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Comparative assessment of arterial operations under conventional time-of-day and adaptive traffic signal control

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Abstract

This paper compares three principal arterial corridors in Alabama under both conventional and adaptive traffic signal control (ATSC). The corridors differ in their physical and operational characteristics. The comparison is conducted through microsimulation analysis of each corridor under their latest time-of-day (TOD) signal operations compared with the same field conditions (i.e., traffic volumes, geometry, access management) operating under Sydney Coordinated Adaptive Traffic System (SCATS) control. The three corridors greatly differ in the traffic saturation levels. Thus, the objective of this paper is to analyze and compare the performance of SCATS under varying saturation conditions. The comparison is based on various performance measures, including travel time, delay, average speed, and queue lengths under TOD and SCATS control. Based on the data and analysis results, a general conclusion is reached that in addition to the traditional ways to assess network performance, a range of other performance measures at various scales (i.e., network, corridor, sub-corridor, intersection) should be used to evaluate ATSC depending on overall policy goals. Under SCATS control, shorter side-streets queue lengths and shorter cycle-to-cycle queue lengths contribute to the network-wide performance gains. The improved network-wide performance is also attributed to the lower delays on side-streets and left-turn movements with SCATS. However, SCATS shows immediately measurable operational improvements only on unsaturated networks. SCATS shows less direct improvements in the network-wide performance measures for saturated conditions due to less ability to adapt and give more constrained vehicle movements.

Keywords – Sydney Coordinated Adaptive Traffic System (SCATS), Adaptive traffic signal control (ATSC), VISSIM, Microsimulation

1. Introduction

Traffic signals are used to assign right of way to vehicular and pedestrian traffic at an intersection. Proper traffic signal timing and operations reduce congestion, improve mobility, and enhance safety. Although signal operations impact several individual performance measures, one of the most positive potential benefits is the overall improvement of system efficiency. The process of developing and maintaining traffic signal timing plans can be extremely resource-intensive. Yet, traffic signal retiming is one of the most cost effective ways to mitigate congestion. However, outdated or poor traffic signal timings may cause excessive delays [1].

Furthermore, traditional time-of-day (TOD) plans do not accommodate variable and unpredictable traffic demands and cannot adjust to changing travel demand over time. As such, adaptive traffic signal control (ATSC) systems are becoming more widely used throughout the traffic engineering industry.

ATSC systems continuously detect vehicular traffic data and then compute and implement optimal signal timings in real time [2] . Such systems are complex and incur higher costs for both initial installation and operational maintenance. Nevertheless, ATSC systems offer wide range of benefits which include:

- Reduced congestion and fuel consumption
- Improved travel time reliability
- Prolonged effectiveness of traffic signal timing
- Proactive traffic signal adjustments from monitoring and responding to real-time traffic demands.

ATSCs are widely used in the United Kingdom, Asia, and Australia. In the United States, ATSC technologies are currently used on less than one percent of all signalized intersections. Commonly cited barriers to ATSC deployment include high hardware and software costs, lack of local expertise necessary to configure and maintain the system, the uncertainty about the benefits of adaptive signal control technology, and the lack of active performance measurement [3]. Various ATSCs available in the market include the Sydney Coordinated Adaptive Traffic System (SCATS), Split Cycle Offset Optimization Technique (SCOOT), Optimization Policies for Adaptive Control (OPAC), Adaptive Control Software Lite (ACS Lite), Real-Time Hierarchical Optimized Distributed and Effective System (RHODES), InSync and others. The underlying algorithms in each system vary in approach and structure but essentially optimize operational efficiency by maximizing throughput, minimizing delay, or some combination of both [4].

SCATS is one of the most widely used ATSC. It controls traffic at two levels (strategic and tactical) by determining the three signal timing parameters, namely; phase splits, cycle lengths and offset. The strategic control uses data collected from the lane-by-lane stop bar zones by the local controllers to determine the three signal timing parameters. SCATS uses the degree of saturation (DS) as the basic measure for traffic control. DS is defined as the ratio of efficiently used phase time to the total available phase time at each intersection. SCATS constantly make changes to the cycle length to maintain the DS at the level of around 0.9. The phase splits are varied each cycle to maintain equal DS on competing approaches to minimize delays. SCATS do not optimize offsets. However, offset scheme based on the balance of traffic and the cycle length are selected such that better flow movements are achieved between the intersections. Tactical control is undertaken by the local controllers at each intersection to provide flexibility to meet the cyclic variation in demand. Tactical control consists of operations such as early termination of green phase in case of lower demand and omission of a certain phase in case of no demand. The combination of strategic and tactical control helps SCATS respond to both gradual and rapid but smaller changes in traffic demand and hence, resulting in very efficient operation of the signals [5, 6]. In addition, SCATS is customizable in the sense that the local traffic engineers can configure SCATS to achieve desired policy outcome e.g. congestion management, mainline progression [7, 8].

The objective of this paper is to compare three principal arterial corridors with different physical and operational characteristics under both conventional and adaptive traffic signal control by examining various performance measures, including travel time, delay, average speed, and queue lengths. The comparison is illustrated through a case study. The case study comprises a microsimulation analysis of the three corridors, each under their most recent TOD signal operations. The results are then compared using the same conditions (i.e., traffic volumes, geometry, access management) while operating under SCATS control. The three corridors greatly differ in the traffic saturation levels. Thus, this paper analyzes the SCATS performance under varying traffic saturation conditions. Whereas, many such evaluation studies have been performed in the past, no study to our knowledge was found in the literature that performed such comparative evaluation. As such the contribution of this study is the addition of knowledge to the existing body of literature on performance evaluation of ATSC systems for both researchers and practitioners to benefit from the findings of this research.

2. Literature review

The 2012 National Traffic Signal Report Card emphasizes a greater need for better signal management and operations [9]. On average, poor signal timings contribute up to five percent of total traffic congestion. Other studies have shown ATSC systems to perform better (in certain performance measures) than fixed-time and actuated control. National Cooperative Research Program (NCHRP) 403 presents a comprehensive synthesis of the current knowledge, practices, advantages and limitations of various ATSC implementations [4]. The 2012 Urban Mobility Report published by Texas A&M Transportation Institute reports ATSC systems as performing some three times better than actuated control with regard to delay reduction [10]. Another study on evaluation of ATSC shows that InSync was able to reduce travel times over an arterial study corridor [11]. The improvements, however, were directionally specific and limited to a specific time of day. Another study in Minneapolis showed that SCOOTS significantly improved travel times during special events. Overall peak hour travel times, however, showed no significant change under ATSC [12]. An evaluation of OPAC in Florida showed significant improvements to arterial operations but reported that these were at the expense of side-street efficiency [13]. Taale et al. show that the proper functioning of SCOOT system relies on the parameter settings that can influence the results of any assessment [14]. In addition to this, there are other studies of investigation of suboptimal deployment of ATSC [15].

