6-1-2012

An Evaluation of the Impacts of an Adaptive Coordinated Traffic Signal System on Transit Performance: a case study on Powell Boulevard (Portland, Oregon)

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Citation Details

Slavin, C., Feng, W., Figliozzi, M., An Evaluation of the Impacts of an Adaptive Coordinated Traffic Signal System on Transit Performance: a case study on Powell Boulevard (Portland, Oregon), Proceedings of the Conference on Advanced Systems for Public Transport (CASPT), June 2012, Santiago, Chile.

An Evaluation of the Impacts of an Adaptive Coordinated Traffic Signal System on Transit Performance: a case study on Powell Boulevard (Portland, Oregon)

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Keywords: transit performance, adaptive traffic signal control, transit signal priority, travel time

Abstract

Powell Boulevard is a prime example of a congested urban arterial; this roadway connects US-26 to downtown Portland, Oregon. This facility is one of the most congested arterial corridors in the Portland-metropolitan region. The City of Portland implemented the Sydney Coordinated Adaptive Traffic System (SCATS) in October 2011 in order to improve the operations of the corridor. SCATS has been implemented in a few US cities with mixed results so far. A properly calibrated system can have a significant positive impact on the performance of the traffic signals but its impact on transit performance has not been documented. This was the first SCATS implementation to integrate transit signal priority (TSP) and adaptive traffic systems in the United States and possibly in the world. The unique contributions of this study are: the evaluation of SCATS and bus transit performance utilizing permanent data collection stations monitoring traffic and transit signal priority. This work presents results and the methodology to evaluate transit performance with and without adaptive traffic signal control system on Powell Boulevard. The analysis examined the effect of SCATS on bus performance at the stop level and for the entire corridor by using a variety of performance measures. Statistically significant differences were observed in terms of travel times and SCATS related regression parameters. Overall, the travel time changes or improvements related to SCATS seem to depend greatly on the direction of travel and the time of day.

1. Introduction

Congestion in urban areas is a growing concern in the United States. Over the past 20 years, not only has congestion increased in cities, but also it has spread out to longer peak periods and is continuing to reduce travel time reliability (FHWA, 2005). Because of this, public transportation has become a priority to alleviate congestion in urban areas. Public transportation provides a more affordable option for many citizens and is able to transport more passengers per vehicle than private vehicles. Of the public transportation modes, buses made up the largest percentage compared to other modes in the United States in 2009, with 52.5% of the number of passenger trips and 38.9% of the passenger miles. Transit use has been increasing for all modes (APTA, 2011). Buses typically share the right of way with general traffic, forcing them to deal with congestion.

Public transportation plays an important role in the transportation system in urban areas. The performance of public transit is affected by general traffic conditions and signal timing at intersections especially in congested corridors. Hence, improvements in terms of reducing congestion and/or timing traffic signals that aid buses can make a significant difference in their ability to stick to their schedule. A tool that can be used to help buses to stay on schedule is transit signal priority (TSP). A late bus communicates to the traffic signal controller that it is requesting priority, and the controller adjusts the settings to allow for additional time for the bus. This system is able to help the bus stay on schedule and improve their travel time and reliability (Smith et. al., 2005).

Another tool used to manage traffic signals more effectively is adaptive traffic signal control. Adaptive traffic signal control operates the traffic signals using real time traffic conditions to optimize the performance of the corridor. While adaptive traffic signal control operates from general traffic data and does not differentiate by mode, or specifically cater towards buses, it affects all the users of the corridor. While adaptive traffic signal control has become more commonly used, very few studies have examined the effect on transit performance specifically. In addition, to the best of the authors' knowledge, no previous research has simultaneously studied the effects adaptive traffic signal control, route characteristics, and transit signal priority (TSP) on transit performance.

1.1. Adaptive Traffic Signal Control

Traffic signal timing can be used to alleviate congestion by using the existing infrastructure as efficiently as possible. However, traffic signal timing is often unresponsive to actual traffic conditions and is run by pre-timed plans that are updated every couple of years. This is problematic when unexpected traffic patterns occur, and can lead to worsened congestion especially during heavy commuting periods.

Adaptive traffic signal control is a solution that is responsive to the traffic conditions in the field. These systems use detection and algorithms to adapt the traffic signal timing parameters to optimize the traffic operations. There are various types of adaptive systems available, which operate in slightly different manners. One adaptive system that is widely used is the Sydney Coordinated Adaptive Traffic System (SCATS).

SCATS was developed in Australia in the early 1970's by the Road and Traffic Authority and has successfully been used in Australia for the past 40 years. The system uses loop detection near the stop bars in addition to video cameras to operate in real time conditions. The system optimizes cycle lengths, phase splits and offsets on a cycle-by-cycle basis. The degree of saturation is used to adjust the cycle length. The phase splits are timed by giving each approach an equal degree of saturation or higher priority can be given to the main road. SCATS selects offsets based on free flow travel time and degree of saturation, which provides minimum stops for the vehicles on the main roadway. Its popularity has grown over time and thus it has expanded to other countries and within the United States (TransCore, 2011).

1.2. Evaluation of SCATS

SCATS has been installed in various cities across the United States with mixed results. Various before and after studies have been conducted in order to test the improvements of adaptive traffic signal control compared to existing pre-timed or time of day plans. Many claims are made about performance improvements; however, the results vary on a case-by-case basis. There are differences in performance improvements that partly have to do with how the evaluation was conducted in addition to other potential site-specific reasons.

The evaluation of an adaptive traffic signal control requires certain conditions for the comparison to be accurate. One condition is the reference system or the existing timing plans. The more optimized and responsive to traffic conditions the existing timing plans already are, the more difficult it is to see improvements with the implementation of an adaptive system. Because of this, defining the baseline system is crucial when reporting improvements (Soyke et. al., 2006).

Other factors that affect an evaluation are roadway specific, such as traffic volumes and geometry of the intersections. Geometric changes and not controlling for traffic volumes between the before and after periods is another flaw in the evaluation design. Data should be collected very close in time to each other in order to avoid this problem. None of the previous case studies evaluated transit in detail. Most of the studies did not use permanent data collection stations, and instead focused their evaluation on peak and off-peak periods. This is insufficient due to the fact that traffic volumes fluctuate greatly throughout the day.

Very few SCATS evaluations have been conducted in the United States, even less have examined the relationship between SCATS and transit performance. The City of Beaverton in Oregon implemented SCATS on Farmington Road in 2011. However, only six of the intersections are operating under adaptive signal control. The segment, which is 0.7 miles in length, carries heavy traffic in the eastbound and westbound directions. The corridor has two travel lanes in each direction and a speed limit of 30 miles per hour. The before and after study conducted by Peters et. al. (2011) from DKS Associates, examined three performance measures: side street delay, travel time, and recovery from signal preemption. Side street delay was obtained from a Synchro model, the travel time from Bluetooth MAC reader devices, and the recovery from signal preemption was found with preemption logs. The results indicated that the largest improvement was a faster recovery time after preemption from the TriMet WES commuter train. Before SCATS was implemented, recovery from preemption took up to six minutes, afterwards, the recovery reduced to less than two minutes. With preemption triggered every ten to 15 minutes during peak periods, this reduction in recovery makes a significant impact. However, side street delay was reduced only when traffic arrived randomly and not in a platoon, while the greatest travel time improvements occurred during off peak periods. There were no statistical tests conducted. In the future, Phase 2 of the project will include Canyon Road, which runs parallel to Farmington Road, on the north side. This should improve the results because the corridors will return to operating in coordination with each other, as they did before the implementation. Another liming factor in the functionality of the system it the proximity to the on-ramp for OR 217, which frequently backs up during peak periods (Peters et. al., 2011).

No studies that the authors are aware of have evaluated the simultaneous impacts of SCATS and TSP on bus performance. The purpose of this study is to determine if: (1) transit signal priority improves bus performance and (2) adaptive traffic signal control improves bus performance. This paper is organized as follows: Section two introduces the background of the study area. Section three presents the performance measures that are used to evaluate the traffic and bus performance. Section four presents various evaluation results for both the roadway traffic and bus performance. Finally, section five wraps up the paper with conclusions.

