Adaptive Traffic Signals, Comparison and Case Studies
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ABSTRACT
Interest in adaptive traffic signals in the USA is increasing and the use of adaptive signals is strongly supported by FHWA. There are several systems (notably SCOOT and SCATS) that are widely used throughout the world and several new adaptive products have recently been released.

This paper compares and contrasts the systems that have been successfully installed in the USA and discusses their advantages and disadvantages. The discussion includes several case studies in which the authors investigated the options available to agencies, discusses the reasons why different systems were selected for installation, and presents the results of detailed evaluations of the effectiveness of each installed system.

The paper also describes the evaluation techniques that were used to provide statistically reliable evaluation results, overcoming the shortcomings that are often found in traffic engineering surveys. These include survey design based on statistical principles and the use of new technology to increase sample size and reduce the resources needed for detailed data analysis.

INTRODUCTION
Adaptive traffic signal systems have been operating successfully in many countries since the early 1970’s. The two most widely deployed systems are SCATS (Sydney Coordinated Adaptive Traffic System) and SCOOT (Split Cycle and Offset Optimization Technique) being. (See, for example: Schroeder, 1989; Hadi, 2002; Fehon, 2004.) Since 1990, FHWA has recognized the benefits to be achieved by the implementation of adaptive control over the traditional time-of-day (TOD) selection of fixed cycle length timing patterns, and has sponsored several programs aimed at developing adaptive signal systems, such as RT-TRACS in the 1990’s and ACS-Lite during the 2000’s. (See, for example: Ghaman, et al., 2002; Ghaman, et al., 2004; and FHWA, 2010)

In recent years, several new systems have come onto the market in the USA, and these are generating significant interest. There are still substantial barriers to the widespread introduction of adaptive control. With over 272,000 traffic signals in USA (NTOC, 2007), less than 1% are operating adaptively. In contrast, while there appear to be no published statistics, the authors estimate that possibly 50% of the signals in Australia operate adaptively, and the majority of coordination in the larger cities is adaptive.

ADAPTIVE SYSTEMS IMPLEMENTED IN USA
Overview
Stevanovic (2010) undertook a very detailed survey of all known adaptive traffic signal system operators in North America during 2008-9 as part of an NCHRP project entitled “Adaptive Traffic Signals State of the Art, Foreign and Domestic” (Stevanovic, 2010). He also surveyed a sample of adaptive system operators in UK, Australia, New Zealand, Canada, Chile, Ireland and China. Responses were received from 45 agencies, 34 of
them in the North America, representing approximately 81 percent of domestic operators. Selinger (2009) completed a more limited survey of USA operators, with responses from 34 respondents, that addressed some of Stevanovic’s questions as well as some additional aspects. The adaptive systems covered by the surveys of Stevanovic and Selinger were:

- SCOOT (Split Cycle Offset Optimization Technique)
- SCATS (Sydney Coordinated Adaptive Traffic System)
- LA ATCS (LA DOT Adaptive Traffic Control System)
- RHODES (Real Time Hierarchical Optimized Distributed Effective System)
- ACS-Lite
- OPAC (Optimization Policies for Adaptive Control)
- InSync

Other adaptive systems that have been deployed or trialed in the USA include:

- ATMS.now (formerly Streetwise, by Naztec)
- RTACL (Real Time Adaptive Control Logic)
- QuicTrac Adaptive (by McCain)
- SPOT (Omaha, Nebraska)

**SCATS**

As of March 2010, SCATS (described in Sims and Dobinson, 1979 and Lowrie, 1983) has been distributed to 141 cities worldwide controlling over 31,700 intersections (SCATS, 2010). It has been successfully deployed on arterial roads, downtown grid networks, and at small groups of intersections. There are 14 deployments in USA, ranging in size from 11 signals up to 625 in Oakland County, MI. SCATS calculates cycle length, splits and offsets cycle-by-cycle and dynamically changes the grouping of signals in as traffic changes.

