Identifying quick win opportunities for surface transit, delay reductions obtained through traffic signal timing distribution.

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Abstract Congestion is one of the main problems faced by surface public transport systems, affecting users’ travel time, services’ regularity, and system’s costs. Traffic signals explain part of this delay and programming them to prioritize transit can substantially increase operating speeds. Particularly, green split redistributions are simple and practically free adjustments that can have significant impacts. However, it might be expensive to collect the necessary traffic flow information. This article proposes a methodology that uses information of buses’ speeds to identify bottlenecks that are easy to solve through small time distribution adjustments in traffic signals, defined as quick wins. The quick win identification model is an extension of a previous bottleneck detection methodology, based on automated vehicle location (AVL) data. Furthermore, we propose a process to guide their intervention, allowing to fine-tune the traffic signal’s timings remotely and massively. This methodology was applied in the city of Santiago, detecting numerous quick win and ranking them according to their potential travel time saving. As an initial validation, 13 intersections were selected, visited, and analyzed. Despite significant temporal gap between the data, site visits, and implementation, green split redistributions were made, allowing for up to 117% speed increases. Finally, the methodology could also be used to fine-tune traffic control signals in general, not being limited to improvements in public transport, if more detailed speed information is available.

Keywords: Public transport · Traffic Signal · Quick Win · Operational speed · Operational bottleneck.
1 Introduction

Congestion is one of the main problems faced by surface public transport systems. Buses’ speeds show a downward trend in numerous cities, explained in part by an increasing motorization rate that has a negative impact on the transit system, as it increases congestion. This speed drop not only increases travel time, but also harms services’ regularity and the system’s costs, increasing fleet requirements needed to comply with programmed supply.

To prioritize public transport and guard it from congestion effects, buses can be separated from mixed traffic through specialized infrastructure. Examples are bus corridors and exclusive bus lanes, allowing significant speed increases (Alpkokin and Ergun, 2012; Vaz and Venter, 2012; Lindau et al., 2016). However, these solutions are not always achievable, since they generally have high costs and implementation times. This is especially relevant in developing countries, where institutions’ budgets have other priorities or are not able to develop these projects efficiently.

Traffic signals also have a high impact in traffic, and they can be easily modified at a low cost. They are one of the main causes of delay in urban contexts (Vanasse Hangen Brustlin, 2011), and their programming has a significant impact on traffic flow’s speeds. If they are programmed to prioritize public transport, buses’ speeds can substantially increase. However, even though changing a traffic signal’s timing is relatively easy and practically free, what might be expensive is the process of collecting information to do it effectively, especially if that means having to count traffic flow.

This article proposes a methodology that uses information of buses’ speeds to identify bottlenecks that are easy to solve through small time distribution adjustments in traffic signals. It is based on the bottleneck detection methodology proposed by Bucknell et al. (2017) (further improved in Schmidt et al., 2017), and we identify which bottlenecks are quick win opportunities. Then, we propose minor adjustments to the traffic signal’ timing and monitor the effects on the intersections’ delays. This process is repeated in order to minimize the delays.

It is important to note that the proposed methodology does not aim at solving the most critical operational bottlenecks in the city. These cases most likely involve complex solutions that go beyond traffic signal adjustments. The objective of this paper is to reduce the delay in intersections that can be easily improved at a low cost, increasing the system’s overall efficiency. Most of these problems are identified in off-peak time-periods or in peripheral areas, where there is less active monitoring and their networks are less optimized, especially in developing countries. Also, solving small inefficiencies in off-peak hours could lead to reducing congestion in peak hours if the changes reduce congestion in periods prior to these critical hours, facing them with better traffic conditions.

The remainder of this paper is structured as follows. Section 2 outlines the proposed methodology, describing the necessary input data, the quick win detection model, and the process of traffic signal adjustments. In Section 3, we present the results of applying the methodology to the public transport system of Santiago de Chile, Transantiago. Then, Section 4 shows a practical application, consisting in a first phase of initial validation, in which five intersections were intervened, allowing for significant delay reductions. Finally, conclusions are drawn in Section 5, presenting the upcoming work and possibilities for further extensions.

