Traffic Signal Bus Priority:

Is it time for a health check?

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Synopsis

Traffic Signal Bus Priority (TSP) is widely regarded as an effective way to reduce the delay caused to buses at traffic signals and is widely used by local authorities in the UK. Bristol is one such city, with a significant proportion of the city's signals being equipped for TSP.

There are a wide range of studies detailing the benefits of TSP and making recommendations about its use. However, whilst TSP can produce significant benefits for buses, there are also a wide range of factors that restrict its effectiveness. This information is not quite so widely published.

Bristol City Council have just carried out a full review of both the current literature on the subject and its own TSP installations, in order to better understand its limitations and to make adjustments that will maximise the benefits delivered by the system. This has led to a better understanding of which sites are suitable for TSP, along with a better understanding of the SCOOT validation process and most effective parameters to use. As a result of the changes made, significant improvements have been made to the performance of the Bristol TSP system.

This paper aims to share the best practice with regards to site suitability and SCOOT validation that was identified during this study.

Introduction

Bus journey times are affected by congestion to a greater degree than general traffic, as buses cannot re-time or re-route their journeys to avoid congestion (DfT 2004). Bus passengers cite service punctuality as an important factor in choosing this transport mode (Dobbie *et al* 2010), therefore efforts have been made in the UK to reduce the impact of congestion on buses in order to increase bus patronage.

A number of measures are used to improve bus journey time reliability, such as bus lanes and bus only roads (DTLGR 1997). However, where there is insufficient budget or road space for these measures, traffic signal bus priority (TSP) is commonly used to assist buses at traffic signal junctions. TSP is a term that describes a variety of methods which provide priority to buses or traffic movements at traffic signals by affecting the time of appearance or the stage length of the related traffic stage. This reduces delay for buses at the signals by making it more likely that they will arrive at the signals during green (O'Flaherty 1997) or by shortening the red period for their benefit.

Numerous studies have indicated that TSP can provide an improvement in bus journey times or punctuality, examples include work carried out in Cardiff (Hill 2001), Brighton & Hove (Crowther 2008), Glasgow, Southampton and London (Gardner *et al* 2009). Average journey time improvements of 1-10 second per junction per bus are expected (TAL 2001). TSP can also provide improvements in fuel efficiency, emissions and vehicle wear and tear. As a result, TSP is widely used in the UK and many local authorities have invested in it.

Despite the proven benefits, there are a range of factors that can restrict or negate the effectiveness of TSP. There are far fewer studies that detail the limitations of TSP or provide any guidance on these limitations to local authorities who are installing it. Overall the research indicates that TSP can bring benefits for buses, but it needs to be carefully designed and implemented (University of Southampton 2002), to prevent it from being ineffective or even detrimental.

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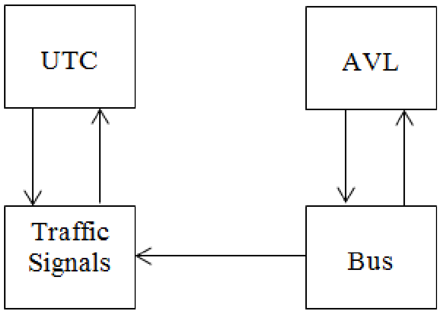
This paper aims to share best practice with regards to site suitability and SCOOT validation that were identified during this study.

Bristol's TSP System

Between 2008–2012, Bristol City Council, neighbouring local authorities and First Bus invested £79 million in a project called the Greater Bristol Bus Network (GBBN) (West of England Partnership 2012). The GBBN project carried out a range of public transport improvements, including widespread installation of the Vix Bus-Net TSP system at 112 junctions on Bristol's main corridors and in the city centre.

The Bristol TSP system is a corridor installation, in line with best practice recommendations (TAL 2001). This allows the benefits of TSP to accumulate along the route by installing it at each suitable junction. As TSP is very sensitive to local conditions, it should only be installed at appropriate junctions (University of Southampton 2002). Site suitability will be discussed in a later section.

