The Use of ITS for Improving Bus Priority at Traffic Signals

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Abstract
A modal shift from private to public transport, which will lighten traffic congestion and environmental impact, can be achieved only if bus service is made more efficient and attractive to passengers. One of the ways to achieve the goal is to exploit Intelligent Transport Systems (ITS) within public transport. This paper examines the potential of ITS for improving bus priority at traffic signals, based on comparison and analyses of different bus priority systems, aiming at detecting weaknesses and strengths of each of them. Moreover, a framework for the evaluation of bus priority systems is presented, together with examples of benefits achieved internationally and challenges for research.

Introduction
Nowadays, a central challenge in traffic planning is to cope with ever-growing mobility demand without increasing congestion and pollution in urban areas. This means that new solutions have to be investigated, which focus on optimizing the existing infrastructure and on achieving more efficient and sustainable transport.

One of the ways to optimize the existing infrastructure and the use of the available road space is to encourage a modal shift from private to public transport. In fact, if more passengers are using public transport instead of private cars, this will result in a smaller amount of vehicles on the road, with beneficial effects for traffic and air quality.

The modal shift from private to public transport can be achieved through measures that aim at increasing the attractiveness of public transport, integrated with marketing strategies that communicate what the service can offer in an attractive way. In particular, when dealing with urban traffic, since the public transport network in cities generally consists of buses, the measures that should increase the attractiveness of public transport have to be targeted to buses and should focus on improving the parameters that mostly affect the passengers' perception of the service, namely travel time and travel speed, punctuality and reliability, and comfort.

An interesting measure to enhance bus service is to provide buses with priority at traffic signals. According to Vejdirektoratet (2009), since the waiting time at traffic signals is a significant part of the total travel time for buses in urban areas, reducing that waiting time will reduce bus travel times and improve punctuality. However, the success of the measure depends on how it is implemented.

Recently, Intelligent Transport Systems (ITS) have become an interesting solution to improve the efficiency of transport operations and traffic management. ITS are the application of information and communication technologies to vehicles and infrastructure, providing a set of tools that can significantly improve efficiency, safety and environmental impact in transport. In the recent years, different ITS technologies have been used for implementing bus priority at traffic signals.

This paper analyzes the potential of ITS for improving efficiency and attractiveness of bus service, with focus on bus priority. A classification of bus priority technologies is provided, with the aim of

investigating advantages and disadvantages of using different ITS technologies for bus priority. Moreover, a framework for the evaluation of bus priority projects is developed and presented.
The study is based on a literature study and on analyses of national and international bus priority experiences, for categorization and criticism purposes.

Classification of bus priority systems

Bus priority measures are used to prioritize buses through the network, both on the links (link-based measures) and at the nodes (junction-based measures).
Bus priority at traffic signals is provided through junction-based measures, which are typically divided into passive and active systems, depending on whether the priority is given in a pre-determined or in a dynamic way.
In passive systems, bus priority is pre-determined and fixed and it cannot be modified according to the real vehicle flow. In active systems, instead, bus priority is given in response to signals sent by buses approaching the intersection (Vejdirektoratet, 2009). Therefore, active priority requires a detection system and a form of communication between the buses and the signal controller.
Historically, different types of bus priority – both passive and active – have been implemented in Europe. In this research, several experiences have been studied and the bus priority systems have been divided into the following three categories:

- Non-adaptive bus priority: priority is given in a passive way, through the use of bus lanes and pre-determined green waves between signals;
- Detector-based bus priority: priority is provided in an active way, based on fixed detectors, as roadside beacons, inductive loops and infrared or microwave detectors;
- GPS-based bus priority: priority is given in an active way, through the use of GPS technology.

