

## Research Updates in Intelligent Transportation Systems

Volume 8 No. 3  
1999

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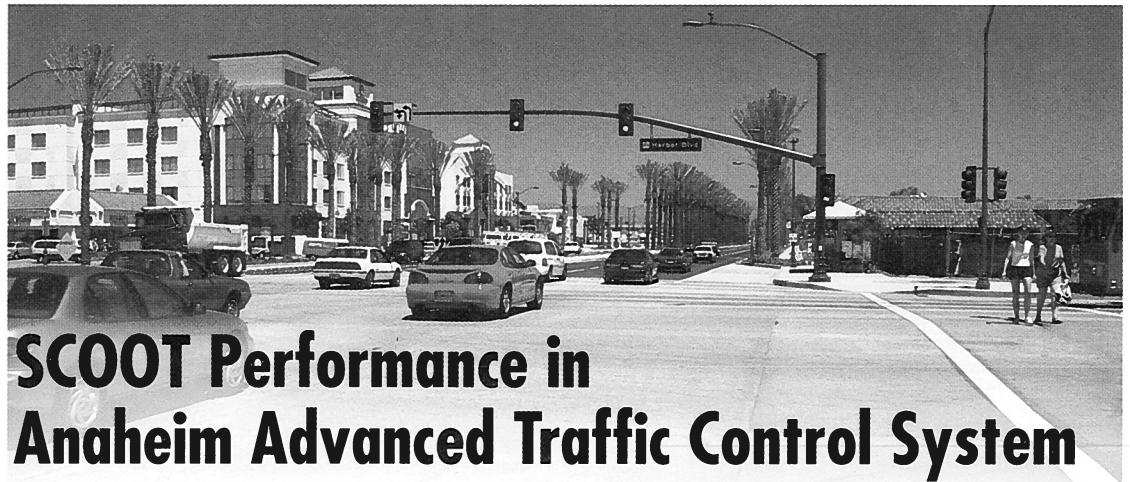
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*PATH – Partners for Advanced Transit and Highways – is a collaboration between the California Department of Transportation (Caltrans), the University of California, other public and private academic institutions, and private industry. PATH's mission: applying advanced technology to increase highway capacity and safety, and to reduce traffic congestion, air pollution, and energy consumption.*

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## SCOOT Performance in Anaheim Advanced Traffic Control System

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Anaheim, California, best known for Disneyland, is also the site of Anaheim Stadium and Arrowhead Pond, homes to major league baseball's Angels and the National Hockey League's Mighty Ducks. These major event centers, plus the Anaheim Convention Center, have a combined maximum attendance of 200,000 people. To accommodate this massive influx of visitors, 15,000 hotel/motel rooms are located within a 3 square mile area of the City. Anaheim itself has a population of 300,000, with 150,000 jobs within an area of nearly 50 square miles. On occasion—July Fourth weekend, for example—every room is taken, every ticket is sold, and every parking place is full. Not surprisingly, the city's arterial street system is often subject to irregular periods of elevated demand due to special event traffic. The surface streets have many signalized intersections and short road links, and speeds and travel times are dominated by queue delay at intersections. Ongoing expansion of the Convention Center, construction of a new Disney theme park and hotels, and widening of Interstate 5, all of which are happening simultaneously, exacerbate congestion.

PATH researchers systematically evaluated the performance and effectiveness of Anaheim's traffic management systems from fall 1994 through spring 1998, for the federally-sponsored Anaheim

Advanced Traffic Control System Field Operations Test (FOT). This FOT involved an integrated Advanced Transportation Management System (ATMS) that extends the capabilities of Anaheim's existing arterial traffic management systems. The FOT was conducted by a consortium consisting of the California Department of Transportation (Caltrans), the City of Anaheim, and Odetics, Inc., a private sector provider of advanced technology systems, with the City of Anaheim as the lead agency. The FOT was cost-share funded by the Federal Highway Administration (FHWA) as part of the Intelligent Vehicle Highway System (IVHS) Field Operational Test Program.

