DESIGN CONSIDERATIONS FOR BUS PRIORITY

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ABSTRACT

Providing priority to buses at traffic signals is widely used in Cities all over the world, but not in South Africa. The Department of Transport is rolling out Bus Rapid Transit (BRT) in all the major cities in South Africa, and providing priority to buses at signalized intersections, should form part of the overall design.

A need exist to develop local experience and methodologies for the design of bus priority systems. The paper explains basic concepts such as passive and active bus priority as well as the technology required to implement active bus priority.

Illustrations are provided of the basic active priority, namely extension of a stage, advancing a stage and skipping a stage. The potential benefit of bus priority, using these 3 methods are shown for 80 second cycle lengths and 120 second cycle lengths and the negative impacts, such as long cross road delay, is highlighted. The challenges of providing bus priority on routes where the block lengths are short and traffic signals are spaced less than 200 m to 300 m apart, are also highlighted.

A logic for making the decisions related to bus priority is provided that aim to provide planners with a structured way to design bus priority, and also to act as a way of communication between bus schedulers, providers of controllers and other systems and traffic engineers.
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1. Introduction

Providing priority for public transport vehicles is not something new and has been done in many cities all over the world. In South Africa, there is at present no working application of bus priority.

The Department of Transport is in the process of funding the roll out of Bus Rapid Transit (BRT) systems in several cities in the country, namely Johannesburg, Cape Town, eThekwini, Tshwane, Nelson Mandela Bay and Polokwane. Providing bus priority has been considered in all cases, but not really implemented – the City of Tshwane will be the first to probably implement bus priority with their initial phase of implementation.

In researching the available literature, case studies and talking to equipment suppliers, it became apparent that little on the real methodology of designing and implementing bus priority has been documented. As with many Intelligent Transport Systems, there is much hype and talk about a topic, but with little "nuts and bolts" type documentation on how it is done, the real lessons learned, and a step by step guide of what the considerations are when designing for bus priority. Most manufacturers of controllers in South Africa have some knowledge on bus priority, but limited real experience exists.

The focus of the paper is therefore on the rational design considerations that need to be taken into account when planning and designing traffic signal priority for buses. The paper further aims to describe the concepts that are at present loosely used in the industry, but with limited knowledge of what is practically possible. Certain concepts are illustrated by using simplistic examples. There is a need for “communication tools”, in the form of diagrams, tables and flow charts to allow the communication between contractors, municipal officials, suppliers of controllers, traffic engineers, bus planners etc.

The paper is regarded as one of the first, of hopefully several technical papers on bus priority in South Africa that will contribute to the local knowledge on the topic. Due to space limitations, not all aspects are covered.

2. What is Bus Priority

To promote the use of public transport, high occupancy vehicles such as buses (or mini-bus taxis in the South African context) is provided with priority over other vehicle movements at traffic signals.

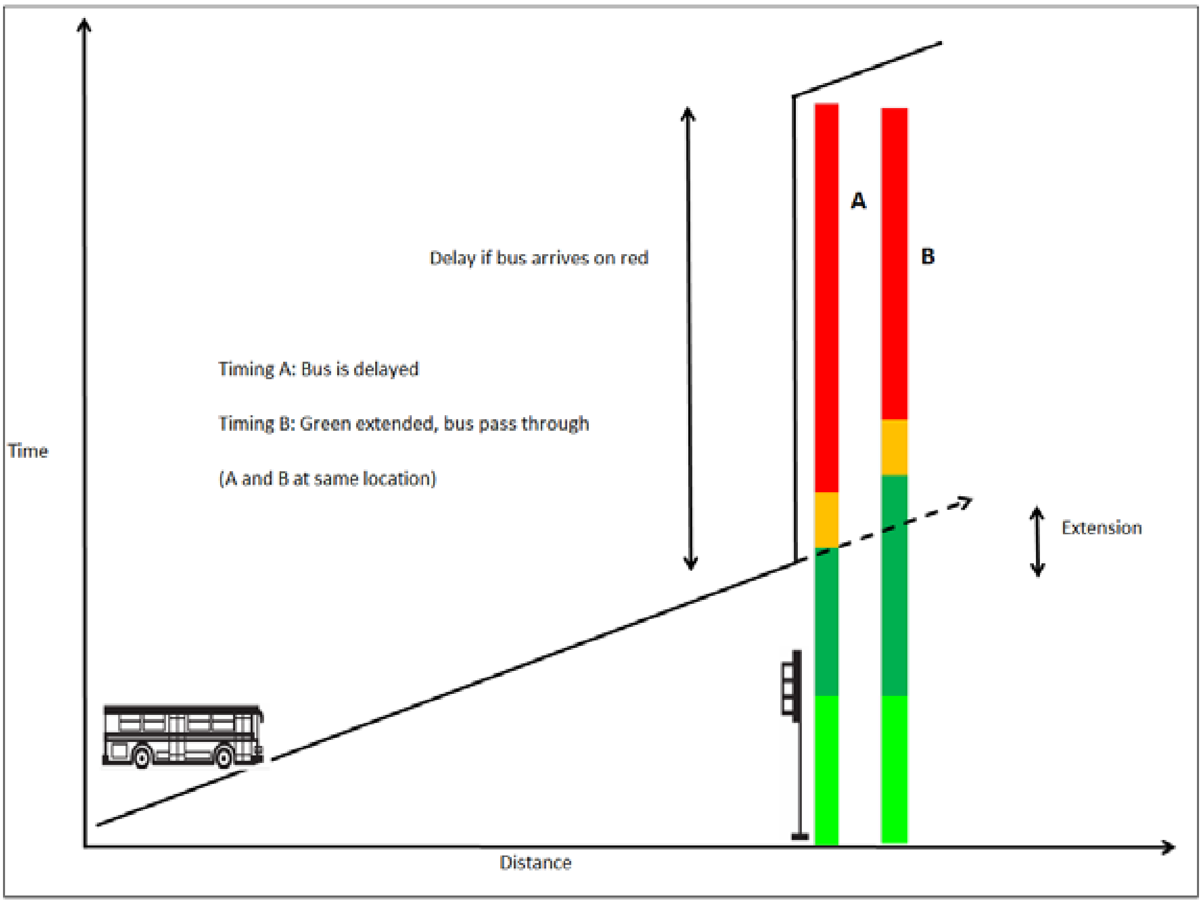
Bus Rapid Transit, as the name apply, should achieve high operating speeds and should travel faster between two points than normal traffic. The high speed and reliable schedule is what should make BRT attractive to the travelling public.