Non-adaptive bus priority systems

Non-adaptive bus priority systems include link-based measures that prioritize buses on some links in the network and passive measures providing bus priority at traffic signals.
The most common non-adaptive bus priority measures are bus lanes. In some cases, bus lanes provide uninterrupted flow, so that buses never have to mix with other traffic (busways or freeways); in other cases, the flow is interrupted at intersections. A special case of bus lanes is represented by High Occupancy Vehicles (HOV) lanes, where all vehicles carrying more than a certain number of passengers are allowed to drive (Transportation Research Board, 2003).
Moreover, bus lanes can be placed at the right side of the road or in the middle and they can be "with-flow", if buses drive in the same direction as other traffic, or "contra-flow", in the opposite case.
Finally, bus lanes can either be permanent or work "part-time", only when needed, usually during the morning peak hour, being used as normal lanes during the rest of the day (Transportation Research Board, 2003).
The use of bus lanes is convenient when both bus and car flows are significant. Bus frequency thresholds have been defined by Transportation Research Board (2003), which justify the creation of a bus lane. In addition, the level of congestion on the road should be taken into account, since the benefits generated by bus lanes are bigger when the road is congested. On the other hand, bus lanes subtract road space to ordinary traffic, which can cause problems when congestion is high. Therefore, a compromise should be sought.
Bus lanes can also be exploited to provide bus priority at traffic signals. In fact, when bus lanes are present, dedicated traffic signals for buses are required as well. Therefore, it is possible to give longer green times to buses compared to other traffic driving in the same direction, for example by giving the

green signal to buses some seconds before giving it to other vehicles, thus allowing buses to jump in front of other traffic.
Moreover, the use of bus lanes is beneficial when the coordination between phases at consecutive signals is sought (green waves). In fact, when buses drive on dedicated lanes, it is easier to predict the bus travel time between two consecutive junctions, especially when no bus stops are located in the stretch.

Detector-based bus priority systems
A more advanced way to provide buses with priority at traffic signals is to make use of Selective Vehicle Detection to detect buses approaching the junction and consequently adapt the signal plan to prioritize buses, in an active way.
Selective Vehicle Detection (SVD) is a system that "selectively detects vehicles at particular points on the road network, often requiring communication between equipment on the vehicle and at the roadside" (Department of Transport, UK). Once the bus is detected, a signal is transmitted, usually via radio, to the signal controller, where the signal plan modification decisions are made.
When using SVD, different modifications of the signal plan can be implemented, called priority functions (Sane, 1998), as:

- Green extension: when the bus is detected at the end of the green phase, the green phase is extended as long as needed for the bus to clear the junction;
- Green recall: when the bus is detected at the end of the red phase, the green phase for the conflicting flows is shortened and the green phase for the bus is called earlier;
- Insertion (extra stage): when the bus is detected neither at the end of the green or red phase, a stage can be inserted, either being an extra stage or an existing one, in order to provide the bus with priority.

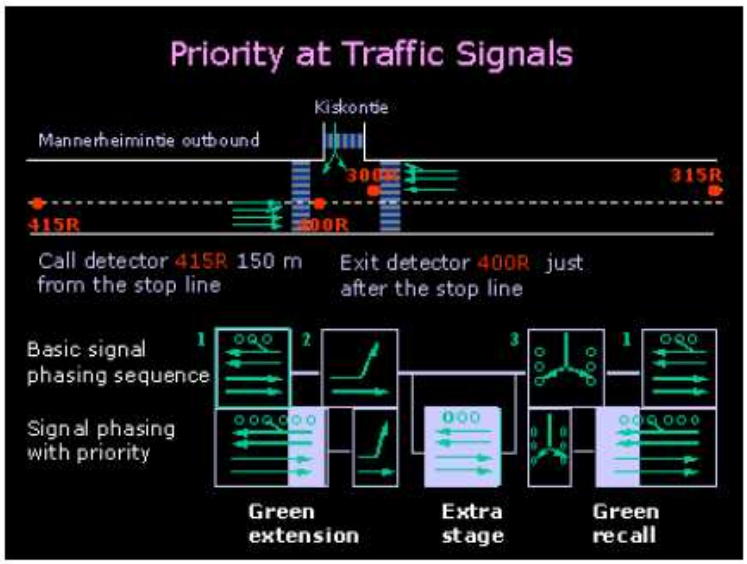

Figure 1: Exemplification of bus priority at traffic signals in Helsinki (Sane, 1998)

Figure 1 illustrates how bus priority at traffic signals is implemented in Helsinki using SVD. In the figure, a call detector is placed 150 m before the stop line, which detects the bus approaching the junction, and an exit detector is located just after the stop line, which communicates that the bus has cleared the junction and priority is not needed anymore. The figure illustrates also the priority functions described above.

