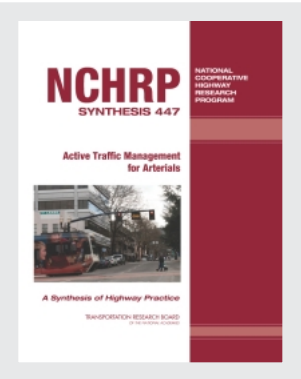

Active Traffic Management for Arterials

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 447

Active Traffic Management for Arterials

A Synthesis of Highway Practice

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The project that is the subject of this report was a part of the National Cooperative Highway Research Program, conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council.

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Cover Figure: Example of active traffic management in downtown Portland, Oregon. In advance of arrival, LRT receives priority through an extended green and also activates warning sign. *Credit:* Kittelson & Associates, Inc., Feb. 2013.

FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Jo Allen Gause
Senior Program Officer
Transportation Research Board

Active traffic management (ATM) includes a suite of traffic management and control strategies that improve operational efficiency. These strategies are used to manage traffic flow to enhance capacity and safety. This synthesis documents the state of the practice associated with designing, implementing, and operating ATM on arterial roadways.

Information used in this study was acquired through a review of the literature and in-depth interviews of selected transportation agencies.

Richard G. Dowling and Aaron Elias, Kittelson & Associates, Inc., Oakland, California, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable with the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

ACTIVE TRAFFIC MANAGEMENT FOR ARTERIALS

SUMMARY

Active traffic management (or ATM) is the regular adaptation of facility configuration and controls in response to (or in anticipation of) variations in demand, incidents, and weather to maintain optimal facility productivity.

This synthesis documents the state of the practice associated with designing, implementing, and operating ATM on arterials. Of particular interest to this study has been information on strategies used to actively manage traffic and congestion on arterials; situations and operating conditions in which ATM strategies have been successfully and unsuccessfully deployed on arterials; and system and technology requirements associated with implementing the strategies. Of secondary interest to this study has been information on institutional issues associated with implementing ATM for arterials; operations and maintenance requirements associated with implementing these strategies; and the benefits and costs associated with implementing these strategies.

Although demand management has not been the focus of this synthesis, traveler information and route guidance tactics are covered in this report.

ATM measures involving adaptive signal control, congestion pricing, or speed harmonization on arterials were not included in this synthesis because these topics have been covered in another recent synthesis (as is the case for adaptive signal control) or because there are insufficient installations of the measures on U.S. arterials for a synthesis of current U.S. practice.

Information for this synthesis was gathered through a literature review of advanced ATM methods for arterials and in-depth telephone interviews of selected agencies. Agencies were selected for the interviews based on a screening survey that was sent to members of the ITE Traffic Engineers Council, the ITE Public Agency Council, the AASHTO Subcommittee on Traffic Engineering, the TRB ATM Joint Subcommittee, and the TRB Signal Systems Committee.

Members of these groups indicating that their agency had a high level of experience with the ATM strategies were chosen for the telephone interviews. Note that this synthesis is therefore not a complete inventory of agencies and ATM installations in the United States. It is a synthesis of ATM arterial strategies being used today and the lessons learned from their implementation.

The objectives of this synthesis are as follows:

- The literature review and survey identified the following strategies for actively managing traffic and congestion on arterials: monitoring arterial performance, dynamic signal control (special plans, signal priority, queue jump), dynamic geometric controls (reversible lanes, dynamic turn prohibitions, dynamic turn lanes), and traveler information.

