Traffic signal control for preferential treatment of public transport

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Introduction

Traffic control strategies for bus priority or Transit Signal Priority (TSP) at traffic signals have proven their effectiveness in improving the performances and schedule reliability, reducing operating cost and increasing ridership. TSP has been widely introduced at isolated signals, however its implementation in complex coordinated signal systems (arterial routes) becomes very difficult because of potential adverse impacts on the rest of the traffic stream, e.g. imposing higher delays on cross streets traffic, loss of coordination, etc. This paper investigates the optimal signal settings for the whole system aiming at minimising the passenger delay (cars and buses).

Wadjas and Furth (2002) addressed TSP for an arterial route using advanced detection strategy. They investigate an arterial route which has a detected lane for 2/3 of the arterial and shares the last 1/3 on a shared lane. Their goal is to give priority to the transit vehicle in order to keep its schedule while minimising the negative impacts (greater delays, loss of coordination) for the rest of the traffic along the arterial and on cross streets. Therefore transit vehicles are detected in advance (2-3 cycles) and signal settings are changed in order to have them arrive during the green phase. A main problem with such an TSP approach is the fact that because of the different speeds of cars and buses along the arterial (buses are slower and have to stop at bus stops), optimising the signal settings to give priority to buses will destroy the platoon flow of the cars along the arterial. This negative effect is even worse when the bus passenger occupancy is not significant compared to the car passenger occupancy. This supports a person based approach that considers the relative passenger occupancy of buses and cars.

Skabardonis and Geroliminis (2008) integrated a travel time model in TSP for mixed traffic lanes with an objective to clear the queues of cars before bus arrivals. While the strategy has been proved beneficial for the system, bus occupancies were not taken into consideration.

A person based optimisation of an isolated intersection is investigated in Christofa et al. (2013). At this isolated intersection there are buses on shared lanes (cars and buses) crossing the intersection in conflicting directions and therefore one of the problems is to determine which direction will get priority. This can be realised by introducing the person based optimisation which considers passenger occupancies and as a result the priority tends to go to the bus with higher passenger occupancy. Christofa et al. (2013) shows the potential gain in bus passenger delay with only a small increase in car passenger delay but with an overall decrease of total passenger delay. As they investigate an isolated intersection, they make the assumption of a steady traffic arrival flow at the signal which will not be the case for an arterial route where platoon flow will be created due to upstream intersections. So the estimation of car delays needs to be reconsidered. A more detailed literature review will be provided in the final paper due to space limitations.

Methodology

Delays

In order to estimate the total passenger delay, we need to estimate the cars and buses delays and multiply both of them with the corresponding passenger occupancy. We assume an arterial route with several cross streets and only through flow (no turning movements) and dedicated bus lanes (this assumption will be relaxed at later stage of this research). So there is no interaction between the cars and the buses and therefore the delay of both can be calculated separately.

Car Delay The delay for cars is estimated by considering a steady arrival flow over some time period. Typically there are three different flows arriving at a signal: flow 0 during the time when the upstream traffic signal is red, capacity flow during the time the queue of the upstream link discharges and normal arrival flow q during the rest of the green phase. Having a steady arrival flow, queues can be described with queuing shockwave diagrams as shown in figure 1. Note that a piecewise linear time-dependent arrival flow is considered at the first intersection. For the following intersections arrivals are estimated based on the departures from the upstream intersection and the influence of signal offsets following Skabardonis and Geroliminis (2005). Platoon dispersion is not considered in our model.

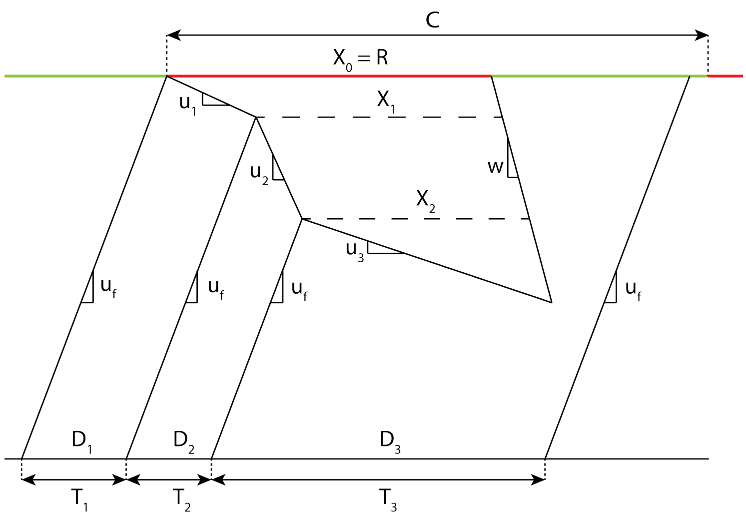

Figure 1: Queuing diagram at traffic signal

The arrival traffic flow can be described by different levels of demands $(D_1, D_2, ..., D_N)$ each lasting over a certain time period $(T_1, T_2, ..., T_N)$. Given the duration of the red phase R and assuming a triangular fundamental diagram, the delay can be estimated as follows

