay savings, improve regularity or overall economic benefits.

Whilst giving priority to late buses only is a feasible strategy, an earlier feasibility study carried out by TRG [8] concluded that differential priority giving varying levels of priority according to the lateness of the buses is feasible and beneficial. The study which was carried out in the context of a beacon-based AVL system looked at different priority logics utilising combinations of different priority levels and degrees of lateness. With the change in the AVL system in London to iBUS, these strategies have to be revisited and explored for further improvements in the context of the iBUS priority architecture described below.

3. IBUS ARCHITECTURE

The priority architecture for differential priority can vary from one system to another in terms of the location of intelligence where the priority calculation is made and the way priority is communicated to the traffic signals. With a growing number of differential priority schemes, it is apparent that a wide range of architectures are being employed in different cities to achieve the objectives. A comparison of the effectiveness of these different bus priority architectures on the basis of their important aspects and options available was carried out in earlier research (Hounsell and Shrestha, 2005). On this basis, the iBUS architecture should be efficient for differential priority implementation in terms of the intelligence location and the way of communication. A functional diagram showing the working of differential priority at traffic signals using iBUS is given in Figure 1.

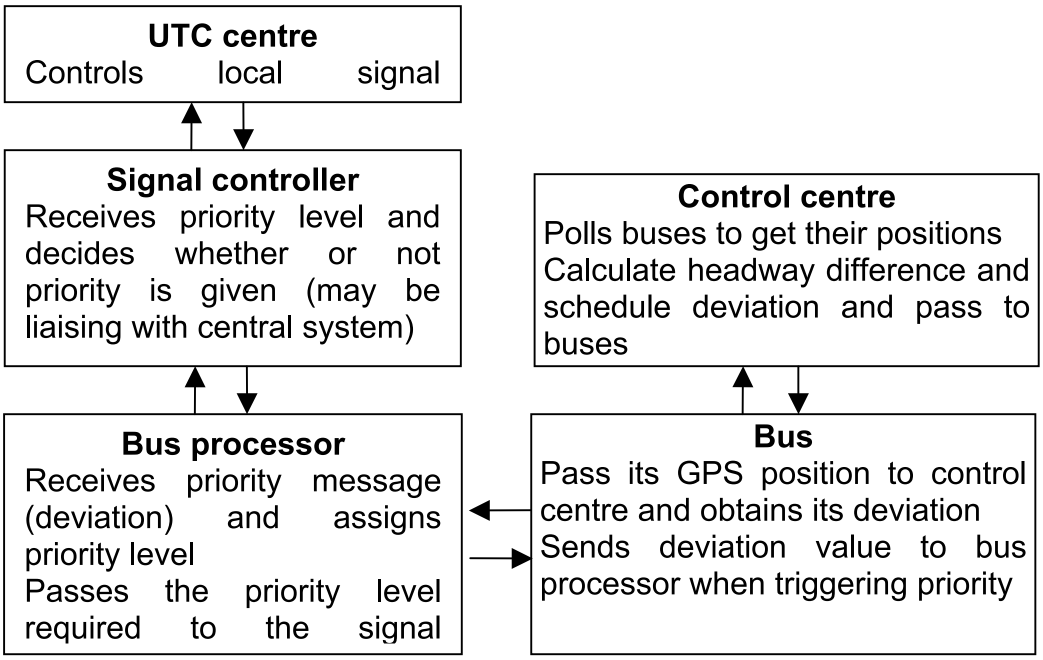

Figure 1: Functional diagram of working of differential priority using iBUS

In this priority architecture, each bus receives its location every second from its onboard GPS unit and is continuously monitored by the control centre. Monitoring is done by polling buses in 30-60 second intervals in addition to the information of arrival time at a bus stop that each bus sends when departing from a bus stop. The control centre uses the location information to update locations of the buses in its system and to calculate the headway deviation of the bus. The headway deviation hence calculated is passed to the bus in a coded format. When a bus arrives near a traffic signal, the bus is detected at one or more predefined locations on the approach and a priority request is sent by radio to the bus processor housed with the traffic signal controller. The detection is carried out by comparing the location of the bus with the predefined location of the detection point(s) on the route, stored in the on-board computer. These detection points are also known as virtual detectors (as they have no physical presence). When priority is triggered, the bus sends the deviation to the bus processor (in the signal controller) in a coded format when sending priority requests.

