ADAPTIVE SIGNAL CONTROL V

SCATS Evaluation in Park City, UT

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Disclaimer

ABSTRACT

In 2005, the Utah Department of Transportation (UDOT) installed the Sydney Coordinated Adaptive Traffic System (SCATS) in Park City, Utah, on its network of 14 signalized intersections. A field evaluation compared previous time-of-day actuated-coordinated signal timings with those dynamically computed by SCATS. Travel times, travel time stopped delay and number of stops were collected by driving probe vehicles on the major routes. Intersection stopped delays were also collected to investigate traffic performance on side streets. Overall, SCATS consistently reduced travel times and travel time stopped delay, the average number of stops, and intersection stopped delay for major and minor through movements.

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EXECUTIVE SUMMARY

In the fall of 2005, UDOT installed and fine-tuned SCATS on all 12 signalized intersections in Park City, UT. Park City was selected as the deployment site because it is a fast-growing area which often experiences shifts in traffic demand. There also are many recreational and artistic events in the area. The objective of the SCATS deployment was to reduce travel times, vehicle delays, and number of stops in the network. The goal of the evaluation was to investigate SCATS's ability to improve these performance measures. This report documents the evaluation of the SCATS deployment in Park City as performed by the Utah Traffic Lab.

The original idea was to do a "before and after" evaluation. The performance measures would have been collected before SCATS was installed and after its installation and fine-tuning. However, two new intersections were signalized and added to the existing system of 12 signalized intersections. Also, one of the existing signalized intersections was redesigned from a three-leg into a four-leg intersection. These modifications happened during SCATS installation. The three modified intersections were brought under SCATS control and fine-tuned a year and a half after the SCATS installation began. These modifications invalidated the "before and after" method. So, the evaluation switched from a "before and after" study to a "SCATS On and SCATS Off" evaluation.

Two types of traffic data were collected. A vehicle probe measured traffic performance along major roads in the Park City network. Stopped-delay studies at intersections enabled the team to investigate the impact of SCATS performance on both side-street and main-street traffic during peak traffic periods. All traffic data were collected during two weeks in September 2007. Traffic data for the "SCATS Off" scenario were collected from Sept. 9 to Sept. 15. Data for the "SCATS On" scenario was collected the following week, from Sept. 16 to Sept. 22. All data were collected between 7and 9 A.M. (morning peak), and 4 and 6 P.M. (afternoon peak) on all weekdays, and Noon and 2 P.M. (midday peak) on weekends under fair weather and dry pavement conditions.

Results of the data collections show that travel times with "SCATS Off" were longer than with "SCATS On" for all weekday and weekend periods regardless of direction. The northbound PM period travel times were not statistically different when SCATS was turned on or turned off. This was also the case for both directions on the weekends. During the weekdays, "SCATS On" had the greatest impact during the AM period by reducing travel times by an average of 7.6% for both directions. Reductions in travel times for the PM weekday period averaged 3.9%, or about half that of the AM period. Weekend travel times were reduced by 1.9% or about half of the AM period reduction.

In terms of number of stops, "SCATS On" lessened stops by an average of one-half stop for all time periods and directions. The most consistent reduction in stops was for the AM period where NB and SB traffic experienced 1.5 and 1.2 fewer stops, respectively. During the weekday PM and weekend periods, "SCATS On" had fewer stops in the SB direction. Averaging both directions for the weekday PM period generated the same number of stops regardless of SCATS control while there was a slight advantage for "SCATS On" during the weekend period. However, most of the stops (except those for the weekday AM period) were not significantly different between "SCATS On" and "SCATS Off."

Travel time stopped delay was measured as stopped time experienced during the travel time runs mostly due to waiting at traffic signals. Stopped delays from travel time runs, similarly to the travel times, were clearly lower for "SCATS On" scenario for all time periods and directions. Travel time stopped delay was also reduced during "SCATS On" by approximately one-half minute on the weekend to one full minute during the weekday, or 13% to 20% respectively.

Intersection stopped delay results showed that the largest average reduction in stopped delay was for through movements. Both the main and side roads experienced 2 seconds less delay during “SCATS On.” Stopped delay for left turns was less consistent. On the main roads, left turn stopped delay was reduced by approximately one-half of a second during “SCATS On;” on the side road, left turn stopped delay increased approximately one full second during “SCATS On.”

In general, it can be concluded that the SCATS deployment in Park City, Utah, has improved traffic operations in terms of reduced travel time, reduced stopped delay and reduced number of stops. The travel times and delays on the major route in the Park City network are always smaller with SCATS control than with TOD plans. The best improvements were for the AM peak, and the smallest were for weekend MD peaks. The stopped-delay analysis shows that SCATS improves performance on the major roads without worsening side street operations significantly. Average side-street delays for through vehicles are lower for SCATS than for TOD plans. The initial feedback from UDOT traffic signal engineers is also positive. It is expected that the SCATS installation will reduce operational costs to maintain proper signal timings and coordination on the Park City network.

1. INTRODUCTION

Traffic signal systems that respond in real time to changes in traffic patterns are known as “adaptive.” adaptive traffic control systems (ATCSs) belong to the latest generation of signalized intersection control. ATCSs continuously detect vehicular traffic volume, compute signal timings that are closer to optimal; then simultaneously implement them. Adapting to traffic volume variation generally reduces delays, shortens queues, and decreases travel times. ATCSs are designed to overcome the limitations of pre-timed control and respond to changes in traffic flow by adjusting signal timings in accordance with fluctuations in traffic demand.

There are more than 350,000 traffic signals in the United States, and, according to the U.S. Department of Transportation, as many as 75% could operate more efficiently if their timing plans, coordination with adjacent signals, or equipment were updated on a regular basis.[1] Sometimes, better efficiency in traffic operations can be achieved by updating existing signal timing plans to reflect changes in traffic demand in the field. But updating is expensive. A survey of 417 operating agencies for the *National Traffic Signal Report Card* found that about 38 percent of agencies fail to routinely review signal timings at least once every three years. [2] Almost half (49%) of the interviewed agencies do not have staff or resources to monitor or manage traffic on a regularly scheduled basis.[2]

Intelligent transportation system (ITS) technology enables the process of traffic signal timing to be performed more efficiently through enhancements in data collection, monitoring capabilities, and automation of the process. ITS tools such as automated traffic data collection, centrally controlled traffic signal systems, closed loop signal systems, interconnected traffic signals, and adaptive traffic control systems (ATCSs) help make the traffic signal timing process efficient and cost effective.

ATCSs, also known as real-time traffic control systems, have been used broadly since the early 1980’s. Although still not extensively used in American cities, these systems have been deployed in more than 30 locations in the United States.[3] Sydney Coordinated Adaptive Traffic System (SCATS), developed by Road and Traffic Authority (RTA) of New South Wales, Australia, is a system that has been installed extensively world-wide.[4]

SCATS and ATCSs in general, have been evaluated.[5-8] These North American field evaluations showed that most of these systems improve traffic performance. These improvements vary between 5% and 45% in terms of various measures of effectiveness although deployment of ATCSs does not always improve all performance measures. ATCSs are usually evaluated by comparing their impacts on traffic with impacts from conventional traffic control systems. The impacts are captured through various performance measures which are either collected in the field or delivered by microsimulation tools. Conventional traffic control is usually represented either by signal timings from the field or optimized signal timings from offline optimization tools such as TRANSYT-7F, SYNCHRO, and PASSER. Conventional signal timings are often called time-of-day (TOD) plans because variations of them are implemented through day, reflecting diurnal and other fluctuations in traffic demand. The TOD plans are implemented either through fixed-time traffic control or vehicle-actuated traffic control.

After several years of investigating adaptive traffic control in microsimulation environments, the Utah Department of Transportation (UDOT) opted to install a real-world adaptive traffic control system. After careful consideration of various ATCSs, UDOT decided to install SCATS. Park City was selected as a deployment site because it is a fast-growing area which often experiences significant shifts in traffic demand due to its frequent recreational and artistic events. The objective of the SCATS deployment was to reduce travel times, vehicle delays, and number of stops in the network. The Utah Traffic Lab evaluated SCATS' performance. The goal of the evaluation was to investigate SCATS's ability to improve the aforementioned performance measures. This report documents the change in traffic performance in the Park City network due to the deployment of SCATS control.

2. LITERATURE REVIEW

2.1 SCATS Logic and Implementation

SCATS is a two-level hierarchical traffic adaptive signal control system developed in Australia in the early 1980s by the Roads and Traffic Authority (RTA).[9, 10] SCATS uses information from vehicle detectors (2m x 5m in dimension), 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. SCATS acts as a heuristic feedback system adjusting signal timings based on the changes in traffic flows during previous cycle(s). Two basic measures from detectors are used to adjust signal timings: degree of saturation (DS) and traffic flows (denoted LQ for link queue). Both are measured each cycle. They serve to calculate cycle lengths, splits, and offsets for the following cycle. The SCATS strategy assumes that higher cycle lengths increase intersection capacity, increase splits proportional to approach demand, and provide longer offsets for increased traffic volumes. For saturated and over-saturated traffic conditions, SCATS usually abandons the concept of splits proportional to saturation and provides more green for higher traffic flows on major roads. For more information about SCATS logic go to the relevant literature .[11]

In the field, SCATS can be deployed with *2070* and *170* traffic signal controllers with a modified central processing unit. A central server running the SCATS algorithms processes DS and LQ from selected detectors in the system and adjusts signal timings in real time. The new signal timings are then sent to local controllers, via the communication server, and implemented in the field. SCATS can deploy various levels of responsiveness when selecting the best signal timings (i.e. Masterlink, Flexilink, Isolated, Master Isolated, and Fixed Time).[12] If communication between the central and field components fails, TOD signal timings from local controllers are implemented.

2.2 Field Evaluations

The Roads and Traffic Authority (RTA) of New South Wales, Australia developed SCATS. They were first to evaluate SCATS in the field. Known as the Parramatta Experiment, field performances were measured for various traffic control types on both open and closed networks.[13] On the closed (CBD) network, SCATS was better than both isolated vehicle-actuated control and fixed-time control, in terms of stops and journey times. Similar results were seen on the open (arterial) network. In a few cases, where journey times under SCATS control were not reduced, they were similar those measured under other traffic controls.

Oakland County in Michigan has the most installations of SCATS-controlled intersections in the United States and was field evaluated extensively.[14] The findings showed that SCATS reduced the number of stops, side-street delays, and left-turn delays when compared to fixed-time control.

More recently, SCATS has been evaluated in Cobb County, Georgia, and Gresham, Oregon.[16] In Cobb County, SCATS was compared to recently updated signal timing plans for semi-actuated traffic control. The evaluation had two components: technical performance and driver satisfaction. A rigorous comparison of technical performances showed that neither control system was superior.[15] Results of the driver satisfaction study were similar. They did not show that either control was significantly better than the other, with the explanation that travel times, speeds and delays were similar for each signal system.

In Gresham's field evaluation, SCATS was compared to 3-year old coordinated-actuated signal timing plans.[17] The study focused on traffic performance on the main corridor with investigation of side-street performances planned for the future. Initial results showed that SCATS reduced travel time by 16% and delay by 42% on weekdays. The impact on weekends was even greater.

In summary, there have been a variety of field evaluations of SCATS. SCATS has been shown to be much better in terms of travel times and delays, when compared to conventional signal timings, especially when timings have not been updated recently. It also seems that newer and more rigorous studies show fewer benefits than the initial evaluations. This is perhaps due to the fact that conventional traffic control itself has become more adaptive in recent years. Vehicle-actuated traffic control (usually coordinated for a system of closely spaced intersections) has become the predominant type of traffic control in the United States.[18] Moreover, new features of signal controllers support vehicle-actuated operations that are more responsive than ever before.

3. METHODOLOGY

3.1 Measures of Effectiveness

Table 3.1 shows MOEs that were collected for the SCATS evaluation. Table 3.1 briefly describes each MOE, its data collection method, and its application range. The last column describes how each MOE contributes to the assessment.

Table 3.1 MOEs for SCATS Evaluation

MOE	Description	Method	Range	Assessment
Stopped Delay	Average stopped delay per vehicle (sec)	Manual collection	Major intersections & approaches	Shows delay generated by a traffic signal
Corridor Travel Time	Journey time on the corridor (sec)	Floating car & GPS (or manual)	Main corridor	Shows system's ability to coordinate traffic
Average Speed	Average travel speed on the corridor segments (mph)	Floating car & GPS (or manual)	All segments on the corridor	Shows average vehicle speed on each segment
Number of Stops	Average number of stops at intersection on corridors (#)	Floating car & GPS (or manual)	All corridors	Shows system's ability to coordinate traffic
Total Delay	Delayed time while traveling on the major route (sec)	Floating car & GPS (or manual)	All intersections (major approaches)	Shows total delay imposed by traffic signals and traffic demand

3.2 Description of Study Network

Figure 3.1 shows how SCATS is deployed at 14 intersections on the Park City network which consists of two suburban arterials, state route (SR) 224, SR 248, and many cross roads. SR 224 is a 5-lane major arterial and SR 248 is a 3-lane minor arterial. Both arterials have a median left-turn lane. Posted speed limits on SR 224 range from 64.5 km/h (40 mph) to 88.5 km/h (55 mph). Speed limits on SR 248 are mostly 56.3 km/h (35 mph). Recent traffic counts have shown that SR 224 and SR 248 carry about 26,000 and 15,000 vehicles per day, respectively. This corridor is the primary route for recreational traffic from Salt Lake City and other areas to ski resorts and recreational areas in Park City and serves as a connector between Interstate 80 and U.S. Route 40.