2 Methodology

The proposed methodology aims at identifying quick win opportunities in traffic signals. Quick wins (QW) are defined as intersections where there is an opportunity to decrease public transport’s delays through green split redistributions in a specific signal timing plan. This section details the methodology, starting with input data processing to continue with identifying quick wins and the proposed solution process.
2.1 Input data

There are three main types of data needed to develop this methodology: (i) network information with bus lines services (ii) buses’ bottlenecks, and (iii) traffic signal control information of intersections.

(i) **Network information with bus lines services:** The city needs to be geographically coded and include information regarding bus routes, allowing to spatially identify future QW.

(ii) **Buses’ bottlenecks:** Bottleneck information can be obtained through the methodology proposed by Schmidt et al. (2017), which analyzes bus speeds in roadways based on GPS emissions to identify bottlenecks (BN). A BN is a point in the road network, mainly intersections, where a significant speed increase of buses is produced. Figure 1 shows a BN based on the roadways’ speeds. Upstream speeds (red cells) significantly increase after the BN (green cells). This analysis considers all bus routes for every 15-min interval during the day. This study uses the methodology described in Schmidt et al. (2017) as a starting point, where a delay indicator is calculated based in the total time saving produced by solving each particular BN, and the amount of buses involved. This data is aggregated at an intersection level, resulting in a BN prioritized list with a delay indicator associated to each intersection.

![Figure 1: Buses’ bottleneck representation](image)

(iii) **Traffic signal information:** Detailed information regarding the position and programming of traffic signals are needed to analyze if there is an improvement opportunity in the intersection. Traffic movements, traffic signals’ phases and their green splits need to be correctly characterized.

2.2 Quick win detection

The methodology identifies QW in signaled intersections only where one of the phases has slack in terms of buses’ operational delay. Redistributing green splits from the phase with slack to the critical phase is expected to result in quick improvements in the intersection’s global indicators. Figure 2 describes the identification process of QW.

![Figure 2: Quick win detection model](image)
The steps to identify QW are described as follow:

**First step:** Among the bottlenecks identified through the methodology proposed by Schmidt *et al.* (2017), we identify those related to intersections with traffic signal control. With this, we have a first list of possible quick win candidates.

**Second step:** For each intersection and operation period (defined by the traffic signal control plan), delay indicators are analyzed for each phase. If one phase has a low distribution of the total intersection delay indicator (a model’s parameter, initially defined as less than 15%, but this percentage need to be calibrated), that intersection is identified as a QW for that specific period of operation.

**Third step:** Once a QW is identified for a specific intersection and operation plan, it is classified as (i) observable or (ii) not observable. An observable QW is when all access links have at least one bus line, meaning that it is possible to monitor the impact of a certain change in the speed of all access links. A non-observable QW is when there is at least one access link without buses, meaning that the impact of a change in green split is unknown for that specific phase because modes different to the bus do not provide speed information in this study. It is important to note that this definition assumes that buses travel in mixed traffic, so their speed is a good approximation of other vehicles that travel through the intersection. If buses do not travel in mixed traffic (i.e. bus lane or bus corridor), they should be modelled as a separated access link.

**2.3 Adjustment process**

Once the QW are detected through the previous model, we defined a process to guide their intervention. First, the tool needs to be automatic and run periodically (i.e. each week), monitoring changes in the delay indicators in all the city’s intersections.

The proposed process consists on slightly intervening each selected QW’s program by removing two seconds to the phase with slack and adding them to the critical phase. Then, after the periodic monitoring, if the intersection’s delay indicator decreased, another two seconds would be distributed, following the same logic as before. This is repeated until the overall intersection’s delay indicator increases, which means that the signal timing that minimizes the delay is the previous one.

