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# Optimising Activation of Bus Pre-signals

*Victoria J. Hodge[1], Tom Jackson[2], Jim Austin[3]*

*Abstract*

This report describes preliminary analysis of strategies to activate and deactivate a bus pre-signal using vehicle count data. The bus pre-signal currently operates during preset times to regulate access to a length of road controlled at the other end by vehicle-actuated traffic signals. However, vehicle flows at the pre-signal vary on a daily basis so a more demand-based approach would be more effective. There has been much research performed to optimise pre-signal cycle times and bus priority at pre-signals. We focus on identifying the optimal strategy to activate and deactivate the bus pre-signal using vehicle demand rather than the current fixed time strategy. The ideal strategy should be stable, robust, consistent and timely. We investigate strategies using vehicle counts, queueing theory and estimation and prediction. Our recommended strategy combines aspects of all three areas.

## 1. Introduction

At Hull Road York, two lanes of traffic, one a bus lane, merge to single lane traffic. The first set of signals (the bus pre-signal) control entry from the two lane section into the single lane section (reservoir). A loop is sited at the bus pre–signal and counts the number of non-bus vehicles entering the reservoir (the particular loop deployed can only count vehicles in multiples of four). A second set of vehicle-actuated traffic signals control the exit from the single lane road section. At present the bus pre-signal at Hull Road, York runs a fixed time signal plan (activated) between 07:45 and 09:15 Monday to Friday inclusive and reverts to vehicle-actuated operation outside these times (deactivated). While activated, the bus pre-signal limits the flow of non-bus vehicles into the reservoir downstream of the pre-signal to prevent congestion and to relocate the queue upstream of the bus pre-signal (queue relocation), Wu and Hounsell (1998). Ideally, the pre-signal should only activate when there is a sufficient traffic and a clear requirement to

[1] vicky@cs.york.ac.uk, Dept of Computer Science, University of York, York, YO10 5DD, UK.
[2] tomj@cs.york.ac.uk, Dept of Computer Science, University of York, York, YO10 5DD, UK.
[3] austin@cs.york.ac.uk, Dept of Computer Science, University of York, York, YO10 5DD, UK.

provide clearance for buses. It should be deactivated at all other times to prevent unnecessary queue relocation. The aim of the analysis in this paper is to determine whether using a fixed time approach is appropriate or whether a more flexible approach based on the number of vehicles passing through the signals would be more desirable.

Various authors have investigated bus pre-signalling, e.g., Hounsell and Shrestha (2005), Wu and Hounsell (1998). Most authors have focussed on optimising the signal timings and ensuring that the signals switch to green as buses approach yet maximise the throughput of non–bus traffic. Bus priority approaches such as SCOOT, Bowen (1994), use bus detection to ensure that the buses proceed as smoothly as possible while balancing the requirements of the other traffic which must not be unduly inconvenienced. Mcleod and Hounsell (2003) and Skabardonis (1998) analyse different strategies for awarding bus priority by varying both the choice of buses awarded priority and the degree of priority awarded. Weerasooriya et al. (2008) amend the calculation of the expected arrival time of the bus at the bus pre-signal to account for the current traffic delays. Tan et al. (2008) estimate the arrival time for buses at the traffic signals using a fusion of historical data and adaptive data models. None of these reports investigated varying the activation times for the bus pre-signal. Eichler and Daganzo (2006) investigated using bus lanes with intermittent priority (BLIP) which exploits kinematic wave theory to create "rolling spatial cocoons" ahead of the bus to allow the bus to drive through the road section unimpeded. The traffic is dynamically restricted using VMS messages displayed to drivers. However, BLIPs are not intended for roads running near or in excess of their capacity, Eichler and Daganzo (2006), which is exactly when we intend to activate the fixed time pre-signal plan.

In this report, we analyse median daily flows and actual daily flows at the counter loop to determine whether a demand-based activation would be more effective. The signals have already been optimised to meet the key performance indicators of the local authority and we do not wish to alter the timings within the traffic plan. We then evaluate a number of possible pre-signal activation strategies for timeliness, consistency and stability that use real-time vehicle counting, queueing theory and prediction and estimation to activate and deactivate the bus pre-signals.

