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DETERMINING THE CAPACITY BENEFITS OF REAL-TIME SIGNAL CONTROL AT AN INTERSECTION

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ABSTRACT

Traffic responsive control strategies are increasingly being implemented to improve intersection performance. Critical intersection control (CIC) is using real-time traffic data to better assign green times to conflicting movements. However, the benefits of CIC have not been assessed, and existing methodologies for estimating intersection performance do not account for CIC or other traffic responsive control strategies. The effectiveness of CIC was evaluated at seven signalized intersections in the City of Los Angeles. The findings indicate that CIC generally improves traffic operations. The ongoing evaluation of additional test sites will result in guidelines and adjustment factors in estimating intersection performance under CIC using the Highway Capacity Manual and other analysis techniques.

Key Words: Traffic Signals, Capacity, Level of Service, Critical Intersection Control (CIC)
INTRODUCTION

Traffic signals on urban arterials and in grid networks operate in coordinated systems to provide for progression of major traffic movements. Most of these systems currently operate under fixed-time control. A significant number of modern microprocessor signal controllers are in use on these systems and permit traffic signals to operate as semi- or fully-actuated, or traffic responsive through centralized control. This flexibility in signal operations may improve the traffic performance at a specific intersection or over the total system, because actuated signals are able to respond to cycle-by-cycle variations in traffic volumes, and better assign green times to conflicting movements, thus reducing unnecessary delays and stops.

Many growing cities across the United States mitigate traffic growth by studying the impacts that development projects have on the existing street systems. Transportation planning methods have the ability to project how many additional peak hour trips will be added to specific intersections surrounding the project. Once the additional trips are known, the impact of the project on the capacity of the signalized intersection can be determined through analytical techniques.

The existing analysis techniques traditionally calculate the peak period signal timing for an intersection by using the peak hour traffic, with the splits remaining the same every cycle for the entire peak period, even if a traffic responsive system is in place.

A real-time traffic control system can use vehicle detectors to collect cyclic traffic counts, which can then be smoothed by historical time-of-day, day-of-week data, and input into an algorithm to determine the best signal timings for each cycle. This allows the splits to never be more than one cycle behind the actual traffic conditions, which seems superior to being months or years behind. There must be some efficiencies by having the signal timing fit the volumes on a cyclic basis instead of using an average hourly volume and having a fixed split. However, real-time control has not been addressed in the existing intersection analysis procedures.

A collaborative study has been undertaken between the City of Los Angeles Department of Transportation (LADOT) and UC Berkeley to assess the impacts of critical intersection control (CIC), a traffic responsive control algorithm for green times estimation. The objectives of the study is to evaluate the CIC operation, and produce a procedure that takes into account CIC control into the intersection analysis techniques. The paper describes the results to-date from this effort.

The paper or organized as follows. First, we describe the development and testing of control strategies for intersections along arterials. Next, we describe the evaluation of CIC at seven intersections in Los Angeles. The final section summarizes the study findings.
BACKGROUND

CIC Control

The Critical Intersection control feature of the UTCS Software (CIC) is designed so that at a critical intersection, the green demand for each phase is calculated every cycle, while the cycle length and offsets remain fixed to maintain coordination. Unlike coordinated actuated signals, for which all the spare time from the "early" termination of the actuated phases is provided to the through (sync) phase, CIC allocates the green times to the conflicting critical approaches based on volume and occupancy data from all the conflicting critical approaches.

The CIC control software implemented in the LADOT Automated Traffic Surveillance and Control System (ATSAC) performs the calculation every cycle, based upon green demand for each detector. If a phase has more than one detector assigned, the green demand is set to the largest of the detector green demands. Each phase is given a duration proportional to its green demand time; this duration is limited by minimum phase limits, and established upper and lower thresholds set in the CIC software. The Green Demand Time Calculation is as follows:

\[ GD = AV^B + CO^D \]  

where:
\[ A = 7.5 \quad GD = \text{Green Demand (\% of cycle)} \]
\[ B = 0.5 \quad V = \text{Smoothed Volume (vph)} \]
\[ C = 0.33 \quad O = \text{Smoothed Occupancy (Percent)} \]
\[ D = 1.0 \]

Detailed description of the ATSAC CIC algorithm is given elsewhere (1).