**SCOOT**

SCOOT was originally designed to control dense urban networks, such as large towns and cities. It is also successful in small networks, especially for areas where traffic patterns are unpredictable. There are over 200 SCOOT systems worldwide working in large congested cities, small towns and around freeway interchanges (SCOOT-UTC, 2010). There are ten SCOOT installations in North America. SCOOT continually calculates the required coordination pattern for a group of signals in real time and immediately implements the changes.

**ACS-Lite**

Examination by FHWA of the barriers to deployment of adaptive control led to the development of ACS-Lite, a cooperative effort with Siemens, McCain, Peek and Econolite. Its approach, described in Ghaman, et al. (2004) and Bullock, et al. (2003), aims to improve the quality of coordinated control while retaining existing systems with on-street masters, without the installation of large numbers of detectors. Its algorithm gradually adjusts the background TOD plans to adapt to gradual changes in traffic conditions, but does not make real-time adjustments as traffic volumes change. The aim is to keep the TOD patterns (and the plan introduction times) “fresh” and prevent the degradation in performance that accompanies the aging of patterns. Four demonstration installations were undertaken in 2006: in Houston TX, Gahanna OH, Bradenton FL and El Cajon CA. Evaluations showing positive results were reported in Shelby, et al. (2008).
**ATMS.now**

Naztec, Inc. offers an adaptive option for its ATMS.now traffic signal system. First deployed in Cupertino CA in 2002 with a Streetwise system, it has recently been deployed in Walnut Creek CA and three more installations are expected during 2010. ATMS.now modifies splits on a cycle-by-cycle basis and selects cycle length and offsets from lookup tables on a user-specified time interval.

**RHODES**

RHODES was developed by researchers at the University of Arizona. It currently operates in Pinellas County, FL, and at several others that are being used as test-beds for further development. RHODES, (see for example, Mirchindani and Head, 2001) departs from the traditional cycle length, splits and offset approach. It determines when to change state based on current demand at an intersection and predictions of future arrivals at that intersection. RHODES continues to be used in research supported by FHWA (FHWA, 2010).

**InSync**

Rhythm Engineering released InSync in 2009 and it has been installed and tested in several locations. (Rhythm, 2010.) Current installations are on arterial roads with up to 12 intersections, and the reported results have been positive. Installations are planned in Pennsylvania, Georgia, Kansas, Missouri and elsewhere in 2010. The underlying philosophy of InSync abandons the concepts of cycle length and phase sequence. It continually evaluates whether a signal should remain in its current state or move to a different state, based on both the known demand of traffic at the intersection and predicted arrivals of platoons from other intersections. The operational concept of InSync appears to have some similarities with that of RHODES, but its implementation is quite different. It’s installation philosophy is to retain the existing traffic signal controller and other equipment, and install additional hardware that does the adaptive calculations and commands the controller to remain in its existing state or move to another.

**PERFORMANCE EVALUATION TECHNIQUES FOR ADAPTIVE SYSTEMS**

The authors have evaluated the performance of several adaptive signal systems, and the results of some studies have been reported in Fehon (2005) and Peters et al. (2008). Developed from an approach first documented by Negus and Moore (1984), our evaluation approach incorporates elements that are particularly important when evaluating adaptive signal operation, because the very premise of the system is to respond to variations, large and small, in traffic conditions. Therefore, ignoring those variations or averaging results (as commonly done in signal system performance evaluation) can only mask the effectiveness of the system.

**Survey Design Issues**

There are several potentially serious flaws in the standard practice of doing “before and after” travel time runs along an arterial road when evaluating the performance of an adaptive system.

