SCOOT and SCATS: A Closer Look into Their Operations

Conference Paper · January 2009

3 authors:

Aleksandar Stevanovic
University of Pittsburgh

Cameron Kergaye
Utah Department of Transportation

Peter T. Martin
New Mexico State University

SCOOT and SCATS: A Closer Look into Their Operations

Aleksandar Stevanovic*
Research Assistant Professor
Department of Civil and Environmental Engineering
University of Utah
122 S. Central Campus Dr., Rm.104
Salt Lake City, Utah 84112-0561
Phone: (801) 581-4151
Fax: (801) 585-5860
E-mail: aleks@trafficlab.utah.edu
*Corresponding Author

Cameron Kergaye
Program Manager
Utah Department of Transportation
4501 South 2700 West,
Salt Lake City, Utah 84119
Phone: (801) 965-4000
Fax: (801) 965-4796
E-mail: ckergaye@utah.gov

Peter T. Martin
Professor
Department of Civil and Environmental Engineering
University of Utah
122 S. Central Campus Dr., Rm.104
Salt Lake City, Utah 84112-0561
Phone: (801) 581-7144
Fax: (801) 585-5860
E-mail: peter@trafficlab.utah.edu

Word Count: 5,891 + 1,500 (6 Figures) = 7,391

Prepared for the
Transportation Research Board Annual Meeting, 2009

Revised: November 14th, 2008

ABSTRACT

SCOOT and SCATS are the most widely deployed Adaptive Traffic Control Systems worldwide. These proprietary systems have long been surrounded by their advocates and critics. This paper serves to illuminate the structural differences between these two methods. We present a detailed comparison of SCOOT and SCATS signal timings and their influence on traffic performance measures in microsimulation. SCOOT traffic control was provided by an academic site license and simulated in VISSIM. SCATS traffic control was deployed in Park City, Utah, which served as the test bed. Two segments from the 14-intersection Park City network were selected for analysis. We analyze and discuss SCOOT and SCATS implementations of cycle lengths, offsets, splits, and relevant performance measures from VISSIM. Findings show overall that SCOOT and SCATS deliver similar delays with different cycle lengths. SCATS seems to be somewhat better in implementing offsets and splits than SCOOT. Further research should address proper calibration and fine-tuning of these systems. Deficiencies in these processes may have a more profound effect on system performance than differences between SCOOT and SCATS algorithms.

INTRODUCTION

Split Cycle Offset Optimization Technique (SCOOT) and Sydney Coordinated Adaptive Traffic System (SCATS) have drawn attention from researchers since they emerged in the late 1970s (*1*, *2*). The two systems have been evaluated independently and have consistently been shown to reduce delays, stops, and journey times (*3*-*5*). Their conceptual differences have been explained and compared previously (*6*, *7*). Researchers have built surrogates to compare their traffic performances (*8*). Yet, in spite of their numerous installations and many evaluations, they have only been compared side-by-side recently (*5*). Kergaye *et al*. comparatively evaluated SCOOT and SCATS with actuated-coordinated- traffic control in Park City, Utah. SCOOT and SCATS were found to reduce overall network delays and stops by at least 14% and 9%, respectively, when compared to actuated-coordinated control from the field. When compared side-by-side, it was found that their overall network delays were not significantly different from each other though SCATS caused fewer stops to travelers than SCOOT. The evaluation described the study area, validation of the ATCSs, experiments, and region-wide results (*5*).

This paper was motivated by authors' aspiration to further investigate effects of SCOOT and SCATS adaptive logics on performance of individual intersections. Both systems are well known for their abilities to progress traffic through multi-node networks. Hence, it was decided to investigate their performance on a pair of intersections as the simplest multi-node network that facilitates traffic progression. This approach evaluates traffic performance at a microscopic level versus a macroscopic level which is pertinent to region-wide evaluations. So, the objective of this paper is to explain the effectiveness of SCOOT and SCATS operations at a microscopic level for two pairs of intersections which represent two segments of the major arterial in Park City – SR 224. We analyzed how SCOOT and SCATS adjust their signal timings to respond to changes in traffic flows. The analysis is followed by a discussion of their impacts on various performance measures for the two segments.

ADAPTIVE TRAFFIC CONTROL SYSTEMS

A comprehensive description of SCOOT and SCATS operations would require hundreds of pages. Objective of this paper is to provide a basic description of the optimization and adjustment processes that represent the core of SCOOT and SCATS adaptive operations. Other important concepts of SCOOT and SCATS operations can be found in relevant literature (*9*, *10*).

SCOOT Traffic Control

SCOOT is a centralized adaptive traffic signal control system developed in the UK in the early 1980s by the Transport Research Laboratory (*1*). The system has been modified and enhanced several times since its inception (*11*). The recent version of SCOOT is "Managing Congestion, Communications and Control" or MC3 (*12*). For SCOOT principles, evaluations and features, the reader is referred to the SCOOT User Guide (*9*).

The SCOOT-VISSIM connection is established as a partial Hardware-In-the-Loop Simulation (HILS) and Emulation-In-the-Loop Simulation (EILS) setup. The central SCOOT kernel is based on an Alpha DEC computer connected to a PC running VISSIM microsimulation (*13*). The interface between the two computers is through EILS, which is used to communicate between VISSIM's traffic model, SCOOT, and emulation of local intersection controllers in

VISSIM. For description of SCOOT-VISSIM setup, and calibration and validation of the SCOOT-VISSIM model of Park City we refer to previous studies (*13-16*).

SCOOT Optimization of Signal Timings

SCOOT, often called an online version of TRANSYT signal optimization tool, continuously measures the traffic demand on all roads in a coordinated network and optimizes signal timings for detected traffic. SCOOT uses an on-line model of traffic behavior, based on data from on-street detection, to estimate stops and delays within the network for the next cycle of traffic lights. The basic philosophy of SCOOT is to modify existing traffic signal settings in such a way that disturbance to traffic is minimal. Thus, the optimization routines are limited to evaluating only the impacts of small changes in signal settings on the estimated performance measures (delays and stops). Signal timings such as splits, offsets, and cycle lengths are optimized separately.

Split Optimizer The split optimizer in SCOOT equalizes saturation on a node (intersection) by minimizing the maximum degree of saturation on links approaching the node. The degree of saturation in SCOOT is calculated as the ratio of the Flow Profile (traffic demand) to Saturation Occupancy (discharge rate) multiplied by the duration of the effective green time. The split optimizer, which runs 5 seconds before each stage's change time, decides whether a stage should start 4 seconds earlier, remain the same, or start 4 seconds later. The split optimizer considers the effects of each of the three options on the degrees of saturation of the links. Once a decision is implemented, a split is reversed by 3 seconds to avoid high split oscillations for fluctuating traffic demand. For example, a stage that advances from 10 to 14 seconds after implementation will be returned to 11 seconds, which will become the stage length for the next split optimizer run. The split optimizer also accounts for congestion detected on a link (4+ seconds of constant occupancy at the upstream detector) by including a portion of the previously congested cycle to the degree of saturation when making the decision. Splits in SCOOT are constrained by minimum and maximum phase durations. The latter are usually set high so that they do not constrain splits. SCOOT does not support vehicle actuations and consequentially there are no gap outs. On the other hand, SCOOT does support demand-dependant phases where a phase can be skipped if no demand is present. In such a case local controllers take over control of actual greens on the street. The feedback from local controllers informs SCOOT central computer that a different phase is running from the one planned in the sequence. This concept allows SCOOT flexibility to run a sort of semi-actuated operation with no gap outs.