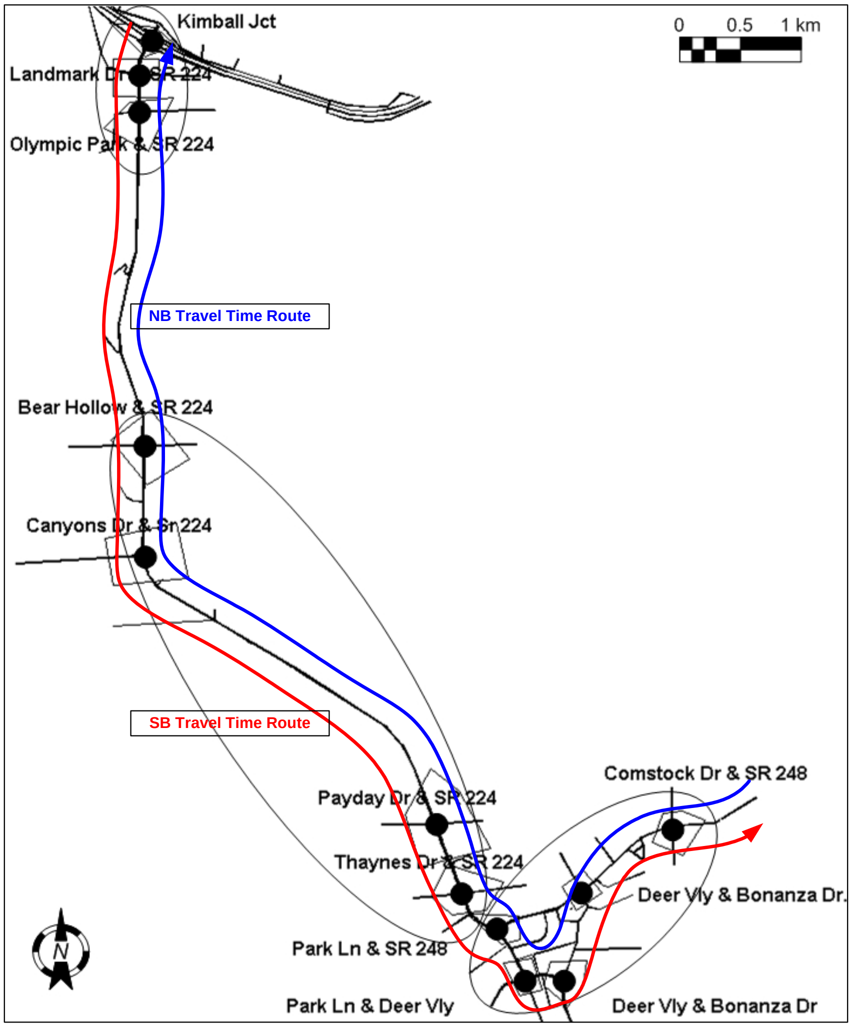

Figure 3.1 SCATS Intersections in Park City, Utah

The network can be divided into three distinct parts on the basis of prevailing traffic conditions: "Kimball Junction" single point urban interchange (SPUI) for SR 224 and I-80 with neighboring signalized intersections (Landmark Drive and Olympic Park). This area hosts many local businesses generating work-related and shopping traffic. It has the highest traffic demand throughout the day with level of service (LOS) C at the three intersections during the PM peak. The close proximity of the intersections dictates the need for coordination.

Bobsled Drive, Bear Hollow, Sun Peak Drive, Canyon Road, Payday Road, and Thaynes Canyon. These six intersections in the middle of the network and at the beginning of the downtown area provide access to residential and recreational areas. Intersections in this area have LOS A or B during the PM peak. Spacing between intersections allows some signals to run uncoordinated.

Park Avenue & SR 248, Park Avenue and Deer Valley, Deer Valley and Bonanza Drive, Bonanza Drive and SR 248, and SR 248 and Comstock Drive. These intersections form a small gyratory system that provides circulation for the traffic to access cultural and historical downtown of Park City. The LOS for these intersections is B-A during the PM peak. Spacing between intersections warrant coordination, which is not mandatory because traffic flows at some of the intersections can be very low.

3.3 Data Collection Periods

Two types of traffic data were collected. Vehicle probe data was collected to measure traffic performance along major roads in the Park City network. Stopped-delay was measured at intersections to investigate the impact of SCATS performance on both side-street and main-street traffic during the peak traffic periods. All traffic data were collected during two weeks in September 2007. Traffic data for the “SCATS Off” scenario were collected from Sept. 9 to Sept. 15. The data for the “SCATS On” scenario was collected the following week, from Sept. 16 to Sept. 22. All data were collected between 7and 9 AM (morning peak), and 4 and 6 PM (afternoon peak) on all weekdays, and Noon and 2 PM (midday peak) on weekends under fair weather and dry pavement conditions (Table 3.2).

Table 3.2 Data Collection Periods

	Weekday		**Weekend**
Data Collection	**AM Peak**	**PM Peak**	**MD Peak**
Travel Time/Delay Runs	7-9 AM	4-6 PM	12-2 PM
Controlled Delay Studies	7-9 AM	4-6 PM	12-2 PM

3.4 SCATS On vs. SCATS Off

In fall 2005, UDOT installed and fine-tuned SCATS on all 12 signalized intersections in Park City. The original idea was to do a “before and after” evaluation. The performance measures would have been collected before SCATS was installed and after its installation and fine-tuning. In this way, performance measures under the original actuated-coordinated field control would have been compared to the performance measures under SCATS control. However, two new intersections were signalized and added to the existing system of 12 signalized intersections. Also, one of the existing signalized intersections was redesigned from a three-leg into a four-leg intersection. These modifications occurred before SCATS was fully deployed but after “before” data was collected. The three modified intersections were eventually brought under the SCATS umbrella and fine-tuned within a year and a half of the start of the SCATS installation (in fall 2005). Modifications of the three intersections made the original evaluation ‘before & after’ plan irrelevant. So a new method was adopted: “SCATS On and SCATS Off.

When turned on, SCATS runs its adaptive algorithms (Masterlink mode). When SCATS is turned off, TOD plans which reside in SCATS’s background operate (Flexilink mode). Note that the TOD plans implemented by SCATS may or may not be the same as the original actuated-coordinated TOD plans. Sometimes these timing plans are slightly modified to fit SCATS phases, which can differ from previous phases with actuated-coordinated control. Other operational settings (e.g. minimum green) may be adjusted to support conventional SCATS operations. SCATS usually favors the major traffic flows at the expense of minor traffic flows. For Park City, the TOD plans used for SCATS’s Flexilink operation differed only minimally from the original actuated-coordinated TOD plans.

3.5 Travel Time/Delay Studies

The travel time/delay studies were the floating car technique as described in the ITE Manual of Transportation Engineering Studies.[20] The test vehicle is driven according to the floating-car method in which the vehicle passes as many vehicles as those that pass the test vehicle. The study team consists of two persons if data is recorded manually. One person drives the test car while the other person measures travel times and delays with a stopwatch and records the measurements on a data collection form. The test car is driven in both directions on each street during the same time periods in which the stopped-time delay studies are conducted. Approximately the same numbers of runs were made in the median and curb lanes. Drivers of the probe vehicles used handheld computers with global positioning systems to log vehicle latitude and longitude at 1-second intervals. More than 500 vehicle runs were collected. All of the collected data were exported to a spreadsheet for further analysis using a customized computer application. The numbers of required runs are calculated according to NCHRP Report 398 for suggested sample size for data collection on arterial streets.[19]

$$Sample\ \ Size,\ n \cong \frac{z^2 \cdot c.v.^2}{e^2}$$

Where

n = sample size for normal distribution
z = standard normal variation based on desired confidence level
c.v. = coefficient of variation of travel times (%), and
e = specified relative error (%), e.g. for ± 10% error, 30 ± 3 minutes.

Coefficient of variation is a key factor which influences the sample size. Coefficient of variation represents the variability of travel time data. To minimize the number of required runs, coefficients of variation were investigated for road segments with similar operating characteristics.[19] Two major stratifications were done for arterial streets based on hundreds of observations. The first stratification is based on signal density. The second stratification is based on ADT (Average Daily Traffic) per lane group.

In 2005 the UTL team obtained test travel time data and volume counts. The length of the route, from the intersection of Interstate 80 and SR 224 and the intersection of SR 224 and Comstock Drive, is 7.35 miles. At that time, there were 12 signalized intersections on the route, which is fewer than two signals per mile. With this signal density, the route belongs to the Low Signal Density stratum group[19] which has an 85^{th} percentile c.v. of 13.2 %.

Traffic volume data collected recently at the Bear Hollow and SR 224 intersections showed about 1300 vehicles per hour in the peak direction during the peak hour. Converting this flow to daily traffic volume (using a peak conversion factor of approximately 10%), gives approximately 6500 ADT per lane on the route. This moderate traffic volume places the route in the moderate ADT per lane stratum group.[19] This stratum group yields to 19.3% of the 85^{th} percentile of c.v.

Conservatively, the analysis adopts the higher value for c.v. (the one that comes from ADT per lane stratification). With a 95% level of confidence and 10% of allowable error, the number of required runs is given by:

$$Sample\ \ Size,\ n \cong \frac{z^2 \cdot c.v.^2}{e^2} = \frac{1.96^2 \cdot 19.3^2}{10^2} = \frac{3.84 \cdot 372.49}{100} = 14.3 \approx 15\ runs$$

Therefore, runs on the route were recorded 15 times for each of the data collection periods to obtain a representative data sample of the travel times.

Routes for the vehicle probe data collection were based on major traffic flows on the Park City corridor. Figure 3.1 shows northbound (NB) and southbound (SB) routes which were traversed to collect the travel times, stopped delays, and number of stops. The SB route begins at a stop sign near to Kimball Junction and goes along SR 224. The road name changes to Park Lane after intersection with SR 248 until Deer Valley is reached. The route then turns left into Deer Valley and then turns again left into Bonanza Drive at Deer Valley and Bonanza Drive. The final turn is made at Bonanza Drive and SR 248 where the route goes right toward Comstock Drive. The route ends shortly after Comstock Drive is reached. The same path delivered the performance measures in the opposite direction (Figure 3.1). The length of the route is about 11.8 km (7.35 mi). The minimum required number of 13 test runs (for each direction) was computed according to guidelines from NCHRP Report 398 for the suggested sample size for data collection on arterial streets.[19] There are an average of 15 vehicle probe runs for weekend data collection where small variations in travel times were observed. There are more travel time runs for the AM and PM peaks on workdays (Table 3.2).

3.6 Stopped-Time Delay Studies

Stopped-time delay studies served to assess the influence of the ATCS system on stopped-time delay and stops at all 12 intersections. The stopped-time delay studies relied on two observers according to the procedure specified in the 2000 Highway Capacity Manual. A series of five-minute studies of each lane group at the intersections used the suggested sampling intervals (13-17 seconds). When a five-minute study of one lane group was completed, a five-minute study of another lane group followed until all lane groups at the intersection had been studied.

The intersection stopped delay studies enabled the assessment of the influence of the SCATS system on stopped delay for major traffic movements at the intersections. These studies followed the procedure specified in the 2000 Highway Capacity Manual.[21] A series of five-minute studies of each major lane group at the intersections (through and left-turn movements) used 16-second sampling intervals. Stopped delay data were collected for eight major movements (four through movements and four left movements) at 12 intersections. In total, more than 50 peak traffic hours of stopped delay data were collected.

4. RESULTS

Travel time run and intersection delay study data are summarized in Table 4.1 and Figure 4.1. Data for the travel time runs shows measures for travel time, number of stops, and travel time stopped delay for the periods listed in Table 3.2. Tests derived the statistical difference between “SCATS Off” and “SCATS On” data sets at the 95% confidence level. Stopped delay data for “SCATS On” and “SCATS Off” scenarios from all intersections and all collection periods were aggregated to show delays for eight major traffic movements for an average intersection in the Park City road network.

4.1 Travel Times

Table 4.1 shows that travel times with “SCATS Off” were longer than with “SCATS On” for all weekday and weekend time periods regardless of direction. The weekday travel times were statistically different for both NB and SB directions in the AM period and SB direction in the PM period. The northbound PM period travel times were not statistically different when SCATS was turned on or turned off. This was also the case for both directions on the weekends. The sample size on weekday runs was at least 44 for “SCATS Off” and 60 for “SCATS On.” Weekend sample sizes ranged between 13 and 17.