Different types of detection systems can be used for providing bus priority at traffic signals (Långström and Sane, 1998):

- Infrared bus detectors (Figure 2a): the detection is based on infrared transmitters placed on the bus and overhead transponders at junctions;
- Microwave bus detectors (Figure 2b): the detection is based on microwave communication between a transponder placed on the bus and roadside beacons;

- Microwave bus detectors with tag: the detection is based on microwave communication between a tag placed on the bus and roadside beacons;
- Inductive loop detectors with bus transmitter (Figure 2c): the detection is based on loop detectors placed on the road surface that detect all vehicles and a loop antenna placed under the bus that allows buses to be distinguished from other vehicles;
- Long-vehicle inductive loops (Figure 2d): the detection requires no equipment on the bus and it is based only on loops placed on the road surface, which detect the presence of a long vehicle where the loop inductance exceeds a threshold value.

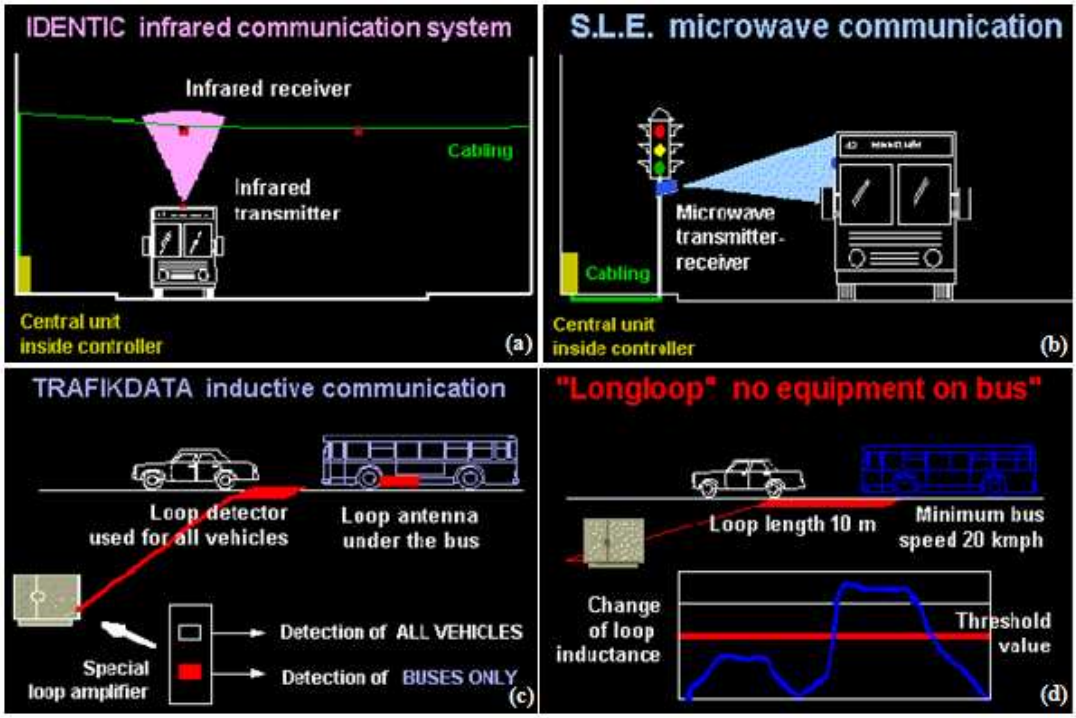

Figure 2: Different types of fixed detectors (Långström and Sane, 1998)