2. Study Area

Powell Boulevard is an urban arterial corridor located in Portland, Oregon that connects the Portland downtown and the City of Gresham. Powell Boulevard, also known as Highway US-26, has two lanes of traffic in each direction and a variety of land uses. The route runs in the eastbound and westbound direction and includes the Ross Island Bridge, which crosses over the Willamette River. Powell Boulevard is a major commuter arterial that has been experiencing growing conditions of congestion which occur in the westbound direction in the morning peak period and in the eastbound direction in the evening peak period. The study area is shown below in Fig. 1, where downtown Portland is shown to the west of Powell Boulevard. In the map, points “A” and “B” are the start and end points of the study corridor along Powell Boulevard. The arterial is unable to meet its purpose of efficiently moving users due to its congested conditions. However, improving the performance of this arterial is difficult due to the competing needs of different types of users such as pedestrians, transit, and private automobiles as well as balancing mobility and accessibility for a diverse array of activities and land uses along the corridor.

Powell Boulevard experiences congested or over capacity conditions during peak periods. In 2009, the average annual daily traffic ranged from 56,500 vehicles right off the Ross Island Bridge, to 41,000 vehicles at the intersection of Powell and Milwaukie, and 34,100 vehicles at the intersection of Powell and 39th (ODOT, 2009). For example, following the Highway Capacity Manual procedures for signalized intersection level of service (HCM, 2000) it was found that Powell and 39th has low level of service during the peak periods, ranging from C to F, with F being the worst. For the morning peak period, from 8-9 am, one of the movements operates at a level of service of F and the westbound through movements are at a level of service of E. For the afternoon peak period, from 5-6 pm, four of the movements operate at a level of service of F with two of them being left turns and the other two being the eastbound through movements. The level of service by movement for Powell and 39th Avenue is shown in Fig. 2 for both peak periods. The intersection level of service was calculated based on delay per movement (Kittelson and Associates et. al., 2010).

Not only does Powell Boulevard experience congestion due to high general traffic volumes, it also facilitates a high frequency bus route. Route 9, a high frequency route, which runs on the Powell corridor, is within the top ten TriMet routes for in terms of productivity. In 2011, Route 9 served 37.9 passengers per vehicle hour (TriMet, 2012). The peak periods for Route 9 occur in the morning for the westbound direction and in the afternoon for the eastbound direction. During peak commuting periods, the bus headways are at least 15 minutes for high frequency routes.

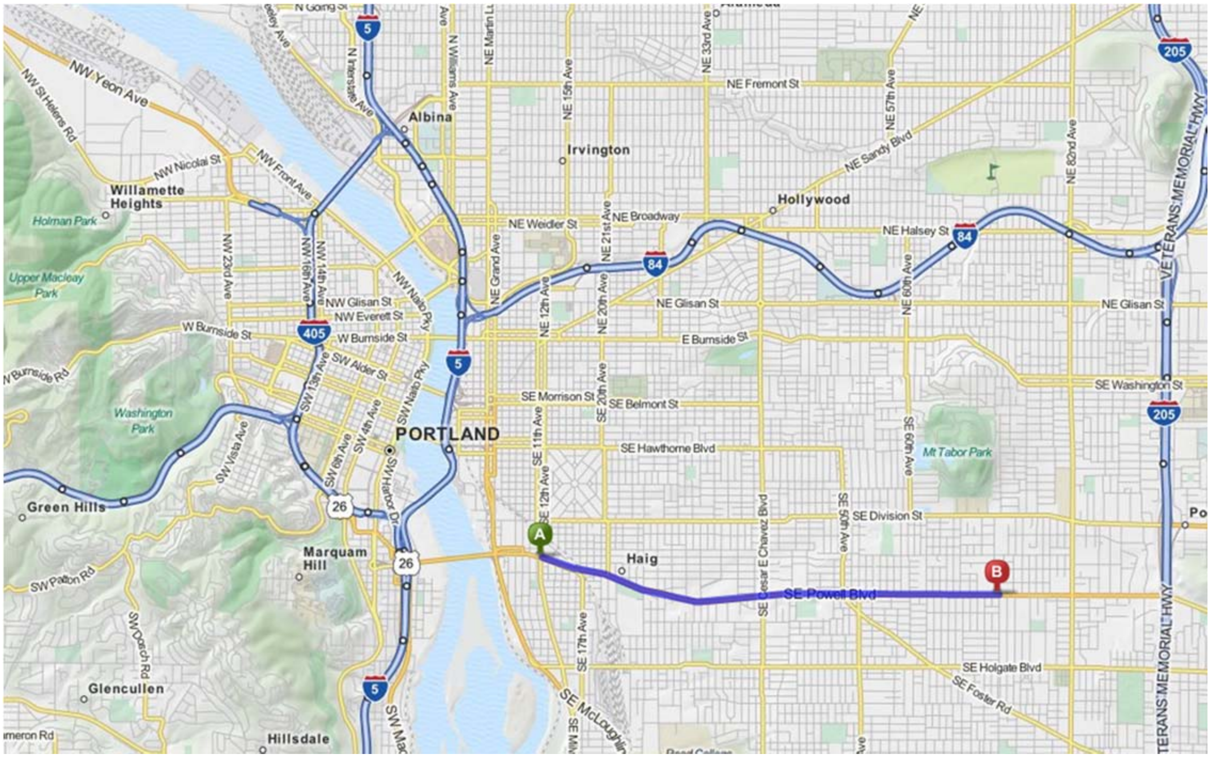


Fig. 1. Study Area

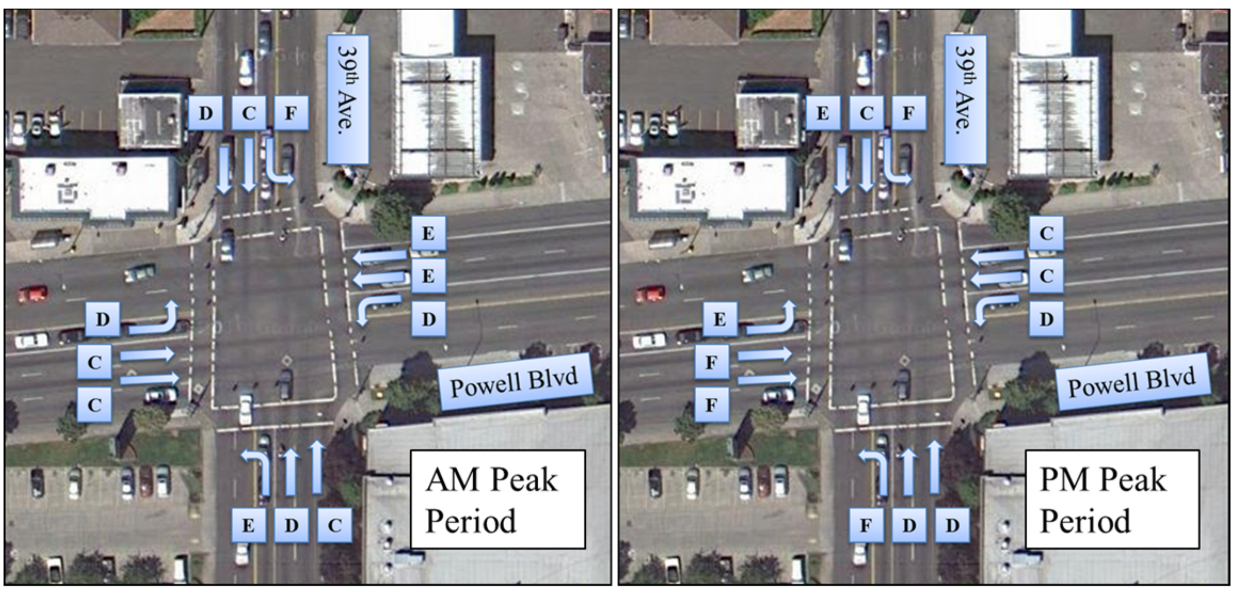
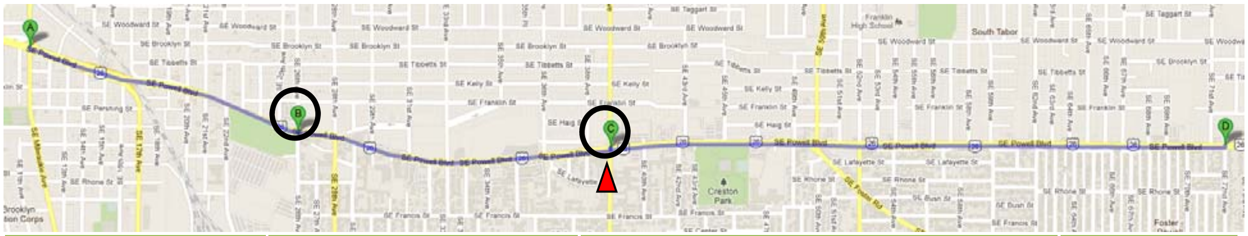


Fig. 2. Powell and 39th Level of Service

The SCATS implementation goes from SE Milwaukie Avenue to SE 72nd Avenue along Powell Boulevard as shown below in Fig. 3. The intersections of particular interest are highlight below with either a triangle or a circle. The intersection pointed at with a triangle is a transit time point, bus stop where holding might occur, if the operator is ahead of schedule. The two intersections that are circled are the locations of traffic counters. SCATS is implemented in the segment between point "A" (SE Milwaukie Avenue and Powell Blvd.) and "D" (SE 72nd Avenue and Powell Blvd.) shown in Fig. 3. This was the first SCATS implementation to integrate transit system priority (TSP) in the United States (City of Portland, 2008).