Previous evaluations of SCATS have reported mixed results. Peters et al. (2007) reported that SCATS reduced travel times during the AM peak period in one direction but an increase in the opposite direction on the Burnside corridor in Gresham, Oregon. The before-after SCATS comparison, however, might have been biased as the original timing plans explicitly favored one direction during the AM peak period [16]. Although none of the studies showed worsening operations under SCATS control, several showed only limited improvements with regard to travel time [17, 18]. Martin and Stevanovic (2008) reported that a SCATS deployment in UTAH resulted in improved travel times in addition to reduced stopped delay and number of stops [19]. This review suggests the need for careful evaluation of the ATSC performances.

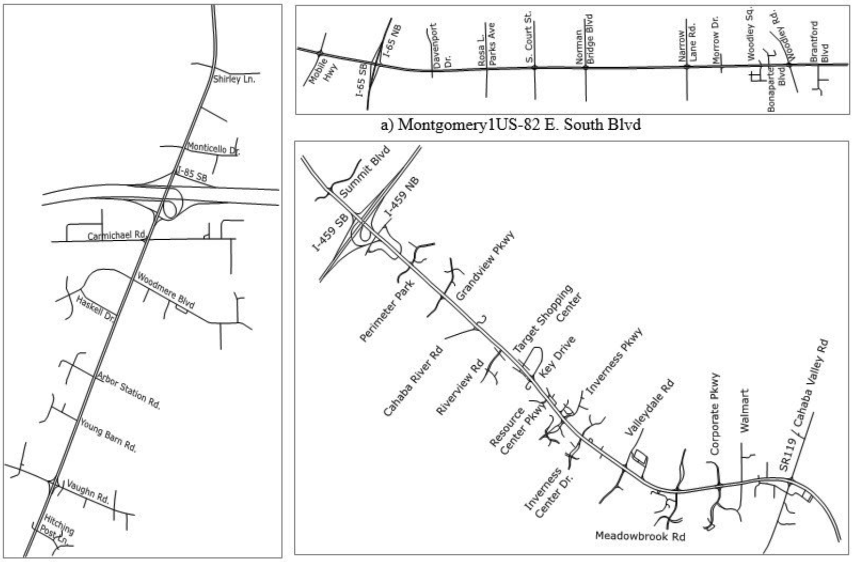
3. Case study

Three separate arterial corridors were studied using a variety of performance metrics. The corridors differ in prevailing operational speeds, volume characteristics (mainline vs. side-street, turning movements, etc.), as well as in terms of geometric and access management conditions. All three arterial corridors primarily serve as commuter routes. Furthermore, there are no relevant alternate routes - only some minor, often circuitous residential streets. The Montgomery 1 corridor exhibits the lowest overall traffic among the three corridors with an AADT of 38,000 vehicles per day (vpd). Montgomery 2 serves 43,000 vpd and Birmingham about 70,000 vpd. Thus based on the field condition and traffic volumes, the congestion levels are subjectively assessed as low, medium and high respectively. This allows a comparison of SCATS performance across very different conditions as all three operated under independent SCATS configurations (i.e. subsystems). Schematic layouts of the corridors are shown in Figure 1 and relevant details are summarized in Table 1.

Field data collected before the SCATS installation was used to develop VISSIM (version 5.4) microsimulation model. Weekday turning movement counts at each intersection and vehicle compositions were collected between 14:00 – 18:00 for the study corridor. Volume balancing was performed using Synchro to avoid any directional data inconsistencies. These were further used as vehicle inputs in the VISSIM model.

Additionally, floating car travel time data along the corridors and between the signalized intersections was collected. Saturation flow data for intersections which was initially collected for a separate study was also used for this study [20]. For the before-SCATS model, optimized field TOD signal timing parameters were retained from the Traffic Engineering Department. These actuated coordinated signal timing plans were modeled using the RBC controller in VISSIM. Detector locations and other relevant geometric data collected from field observations and aerial imagery were adjusted to match those in the field. Speed distributions were based on posted speed limits and travel times.

The TOD model was calibrated by adjusting various VISSIM user-parameters (driving behavior, lane change, routing decisions and speed distributions) to match the link volumes, turning movement counts and queues at each intersection. The models were validated by comparing the modeled and field turning movement counts at each signalized intersection, travel times between the signalized intersections and end-to-end corridor travel times. GEH statistics was used for validating the counts. GEH statistics less than 5 is highly desired for a properly validated model. Figure 2 show the results of the GEH analysis for the three corridors. In addition to the field travel times, Bluetooth and crowdsourced travel times for the respective corridors were also used to validate the modeled travel times [21].



a) Montgomery1US-82 E. South Blvd

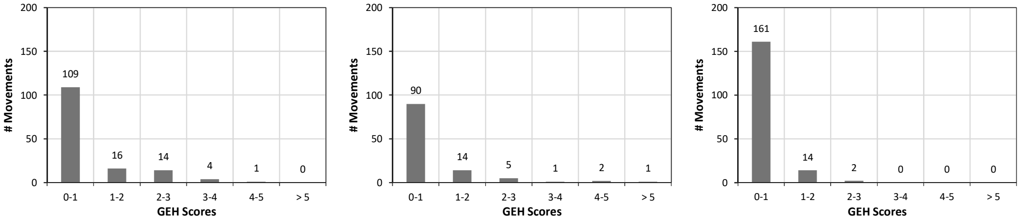
b) Montgomery2 US-231 Eastern Blvd

c) Birmingham US-280

Fig. 1 - SCATS corridor network diagrams

Tab. 1 - Corridor characteristics

Corridor	**Montgomery1**	**Montgomery2**	**Birmingham**
	(Montgomery US-82/ E. South Blvd)	*(Montgomery US-231/ Eastern Blvd)*	*(Birmingham US-280)*
Characteristics	Low volume; Irregular-spaced intersections	Moderate volume; Closely spaced intersections	High volume; Many closely-spaced intersections
# lanes	4	6	6
# Intersections (Interchanges)	13	10	17
Total Corridor Length (miles)	4.9	2.3	4.6
Average Spacing between Intersections (miles)	0.4	0.26	0.27
Average Traffic Volume (vph) per Intersection	1250	1900	2850
Average Cross Street Traffic Volume (vph) per Intersection	200	150	150
Congestion levels	Low	Medium	High
Peak traffic periods	16:30 – 17:30	16:30 – 17:30	16:30 – 17:30



Montgomery 1 **Montgomery 2** **Birmingham**

Fig. 2 - GEH scores for the three study corridors

Kergaye et al. (2010) reported that microsimulation is an effective tool for evaluating ATSC systems [22]. SCATSIM software allows for the replication of SCATS adaptive control (detection via Simhub and control via WinTraff) directly within the VISSIM simulation environment [23, 24]. Figure 3 shows the elements of the microsimulation process. SCATSIM was used to run the three simulation models under SCATS control. The fine-tuned field SCATS configurations were obtained from the SCATS vendor to be used in the SCATSIM. The SCATS controlled simulation models were similar to the TOD models in all respects except for the signal control. SCATS model results were compared with phase splits, cycle length, and volumes from the Strategic Monitor against VISSIM outputs. Additionally, model travel times were checked against travel times collected from Bluetooth and crowdsourced data. This allowed for the comparison of same baseline conditions under different signal control systems and hence objective evaluation of SCATS performance.