- The literature review and survey indicated that ATM strategies have been deployed successfully on arterials where there was:
  - A need for dynamic management of arterial operations (recurring and nonrecurring traffic congestion coupled with limited capacity improvement options);
  - An operating agency with the maintenance and operation resources to implement and fine-tune the ATM application; and
  - The active participation and coordination of multiple divisions within a single agency and multiple agencies in the ATM application.
- The literature review and survey found few ATM strategies that were sufficiently mature to enable a final determination that the strategies were unsuccessful. However, reversible lanes are one ATM strategy mature enough that the literature identifies situations in which the strategy has been retired because it is no longer needed or because the costs outweigh the benefits. As traffic grows in both directions of travel, reversible lanes start to impose delays on the reverse direction that dilute the benefits of the strategies.
- The literature and survey found that system and technology requirements associated with implementation vary by strategy.
  - Continuous real-time monitoring of arterial performance requires permanent detectors in the field (a wide variety of technologies are available) and moderate capacity communications between the field and the central office. Storage of the information in the central office enables the data to be used for engineering studies as well as for real-time control.
  - Dynamic signal control requires sophisticated software at the control center and/or in the field.
  - Dynamic geometric control (dynamic turn lanes, prohibitions, and so forth) requires sophisticated software in the field and in the control center plus specialized display hardware in the field.
  - Depending on the technology selected, dynamic traveler information may require specialized display hardware in the field with communications between central office and the field, or it may require cell phone and website technology.
- Regarding issues of secondary interest to this study (institutional issues associated with implementation, operations and maintenance requirements; and the benefits and costs associated with implementing these strategies):
  - Interviewees considered institutional issues to be among the greatest challenges to implementing ATM on arterials;
  - Interviewees pointed out the need to budget for maintenance and operations (M&O) costs of ATM on arterials but did not provide information on ATM M&O costs separate from other agency costs; and
  - Although all interviewees considered ATM on arterials to be a positive benefit to the public, none were prepared to offer quantified computations or measurements of the benefits of ATM on arterials. Most interviewees considered themselves to still be in the developmental phase of their specific ATM application and did not think their particular application was sufficiently mature at this point for the formal evaluation of the benefits.

The literature review identified numerous instances in research, in the literature, and in the practice of ATM measures related to monitoring arterial performance, dynamic signal control, reversible lanes, dynamic turn prohibitions, and traveler information. Less common in the literature and in practice were instances in which agencies had implemented dynamic turn lanes. Dynamic parking management is also a relatively recent innovation that is only beginning to be documented in the literature and implemented in pilot programs.

The literature review revealed that although there is a great deal of literature and available technologies for arterial performance monitoring, public agencies rate themselves as failing when it comes to monitoring arterial performance, based on the 2012 *National Traffic Signal Report Card* by the National Transportation Operations Coalition. From what can be discerned from the literature, this is not because of a lack of available technologies or information on their installation and operation. The discussion under this topic in the *National Traffic Signal Report Card* suggests that the problem may be lack of resources, but the Coalition did not actually query participating agencies regarding the reasons for their low self-assessment. Future research might investigate this result to understand more fully the obstacles to better arterial monitoring.

The dominant theme emerging from the interviews was that the major requirements for a successful ATM implementation on arterial streets are much the same as for any major investment project undertaken by the agency:

1. Political support.
2. Funding.
3. Identification and engagement of stakeholders (within and across agencies).
4. Appropriate technological expertise (hired if not available in-house).
5. Detailed planning and design of the proposed investment, which includes
   a. An accurate inventory of the infrastructure necessary to support the new technology.
   b. Recognition that technology is not perfect and an accounting for this in the planning.
   c. Consideration of the effect of the project on ongoing maintenance costs.
   d. Recognition that it is easy to underestimate the required investment costs and the costs for ongoing maintenance.

The agencies interviewed each identified at least one and often many more of the above points as their "lessons learned" when implementing ATM on their streets.

The major differences between the challenges of conventional capacity improvements and ATM investments appear from the interviews to be the degree to which ATM requires the involvement of multiple stakeholders, and the use of new technology unfamiliar to the agencies. Involvement of stakeholders and new technology stand out as major challenges to ATM project implementations.

Many interviewees noted that predicting and monitoring the benefits of ATM implementation can be key to securing initial and continuing political and stakeholder support, yet few agencies interviewed had formal "before and after" studies. Similarly, most interviewees were unable to say with certainty which performance measures they considered most appropriate for measuring the costs and benefits of ATM installations (mostly because they were still working on refining their ATM installations and had not yet gotten to the point where they were ready to start thinking about formal performance measures). They were generally unable to respond quantitatively to requests for information on the precise benefits of their respective ATM installations. Part of this most likely is the result of the relative immaturity of U.S. ATM installations. The installations are still evolving and have not matured to a steady state at which a formal "before and after analysis" is appropriate.