Offset Optimizer Once per cycle the offset optimizer uses the Flow Profiles to predict the stops and delays throughout a cycle for all normal links (entering, exiting, and filter links excluded) upstream and downstream of a particular node. These predictions are made for three options: to reduce offset by 4 seconds, to keep the same offset, or to increase the offset by 4 seconds (up to ±8 seconds for higher cycle lengths). The estimated stops and delays for all normal links of a node are weighted and summed to give a Performance Index (PI). The offset optimizer chooses an offset adjustment which minimizes the PI. In this way offset is optimized to provide the best progression between nodes with calculated offsets and the neighboring nodes. If a link is congested the offset optimizer will also try to give that link priority over links without congestion. The offset optimizer usually runs during the longest SCOOT stage. A new offset is implemented by adjusting the node's 'time now' for either ±4 or 0 seconds, which impacts all stages in the sequence. The new offset may spoil progression for some of the links (e.g. cross roads) but the overall performance should improve.

Cycle Length Optimizer The cycle length optimizer operates on a region of nodes (intersections) that are expected to have good progression between them. The cycle optimizer will look at the degree of saturation for all links (between nodes) in the region. If any of these are at the ideal saturation level (user configurable but typically 90%) the Minimum Practical CYcle length (MPCY) for that node is increased by a small fixed step. If all links are below the ideal saturation level, the MPCY length for that node is reduced by a small fixed step. Initial MPCY lengths for each node are specified by the user. The fixed steps are ±4, ±8, and ±16 seconds for cycle lengths up to 64 seconds, between 72 and 128 seconds, and above 144 seconds, respectively. The bordering cycle lengths use combinations of these steps to transition to the closest neighboring values (e.g. cycle length at 64 seconds can step +8 seconds or –4 seconds).

The cycle length optimizer considers all cycle lengths from the highest MPCY length of all nodes up to the maximum region cycle length. In general, the highest MPCY is chosen but sometimes a higher cycle length is selected to allow for 'double cycling' of intersections with light traffic, if permitted by the user. Although ‘double cycling’ sometimes reduces delay in the network, it is rarely recommended due to its negative effects on progression. The cycle optimizer usually runs every 5 minutes although this can be varied by the user (from 2 to 10 minutes). More frequent runs of the cycle length optimizer are usually triggered by a trend of rising or falling traffic flows. All nodes within a region share a common cycle length. Exceptions are nodes that double cycle. A node can change regions only if such a command is executed by an operator or timetable.

SCATS Traffic Control

SCATS is a two-level hierarchical adaptive traffic signal control system developed in Australia in the early 1980s by the RTA (*2, 3*). SCATS uses information from vehicle detectors, located in each lane immediately in advance of the stop line, to adjust signal timings in response to variations in traffic demand and system capacity. For more information about SCATS logic and features, the reader is referred to Lowrie (*17*).

This study facilitates the first real-world application of a SCATS-VISSIM interface. The SCATS which controls traffic in VISSIM represents an exact copy of the field-deployed SCATS in Park City. The SCATS-VISSIM is established as a partial Software-In-the-Loop Simulation (SILS) and EILS setup. The central SCATS server is installed on the same computer running VISSIM. The interface between SCATS and VISSIM is established through an EILS application (WinTraff). The same application is responsible for communication between a central SCATS server and local traffic controllers. Communication between SCATS and VISSIM, setup of detectors and signal phases, SCATS fine-tuning, and other details of the SCATS-VISSIM model are reported elsewhere (*5, 13*).

SCATS Adjustments of Signal Timings

Unlike SCOOT, SCATS does not optimize. Instead, it acts as a heuristic feedback system adjusting signal timings based on changes in traffic flows from previous cycles. The SCATS strategy assumes that higher cycle lengths mean greater intersection capacity. The strategy advocates splits proportional to approach demand and longer offsets for increased volumes (and slower traffic flows). Similar to SCOOT, SCATS also considers adjustments of various signal timings separately. First, SCATS collects traffic measurements from field detectors and calculates Degrees of Saturation (DSs) and Link Flows (LFs). Then, it uses DSs and LFs to calculate cycle lengths, phase splits, and offsets. All of the signal timings are calculated once per cycle after new values for DSs and LFs are obtained.

Cycle Length Adjustment A cycle length adjustment is performed for each subsystem of one or more intersections. If there is a good progression between subsystems, SCATS will 'marry' them. The 'marriage' can be permanent or conditional subject to intersection cycle length differences (≤ 10 seconds). Alternatively, subsystems may 'divorce' if the difference between cycle lengths is greater than 10 seconds (*10*).

Cycle lengths in SCATS are computed differently for low and high traffic demands. For low traffic demand, LFs control cycle length variations. The lowest cycle length (LOWPER) represents an absolute minimum (40-60 seconds) and is used for very low traffic flows. Two other cycle lengths (STOPPER 1 and STOPPER 2) range 50-70 seconds and 75-95 seconds, respectively (*10*). The higher LF is, the higher of the three low-volume cycle lengths will be selected. The cycle length cannot have any intermediate value between LOWPER and STOPPERs. A set of requirements for LFs is introduced to prevent frequent jumps between LOWPER, STOPPER 1, and STOPPER 2 (*10*). Once the highest DS in the subsystem exceeds a user-defined DS value (SZ1-10), LFs stop controlling cycle length and DS takes that role.

For high traffic demand, a recommended cycle length (RLo) is computed based on linear relationships between cycle length and DS. There are three pre-defined values for both cycle length and DS which define their linear relationships. Cycle lengths are maximum cycle length (HIPER), threshold cycle length (XPER), and the highest STOPPER (1 or 2). Three DS values which respectively correspond to the three cycle lengths are SZ2, SZ1, and SZ1-10. For example, a HIPER of 150 seconds, XPER of 110 seconds, and STOPPER of 80 seconds may have corresponding DS values of 115% (SZ2), 93% (SZ1), and 83% (SZ1-10). The six values form two linear relationships between cycle length and DS. RLo is calculated using one of the relationships based on where a recently measured DS value falls. After an initial RLo is determined, there is a set of cycle length adjustments. Cycle length is attenuated and usually weighted over the last three cycles to avoid large fluctuations. In the next step, cycle lengths from all intersections that are allowed to marry are compared and the highest one is selected as a "distributed" cycle length for all that satisfy the marrying criteria. Later, cycle length is allowed to change (usually up to ± 6 or ± 9 seconds) when compared to the length of the previous cycle. If cycle length is higher than XPER all extra time in the cycle may be given to the major stage. XPER also represents a point from which cycle length is either less or more sensitive to the increase in DS.

Split Adjustment A split adjustment in SCATS equalizes saturation of an intersection by minimizing the maximum DS on all participating approaches (defined by the user). DS in SCATS is calculated as the ratio of used green time to available green time (*8*). SCATS usually selects the most appropriate split plan (or time sharing ratio) by a method called Incremental Split Selection (ISS). ISS is a process of incrementing and decrementing phase splits by small amounts each cycle where the aim is to reduce the DS of the busiest movement. The split plans, which can vary up to ±4% of cycle time, are stored in the ISS tables.