Predicting Intersection Performance

The 1994 Highway Capacity Manual (HCM) (2)--Chapter 9 Signalized Intersections--is the standard analysis procedure used to analyze the intersection traffic performance under prevailing geometric, traffic and control conditions, and to predict the impacts of traffic growth and alternative scenarios. The HCM method is using the volume to capacity ratio (v/c) to determine the intersection capacity, and the average stopped delay (sec/veh) to determine the Level of Service (LOS). The analysis is performed using peak 15 minutes flow rates, and existing or assumed signal settings. The (v/c) for a lane group is:
\[ X = (v / c) = v / (sg / C) \]  \hspace{1cm} (2)

where:
- \( v \) = actual or projected demand flow rate for the lane group (vph)
- \( c \) = capacity of the lane group (vph)
- \( s \) = saturation flow rate for the lane group (vphg)
- \( g \) = effective green time for the lane group (sec)
- \( C \) = cycle length (sec)

Sustainable values of \((v/c)\) range from 1.0, when the flow rate equals capacity, to zero when the flow rate is zero. Values above 1.0 indicate an excess of demand over capacity. The critical \(v/c\) ratio for the intersection is defined in terms of critical lane groups or approaches:

\[ X = \sum (v / s)[C / (C - L)] \]  \hspace{1cm} (3)

where:
- \( X \) = critical \(v/c\) ratio for the intersection
- \( \sum (v / s) \) = summation of the critical flow ratios for all critical lane groups
- \( C \) = cycle length (sec)
- \( L \) = total lost time per cycle (sec)

The average stopped delay per vehicle for a given lane group is given by

\[ d = d_1 DF + d_2 \]  \hspace{1cm} (4)

\[ d_1 = 0.38C[1 - g / C]^2 / [1 - (g / C)[Min(X,1.0)]] \]  \hspace{1cm} (5)

\[ d_2 = 173X^2 \{(X - 1) + [(X - 1)^2 + mX / c]^{0.5} \} \]  \hspace{1cm} (6)

where:
- \( d \) = stopped delay (sec/veh)
- \( d_1 \) = uniform delay (sec/veh)
- \( d_2 \) = incremental delay for 15 min duration (sec/veh)
- \( DF \) = delay adjustment factor for quality of progression and control type
\[ X = \frac{v}{c} \text{ ratio or degree of saturation} \]

It can be clearly seen from the above formulae (and emphasized in the HCM) that the quality of signal settings significantly affects traffic performance, especially for intersections close to saturation. The HCM procedure assumes that the signal settings remain fixed throughout the analysis period. The delay equation does account for the effects of progression and actuated signal control, but no consideration is given for intersections operating under real-time control such as CIC.

The lack of formal procedure for analysis of signalized intersections under CIC (and other forms of traffic responsive control) has led into adoption of adjustment factors that have often not been derived. For example, since the mid 1980's, the City of Los Angeles has allowed developers to take a 7 percent \((v/c)\) reduction credit if they provide funding for the ATSAC System with CIC at affected intersections. Is a system like CIC/ATSAC really the seven percent solution?

**EVALUATION OF CIC**

Seven intersections were selected for the evaluation of the CIC. The test sites were selected to represent typical intersection configurations and a range of traffic and control conditions.

Table 1 lists the seven selected study intersections, which are part of the LADOT ATSAC system, and operate as coordinated. The intersections along 6th street (a one way arterial) are closely spaced at an average spacing of 120 meters (400 ft). The intersection at Olympic/Selpuveda has a protected phase for the westbound left-turn movement, and the intersection at National/Overland has split phasing for the eastbound/westbound approaches. The rest of the intersections are two-phase with permitted left turns. All the intersections had CIC approach detectors on all the approaches and all detectors were working properly during the study.