To achieve traffic signal priority, the following is required:

- Integrated bus schedule design and traffic signal design to ensure the fastest practical operating speeds (thus shortest travel times) can be achieved between stations.
- A method of determining if a bus is late (due to unforeseen circumstances, such as a bus breakdown).
- Communication between the bus and the downstream traffic signal to pre-empt or notify the traffic signal of the approaching bus.
- A traffic signal controller that has the ability to extend the stage containing the bus phase, advance the stage or to skip a stage on the cross road if necessary.

The following figure illustrates the simplistic concept of extending a stage to allow a bus to pass through on green.

FIGURE 1: BASIC CONCEPT OF STAGE EXTENSION



Passive bus priority versus Active bus priority

Bus priority does not always have to include communication between the traffic signal and the bus, but can also be achieved by “passive priority”. This includes dedicated bus lanes (as with BRT in most South African cities), coordinating traffic signals to allow a green wave for the bus or maximum main road green split to ensure increased likelihood of the bus receiving green.

“Active priority” involves the changing of the traffic signal settings, based on input from the bus. In terms of the possible changes to the traffic signal timings, there are 3 widely used changes that can be done to the phasing and staging at a junction if there is a call for bus priority, namely:

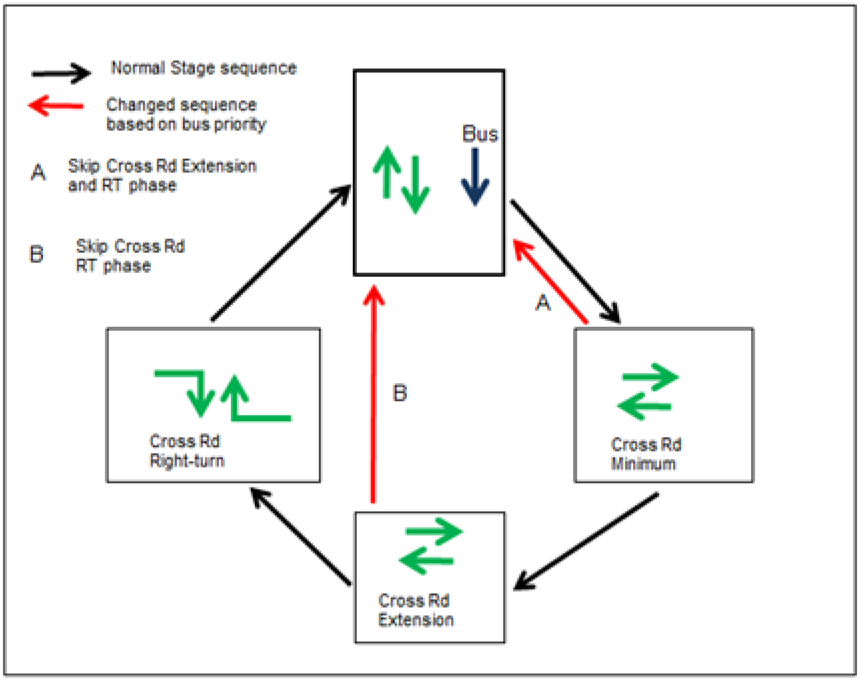
- Green extension (delaying the start of the cross road stages), to allow the bus to pass through at the end of the stage serving the bus. The extension is achieved by reducing the cross road green and / or skipping a stage on the cross road.
- Early Green or advancing the start (reducing the cross road minimum and starting the main road stage early to allow the bus to pass through). The early green or advance is achieved by again reducing the cross road green and / or skipping a stage on the cross road.