$$u_n = \frac{D_n \cdot u_f}{D_n - k_{jam} \cdot u_f} \qquad \forall n = 1, ..., N \tag{1}$$

$$X_0 = R, \qquad X_n = X_{n-1} + \frac{T_n \cdot u_f}{u_f + u_n} \left(\frac{u_n}{w} - 1\right) \qquad \forall n = 1, ..., N \tag{2}$$

$$D_{car} = \left\{ \sum_{n=1}^{N-1} \frac{(X_{n-1} + X_n) \cdot T_n \cdot u_f \cdot u_n}{2 \cdot (u_f + u_n)} + \frac{X_{N-1}^2 \cdot u_N \cdot w}{2 \cdot (w - u_N)} \right\} \cdot k_{jam} \tag{3}$$

where u_f is free flow speed, k_{jam} is jam density and w represents the shockwave from jam state to capacity state. The value for N (the number of demand levels which needs to be considered) is equal to the n that results in the first negative X_n (in figure 1 that would be $X_3 \rightarrow N = 3$).

In the case of saturated conditions the queue will not discharge during the green phase and the remainder of the queue will queue up for the next red phase. This can be taken into consideration by just serving the first demand D_1 at discharge flow and the corresponding time interval T_1 to the duration it takes to clear the oversaturated queue. When multiple intersections are considered, the demands D_i and time durations T_i for the next intersection are needed to be determined from the queues formed at the upstream intersection.

Bus Delay The bus delay on the other hand needs a different approach to be calculated. We assume that a transit schedule is known with some accuracy level, so the arrival time of each bus can be modelled with a normal random component. In addition buses need to stop at the bus stops where they face various dwell times. The arrival time of buses at traffic signals can be calculated as follows

$$A = E + N_E + \frac{L}{v_B} + D \tag{4}$$

where E is the expected entrance time into the system, N_E is the measurement error of the entrance time which can be represented by a normal distribution, L/v_B is the travel time of the bus to the traffic signal and D is the dwell time of the bus at the bus stop which can be represented by a uniform distribution.

So the arrival of the bus at the traffic light can be represented with a probability distribution. In order to estimate the delay, we need to check for each time of the arrival distribution if the bus arrives during red or green phase. If the bus arrives during the green phase, the associated delay will be zero. But if the bus arrives during the red phase the corresponding delay will be the difference of the arrival time t and the beginning of the next green phase (G_{i+1}) multiplied by the probability of bus arrival at time t, p_t.

$$D_{bus} = \int_t \begin{cases} 0 & \text{if } G_i \leq t < R_i, \\ (G_{i+1} - t) \cdot p_t & \text{if } R_i \leq t < G_{i+1}. \end{cases} \tag{5}$$

Total Delay In order to calculate the total passenger delay, we need to sum up the delays for buses and cars. Note that bus delay is the delay of single buses and car delay corresponds to a steady flow, so we need to determine a time window for which the total delay is calculated. Car flow is constant, buses arrive at a certain frequency and signal setting are periodic. So the time window should represent periodicity for buses and signal settings together.

Having the time window determined, the car delay for this interval can be added to the delay for all buses multiplied by the corresponding passenger occupancy, where o_{car} and o_{bus} respectively denote car and bus passenger occupancy.

$$D_{tot} = D_{car} \cdot o_{car} + D_{bus} \cdot o_{bus} \tag{6}$$

Optimisation

This paper introduces a framework that optimises the system delay by controlling the offset of the signal settings. The goal is to find the offset (for each intersection) that minimises the total delay for all passengers (bus and cars). Given a group of intersections in arterials, the optimisation space grows exponentially with each additional intersection. In the following, the preliminary results for one intersection with the aforementioned assumptions (no turning movements, dedicated bus lane, pre-timed signal settings) are shown.

Results

In figure 2, we can see the different passenger delays for cars, buses and all passengers. In this specific example we assume cycle length equal to 120 seconds (red=50sec, green=70sec), bus frequency of one per three minutes, car occupancy of 1 passenger per car and average car traffic arrival flow of 1100 cars per hour divided into 3 different demand levels D_1 to D_3 (as shown in figure 1). Note that the ideal offset for buses is different than the one for cars.