During the weekday, “SCATS On” had the higher impact on travel times during the AM period when these were reduced by an average of 7.6% for both NB and SB directions. Reductions in travel times for the PM weekday period averaged 3.9%, or about half that of the AM period. Weekend travel times were reduced by 1.9% or about half of the AM period reduction. This pattern, though, is not repeated for the number of stops or travel time delay.

4.2 Number of Stops

“SCATS On” reduced the number of stops by an average of one-half stop per route trip for all time periods and directions as computed from the data summarized in Table 4.1. The most consistent reduction in stops occurred for the AM period where NB and SB traffic experienced 1.5 and 1.2 fewer stops, respectively. During the weekday PM and weekend periods “SCATS On” had fewer stops in the SB direction. Averaging both directions for the weekday PM period generated the same number of stops regardless on SCATS control while there was a slight advantage for “SCATS On” during the weekend period. However, most of the stops (except those for the weekday AM period) were not significantly different between “SCATS On” and “SCATS Off.”

4.3 Travel Time Stopped Delay

Travel time stopped delay was measured as stopped time experienced during the travel time runs mostly due to waiting at traffic signals. Stopped delays from travel time runs, similarly to the travel times, were clearly lower for "SCATS On" scenario for all time periods and directions, as shown in Table 4.1. The data sets for all directions and periods were statistically different except for the NB direction on the weekend. Travel time stopped delay was also reduced during "SCATS On" by approximately one-half minute per route trip (averaged for NB and SB directions) on the weekend to one full minute during the weekday, or 13% to 20% respectively.

Table 4.1 Comparison of Performance Measures

			Weekday				Weekend	
			AM (7-9)		PM (4-6)		MD (12-2)	
			NB	SB	NB	SB	NB	SB
Travel Time	Average	SCATS Off	907.3	895.8	888.0	951.3	786.4	840.7
		SCATS On	839.3	825.9	* 854.3	912.6	* 773.8	* 821.5
	St Dev	SCATS Off	109.9	98.6	97.9	105.3	52.7	41.4
		SCATS On	87.1	87.6	76.0	72.4	44.1	58.6
	Samples	SCATS Off	49	49	44	46	14	13
		SCATS On	64	65	60	61	17	17
Stops	Average	SCATS Off	7.8	7.2	* 6.0	8.5	* 4.4	6.0
		SCATS On	6.3	6.0	6.3	* 8.2	4.5	* 5.3
	St Dev	SCATS Off	3.4	3.3	2.5	3.0	2.0	1.4
		SCATS On	3.5	2.0	2.0	2.4	1.5	1.5
	Samples	SCATS Off	49	49	44	46	14	13
		SCATS On	64	65	60	61	17	17
Total Delay	Average	SCATS Off	335.0	307.4	305.4	375.5	211.1	266.0
		SCATS On	266.6	254.2	268.9	329.7	* 183.9	230.2
	St Dev	SCATS Off	100.2	92.0	89.8	107.5	47.0	39.1
		SCATS On	80.9	54.4	71.4	70.2	40.4	54.4
	Samples	SCATS Off	49	49	44	46	14	13
		SCATS On	64	65	60	61	17	17

* Difference between SCATS Off/On data not statistically significant
(Values in **bold** indicate SCATS' superior performance)

4.4 Intersection Stopped Delay

Intersection stopped delay is the average delay for stopped vehicles. The data summarized in Figure 4.1 shows stopped delay for "SCATS On" and "SCATS Off" for through and left turning movements along the main and side roads. The largest average reduction in stopped delay was observed for through movements. Both the main and side roads experienced two seconds less delay during "SCATS On." Stopped delay for left turns was less consistent. On the main roads left turn stopped delay was reduced approximately one-half second, for each vehicle making such a turn, during "SCATS On." Alternatively, on the side road left turn stopped delay increased approximately one full second, for each vehicle turning left on the main road, during "SCATS On."

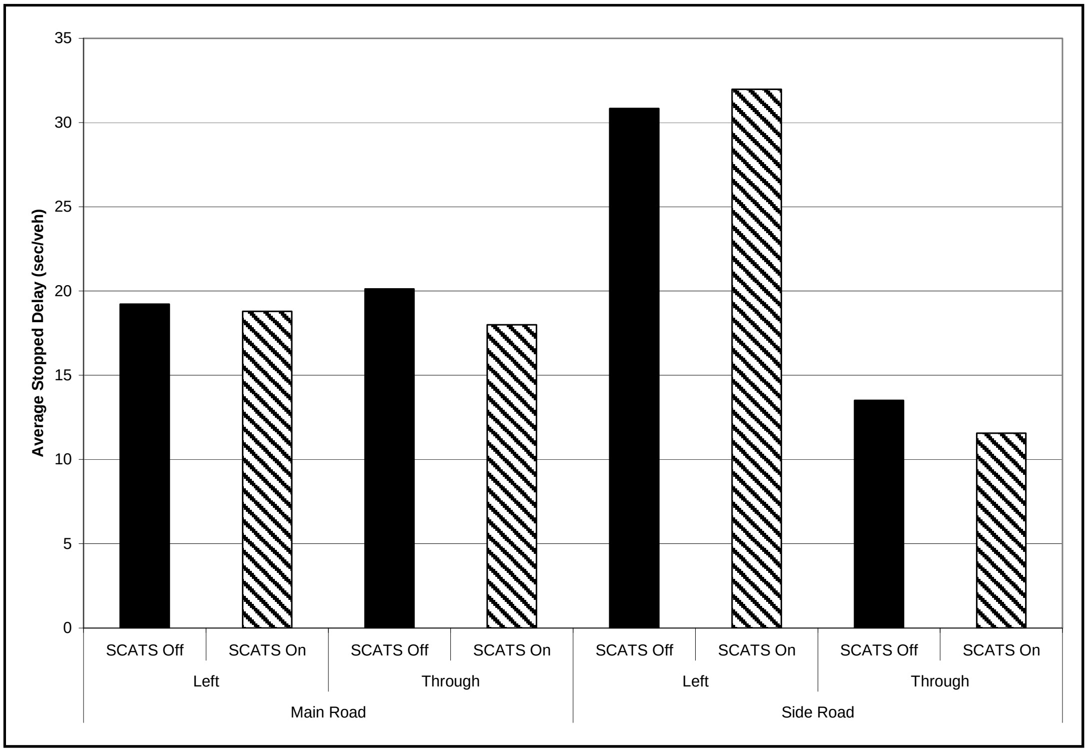

Figure 4.1 Average Stopped Delay for SCATS Off and SCATS On scenarios

5. DISCUSSION

Aforementioned performance measures (travel times, delays, and stops) reflect ‘costs of travel’ for individual vehicles either traversing the entire route on Park City network or making specific turns at each intersection’s approaches. For example, when two seconds of average stopped delay are saved by SCATS control for vehicles traveling through on the main road (Figure 4.1, third and fourth bar) this means that without SCATS every vehicle traveling through on the main road would wait two seconds more (only due to traffic signals) at each intersection in the network. When this number is multiplied by main-road through volumes for each intersection, the saved time can add up to several hours of delay per hour of observed traffic operations. Similarly, “one and a half a stop” difference per vehicle (between “SCATS On” and “SCATS Off”) means approximately several thousand of unnecessary stops (in case of “SCATS Off”) for travelers in morning and afternoon peaks in the Park City network.

The timing plans for the “SCATS Off” condition were based on fine-tuned and periodically adjusted settings for coordinated-actuated control. SYNCHRO was used to determine initial cycle lengths, splits, phasing and offsets, followed by extensive field adjustments. UDOT maintained a staff of five experienced technicians to fine-tune and respond to complaints. On average, these technicians serviced one or more intersections twice a month.

Configuration for “SCATS On” operations were defined with similar rigor by Transcore, the engineering Consulting firm employed by UDOT to install SCATS in Park City. Transcore experts fine-tuned and other adjusted settings after initial installation and until the time of data collection. “SCATS On” performance measures therefore reflect over a year of signal timing service and parameter adjustments.

Therefore, the comparison between “SCATS On” and “SCATS Off” represents an assessment of two well-maintained traffic control systems. Findings from the data collection presented in Table 4.1 and Figure 4.1 provide a clear contrast. One would expect a responsive traffic control system to perform better than a control with TOD plans. Indeed, results from Table 4.1 and Figure 4.1 show SCATS superiority over TOD plans. However, that SCATS is not always better than the TOD plans shows that previous actuated-coordinated traffic control was also working well. Figure 4.1 shows, for example, that vehicles at side-street left-turn bays must wait an average of one second longer under “SCATS On” than “SCATS Off.” This points to an advantage for TOD plans although it may be the result of SCATS favoring major traffic flows at the expense of side-street traffic.

Figure 5.1 is an example of signal timing plans from “SCATS On” and “SCATS Off” for a critical intersection in Kimball Junction area (Landmark Drive & SR 224). “SCATS Off” fixed cycle length plans are identified according to UDOT’s nomenclature Plan 2, 3, 4 and 5. Isolated actuated control is active between the hours of 10:00 P.M. and 6:30 A.M. The nearly continuously changing cycle lengths in the figure represent “SCATS On” responses to fluctuations in traffic demand. The difference between “SCATS Off” and “SCATS On” cycle lengths can explain some of the performance measures presented in Table 4.1.

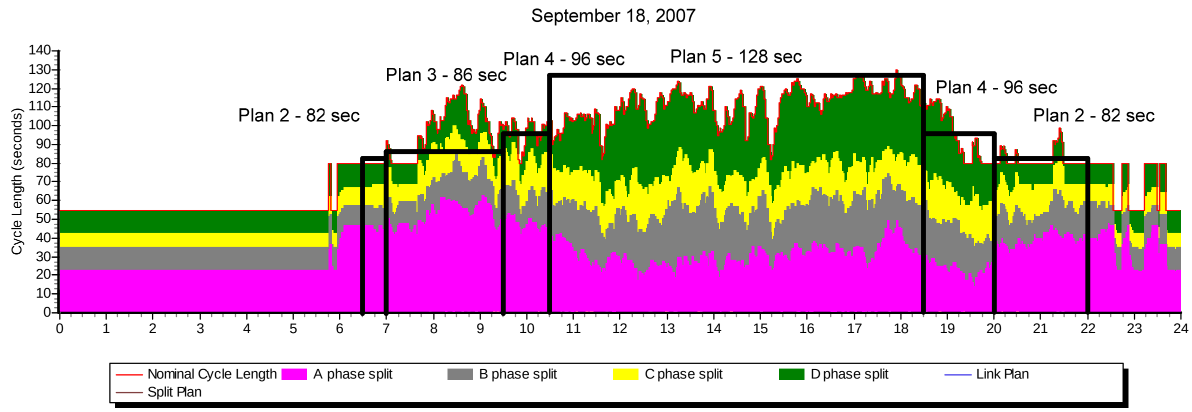

Figure 5.1 Sample Comparisons of SCATS and Time-of-Day Cycle Lengths

As a critical intersection in the Kimball Junction area, the intersection of Landmark Drive and SR 224 governs cycle length. Consequentially, signal timings from this intersection dictate magnitude of delays in the upper portion of the Park City network (Figure 3.1). Considering that this area experiences much higher traffic flows than any other area in the network one might argue that travelers' delays at the Kimball Junction area contribute disproportionately to overall travel times and delays. The difference in cycle lengths for "SCATS On" and "SCATS Off" in Figure 5.1 is highest during the AM peak. During this period signal timings from "SCATS On" suggest that there is not enough capacity for the prevailing traffic demand and that cycle length should be increased. For this reason, we see that performance measures (travel times, delays, or stops) between the two traffic controls during the AM peak are always significantly different. On the other hand, differences in cycle length is not so emphasized in the PM peak. Consistently, we see that not all of the performance measures are significantly better with SCATS control for the PM peak. This observation shows that: findings from our data collection are consistent with performance of "SCATS On" and "SCATS Off" scenarios, and that PM peak signal timing plans have probably been better designed than AM peak signal timing plans to reflect current traffic demand.

6. CONCLUSIONS

In general, it can be concluded that the SCATS deployment in Park City, Utah, has improved traffic operations in terms of travel time, stopped delay and number of stops. The travel times and delays on the major route in the Park City network are always shorter with SCATS control than with TOD plans. However, this difference in travel times and delays is insignificant in four cases. The highest improvements have been observed for the AM peak, while they are the smallest for weekend MD peaks. The findings do not show essential differences in travel times and delays for SB and NB travel time runs conducted on weekends. The stopped-delay analysis shows that SCATS reduces stopped delays on the major roads without worsening side street operations significantly. Side-street average delays for through vehicles are better for SCATS than for TOD plans. The only performance measures where TOD plans are superior to SCATS control is average stopped delay per vehicle for side-street left turns. However, if one considers that one second of delay for a small number of left turning vehicles on side streets allows for a proportionally larger number of vehicles on the main road, this finding becomes a strong advocate of SCATS' performance.