The system architecture used for a TSP system can vary widely as it must be designed for each local authorities' needs and goals, as such there is no one optimum architecture. The architecture in use in Bristol is as shown here, and many of the comments made are specific to this architecture type. The AVL system generates conditional TSP requests, meaning that only late buses are able to request priority. The requests are sent to the bus, then the bus communicates directly with the traffic signals. If the traffic signals are operating under SCOOT control, the request is considered and then serviced or refused by the SCOOT model.



TSP can provide priority for buses in a range of ways. However, the Bristol system only uses two of the available methods, stage extensions or recalls. Stage extensions are where the current green stage is extended to a pre-set maximum (TAL 2000), benefitting the small proportion of buses detected towards the end of the green period (Bowen *et al* 1994). Stage recalls are where non-priority stages are truncated so the priority stage can occur early, reducing bus delay (University of Southampton 2002).

Bristol does not use stage skipping or reordering which provides a faster recall, increasing the likelihood of the bus arriving at green. This is because road safety concerns have been raised as drivers/pedestrians who are familiar with the junction may pull away/cross the road in anticipation of the staging order they expect (Gardener *et al* 2009).

Issues Identified that Affect the Operation of TSP

Junction Staging

The staging of a junction, along with the average stage lengths in operation, impact the effectiveness of TSP. The most significant journey time benefits are achieved by buses on approaches with short greens (Hounsell & McDonald 1988). However where buses are approaching onto a stage that is green for a significant proportion of the cycle time, the benefits of TSP can be very small. This is because of how TSP acts to provide priority for buses. As already explained, extensions can only benefit the small proportion of buses that approach the signals towards the end of the green period. Recalls can be very disruptive and if the non-priority stages at the junction are quite short, there is little scope to reduce them further, significantly reducing the level of benefit achievable from a recall (TAL 2000). At sites of this nature, TSP can only achieve a very slight benefit for buses, but the disruption caused by servicing the TSP requests may be significant. The effectiveness of TSP can therefore be limited or negated at such sites, and a judgment of the costs of TSP against the expected benefits must be made.

The following section details the assessment process that has been used in Bristol to assess the effectiveness of TSP at each site. The formula has been adapted from Hounsell (2013) and allows the maximum possible benefits of TSP at a site to be estimated:

Total delay saving = ((t/c) x r) + ((r/c) x ((r-MinC)/2))

The equation terms are as follows:
t = Bus free flow journey time from detector to stop-line
c = Average junction cycle time.
g = Average effective green time.
r = Average red time. This should equal the cycle time minus the green time: c-g.
MinC = This is the minimum stage lengths for each stage plus the intergreens. This is because SCOOT cannot reduce stage lengths below the stage minimums specified in the controller, or reduce the intergreens, therefore this time must be removed from the calculated benefits.

The first expression calculates the maximum journey time saving achieved by operating a stage extension. It calculates the benefit to buses based on the time saved and the maximum proportion of buses that will benefit from an extension, then expresses this is seconds per bus per junction. The second expression calculates the maximum benefit achieved in the operation of a recall. It assumes the random arrival of buses, and calculates the benefit based on the maximum proportion of buses that will benefit from a recall, expressing the time saved as half the maximum time saving a recall can achieve in seconds per bus per junction.

The result of the calculations will estimate the maximum expected benefits for buses, but the method has a number of inherent assumptions that mean it will overestimate the benefits achieved at SCOOT sites. The engineer must therefore take into account the fact that the benefits may be significantly lower in reality:

- The formula assumes that every bus priority request is serviced (This is untrue as not every bus is equipped, and when running under SCOOT not every request is serviced).
- The formula assumes that running bus priority will cause no disruption to the traffic conditions and subsequent buses. (This is untrue, as bus priority frequently can cause traffic disruption and negatively affect subsequent buses).
- The formula assumes that no conflicting bus priority demands are being received. (In reality, demands can be received simultaneously on different junction approaches).