Actual phase greens in SCATS are constrained by minimum phase times (minimum plus intergreen) and splits dynamically generated by the ISS method. SCATS supports vehicle actuations; so a phase may gap out any time between the minimum green and split. Finally, SCATS utilizes a set of phase calling features to meet cyclic demand variation at each intersection such as permanent demand, phase skipping, no gap outs, use of extra green from the following non-demanded phase, use of extra green from all previous phases, and double-cycling.

Offset Adjustment In SCATS, offset adjustments follow selection of the offset plan (called Link Plan or LP in SCATS), which represents a pair of offsets accompanied by a pair of cycle lengths. SCATS has four LPs which offer offsets to facilitate good progression for various traffic conditions on a segment between two intersections. Thus, in common SCATS convention LP 1 and LP 3 provide good progression in both directions. LP 2 and LP 4 provide good progressions for heavy inbound and outbound flows, respectively. The user can define four Directional Bias (DB) values (one for each of the four offset plans), which represent biases in the voting process for each directional link approach. These DB values are multiplied by average three-cycle flows for each approach and those products are summed for an LP. The LP with the highest sum is selected. To avoid high fluctuations of LPs, an LP should get 4 or 5 consecutive votes before implementation.

Offsets within an LP are adjusted according to a linear relationship with cycle lengths. Each of the LPs will have two offset values (Low Offset and High Offset) for two bordering cycle lengths. For example, LP 3 may have low and high offsets of 2 and 8 seconds which correspond to cycle lengths of 90 and 125 seconds, respectively. Then, offsets for all cycle lengths $\leq$ 90 seconds will be 2 seconds, while offset for all cycle lengths $\geq$ 125 seconds will be 8 seconds. For all other cycle lengths offsets will be interpolated between 2 and 8 seconds. Each of the low-volume cycle lengths is usually assigned to an LP that provides good progression in both directions.

EVALUATIONS OF SCOOT AND SCATS IN THE TEST NETWORK

The focus of the study reported here is SCOOT and SCATS performance on the two segments (each with a pair of intersections) of the Park City network. All segments from the network were considered as candidates for a detailed analysis. The two segments which showed the highest differences in delays between SCOOT and SCATS were chosen. The first segment consists of intersections Landmark Drive on SR 224 and Olympic Park on SR 224. Most of the traffic movements at Landmark Drive experience heavy traffic during the peak periods. The second segment has two intersections: Thaynes Canyon on SR 224 and SR 248 at SR 224. Side-street traffic on the second pair of intersections is very low. SCATS performed better than SCOOT on the first segment, while SCOOT performed better on the second segment. The differences in delays of the two systems were moderate but statistically significant. The segments are shown in Figure 1 accompanied by simple intersection layouts, distances between intersections, and intersections' Level of Service (LOS). The LOSs reported in Figure 1 were based on traffic operations under the former actuated-coordinated traffic control regime.

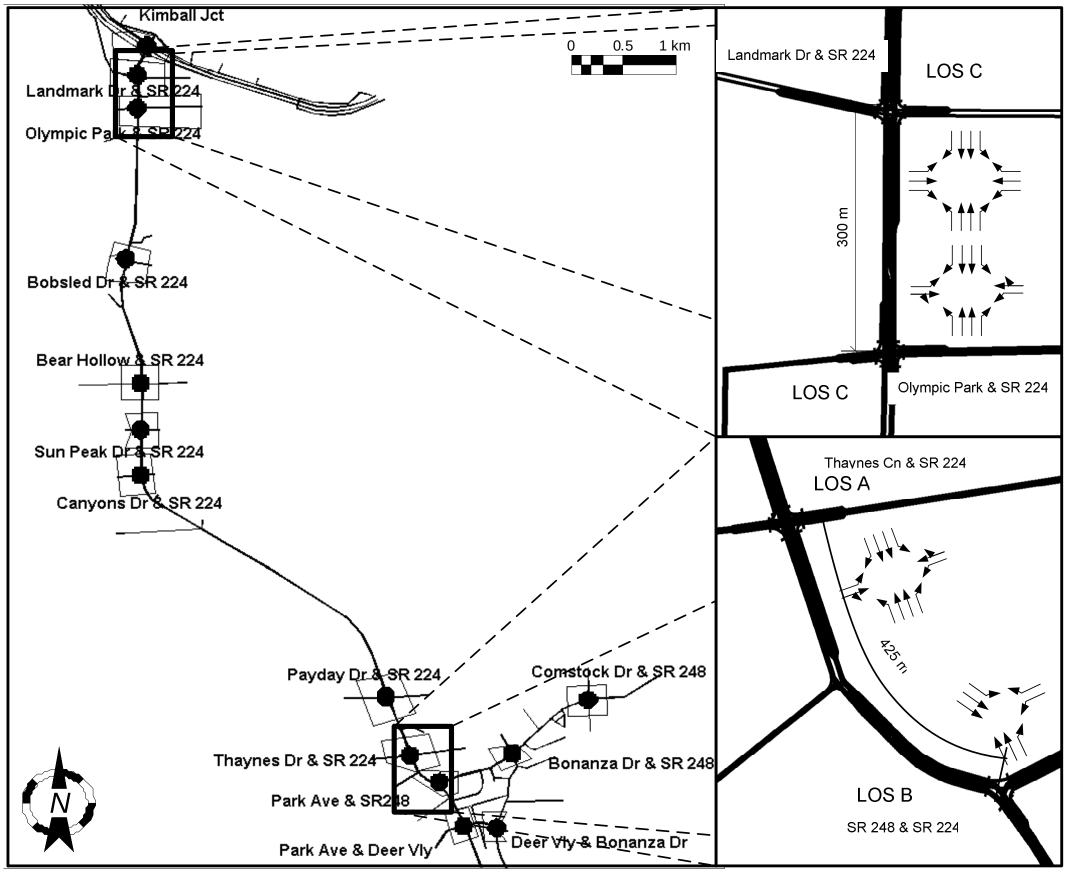
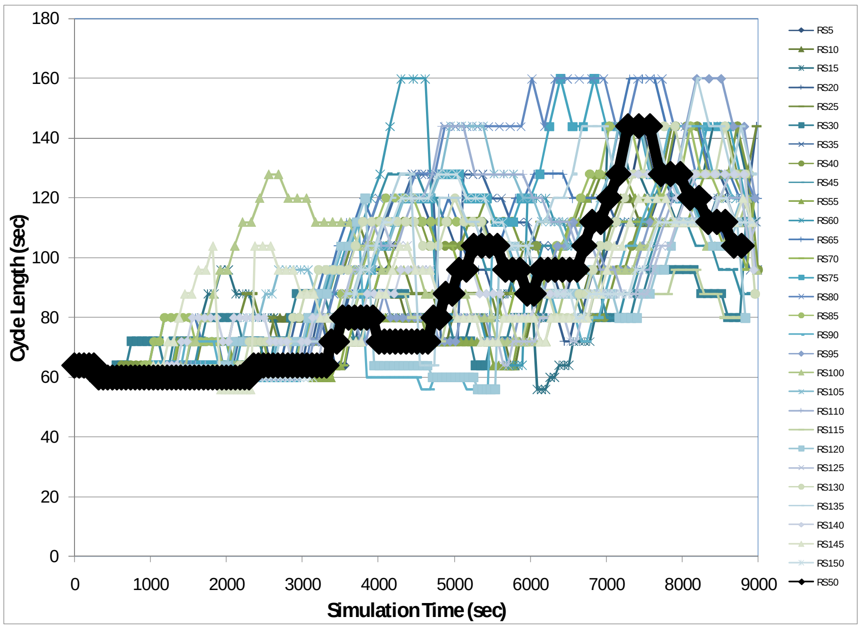


FIGURE 1 Two segments in Park City network.