## 2. Queueing Theory

Researchers have analysed queueing theory to devise strategies for various traffic problems, van Woensel and Vandaele (2007). Newell (1982) and Daganzo (1997) in particular have investigated queuing theory in traffic flow applications. They consider the service rate of roads – the maximum number of vehicles that can flow along a road without congestion. We can use the service rate to control the flow through our road section. By throttling the flow of vehicles at the pre- signals, we control the flow through the reservoir and thus the flow arriving at the second set of signals. Thus, if managed correctly, we should prevent congestion in the reservoir and thus smooth the passage of buses through the reservoir. Key to this is ensuring that when demand is heavy the bus pre-signal will be active but during lighter demand we need to ensure that the pre-signal is not active

In queueing theory, the service rate is an adjustment of the maximum flow rate (capacity) for the road section to incorporate the signal timing. Traffic signals do not normally allow continuous movement (green light) of one phase in the signals so each phase receives a percentage of green time within each signal cycle. The service rate, therefore, is the maximum flow of vehicles that can exit the road section under the prevailing traffic, road, and signal conditions. The formula for calculating service rate (SR) in vehicles/hour is given by:

$$\mathbf{SR = (g/C) \cdot M}$$

where **g** is the green time for the signal phase (sec), **C** is the cycle length in seconds and **M** is the maximum flow rate or capacity (vehicles/hour) of the road section to be controlled.

### *1.1 Service Rate*

To calculate the service rate for our road topology, the maximum capacity of our road section is 1700 VPH or 142 vehicles every 5 minutes, Evely (2006). The second set signals which control the departure rate are vehicle actuated and also have a pedestrian crossing facility. Calculating an exact green time is thus not possible so we have to make an estimate. We have examined the specification of the set of signals and assumed that the signals are green in the inbound direction for approx 50% of the cycle giving a 5 minute service rate of 71 vehicles per 5 minutes. We examined 72 and 68 as potential service rate threshold values (the nearest multiples of four to 71 as all vehicle counts from the loop are multiples of four) and found that using 68 vehicles tallies better with the current on/off values at 07:45 and 09:15 as shown in

Table 1. Therefore, we will use 68 vehicles as our threshold in the following demand-based activation strategies for the pre-signal.

The bus pre-signal itself has a fixed time plan which awards green time to the non-bus traffic for approximately 51% of the cycle time allowing for 12 buses per hour using a bus hurry call to override the fixed time plan. This is in line with the 50% green time for the second set of signals controlling the departures.

Queueing theory allows us to compare cumulative vehicle arrivals (cumulative vehicle count) against the cumulative vehicle departures (cumulative service rate). This allows us to determine the intersection time, i.e., where the cumulative departures exceed the cumulative arrivals and the queue has dissipated. This is the point time that the bus pre-signal should be deactivated as there is now no queue to obstruct the passage of the buses.

## 3. Data

The data covers a loop detector from 25/11/2008 to 08/01/09. ***We note that the data includes the Xmas and New Year period when Xmas Day and New Year's Day both fell on a Thursday. Thus the median vehicle counts for Thursday are lower than the other weekdays (Monday-Friday).*** All times of day listed are the data stop times. This is the time that the data for the 5 minute time interval would be available. For example, the vehicle flow for 00:00 to 00:05 would be available to download at 00:05. As the bus pre-signal is currently in operation, the count data used in the following analyses incorporates vehicle counts generated while the bus pre-signal is active between 07:45 and 09:15. We do not take this into consideration in the analyses performed.

## 4. Analyses Performed

From the absolute vehicle count values we calculate the median vehicle count for each 5 minute interval of the seven days of the week. Median provides a more consistent averaging value than mean for chaotic data such as traffic data as the median is less susceptible to outliers than the mean. We then randomly select seven 'actual' days (a random Monday, a random Tuesday, ... a random Sunday). We analyse whether the current fixed activation/deactivation times are suitable or whether vehicle demand should be used. We assess various strategies to activate and deactivate the bus pre-signal. Simple strategies use the count of vehicles passing over the loop counter to compare the current count to the threshold value of 68 to determine whether the bus pre-signal should be activated or deactivated. In the course of these analyses, we introduce both queueing theory and simple prediction. We analyse the different strategies for stability, robustness, timeliness and consistency.

*4.1 Current Signalling*

Applying the current fixed strategy of activating and deactivating at 07:45 and 09:15 respectively,

Table 1 lists the vehicle counts for the 5 minutes prior to 07:45 and the 5 minutes prior to 09:15 in a median week and an actual Monday, Tuesday etc. This will provide an illustration of the vehicle count levels currently experienced and will allow us to justify changing to a more demand based approach.