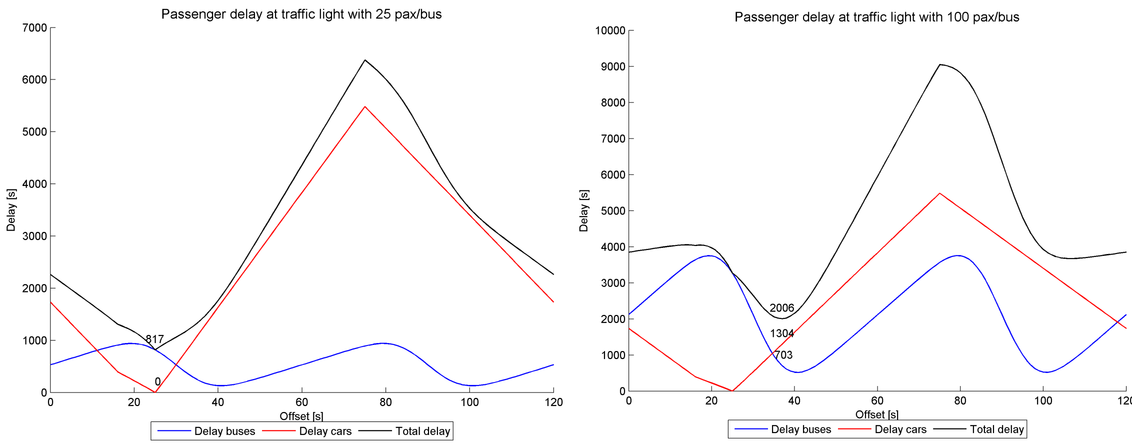

Figure 2: Passenger delay for 25 and 100 pax/bus

The periodic trend for the bus offset is due to the different frequency of buses (compared to the signal cycle). Traffic signals upstream can also influence the bus arrivals. Multiple intersections will be analysed in the full paper.

Note that offsets can significantly influence the car delay as flow of cars is high, while in this specific example the influence in the bus delay is smaller due to their arrival profile at the traffic light. We present here a conservative example. More details and other cases will be analysed in the full paper. Figure 2 also shows the influence the bus passenger occupancy can have on the final optimal offset. A small bus occupancy will not be able to change total delay in a manner so that the bus gets priority contrary to high bus occupancy.

In figure 3, the total passenger delay is plotted as a function of the bus occupancy. It is apparent that a small occupancy for buses does not result in a change of offsets (red line

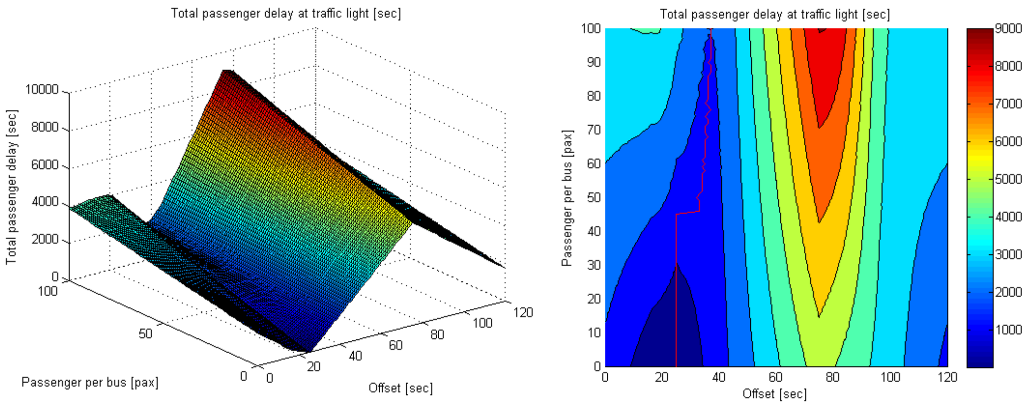

Figure 3: Passenger delay at traffic light

in figure 3, right), because the increase in car passenger delay would be too high. As the bus occupancy increases the total passenger delay grows constantly (figure 3, left) which makes sense as there are more people in the system. But more important is the relative increase of bus passenger delay compared to car passenger delay which grows faster and is therefore able to change the offset in favour of the bus.

Conclusion

The preliminary results show that there is a potential to improve signal settings in order to minimise delay for passengers. By showing the potential for a single intersection, we set the basis for the rest of this work where the goal is to implement this strategy over a full arterial and to develop an optimisation process that minimises the total passenger delay for the whole arterial taking into account all turning movements from and towards cross streets and considering more possibilities of priority like phase extensions and cycle adaptation for actuated signal settings. Further results will be presented in the full paper.

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