A	B	C	D
Milwaukie	**26th Ave** *Traffic Counter*	**39th Ave** *Transit Time Point & Traffic Counter*	**72nd Ave**

Fig. 3. Powell Blvd. Study Segment

3. Performance Measures

Traffic volumes and speeds will be used in order to control for changes in travel patterns. Bus performance is greatly affected by traffic, so this be evaluated to account for this factor in the analysis. The source of the traffic volume comparison is from two Wavetronix units that were installed by the City of Portland. The units digitally generate a radar signal in order to collect vehicle counts, speeds, and classifications. The units were installed at Powell and 26th and Powell and 39th. The actual units are located near 24th Ave. and between 35th Pl. and 36th Pl., set back from the intersection, to assure free flow traffic conditions even during the peak periods for the most accurate data.

Transit performance measures are used in the case study in order to compare the transit performance before and after installation of the adaptive system. Data will be provided by TriMet, who stores a vast amount of data, including automatic vehicle location (AVL) and passenger counts. Route 9, which is the main route on Powell Blvd, will be a focus of the evaluation. The performance measures used will be: schedule delay, headway delay, idling time, and travel time. Passenger boarding activities will be used to control for differences between the two time periods.

On-time performance and headway adherence are the two most popular reliability measures used in the transit industry that are applied for low and high frequency service (bus headways longer or shorter than 10 minutes respectively) (TCQSM 2nd, 2003). These performance measures will be paired accordingly with schedule and headway delay, in order to provide various options for comparison. On-time performance represents the percentage of "on-time" departures at a stop. While the TCQSM 2nd suggests "on-time" performance as being "0 to 5 minutes late", TriMet defines "on-time" performance as being "no more than 1 minute early to no later than 5 minutes past scheduled departure time." Therefore, the index for on-time performance percentage is calculated using the following, which is TriMet's version of the formula:

$$1 - \left(\frac{early\ depart\ records}{all\ depart\ records}\right) - \left(\frac{late\ depart\ records}{all\ depart\ records}\right) \tag{1}$$

Headway adherence represents how regular bus headways; the formula for calculating headway adherence is shown below (TCQSM 2nd, 2003):

$$c_{vh} = \left(\frac{standard\ deviation\ of\ headway\ deviations}{mean\ scheduled\ headway}\right) \tag{2}$$

Where c_{vh} is the coefficient of variation of headways; and headway deviation is the difference between the actual departure headway and the scheduled departure headway at a stop. TCQSM 2nd (2003) also suggests a level of service (LOS) threshold for each reliability index as shown in Table 1. The greater on-time performance ratio, or the lower headway adherence index, the more reliable the service.

Table 1 Level of service index for on-time performance and headway adherence (TCQSM 2nd, 2003)

LOS	On-time performance	Headway adherence
A	0.95-1.00	0.00-0.21
B	0.90-0.949	0.22-0.30
C	0.85-0.899	0.31-0.39
D	0.80-0.849	0.40-0.52
E	0.75-0.799	0.53-0.74
F	<0.75	>=0.75

The idling time is defined as the difference between actual departure time and actual arrival time at a stop minus dwell time at that stop. This represents extra time that a bus is waiting at a stop. For example, if the bus stop is a near side stop, meaning that the stop occurs before the bus enters the intersection, then idling time can be partially attributed to time waiting at a red light, after serving passengers.

Ideally, all of the performance measures would be estimated controlling exactly for all the variables that can affect travel time both before and after SCATS. We examine before and after during the same month, a year apart, to account for seasonal variation. Since the traffic data was not available for the year before the SCATS system was installed traffic and transit performance measures were calculated for different time periods. For traffic data, a week before the SCATS system was installed is the before time period, and a week two months later was used for the after time period. There was a calibration period right after the installation which is why the after time period is not as close in time to the before period. For transit data, there was no limitation on the data available. Because of this, the month of November was used, both the year before and a month after the system was installed. Additionally, different intersections were focal points for traffic and transit because of data availability. As shown in Fig. 3, the two intersections collecting traffic data (circled on map), 26th and 39th were used for the traffic evaluation, whereas, the intersection that is a transit time point (denoted by triangle), 39th, was used for parts of the transit evaluation that involved scheduled stops.

4. Evaluation Results

4.1. Traffic Evaluation

Traffic data was collected at two intersections, Powell and 26th and Powell and 39th, during a whole week before SCATS was installed and a week after the system was calibrated. The analysis was done for the morning, from 7-9 am, and afternoon, from 4-6 pm, weekday peak periods in order to examine the time that would most affect transit. Additionally, only the peak period corresponding to commuter traffic was used, so in the morning it was westbound traffic to account for traffic heading into downtown, while the afternoon was eastbound traffic to account for traffic leaving downtown. In order to account for normal variation in traffic, the data from Monday, Tuesday, Wednesday, Thursday, and Friday was averaged. The before time period goes from Monday, October 3rd to Friday, October 7th, 2011, while the after goes from Monday, November 28th to Friday, December 2nd, 2011. The analysis examined differences in travel speed and volume. For both cases, the difference was always calculated by: $Difference = After\ SCATS\ observation - Before\ SCATS\ observation$.

The results showed that at Powell and 26th, during the morning and afternoon peak periods, there were both speed improvements and higher traffic volumes after SCATS was installed. Powell and 39th yielded more mixed results than at 26th. For the morning peak period, there were speed and volume improvements. However, during the afternoon peak period, there were speed decreases and the volume remained fairly constant. Shown in Table 2 are the summary results, including differences in speed in miles per hour and as a percentage, and differences in volume in vehicles per five minutes and as a percentage.

Table 2. Traffic Comparison Summary Results

Difference:	Speed		Volume	
After - Before	mph	%	Vehs	%
26th AM WB	4	21	7	7
26th PM EB	2	7	7	5
39th AM WB	2	7	4	3
39th PM EB	-6	-22	-1	0

In order to find out if the speed and volume were significantly higher after SCATS compared to before, one sided paired t-tests were conducted for each intersection and peak period. The paired t-test examines the differences in before and after measurements, where μ_d is defined as the difference in population means between the two groups. The hypothesis test is shown below:

H_0: $\mu_d \leq 0$
H_1: $\mu_d > 0$

If the null hypothesis is accepted then the change is not significant, if the null is rejected, then we observe significantly higher mean speed or volumes after SCATS. The results in Table 3 show that for all comparisons the null hypothesis was rejected at the significance level of 0.05, except for the afternoon peak period at Powell and 39th.

The morning peak period was selected at Powell and 26th to illustrate the speed difference for the morning peak period (see Fig. 4). The data shown is at five-minute aggregations, showing speed improvements during the two-hour period. Powell has a speed limit of 35 miles per hour, it can be seen from Fig. 4 that after SCATS the speeds were able to increase and get closer to the speed limit. The volume changes for the morning peak period are shown at Powell and 26th in Fig. 5. It can be seen that during most of the morning peak period, a higher volume of vehicles was present after SCATS was implemented.