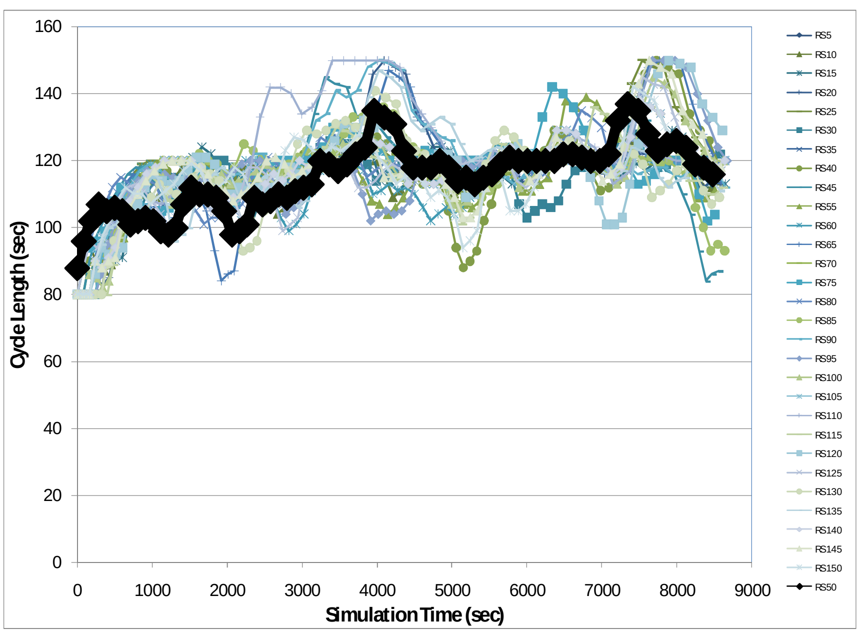
Evaluations of the traffic control regimes were performed in VISSIM through 30 randomly seeded simulations. Each random seed generates its own sequence of vehicle arrivals in the network which are detected in SCOOT and SCATS. Each sequence of vehicle arrivals will cause SCOOT and SCATS to generate a unique sequence of signal timings. Figure 2 shows how 30 random seeds, all generating very similar hourly traffic flows, cause significant variations in SCOOT and SCATS cycle lengths. Duration of each simulation was 2 hours long (PM peak period) with an additional 30 minutes for warm-up and cool-off (dissipating congestion at the end). Usually, performance measures are averaged before a comparison. However, a challenge in this study was that no average performance measure corresponds to a single sequence of signal timings. Similarly, it would not make sense to look at average signal timings because such timings would not represent a sequence observable in the real world. For example, if an average SCOOT cycle length is used, its value could be 82 seconds. In reality, SCOOT would never compute such a value (it would be either 80 or 88 seconds). Therefore, analysis is performed for a single representative SCOOT and SCATS simulation run (the same random seed). For a simulation run to be considered representative, its outputs (delays, stops, throughput, average speed, etc.) needed to be closest to median values, from the 30 simulation runs, for both SCOOT and SCATS. After a detailed analysis it was found that a simulation run with random seed 50 most closely matched the selection criteria.

RESULTS AND DISCUSSION

To assess the quality of SCOOT and SCATS operations, authors observed variations of cycle lengths, offsets, and splits, and how each of these influenced various performance measures at the selected intersections. Figure 2 shows how SCOOT and SCATS cycle lengths, from 30 randomly seeded runs, vary over the simulation period.



a) SCOOT Cycle Lengths



b) SCATS Cycle Lengths

FIGURE 2 Variability of Cycle Lengths at Landmark Dr and SR 224.

The bolded lines represent cycle lengths for random seed 50, which was analyzed in this paper. In Figure 2 SCOOT cycle lengths are more spread out (from 60 to 160 seconds) than SCATS cycle lengths (80 to 150). These variations are due to the fact that SCOOT and SCATS have different cycle length ranges and incremental steps. SCOOT maximum and minimum cycle lengths were selected to be as close as possible (160 sec, 60 sec) to the maximum and minimum of SCATS cycle lengths (150 sec, 55 sec) which had been defined by practitioners in the field.

Evaluation of SCOOT and SCATS Cycle Lengths

Figure 3 shows how cycle lengths from SCOOT and SCATS vary during the peak period. The lowest pair of curves shown in Figure 3-a) represents combined intersection delays on Segment 1 for SCOOT and SCATS. These segment delays represent the sum of delays for each of the two intersections and include delays on all intersection movements. The delay for each movement is extracted from VISSIM's node delay output. The nodes in VISSIM are bounded by user-defined polygons and their delays are conveniently reported here in minutes per 5-minute period. The pair of curves in the middle represents SCOOT and SCATS total intersection throughputs, given in number of vehicles per each 5-minute period. A 5-minute aggregation interval was chosen because it is small enough to capture variations in traffic performance and large enough not to report performances within a single cycle length (different for each system). The third (from the bottom) set of curves represents SCOOT and SCATS cycle lengths, which are common for both intersections in Segment 1.

Figure 3-a) shows that SCATS cycle length is much faster than SCOOT cycle length in responding to increases in traffic demand during the peak. On the other hand, SCOOT cycle lengths stays at a low value much longer than SCATS cycle lengths. While lower cycle lengths generate less delay they sometimes fail to provide enough throughput (number of vehicles passing through the system). The converse happens with higher cycle lengths. A large challenge was to compare SCOOT and SCATS performances if within the same time interval one system generates more delay (negative) but higher throughput (positive) than the other system. To address this challenge, and compare SCOOT and SCATS performances, the following method was used to combine delay and throughput into a single Performance Measure (PM):

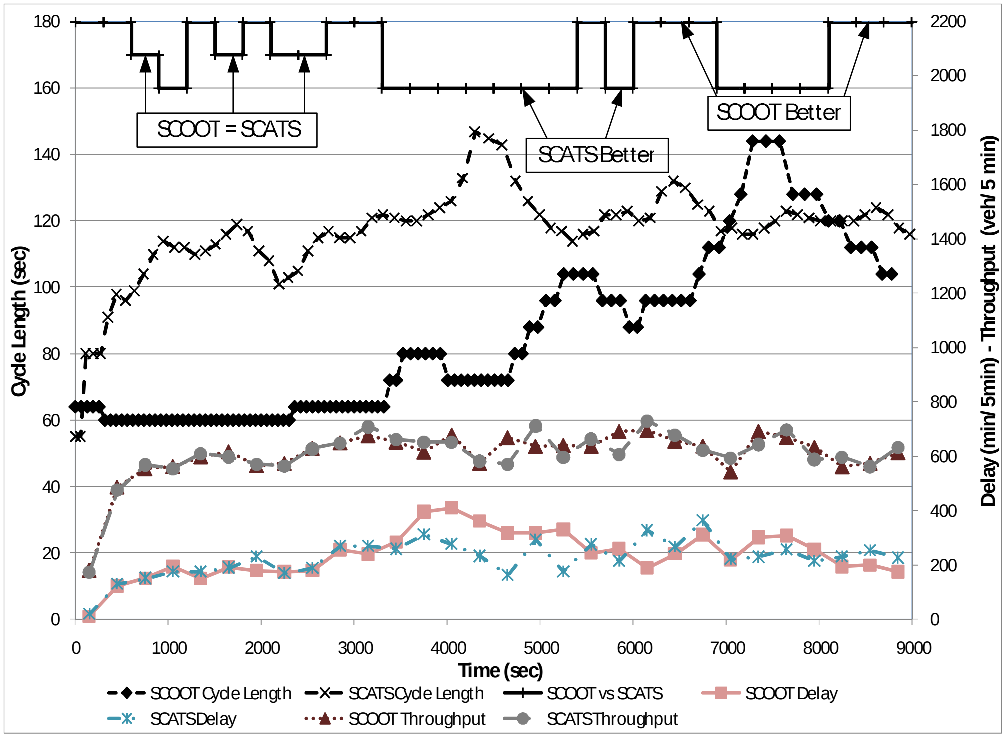
$$SCOOT\ PM = SCOOT\ Delay + \left(\frac{SCOOT\ Delay}{SCOOT\ Throughput}\right) \times ABS\left|SCOOT\ Throughput - SCATS\ Throughput\right| \times (1 - x)$$