Both TOD and with-SCATS models were simulated for 10 replications of 90 minutes each [25]. Warm-up periods of initial 30 minutes were used to fill the network corridor to the required traffic conditions prior to recording performance measures. The remaining 60 minutes were used to evaluate the network performance. Different random seeds were used across the 10 replications to capture the stochastic variation in traffic characteristics.

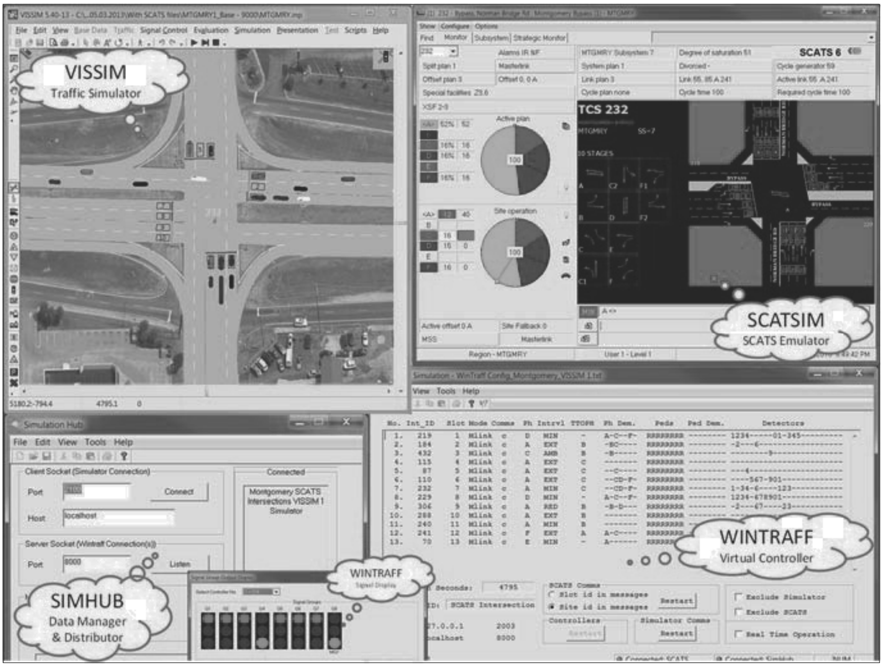


Fig. 3 - Components of SCATS microsimulation

4. Findings and results

There are numerous performance measures available for comparative evaluation of ATSC vs. non-ATSC operations. Overall, corridor travel time (or delay) is most common followed by number of stops, intersection delays, average speed and queue lengths in that order [4]. All three study corridors were evaluated on the basis of overall corridor travel time as well as network-wide average delay, average queue lengths, and average speed. Additional analyses were conducted at the sub-corridor level to identify specific points that illustrate detailed operational differences between SCATS and the latest TOD plans.

4.1. Travel time assessment

The first assessment looks at travel time, but a major finding in this paper is that travel time does not accurately characterize the entire performance of adaptive control systems and subsequent sections show a more comprehensive picture. The results of the end-to-end corridor travel times and delays for each corridor are shown in Figure 4 and Figure 5 respectively. By end-to-end corridor, it means starting from the first intersection and ending at the last intersection of the corridor in the mainline direction. The end-to-end corridor travel time sections start from the mainline stop line at the first intersection to the stop line at the last intersection. While the Major 1 is defined as the dominant (i.e. higher volume) directional movement during peak period analyzed, Major 2, then, is the lower volume peak period traffic in the opposing direction.

As can be seen from Figure 4, the travel time for the Montgomery1 in the Major 1 direction with SCATS is little higher as compared to the TOD plan and little lower for Montgomery2 (callouts “4.i” and “4.iii”, where “4.i” refers to callout “i" in Figure 4 and so on). However, the travel times with SCATS in Major 2 directions are higher as compared to the TOD plan (callouts “4.ii” and “4.iv”).