Table 3. Traffic Paired T-Test Results

Paired T-Test	Speed		Volume	
	P-Value	$\mu_d \leq 0$	P-Value	$\mu_d \leq 0$
26th AM WB	0.000	**Reject**	0.003	**Reject**
26th PM EB	0.001	**Reject**	0.000	**Reject**
39th AM WB	0.000	**Reject**	0.016	**Reject**
39th PM EB	1.000	Accept	0.693	Accept

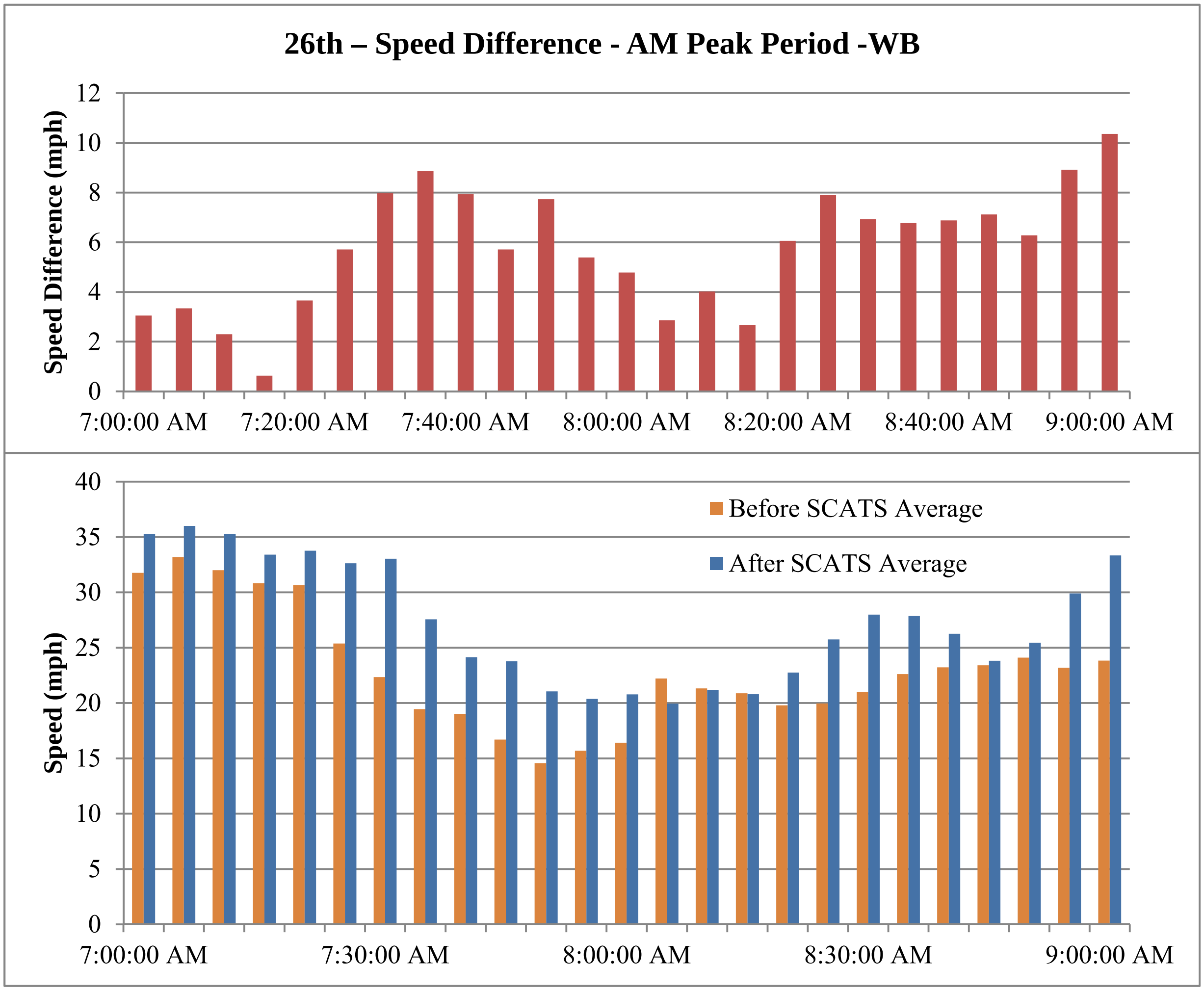


Fig. 4. Traffic Speed Comparisons

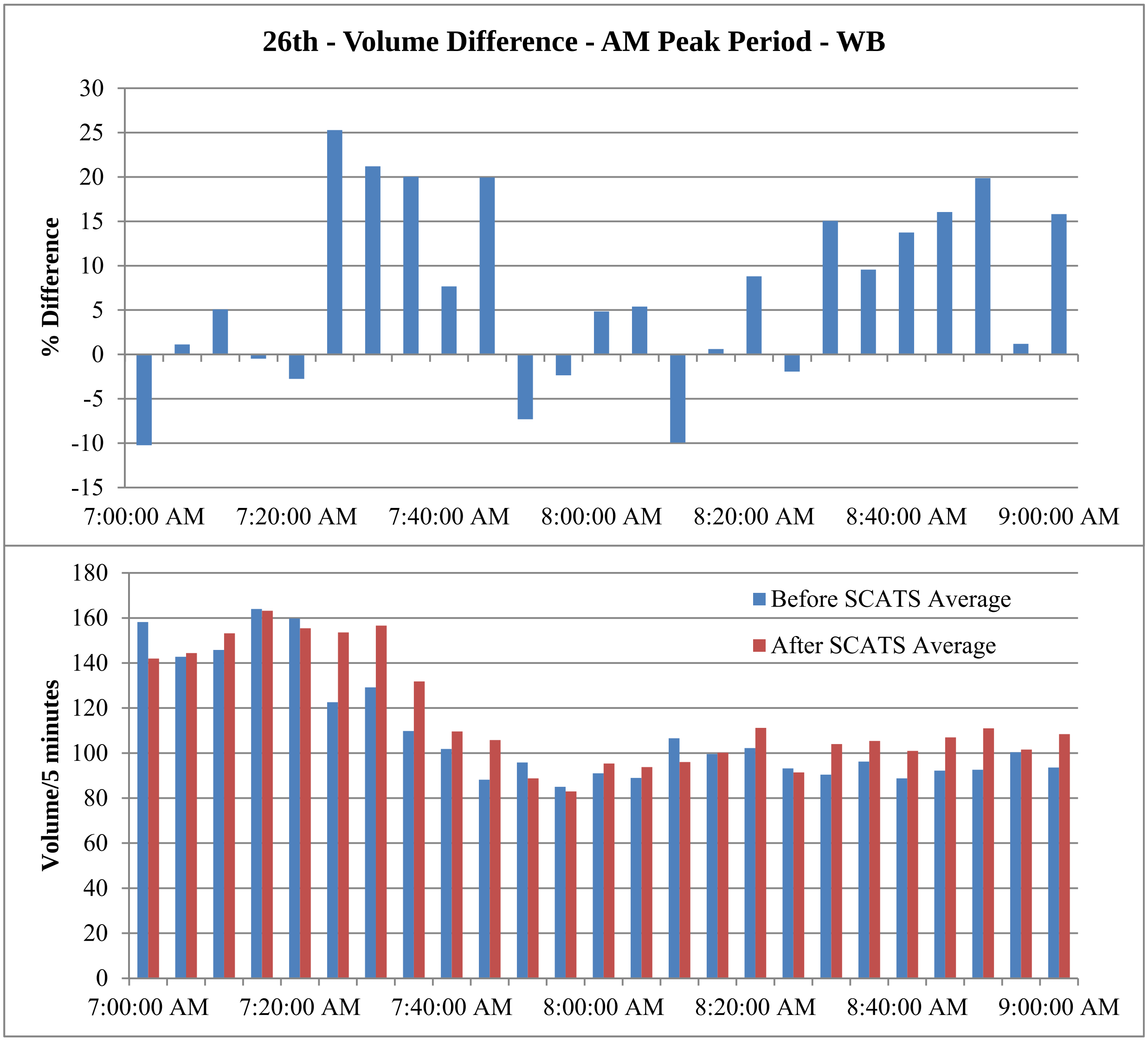


Fig. 5. Traffic Volume Comparisons

In order to find out if the distributions were different before and after the SCATS implementation, chi-square tests were conducted. The null and alternative hypotheses are shown below:

H_0: The histogram (proportion of volumes or speeds) has not changed before and after scats
H_1: The histogram has changed (before ≠after)

Table 4. Traffic Chi-Square Results

Chi-Square	Speed		Volume	
	P-Value	H_0	P-Value	H_0
26th AM WB	0.000	**Reject**	0.000	**Reject**
26th PM EB	0.000	**Reject**	0.000	**Reject**
39th AM WB	0.000	**Reject**	0.000	**Reject**
39th PM EB	0.000	**Reject**	0.179	Accept

The results in Table 4 show that the null hypothesis was rejected for all comparisons of the distribution before and after SCATS for speed and volumes, except for one comparison. The traffic volumes in the afternoon peak period at Powell and 39th followed the same distribution for the before and after time period. These results are consistent with the paired t-test with the afternoon peak period at Powell and 39th. Overall, the traffic conditions before and after SCATS were significantly different both in terms of speed and volume. The differences were more apparent at Powell and 26th than at Powell and 39th, where the results were more mixed. It is possible that this is the case because 26th is a more minor cross street with smaller volume, whereas 39th is a large arterial with a high volume. The SCATS system favors or gives priority to the main line, which in this case is Powell Boulevard, over a secondary street such as 26th. From the traffic evaluation, it seems that SCATS is improving traffic speeds but that transit buses may be dealing with the same congested conditions at major intersections.