- Conducting travel time surveys along the length of a route. When travel times are simply conducted from one end of an arterial system to the other, the effect of the system on the many vehicles that enter or leave the route at intermediate intersections is ignored.
- Having insufficient sample size. Turner (1995) noted the ITE Manual of Transportation Engineering Studies recommended sample sizes ranging from 2 to 14 individual test vehicle runs, depending upon the desired level of confidence and the permitted error. He also noted that an NCHRP study, “Quantifying Congestion,” recommended sample sizes ranging from 3 to 8 runs for a 90% level of confidence and 10% relative error.
However, these sample sizes are based on performance measures that compare mean values and are not intended to provide a basis for comparing measures of variability in travel time. In addition, they assume an underlying stability in the traffic conditions during the survey period, which may not be the case in many applications of adaptive signal systems and fails to acknowledge that the intention of the adaptive system is to modify its operation to efficiently accommodate those variations.

- Changes in traffic volume and pattern. Separation of the “before” survey and “after” survey introduces uncertainty about the total volume and the relative volume of traffic on different parts of the network.
- Ignoring side street delays. Unless the order of magnitude of the contribution of the performance of minor movements is quantified, then the results of a survey cannot be accepted with certainty. It is not sufficient to make the assumption that the performance of minor movements is not affected significantly by the system.

**Survey Technology**

The technology available for performance evaluation has changed dramatically in recent years. The equipment now available includes Bluetooth-enabled MAC address readers, GPS-enabled data loggers and signal systems with better data logging and vastly expanded storage capabilities. The Bluetooth devices are well described in Tarnoff (2009a), Tarnoff (2009b) and by Caltrans (2010).

**CASE STUDIES**

In each of the following cases, the agency had a TOD system in operation and considered that its performance was not sufficient for the traffic conditions that prevailed. These conditions included high traffic volumes, variability in traffic patterns during the peak periods, variability in volumes as a result of incidents that often occur on nearby freeways, variability in off-peak volumes because of major events at nearby locations and significant daily recurrent congestion.

**Gresham OR (SCATS)**

**Overview**

The Burnside corridor is a five-lane major arterial that carries approximately 38,000 ADT through a growing commercial and retail district of the City. It is the primary route through Gresham to Mt. Hood and other weekend destinations in Central Oregon, connecting I-84 and US26. It also serves as a key freight route through Gresham. After ten years of regularly updating TOD timing plans, SCATS was deployed at 11 signals on Burnside Road, Gresham (including a difficult triangular section with crossing arterials).

**Performance Evaluation**

The performance of SCATS was compared with newly-optimized TOD plans and historical records from surveys in 1997 and 2004. Performance measures included travel time surveys, queuing and delay surveys, cycle failure surveys, number of stops surveys, and agency staff perception surveys.

Figure 1 shows the eastbound (EB) and westbound (WB) travel times on the Burnside corridor for each of these scenarios. After new timing plans were installed in 1998 the EB travel times averaged 6 minutes 8 seconds, but by 2004 the EB travel times averaged 6 minutes 33 seconds. This indicates that the TOD coordinated plans had degraded over time as volumes changed. This same effect is evident between 2004 and 2007. Now, after the implementation of the SCATS adaptive system, travel times on the Burnside corridor have
reduced to the recorded lowest levels. Figure 2 shows comparisons of average travel along the route and Figure 3 illustrates the improvement in reliability of travel times. These three parameters quantify measures of performance that are important to the evaluation of the effectiveness of adaptive systems.

**Figure 1** PM peak travel time comparison, Burnside corridor

**Figure 2** Comparison of average travel time along route

**Figure 3** Comparison of reliability using 95th percentile

**Walnut Creek, CA (ATMS.now)**

**Overview**

Ygnacio Valley Road, carrying approximately 78,000 vehicles per day, is an important commute route to and from I-680 and SR-24. In addition to serving downtown Walnut Creek, it has several major generators that have markedly differing traffic characteristics, including the Lesher Regional Arts Center, Concord’s Sleeptrain Pavilion, John Muir Hospital, Shadelands business park and several schools.