$$SCATS\ PM = SCATS\ Delay + \left(\frac{SCATS\ Delay}{SCATS\ Throughput}\right) \times ABS\left|SCOOT\ Throughput - SCATS\ Throughput\right| \times (x)$$

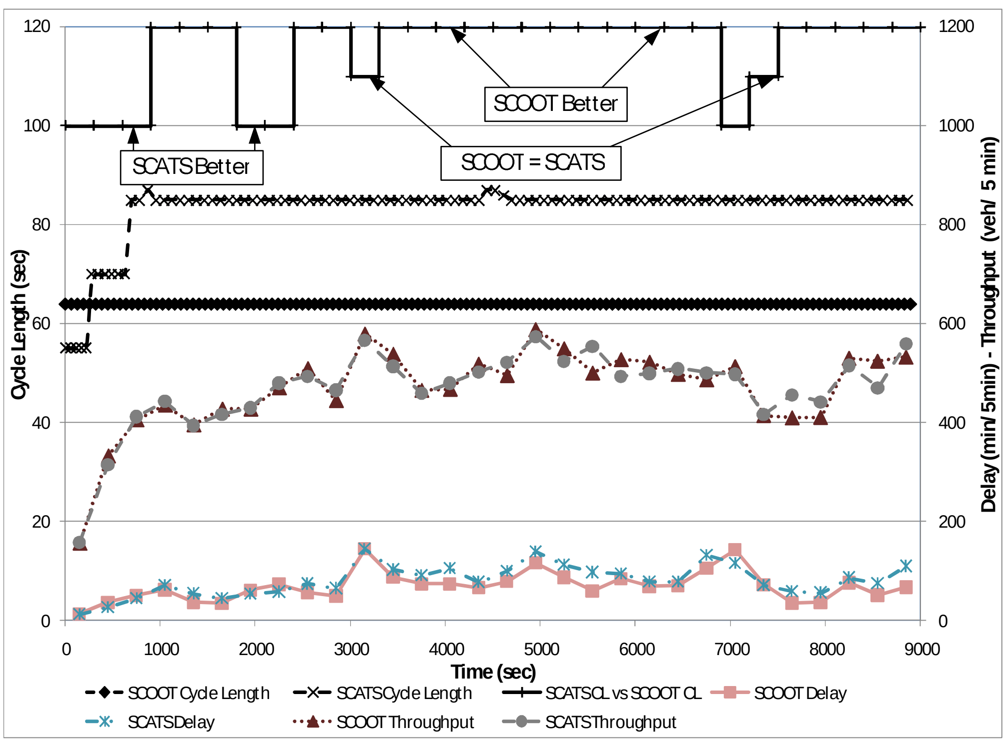
Where

$$x = 1,\ for\ SCOOT\ Throughput > SCATS\ Throughput$$

$$x = 0,\ for\ SCOOT\ Throughput < SCATS\ Throughput$$



a) Segment 1



b) Segment 2

FIGURE 3 SCOOT and SCATS: Cycle Lengths, Delays and Throughputs.

For each 5-minute interval SCOOT PM and SCATS PM were calculated based on 5-minute aggregated delays and throughputs. If one system (SCOOT or SCATS) generated higher throughput than the other, the other system was penalized with added delay. This additional delay was calculated as the product of average delay of vehicles that passed through and absolute difference between SCOOT and SCATS throughputs.

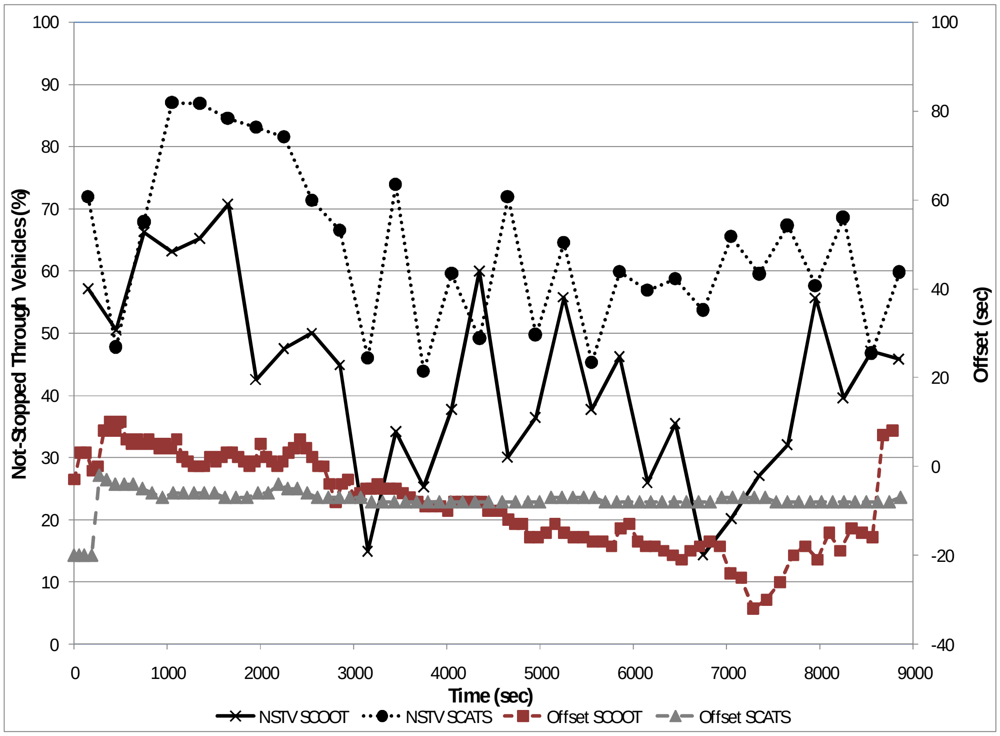
If SCOOT PM was lower than SCATS PM, SCOOT was recognized as a better system for that particular 5-min period and an upper line segment was drawn along the digital-impulse (top) line in Figure 3. If SCATS was better than SCOOT a bottom line segment was drawn along the digital-impulse line. Finally, if neither system was better (SCOOT PM = SCATS PM) a middle line segment was drawn along the digital-impulse line.