4.2. Transit Evaluation

One month of detailed bus stop event data in November 2010 and November 2011 were used to evaluate the transit performance before and after the SCATS implementation. The transit evaluation includes analysis sections for the following areas: passenger activity, time point reliability, idling time, and travel time. Passenger activity affects transit performance and its ability to travel through the corridor. This was examined first in order to control for this factor before comparing before and after SCATS through various the use of a variety of performance measures.

4.2.1. Passenger Activity

To control for passenger demand and variability, November 2010 and November 2011bus data are compared. This was done by examining the passenger boarding activity and the loads. First, the passenger boarding activity per hour was examined before and after SCATS for five locations, including: at Milwaukie, between Milwaukie and 39th, at 39th , between 39th and 72nd, and at 72nd. This was broken down directionally and for time of day, accounting for the eastbound and westbound direction, the peak period, off peak period, and the entire day. This was done for weekdays only, so the sample size is the number of weekdays in the month, which is 22. T-tests were conducted to compare the boarding per hour before SCATS to after SCATS, where: μ_1 = population mean of group 1 (before SCATS) and μ_2 = population mean of group 2 (after SCATS).

The hypotheses are shown below:
H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$

Table 5 shows that the passenger demands are not significantly different before and after the SCATS implementation, except for one location. At Powell and Milwaukie during the off peak period, the mean passenger boarding per hour is marginally different, with after SCATS having 1.4 less passenger boarding per hour than before. Other than this one difference in passenger boarding activity, the other locations, directions, and time periods are the same before and after SCATS.

Table 5 Passenger boarding per hour comparison

Eastbound		Milwaukie		Between		39th		Between		72nd	
		Before	After	Before	After	Before	After	Before	After	Before	After
Off Peak	Mean	8.4	7.0	16.7	17.5	7.8	8.0	11.9	11.9	0.9	0.8
	Std.	2.6	2.0	5.5	4.7	1.7	1.4	3.1	3.0	0.3	0.3
	P-Value		**0.052***		0.607		0.672		1.000		0.275
PM peak (4-6pm)	Mean	13.3	12.6	30.4	31.3	19.9	19.8	24.2	26.2	1.3	1.4
	Std.	4.1	4.7	10.9	11.6	6.1	5.8	8.5	10.3	0.8	1.2
	P-Value		0.601		0.792		0.956		0.486		0.747
All day	Mean	8.9	7.5	18.1	18.8	9.1	9.2	13.1	13.3	1.0	0.9
	Std.	2.5	2.0	5.7	5.1	2.0	1.7	3.4	3.5	0.3	0.3
	P-Value		**0.047***		0.670		0.859		0.848		0.275
Westbound											
Off Peak	Mean	4.4	4.9	25.2	23.7	13.0	12.4	20.2	20.4	3.1	3.1
	Std.	0.9	1.1	6.8	6.2	2.5	2.4	4.7	4.9	0.7	0.5
	P-Value		0.107		0.449		0.421		0.891		1.000
AM peak (7-8am)	Mean	17.0	15.7	49.9	45.5	37.5	29.8	72.2	68.4	12.4	11.4
	Std.	5.7	8.7	17.2	15.1	16.2	12.5	28.5	25.7	5.0	6.2
	P-Value		0.561		0.372		0.085		0.645		0.559
All day	Mean	5.3	5.7	27.0	25.3	14.8	13.7	24.1	24.0	3.8	3.7
	Std.	1.1	1.5	7.3	6.7	3.2	2.9	5.8	6.1	0.9	0.8
	P-Value		0.320		0.426		0.239		0.956		0.699

It is important to compare passenger load per bus to account for differences in how full the buses were during the two months. The same analysis that was conducted for passenger boarding was applied to passenger loads. Table 6 shows that the passenger loads are not significantly different before and after the SCATS implementation, for stops and segments in both directions and during different times of day.

Table 6 Passenger load per bus comparison

Eastbound		Milwaukie		Between		39th		Between		72nd	
		Before	After	Before	After	Before	After	Before	After	Before	After
Off Peak	Mean	19.0	18.1	17.8	17.5	15.7	15.8	14.3	14.5	12.9	13.1
	Std.	3.0	2.9	2.8	2.8	2.5	2.2	2.2	2.0	2.0	1.7
	P-Value		0.318		0.724		0.889		0.754		0.723
PM peak (4-6pm)	Mean	21.4	20.3	20.7	19.5	17.5	17.0	15.1	14.5	12.5	12.8
	Std.	5.0	4.3	4.5	4.3	3.6	3.6	3.0	3.4	2.6	3.3
	P-Value		0.438		0.371		0.647		0.538		0.739
All day	Mean	19.5	18.6	18.4	17.9	16.1	16.1	14.4	14.5	12.8	13.0
	Std.	3.1	3.1	2.8	3.0	2.5	2.4	2.2	2.2	1.9	1.8
	P-Value		0.341		0.571		1.000		0.881		0.722
Westbound											
Off Peak	Mean	18.8	17.8	18.4	17.8	17.0	16.8	14.2	14.2	13.0	12.9
	Std.	2.8	2.9	2.8	2.9	2.4	2.8	2.0	2.2	1.8	1.8
	P-Value		0.251		0.489		0.800		1.000		0.855
AM peak (7-8am)	Mean	22.9	22.3	23.8	22.3	23.4	21.5	17.1	16.5	13.0	13.0
	Std.	5.8	5.5	6.6	6.1	7.5	6.8	5.1	5.0	4.0	4.3
	P-Value		0.727		0.438		0.384		0.696		1.000
All day	Mean	19.4	18.5	19.2	18.4	18.0	17.5	14.7	14.6	13.0	13.0
	Std.	3.0	3.3	3.2	3.3	2.9	3.1	2.3	2.4	1.9	2.0
	P-Value		0.349		0.419		0.584		0.888		1.000

Overall, it can be concluded that there were no major differences in passenger boarding per hour or passenger load per bus before and after SCATS was implemented. This data also illustrates differences in directional peak demand. In the westbound direction the peak period is in the morning from 7-8 am, during the time when commuters are traveling to Portland. During this time, passengers board at stops all along the Powell corridor, and most of them get off downtown. This peak period occurs during a time period of around an hour. In the eastbound direction the peak period is in the afternoon from 4-6 pm, during the time when commuters are departing from work in the downtown area. Most passengers board in the downtown and alight somewhere along the corridor. The afternoon peak period is wider. From the passenger boarding per hour table (Table 5), it can be seen that the westbound morning peak period consistently has higher boarding per hour along the corridor than the eastbound afternoon peak period. However, there is a much smaller difference between passenger loads per hour during the westbound morning peak period and the eastbound afternoon peak period. This means that the boarding activity is different for the two peak periods but buses carry approximately the same number of passengers during both peak periods (i.e. there is higher frequency in the westbound peak time period).

4.2.2. Time Point Reliability

Transit data for the time point reliability evaluation was collected at Powell and 39th because it is a time point, as shown as a red triangle in Fig. 3. After controlling for differences in boarding and vehicle loads between the two months, the time point was compared using different performance measures for peak and off peak periods in both directions. Performance measures are suggested by the TCQSM 2nd (2003) depending on the frequency of service, where low frequency service is defined as headways longer than 10 minutes, and high frequency service is defined as headways shorter than 10 minutes.