The City of Walnut Creek has operated coordinated traffic signals along Ygnacio Valley Road since the 1970’s, initially with a Multisonsics VMS (220 then 330) system which was replaced with a Naztec Streetwise system in 2001. For several years the VMS ran traffic responsive pattern selection, but it was discontinued because of the demands on staff time to keep it up to date, and adverse impacts when key detectors failed. In 2009-2010,
the Streetwise system was upgraded to ATMS.now, the communications and detection upgraded and Naztec’s adaptive control software installed in the master server and local controllers. The City makes extensive efforts to minimize disruption to traffic on Ygnacio Valley Road, particularly during peak hours, including a moratorium on lane closures between Thanksgiving and Christmas.

To minimize the future cost and traffic disruption of loop maintenance, the City requested non-intrusive detection, and video detection was chosen. This presented a significant challenge for integration with the ATMS.now software, which was designed to operate with loops approximately 15 feet long installed behind the stop bar. The different mounting heights, pole locations, widths of intersections and viewing angles meant that each virtual loop had to be separately calibrated to represent a loop detector. This is the first installation of ATMS.now adaptive with 2070 controllers and video detection.

**Performance Evaluation**

A comprehensive performance evaluation will be available in late 2010. Because the intent of the adaptive system is to be able to accommodate variations in traffic demand throughout the day and night, including weekends, the performance measurements will include all periods during which the adaptive system is expected to perform differently from the existing TOD system. The travel times will be measured 24 hours per day for two weeks, providing equal sample sizes for both “with” and “without” adaptive conditions, using Bluetooth devices to provide a large sample size of travel times between six bi-directional stations.

**Sunnyvale CA (SCATS)**

**Overview**

In 2006/07, the City of Sunnyvale added six signals to extend its SCATS system along a major arterial road, Sunnyvale-Saratoga Road, which links SR237, US101, SR82 (El Camino Real), SR85 and I280 as it passes through Sunnyvale and Cupertino. This section had been operating fixed cycle length TOD plans, passing mainly through residential areas, with SCATS operating to the north.

**Performance Evaluation**

The survey used an innovative design to produce statistically significant results. It included the disruptive effects of transitioning between the stored TOD plans as well as the constantly changing and optimizing timing under SCATS control. In addition to analyzing the effect on travel times and stops for vehicles traveling along the coordinated route, the surveys measured the effects on side street traffic and pedestrians.

Overall, the study concluded that the SCATS system provided substantially superior performance over the TOD system. Along the coordinated route, both the travel times and the number of stops were significantly lower with SCATS. This was achieved using lower cycle lengths during parts of the day than the TOD system, as SCATS continually adjusted to match the changing traffic conditions. Changes in side street and pedestrian delays were not statistically significant. During some of the periods in which SCATS was operating, there were disruptions to traffic caused by unannounced maintenance activities, stalled vehicles and accidents. These incidents did not occur on days when TOD was operating. During all periods, regardless of disruption due to incidents, SCATS performance was superior to the TOD performance.

An innovative method was used to allow for the effects of different traffic volumes during various survey periods and to illustrate the results in a readily understandable fashion. Each travel time was matched to the traffic volume measured at the same time, using 15-minute time slices, giving a single statistic of the total corridor
performance for each time slice. All the data points derived for the two weeks of surveys were then plotted in the form illustrated in Figure 4 and a regression line plotted for the “before” and “after” cases. In this way it was possible to clearly separate the effects of different volume levels. In the PM peak case illustrated in Figure 4, it is clear that the range of volumes experienced under the two operating regimes was the same, and that the SCATS operation was clearly superior to the TOD operation under all conditions experienced during the PM peak. A similar process was used to document the stops along the route. In the period illustrated in Figure 5 (mid-day in the northbound direction), it can be seen that there is substantial overlap between the two operating regimes that would hide the difference in performance if only the average number of stops was considered. The overall changes in performance in terms of travel times and stops are shown in Table 1.