Stage Skipping – if the cross road minimum times does not provide adequate priority, a full stage can be skipped to provide priority to the stage containing the bus phase

Other options include inserting a special bus stage, or skipping a stage on the main road (where there is a right –turn in the opposite direction from the bus).

The following figure illustrates the stage sequence. The figure shows the Cross Road extension as a separate stage – only to illustrate that after the minimum green the priority can return to the main stage.

FIGURE 2: TYPICAL STAGE SEQUENCE



3. Bus Priority – International Experience

Transit Signal Priority (TSP) was first introduced in the 1960's in Europe and in the early 1970's in the United States. Many of the early bus priority systems were discontinued primarily because of significant increases in cross road delay and disruption to signal coordination. Because of a rapid increase in vehicle demand on the urban traffic system together with progression and queuing problems, there was a movement towards the elimination of these systems.

It was not until the 1990s that transit priority was reintroduced as a viable solution to enhance regional mobility, primarily due to technological advancement. The processing power of computers was drastically improved, and communication capabilities were more efficient.

The first signal priority experiment for buses occurred in Los Angeles in 1970 (Evans & Skiles, 1970). The system operated on a preemption strategy and other similar projects soon followed. Although these transit priority projects proved to reduce delays experienced by transit vehicles, other problems emerged. Adequate progression on arterials was sacrificed and cross road queuing problems were prevalent along the streets running the preemption. Some examples of positive results achieved by TSP are described below:

- Oakland experienced approximately 9% savings in travel time with little to no impact on non-priority street traffic.
- In Seattle, the King County Metro recorded 25-34% reduced average junctions delay for buses, 14-24% reduced stops at junctions and 35 - 40% reduced trip travel time variability with minimal impact on other traffic.
- In Los Angeles the LA County Metropolitan Transportation Authority experienced a 19-25% reduction in travel time with TSP contributing to approximately 1/3 of this amount.
- In Chicago the Regional Transit Authority's (RTA) TSP system reduced the bus running time with 15% and had little impact on non-priority street traffic.
- The Pierce Transit agency of Tacoma also recorded very little impact on cross road traffic and experienced a reduction in transit signal delay of about 40%.
- In Vancouver, Portland and Virginia the TSP system also had distinguishable benefits without largely negatively effecting non-priority street traffic.

(Smith, Hemily, Ivanovic, & Fleming, 2005)

4. Bus Priority in South Africa

Bus Priority has not been implemented in South Africa to date. There were some experimental implementation in Johannesburg say 15 years ago, but this was not maintained for long.

South Africa is different from Europe or the USA in that road based public transport is only now starting to receive the priority it deserves as a mass mover of people. Little attention has been paid to adjusting traffic signal timing plans or traffic signal priority for any form of public transport in the past.

The result is that limited knowledge on the implementation of bus priority exists in the country, both on a planning level and from the suppliers of controllers and traffic signal equipment. An assessment was done of the capability of local controllers, and no proven implementation of technology exists, and the understanding of the basic principles behind traffic signal priority is limited. A thorough internet search and discussions with international consultants revealed that limited written methodologies exist to provide of general overview that is required to start planning for bus priority.

The major difference is therefore that South Africa lags 30 to 40 years behind other cities in the implementation of bus priority, the local industry has limited knowledge and experience, and lessons will have to be learned to gain the required knowledge and experience. Funding and specifically sustained funding for the maintenance of these sophisticated systems is a concern in the long run, and one can only hope that the BRT systems currently deployed with their high-tech systems will be maintained over the next 10 to 15 years.

5. Relevant concepts in planning bus priority

The difference between passive and active priority for buses was outlined above. There are several important concepts that are described below, that need to be considered when planning for bus priority. The appropriate design for the passive priority measures, such as integrated planning of the bus schedule and the traffic signal timings, can result in good priority for buses and good schedule adherence without implementing the advanced technology that is required for active priority.

Mixed traffic or dedicated lanes: This is probably the design consideration that has the largest impact on the type of bus priority used. Buses in their own lanes can travel at their own desired speed, and can much easier make up lost time. Their arrival time at a traffic signal stop line has to be predicted and no allowance has to be made to clear other traffic queuing in front of the bus at the stop line. Buses in mixed traffic, with no queue jump lanes on the left lane, have to wait for the queue to clear.