Although most ATM measures appeared in the interviews to be sufficiently far along in their technological development to enable agencies to use readily available in-house or commercially available technical expertise to plan, design, construct, and operate most ATM measures, the dynamic turn lanes ATM measure appears to be earliest in its technological development. The agencies implementing dynamic turn lanes had to develop from scratch some of the software and hardware systems needed to implement the measure.

The knowledge gaps identified in this synthesis include:

1. Lack of consensus on the appropriate measures of effectiveness and appropriate analysis methods for evaluating ATM investments, and
2. Lack of sufficient expertise in the hardware, software, and operation of dynamic turn lanes in coordination with traffic signals.

The SHRP 2 Reliability program has developed performance measures and analysis methods for predicting travel reliability. This information, all recently developed and not yet fully disseminated, should be beneficial to the community of agencies implementing or considering the implementation of ATM measures on their arterials.

With regard to predicting the benefits of ATM investments, research is needed to develop analytical tools for predicting how different ATM investments can affect travel time reliability and delay in an arterial system (either alone or integrated with a freeway).

Additional research is needed to determine under which conditions these ATM strategies can best be applied to arterial roadways. Additional information on applications would help agencies determine which arterial ATM strategies will best improve their arterial operations.

CHAPTER ONE

INTRODUCTION

Active traffic management (ATM) is the regular adaptation of facility configuration and controls in response to (or in anticipation of) variations in demand, incidents, and weather to maintain optimal facility productivity. The focus of this synthesis is on the experience of agencies applying ATM to arterial streets.

ATM for arterials includes a suite of traffic management and control strategies that improve operational efficiency. These strategies are used to

- Maximize safety and traffic flow;
- Optimize the use of the existing infrastructure;
- Improve trip reliability;
- Provide additional capacity during periods of congestion, special events, and incidents;
- Simultaneously consider the needs of all travel modes (including pedestrians, bicycles, transit) and emergency services; and
- Allow for integrated management of roadway facilities across the transportation network.

SYNTHESIS OBJECTIVE

The purpose of this synthesis has been to document the state of the practice associated with designing, implementing, and operating ATM on arterials. Of particular interest was information on:

- Strategies used to actively manage traffic and congestion on arterials;
- Situations and operating conditions in which ATM strategies have been successfully and unsuccessfully deployed on arterials; and
- System and technology requirements associated with implementing the strategies.

Of secondary interest to this study has been information on institutional issues associated with implementing ATM for arterials; maintenance and operations (M&O) requirements associated with implementing these strategies; and the benefits and costs associated with implementing these strategies.

The objective of this project has been to create a report documenting the state of the practice in using ATM strategies on arterials. Because of the availability of a recent synthesis on adaptive signal control (Stevanovic 2010), this study was not intended to address adaptive signal control unless it was implemented in coordination with other arterial ATM strategies. Because this synthesis is about arterial ATM strategies, it does not look at ATM strategies associated with freeways, such as ramp metering and variable speed limits.

Although this synthesis has gone into depth describing the experiences of selected agencies implementing various ATM measures on streets in the United States, it is not intended to be an exhaustive inventory of agencies using ATM on urban streets in the United States.

METHODOLOGY

The synthesis was developed based on a literature review of advanced ATM methods for arterials and an in-depth telephone survey of selected agencies that had indicated in a prescreening survey that they had a high degree of knowledge and experience implementing ATM on their arterial streets.

The literature search focused on papers and other items on ATM that have been published since 2000, with a special emphasis on arterial street applications. Key results are reported in chapter two.