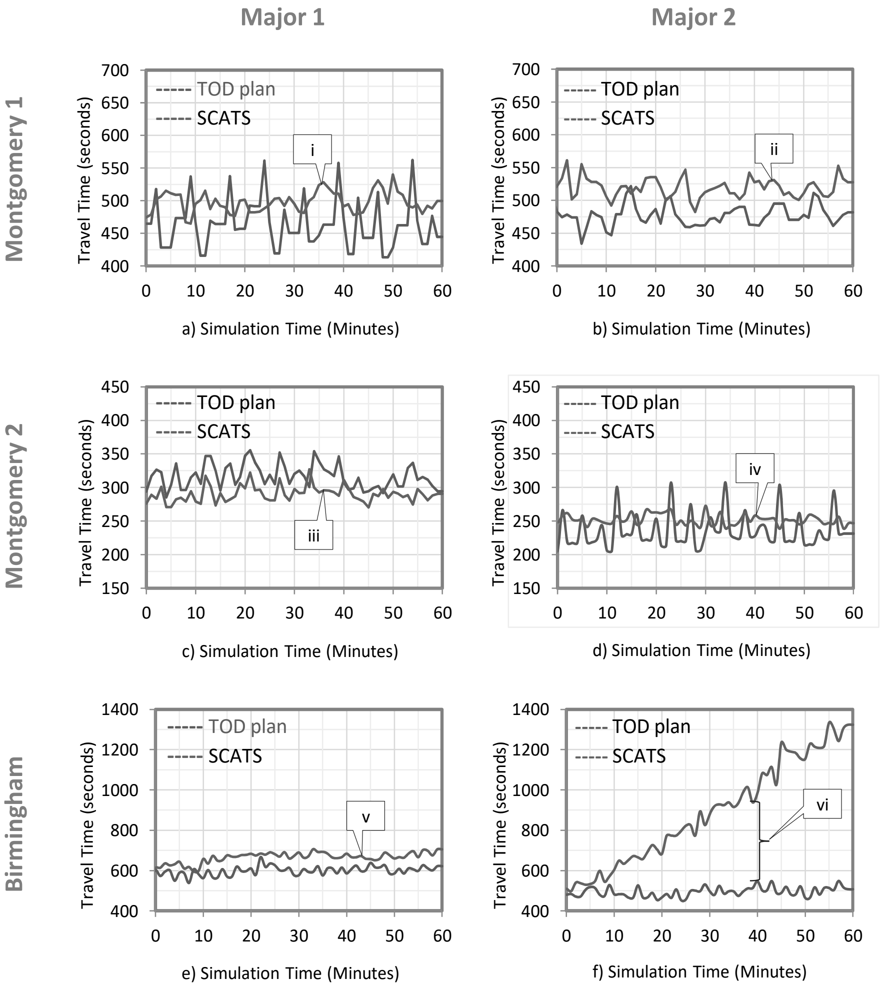


Fig. 4 - End-to-end corridor level travel times

The delay with SCATS for these two corridors in both directions shows the same trend as shown by callouts “5.i”, “5.ii”, “5.iii” and “5.iv”. In the case of the Birmingham corridor, the travel time in the Major 1 direction with SCATS is higher than with the TOD plan (callout “4.v”). In Major 2 direction, the travel time with SCATS starts initially on the lower side, but eventually shifts to being higher than the TOD plan (callout “4.vi”). The same phenomenon can be seen with delays for the Birmingham corridor (callouts “5.v” and “5.vi”). This might be the case because Major 1 is the peak direction of travel, and thus takes priority over Major 2 traffic. To summarize the results, both travel time and delay follow the same pattern. Across all three study corridors, travel time and delay with SCATS are either equal or slightly higher than the TOD plan. As discussed in the literature review section, ATSC may not always show improvement at corridor level. However, the end-to-end corridor is only one way among many other possible ways that could be further analyzed as needed. In the next section, other network-wide and intersection level performance measures are further examined.

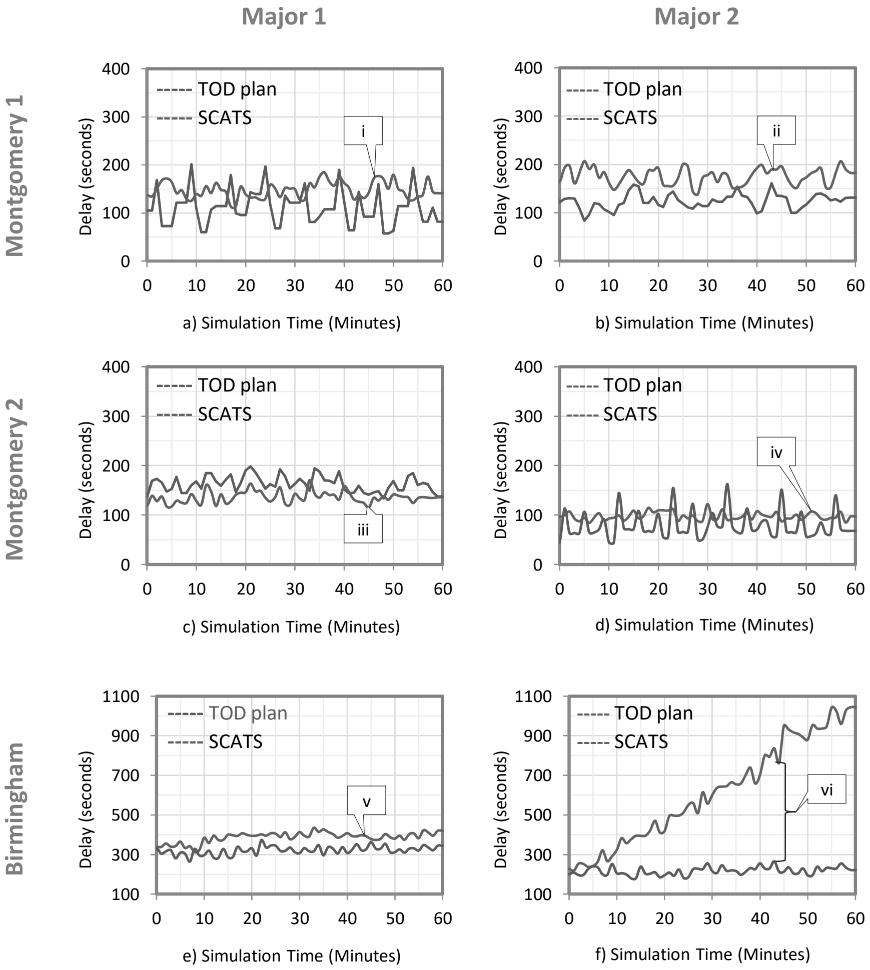


Fig. 5 - End-to-end corridor level delays

4.2. Average delay and speed

Going beyond just the traditional analysis of using travel time and delay, Figure 6 shows a comparison between network-wide travel time, average delay and average speed for the three study corridors. These three performance measures are available as part of Network Performance in VISSIM. Network-wide travel time is the cumulative sum of travel times of all vehicles that entered the network. Average speed is the total distance travelled by all vehicles divided by the network-wide travel time and average delay is a cumulative sum of delay times of individual vehicles divided by total vehicles that entered the network [26]. Each symbol (circle, triangle or square) represents one of the 10 replications. Montgomery1 (the most uncongested network with least traffic volume) and Montgomery2 (an average level corridor with average saturation level) clearly show SCATS performing better over TOD on all network-wide performance measures. In contrast to the end-to-end travel time, the network-wide travel time for Montgomery1 and Montgomery2 shows a decrease with SCATS when compared to the TOD plan (callouts “6.i” and

“6.ii”). Similarly, the network-wide average delay shows significant improvements (callouts “6.iv” and “6.v”). The network-wide average speed for these two corridors is higher with SCATS compared to the TOD (callouts “6.vii” and “6.viii”).

The results for the Birmingham corridor, the oversaturated network, indicate no real operational improvements are attributable to SCATS. Figure 6 (callout “6.iii”) shows that the network-wide travel time for the Birmingham corridor with SCATS is slightly higher than that achieved under TOD control. Similarly, the network-wide average delay and network-wide average speed (callouts “6.vi” and “6.ix”) fail to show improvements. Such findings are not entirely unexpected as it can be quite difficult to achieve improvements for oversaturated corridors [4]. NCHRP Synthesis 403 cites several other reasons for poor performance of ATSCs such as systems not fine-tuned or customized as needed [4].

ATSC improves the traffic condition by continuously monitoring the demand and then intelligently distributing the signal cycle time over different traffic movements at each intersection as well as over the entire network. In a congested condition where continuous queues are formed and are never cleared, the extent of real traffic demand is difficult to be measured. It is documented that SCATS can be configured with congestion management techniques which can be more efficiently used to manage the congested condition, provided it is configured for that purpose [8]. Under such circumstances, SCATS follows the policy for which it is configured. Thus, the results might be the outcome of the use of an inefficient policy. This explains the reason why SCATS fails to yield any benefits in the Birmingham corridor. This result is consistent with other ATSC evaluation study [13] which state that the effectiveness of ATSC is constrained where demand exceeds available capacity.