In summary, evaluation of SCATS in Park City has shown that SCATS is able to improve travel times, delays and stops for travelers on arterials in Park City. The initial feedback from UDOT traffic signal engineers is also positive. It is expected that the SCATS installation will reduce operational costs to maintain proper signal timings and coordination on the Park City network. The advantages of better performance measures also translate into direct benefits to commuters.

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8. APPENDIX A: TRAVEL TIMES

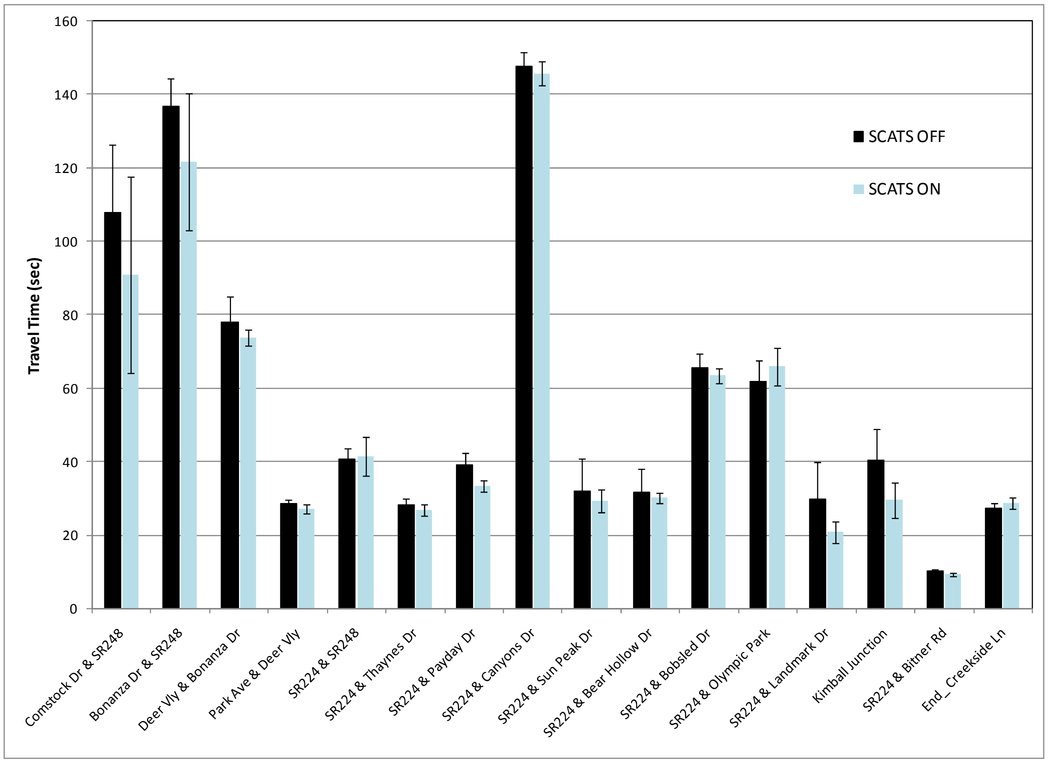

Figure A-1 Travel times - Northbound - AM Peak

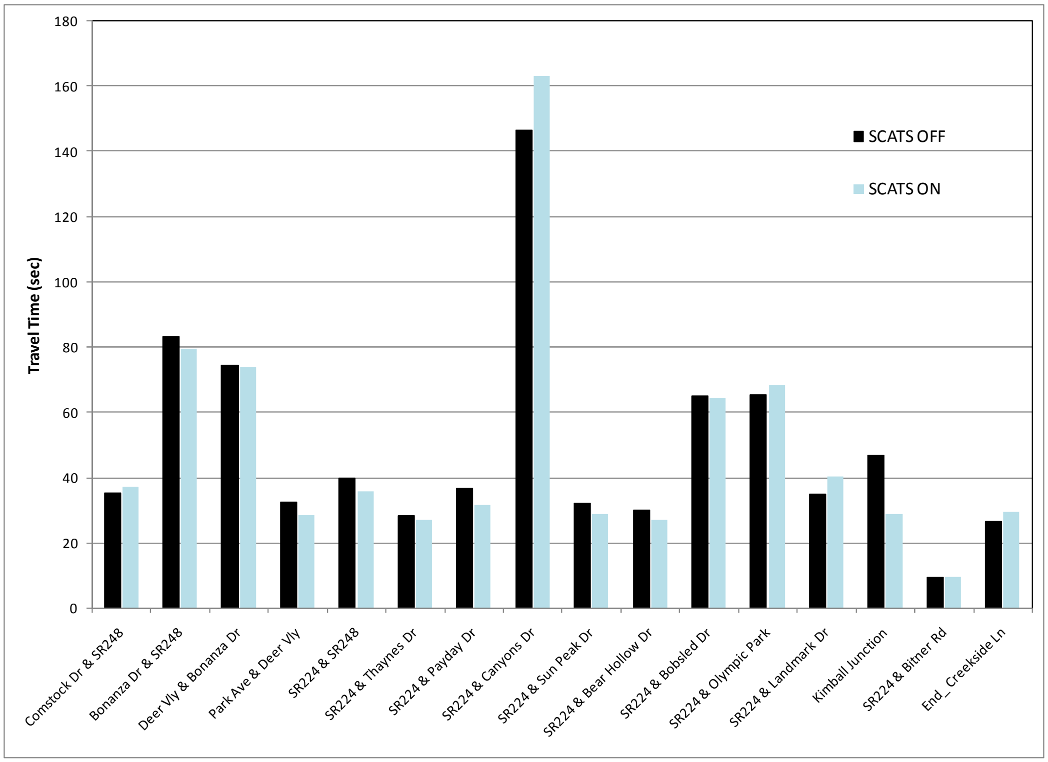

Figure A-2 Travel times - Northbound - MD Peak

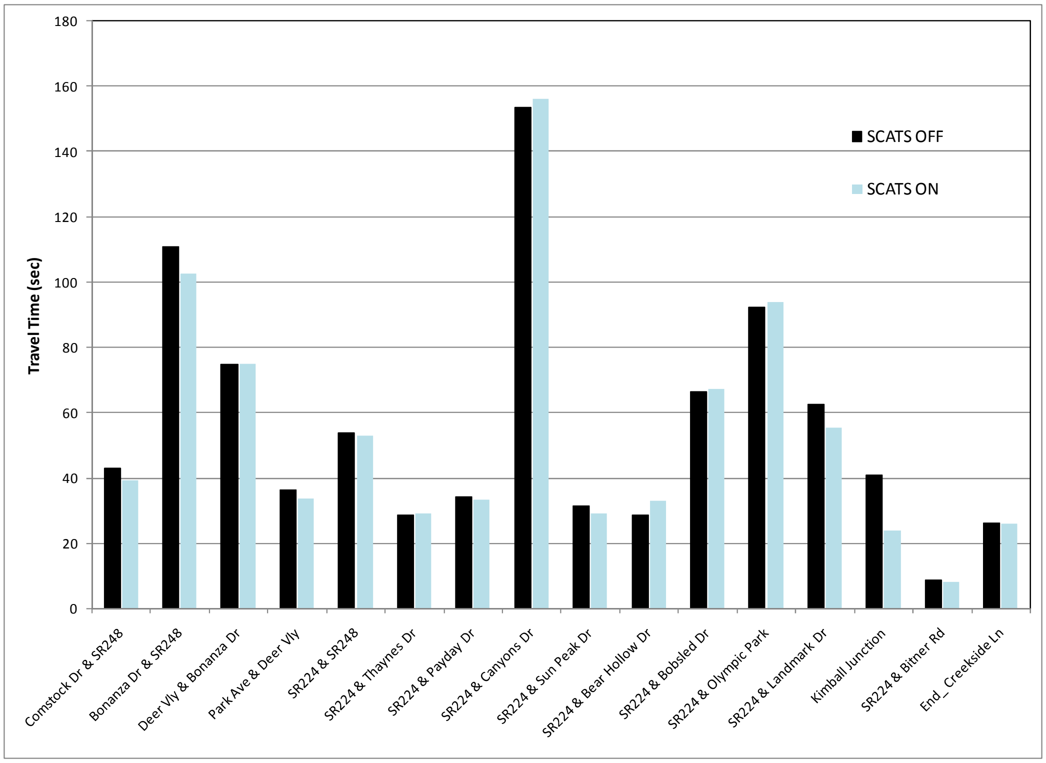

Figure A-3 Travel times - Northbound - PM Peak

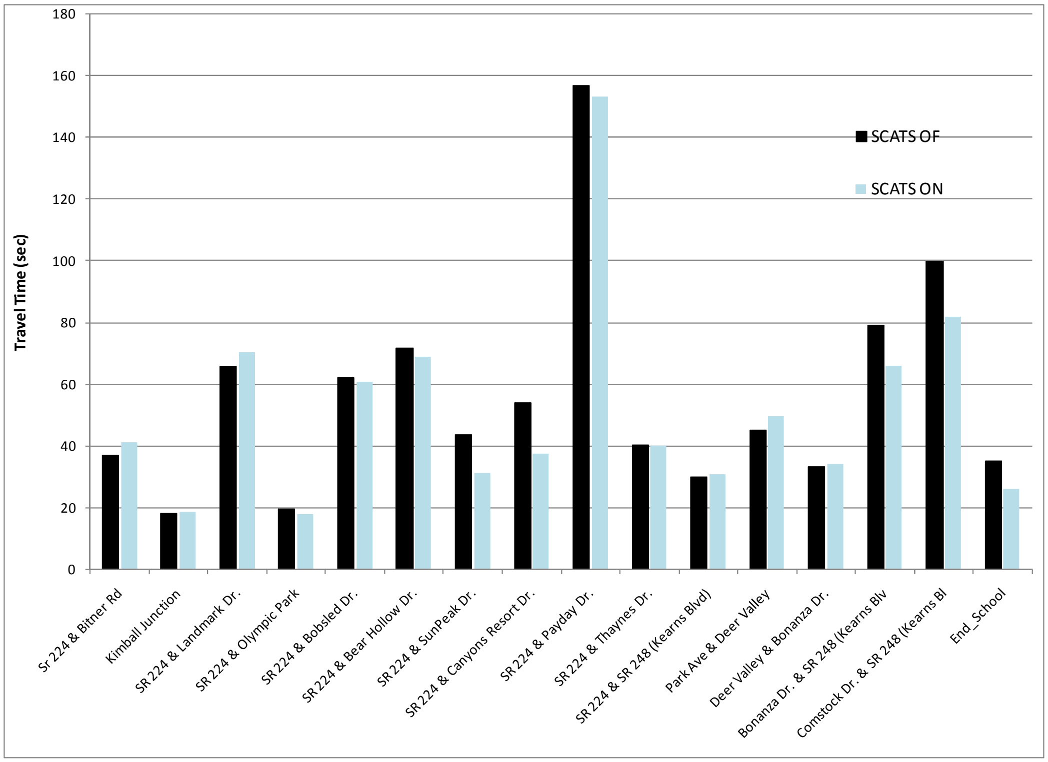

Figure A-4 Travel times - Southbound - AM Peak

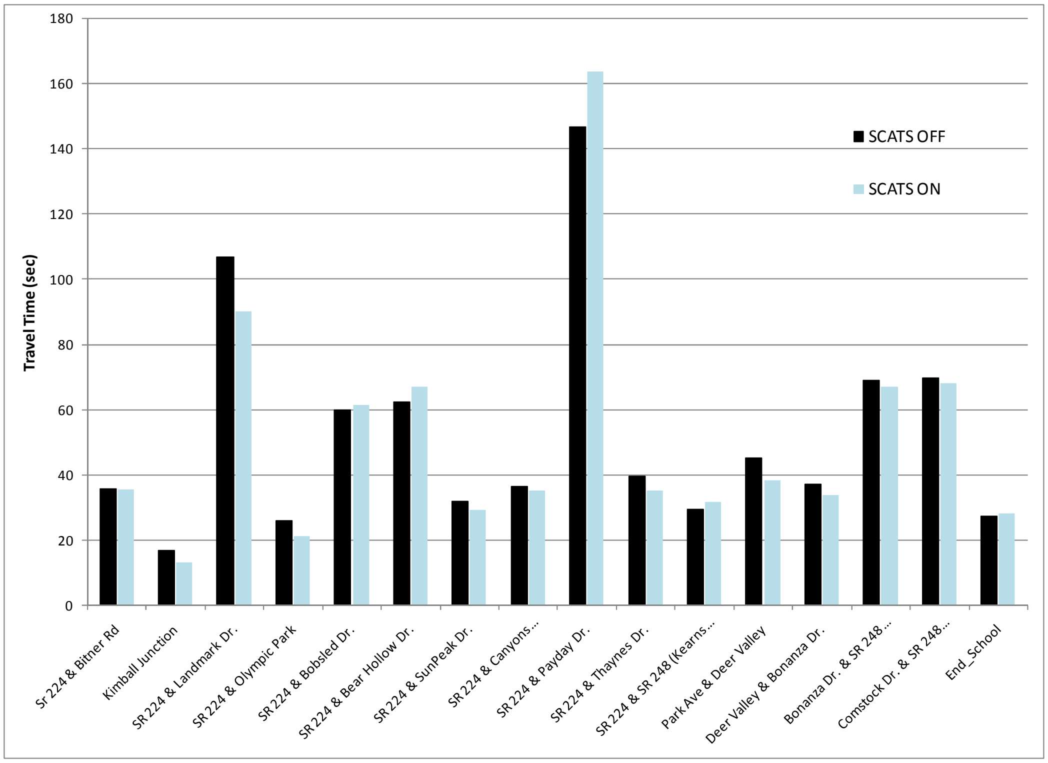

Figure A-5 Travel times - Southbound - MD Peak

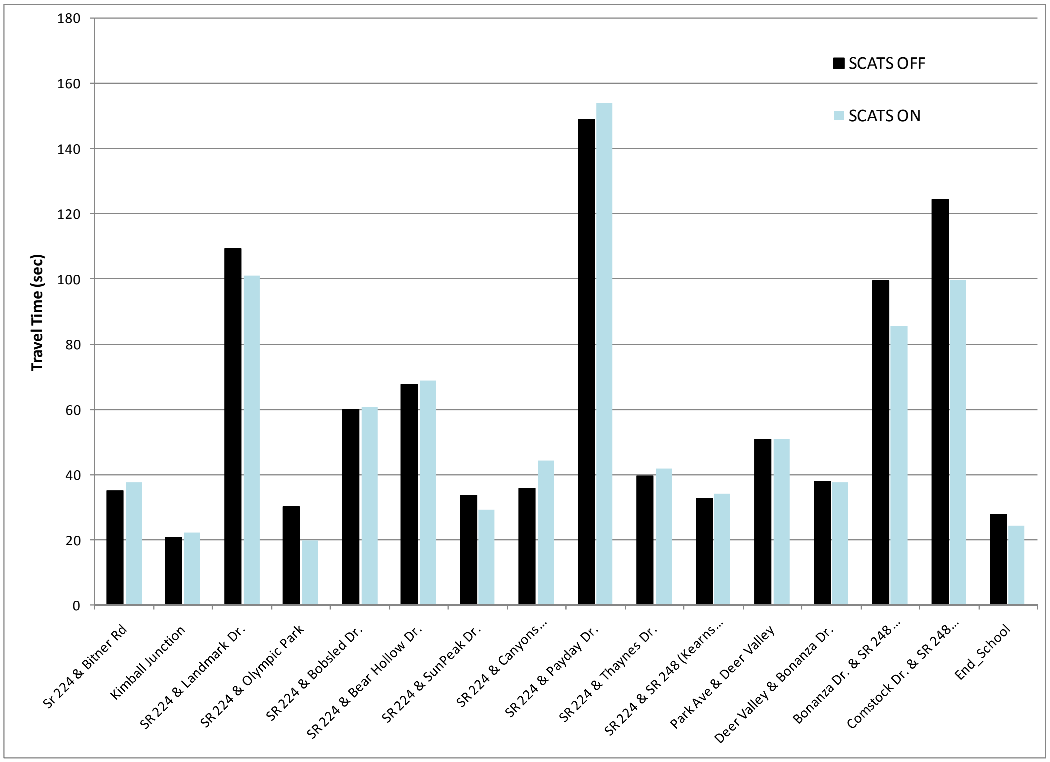

Figure A-6 Travel times - Southbound - PM Peak

9. APPENDIX B: TOTAL DELAYS