A web-based screening survey was developed to help identify agencies in the United States with a high degree of knowledge and experience in the implementation and operation of ATM on arterial streets. Members of the ITE Traffic Engineers Council, the ITE Public Agency Council, the AASHTO Subcommittee on Traffic Engineering, the TRB ATM Joint Subcommittee, and the TRB Signal Systems Committee were recruited to participate in the screening survey. One hundred twenty-one complete responses were obtained from professionals in 39 states. Because the screening survey was sent to members from a variety of organizations and used only for identifying agencies with specialized knowledge of ATM on arterial streets, it was determined not to be necessary to track the total number of those who received the survey. Respondents were grouped according to their self-indicated degree of knowledge with each of nine possible categories of ATM measures on urban streets. A minimum of two people in each category who had indicated a high degree of experience with each ATM measure type were then selected for an in-depth phone interview regarding their lessons learned for that ATM measure. More details on the survey approach are presented in the introductory section of chapter three and in the appendices.

ACTIVE TRAFFIC MANAGEMENT STRATEGIES

The objective of an ATM strategy for an arterial is to maximize the cost-effectiveness of the facility. This is achieved by maximizing productivity (capacity) while minimizing cost (delay, stops). To achieve this objective, the operator of an arterial street must employ several tactics, including tactics related to

- Arterial monitoring,
- Speed and signal control,
- Geometric configuration, and
- Demand modification.

Each tactic in turn consists of a combination of specific ATM measures designed to achieve the objective of that tactic (see chapter two for details).

For example, the objective of ATM measures grouped within the Monitoring Tactical Group is to obtain actionable real-time information on arterial performance. This objective may be achieved by several means, such as using closed-circuit television (CCTV) cameras and vehicle detectors or by purchasing travel speed data from a commercial vendor of real-time traffic data. The specific choice of measures to achieve the tactical objective of monitoring becomes the agency's monitoring tactic for the facility.

COMMON ISSUES AMONG AGENCIES

Readers of the literature review and the case examples will note that although the literature often documents some fairly detailed assessments of the benefits and costs of implementing ATM strategies on arterial streets, the survey indicated that operators of arterial systems tended to be less formal in their evaluation of the benefits of ATM and in their documentation. Although a few operators conduct formal and regular evaluations of the benefits of their ATM investments, most do not. This could be an outcome of the survey process used. System operators, rather than agency management, were interviewed. Although management has specific performance objectives in mind for their agency's ATM investment, system operators are more concerned with day-to-day operations.

Another theme from the interviews was how much agencies have had to build from scratch (writing custom software, integration of disparate equipment, quality assurance testing) to implement dynamic lane use and turn lanes on arterials. Arterial monitoring and dynamic signal control are comparatively more mature ATM technologies (with commercially developed systems readily available) than is dynamic lane use.

TOPICS NOT ADDRESSED

This synthesis intentionally avoided most aspects of dynamic signal control because that topic is well covered in previous syntheses. However, special event signal plans, transit priority, and emergency vehicle priority are covered in this synthesis.

This synthesis and the survey were not intended to provide a complete inventory of all ATM installations on U.S. streets, but rather to provide in-depth coverage of the lessons learned (as reported by the target agencies) from specific examples of ATM installations.

CHAPTER TWO

LITERATURE REVIEW

This synthesis has attempted to organize the literature on ATM measures into tactical groups. Each group of measures has a particular tactical objective: monitoring, control, geometry, or demand modification. The particular ATM measures selected under each tactical group together form the agency's ATM strategy for the facility. Unfortunately, the literature commonly refers to every individual ATM measure as a strategy in its own right, when in reality it is measures grouped by tactic that together form a particular agency strategy for achieving the agency's goals for ATM. Because the overuse of the term "strategy" is so pervasive in the literature, this synthesis has preserved the original usage of the term when describing the contents of a particular work. The review of each work, however, is then set within the broader tactical group's context adopted by this synthesis.

TYPOLOGY OF ACTIVE TRAFFIC MANAGEMENT STRATEGIES, TACTICS, AND MEASURES

The goal of an ATM strategy for an arterial is to maximize the cost-effectiveness of the facility. This is achieved by maximizing productivity (capacity) while minimizing cost (delay, stops). To achieve this goal, the operator of an arterial street must employ the following tactics:

- Arterial monitoring,
- Speed and signal control,
- Geometric configuration, and
- Demand modification.

Each tactic in turn consists of a combination of specific ATM measures designed to achieve the objective of that tactic (see Figure 1).