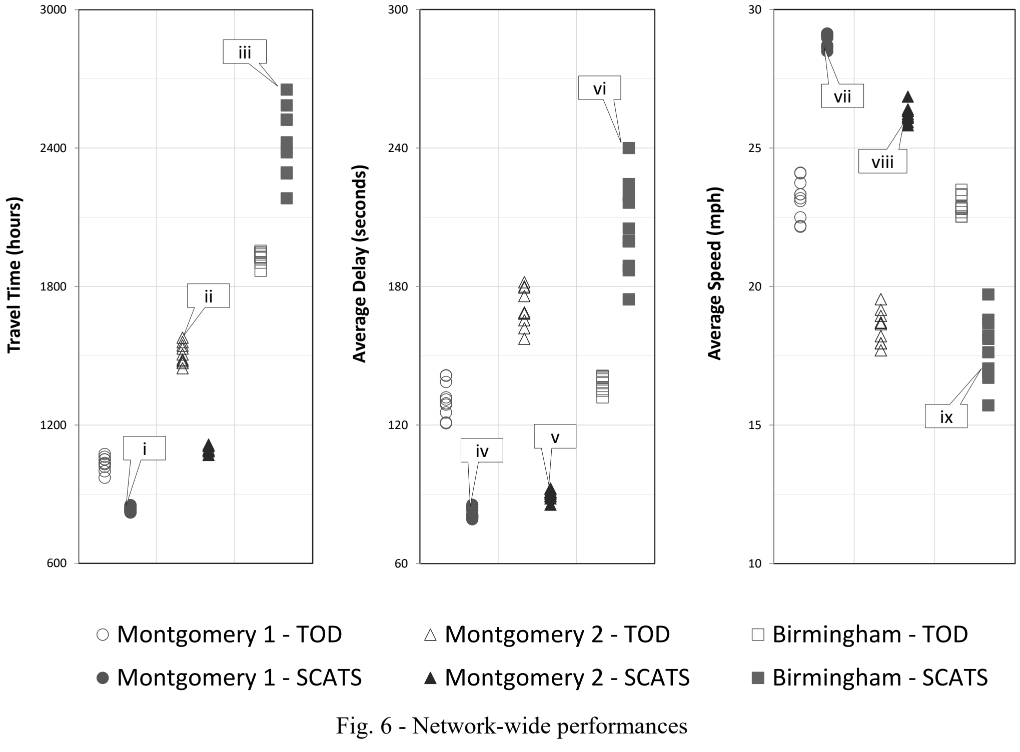
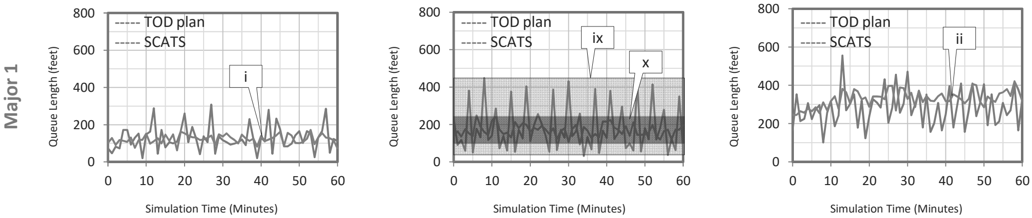


Fig. 6 - Network-wide performances

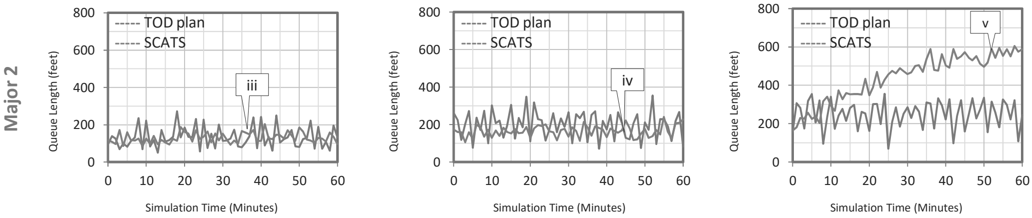
It is interesting to see that while the end-to-end corridor travel time does not improve, the network-wide travel time (and other performance measures) shows significant improvements. This contrasting finding is investigated further by looking at three movements separately. 'Major' movement is the traffic along the arterial mainline corridor and 'Minor' movement is the both side- streets traffic combined. For each study corridor, the Major 1 is the movement in the peak direction and Major 2 is the movement in the non-peak direction.

4.3. Queue length assessment

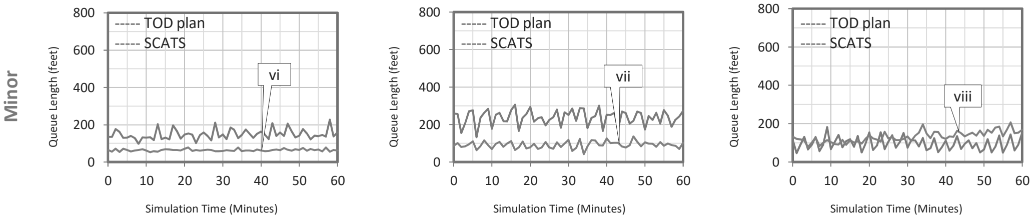
Figure 7 shows the queue lengths for the Major 1, Major 2 and Minor directions for the three corridors plotted over one hour of simulation period (excluding warm-up period). These plots show that the queue lengths with SCATS for the two major directions are either almost same as TOD or slightly longer than those with TOD. In the case of Montgomery1 and Montgomery2, the average queue lengths with SCATS in the Major 1 and Major 2 directions maintain almost same levels (callouts "7.i", "7.iii" and "7.iv") as TOD. However, the queue lengths for the minor direction significantly improve (shortens) with SCATS for the Montgomery1 and Montgomery2 corridors (callouts "7.vi" and "7.vii"). For Birmingham, the SCATS queue lengths are little longer than with TOD (callouts "7.ii" and "7.v") in the Major 1 and Major 2 directions. In fact, the average queue length with SCATS for the Major 2 direction initially starts at a lower level, but eventually grows to exceed the queue length level with the TOD plan (callout "7.v").



a) Montgomery 1 b) Montgomery 2 c) Birmingham



d) Montgomery 1 e) Montgomery 2 f) Birmingham



g) Montgomery 1 h) Montgomery 2 i) Birmingham

Fig. 7 - Average queue lengths

This phenomenon was earlier seen in the case of the travel time and delay for the Birmingham corridor for the Major 2 direction (callouts “4.vi” and “5.vi”). There is no significant change in queue lengths between the TOD and SCATS for the Birmingham minor movement (callout “7.viii”).