In addition to the calculations, the SCOOT engineer needs to assess the site to identify if there are any factors that render each site under consideration inappropriate for TSP. Other factors that need to be considered will be discussed below and include the level of congestion at the site, the TSP link length and the traffic signal network geometry.

Traffic Conditions

TSP is designed to reduce traffic signal induced delays, i.e, delays caused directly by the point within the cycle that the bus arrives at the junction. TSP aims to assist the bus to arrive onto a green signal, operating under the assumption that the bus is able to clear the junction within one cycle. TSP is not designed to reduce delays caused by congestion (Hounsell *et* al 2004). This is because it works by reallocating spare green for the benefit of buses and is therefore most effective at junctions with spare capacity (TAL 2000). Where a junction is congested for much of the day, TSP can have a detrimental impact (Chada & Newland 2002), as each TSP request that is serviced causes disruption to the SCOOT model. This is because it can cause significant queuing on non-priority approaches and will cause offsets between sets of signals to drift away from the optimum, which can create significant additional delay. After servicing a TSP request, the SCOOT model must then ‘recover’ from the request by returning to optimum offsets/stage lengths and clearing the queues caused. Under congested conditions, recovery can be very difficult and as a result, TSP can cause a build-up of congestion that can make subsequent buses late, causing an overall net disbenefit for buses. In highly congested areas, congestion management techniques may be more appropriate than TSP (Hounsell *et al* 2004).

A study that demonstrates this limitation was carried out in Fortaleza, Brazil, which compared TSP against SCOOT traffic signal control on a highly congested urban corridor. The study reported that SCOOT control performed better than TSP at reducing delays at signalised intersections along the corridor (Olivieira-Neto *et al* 2009). In very congested areas of Bristol, this study found that no journey time benefits were being achieved for buses by operating TSP. When SCOOT TSP was operated up to a high degree of saturation, journey time disbenefits resulted, and when operating at low degrees of saturation, no journey time differences were achieved. Journey time savings were only achieved when TSP was amended to operate with a time of day tidal bias added into the saturation parameters in use. This means that in certain areas of Bristol, buses only receive priority on the inbound in the morning peak and the outbound in the evening peak. At highly congested locations, this was the only way to deliver journey time benefits.

Number of TSP Requests

The benefits per bus for TSP reduce as bus flows increase (Hounsell & McDonald 1988) (TAL 2000). This is partly due to conflicting priority requests (Hounsell *et al* 2004) but mainly as the signals need to recover from TSP and return to optimum offsets and stage lengths, clearing the queues caused before servicing the next TSP request. Where bus flows are high, the signals cannot recover and congestion builds around the junction, detrimentally affecting the journey times of subsequent buses (Chada & Newland 2002) (Waterson *et al* 2003).

This issue highlights the need to restrict the proportion of requests serviced to the level where an overall benefit is achieved (University of Southampton 2002). This can be partly achieved within the AVL system by the use of conditional priority. Furth & Muller (2000) demonstrated that servicing high numbers of TSP requests can cause a detrimental impact. Research shows that conditional priority (servicing requests for late buses only) is more effective (TAL 2000) (Gardner *et al* 2009), as it reduces network disruption caused by TSP and provides a ‘push-pull’ action on bus journey times (Chada & Newland 2002). This also holds true for headway based services (Hounsell *et al* 2000), where TSP aims to maintain bus frequency, (Hounsell & Shrestha 2012). It is possible within many AVL systems for conditional priority to operate with multiple priority levels with varying lateness thresholds, also to operate different priority levels for different bus routes. Research is also being carried out into using the location of other buses on the network as a factor when generating TSP requests.

