Available online at www.sciencedirect.com
ScienceDirect
Procedia Social and Behavioral Sciences 16 (2011) 612–619
Procedia
Social and Behavioral Sciences

6th International Symposium on Highway Capacity and Quality of Service
Stockholm, Sweden June 28 – July 1, 2011

# Impact of Transit Signal Priority on Level of Service at Signalized Intersections

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**Abstract**

The assessment of Transit Signal Priority (TSP) impacts at traffic signals is typically based on simulation and field studies. There is a need for macroscopic procedures for analysis of TSP as part of the Highway Capacity Manual (HCM) analysis methodology for signalized intersections. This capability will allow prediction of TSP impacts (and related control strategies) at a planning and operations level without the complexity of simulation modeling. The paper presents a technique of estimating the average green times for each lane group, and modifications to the HCM formula for estimating control delay in order to estimate the impact of TSP on the Level of Service (LOS) at each approach and the whole intersection. The technique uses readily available information on the frequency of the transit vehicles, TSP features (e.g., green extension, or red truncation), and also takes into consideration the additional delays because of the residual queues that are likely to occur on non priority approaches operating close to saturation. Application of the method at a signalized intersection with signal priority in the San Francisco Bay Area, and comparisons with simulated data show that the proposed methodology provides reasonable estimates of the TSP impacts, and it can be incorporated into the HCM analysis procedures for signalized intersections.


*Keywords*: transit signal priority; intersection capacity; level of service

## 1. Introduction

Transit Signal Priority (TSP) is a control strategy that has been increasingly used to improve transit operations in urban networks. The magnitude of the benefit obtained varies among networks that differ in their operating and transit characteristics (e.g., volume to capacity ratios for the different approaches, cycle lengths, transit frequencies) as well as their TSP features (e.g., minimum green extension, frequency of green extension versus red truncation). Several studies have shown that the implementation of TSP strategies can result to lower delays for priority transit vehicles and cars that travel in the same directions, but can have negative impacts on the delays of the cross (non-priority) streets. The magnitude of this negative impact varies from insignificant increases in their delays to major ones, mainly when the cross-streets operate close to saturation.

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doi:10.1016/j.sbspro.2011.04.481

This assessment of TSP strategies has been mainly based on simulation. Simulation studies are data-intensive and as a result, time consuming (Rakha and Zhang, 2004, Ahn and Rakha, 2006). In addition, most of them do not incorporate accurately the TSP logic and features, failing to realistically model the TSP systems. Another typical way of evaluating TSP strategies is through field tests (Ahn et al., 2005). In addition to their high costs (i.e., equipment, extra delays to traffic during the experiment) they are time consuming and depend on specific characteristics of the study site. Analytical models have also been proposed (Sunkari et al., 1995, Liu et al., 2008) which however, ignore random and oversaturation delays. As a result, they do not estimate accurately the impact in oversaturated conditions which is the case for non-priority approaches that operate close to saturation and can easily move to oversaturated operations once TSP strategies are introduced.

There is a need to develop methodologies that are able of estimating accurately and easily the impact that TSP strategies have on the delays of all vehicles traveling through the network in order to be able to evaluate in advance the benefits from implementing such strategies, before investing for them. The paper presents a technique of estimating the impact of TSP on the delays of all approaches and consequently, the LOS for each of those in a more macroscopic way. It uses readily available information on the TSP features and the distribution of transit arrivals to estimate the average green times for all phases. Then it uses that information along with the frequency of the buses to estimate the delays and the LOS for each of the approaches using the delay estimation formula and LOS thresholds of the HCM. The main advantage of this technique is that it is easy and accurate and does not require extensive data collection or calculations.

This paper is organized as follows: First, the methodology for estimating the average green times as a function of transit vehicle frequency and TSP characteristics, for each of the phases is presented. Next, this methodology is tested with data from a hypothetical intersection. Finally, simulated data from a real-world signalized intersection with signal priority in El Camino Real, in the San Francisco Bay Area, are used to compare the estimates of the TSP impacts obtained from the proposed methodology.

## 2. Average green time estimation

The average green time for all phases is estimated as a function of the distribution of the bus arrivals during a cycle as well as the TSP features (i.e., minimum and maximum extension and truncation). The estimation is based on the assumption of uniform arrivals during each signal cycle, meaning that there is equal probability of the bus arriving during any of the time intervals within a cycle. It is also assumed that the green time can be extended or advanced by fixed intervals of $e$ and $\tau$. The probability of that bus receiving priority treatment is equal to the probability of it arriving within the intervals of maximum length equal to $e_{max}$ and $\tau_{max}$ before or after the initial phase extension respectively and it is:

$$\mathrm{P(Priority)} = \mathrm{P(Green\ extension)} + \mathrm{P(Early\ green)} = \frac{e_{max}}{C} + \frac{\tau_{max}}{C} \tag{1}$$

where:

$e_{max}$: maximum green extension allowed [sec]

$\tau_{max}$: maximum red truncation allowed [sec]

$C$: cycle length [sec]

The expected value for green time for the priority phase given no priority is provided during that cycle, is equal to the initial green time allocated to it and it is:

$$\mathrm{E}[G_P|\mathrm{No\ priority}] = g_P \tag{2}$$

and if priority is provided it is:

$$\mathrm{E}[G_P|\mathrm{Priority}] = g_P + e \times \mathrm{P(Green\ extension} = e) + e_{max} \times \mathrm{P(Green\ extension} = e_{max}) + \tau \times \mathrm{P(Early\ green} = \tau) + \tau_{max} \times \mathrm{P(Early\ green} = \tau_{max}) = \frac{e^2}{C} + \frac{e \times e_{max}}{C} + \frac{\tau^2}{C} + \frac{\tau \times \tau_{max}}{C} \tag{3}$$