![Figure 4 Sample travel time vs travel demand](image)

![Figure 5 Sample vehicle stops vs. travel demand](image)

### Table 1 Comparison of overall travel time

<table>
<thead>
<tr>
<th>Period</th>
<th>Vehicle-hours per hour</th>
<th>Percentage change</th>
<th>Vehicle-stops per hour</th>
<th>Percentage change</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM peak</td>
<td>-39.7</td>
<td>-18%</td>
<td>-4,455</td>
<td>-54%</td>
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<tr>
<td>AM off-peak</td>
<td>-19.7</td>
<td>-16%</td>
<td>-1,811</td>
<td>-37%</td>
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<tr>
<td>Mid-day peak</td>
<td>-26.8</td>
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<td>-50%</td>
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<tr>
<td>PM off-peak</td>
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<td>-45%</td>
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<tr>
<td>PM peak</td>
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<td>-1,614</td>
<td>-28%</td>
</tr>
<tr>
<td>Weekend</td>
<td>-27.1</td>
<td>-18%</td>
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</tr>
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</table>

Difference is SCATS value minus TOD value. Negative number means SCATS has better performance.

### Santa Clara County/Sunnyvale CA (RHODES)

**Overview**

Between 1998 and 2002, Santa Clara County and City of Sunnyvale demonstrated the application of RHODES to a difficult network of intersections in Silicon Valley. The network consisted of nine intersections: three on Lawrence Expressway, an important restricted access road a grade-separated intersection with Central Expressway; and one intersection to the east and west on each of the three cross streets. These streets contained major generators with different peaking characteristics such as National Semiconductor, Costco and
Fry’s Electronics, and the signals on the local streets required significantly lower cycle lengths than those on Lawrence Expressway.

**Performance Evaluation**

The results of this performance evaluation have previously been reported in Fehon (2005), and are summarized below. Eight routes were defined to represent travel within the network. Four vehicles followed the various routes using a pre-defined schedule. The data was processed using a GIS package to translate the time and position data into individual vehicle traces from which detailed statistics of travel time, stops and delay could be derived for each run on each route.

Using a technique similar to that described for Sunnyvale above, the weighted travel times were plotted against volume levels, so that the performance of the two regimes could be examine under varying traffic conditions. When plotted against volume rather than vehicle-miles of travel, the results for different routes cannot be added. An example of the results for one survey route is illustrated in Figure 6. For each pair of days, total travel on all routes was added and the difference in total vehicle-hours of travel was also plotted for each period (Figure 7). To examine the statistical significance of these results, pair-wise comparisons were made of the differences for each route during each time slice, and a non-parametric statistical test applied. The results are summarized in Table 2. This provides a robust technique to draw conclusions when the simple average obscures the variability.

**Figure 6 Weighted travel time, Route 1**

**Figure 7 Overall change in travel time**

**Table 2 Statistical analysis of travel time differences**

<table>
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<tr>
<th>Parameter</th>
<th>Number</th>
<th>Percentage</th>
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</thead>
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<tr>
<td>Number of travel time comparisons</td>
<td>62</td>
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<tr>
<td>Number with statistically significant differences</td>
<td>35</td>
<td>56%</td>
</tr>
<tr>
<td>Number significantly better under RHODES</td>
<td>15</td>
<td>24%</td>
</tr>
<tr>
<td>Number significantly worse under RHODES</td>
<td>20</td>
<td>32%</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

The evaluation of the performance of adaptive traffic signal systems requires care to ensure that the measures actually reflect the manner in which the systems operate and measure the impact on all road users who are
affected by the system. Traditional “before and after” travel time surveys do not have sufficient level of detail to be able to separately account for the impacts of adaptive operation and therefore often under-report the benefits derived. In addition, the lack of robustness of simple “before and after” surveys ensures that the conclusions drawn from many reported surveys are unreliable.

The case studies reported in this paper have illustrated robust comprehensive survey techniques that produced results showing that some adaptive systems provide clearly-observable and significant benefits over traditional TOD operation, even during congested peak periods and incidents.

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i Trialed in Chicago (Battelle, 2001)
ii Initial development trials in Sunnyvale, circa 2002, by BiTran Systems
iii Unsuccessfully trialed in Omaha, Nebraska, circa 1997