However, it is also necessary within the SCOOT model to select the maximum degree of saturation up to which extensions and recalls are serviced (Siemens Traffic Solutions 2012). This forms an important part of the validation process (Bowen *et al* 1994), however, there is no established method to calculate optimum values (Wahlstedt 2011). Transport for London have used microsimulation modelling to determine the appropriate saturation levels, however, where Local Authorities have no access to microsimulation modelling, trials on the live network are needed.

Different saturation levels can be selected for both extensions and recalls, using the BES & BRS parameters (in the Siemens UTC system). Extensions are usually permitted at most SCOOT sites, as they do not strongly disrupt the model and the effect can be limited by restricting the maximum extension time (Siemens Traffic Solutions 2012). However, recalls are more disruptive to the SCOOT model as they more strongly move the offsets between sets of signals away from the optimum. Also, the short stage lengths run can create congestion on the affected approaches (TAL 2000). Recalls must be used more sparingly within the SCOOT model, especially at junctions where offsets are critical, as the disruption can be greater than the benefit achieved (University of Southampton 2002).

The study carried out in Bristol found that the saturation parameters (BES/BRS) had the greatest impact on the effectiveness of TSP of all of the factors tested. Each site needed a different level based on factors including link length, traffic flow levels and the importance of offsets with surrounding junctions. Also, different saturation levels were needed at different times of day, so the values were timetabled to change for the morning, off peak and evening peak periods.

TSP Link Length

SCOOT TSP works more effectively if trigger points are sited in the most effective locations, which the literature states is a 10-15 second journey time from the stop-line (TAL 2000) (Gardner *et al* 2009). The journey time must be consistent, as the SCOOT model must be able to accurately estimate the location of the bus on the link. However, trigger point positioning is limited by the range of the receiver and more crucially, the positioning of bus stops or other factors on the highway that cause a variable bus journey time. Bus stop locations are particularly problematic as they create variable bus journey times, detrimentally affecting the operation of TSP (TAL 2000). It is common to therefore position the trigger point downstream of the bus stops. However, where bus stops are within a 10 second journey time of the junction stop line, this can cause TSP to be of limited effectiveness as the signals cannot react quickly enough to assist buses to arrive onto a green signal.

Where a TSP trigger point is located within a 5 second journey time of the stop-line, SCOOT TSP can be detrimental. This is because it takes up to 5 seconds for the SCOOT model to receive the TSP request from the junction controller, process it and return the staging instruction back to the controller. Where journey times are less than 6 seconds, it is not possible for the model to provide stage extensions before the bus finishes passing through the junction (Siemens Traffic Solutions 2012). Extensions should therefore be refused at sites of this nature. With regards to recalls, TSP can reduce the signal induced delays, but buses will almost never arrive on a green signal. This means very little impact in terms of emissions and fuel consumption, but TSP will still disrupt the SCOOT model and cause residual delays around the junction, potentially impacting on subsequent buses in the area. The effectiveness of TSP is therefore severely limited at sites of this nature and where possible, bus stops should be relocated away from the junction stop-lines (Viegas & Lu 2007). If this is not possible, the use of enhanced detection should be considered.

It is possible to install enhanced TSP detection at problematic sites, this can involve the use of an upstream detector, a secondary detector just after the bus stops or an exit detector after the stop-line (D'Souza *et al* 2010). Using enhanced detection can improve the benefits of TSP and reduce traffic impacts (Hounsell *et al* 2004).

Where bus stops are close to the junction stop-line and dwell times at the stop are fairly consistent, detecting the bus upstream of the junction and then just after the bus stop can improve the effectiveness of SCOOT TSP (Hounsell *et al* 2008).

The use of exit detectors can reduce the problem of variable bus journey times (Hounsell *et al* 2004). Where journey times are variable, extensions can run for too long causing delay to traffic or the signals may change to red before the bus has cleared the junction (Gardner *et al* 2009). With exit detection, buses clear the junction and the extension is then cancelled, meaning unnecessary additional green time is not given (D'Souza *et al* 2010).