The arterial traffic control systems implemented in Anaheim for the FOT include SCOOT (Split, Cycle and Offset Optimizer Technique), an adaptive traffic control system developed in the United Kingdom by Ferranti, GEC, and Siemens under the supervision of the UK's Transportation and Road Research Laboratory (TRRL). SCOOT is employed extensively in Great Britain. A version 3.1 SCOOT system was installed by Siemens for a portion of the City of Anaheim network near Arrowhead Pond and Anaheim Stadium. The FOT tested the SCOOT system against Anaheim's existing Urban Traffic Control System (UTCS), considered state-of-the-art in US transportation management practice.

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SCOOT controls the operation of systems of signals rather than isolated intersections. The SCOOT traffic model uses data that varies over time, such as the green and red time of the signal and vehicle-presence measurements, together with data that are fixed for the area under control, such as detector locations, signal stage order, and a variety of other parameters. The SCOOT system collects traffic data from loop detectors embedded in the pavement of intersection approaches. The system uses this data to project conditions in the form of Cyclic Flow Profiles (CFP), simulating traffic characteristics (stops, delays, flows, and queue length) downstream from the detectors. SCOOT's split, cycle, and offset optimizers locally optimize signal timing by searching for improvements in terms of the CFP.

Theoretically, the benefits of SCOOT should be highest when traffic flow is heavy, complex, and unpredictable. In the best case, SCOOT should delay the onset of congestion, as well as providing early relief from it. In unsaturated networks, under certain conditions, SCOOT can prevent congestion by delaying it long enough to permit a short-duration demand overload to be completely overcome by appropriate adjustments in supply.

### Necessary Conditions for Improvement: SCOOT's Representation of Traffic Flow

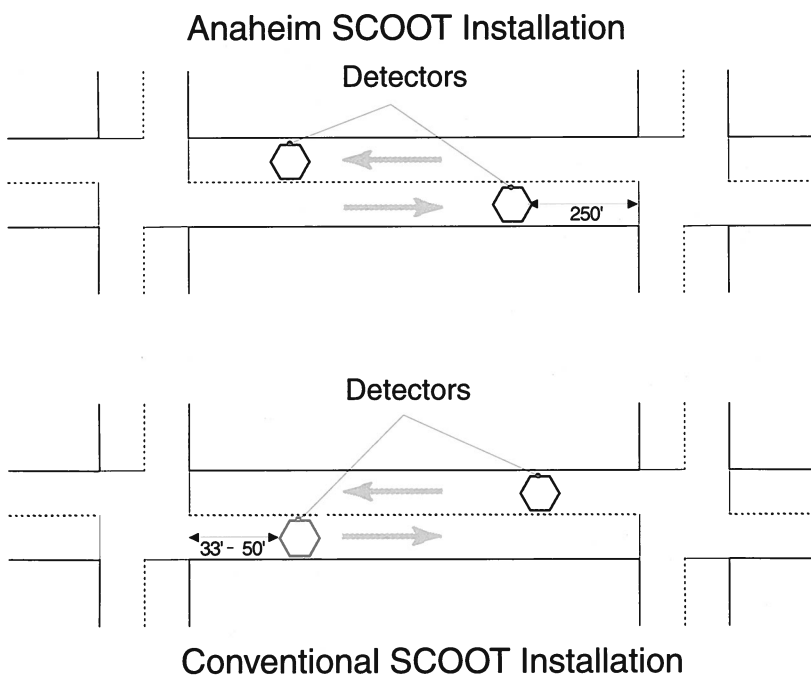
The quality of SCOOT implementation and performance is constrained by the system's ability to represent traffic conditions at intersections. If SCOOT can model traffic conditions accurately, it may be able to improve these conditions. If this necessary condition of accurate representation is not met, it is impossible for SCOOT to meet sufficient conditions for improvements. However, meeting necessary conditions without also meeting sufficient conditions is an inconclusive outcome that leaves open the possibility that SCOOT can provide improvements, but did not because of reasons that might be changed.