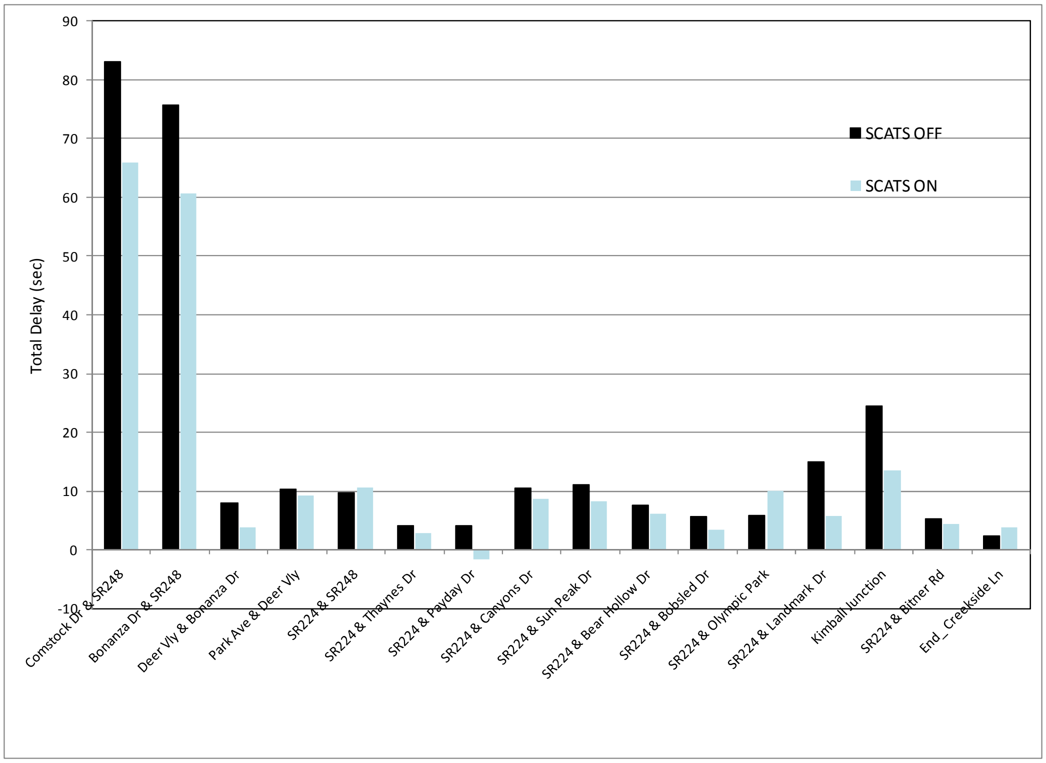

Figure B-1 Total delays - Northbound - AM Peak

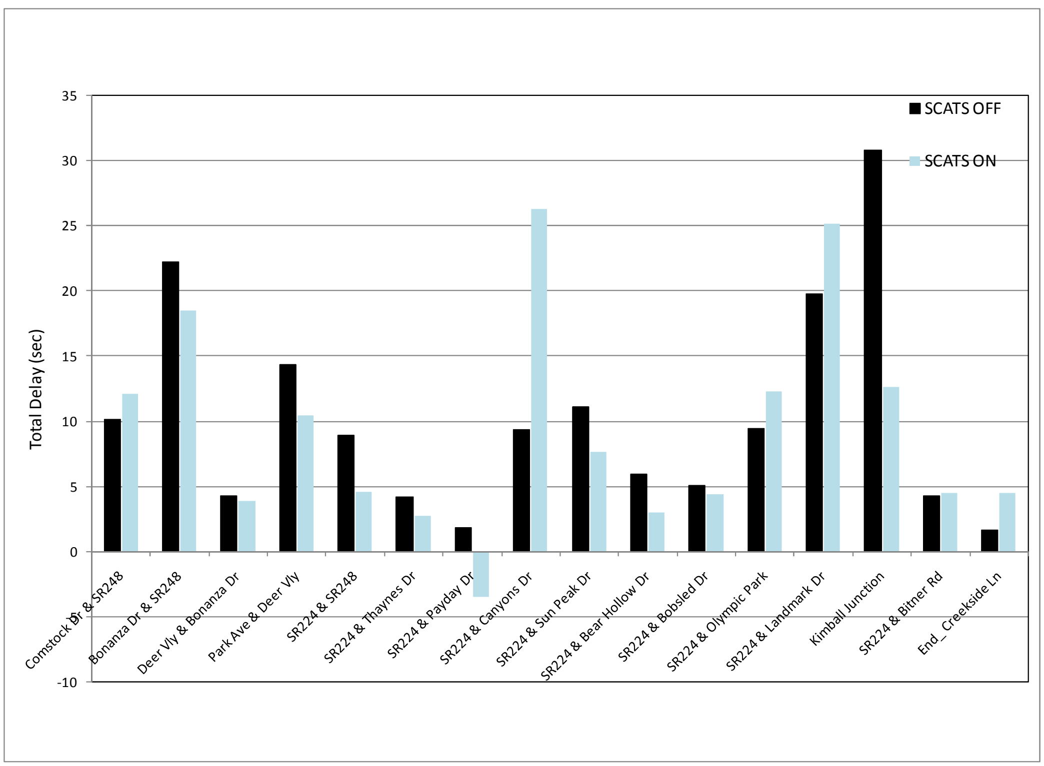

Figure B-2 Total delays - Northbound - MD Peak

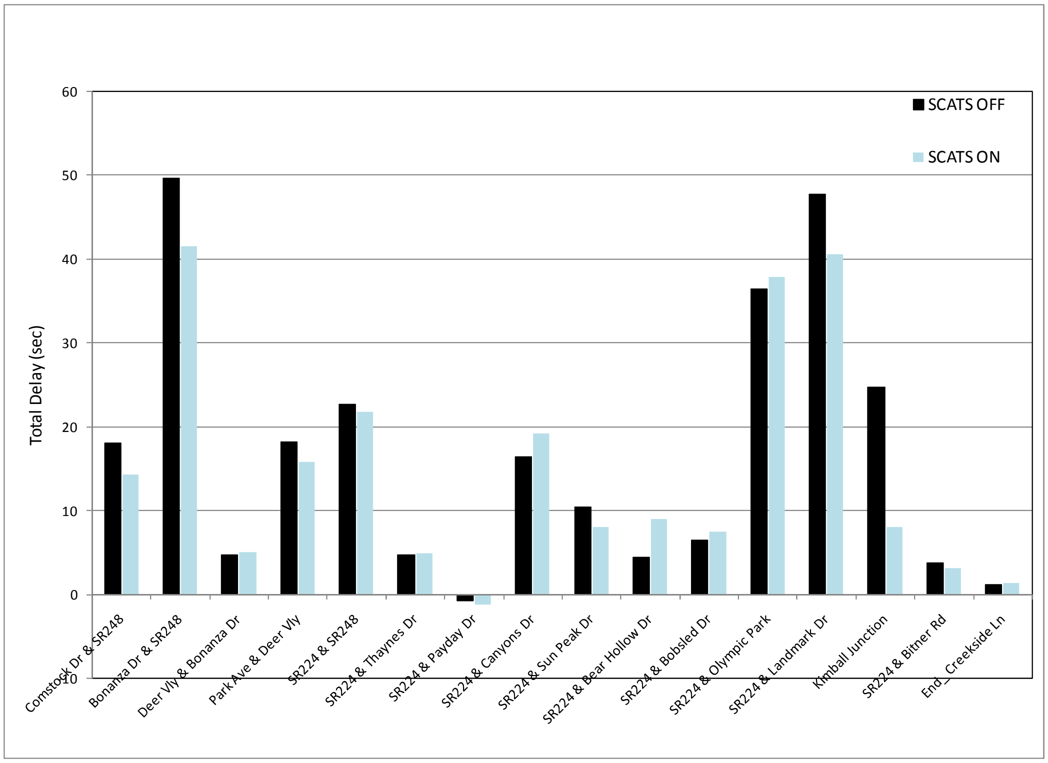

Figure B-3 Total delays - Northbound - PM Peak

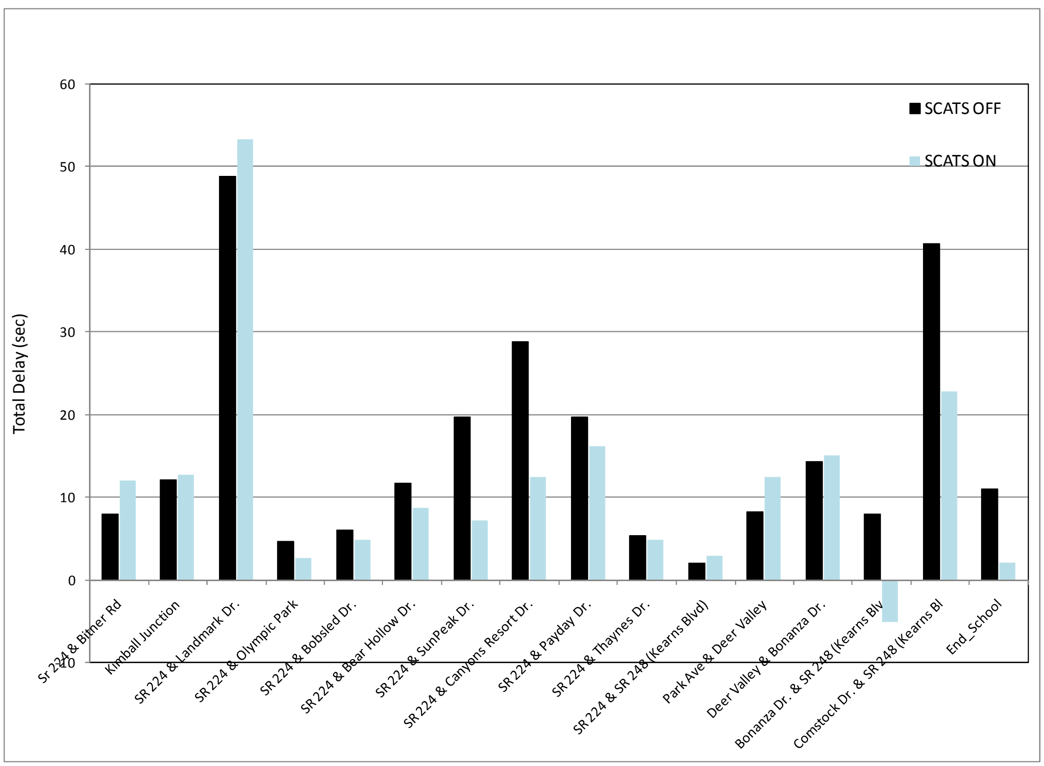

Figure B-4 Total delays - Southbound - AM Peak

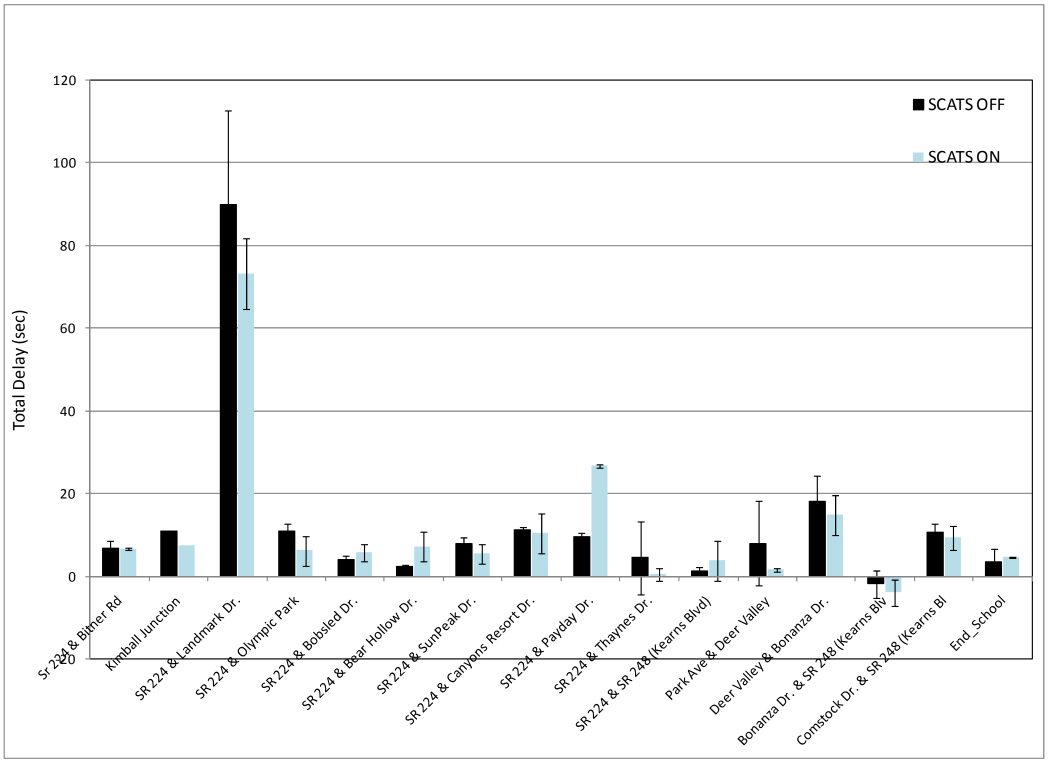

Figure B-5 Total delays - Southbound - MD Peak

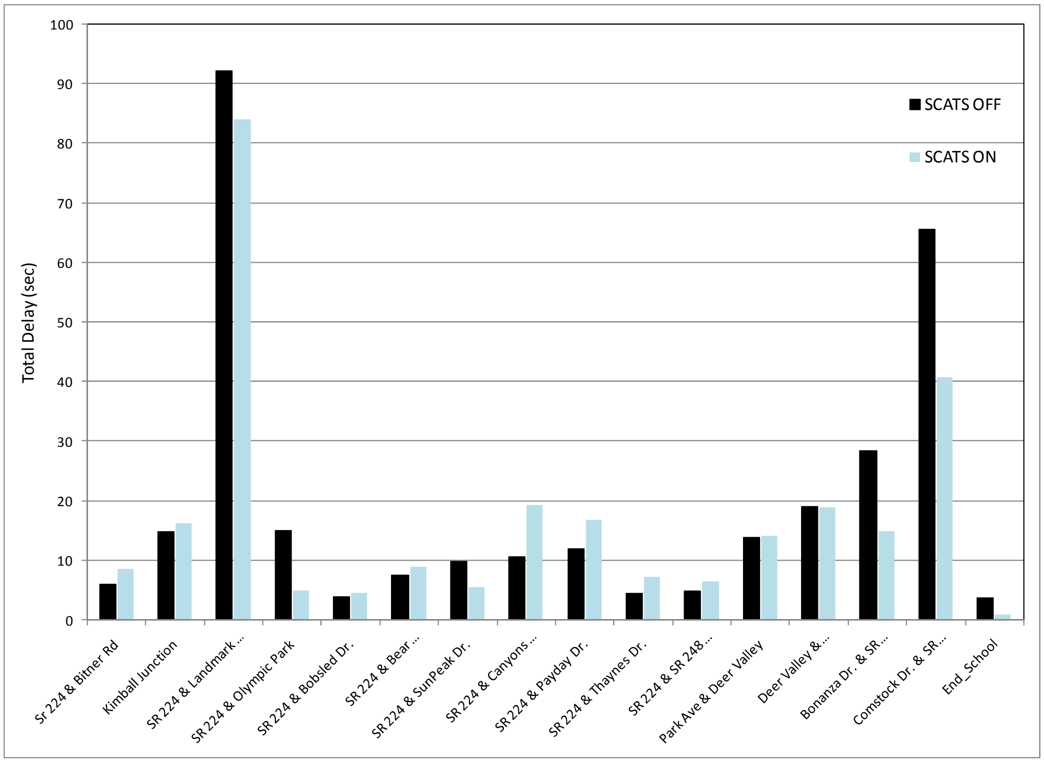

Figure B-6 Total delays - Southbound - PM Peak

10. APPENDIX C: NUMBER OF STOPS