If it is not possible to install enhanced detection to resolve issues at problem sites, it may become necessary to weigh up the costs and expected benefits of a TSP installation, with a view to recommending against installation where it will not deliver sufficient benefits.

Traffic Signal Network Geometry

TSP is problematic where junctions are close together, such as on gyratory systems or roundabouts. This is because the offsets between the sets of signals are critical to maximising the junction efficiency. As explained above, TSP causes the stage splits and offsets between sets of signals to move away from optimum, causing exit blocking and congestion. Observations in Bristol supported the logical assumption that sites where offsets are more critical to their operation, are more strongly affected by the operation of TSP. TSP is therefore not recommended for use where signals are very close together, such as on roundabouts or gyratory systems. In Bristol, turning off TSP at congested sites with very short links, where offsets were critical to network efficiency caused bus journey time improvements through those sites. This illustrates that TSP cannot generate benefits at all sites under consideration, but must be applied with care.

Pedestrian Crossings

TSP can be applied to pedestrian crossings, however, the journey time benefits are extremely small and installations are not usually cost effective. This is because it is not possible to provide stage recalls as the pedestrian stage cannot be shortened for safety reasons (Hounsell *et al* 2004). Also, pedestrian signals dwell on the traffic stage for much of the time, so the proportion of buses benefitting from TSP extensions is very low.

Finally, there is a concern in the literature that pedestrians may attempt to cross when it is unsafe due to long wait times or being accustomed to stage appearance at a specific time. On balance, the cost and time saving for buses do not out-weigh the needs and safety of pedestrians (Hounsell *et al* 2004). It is therefore recommended that TSP is not installed at pedestrian crossings.

SCOOT Recovery

Recovery is the process of bringing the SCOOT model back to optimum signal timings (TAL 2000). Within SCOOT TSP, it is possible to set the recovery type using the extension recovery (BEXR) and recall recovery (BRER) commands (in the Siemens UTC system). Where there is little spare capacity and offsets are important, the speed of recovery becomes very important. Therefore, the most efficient recovery method should be used. SCOOT recovery can be set to 'default', or it can be configured during the validation process (Siemens Traffic Solutions 2012). The default method is to allow the SCOOT model to select the most appropriate recovery method. However, research indicates that this default setting is not the most efficient recovery method to use. Rather, restricting the SCOOT model to selecting long or short SCOOT stages (MORL) until the appropriate offset is achieved is the most effective recovery setting (Bowen 1997). In Bristol, both Default and MORL recovery methods were trialled and it was found that switching to the MORL setting recommended by Bowen did cause SCOOT to recover more quickly. This setting is therefore recommended.

Closing Comments

It is clear from the wealth of research available that TSP can bring significant journey time benefits for buses at equipped sites. However, the research reviewed and the recent findings in Bristol also make it clear that TSP must be applied with care in order to deliver journey time benefits, as it is also possible for TSP to deliver significant journey time disbenefits.

This research indicated that it is beneficial to assess the expected level of benefit on each approach given the junction staging and stage lengths in operation. It is important to consider the expected costs against the expected benefits, especially at pedestrian crossings, or sites which form part of gyratory systems or roundabouts. It is important to consider the maximum link length than can be accommodated due to bus stops and other highway infrastructure, as this impacts the effectiveness of TSP at each site.

At locations with medium or high bus flows, conditional priority can significantly enhance the benefits that TSP can bring. The use of additional logic within the AVL system to request priority for late buses, or to prioritise certain bus services can focus the priority given where it is most needed.

When validating a site to operate SCOOT TSP, it is clear that the most critical factor in the performance of TSP is the maximum saturation level up to which TSP is permitted to operate. A range of factors must be considered when setting the saturation level, including the level of traffic flow, congestion and exit blocking in the area. This determines whether recalls will be permitted and whether TSP should be applied with a time of day bias to achieve positive results. It is important to consider the impact of the link length on the operation of TSP and inhibit extensions where links are too short. Finally it is important to ensure that the most efficient recovery method possible is in use.

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