GPS-based bus priority systems

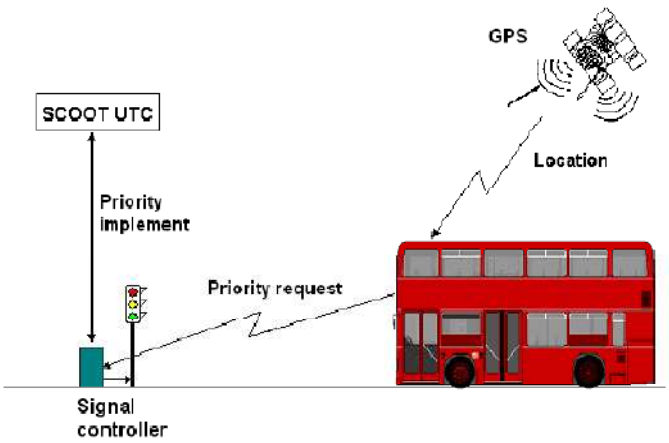

Figure 3: GPS-based bus priority at traffic signals in London (Hounsell et al., 2005)

GPS-based bus priority systems can be considered a special type of detector-based bus priority systems, where the detection is based on virtual detectors.

Figure 3 shows a simple representation of the GPS-based bus priority system used in London. The bus is equipped with a GPS-receiver, which continuously gets the bus location from the GPS satellites. When the location of the bus, determined by GPS, corresponds to the location of a pre-determined detection point (virtual detector), placed at a certain distance before the traffic signal, a priority request is sent, usually via radio, to the signal controller and the priority implementation is done.

Therefore, the functioning principle is the same as the one used in detector-based bus priority systems. The great innovation is that detectors are virtual and buses are located continuously on the network.

The potential of ITS for bus priority

The last two bus priority systems described above provide active priority and need both a detection system to detect the buses and a communication system between the buses and the signal controller. Both the detection and communication functions are provided by ITS: the difference between the two categories is the type of technology used to detect the buses, either fixed detectors or virtual detectors based on GPS.

The main advantage of using ITS in bus priority, regardless of the technology used, is straightforward: ITS allow to detect buses and communicate their presence to the signal, thus enabling the implementation of active priority. As a consequence, bus priority is provided only when needed, thus minimizing the disruption to other traffic. Moreover, in such systems the use of bus lanes is not mandatory, so that no additional road space is needed and enforcement problems are avoided.

However, differences exist between Selective Vehicle Detection based on fixed detectors compared to the one based on GPS technology. The main difference is that fixed detectors usually require a high amount of physical equipment, resulting in high costs and inflexibility for relocation. Moreover, physical obstacles on the road can prevent the detection (Långström and Sane, 1998).

Therefore, bus priority systems based on GPS offer a clear advantage: physical detectors are replaced by virtual ones, thus reducing construction and maintenance costs and providing an extremely flexible system. Using virtual detectors, the additional costs of enlarging the system or modifying it are very low, so that the system can easily be adapted to changes in the network or in the requirements for bus priority.

Moreover, an interesting opportunity of GPS-based bus priority is the possibility of implementing differential priority, i.e. providing buses with different levels of priority based on predefined criteria. Differential priority is especially used to distinguish between buses driving on time and buses driving behind schedule and therefore give priority only to the last ones. Such a priority logic has the advantage of minimizing the disruption to other traffic. Finally, if buses are equipped with GPS to be used for priority purposes, the equipment can be easily used to provide additional services as real-time information, which increase the comfort of bus service.

On the other hand, a bus priority system based on GPS is more complex and usually needs to be supplemented by other tools, as differential correction or odometer and door opening data, in order to compensate location errors due to positioning inaccuracy or poor satellite coverage.

Table 1 provides a comparison of the three bus priority categories, summarizing advantages and disadvantages described above.