Figure 3-a) shows that out of 30 5-minute intervals, each system was better than the other during 13 intervals; while in the remaining 4 intervals, there was no significant difference. However, during intervals when SCATS was better than SCOOT the difference was higher than in the opposite cases. One should note here that the SCOOT PM and SCATS PM are not solely influenced by the cycle lengths of the two systems but by the combined effects of all signal timing parameters. However, SCOOT cycle length in Figure 3-a) cannot be a reason for higher SCOOT delays in the middle of the peak period (3500-5500 seconds) because this cycle length is lower than SCATS cycle length. Consequently, SCOOT delays should be lower than SCATS delays if the cycle length was the only parameter that impacted the delay. So, by looking at Figure 3-a) one can speculate that poor SCOOT performance on Segment 1 is due to other signal timing parameters.

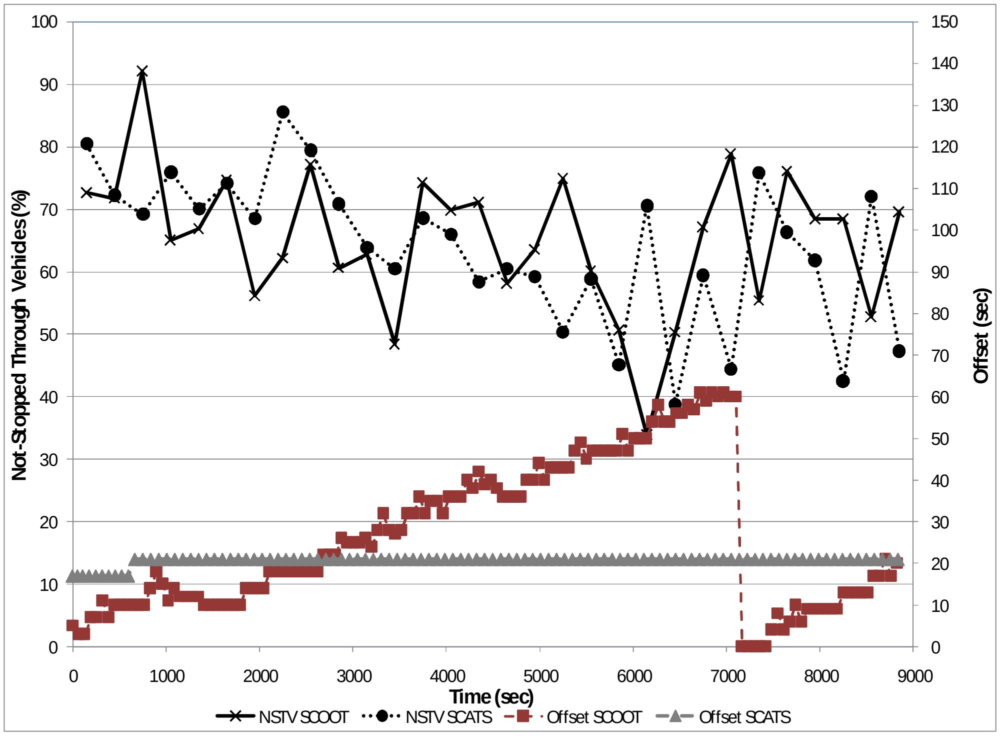
Similarly to part a), part b) of Figure 3 shows cycle lengths, delays, and throughputs for two intersections in Segment 2. In this case, we do not see high fluctuations in cycle lengths. Except for the initial rise in SCATS cycle length in the first 1000 seconds, both cycle lengths are nearly constant all the time. Figure 3-b) shows (at the top line which resembles digital impulses) that SCOOT outperforms SCATS in 22 out of 30 5-minute intervals. SCATS is better than SCOOT in 6 intervals, whereas the systems are similar in 2 intervals. However, the differences between SCOOT and SCATS are much smaller than those observed for Segment 1.

Evaluation of SCOOT and SCATS Offsets

Figure 4-a) shows quality of SCOOT and SCATS progression for traffic traveling between the two intersections in Segment 1. The two lower curves show offsets in SCOOT and SCATS. The original SCATS offsets are reported as relative offsets between coordinated phases at two adjacent intersections. Original SCOOT offsets are reported as intersection's "time now" which could refer to one of the coordinated phases. There were only two SCOOT phases that could be coordinated: Phase 2 and Phase 6 (the same as in SCATS) because none of the side-street phases were eligible for coordination. So, original SCOOT offsets ("times now" of coordinated phases) for the two intersections were subtracted to get offset values comparable to SCATS offsets. Figure 4-a) shows that while SCATS offset does not fluctuate a lot (from – 2 to – 8 seconds for LP 3) SCOOT offset varies significantly (from 10 to – 33 seconds). Quality of progression for both systems is measured by a percentage of through vehicles (for coordinated phases) which do not stop at the downstream intersections (Not-Stopped Through Vehicles or NSTV in Figure 4). These percentages were computed by using a specially designed post-processor for VISSIM outputs. The percentages are aggregated for both directions and each 5-minute interval.



a) Segment 1



b) Segment 2

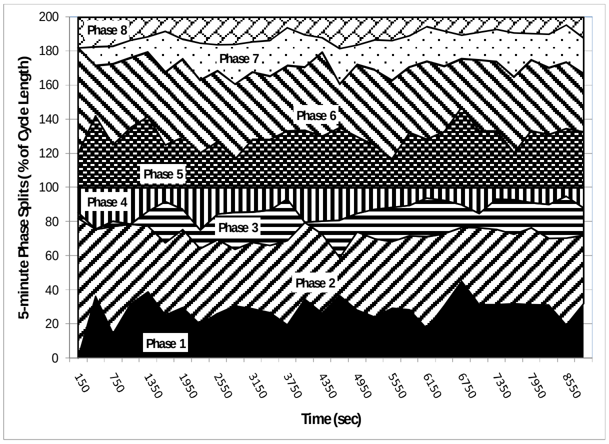
FIGURE 4 SCOOT and SCATS: Offsets and Quality of Progression.

Figure 4-a) shows that SCATS provides better progression on Segment 1 than SCOOT. Interestingly, the progressions from the two systems are not so different when SCOOT performed worse than SCATS (Figure 3-a); 3500 – 5500 seconds). This finding suggests, through a process of elimination, that poor splits more than poor offsets may be a reason for this specific increase in SCOOT delay.

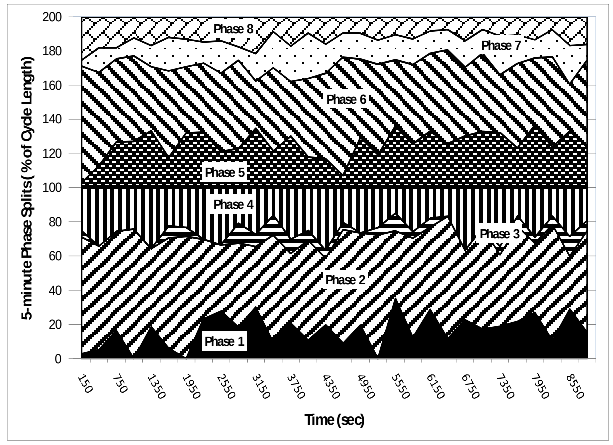
Unlike on Segment 1, SCOOT and SCATS progressions on Segment 2, shown in Figure 4-b), are very similar. The offsets still behave quite differently (SCATS offset is constant while SCOOT offset varies significantly) but the percentages of vehicles that do not stop (NSTV) at downstream intersections are very similar. This similarity in SCOOT and SCATS progression trends can be attributed to the fact that offsets do not play a very important role in progression when side-street phases are frequently skipped and major through flows enjoy green times over several cycles.