From the Route 9 data, the high frequency periods occur between 4 pm to 6 pm (pm peak) in the eastbound direction and from 7 am to 8 am (am peak) in the westbound direction. All other times are low frequency service and are referred to as off peak. For the off peak periods, which have low frequency, schedule delay and on time performance are the suggested performance measures. For the peak periods, which have high frequency, headway delay and headway adherence are the suggested performance measures.

Schedule delay, which is the actual departure time minus the schedule departure time, was calculated at Powell and 39th, for eastbound and westbound off peak periods. The significance test is from conducting a one sided t-test to see if the mean schedule delay after is significantly less than the mean schedule delay before, where: μ_1 = population mean of group 1 (before SCATS) and

μ_2 = population mean of group 2 (after SCATS). The mean was used for comparison because we want to test whether schedule delay is significantly different.

The hypotheses are shown below:
H_0: $\mu_1 \leq \mu_2$
H_1: $\mu_1 > \mu_2$

Headway delay, which is the actual headway minus the scheduled headway, was calculated at Powell and 39th, for eastbound and westbound peak periods. In this case, a one sided F test was used to see if the standard deviation of headway delay after is significantly less than before, where: σ^2_1 = population variance of group 1 (before SCATS) and σ^2_2 = population variance of group 2 (after SCATS). For headway adherence the important information is the deviation, not the mean. The hypotheses are shown below:

H_0: $\sigma^2_1/\sigma^2_2 \leq 1$
H_1: $\sigma^2_1/\sigma^2_2 > 1$

The results are shown below in Table 7, including the mean, standard deviation, sample size and significance test for both schedule delay and headway delay. Additionally, the on-time performance and level of service are shown for the off peak periods, while the headway adherence and level of service are shown for the peak periods.

Table 7 Time points off peak hour reliability performance

Powell & 39th	Schedule Delay				Headway Delay			
	Eastbound Off Peak		Westbound Off Peak		Eastbound PM Peak (4-6 pm)		Westbound AM Peak (7-8 am)	
	Before	After	Before	After	Before	After	Before	After
Mean (seconds)	168	172	138	109	0	-10	7	2
Std. (seconds)	238	227	222	210	270	295	205	234
Sample size	1557	1578	1643	1679	354	377	255	270
P-value		0.685		**0.000***		0.954		0.983
On-time performance	0.74	0.74	0.83	0.84				
Headway adherence					0.42	0.47	0.31	0.38
LOS	F	F	D	D	C	C	C	C

The schedule delay is not significantly improved in the eastbound off peak period. However, in the westbound off peak, the schedule delay is significantly less after SCATS was implemented compared to before. The time point schedule delay is better in the westbound off peak hours compared to the eastbound direction. There are no major changes in on-time performance in either direction of travel. The level of service is low both before and after SCATS was implemented, it is at an F in the eastbound direction, and is slightly better (D) in the westbound direction.

The mean headway delay is close to zero seconds, but the standard deviations range from 4 to 5 minutes. There were no significant improvements in the deviation of headway delay after SCATS was implemented. The headway adherence remained the same or became slightly worse after the SCATS implementation. The level of service remained in the same category. Therefore, in general, the implementation of SCATS did not significantly improve the time point performance at Powell and 39th. The exception is the reduction in schedule delay in the westbound direction after SCATS.

Table 8. Idling Time

	Total Idling Time (secs)		Average Idling Time (secs)	
Eastbound	Before	After	Before	After
PM peak (4-6pm)	384	388	18.3	18.5
Off peak	315	320	15.0	15.3
All day	328	333	15.6	15.9

Westbound				
AM Peak (7-8am)	380	390	18.1	18.6
Off peak	324	328	15.4	15.6
All day	331	337	15.8	16.0

4.2.3. Idling Time

Idling time, which is the extra time after serving passengers (the difference between actual departure time and arrival time minus dwell time), was calculated at every stop in the segment where SCATS has been implemented. The idling time was summed and averaged over all the stops in each direction for several time periods. The results, shown in Table 8, indicate no major changes in idling time over the corridor, from Powell and Milwaukie to Powell and 72^{nd}. The idling time results over the entire corridor do not show any differences, so idling time was then examined at each stop. This was done for different times of day in the eastbound and westbound directions. During the off peak periods, the changes in idling time at the stops did not show a trend in terms of differences observed. However, the mean idling times during the peak periods, shown below in Fig. 6 and Fig. 7, showed some consistent results. The labels in the x-axis show not only the name of the street, but additionally are labeled by the type of bus stop. The types of bus stops included are: near side (before entering a signalized intersection), far side (after passing through a signalized intersection), and midblock (not near an signalized intersection).

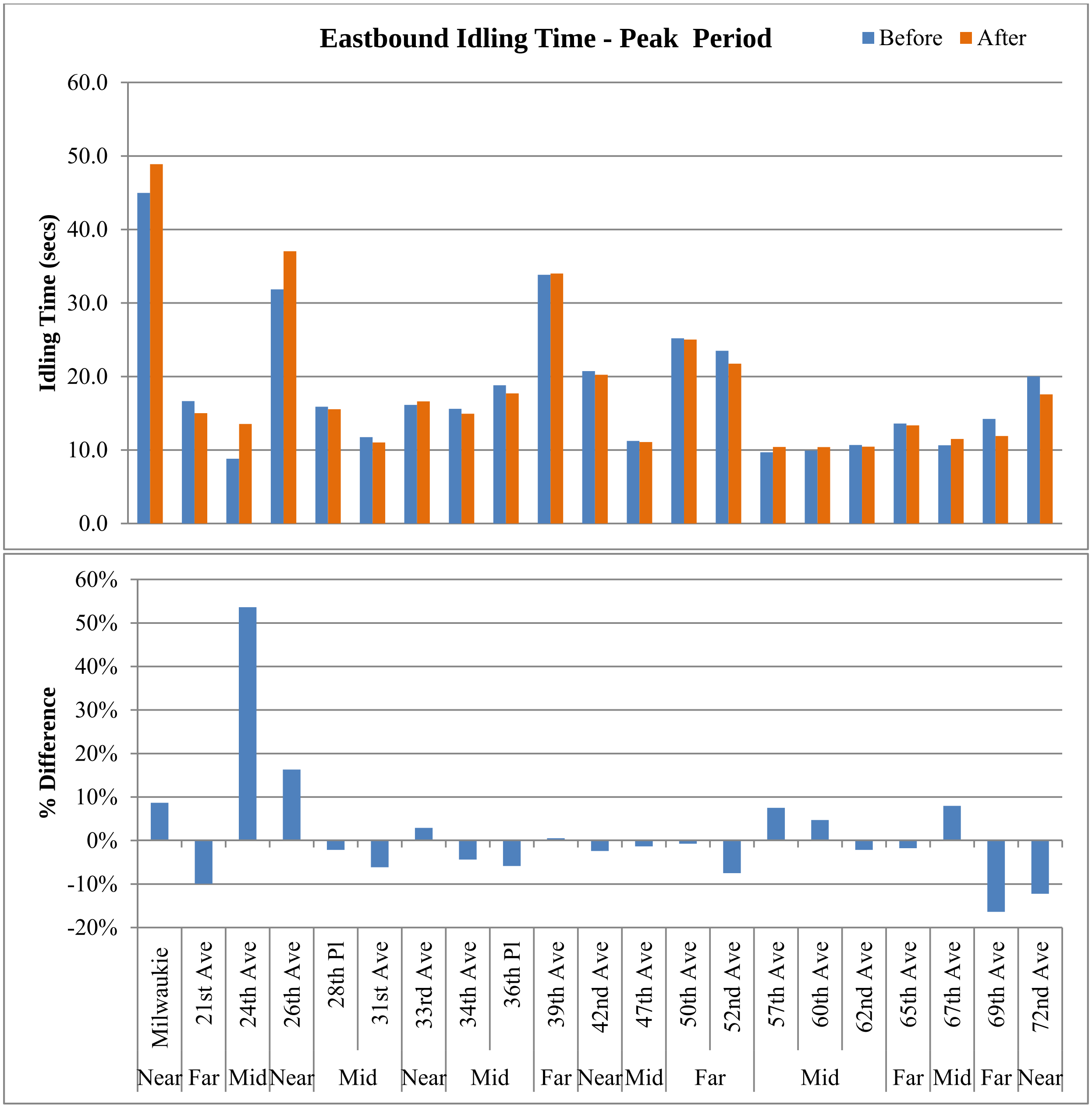


Fig. 6 Eastbound PM Peak Idling Time

In the eastbound direction, at the majority of the stops, the idling time was similar before and after SCATS. However, the largest increases in idling time were observed at 24th and 26th. In this case, the longer idling times occurred earlier in the trip, while the shorter ones happened towards the end of the corridor. The section of the corridor between 21st and 26th borders a city park and the stop at 24th is midblock.