Non-adaptive		*Detector-based*		*GPS-based*	
Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages
Simple to implement	Need for road space	Minimum disruption to other traffic	High costs	Low costs	More complex
	Enforcement issues	No additional road space needed	Inflexibility for relocation	High flexibility	Positioning inaccuracy
	Disruption to other traffic	No enforcement problems	Obstacles can prevent detection	Integration with real-time information	Poor satellite coverage in some areas
				Differential priority	

Table 1: Comparison between different bus priority systems

Evaluation of bus priority systems

Key Performance Indicators

In order to evaluate the effects of the implementation of a bus priority system, some Key Performance Indicators (KPIs) have to be defined to quantify both benefits and disruption created by the system.

The evaluation of a bus priority system needs to assess both the benefits for bus service, which is the goal when implementing bus priority, and the consequences for traffic in general, since disruption to ordinary traffic should be limited. When assessing the success of a bus priority system, a balance between effects on bus performance and consequences on other traffic should be sought.

Considering the effects on bus performance, the areas that are most affected by the implementation of a bus priority system are:

- Punctuality and reliability: prioritizing buses at traffic signals is expected to reduce travel time and travel time variability, thus resulting in smaller delays and higher adherence to schedule;
- Operational savings: if travel time reductions are achieved, the same service can be provided with fewer vehicles or, with the same amount of vehicles, a higher frequency can be obtained;
- Environmental impact: if buses do not stop at signals, the acceleration and deceleration phases related to the stop are avoided, with benefits for fuel consumption, emissions and noise;
- Attractiveness of bus service: if shorter travel times and higher punctuality are achieved, users' satisfaction is likely to increase and new users can be attracted to the service.

Relevant KPIs to measure the effects in the above mentioned areas can thus be defined. Punctuality and reliability achievements can be assessed by measurements of travel time and delay savings and, for high-frequency services, headway between buses. In fact, high-frequency bus services are not timetable-based but headway-based and a more even distribution of headways between buses indicates a more reliable service. Operational savings can be assessed by calculating the number of vehicles needed as the product between round-trip time and frequency, where the round-trip time is given by the sum of travel times in both directions and the layover time at each end of the route (Andersen, 2009). The environmental impact can be assessed by measurements of variations in fuel consumption, gas emissions and noise, while the attractiveness of bus service can be estimated by surveys investigating the users' satisfaction and by data about changes in bus patronage.

In order to evaluate the consequences of the implementation of a bus priority system to ordinary traffic, relevant KPIs are:

- Travel time, in order to detect significant delays for other vehicles in some stretches;
- Queue length at traffic signals on roads crossing the prioritized bus corridors, to evaluate the disruption created to those traffic flows;
- Fuel consumption, emissions and noise, since bus priority can force more vehicles to stop, which may cause more emissions.

Table 2 summarizes the KPIs described above, which cover the most affected areas and therefore should be used when evaluating a bus priority system.

Punctuality and reliability	*Environmental impact*	*Operational savings*	*Attractiveness of bus service*	*General traffic performance*
Travel time savings	Fuel consumption	Number of vehicles needed	Users' satisfaction	Travel time
Delay savings	Emissions		Change in bus patronage	Queue length
Headway between buses	Noise			Emissions, noise, fuel consumption

Table 2: Key Performance Indicators for the evaluation of a bus priority system

Evaluation methods

KPIs can either be measured on site, comparing "before" and "after" situations, or be estimated through simulations. Analytical methods, instead, are not suitable because of the stochastic nature of traffic and the high level of detail needed (Fellendorf, 1994).

When the task is to evaluate the effects of future implementation of bus priority systems, simulations are generally acknowledged as the most suitable tool (Fellendorf, 1994). In fact, simulations allow to test a variety of strategies, with different parameter settings, in a much easier way than field trials would permit. When dealing with bus priority systems, even small changes in the system layout and functioning can make the difference. Therefore, it is important to test different variants to find the most successful one.