To identify the delay indicator variations for each QW, it is necessary to aggregate delay indicators of each access link to the intersection in every time-period. It is worth noting that delay indicators have high variability over time, even if the intersection is not intervened. Therefore, it is important to define reasonable time thresholds that allow delay indicators to be statistically significant.

The proposed methodology allows to fine-tune the traffic signal timings massively and remotely, minimizing total delays by adjusting green splits of intersections.

**3 Data and identification results for Transantiago**

The methodology was applied to the bus public transport system of Santiago, Transantiago. This section details each step, following the same generic structure defined in Section 2.

**3.1 Input data processing**

This section details the origin of the input data needed to apply the methodology proposed in this paper.

The road network information needed to georeferenced the QW and the bus routes were provided by the agency in charge of bus regulation in Santiago (DTPM). The road network code is based on nodes and arcs,
and the bus routes are projected over them. Bottlenecks were obtained by means of the methodology developed by Schmidt et al. (2017) in Santiago, Chile.

For the traffic signal controls, we used the current available information regarding the operational plans, programming and position of the 2,300 traffic signals in Santiago. It is worth noting that a data base with vehicle movements associated to signal phases did not exist, so assumptions had to be made for its construction.

3.2 Quick win detection results

After applying the proposed quick win detection model to Santiago using the previous data, we obtained a prioritized list of intersections and time periods with an opportunity to reduce bus delays through changes in traffic signals’ timings.

For example, if we consider the peak morning hours (6:00 to 11:00), the methodology proposed by Schmidt et al. (2017) identifies 4,870 bottlenecks from the 22,000 intersections of Santiago where buses circulate. Of these 4,870, 880 were identified as QW. Figure 3 shows the results of QW’s at 10:00 AM in Santiago.

![Figure 3: Map of Santiago’s quick wins at 10:00](image)

The results were constructed according to the traffic signal’s operational plans, identifying specific plans where a green-split redistribution could reduce public transport’s delays.

Figure 4 shows the global delay indicator’s distribution throughout the city for one day. It shows that the higher improvement opportunities in terms of delay decreases are presented between 17:00 and 20:00. On the other hand, the highest number of problems are identified at 8:00, shown by the orange curve. This reveals that in the morning rush hour there is a higher number of problems, but with a smaller individual impact in average than in the afternoon rush hour.
3.3 Adjustment process definition

After identifying QW opportunities, a detailed intervention process is defined:

i. Frequency of data report: After analyzing the amount and stability of speed’s data, the periodicity for adjustment and monitoring was defined as one week. This decision was based on the automatic GPS information availability, the frequency of its emissions (every 30 seconds), and the number of buses in circulation during the different periods of the day. This means that every week there are new delay indicators for the city, but that does not necessarily mean that changes will be done every week.

ii. Adjustments: Once all the observable QW cases are identified, the green-splits are adjusted. The critical access link increases its green time in 2 seconds, and the looser phase decreases its green time in 2 seconds.

iii. Monitoring: Once the change is implemented, this can be maintained over time, reversed or further increased by 2 seconds each time. This decision depends on the delay indicators obtained in the weeks after the change. It is worth noting that the number of weeks to consider after the intervention need to be further calibrated. This experiment considers a two week interval.

If the delay indicators of the weeks after the intervention decrease, but still are significantly greater than zero, further green-split changes should be implemented. If the indicator increases, then the change should be reversed.

4 Practical application: initial validation

Prior to the massive and remote application of the methodology, we developed a first phase of initial validation. Its objective was to verify that the tool is able to correctly identify quick wins associated with traffic signals, and that significant improvements can be achieved by simple green splits redistributions.