Anaheim's existing system detectors are located mid-block, upstream of the intersection being controlled. These detectors provide SCOOT with traffic volume counts, but SCOOT is designed to rely on detectors in a different location. The standard configuration is just downstream of the intersection upstream from the intersection being controlled (see Figure 1). Full evaluation of the constraints associated with using nonstandard detector information would require installing upstream loops in a standard SCOOT configuration in addition to existing mid-block detectors, and then comparing SCOOT's operation with different sets of detectors. Such an installation is not feasible; consequently, in this evaluation the effects of using SCOOT are inextricably mixed with the effects of using mid-block detectors.

### Field Observations

SCOOT's ability to represent intersection conditions was tested using pairs of traffic data sets. The first data set was provided by downloading message reports directly from the SCOOT system. The second data set consists of empirical field observations, provided by post-processing video tapes of conditions on approaches to intersections subject to SCOOT control. SCOOT system estimates of queue length and queue clearance time were compared with conditions recorded on video. During data collection, a graduate research assistant working as a regular employee in the Anaheim Transportation Management Center (TMC) carefully coordinated collection of the estimated values reported in SCOOT messages with real-time videotapes of traffic conditions recorded via TMC cameras.

Figure 1: Anaheim and conventional SCOOT loop detector locations.



A real-time display of the traffic conditions estimated by SCOOT can also be invoked via SCOOT's Node Fine Tuning Display (NFTD). The NFTD command reports the times at which all approaches to a given intersection begin the green phase, shows the queue length when an approach is green, and the associated queue clearance time. Comparing real-time green starts and queue clearance times reported by SCOOT to real-time video images revealed large inconsistencies at some intersections.

### Internal Representation Results

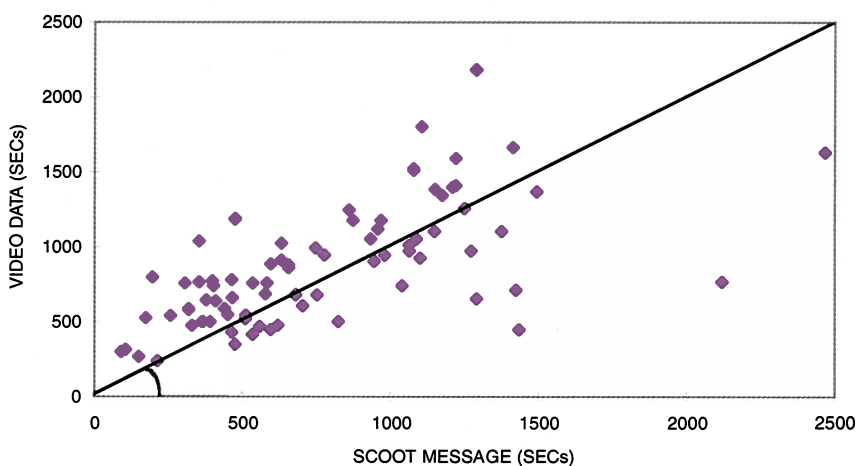
We observed that as a result of cumulative communication or other system faults, the SCOOT intersections were unexpectedly being isolated from SCOOT control. Such faults can be cleared manually in most cases, but this requires active intervention on the part of the TMC operator. If faults are actively cleared rather than being permitted to accumulate, the signals involved usually remain under SCOOT control. The number of signals slipping from SCOOT control decreased substantially once the evaluation team demonstrated to Anaheim TMC operators the need to clear faults as they occurred. Unfortunately, these conditions still resulted in substantial data loss for this portion of the evaluation, because SCOOT message data associated with signals subject to cumulative communication faults are meaningless. The conditions reported in such messages diverge from conditions observed via video. Fortunately, some intersections remained under SCOOT control, and data from these intersections still provide statistically significant results. Correlation coefficients between the SCOOT message data and the videotape data were estimated for stops, delays, flows, queue length, and queue clearance times.