Bus Schedule design and schedule adherence: The design of the bus schedule should not be done in isolation of the traffic signal design. The bus schedule typically depends on the assumed operational speed achievable along a certain section of the route, the expected waiting time at junctions (on red), the time required for off-loading and loading of passengers, and other possible delays. Surveys are typically done to determine the travel times and speeds along the bus route – these should be done with the relevant traffic signal settings, and should be coordinated with the traffic signal designers.

The maximum acceptable delay in the bus schedule is a key design input that will affect the whole schedule as well as how often bus priority may be called. The headway between buses also impacts on the acceptable delay – if a passenger knows another bus will be arriving in 3 minutes it will be acceptable to wait 1 minute, but if the headway is 20 minutes between buses, waiting 3 minutes may be unacceptable.

In normal circumstances, as a principle, the bus schedule should be relative easy achievable using the normal traffic signal settings and bus priority only needs to be provided if the bus is delayed. Bus schedule and traffic signal planning integration is regarded as very important.

Bus late or on schedule: Only buses that are late more than a certain time period should be provided with bus priority to ensure that they regain adherence to the schedule. Buses ahead of schedule or on time should not receive any priority.

One-way streets versus two way streets: Providing progression and traffic signal coordination along a one-way street is easier achieved than doing so for a two-way street. To achieve bus priority in two directions during a peak period becomes complex and quite often a peak direction is selected and only priority in the peak direction is provided.

Buses on cross roads that must also receive priority: It is possible that two major bus routes will intersect at a major junction. To select which of the approaching buses has priority, can be done simply by the priority of the bus route, the time of day or the overall congestion of the junction.

Isolated junction versus part of a coordinated system: It is obvious that there will be limited other considerations at an isolated junction when providing bus priority to one approach, versus a coordinated system where the impact of progression along the main route or on the cross road will have to be considered. An isolated junction will, however, in most cases be located far from other junctions and it should in most cases be able to provide a long detection time of the arrival of the bus.

Headway between buses: If the headway between buses is shorter than 5 minutes, bus priority is generally not provided. If, for example, a cycle length of 100 seconds is used, 3 cycles will take 5 minutes. If priority for a late bus is provided in cycle 1 by reducing the cross road green to a minimum, one would want to allow more time over the next one or two cycles to the cross road green. Having a bus every second or third cycle and priority is called constantly, may result in the cross road constantly receiving minimum green times, with subsequent build up of queues and long delays. For shorter headways, bus priority may be used to avoid bunching, where one bus, with a more aggressive driver, catches up with the bus in front of it. Priority can be given to the slower bus, but generally it will be easier to send a message to the faster bus to slow down if they both are on schedule.

Absolute priority to buses versus priority to major streets: A bus route will cross different classes of other roads, and a key decision is whether the progression on major crossing roads will be disrupted to provide priority to the bus, or will it be done under certain conditions only. For example, will the cross street green times be reduced to minimums and possible right turn phases be skipped. On minor crossing roads, it can be done easier without affecting the overall traffic system. If the crossing street also carries buses which may require priority, the considerations become more complex.

Green bandwidth: This refers to the portion of green time allocated to all the junctions on the main road, where bus priority is required. The bandwidth is the seconds of green available for vehicles or to a bus to pass through when viewing it on a time-space diagram. The wider the bandwidth, i.e. the more seconds available for through traffic. This will improve the likelihood that the bus will encounter green when arriving at the traffic signal. Providing the maximum green bandwidth to the main route carrying buses, and deliberately allocating less time to cross roads, is a simplistic way of providing bus priority, but not always the most effective as it will result in cross roads getting less than required green times at certain times.

Cycle length: The selection of the appropriate cycle length has a major impact on how bus priority can be achieved. The longer the cycle length, the longer the delay for a bus arriving at the start of red will be. A longer cycle length will however provide a larger bandwidth, making it easier to achieve progression for a bus from one junction to the next. Longer cycle lengths will also increase the cross Road delay. Finding a balance will have to be done based on a logical flow of decisions, as well as capacity calculations to determine which cycle will result in the overall minimum system delay.

Block length or spacing between junctions: The ideal spacing for traffic signal along two-way streets is between say 600m and 800m, depending on the operating speed. Buses typically pass through CBD areas where the spacing between junctions is 150m to 200m. This makes two-way progression impossible, and also limits the cycle length that can be used, as a long cycle will result in longer queues that can easily block upstream junctions. Short block lengths has the further complication that if the bus is only detected downstream of the previous junction, the travel time from detection to arrival is too short to allow the traffic signal to change to green before the bus arrives. This is addressed in more detail in section 8.

Location of the bus station – downstream or upstream from a junction: When a station is located directly upstream of a junction, the approach in the design is different to when a station is located directly downstream of a junction. The travel time from an upstream bus station may be too short, and the bus may have to wait at the first traffic signal. A priority call is typically made when the bus doors close before the bus leaves the station. A priority call cannot be made before loading passengers, as the loading time may vary too much.