Evaluation of SCOOT and SCATS Splits

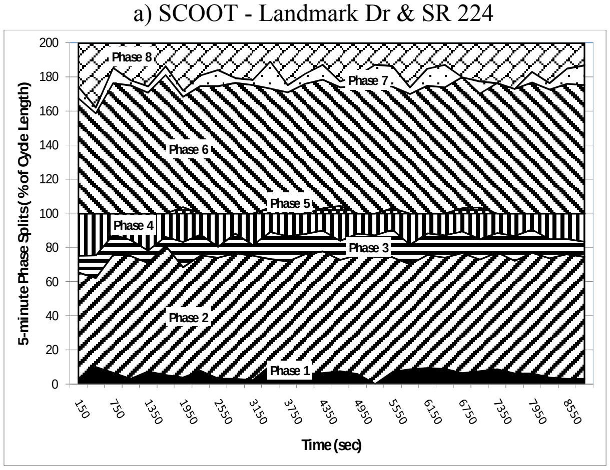
Variations in SCOOT and SCATS phase splits for Segment 1 are shown in Figure 5. Parts a) and b) of Figure 5 show 5-minute phase splits (as percentage of cycle length) for Landmark Drive on SR 224 (the critical intersection). SCATS ability to implement vehicle-actuated operations proves to be a better tool to adjust splits and determine how much green is really necessary for each phase. Parts a) and b) of Figure 5 shows that SCOOT provides ‘unnecessary’ long greens to Phases 1 and 3, which are left-turn phases. These extra left-turn green times take green from high-demand through phases, which in turn cause increases in overall delay. Major reasons for ‘poor’ SCOOT’s left-turn greens are SCOOT inflexibility to change splits for more than 4 seconds in two consecutive cycles, potential errors in estimated degree of saturation on links, and delay in adjusting duration of left-turn phases on filter links. Parts c) and d) of Figure 5 shows a similar trend at the intersection of Olympic Park on SR 224. In general SCOOT is not able to adjust its splits quickly enough to efficiently respond to traffic fluctuations at various intersection approaches.



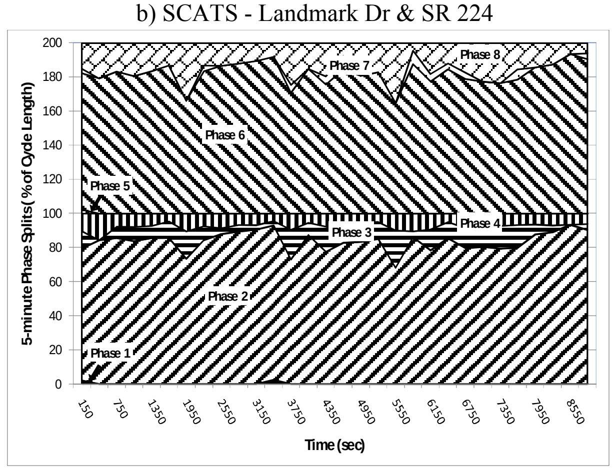
a) SCOOT - Landmark Dr & SR 224



b) SCATS - Landmark Dr & SR 224



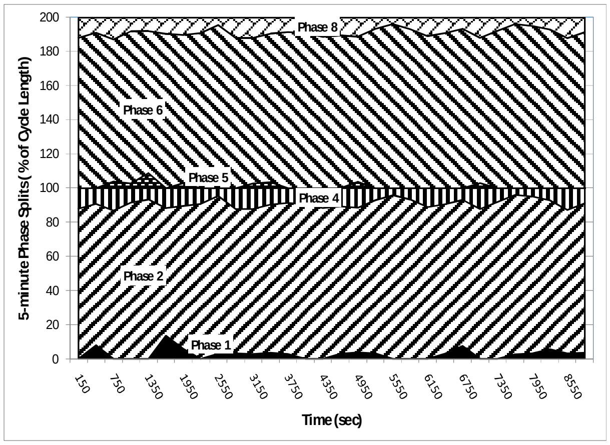
c) SCOOT - Olympic Park & SR 224



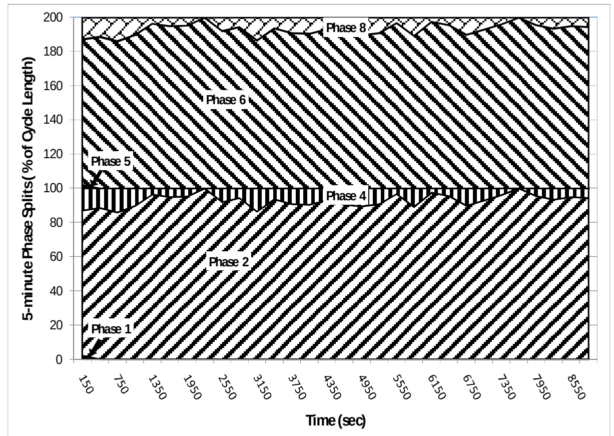
d) SCATS - Olympic Park & SR 224

FIGURE 5 SCOOT and SCATS: Phase Splits – Segment 1.

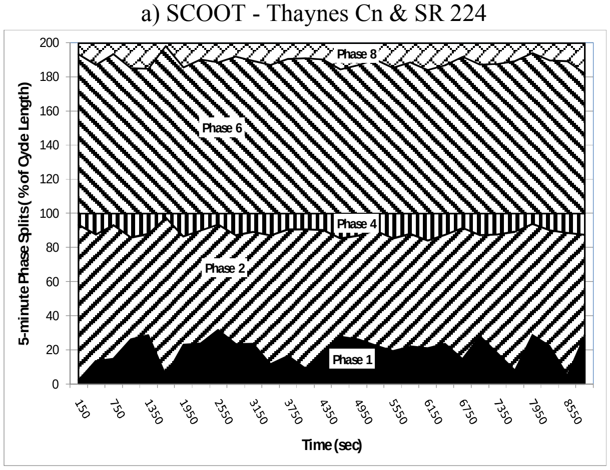
Figure 6 shows that differences in 5-minute green splits for intersections in Segment 2 are not as accentuated as the ones observed in Segment 1 (Figure 5). On this segment SCOOT does not have to adjust its splits for side-streets to the same extent it did on Segment 1. A couple of vehicles waiting for the green on a side-street approach should clear the intersection within the provided minimum green time. Hence, there are much smaller differences between SCOOT and SCATS splits for these intersections. So finally, we can explain the difference in SCOOT and SCATS performance observed in Figure 3-b). With similar quality of progressions between intersections (shown in Figure 4-b)), and similar splits (mostly providing green for major phases), the cycle length has a critical impact on total delay on Segment 2. SCOOT's cycle length is shorter; thus, its average delay per vehicle is lower than for SCATS. At the same time, the throughput is not significantly impacted by the lower cycle length because low side-street traffic provides enough opportunities to run multiple cycles without giving green to the side-street traffic.