Table 1. *Table listing the vehicle counts at the activation and deactivation times (07:45 to 09:15) for the bus pre-signal for a median week and a week of actual readings.*

| | | *Mon* | *Tue* | *Wed* | *Thu* | *Fri* | *Sat* | *Sun* |
|---|---|---|---|---|---|---|---|---|
| *Median Week* | *On* | 64 | 56 | 64 | 56 | 56 | X | X |
| | *Off* | 68 | 64 | 68 | 68 | 68 | X | X |
| *Actual Week* | *On* | 64 | 52 | 68 | 56 | 60 | X | X |
| | *Off* | 68 | 80 | 68 | 80 | 68 | X | X |

Table 1 shows that the vehicle count at the time of activation and deactivation is relatively stable for a median week but, for actual days, the vehicle count varies markedly between 52 and 80. This clearly demonstrates that a demand-based activation and deactivation strategy would be more appropriate on ‘actual’ days.

*4.2 Activation/deactivation Strategies*

There are various strategies that may be used to activate and deactivate the bus pre-signal. Our simplest strategy activates the pre-signal as soon as the vehicle count equals or exceeds the threshold (68) and deactivates as soon as the vehicle count falls below the threshold. We call this 1-On/Off. Similarly, 2-On/Off activates the pre-signal as soon as two consecutive vehicle counts equal or exceed the threshold and deactivating as soon as two consecutive vehicle counts fall below the threshold and 3-On/Off compares three consecutive vehicle counts. Sum_3 activates the pre-signal when the sum of three consecutive vehicle counts equal or exceed the threshold multiplied by 3 and deactivates when the sum of three consecutive vehicle counts falls below the threshold multiplied by 3. The aim of using the sum of vehicle counts is to smooth any spikes in the vehicle counts that would affect comparing consecutive vehicle counts to thresholds. A more advanced activation strategy is SfE-3 which is similar to 3-On/Off as it activates the pre-signal when three consecutive vehicle counts equal or exceed the threshold but SfE-3 deactivates using queueing theory. The deactivation time is the time when the sum of the arrival rate falls below the sum of the departure rate threshold AND three consecutive vehicle counts are all below the threshold. Using queueing theory ensures we do not deactivate too early, the pre-signal remains active until the excess vehicle count has dissipated. Further, incorporating three consecutive vehicle counts into this also ensures that deactivation is not closely followed by reactivation. Growth 45 minutes uses a combination of queueing theory and the GROWTH function available in Microsoft Excel to perform prediction using the data values for the previous 45 minutes to estimate the expected exponential growth for the data value 5 minutes ahead. Then, if the estimated vehicle count for 5 minutes ahead equals or exceeds the threshold then the pre-signal is activated to the fixed time traffic plan. The pre-signal is deactivated using the same deactivation strategy as SfE-3. Similarly, growth 60 minutes uses 60 minutes of historical data to estimate the value 5 minutes ahead. Using the GROWTH function introduces prediction and estimation. A problem with the SfE-3 strategy, which we will discuss later, is that it delays the decision to activate the pre-signal for 15 minutes as the thresholds are checked. By introducing prediction and estimation we aim to anticipate the morning rush hour and activate in a timely manner.

### *4.3 Activation Rate*

Next we evaluate the number of times per day the various strategies would activate/deactivate the bus pre-signal. We do not want the pre-signal to be activating and deactivating in quick succession (hysteresis). We also do not want the pre-signal activating/deactivating multiple times throughout the day unless absolutely necessary. Our desired strategy should activate and deactivate in a timely manner while being stable (not prone to hysteresis), robust (not affected by small perturbations in the data) and consistent (not switching on and off multiple times).

In Table 2, we list how many times throughout the day each strategy would activate/deactivate the bus pre-signal for each day of a median week (Med) and each day of the randomly selected actual week (Act).

Table 2. *Table listing the number of activation/deactivation pairs for the various strategies for Monday to Sunday in a median week (Med) and in a week of actual days (Act).*

| | *1-On/Off* | | *2-On/Off* | | *3-On/Off* | | *Sum_3* | | *Growth-45* | | *Growth-60* | | *SfE-3* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Med | Act | Med | Act | Med | Act | Med | Act | Med | Act | Med | Act | Med | Act |
| *Total* | 55 | 91 | 9 | 22 | 6 | 13 | 12 | 26 | 10 | 18 | 9 | 16 | 6 | 9 |

From Table 2, SfE-3 has the lowest number of activations of the strategies and is thus the most stable, robust and consistent, closely followed by 3 on/off. Growth-60 is the next most robust and consistent but does occasionally activate then deactivate due to a false prediction above the threshold (>=68). We further analyse these 3 strategies to investigate the activation and deactivation times to ensure that the strategies are activating in a timely manner.