The bus processor receives the deviation after decoding the priority message from the bus. Then it decides the priority level based on the deviation and the priority strategy implemented. In the case of traffic signals under SCOOT UTC control, the priority level sets the parameter for SCOOT to calculate the amount of the priority time available to the detected bus at the junction. This priority level is then passed back to the signal controller for implementation. Within the constraint of the amount of priority time available, the priority request is implemented mainly in two ways: extensions and recalls. With 'Extensions' the present green time is extended, if it is expected that the bus detected would otherwise just miss the present green period. A 'Recall' is where the green time is recalled to give green to the bus more quickly if the bus is detected in the red period and is expected to arrive at the stopline before the start of the next green period. Facilities to compensate traffic on non-priority stages are also usually provided according to the type of signal control (e.g. SCOOT).

iBUS priority architecture has intelligence at the control centre (to calculate the deviation of buses) as well as in the local bus processor (to assign the level of priority). This allows various types of differential priority strategies to be implemented taking account of individual buses as well as the wider network. The differential priority strategies that can be implemented currently by iBUS are discussed below.

4. DIFFERENTIAL PRIORITY STRATEGIES

The priority strategy defines the criteria to assign the level of priority a bus can get depending on its lateness. The lateness could be measured referring to the predefined timetable (in the case of timetable service) or referring to the planned headway (in the case of high frequency services). These strategies alter the number of buses eligible for priority (depending on the lateness criteria) and the amount of priority they can get (depending on the priority level assigned). When priority is implemented via SCOOT, the priority levels relate to the different target degree of saturations for different types of priority (extensions or recalls) configured in the SCOOT controller (DETR, 2000). The target degree of saturation (DOS) specifies the saturation level that is allowable on non-priority stages. The higher this target DOS, the more ‘spare green time’ can be re-allocated for the priority stage(s), but at the expense of additional delay on the non-priority stages(s). The proportion of buses getting different priority levels changes the outcome of the bus priority in terms of bus delay savings, regularity benefits, impacts on other traffic and total economic benefits.

Various strategies for differential priority that that can be implemented in iBUS were studied in the earlier TRG study PRO 310 (TRG, 1997) and TRL study for DfT (Project UG274). These strategies included: similar priority to all buses; high priority to late buses and no priority to others; and high priority to late buses and low priority to others. The UG274 study estimated the benefits from these different priority strategies based partly on the results of on-street trials (delay savings) and partly on the simulation work (regularity benefits). The estimated benefits from different priority strategies are given in Table 1 (Hounsell et al, 2008).

Table 1: Priority benefits from different strategies for headway based service

Benefit	Strategy		
	Priority to all buses	High priority to late buses and no priority to others	High priority to late buses and extensions to others
Bus delay savings	15% to 30% (3 to 6 sec/bus/junction)	8% to 15% (1.5 to 3 sec/bus/junction)	10 to 20% (2 to 4 sec/bus/junction)
Regularity improvement	-2% to +2%	3% to 10%	0% to 3%
Other traffic delays (increase)	0% to 5%	0% to 3%	0% to 5%
Economic benefits	1%	0.5%	1.5%

Table 1 shows that giving priority to all buses gives the best bus delay savings but is not effective in improving bus regularity. For improving bus regularity, a strategy giving priority to late buses only is the best. Giving high priority to late buses and extensions only to others gives modest bus delay savings as well as regularity improvements. This strategy gives the best overall economic benefits without much disturbance to non-priority traffic. As this strategy aims to cover all the buses with different priority levels, this is the best strategy where the objective is to maximise economic benefits taking account of all traffic. Hence where the performance criteria is not to be based solely on minimum delay or 'optimum' regularity, this strategy providing high priority to late buses and extensions only to others could be the best strategy for differential priority strategy implementation.

5. ENHANCED PRIORITY STRATEGY

In the priority strategy discussed in the previous section, the level of priority given to a bus depends solely on its headway deviation to the bus in front (for headway based system). This method is simple in terms of implementation and targets all buses that are late (i.e. bigger headways than scheduled). However, this method of giving priority may not always be the most efficient. For example, when the following bus has a bigger headway than the bus concerned has, the priority may not be very efficient in terms of the passenger waiting time. Average passenger waiting time may be improved by giving priority to buses with bigger headways rather than all late buses. The basic philosophy behind such a strategy is based on the relationship between bus headways and average passenger waiting time as given below (Mcleod, 1999).