The validation consisted in:

i. Defining a list of QW candidates

ii. Verifying in-site that the intersections presented an improvement opportunity

iii. Implementing green-splits distribution changes

iv. Evaluating the impact in the delay indicator

For this first validation, it was determined that all QW’s should be observable. This had the objective of being able to observe the global delay indicator of the intersection, being sure that changes did not negatively impact other modes that were not detected by our methodology.
Under this criterion, thirteen observable QW’s were selected for evaluation. However, because of data availability problems, these selected intersections were defined using information from April 2017. Considering that site visits were done in November and December of 2017, this means a 7-month gap between the automatic detection of the improvement opportunity and its empirical validation. Still, 5 of the 13 intersections presented a QW, and green-split modifications were introduced. With the improvement of automatization processes and data sources, we expect the gap to be not over one week, significantly increasing the detector’s precision.

The green-split changes that were implemented are summarized in Table 1. Given that a QW presence was verified in-site, these changes were higher than two seconds, which is the proposed adjustment for when it is done remotely. This includes the change in cycle duration in Vivaceta with Gamero, which was an exception because of the site-visit but this type of change will not occur when this is done automatically and remotely.

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Signal Timing Plan</th>
<th>Change</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independencia - Artesanos</td>
<td>10:00 – 14:15</td>
<td>+ 5s to Independencia</td>
<td>2018/03 - week 2</td>
</tr>
<tr>
<td>Nueva Providencia - Manuel Montt</td>
<td>17:00 – 20:30</td>
<td>+ 5s to Nueva Providencia</td>
<td>2018/03 - week 2</td>
</tr>
<tr>
<td>Rinconada - 4 Poniente</td>
<td>18:00 – 21:15</td>
<td>+ 8s to Rinconada OP</td>
<td>2018/03 - week 2</td>
</tr>
<tr>
<td>Santa Rosa - M. A. Matta</td>
<td>10:00 – 16:45</td>
<td>+ 5s to Santa Rosa</td>
<td>2018/03 - week 2</td>
</tr>
<tr>
<td>Vivaceta - Gamero</td>
<td>16:15 – 20:15</td>
<td>Shorter cycle and higher green split to Gamero</td>
<td>2018/03 - week 3</td>
</tr>
</tbody>
</table>

Table 1: Implemented changes in the validation phase

Delay indicator results are shown in Figure 5, where the weeks before the change are marked in red, and after the change are marked in green.

It is important to note that changes were implemented in March 2018, implying once again an important time gap. This might explain the results on the first two intersections, in which no significant gains were achieved.
As shown in Figure 5, by the time changes were implemented in those intersections, the delay indicator was already low, meaning that the situation had changed and there were no longer any QW opportunity. Lastly, an outlier was observed in the fifth intersection on the fifth week (we checked social media and a fire was reported just a few steps away from the intersection), highlighting the need to monitor more than a week before deciding about the impact of any intervention.

5 Conclusions

A generic methodology was developed to identify and improve operational quick wins for buses in traffic signals. For this purpose, a quick win was defined as a bottleneck where delays can be reduced by modifying the traffic signal’s green split, allowing for immediate improvements. The methodology is a cost-effective alternative to improve the surface public transport’s speed, allowing to adjust the traffic signal’s timings remotely and massively.

After applying this methodology to the city of Santiago, numerous quick wins were detected and ranked according to their potential travel time saving. Prior to the massive application, a first phase of initial validation was conducted, in which thirteen observable QW’s were studied. In three of them significant delay reductions were achieved, allowing for up to 117% speed increases. The fact that the remaining eight intersections finally showed no QW opportunity is mainly explained due to major time gaps between model data, site visits, and effective traffic light changes. We are currently working on data availability and processing, in order to decrease these time gaps and increase the effectiveness of the interventions.

As further research, we propose analyzing the delay reductions not only on an isolated intersection, but to define an area of influence. This way, we can assure that the traffic signal change allowed for an overall delay reduction in the network. Additionally, we will study adapting the methodology to include on-time adjustments, allowing to adapt to specific events that could change traffic in an unpredictable manner.

Finally, the proposed methodology could also be used to fine-tune traffic control signals in general, not being limited to improvements in public transport. To develop this case, information on private vehicles’ speeds are needed, which can be obtained through applications such as Google Maps or Waze.

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References