Road Safety considerations: Changing stage sequences to accommodate a bus may result in driver confusion with drivers departing too early based on previous stage sequence experiences. When providing extensions for buses, adequate additional time has to be allowed to ensure the bus driver need not take risks to still pass through on green.
Cost: Implementing and maintaining bus priority has cost implications for the bus system and is a consideration, especially over the life cycle of a bus project. Ensuring sustainable funding for the maintenance of bus priority is therefore critical.

6. Technology requirements

The technology required to allow bus priority, include the following:

1. On board bus tracking, automatic vehicle location and schedule adherence system. This is generally referred to in South Africa as Advanced Public Transport Management Systems (APTMS) and consists of equipment installed in the bus as well as in the control centre, relying on 3G or GPRS communication between the control centre and the bus. The APTMS will typically determine if the bus is late and whether it will require priority at a traffic signal.

2. Communication between the bus and the traffic signal controller. This can be done system to system, i.e. from the bus to the control centre and from the control centre back to the controller, but this normally has latency issues and it is easier to use

direct communication between the bus and the controller. This is also not dependent on the whole communication network to be functional. Local communications is achieved by a wireless antenna on the bus that can send 3 or more signals to an antenna, located on a pole next to the traffic signal controller. Typical signals sent to the controller will be:

a. ”late, require priority”,
b. “very late, require priority (resulting in aggressive changes such as skipping stages),
c. “through junction, cancel priority”, whereby the bus stage can be terminated and time allocated to the cross road again, for example.

3. The traffic signal controller must have the capability to detect signals from the bus and react to them according to a certain predefined logic. Most modern traffic signal controllers have this logic available in various forms.

7. Illustration of extension and advancing stage start times

A Table (See Table 1 below) was prepared that show for two cycle lengths, 120 seconds and 80 seconds, the gain that can be achieved by:

- extending a stage by changing the cross road to the minimum green
- Extending a stage by reducing cross road to a minimum and skipping a right turn stage
- Advancing a stage changing the cross road to the minimum green
- Advancing a stage by reducing cross road to a minimum and skipping a right turn stage

The cycle length is retained as it will run in a synchronized and coordinated system. The reference point in the cycle will also be retained, and once priority has been given to the Main Road, as illustrated in this example, stages will extended to return to the offset reference point.

The following can be observed from Table 1:

- Cycle length has a large impact on the gain that can be achieved for a late bus in seconds, although the percentage change remains similar for the two different cycle lengths.

- Below the table the potential delay when there is no priority, and a bus arrive at the start of the Cross Road green, is indicated. For 120 s cycle this can be 64 seconds and for the 80 s cycle this can be 42 seconds.

- Eliminating these potential delays, say at 5 intersections, can make up 2 to 4 minutes of delay in the bus schedule (say 40 seconds x 5 = 200 sec / 60 = 3,3 min). The adjustments required to accommodate this, is the 24 seconds and 38 seconds indicated in the table. This will impact on cross road delay.

- The Main Road green bandwidth is significantly larger as can be expected with the longer cycle length. The larger bandwidth will allow more flexibility in travelling at different speeds.

- The green split is changed significantly between the Main road and the Cross road - the increase in Main Road green split is from 42% to 62% to 73% for the 120 second cycle. This implies significantly longer delays on the Cross Road. If the buses arrive at short headways, the impact in queue build up on the cross road can be significant, leading to the blocking of other junctions.
- The calculation as illustrated is without a priority call cancellation. If a signal can be send from the bus to the controller as it passed through the junction, to cancel the priority, the extension of the Main Road green phase can be truncated, and the remaining green can be given back to the Cross Road. Where there is a high demand on the Cross Road, this is critical.

TABLE 1: ILLUSTRATION OF EXTENSION AND ADVANCING OF STAGES

Description	Bus									Seconds in cycle as reference				
	Main Rd Minimum	Main Rd Ext	Inter-green	Cross Rd Minimum	Cross Rd Ext	Inter-green	Cross Rd RT	Inter-green	Cycle length	Main Rd Green Start, Second No.:	Main Rd Green End, Second No.:	Adjust to stages	% Change in Main Rd Green	Main Rd Green / Cycle
Base signal plan:	24	26	6	20	24	4	10	6	120	0	50			42%
Extend by reducing Cross Rd to minimum	24	50	6	20	0	4	10	6	120	0	74	24	148%	62%
Extend by reducing Cross Rd to minimum and skip RT stage	24	64	6	20	0	6	0	0	120	0	88	38	176%	73%
Advance by reducing Cross Road to Min	24	50	6	20	0	4	10	6	120	96	50	-24	148%	62%
Advance by reducing Cross Road to Min and Skip RT stage	24	64	6	20	0	6	0	0	120	82	50	-38	176%	73%
Base signal plan:	16	16	6	12	13	4	7	6	80	0	32			40%
Extend by reducing Cross Rd to minimum	16	29	6	12	0	4	7	6	80	0	45	13	141%	56%
Extend by reducing Cross Rd to minimum and skip RT stage	16	40	6	12	0	6	0	0	80	0	56	24	175%	70%
Advance by reducing Cross Road to Min	16	29	6	12	0	4	7	6	80	67	32	-13	141%	56%
Advance by reducing Cross Road to Min and Skip RT stage	16	40	6	12	0	6	0	0	80	56	32	-24	175%	70%