The time period of the study on all the intersections was 5-6 p.m. (1 hr in duration). Real time detector data were obtained from the ATSAC Detector Analysis Report. The corresponding CIC timing splits was obtained from the ATSAC Real Time Split Monitor Report. The existing fixed-time time-of-day signal settings were obtained from the existing timing chart for the p.m. peak period plan. These timing plans have all been updated since 1997, so any benefits obtained from CIC due to obsolete fixed-time timing plans are expected to be minimal. However, the CIC timings can compensate for the inability of staff to update timing plans in a timely manner. Figure 1 shows an intersection display for one of the test sites in the ATSAC system showing detector locations and signal timings.
The HCM94 procedure, as implemented in the Synchro 3.2 software package (3), was utilized in the study to analyze the two different timing schemes: the existing TOD timing versus the CIC timing. Since HCM94 requires an hourly volume and one signal timing plan, the analysis had to be done differently. The cycle length was used to determine how many cycles per hour occurred at each intersection. A separate run was done for each cycle, using the volumes and timing plan for that cycle. The measures of effectiveness were then totaled for each cycle and divided by the number of cycles to obtain an hourly average. For a 90 seconds cycle, 40 runs were done for cyclic volumes using the same fixed-time plan for each run, and 40 runs were also done for the same cyclic volumes with the different CIC generated timing plans input for each run. For each intersection, a new volume was inputted in the software for every cycle. A total of 560 analysis runs were performed (7 intersections X 40 cycles X 2 scenarios).

Figure 2 shows how the CIC timings varied compared to the fixed-time plan for the Melrose/Fairfax intersection in the study area throughout the one-hour analysis period. The difference in the (g/C) ratios between fixed-time and CIC for each cycle should generate (v/c) improvements when aggregated over one hour. The corresponding (v/c) ratios for each critical lane group are shown in Figure 3. It can be seen that the CIC control resulted in lower average (v/c) ratio for the EB/WB approach (which is the critical approach at the intersection). This resulted in about 13 percent reduction in delay for this intersection under CIC control compared to the fixed-time settings (Table 2). The intersection LOS with CIC was better 41 percent of the time, and the same during the other 59 percent.

The estimation of delays under the two forms of control deserves discussion. The HCM94 delay formula assumes 15-minute period of analysis, but we analyze each signal cycle. Thus, the comparison of CIC and fixed-time control is likely to overestimate the incremental delay component. We applied the revised formula for the incremental delay included in the 1997 update of the Signalized Intersection Chapter (4):

\[
d_2 = 900T[(X - 1) + \sqrt{(X - 1)^2 + \frac{8kIX}{cT}}]
\]  

(7)

where:

- \( T \) = duration of analysis period (hours)
- \( k \) = incremental delay factor that is independent on controller settings
- \( c \) = lane group capacity (vph)
- \( X \) = lane group v/c ratio or degree of saturation.
This formula is time-dependent (T can be set for a period of one cycle, with the corresponding cyclic arrivals and capacity values) and allows more accurate estimation of the incremental delay. The Equation (7) estimates the total incremental delay instead of the stopped delay; therefore it was adjusted for stopped delay.

The CORSIM microscopic simulation model (5) was also applied to analyze the intersection performance under CIC and fixed-time control. Comparisons with CORSIM’s predicted values and HCM’s estimated values indicate that both modeling approaches produced similar results.

Table 2 summarizes the analysis of the results to-date for all the test sites. The performance measures used were the reduction in the (v/c) ratio, the average decrease in delay, and the change in the LOS. The results indicate that in all the intersections with two phases CIC resulted in significant improvements, with the exception of the 6th/Spring street intersection. This intersection operates under LOS B (free flow conditions); therefore CIC control would not result in any significant changes. The effectiveness of CIC was limited at the two multiphase intersections (Olympic/Sepulveda and National/Overland). The changes in the splits were small (about 2-3 seconds) on the average, and any improvements one approach resulted in significant disbenefits on the conflicting critical lane groups.