On the other hand, when monitoring an existing bus priority system, measuring the KPIs on site is essential. In fact, monitoring is very important to keep track of the network performance, in order both to evaluate benefits and to detect problems and improve the system.

Focusing on the estimation of bus priority effects, different simulation models can be used. In London, a simulation model developed by the Transportation Research Group (TRG) of the University of Southampton, *SIMBOL*, was used to evaluate the benefits of the *iBUS* system. Different levels of GPS location accuracy, junction saturation and travel time variability could be simulated and different detector locations and priority methods were tested (Hounsell et al., 2005).

In Helsinki, instead, a traffic simulator called *HUTSIM*, together with a microcomputer and a real signal controller, was used to evaluate traffic signal priority for trams, allowing to test the system with different levels of traffic flows and different tram frequencies (Sane, 1999).

Commercial simulation software as *VISSIM* can also be used to evaluate the effects of bus priority systems, as described by Fellendorf (1994). *VISSIM* is a microscopic simulation model, where every single vehicle is modeled, and, according to Fellendorf (1994), it provides large flexibility, since the traffic flow model and the signal control model are separated and can be combined in different ways.

Examples

When assessing a bus priority project, it is useful to compare the KPIs measured by simulations or on site with some benchmark values, obtained in similar projects.

Moreover, examples of benefits and impacts obtained in different cities where bus priority systems are implemented are interesting to have an idea of the size of benefits that can be achieved.

Table 3 shows reported benefits and impacts from bus priority at traffic signals in different cities in the world. In all the cities, active bus priority based on ITS is implemented. The detection techniques, however, are different and vary from loops and beacons to GPS. The reported benefits and impacts are divided into five categories: delay savings, travel time, variability, patronage and general traffic. Delay savings, travel time and patronage can be easily related to the respective KPIs suggested in the previous paragraph, while variability is a measure of punctuality and reliability and general traffic shows the effects on travel time for other traffic. The table shows that the results are quite different case by case: the reason has to be sought both in the uniqueness of each case – the results are dependent on local conditions – and on the calculation method used. However, it is interesting to notice that travel time savings up to about 20% can be achieved.

shows vehicle and tram delays in Helsinki, comparing the results from the simulations with and without priority. As it is possible to see, the delay savings for trams are significant and the amount of delays with priority is considerably less dependent on the traffic volume. On the other hand, the disruption to other vehicles is negligible and becomes larger only with higher traffic volumes.

Figure 5 shows the simulation results in London related to bus delay savings for different detector distances and GPS location errors. The effect of GPS error on bus delay savings is very small, but the detector distance affects the results significantly. Bus delay savings increase almost linearly with the detector distance, showing the importance of choosing the most suitable location for the detectors.

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

Table 3: Reported benefits from bus priority at traffic signals (UITP, 2009)

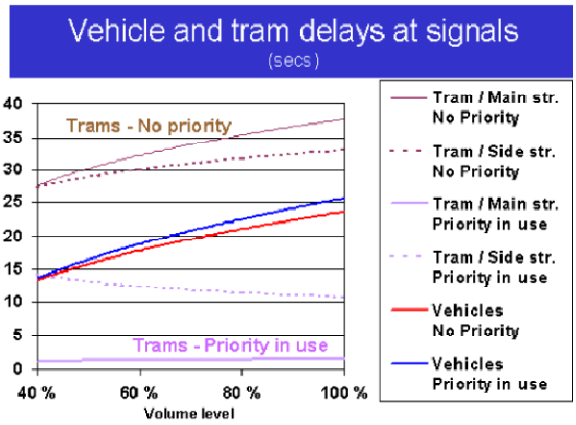

Figure 4: Vehicle and tram delays at signals in Helsinki with and without bus priority (Sane, 1999)