$$Average\ waiting\ time = \frac{\sum_i H_i^2}{2 \times \sum_i H_i} \quad \text{...(a)}$$

This relationship shows that the average waiting time depends on the squared headways (as the sum of headways is a constant term). Hence, reducing bigger headways results in higher passenger waiting time savings than smaller headways. A bus with a bigger headway can be identified by comparing the headway of a bus with the headway of the bus behind. If the bus behind has a bigger headway, then priority would not be awarded to the front bus under this new strategy. The bus behind is then compared with the next bus behind when considering priority for it. The process would continue and priority given to a bus only when the headway of the bus behind is smaller than its headway. This makes sure that the priority helps to improve the headway of both buses and hence improves overall headway regularity more effectively.

A simple analysis can demonstrate this issue by taking an example of a bus system with 10 buses per hour (6 minutes scheduled headways) shown in Figure 2. The actual headways H1, H2, H3, H4 and H5 of buses B1, B2, B3, B4 and B5 are assumed to be different from the scheduled headway H. The total time period between buses B0 and B5 is assumed to be same as scheduled.

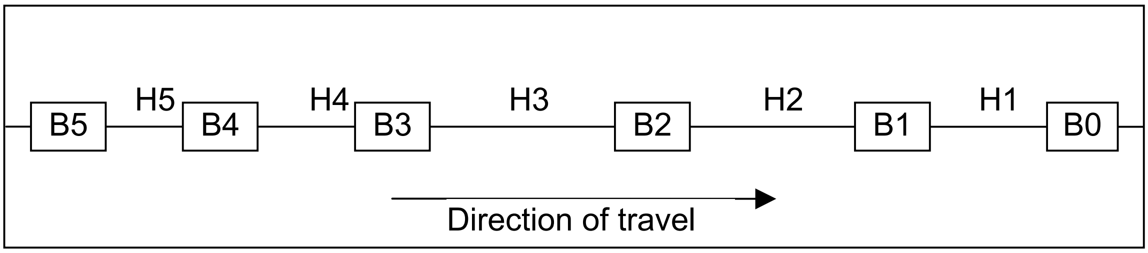

Figure 2: Simple representation of different bus headways in a route

In this example, buses are given priority at traffic signals using two different strategies: priority to buses with headway bigger than scheduled headway (strategy 1); and (ii) priority to buses with headway bigger than that of the bus behind (strategy 2). For simplicity, the priority benefit from bus priority is assumed to be 1 minute for all buses getting priority. Bus headways under different scenarios and corresponding passenger waiting times are shown in Table 7 below. In the table, average passenger waiting time (Average wait time) is calculated using relationship (a) given above.

Implementing priority Strategy 1, Bus B2 (headway H2=7 minutes) and Bus 3 (headway H3=9 minutes) both get priority as their headways are bigger than the scheduled headway (H=6 minutes). As a result, the headway of Bus B2 (H2) is reduced to 6 minutes (shown in 4th row of Table 4). Even though Bus

B3 also gets priority, its headway (in relation to Bus B2) remains same (because both getting priority). The change in the headways as a result of priority is shown in 4th row of Table 2. In this case, the average passenger waiting time calculated is 3.30 minutes (shown in the last column).

Implementing priority Strategy 2, Bus B2 with headway H2=7 minutes which is more than the scheduled headway (H=6 minutes) but less than the headway of Bus 3 (H3=9 minutes) does not get priority. Only Bus B3 gets priority in this case. As a result, the headway of Bus B2 (H2) remains unaltered as 7 minutes. However, the headway of Bus B3 is reduced to 8 minutes. The change in the headways as a result of priority is shown in 5th row of Table 2. In this case, the average passenger waiting time calculated is 3.17 minutes

Table 2: Analysis of waiting time benefits from different priority strategies

Scenarios	Bus headways					Average waiting time (min)
	H1 (min)	H2 (min)	H3 (min)	H4 (min)	H5 (min)	
Scheduled headway (H)	6	6	6	6	6	3.00
Actual headway (No priority)	6	7	9	5	3	3.33
Headway using priority Strategy 1	6	6	9	6	3	3.30
Headway using priority Strategy 2	6	7	8	5	4	3.17

Table 2 shows that giving priority to buses using current practice (Strategy 1) improves average passenger waiting time in comparison to no priority. However, the priority strategy taking account of the bus behind (strategy 2) gives lower passenger waiting time than current practice (Strategy 1). In this example, the improvement in passenger waiting time is achieved despite having the same number of buses (2 buses in each case) getting priority from both priority strategies. It is to be noted that bus journey time savings are not taken into account in this example. Since the numbers of buses getting priority are same in this example, the resulting bus journey time is expected to be the same. However, the numbers of buses getting priority and the journey time savings from bus priority are not necessarily the same in all cases. This depends on the proportion of buses that have a headway bigger than the scheduled headway and the sequence of the bus headways. Further discussion on practical aspects of implementing this strategy is given in Section 7.