**DISCUSSION**

The effectiveness of the CIC control strategy in improving the operational performance at signalized intersections was evaluated at seven real-life intersections, part of the ATSAC control system in Los Angeles. Field data on flows and signal settings on each cycle were collected and analyzed. Traffic performance measures were estimated using analytical techniques and simulation modeling. The results indicate that CIC control generally improves intersection performance (delay and LOS).

The effectiveness of CIC depends on the intersection geometric, traffic and control characteristics. Significant reductions were obtained on two-phase intersections with exclusive turning lanes, and/or unbalanced critical volumes. The flexibility of adjusting the green splits with CIC becomes limited on multiphase signals (because of the constraints of minimum phase times), and on intersections with more than one critical lane group during the same period of the day (i.e., all conflicting critical lane groups are close to saturation). Under such situations, CIC split adjustments are usually small and any improvements to one-approach results in significant disbenefits to other approaches.

There is a need to incorporate the effects of CIC and other forms of traffic responsive control into analysis procedures for predicting the intersection performance. The results of this study and the ongoing evaluation of additional study intersections in Los Angeles will result in guidelines and adjustment factors in estimating traffic performance under CIC using HCM and other analysis techniques.
ACKNOWLEDGMENTS

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The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of or policy of the Department of Transportation. This paper does not constitute a standard, specification or regulation.
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### TABLE 1. Selected Test Sites

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Number of Lanes</th>
<th>Number of Phases</th>
<th>Cycle Length (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melrose/Fairfax</td>
<td>3(1)*</td>
<td>4(1) 4(1)</td>
<td>2 90</td>
</tr>
<tr>
<td></td>
<td>4(1) 4(1)</td>
<td>3(1)</td>
<td>3 90</td>
</tr>
<tr>
<td>Olympic/Sepulveda</td>
<td>3(1) 3 4(1) 4(2)</td>
<td>4</td>
<td>90</td>
</tr>
<tr>
<td>National/Overland</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6th Street:**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Broadway</td>
<td>3 3 3(1)</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>-Spring</td>
<td>3 3</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>-Main</td>
<td>3 3</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>-Los Angeles</td>
<td>3 2 2</td>
<td>2</td>
<td>90</td>
</tr>
</tbody>
</table>

* xx(x): Total # of lanes (exclusive LT lanes).
**One-Way EB.
### TABLE 2. IMPACTS OF CIC

<table>
<thead>
<tr>
<th>Intersection</th>
<th>(v/c) Reduction (%)</th>
<th>Delay Reduction (%)</th>
<th>LOS (% of cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Improved</td>
</tr>
<tr>
<td>Melrose/Fairfax</td>
<td>8.3</td>
<td>13.2</td>
<td>41</td>
</tr>
<tr>
<td>Olympic/Sepulveda</td>
<td>1.8</td>
<td>4.0</td>
<td>0</td>
</tr>
<tr>
<td>National/Overland</td>
<td>0.0</td>
<td>3.1</td>
<td>0</td>
</tr>
<tr>
<td>6th Street: **</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Broadway</td>
<td>14.0</td>
<td>10.8</td>
<td>53</td>
</tr>
<tr>
<td>-Spring</td>
<td>-4.7</td>
<td>4.9</td>
<td>0</td>
</tr>
<tr>
<td>-Main</td>
<td>13.5</td>
<td>17.7</td>
<td>55</td>
</tr>
<tr>
<td>-Los Angeles</td>
<td>12.5*</td>
<td>16.2*</td>
<td>27</td>
</tr>
</tbody>
</table>

*Data for 10 cycles were not used-invalid volumes