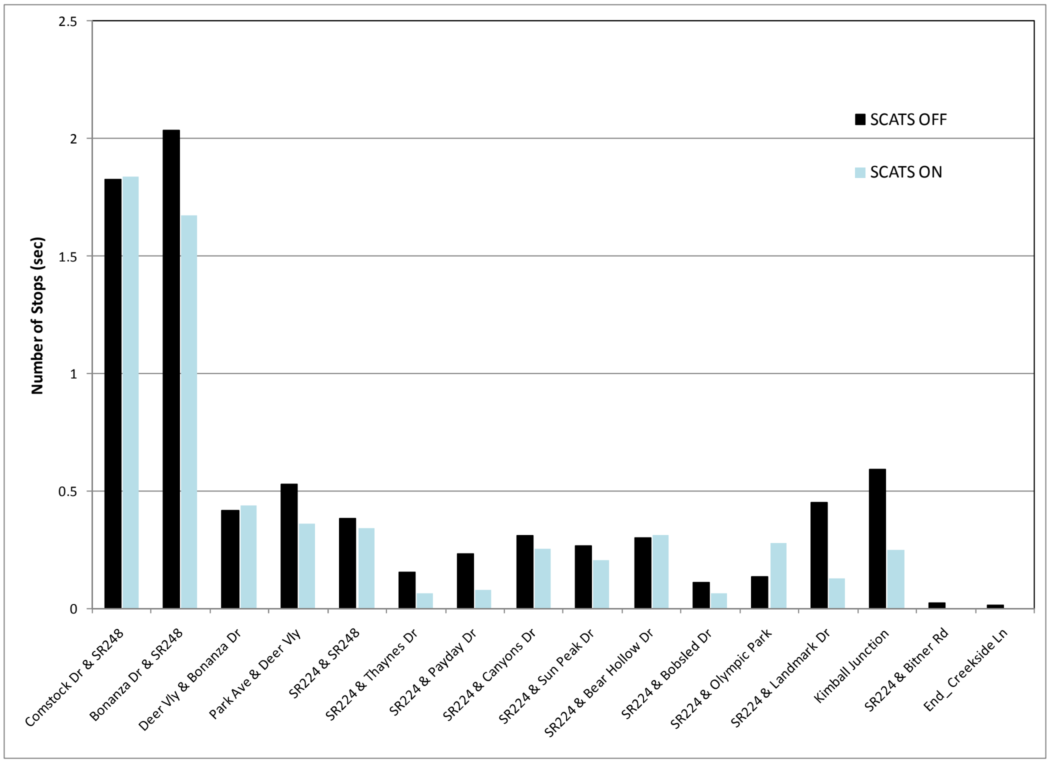

Figure C1 Number of stops - Northbound - AM Peak

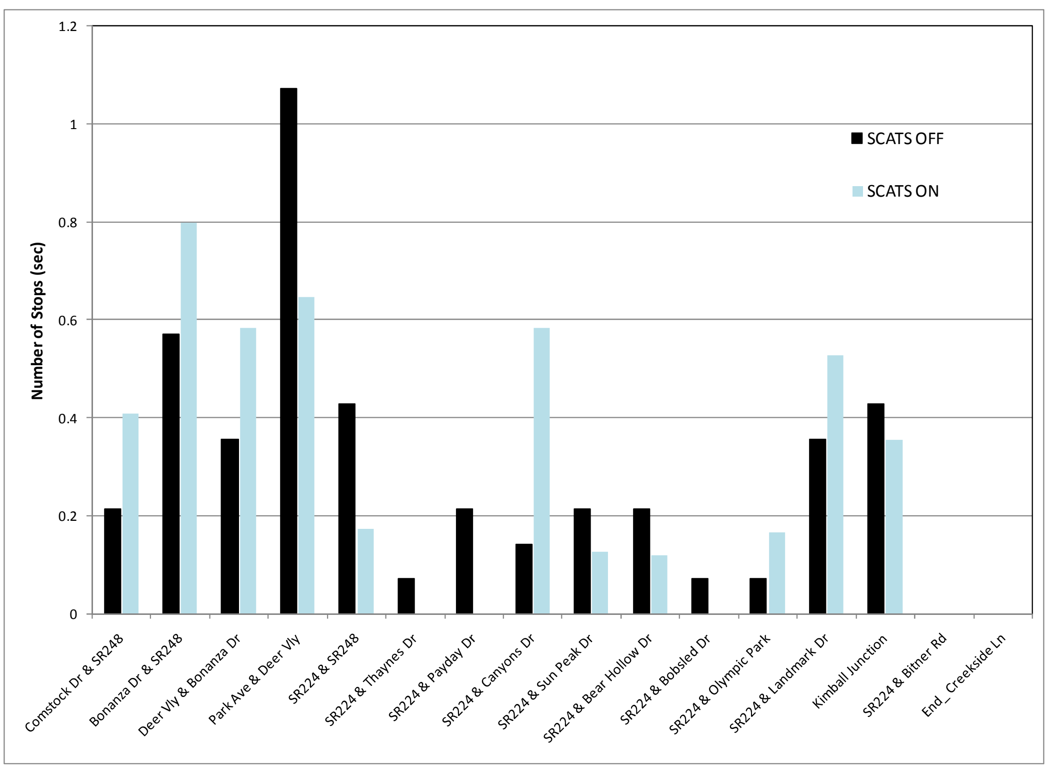

Figure C-3 Number of stops - Northbound - MD Peak

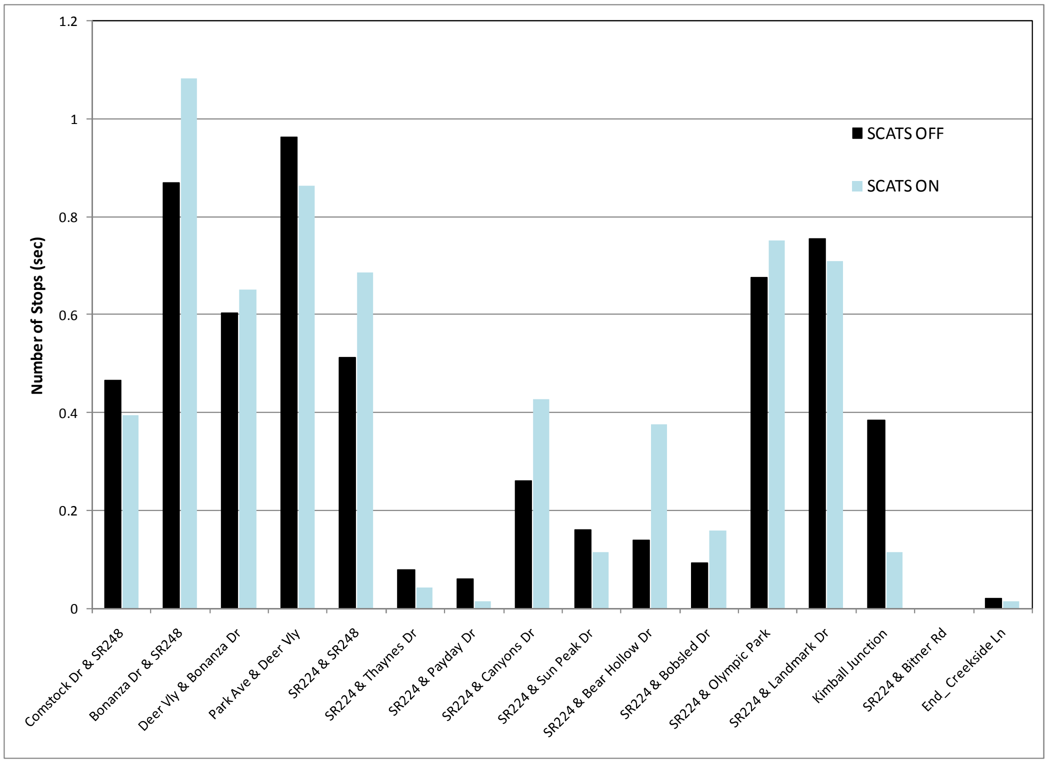

Figure C-3 Number of stops - Northbound - PM Peak

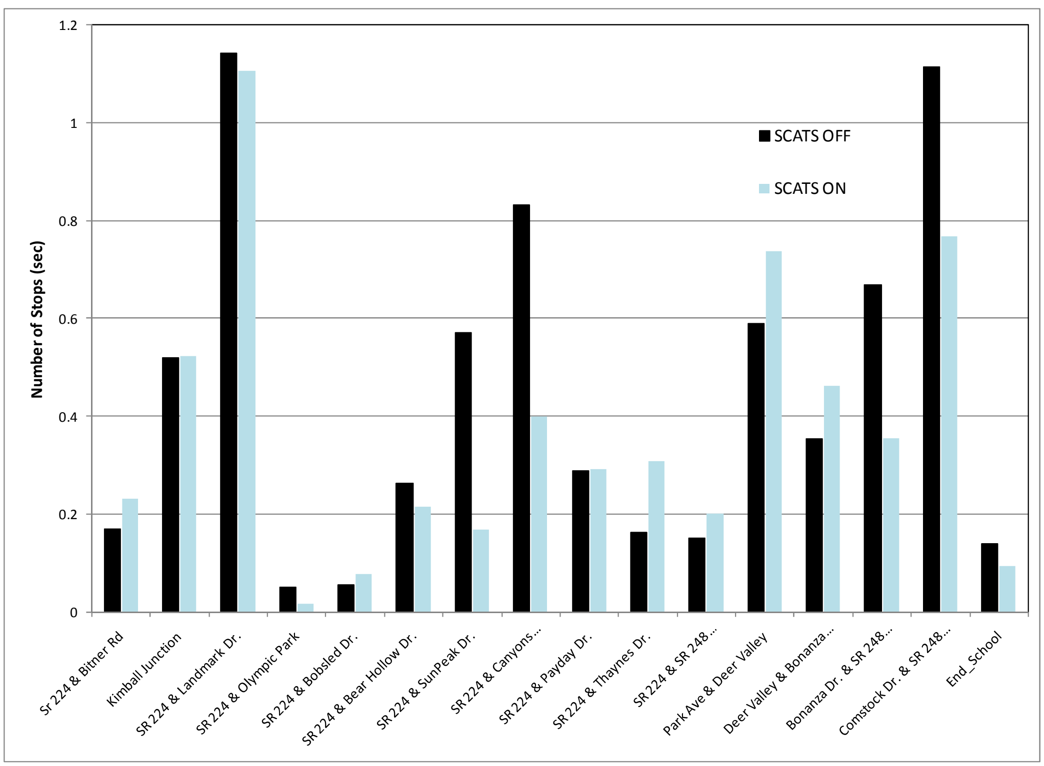

Figure C-4 Number of stops - Southbound - AM Peak

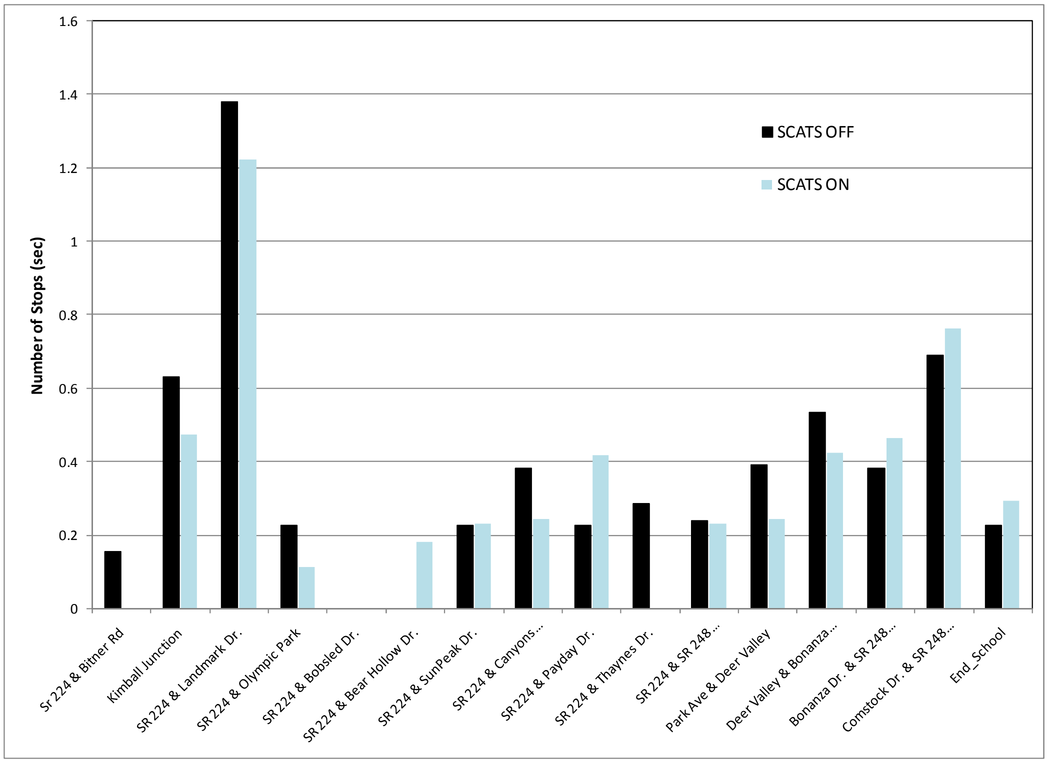

Figure C-5 Number of stops - Southbound - MD Peak

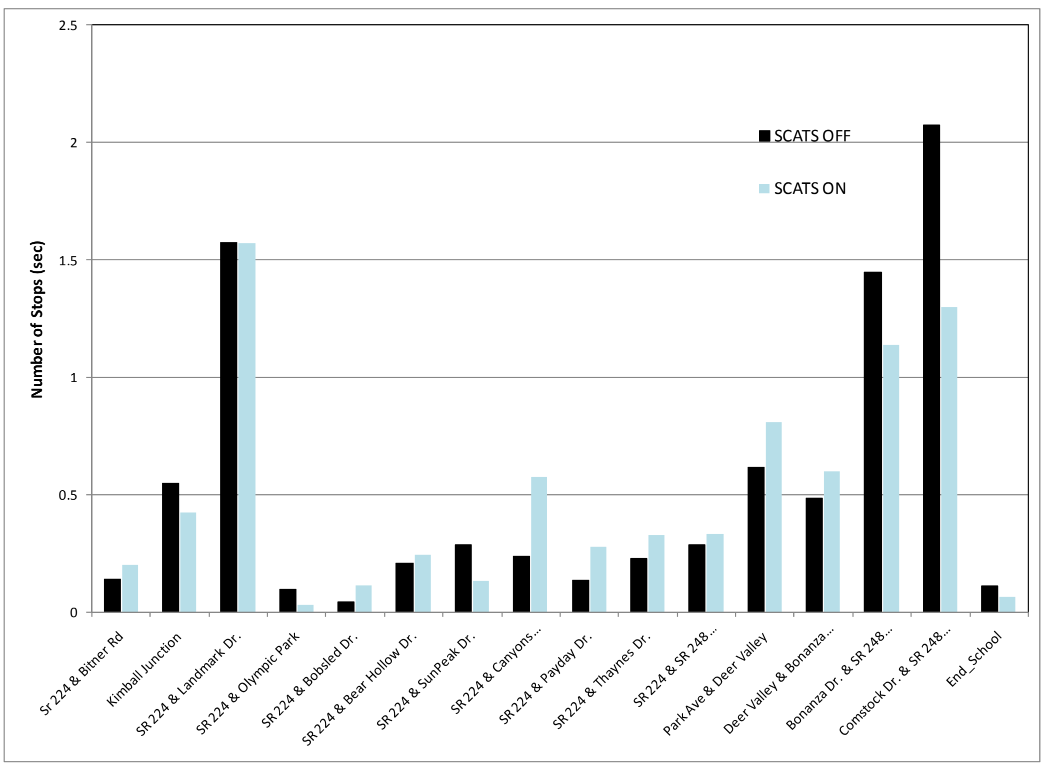

Figure C-6 Number of stops - Southbound - PM Peak