The three activation strategies will activate and deactivate the pre-signal at the times listed in Table 3 when evaluated using the vehicle counts for a median week.

Table 3. *Table listing the activation and deactivation times for the three strategies in a median week.*

| | | *Mon* | *Tue* | *Wed* | *Thu* | *Fri* | *Sat* | | *Sun* | |
|---|---|---|---|---|---|---|---|---|---|---|
| *3 On/off* | On | 08:05 | 08:00 | 08:05 | X | 08:05 | 10:55 | | 12:00 | |
| | Off | 10:15 | 09:45 | 09:55 | X | 10:10 | 12:55 | | 12:40 | |
| *SfE-3* | On | 08:05 | 08:00 | 08:05 | X | 08:05 | 10:55 | | 12:00 | |
| | Off | 10:15 | 10:00 | 10:15 | X | 11:25 | 13:40 | | 12:45 | |
| *Growth 60* | On | 07:50 | 07:50 | 07:50 | 07:50 | 07:50 | 10:00 | 10:45 | 10:45 | 12:00 |
| | Off | 10:20 | 09:45 | 10:10 | 08:50 | 10:50 | 10:15 | 13:25 | 11:15 | 12:45 |

Of the three strategies, only Growth 60 activated the pre-signal on the median Thursday. Growth 60 activated the signal twice on both Saturday and Sunday whereas the other two strategies only activated once on both days. 3 On/off and SfE-3 are thus more consistent, stable and robust than Growth 60. However, the problem with delayed activation is evident for both 3 On/off and SfE-3 which have a median weekday (Mon-Fri) activation time of 08:05 compared to 07:50 for Growth 60. The traffic on Hull Road York peaks at 08:00 so both 3 On/off and SfE-3 would miss the peak vehicle count. This is a serious problem that would adversely affect the journey times of the buses if the traffic was allowed to congest downstream of the bus pre-signal by a delayed activation.

*4.4 Overview*

Comparing the best the strategies selected for further analysis: 3-on/off, SfE-3 and Growth 60 minutes. SfE-3 is the most consistent, robust and stable as it least affected by small perturbations in the data and, due to the use of queueing theory, does not switch off gating only to switch it back on again a short while later. Queueing theory uses the excess demand in the arrivals above the departure rate to ensure the pre-signal is not deactivated prematurely if there is a momentary fall in vehicle counts followed by a rise in the vehicle count. With other strategies that do not consider the excess demand, this fall then rise would lead to a rapid reactivation. However, there is a fundamental issue with using three consecutive readings to determine the decision; this introduces a 15 minute delay in the decision. From Table 3, both SfE-3 and 3-on/off, which use identical activation strategies, delay activation until 08:00 or 08:05. This is in fact after the absolute peak of the morning rush hour which occurs at 08:00. Therefore, of the three strategies analysed further, Growth 60 minutes is the most promising. It is timely, only slightly less consistent than SfE-3, it only occasionally switches on and then off rapidly (activating gating due to small spikes in the data). Thus, we feel further refinement is required due to these occasional false positives. We acknowledge that due to the inherently eccentric nature of traffic there are bound to be some false positives when using the historical traffic counts to estimate near-term future traffic counts. However, we plan to minimise false positives.

## 5. Conclusion

The traffic signals On Hull Road York aim to provide priority to buses where a dedicated bus lane terminates due to limited road width. A report, DfT (2006), states that investigations have shown that this bus pre-signal has helped to reduce bus journey times from the nearby Park and Ride site "*buses have a peak hour advantage of between 4 and 12 minutes over cars as a result of the traffic management*". The current implementation of the bus pre-signal activates and deactivate at preset times regardless of the traffic demand. We have provided statistical evidence to justify a demand based approach through identifying daily variations in the traffic flows. Our detailed statistical analyses of various demand-based strategies have shown that a combination of near future prediction and queueing theory provides the strategy with most potential. The recommended strategy uses prediction to pre-empt the rise in traffic flow and activate the bus pre-signal in a timely manner. The pre-signal activation is maintained using queueing theory until excess traffic flow dissipates and the departure rate exceeds the arrival rate. The strategy waits for three consecutive time intervals to ensure that the pre-signal is not deactivated prematurely and hence will not reactivate quickly.

Our next step for devising a new bus pre-signal strategy is to evaluate more sophisticated prediction algorithms using the statistical analyses here to analyse timeliness, consistency, stability and robustness. Furthermore, we will analyse the preferred strategies in PARAMICS traffic modelling software in conjunction with partners on the FREEFLOW project to analyse vehicle flows and bus journey times.

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