6. ALTERNATIVE IMPLEMENTATION STRATEGY

Differential priority is sufficiently flexible to allow different priority strategies to be implemented at consecutive traffic signals along a bus route, if there is a benefit in doing so. It could be, for example, that towards the end of a bus route there are many more passengers onboard than waiting to board, so that priority to all buses might be better than differential priority. This is illustrated in the following paragraph.

A bus passenger survey carried out earlier in the Portswood corridor (Shrestha, 2003) in Southampton is shown in Figure 3. This figure shows the number of passengers alighting and boarding at 16 bus stops along the route. The data was collected from 30 buses serving the corridor for 2-hour period between 10:00 -12:00. A feature of this corridor is that there is Portswood town centre in the middle of the route on the way to the city centre. With the additional bus routes merging, the number of bus services towards city centre is doubled. The bus stop at Portswood is marked by high passenger activity.

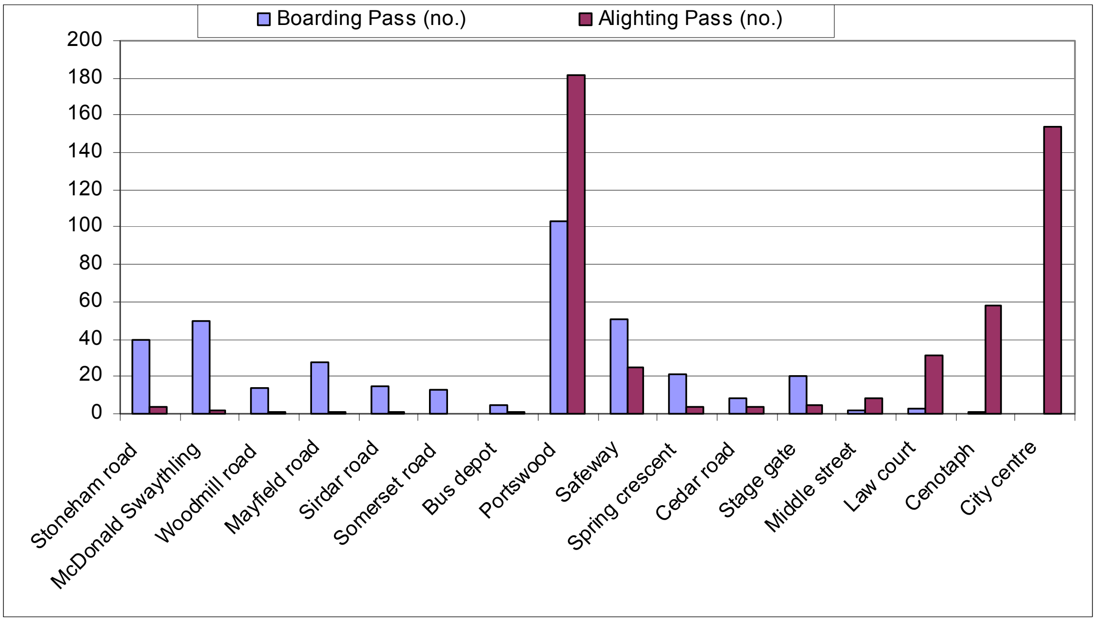

Figure 3: No. of boarding and alighting passengers along Portswood corridor

Figure 3 shows that the bus stops along the latter part of a route have more alighting passengers and very few boarding passengers (N.B. - the unequal number of passenger boarding and alighting are due to the number of passengers already inside the bus at the beginning of the corridor which is upstream of Swaythling.). In this latter part of the route, the waiting time saving from a punctual service has only a very small effect on total passenger waiting time. Making buses punctual by giving priority only to late buses therefore may not be the preferred option. Rather, passenger journey time can be reduced by giving priority to all buses. In this case, the strategy giving priority to all the buses would be more beneficial.