11. APPENDIX D: AVERAGE SPEEDS

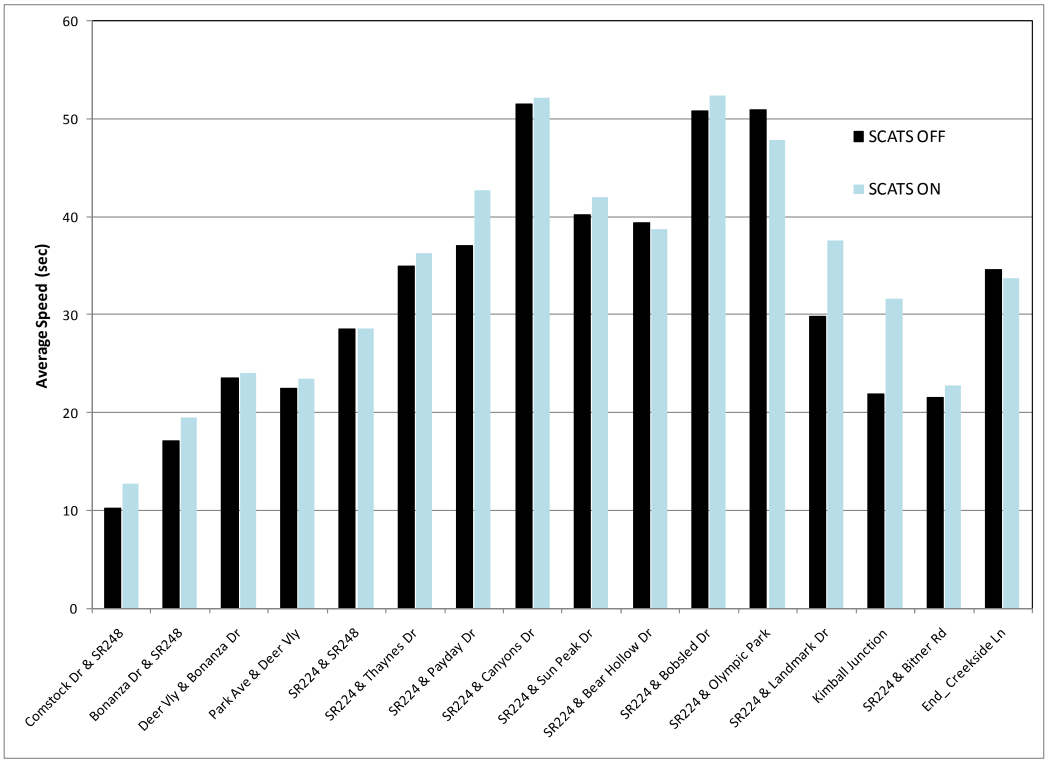

Figure D-1 Average speeds - Northbound - AM Peak

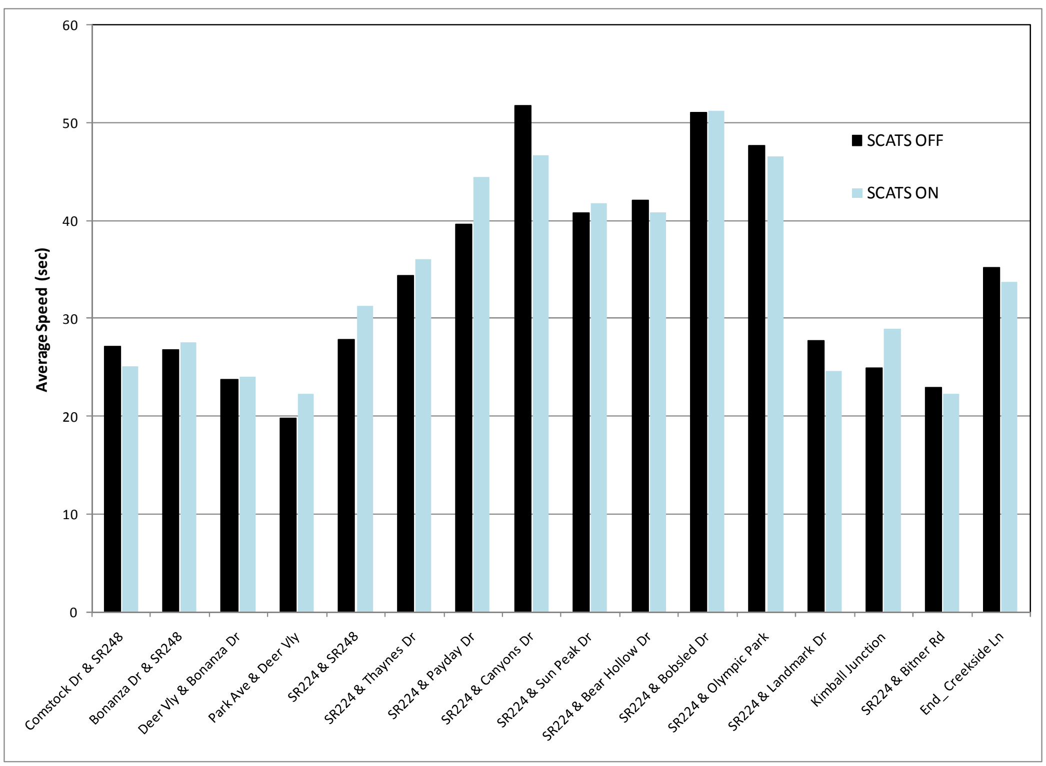

Figure D-2 Average speeds - Northbound - MD Peak

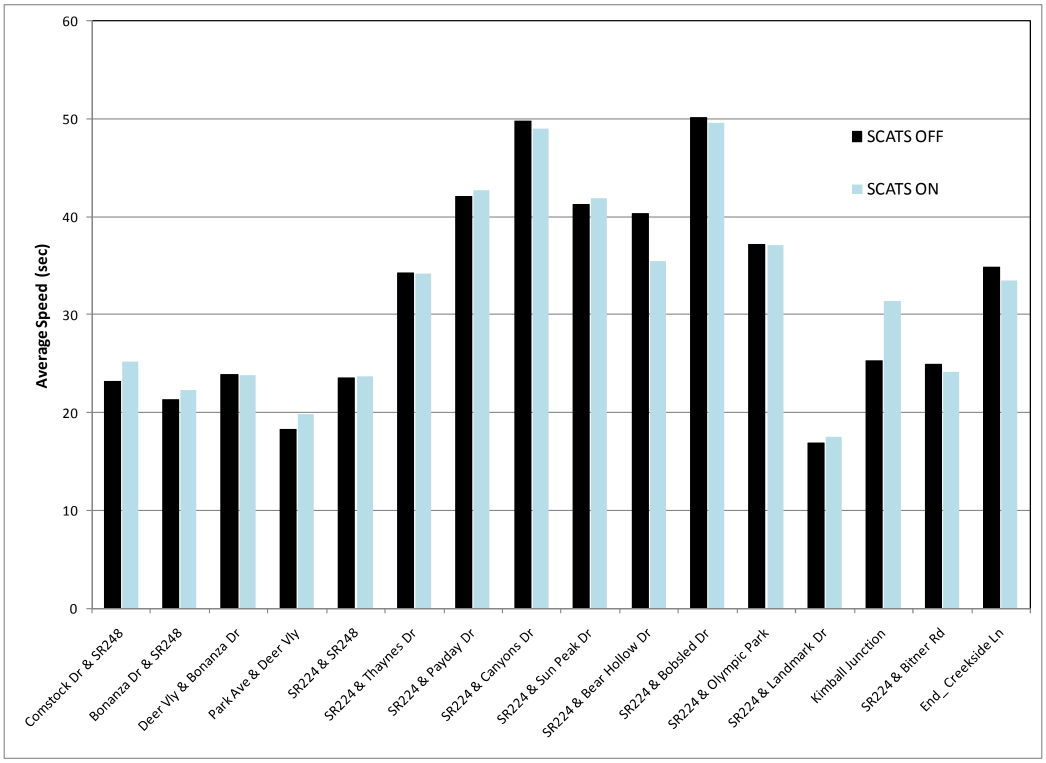

Figure D-3 Average speeds - Northbound - PM Peak

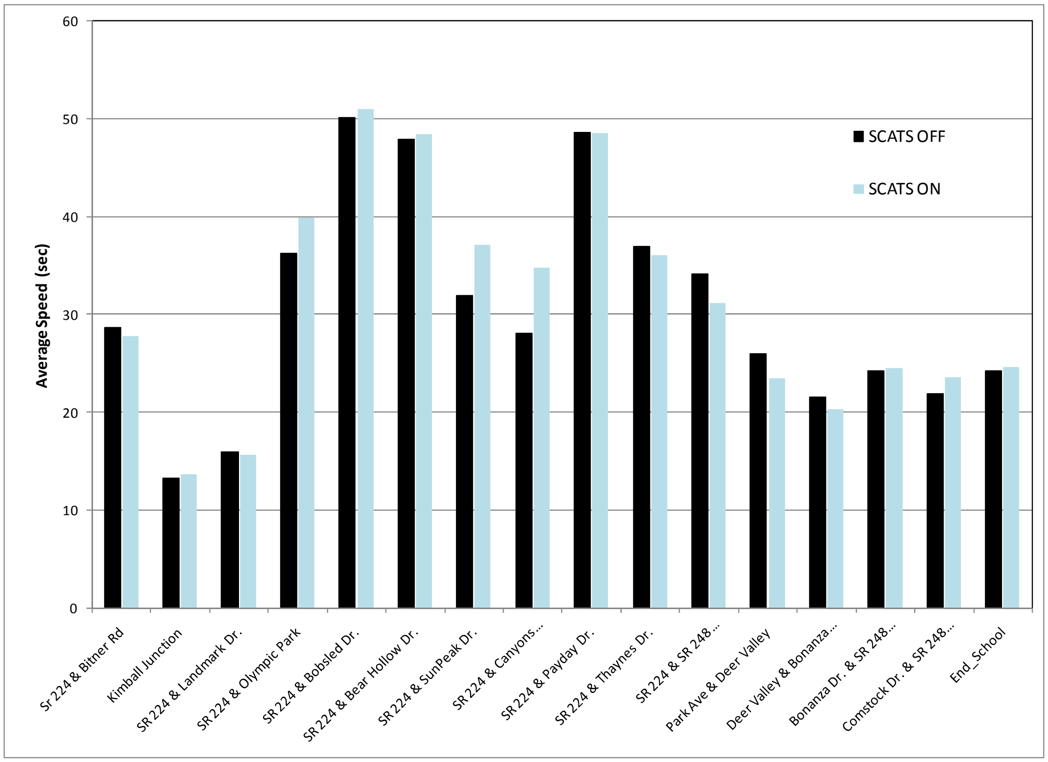

Figure D-4 Average speeds - Southbound - AM Peak

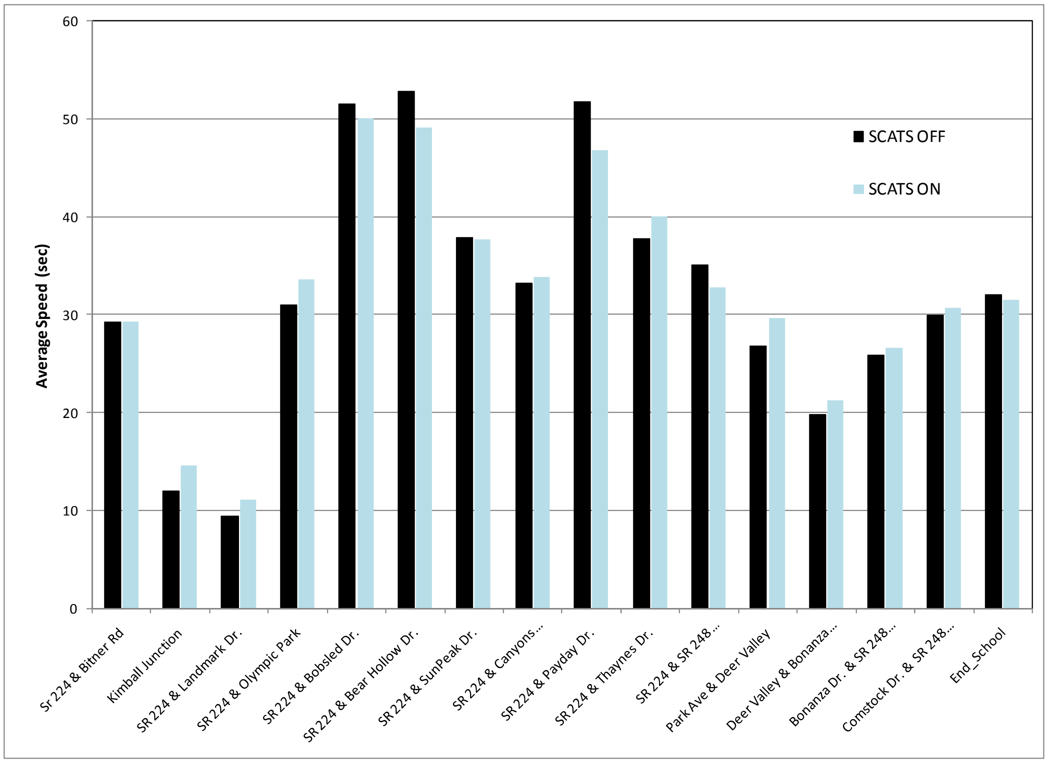

Figure D-5 Average speeds - Southbound - MD Peak

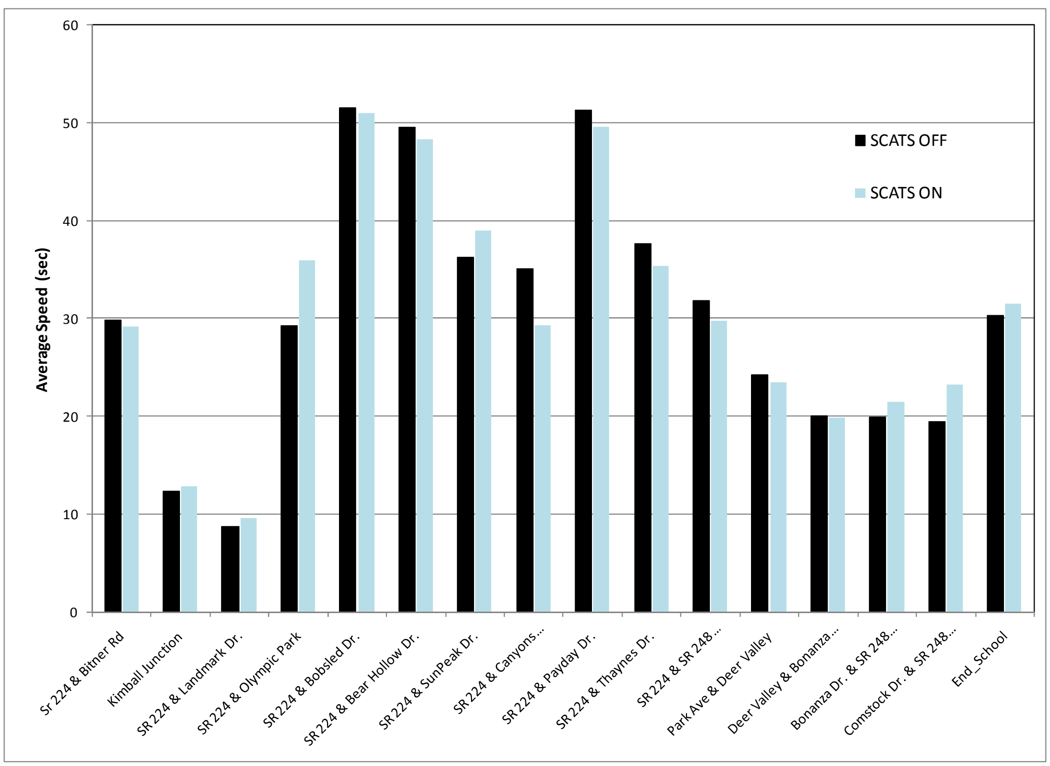

Figure D-6 Average speeds - Southbound - PM Peak