	Potential delay to bus with 120s cycle =	64	seconds
	Potential delay to bus with 80s cycle =	42	seconds

8. Short block lengths

The term pre-emption refers to the fact that the approach of a bus to the traffic signal is detected well in advance, and allows the traffic signal time to change to the correct stage, to allow the bus to pass through on green, or with as little as possible delay.

The travel time, from where the bus sends a signal to the controller ("Priority call"), and travels at a certain speed towards the junction, has to be adequate to allow stage changes to occur, accommodating the safe minimum green and inter-green times at the traffic signal.

Where the block lengths or spacing between adjacent junctions are small, this can become problematic if a bus is only detected downstream of an adjacent junction. Table 2 below illustrates the travel times for different detection distances and different bus operating speeds.

TABLE 2: TRAVEL TIME FROM PRIORITY CALL TO JUNCTION STOP LINE

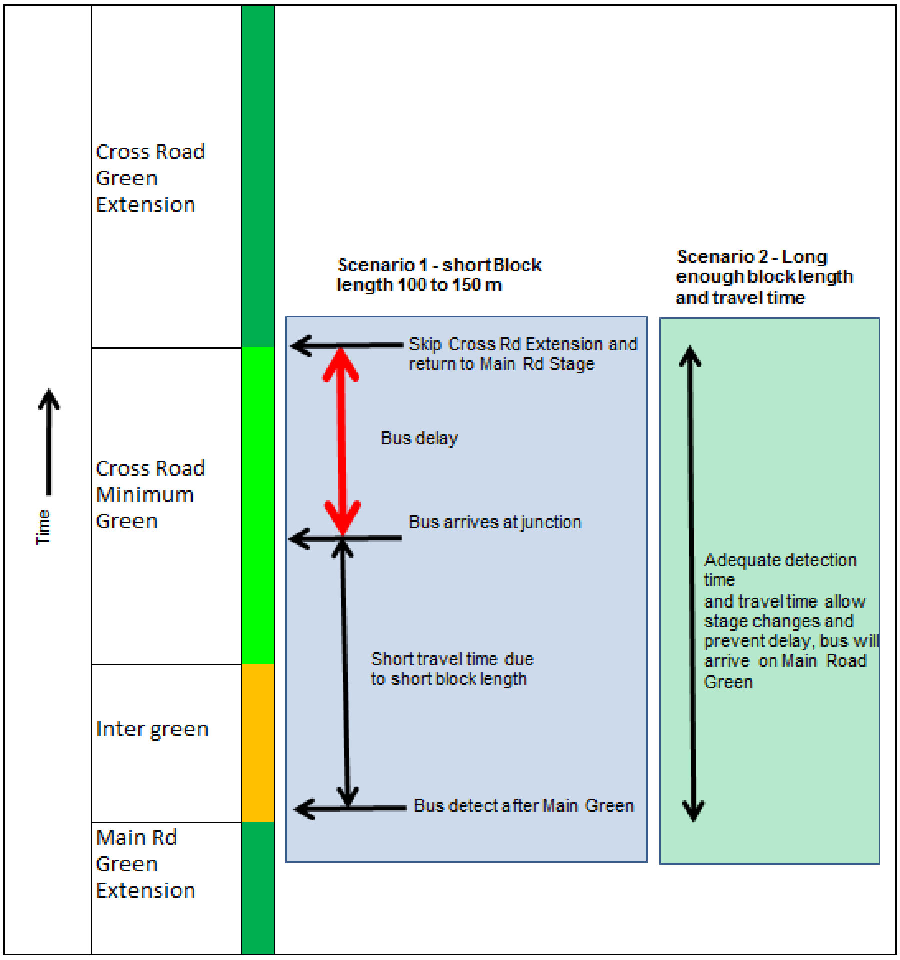
	Travel Time at Bus Avg speed (seconds)					
Speed (km/h): Spacing (m)	45	50	55	60	65	70
100	8	7	7	6	6	5
150	12	11	10	9	8	8
200	16	14	13	12	11	10
250	20	18	16	15	14	13
300	24	22	20	18	17	15

An important variable is that the travel time from detection to arrival of the bus at the junction, should be more than the minimum cross road stage times. Using the 80 second cycle example in table 1 above, this is explained as follows:

If the Priority Call made 1 second after the start of the main road inter green, the Cross Road minimum green will have to be provided before the bus can be served. If the travel time of the bus is less than the Cross Rd minimum green and inter green, the bus will have to stop and be delayed.