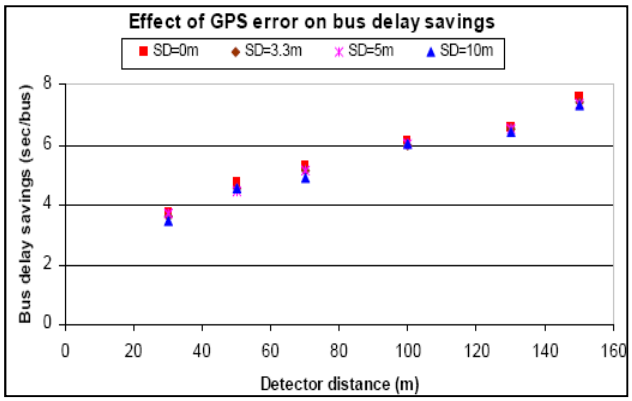

Figure 5: Effect of GPS-error and different detector distances on bus delay savings in London (Hounsell et al., 2005)

Future perspectives

Nowadays, the most advanced technique for providing bus priority at traffic signals is based on GPS. However, research is going on in order to improve the system and respond to challenges as:

- Providing interoperability standards;
- Elaborating advanced strategies for implementing differential priority;
- Synchronizing bus priority at coordinated traffic signals.

Interoperability standards are needed to solve the problems related to the use of buses on different routes, cities or regions. The problems are especially significant when bus routes are long and involve different cities and transport authorities, which is the case with inter-urban services (Department of Transport, UK). Within urban networks, similar problems may not occur, but interoperability standards are still needed to permit the utilization of buses that may have previously been used in another city in the same country or even abroad.

The elaboration of new strategies for implementing differential priority is currently studied with the aim of maximizing the benefits for buses and minimizing the disruption to other traffic. Hounsell and Shrestha (2009) suggests a new method for improving differential priority for high-frequency services. According to this method, the decision of giving priority to a bus is based on the comparison between the bus headway and the headway of the bus behind. Priority is given only if the bus headway is higher than the headway of the bus behind, thus improving regularity and minimizing passenger waiting time.

Finally, synchronization at coordinated traffic signal is another central issue, since the implementation of bus priority at coordinated traffic signals generates often problems, as disturbance to green waves and difficulty of resynchronization after giving priority. Sane and Salonen (2009) present a new flexible signal control system called *SYVARI*. According to simulation results, using *SYVARI* with bus priority gives higher bus delay savings without significantly increasing delays for other traffic.

Conclusion

The challenge of responding to the ever-growing mobility demand without increasing congestion and pollution in urban areas can be solved investing on public transport and ITS. In fact, ITS can be used to enhance public transport and bus service, thus increasing its attractiveness and encouraging a modal shift from private to public transport that is expected to generate benefits for traffic and environment.

The use of ITS for providing bus priority at traffic signals has been exploited in different cities in Europe, with promising results. The application of ITS technologies to bus priority allows the implementation of active priority, prioritizing buses only when needed, thus increasing the effectiveness of the measure and minimizing the disruption to other traffic.

Different ITS technologies can be used in bus priority, from inductive loops and roadside beacons to the more advanced GPS technologies. GPS-based bus priority has the additional advantage that no physical detector installations are needed, thus reducing the costs and increasing the flexibility of the system.

In order to evaluate the effects of a bus priority system, relevant KPIs are defined, related both to bus service and to other traffic. The KPIs include bus and car travel time, bus delay savings, fuel consumption, emissions and noise, number of public transport vehicles needed and change in bus patronage.

When evaluating the effects of the future implementation of a bus priority system, simulations are the most suitable tool, while on-site measurements are appropriate to monitor existing systems.

Results from international experiences, despite significant differences case by case, show that bus travel time savings up to about 20% can be achieved. Results from simulations carried out in London show that the detector distance from the signal affects considerably bus delay savings.

Currently, new technologies are being studied to improve GPS-based bus priority. Some of the challenges involve the creation of interoperability standards, the elaboration of advanced strategies for differential priority and the synchronization of coordinated traffic signals.

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