Another interesting observation is that although the average queue lengths over the entire simulation run either show no gains (in the case of major directions but some gains in minor directions), significant improvements can consistently be seen in the cycle-to-cycle queue lengths. According to Figure 7, the queue lengths resulted from the TOD plan of Major 1 and Major 2 directions on both Montgomery1 and Montgomery2 corridors experienced significant fluctuations during the simulation period (callout “7.ix”), the largest wave range is approximately 400 feet. On the other hand, the queue length under the SCATS control (callout “7.x”) is relatively stable with a wave range of about 100 feet for these two corridors. This result is consistent for all corridors and for all three movements. Thus, based on the results, it can be concluded that SCATS generates relatively shorter cycle to cycle queue lengths. This is an important finding as shorter queue lengths may have considerable benefits such as increased opposed turning capacity, increased shared lane capacities, and reduced chance of downstream queue interference which would lead to additional performance gains [27].

To summarize, significant improvements in the queue lengths were only observed for the minor movement of an unsaturated corridor. Because the network-wide performance measures show improvements while the end-to-end corridor performance measures do not, the shorter queue lengths on the minor streets and the shorter cycle-to-cycle queue lengths under SCATS control can be attributed towards the overall network performance improvement. More explanation on this follows in later paragraphs when the distribution of signal timings is discussed. The added capacity caused by shorter queue lengths on each directional movement over the entire network can even have significant implications for the city transportation planners.

4.4. Delay assessment

In addition to the queue length, delays are also analyzed for the Major 1, Major 2 and Minor directions, separated by left-turn and through movements. Figure 8 shows the improvement in delay with SCATS for each of the intersections/nodes for Montgomery1 corridor, Figure 9 shows the same for Montgomery2 corridor, and Figure 10 for Birmingham corridor. Green bars indicate that the delays with SCATS are lower than with the TOD plan (hence negative difference). The red bars indicate ineffectiveness of SCATS to reduce delays.

The major through movements do not show any improvements for Montgomery1 and Montgomery2 as shown by callouts “8.i” and “8.iii” in Figure 8 and callout “9.i” and “9.iii” in Figure 9. In contrast, significant improvements can be seen with SCATS on the major left movements on some of the intersections for these two corridors (callouts “8.ii”, “8.iv”, “9.ii”and “9.iv”). Significant improvements are seen for all minor movements of Montgomery1 and Montgomery2 corridors (callouts “8.v”, “8.vi”, “9.v” and “9.vi”).

For Birmingham, both major through and major left movements show mixed results. While there are reductions in delays on some intersections, a few others show an increase in delays and the remaining fail to show either. These are indicated by callouts “10.i”, “10.ii”, “10.iii” and “10.iv” in Figure 10. Similar to the major movements for Birmingham corridor, the minor movements show mixed results. Some intersections show improvements in delay, some show deterioration in delay, and some are neutral (callouts “10.v” and “10.vi”). The delay results reiterate the findings from queue lengths where the minor streets show significant improvements in performance while the major movement shows either little or no improvements.

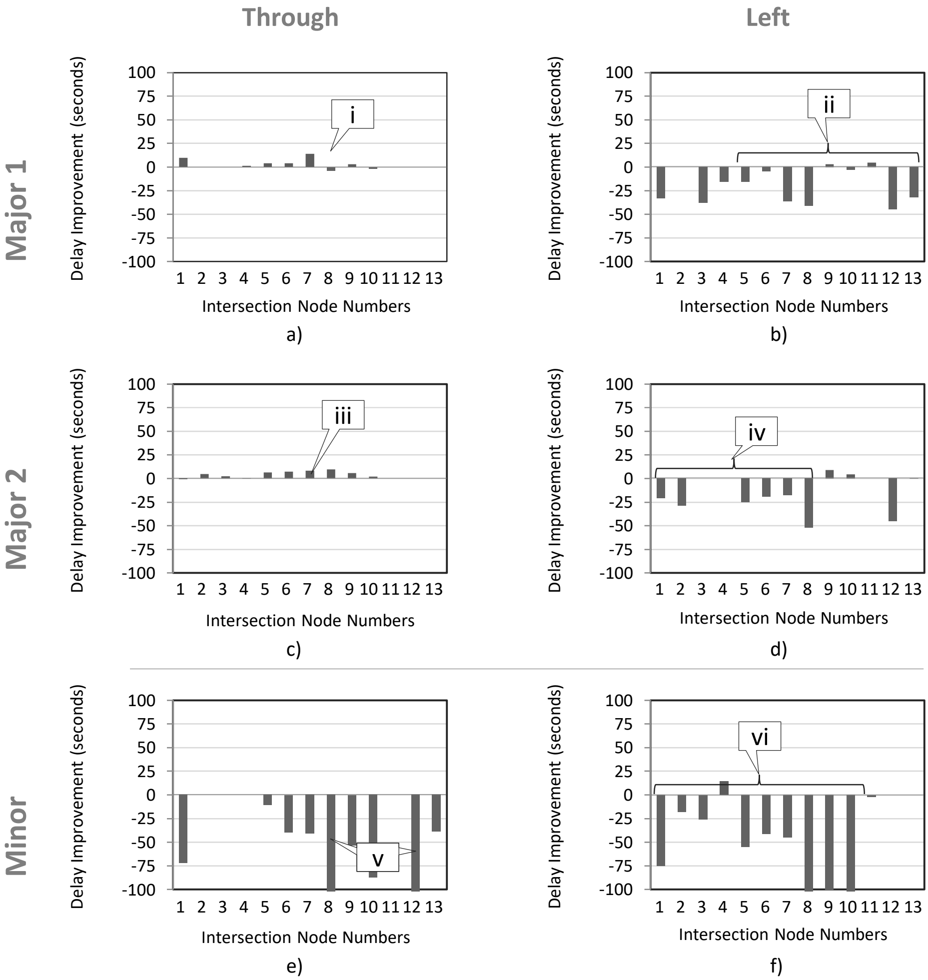


Fig. 8 - Individual intersection delay improvements by movements (Montgomery1)

However, one distinguishing finding from the analysis of delays is that only the major through movements fail to gain. The major left movements do show improvements. It appears that in all three corridors, SCATS balances the network performance rather than favoring only mainline performance.

The results so far can be explained best by analyzing the SCATS behavior. SCATS tries to achieve two things simultaneously;

i) maintain the DS at the level of around 0.9 on the lane with greatest DS and
ii) vary the phase splits to maintain equal DS on competing approaches [6].

To further elaborate on this, an analysis on the comparison of the distribution of signal time is performed.