If the SCOOT system accurately represents traffic conditions on approaches, then the correlation coefficient between the SCOOT message data and the video data will tend toward unity. In all cases, it is both qualitatively and quantitatively clear that the data provided by the SCOOT messages covaries moderately to strongly with the data extracted from the video tapes. For the Anaheim FOT intersections, the overall correlation coefficient between observed flows and flows reported in SCOOT system messages was estimated at 0.86 (see Figure 2). Coefficients for other traffic indicators are lower, which is to be expected: these

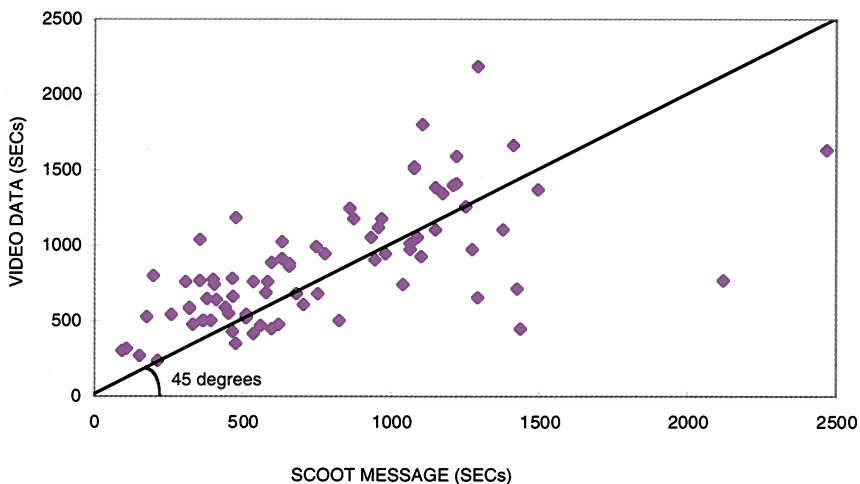
other measures are derived from flow measures, and additional modeling steps are likely to introduce more errors into the values appearing in SCOOT messages. The estimated correlation between observed and SCOOT measures of intersection delay, for example, was 0.65 (see Figure 3). This was the lowest value obtained. Approach delay is also more difficult to compute from video observations than the other quantities. The estimated correlation coefficients for observed stops, queue length, and queue clearance times fall between these values. These are aggregate estimates combining data for three intersections. Estimates for individual intersections have more variance, producing some values above and some below this interval.

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**Figure 2. Flow volumes on approach per SCOOT interval, all data (Nov. 18, 1997). Correlation coefficient  $r = 0.86$ .**



**Figure 3. Total vehicle delays on approach per SCOOT Interval, all data (Nov. 18, 1997). Correlation coefficient  $r = 0.65$**



# SCOOT Performance in Anaheim

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The estimated correlation coefficients observed in Anaheim are lower than values obtained in other locations where SCOOT has been deployed. A pre-version 2.3 SCOOT installation in Leicester, England, produced a correlation coefficient of 0.93 for flows, subsequently improved to 0.96 (Martin, 1992). The Anaheim correlations are most likely a function of nonstandard detector locations. Improvements could be generated either by changing the locations of detectors, or possibly by adjusting SCOOT's global control settings to try and further compensate for the effect of nonstandard detector locations.

## Investigating Sufficient Conditions for Improvement: Traffic Performance under SCOOT

Traffic performance evaluation under SCOOT focuses on delays at SCOOT intersections, as well as running times, stop times, and total times on selected floating car routes in the SCOOT network. A standard "before-after" format was adopted. Measurements were taken of traffic conditions in the PM-peak and evening off-peak both during special events and during non-event traffic conditions.

Delay measurement teams were posted at intersections, and travel-time measurement teams drove floating cars on five routes. Ten observation periods in mid-October 1997 under the pre-existing UTCS control system were selected for the "before" study; ten observation periods in mid-November 1997 under SCOOT were selected for the "after" study.