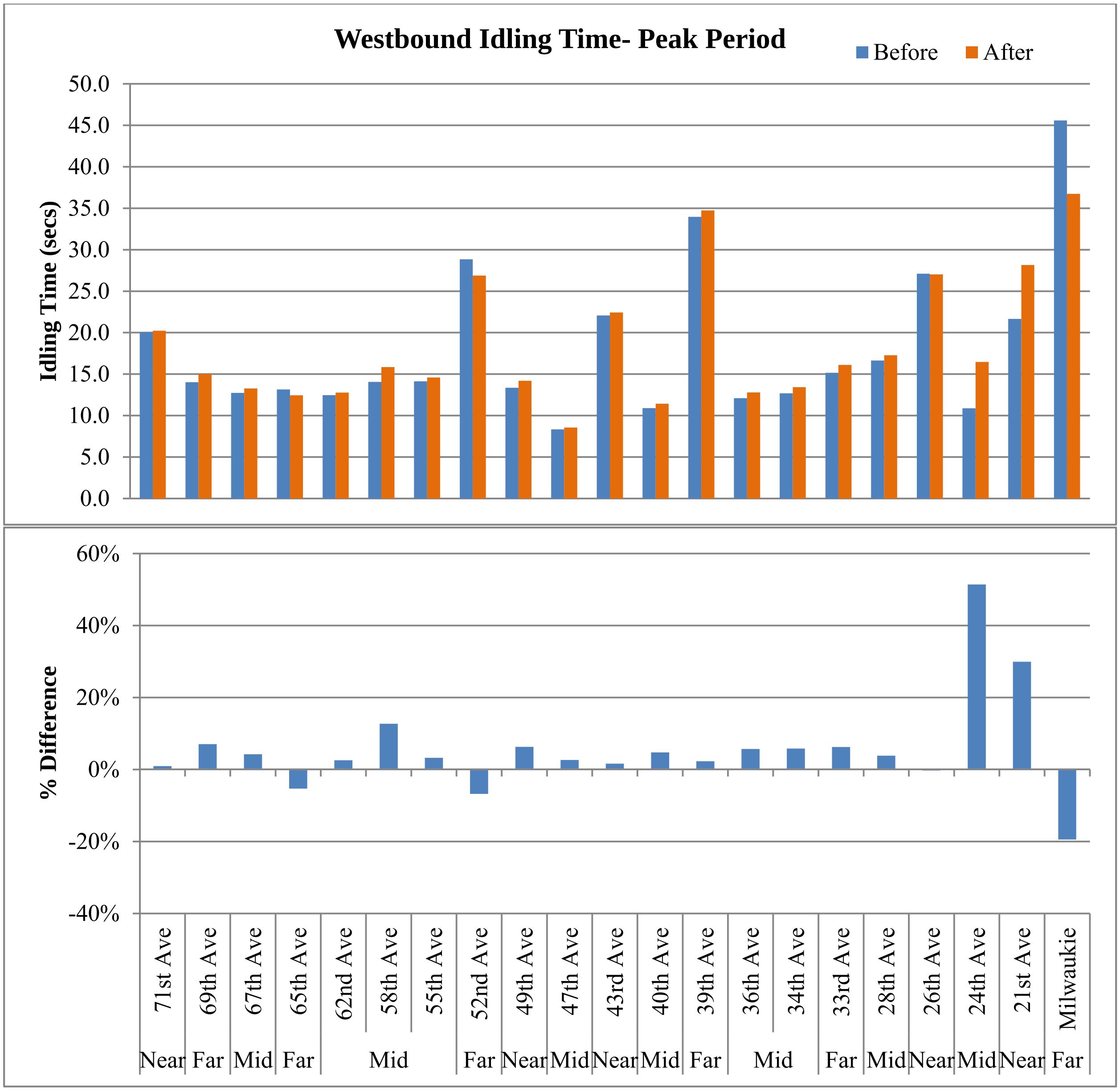


Fig. 7 Westbound AM Peak Idling Time

In the westbound direction, the stops with the largest increases in idling time were observed at 24th and 21st. In this case, the longer idling times occurred near the end of the trip, while there were no major changes throughout the rest of the corridor. Recall that the section of the corridor between 21st and 26th borders a city park and the stop at 24th is midblock. The stop at 24th is most likely affected by the performance of the intersections on either side of it. In the westbound direction, the stop at 24th occurs just before 21st, whereas, in the eastbound direction, the stop at 24th occurs just before 26th. In both of these cases, these are the two stops with increased idling time depending on the direction.

4.2.4. Travel Time

Up to this point, the performance measures have specifically examined the performance at the stop level or along small segments. To further understand how the implementation of SCATS affected this entire corridor, travel time was calculated between Powell & Milwaukie and Powell & 72nd (shown as the study segment in Fig. 3). This was done for both directions, during the peak period, off peak period, and all day. In order to determine if the mean travel time was reduced from before SCATS to after SCATS, one sided t-tests were used, where: μ_1 = population mean of group 1 (before SCATS) and μ_2 = population mean of group 2 (after SCATS). The mean was used for comparison because we want to test whether schedule delay is significantly different. The hypotheses are shown below:

H_0: $\mu_1 \leq \mu_2$
H_1: $\mu_1 > \mu_2$

In addition, to determine if the deviation of travel time was reduced from before SCATS to after SCATS, one sided f-tests were conducted, where: σ^2_1 = population variance of group 1 (before SCATS) and σ^2_2 = population variance of group 2 (after SCATS). The hypotheses are shown below:

H_0: $\sigma^2_1/\sigma^2_2 \leq 1$
H_1: $\sigma^2_1/\sigma^2_2 > 1$

Table 9 Travel time performance

Eastbound	PM Peak (4-6pm)		Off Peak		All Day	
	Before	After	Before	After	Before	After
Mean (seconds)	897	879	755	739	782	765
Std. (seconds)	131	134	144	156	153	162
Sample size	382	376	1578	1592	1960	1968
P-value (t-test)		**0.031***		**0.001***		**0.000***
P-value (f-test)		0.670		0.999		0.994
Westbound	AM Peak (7-8am)		Off Peak		All Day	
	Before	After	Before	After	Before	After
Mean (seconds)	953	1070	808	801	827	839
Std. (seconds)	202	351	146	172	163	226
Sample size	256	272	1641	1677	1897	1949
P-value (t-test)		1.000		0.103		0.971
P-value (f-test)		1.000		1.000		1.000

Results from Table 9 indicate that in the eastbound direction the mean travel times are significantly improved after the SCATS implementation during all times of day. In the westbound direction, the mean travel times were not improved during any of the times of day. The deviation of travel time after the implementation of SCATS was not significantly improved during any time of the day. The scheduled travel time was constant over the two time periods, so this was not a reason for the changes. However, there are other factors that can affect travel time.

Regression analysis was conducted in order to understand the factors that affect travel time on Powell Boulevard from Milwaukie to 72nd both before and after SCATS was implemented. Eight factors were included in the regression analysis in order to explain the variation in travel time, including ons, offs, lift, stops, priority, peak, direction, and SCATS. These inputs are listed in Table 10 including their name, description and a range of values.

The first model including all eight parameters indicated that all variables were significant, except SCATS. This was then excluded to get the base model, where all terms included are statistically significant. Interactions between SCATS and all other variables were tested to determine if the interaction made a significant contribution. It was found that the interactions were not significant between SCATS and priority, SCATS and offs, and SCATS and lifts. The interactions were significant between SCATS and ons, SCATS and stops, SCATS and peak, and SCATS and direction. After further analysis, it was found that the interaction with SCATS and stops was more significant than SCATS and ons, and when used in the same regression model, forced the SCATS and ons to become insignificant.