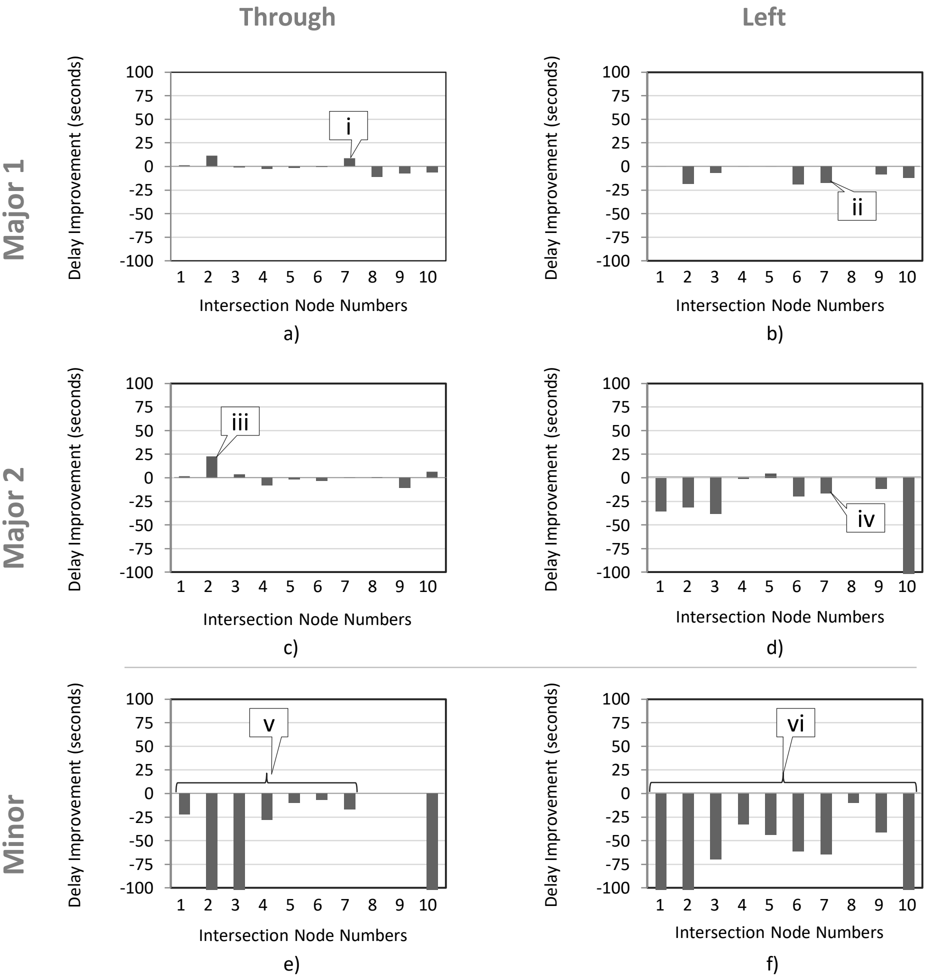
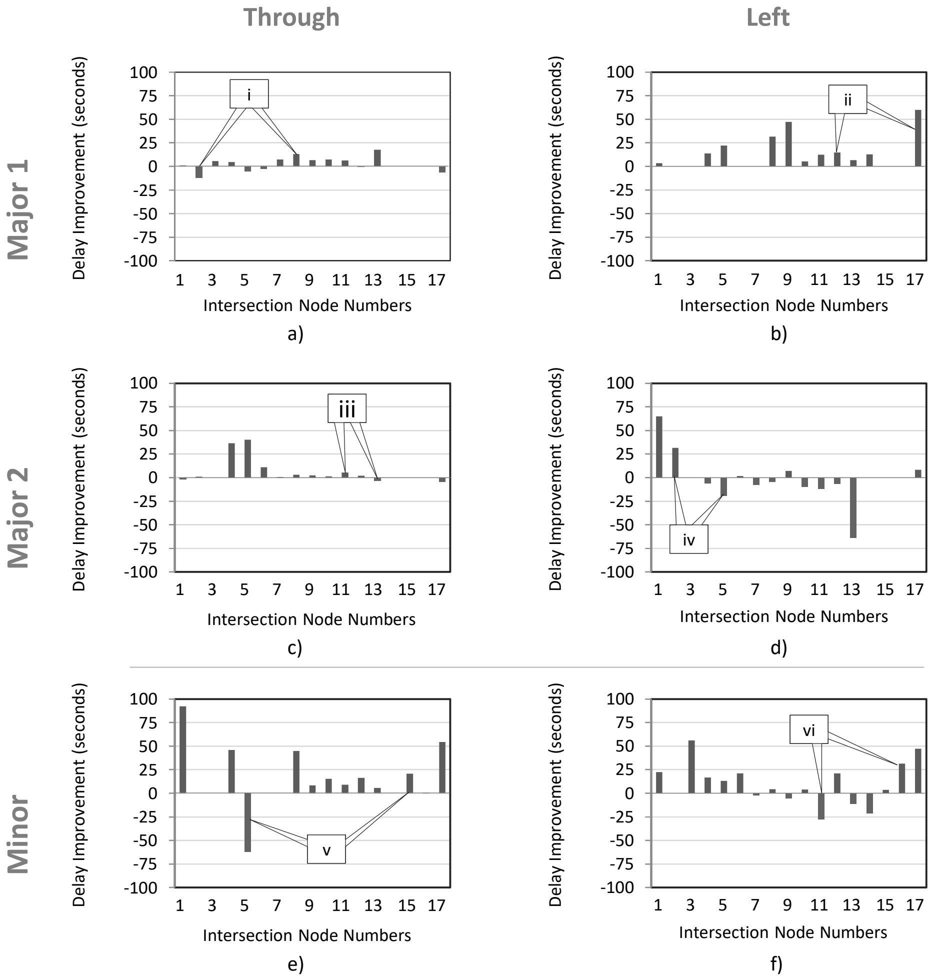


Fig. 9 - Individual intersection delay improvements by movements (Montgomery2)

4.5. Signal timings analysis

Figure 11 shows the typical distribution of the green time and the cycle lengths over one hour of simulation period for any given intersection (with very few exceptions) on the three networks.

The figure shows that, under the TOD plan, excessive green times are given to ϕ2 and ϕ6, which are the major through movements (callouts “11.i” and “11.ii”). As a result, traffic on the side-street suffers and has to wait longer causing longer queues and delays. This was also observed during the visual assessment of the simulation runs. As a result, huge imparity is caused in the DS levels of the mainline and the side-streets. SCATS overcomes this problem by offering smaller green time to the mainline traffic improving its DS (callouts “11.iii” and “11.iv”). Cycle length decreases as a result of shorter ϕ2 and ϕ6. Callout “11.v” shows the cycle length for the TOD plan, which remains at a constant level throughout the span of the simulation run. Callout “11.vi” shows the cycle length, which although builds up over the simulation run, but still remains lower than the TOD cycle length.



a) b)

c) d)

e) f)

Fig. 10 - Individual intersection delay improvements by movements (Birmingham)

Shorter cycle length helps in clearing the side-street traffic at a higher frequency resulting in shorter queues (callouts “7.vi” and “7.vii”). The occurrence of this phenomenon at every intersection on the network results in overall improvement in the network performance as can be seen in Figure 6. However, travel time for the mainline traffic suffers due to shorter green times, as seen in Figure 4. One interesting observation is that side-street traffic condition improves despite getting lesser percentage green time (callouts “8.v”, “8.vi”, “9.v” and “9.vi”).