Resource limitations prevented full-time measurements at all intersections. Intersection delays were calculated by counting the stopped cars at small sample intervals, accumulating totals, and multiplying by the sample interval. The delays were not disaggregated for each turning movement. Routes for the floating-car travel time studies were selected to obtain a reasonable coverage of the network with sufficient turning movements to capture delay patterns. Observed times were aggregated and averaged for each route for each observation day.

## Traffic Performance Results

Results provided by the intersection delay analysis include the following:

- The SCOOT system generally performed better under off-peak conditions than under peak conditions. The relative performance of SCOOT in comparison to the baseline system improved under special-event conditions compared to nonevent conditions for low volume intersections, although the reverse occurred for some high volume intersections. SCOOT performed very well at two intersections subject to heavy egress traffic from the special event locations, pointing to SCOOT's ability to make adaptive adjustments.

- The SCOOT system produced lower intersection delays in some cases, and higher delays in others compared to the baseline system. SCOOT increased delays more frequently than it decreased delays, but there is insufficient evidence to show that this SCOOT installation performs significantly worse or better than the baseline system during peak-periods. In cases where SCOOT performed worse than the baseline system with respect to intersection delays, the increase in delay was rarely more than 10 percent. In cases where SCOOT performed better, improvements were normally less than 5 percent.

- SCOOT and baseline system delays are comparable in most cases. In the cases where SCOOT performed worst, special circumstances associated with the project contributed to this result. These circumstances include nonideal parameter settings, and the inclusion of low-volume intersections that probably should not have been subject to SCOOT control. Forcing a common signal cycle length that is not appropriate for an intersection can cause excessive delays.

- The SCOOT system, despite the substandard implementation and ongoing communication faults, did not produce any instances of unacceptably higher intersection delays, and did not cause any major problems in the system. SCOOT reduced delays at some intersections.

Results derived from the travel-time analysis include the following:

- Travel times on selected routes showed the effect of directional settings in SCOOT. Opposing directions on a route that had different travel times under the baseline system showed similar travel times under SCOOT. Another route showed the opposite.

- Route travel times under SCOOT showed reductions of less than 10 percent in some cases, and increases of less than 15 percent in others. On the more circuitous, longer routes covering more of the network, SCOOT showed travel time reductions of as much as 2 percent, and increases of as much as 6 percent. SCOOT's performance relative to the baseline system was better under non-event conditions than under special event conditions.

## Conclusions

SCOOT can operate in a network with nonstandard detectorization, and can control traffic without causing substantial increases in intersection delays and route travel times. While SCOOT was implemented in Anaheim with some degree of success, it did not show the level of benefits demonstrated by standard SCOOT implementations around the world. This is understandable, considering that the baseline system SCOOT performance was compared with is considered state-of-the-art in US practice. Technical and institutional problems also limited expected performance. Siemens and the City spent minimal time fine-tuning the SCOOT parameters, training for City TMC staff was incomplete, communication and controller systems were of lower quality than anticipated, and there was no acceptance test prior to evaluation of the system. These outcomes were driven by responses to project deadlines. Problems were exacerbated by staff changes affecting project management, and delays due to contractual issues.

In summary, SCOOT's ability to at least partially model traffic conditions based on non-standard detector locations, the fact that traffic conditions remained acceptable under SCOOT, and that no serious traffic problems arose, all suggest that SCOOT is a system worth pursuing in Anaheim and other US cities. Siemens returned to Anaheim following the PATH evaluation to address problems identified during the course of the evaluation. SCOOT remains in current use in selected areas in the City of Anaheim, with plans for system expansion.