Table 10. Explanatory variables in regression model

Name	Description	Range of Values	Mean
Ons	Number of passenger boardings for trip	0-110	16.45
Offs	Number of passenger alightings for trip	0-70	15.35
Lift	Number of times the lift was used during trip	0-4	0.10
Stops	Number of stops during trip	0-21	11.74
Priority	1 if transit signal priority was used at least once during trip, 0 if not	0, 1	0.61
Peak	1 if trip was during peak period, 0 if during off peak period	0, 1	0.16
Direction	1 if trip was in westbound direction, 0 if trip was in eastbound direction	0, 1	0.50
SCATS	1 if SCATS was implemented, 0 if not	0, 1	0.50

In order to further examine the relationship between SCATS, peak, and direction, eight combinations of the three dummy variables were made. These new variables include:

- SCATS during peak period in westbound direction
- SCATS during peak period in eastbound direction
- SCATS during off peak period in westbound direction
- SCATS during off peak period in eastbound direction
- No SCATS during peak period in westbound direction
- No SCATS during peak period in eastbound direction
- No SCATS during off peak period in westbound direction
- No SCATS during off peak period in eastbound direction (reference variable)

The final regression analysis is shown in Table 11 below next to the base model for contrast. In order to determine if the final model is better than the base model, an incremental F test was conducted. The base model must be a nested version of the final model, where the base model is the constrained model, and the final model is the unconstrained one. This tests the hypothesis that the coefficients of the additional variables are equal to zero, meaning that there is no difference between the two models if the hypothesis is accepted. In this case, the unconstrained model has 12 predictors, and the constrained model has 7, so there are 5 additional variables.

The hypothesis test is shown below:
H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$
H_1: At least one of $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5 \neq 0$

The incremental F value is 37.105, with a corresponding p-value of 0.000, meaning that the final model is a significant improvement upon the base model and that there is at least one coefficient that is significantly different than zero.

The travel time regression model explains the variation in travel time by using twelve factors. From both models, the factors related to passengers yield similar results, indicating that each passenger boarding takes about 4 seconds, each passenger alighting takes less than half a second, and each lift usage takes 31additional seconds. For each stop that the bus must make during a trip, it takes 19 additional seconds. Trips that have transit signal priority are reduced by approximately 24 seconds; the value of this parameter is stable and shows that the impact of transit priority is not affected by SCATS. From the base model, trips made during the peak period have higher travel time than trips during the off peak period, about 140 seconds more. Trips made in the westbound direction have higher travel time than trips in the eastbound direction, about 30 seconds more. From the final model, with SCATS implemented, each stop takes an additional 1.685 seconds compared to without SCATS.

The results of the regression analysis make it possible to compare before SCATS to after SCATS for each peak period and direction. A summary table is shown below, Table 12, which includes the coefficient of each combined dummy variable (which represents number of seconds) to illustrate the relationship between direction, time of day and SCATS in explaining travel time while controlling for other variables.

Table 11. Travel Time Regression Analysis Results

	Base Model			Final Model		
R Square	0.534			0.545		
F	1258.326			767.483		
P-Value	0.000			0.000		
N	7687			7687		
	B	***SE_B***	***P-Value***	***B***	***SE_B***	***P-Value***
Constant	476.286	5.415	0.000	494.587	5.348	0.000
Ons	3.973	0.156	0.000	3.961	0.156	0.000
Offs	0.416	0.193	0.031	0.45	0.191	0.019
Lift	31.04	3.92	0.000	30.997	3.875	0.000
Stops	19.528	0.556	0.000	18.663	0.594	0.000
Priority	-24.745	2.929	0.000	-23.994	2.897	0.000
Peak	139.605	3.963	0.000			
Direction	32.971	3.348	0.000			
Scats_Stops				1.685	0.357	0.000
Scats_Peak_West				221.087	8.076	0.000
Scats_Peak_East				87.736	7.648	0.000
Scats_OffPeak_East				-33.226	4.357	0.000
NoScats_Peak_West				112.052	8.754	0.000
NoScats_Peak_East				130.395	7.442	0.000
NoScats_OffPeak_West				24.259	4.511	0.000

*Note: Scats OffPeak West was insignificant and was excluded

Table 12. Interaction between SCATS, direction and time of day

	Peak Period		Off-peak Period	
	West	East	West	East
With SCATS	221	88	0	-33
Without SCATS	112	130	24	0

The variable for SCATS during off peak in the westbound direction was not significant in the model, meaning that the coefficient was zero. In the off peak period traveling eastbound, after SCATS was implemented there was a reduction of 33 seconds. In the off peak period traveling westbound, before SCATS was implemented, the travel time was 24 seconds more compared to off peak eastbound, and after SCATS has a coefficient of zero, meaning that SCATS reduced travel time by 24 seconds during the off peak period traveling westbound. During the off peak period, SCATS is helping to significantly reduce travel times in both directions, but slightly more in the eastbound direction. In the peak period traveling eastbound, after SCATS was implemented there was a reduction of about 43 seconds. In the peak period traveling westbound, after SCATS was implemented there was an surprising addition of about 109 seconds. During the peak period, SCATS is helping to significantly reduce travel times in the eastbound direction, but is increasing travel times in the westbound direction. This results are consistent with the results already observed in Table 9.

In addition to the comparison between before and after SCATS, directional and peak period comparisons can be made. Before SCATS was implemented, during the peak period, eastbound trips took about 18 additional seconds, whereas during the off peak period, eastbound trips took 24 seconds less. After SCATS was implemented, during the peak period, eastbound trips took about 133 less seconds, whereas during the off peak period, eastbound trips took 33 seconds less. During the off peak period, for both before and after SCATS time periods, there was a similar trend where eastbound trips took slightly less time than westbound. However, during the peak period, before SCATS was implemented eastbound trips took slightly more time, and after SCATS westbound trips took substantially more time. There are large differences in the trends in the relationship between peak period, travel direction and travel time for the before and after SCATS time periods.

Although there are many challenges with doing this type of comparison and making sure that the differences observed are being attributed to the correct factors the differences before and after SCATS appear to be significant. As previously discussed, there were limitations in the availability of traffic data. There are other factors that could have changed between the before and after time period that are difficult and/or virtually impossible to account for such as traffic accidents or different traffic flows at cross intersections.

5. Conclusion

SCATS is not designed as a tool to improve transit performance, however it is commonly implemented on corridors with public transit use. It is important to determine how SCATS affects transit performance on this heavily used bus route. This case study examined the performance of SCATS on Powell Boulevard, in Portland, Oregon.

In order to evaluate the transit performance, traffic conditions, such as speed and volume were included to account for additional factors affecting transit performance. Overall, the traffic conditions before and after SCATS were significantly different in terms of speed and volume. From the traffic evaluation it seems that after SCATS transit buses may be dealing with the same congested conditions at major intersections but with improved conditions at a minor intersections. The transit evaluation accounted for passenger ridership, which did not change significantly between the two time periods. Schedule delay, headway delay, idling time, and travel time were the performance measures used to compare before and after SCATS conditions. Schedule delay did not change in the eastbound off peak period, but it did significantly improve in the westbound off peak period, however, the on-time performance did not change significantly in both directions. The headway adherence became significantly worse for the eastbound afternoon peak period and the westbound morning peak period. The idling time yielded mixed results during off peak periods, but showed consistent trends during the peak period, where there were no major changes throughout the corridor except for increases in idling times only between 21st and 26th. The travel time along the corridor was the same in the eastbound direction and significantly worse in the westbound direction after SCATS was implemented.

Overall, it was determined that the improvements available through SCATS vary depending on the time of day and the direction of travel. Travel times were reduced in both directions during the off peak period, which covers most of the day. However, the peak periods are when bus demand is the highest. During the peak periods, improvements in travel time for the entire study corridor segment were observed in the eastbound direction, while there were no improvements in the westbound direction.

Acknowledgements

The authors gratefully acknowledge the Oregon Transportation Research and Education Consortium (OTREC) for sponsoring this research. The authors would like to thank Peter Koonce and Willie Rotich from the Portland Bureau of Transportation American for their support and encouragement. David Crout from TriMet has provided valuable assistance and bus transit data. The authors would like to thank Eric Albright from Portland State University for his help with the transit data analysis. The authors would also like to thank William Farley for providing intersection level of service data. Any errors or omissions are the sole responsibility of the authors.

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