In contrast, bus stops along the early part of the route have more boarding passengers and less alighting passengers. Reducing average waiting time per passenger therefore has a bigger impact on the total passenger waiting time. Conversely, with a lower number of passengers on board, the benefit of reduced journey time may have less effect on the total passenger journey time. Additionally, the main role of differential priority is to play a corrective role to prevent late buses from further deterioration further along the route.

The priority provided at the early part of the route may reduce the increase of lateness with distance/time.

Hence, a priority strategy that gives priority to the late buses in the early part of a bus route and gives priority to all buses in the latter part of the route could perform better. This strategy (termed “Mixed Priority” here) combines the better passenger waiting time from the strategy giving priority to late buses with the passenger journey time benefit from the strategy giving priority to all buses. An earlier simulation of the corridor using a purpose-built simulation model, SIMBOL, showed that mixed priority gives better benefits than priority to late buses only (Shrestha, 2003). Comparison of economic benefits from these two different priority strategies is shown in Table 4.

Table 4: Comparison of priority benefits from different bus priority strategies

Priority strategy	Priority benefit per hour for whole route (in £)		
	Passenger waiting time	Journey time	Total
Late buses (High)	2.58	6.48	9.06
Mixed priority	2.58	8.35	10.93

Table 4 shows that the “Mixed priority” gives similar passenger waiting time as priority to late buses but excels it in terms of journey time savings by giving priority to all buses in the latter part of the route.

7. DISCUSSION

This paper has demonstrated that a differential priority strategy can be targeted to address specific policy objectives such as overall economic benefits and improved passenger waiting time. In terms of the passenger waiting time, a strategy taking account of the headway of the bus behind was found to offer better benefits. In addition to the increased passenger waiting time benefits, another strong point of this priority strategy is the fact that it does not need a pre-defined reference headway to determine the priority requirement of a bus. It just determines the priority requirement of a bus on the basis of its headway in comparison to the headway of the bus behind.

The issue of using scheduled headway or the average headway achieved on a particular day as a reference headway is important for operational efficiency. At present, the priority need of a bus (under headway based operation) is assessed on the basis of a scheduled headway which may not be possible to achieve in some field situations. For example, if there are fewer buses serving a route (e.g. due to a bus breakdown) than required, then it will not be possible to achieve the scheduled headway by all buses. In such cases, the priority algorithm targeting scheduled headway may not improve the situation. This may lead to the situation where nearly all buses get priority because most headways are higher than scheduled. In this situation, regularity would not be greatly improved. The new strategy proposed does not need a reference headway to compare with and hence simplifies the implementation.

The paper has also illustrated that more benefits could be obtained by implementing a combination of priority strategies in a route. Such a combination could combine the benefits of those individual strategies. However, it is to be noted that implementing different strategies at different parts of a route may complicate the field implementation. This may be the case, particularly, when buses are given differential priority in an out-of-city direction and priority to all buses in the direction towards city centre. However, with the iBUS architecture this can be implemented by using the extra priority parameter a bus can send in its priority message.

In addition to the bus priority at traffic signals, iBUS also provides a comprehensive database of second-to-second activities of all the buses in the network. This detailed information could be used to ensure that the system is working as expected and the original level of benefits is maintained. The analysis can be carried out on the basis of a single junction or a sequence of all junctions in a route. This facility available in iBUS should save considerable time and resources required in earlier systems to collect and analyse data.

8. CONCLUSION

This paper has shown that TfL's recently procured AVL system, iBUS, has facilities to potentially provide efficient differential priority to buses at traffic signals. With intelligence at different locations, the iBUS priority architecture has demonstrated that it can support various differential priority strategies. One such effective priority strategy could be the one that performs well in terms of overall economic benefits (taking account of journey time improvement in addition to regularity improvement).

The paper has also showed that the effectiveness of a priority strategy could be improved by taking account of the adjacent bus headways for differential priority operation at traffic signals. A simple analysis included in this paper proved the better performance of such strategy. With a small field example, the paper has also introduced the idea of combining different strategies to maximise the benefits. The idea here was to implement the priority strategy depending on the field situation. These theoretical analyses illustrated that there is a potential for improving efficiency of differential priority utilising the flexibility provided by newer AVL systems such as iBUS. In addition, iBUS also provides comprehensive information for regular evaluation of bus priority performance. Such a facility should save considerable time and resources for evaluation which formerly required considerable manual survey effort.

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