Birmingham corridor differentiates from the other two corridors because of its overly congested nature. As a result, there is a very little flexibility for manipulating the cycle time and phase splits to improve traffic efficiency. Even if it was possible, an improvement in one movement can only be achieved at the expense of performance of other competing movements. As a result, the overall performance of the entire network may still fail to see any improvements. As a result, the Birmingham corridor shows no improvement for any MOEs. This result is consistent with other similar studies on ATSC performance on oversaturated networks [4].

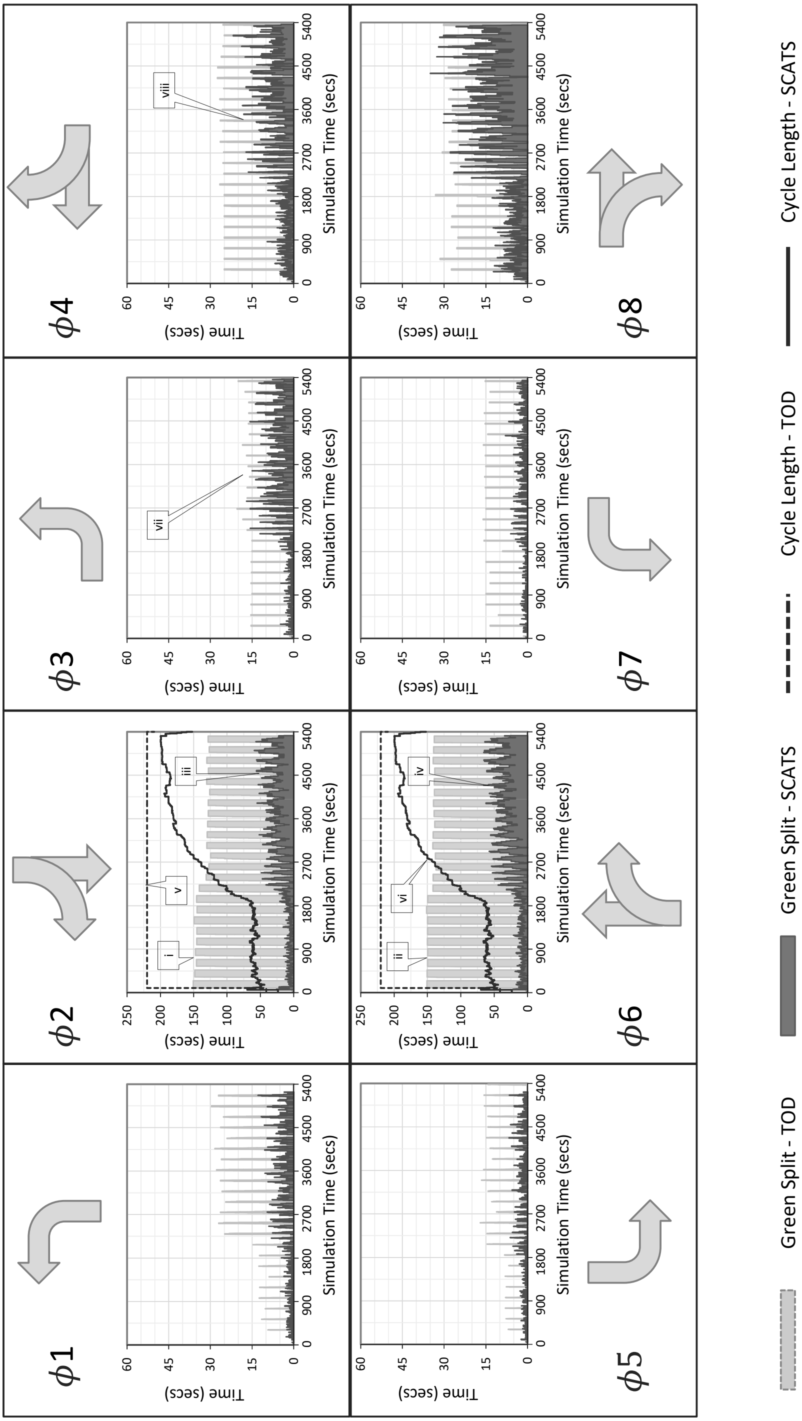


Fig. 11 - Typical signal green times and cycle lengths

In another study that examined the impact of a locally adaptive traffic signal on network stability, it was found that adaptive signals appear to have little or no effect on network stability in heavily congested networks due to more constrained vehicle movements [28].

5. Conclusions

ATSC systems are a useful tool in the continuing quest for more efficient traffic operations. Although largely positive towards ATSC, literature reports somewhat mixed results on ATSC performance.

Most of the literature, however, reports the results from a single corridor where network-wide or corridor level travel times/speeds are the primary performance measures. This study was performed with the aim of comparing three different network corridors with different physical and operational characteristics under TOD and SCATS signal control. The study yielded the following general conclusions/recommendations:

1. Corridor travel time and delay are the traditional way to assess the improvements of an adaptive system. There are other measures available to evaluate ATSC depending on overall policy goals (e.g. optimizing mainline progression or an overall congestion management strategy). As such, it is recommended that traffic engineers and other stakeholders examine a range of performance measures at various scales (i.e., network, corridor, sub-corridor, intersection) to fully assess potential improvements and changes in system operation according to policy preferences [8].
2. SCATS showed significant network-wide performance improvements over the TOD plans, in terms of travel time, average delays, and average speed, on the unsaturated networks studied herein.
3. With SCATS, the shorter side-street queue lengths and the shorter cycle-to-cycle queue lengths on the unsaturated networks can be attributed to the network-wide performance improvements over the TOD. The added capacity created by shorter queue lengths on each directional movement over the entire network is a potential benefit of the systems that can be leveraged for additional operational enhancements within the system.
4. The analyses of delays show that major network-wide performance improvements for the unsaturated networks come from the side-streets movement and left-turn movements.
5. On the oversaturated study corridor, however, the higher volumes (and saturated conditions) constrain the potential vehicle movements limiting the ability of SCATS to meaningfully manipulate timing parameters.

While considering these conclusions, it is worthwhile to note that the real potential of any ATSC is not easy to assess. Similar to what other studies have shown, SCATS (and any other ATSC in general) is found to have a minimal effect on oversaturated conditions. The other, systematic advantages of ATSC such as real-time monitoring of traffic demand and adapting to the changing traffic conditions must still be considered in any complete evaluation of the deployment of a new control system. It is recommended that the potential benefits of ATSC be assessed through scenario-based (e.g.: incidents, lane closure, traffic increase, etc.) sensitivity analyses.

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