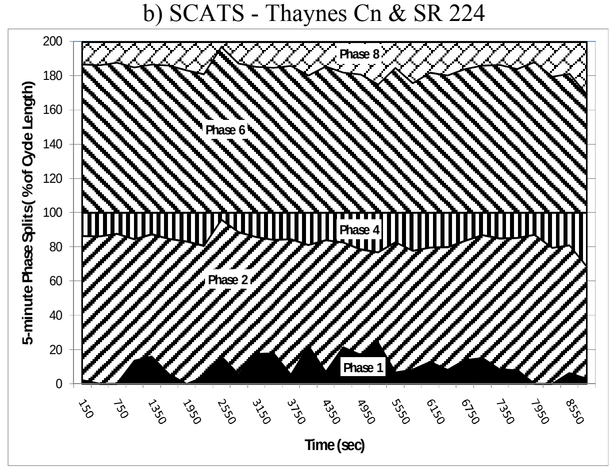
a) SCOOT - Thaynes Cn & SR 224



b) SCATS - Thaynes Cn & SR 224



c) SCOOT - SR 248 & SR 224



d) SCATS - SR 248 & SR 224

FIGURE 6 SCOOT and SCATS: Phase Splits – Segment 2.

CONCLUSIONS

The goal of the study was to analyze and discuss SCOOT and SCATS signal timings at a microscopic level and to increase our understanding of how these systems perform. SCOOT and SCATS implementations of cycle lengths, offsets, and splits are compared to evaluate their impact on performance measures. Two segments, each with two intersections showing the highest differences in SCOOT and SCATS performances were selected for analysis. The paper looked at intersection and segment performance measures such as total intersection delay, throughput and quality of progression between adjacent intersections. Presented results reflect a single representative simulation run, but the observed trends truly describe average SCOOT and SCATS performances on the Park City network.

Although several months were spent in adjusting SCOOT and SCATS setups for the Park City network, there is no guarantee that the best performances for any of the systems were achieved in the fine-tuning process. The findings presented here are based on SCOOT and SCATS systems tailored for the Park City network. When looking at SCOOT and SCATS responsiveness and ability to implement efficient signal timings we reach the following conclusions:

1. Overall SCOOT and SCATS deliver similar delays. The delay findings from the system-wide evaluation (*5*) are confirmed in this study. Both systems seem to be able to cope with predominantly undersaturated traffic demand (*5*). SCATS cycle lengths seem to be more responsive while SCOOT tends to keep cycle lengths at lower levels for longer time. This study does not show that any of these two strategies generates less delay than the other. More research is needed to find out which level of responsiveness in adaptive traffic control brings higher benefits for various traffic conditions.
2. SCATS offsets seem to provide better progression than SCOOT offsets, which results in fewer stops. This trend has been observed both at the macroscopic (network) (*5*) and microscopic (segment) levels.
3. SCATS approach of using common vehicle-actuated facilities (gap-out and max-out) generates more efficient splits than SCOOT approach of constrained (± 4 seconds) split adjustments. This fundamental difference in split adjustments becomes critical for overall intersection operations when there is high traffic demand on most of the intersection approaches.
4. Future evaluations of SCOOT and SCATS should address calibration and fine-tuning processes of these two systems. Findings presented in this study are based on SCOOT and SCATS operations in a linear network and for limited variations in traffic flows. Future research should also address SCOOT and SCATS operations under various operational conditions (e.g. grid arterial networks, a range of traffic demands, multi-modal operations). Especially interesting would be a comparison of SCOOT and SCATS performances (and possibly actuated-coordinated) control under oversaturated traffic conditions. Such a study would reveal benefits of adaptive traffic control systems where traffic operations need a substantially different approach to alleviate congestion.

REFERENCES

1. Hunt, P.B., Robertson, D. I., Bretherton, R.D., and Winton, R.I. (1981). "SCOOT – a Traffic Responsive Method of Coordinating Signals." *Laboratory Report 1014*, Transport and Road Research Lab, Crowthorne, Berkshire, U.K.
2. Lowrie, P.R. (1982). "The Sydney Coordinated Adaptive Traffic System – Principles, Methodology, Algorithms." *Proceedings of International Conference on Road Traffic Signaling*, Institution of Electrical Engineers, London, U.K., 67-70.
3. Luk, J.Y.K., Sims, A.G., and Lowrie, P.R. (1982). "SCATS – Application and Field Comparison with a TRANSYT Optimised Fixed Time System." *Proceedings of International Conference on Road Traffic Signaling*, Institution of Electrical Engineers, London, U.K., 71-74.
4. Powell, R. J. (1985). "SCOOT in Southampton." *Proceedings for the PTRC Annual Summer Meeting at Seminar M*, P269, 97-110.
5. Kergaye, C., Stevanovic, A. and Martin, P.T. (2008). "An Evaluation of SCOOT and SCATS through Microsimulation." *Proceedings of the 10th International Conference on Application of Advanced Technologies in Transportation*. Transportation and Development Institute, Athens, Greece.
6. Luk, J.Y.K. (1984). "Two Traffic-Responsive Area Traffic Control Methods: SCAT and SCOOT." *Traffic Engineering & Control*, 25(1), 14-22. Printerhall Limited, London, U.K.
7. Lam, J.K., and Mahalingam, I.S. (1992). "Review of Traffic Adaptive Control Techniques for the Renewal of the Kowloon ATC System." *Proceedings of the 3rd International*

Conference on Vehicle Navigation & Information Systems, 546-553. Institute of Electrical and Electronics Engineers, Oslo, Norway.

8. Liu, D., and Cheu, R.L. (2004). "Comparative Evaluation of Dynamic TRANSYT and SCATS-Based Signal Control Logic using Microscopic Traffic Simulations." *Preprint CD-ROM of 83rd TRB Annual Meeting*. TRB, National Research Council, Washington, D.C.
9. Siemens Traffic Controls Ltd. (2003). *SCOOT User Guide. Version 4.2.* Poole, Dorset, U.K.
10. Roads and Traffic Authority (2001). *SCATS 6 – Operating Instructions. Version 6.1.2.* RTA-TC-251. New South Wales, Australia.
11. Bretherton, R.D., Wood, K., and Bowen, G. T. (1998). "SCOOT Version 4." *Traffic Engineering and Control*, Vol. 39, No. 7, 425-427.
12. Bretherton, R.D. (2007). "SCOOT MC3 and Current Developments", *Transportation Research Board Annual Meeting 2007*, Paper #07-1543.
13. Stevanovic, A. and Martin, P.T. (2007). "Integration of SCOOT and SCATS in VISSIM Environment." *Presented at PTV Vision International Users Group Meeting*, May 24-25, 2007, Park City, Utah. http://www.trafficlab.utah.edu/documents/Integration%20of%20SCOOT%20&%20SCATS%20in%20VISSIM.pdf (Oct. 10, 2007).
14. Martin, P.T. and Feng, Y. (2002). "SCOOT Bus Priority Evaluation in VISSIM Simulation Environment." Report UTL-0802-017/1. University of Utah Traffic Laboratory, Salt Lake City, Utah.
15. Stevanovic, A., and Martin, P.T. (2008). "SCOOT and Coordinated-Actuated Traffic Control Evaluated through Microsimulation." *Paper presented at the 87th Annual Meeting of the Transportation Research Board*, Washington, D.C.
16. Stevanovic, A., Martin, P.T., and Stevanovic, J. (2007). "VISGAOST: VISSIM-based Genetic Algorithm Optimization of Signal Timings". *Paper presented at the 86th Annual Meeting of the Transportation Research Board*, Washington, D.C.
17. Lowrie, P.R. (1992). *SCATS – A Traffic Responsive Method of Controlling Urban Traffic*. Roads and Traffic Authority, NSW, Australia.