If however, enough time is allowed from when the bus is detected, time to travel to the junction, the stage changes can occur and the bus will not be delayed. The concept is illustrated in the figure below.

FIGURE 3: IMPACT OF TOO SHORT BLOCK LENGTHS



The implication of this, evaluating the values in Table 2 above, is that short block lengths and relative high speeds, will result in delay at junctions for the bus due to inadequate time to change.

The area indicated in orange is typical travel times that are too short to allow stage changes without delay to the bus. This is however indicative only, and will have to be calculated for each approach to each junction.

When short block lengths are present, different strategies have to be used to send the priority call to the controller. These can include:

- Allow the bus to stop at the first junction, but ensure green wave progression from that junction through subsequent junctions by providing fixed off-sets.
- Send the priority call from an intersection before "over" the next intersection, thus gaining more distance and thus travel time. A GPS based location coded signal can then be sent to the controller so that the controller can identify the location of the bus from the priority call.

9. Logic for active bus priority

Providing bus priority at a traffic signal, involves a sequence of decisions that need to be taken during design and some in real time, based on the circumstances of the junction, the position of the bus relative to the schedule, etc.

The following flow diagram illustrates a typical logical decision flow where the following parameters are evaluated:

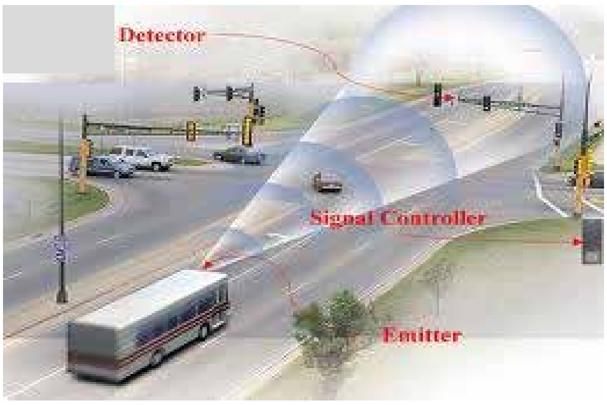
- Bus on time
- Position of station relative to junction
- The road that is crossed – major or minor road
- The presence of other buses requiring priority

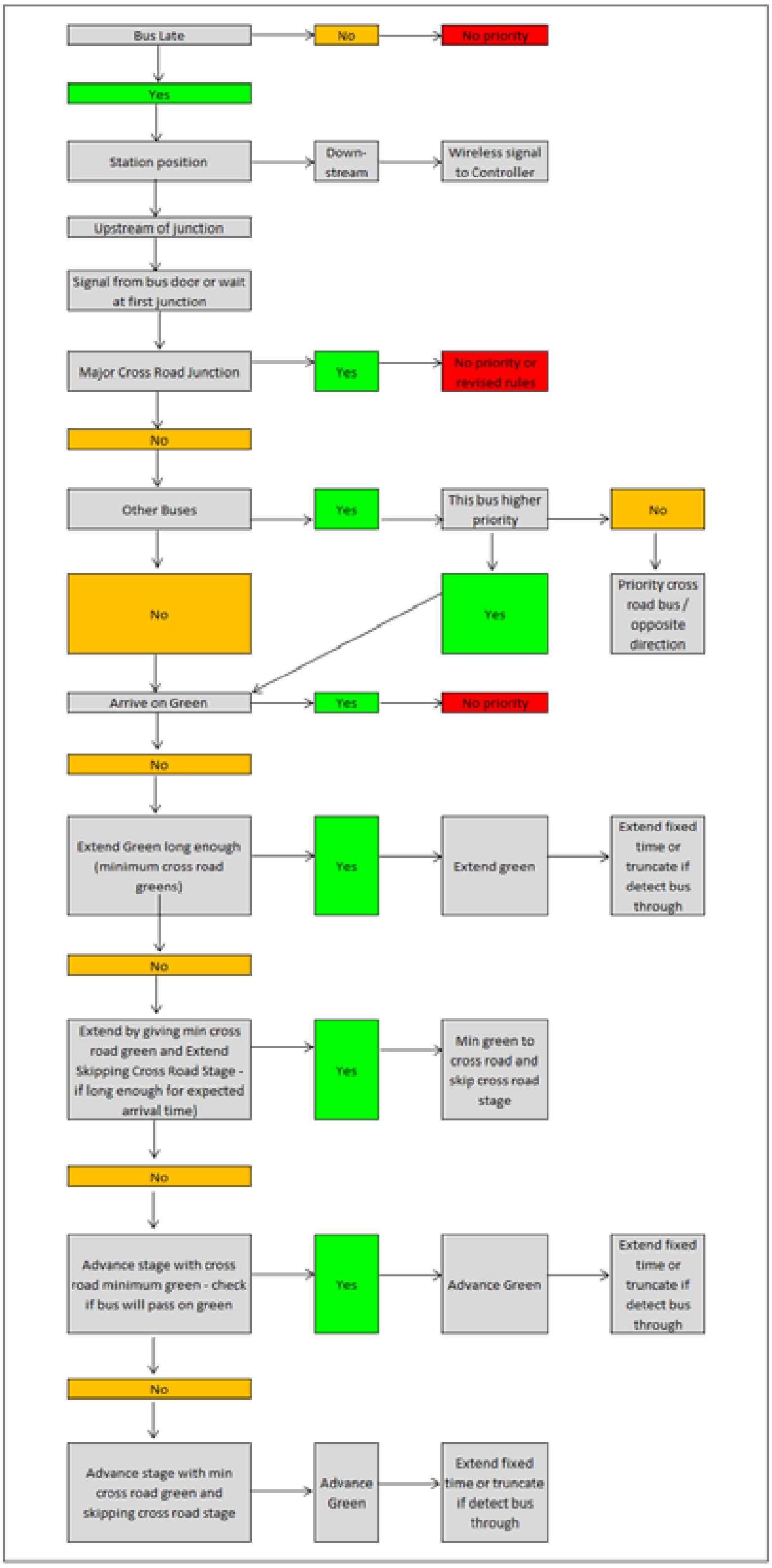
This is followed by the calculation of the estimated arrival time of the bus compared to the position in the cycle time. This will determine the actions that can be taken to give priority to the bus, namely:

- Do nothing (bus will arrive on green)
- Extend bus stage by reducing the Cross Road Green to a minimum, or further by skipping a cross road stage
- Advance the start of the bus stage by reducing the Cross Road green to minimum, or further by skipping a cross road stage

The logic can be further expanded to show the insertion of dedicated bus stages etc, but that is not included in this example. This flow chart has to be developed and refined between the traffic engineer responsible for the traffic signals, the supplier of the controller, the bus schedulers and the provider of the APTMS equipment. The logic further need to be extended to provide for "what if", such as failed communications, incidents preventing the bus from driving at the operating speed, etc.

<u>FIGURE 4: FLOW CHART ILLUSTRATING THE LOGIC TO PROVIDE BUS PRIORITY</u>




Bus Late
No
No priority
Yes
Station position
Down-stream
Wireless signal to Controller
Upstream of junction
Signal from bus door or wait at first junction
Major Cross Road Junction
Yes
No priority or revised rules
No
Other Buses
Yes
This bus higher priority
No
No
Yes
Priority cross road bus / opposite direction
Arrive on Green
Yes
No priority
No
Extend Green long enough (minimum cross road greens)
Yes
Extend green
Extend fixed time or truncate if detect bus through
No
Extend by giving min cross road green and Extend Skipping Cross Road Stage - if long enough for expected arrival time)
Yes
Min green to cross road and skip cross road stage
No
Advance stage with cross road minimum green - check if bus will pass on green
Yes
Advance Green
Extend fixed time or truncate if detect bus through
No
Advance stage with min cross road green and skipping cross road stage
Advance Green
Extend fixed time or truncate if detect bus through

10. Conclusions

The following conclusions are made from this paper:

- There are no working examples of bus priority in South Africa, and there is a need to expand the local knowledge by developing material to communicate designs, principles, etc.
- The difference between passive and active bus priority at traffic signals need to be understood by all planners, as some key decisions early in the design process will impact on what can be achieved during operations.
- Integration and joint design of the bus schedules, traffic signal plans and the bus priority strategy, is important and cannot be done in isolation.
- Technology will be required to make the bus priority possible, but this should be kept to a minimum and should be as robust as possible to reduce maintenance.
- The basic options to provide active bus priority, namely extension, advancing of a stage and skipping a stage, are explained in this paper. Other options such as inserting a dedicated stage or skipping main road stages are also possible.
- Bus priority, when well planned and operated, can result in significant reduction of bus delay, and provide the means to return to the bus schedule following incidents that lead to a delay. Depending on the cycle length and the stage times, between 40 s to 60 s per junction can be gained.
- Short block lengths present a unique challenge for communication between the bus and the junctions. This need careful consideration during design.
- A logical flow chart has to be developed for the specific bus priority system. This is necessary to communicate design principles between bus schedulers, system providers and traffic engineers.
- This paper provides an overview of some of the key concepts in around bus priority, and is by no means comprehensive given the space constraints. There are several other aspects that also need consideration when designing bus priority.

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