## Acknowledgments

USC graduate research assistants Seongkil Cho and Hsi-Hwa Hu, and UCI graduate student researchers Steven P. Mattingly (now Assistant Professor of Civil Engineering at the University of Alaska) and



*Anaheim Transportation Management Center.*

James Roldan made significant contributions to the field work and analysis needed to complete this project. The student investigators persisted in reporting to their disbelieving faculty supervisors that "something is wrong in the field," thereby salvaging the evaluation. Richard Macaluso of Caltrans and Frank Cechini of FHWA demonstrated astounding patience during the five years needed to complete this FOT and evaluation.

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# Intelligent Surveillance Using Inductive Vehicle

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*An excellent opportunity exists to squeeze out more detailed and accurate information from the current detector infrastructure.*

Even as new exciting technologies are being developed for transportation applications and new Intelligent Transportation Systems (ITS) are being tested and implemented, the need for more detailed and accurate transportation data grows apace. Researchers are exploring the use of various new forms of detectors and surveillance systems. These detectors include infrared, microwave, ultrasonic, acoustic, Automatic Vehicle Identification (AVI), piezo-electric, magnetic, Global Positioning System (GPS)/cellular modem, and video image processing devices. However, an excellent opportunity exists to squeeze out more detailed and accurate information from the current detector infrastructure or inductive loops. One way this is accomplished is by using inductive signatures collected from existing loops.

Previously, inductive loop detector cards only operated in a pulse or a presence mode, producing a digital output. However, detector manufacturers are increasingly producing detectors that have the capability to output a vehicle inductive signature through a serial port on the detector card. This inductive signature is the result of the net decrease in detector inductance when a vehicle's metallic mass passes over the magnetic field generated by the inductive loop. (Research work cited in the References below exemplifies the use of inductive signatures.)

One useful result of inductive signature analysis is the derivation of vehicle classification data. Vehicle classification is the process of separating vehicles according to different predefined classes. Vehicle classification information can be used in many transportation applications including road maintenance, emissions/pollution estimation, traffic modeling and simulation, traffic safety, and toll setting. Two different systems were developed for classifying vehicle signatures. One system is based on the self-clusterization approach and uses a Self-Organizing Feature Map (SOFM). A SOFM is an artificial neural network that forms clusters of neurons which reflect similarities in the input vector. The weights of the neurons actually become similar to average class signatures. Although the SOFM was trained by using a very small dataset of twenty-six

vehicle signatures (feature vectors), it was able to classify 300 test vehicles with an accuracy of 85 percent. The classes of vehicles that were identified were car, Sport Utility Vehicle (SUV), limousine, bus, truck, car towing trailer, and semi-trailer truck.

A second vehicle classification system uses a heuristic discriminant algorithm for classification and multi-objective optimization for training the heuristic algorithm. A heuristic discriminant algorithm is a hierarchical combination of discriminant functions, similar to a decision tree, that separates the vehicle pattern space in a piece-wise linear fashion. Feature vectors obtained by processing inductive signatures were used as inputs into the algorithms. The use of feature vectors reduced data storage and communications requirements, and enabled a hierarchical approach for classification. The figures opposite illustrate some examples of feature vectors including the electronic length, inductive magnitude, energy content, signature variance, skewness, kurtosis, Discrete Fourier Transform (DFT) coefficients, and first and second order gradients of the signature. Three different heuristic algorithms were developed for separating vehicle signatures into seven classes. The three algorithms yielded encouraging results of 81%-91% overall classification rates using different test datasets. The results from both vehicle classification systems demonstrate the potential of collecting network-wide vehicle classification data from inductive loops. The availability of vehicle classification data helps to improve traffic surveillance and paints a more detailed picture of dynamic traffic networks.

Another benefit of using vehicle inductive signatures is the derivation of section measures of traffic system performance. These measures include section travel time, section density, lane change, and even dynamic origin/destination demand (see Intellimotion 6.2, available at <http://www.path.berkeley.edu/PATH/Intellimotion>). Origin/destination demands can be derived from unique vehicles that are tracked over multiple sections. In order to derive section measures, individual vehicles are first reidentified. The vehicle reidentification prob-