For example, the objective of ATM measures grouped within the Monitoring Tactical Group is to obtain actionable real-time information on arterial performance. This objective may be achieved by several means, such as using CCTV cameras and vehicle detectors or by purchasing travel speed data from a commercial vendor of real-time traffic data. The specific choice of measures to achieve the tactical objective of monitoring becomes the agency's monitoring tactic for the facility.

The objective of ATM measures within the Speed and Signal Control Tactical Group is to adapt signal timing (and speed limits if appropriate) to maximize production (capacity) and minimize cost (delay and stops). Measures to achieve this object include dynamic signal control (traffic actuated, traffic responsive, and traffic adaptive) and dynamic speed limits. Signal timing affects the capacity of a street by changing the allocation of green time between users of the street (through movements, transit, pedestrians, and turn movements). It can also affect the speed of travel on the facility through signal coordination.

Much has been written on advanced signal timing; see *NCHRP Synthesis 403* (Stevanovic 2010) for one example. Thus, this synthesis will focus on only a few aspects of signal control related to transit priority and emergency vehicle priority/preemption treatments and the integration of signal timing with other aspects of ATM measures on arterials.

The objective of ATM measures within the Geometric Configuration Tactical Group is to dynamically adjust lane use on the arterial to better match demand, thereby increasing the capacity of the street. This can include changing the number of lanes designated for turns, changing the vehicle types allowed to use a lane, or even changing the direction of flow for certain lanes. Practicalities limit the ability to dynamically open and close parking lanes on a street (drivers must be warned when first parking their vehicle of when they must leave). Dynamic turn restrictions are included in this tactical approach.

The objective of ATM measures within the Demand Modification Tactical Group is to better match the demand to the available capacity. In this synthesis, demand management primarily is traveler information services and guidance. The travel information is provided in the hope that a better-informed traveling public will shift to less-congested facilities and thereby better balance demand with available capacity. A more proactive form of demand management is to provide actual dynamic route and mode of travel guidance, making travelers aware of additional routing and modal options. Congestion pricing, although a more direct demand modification measure, will not be covered here owing to limited U.S. experience applying it to arterials (Loudon 2009).

Spectrum of ATM Strategies on Arterials

The objectives of ATM can be achieved to differing degrees using wide ranges of automation and responsiveness to varying conditions. The result is a continuum of ATM that may

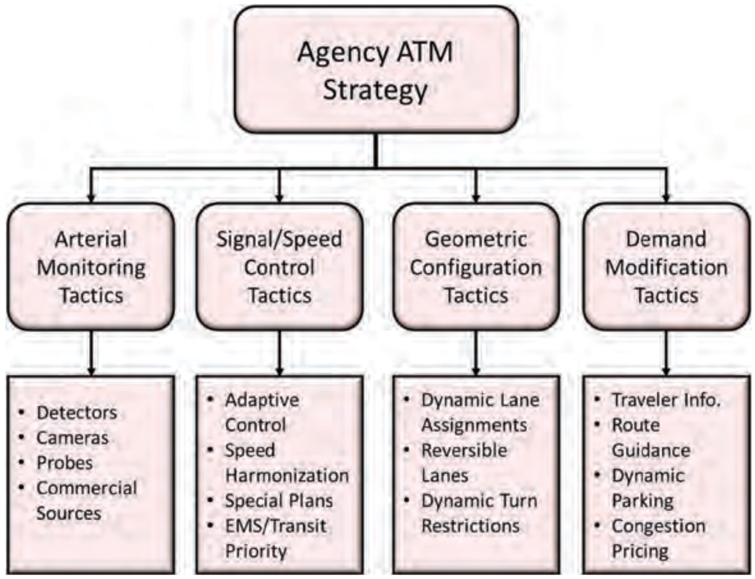

FIGURE 1 Classification of ATM measures into tactical groups.

employ exclusively human management with response times measured in hours and days, or the ATM implementation may be fully automated with split-second responses to changing conditions in the field (see Figure 2). Conventional practice with mostly human control and response times on the order of weeks and days is an ATM strategy if the arterial is being regularly monitored and the controls fine-tuned in response to changing conditions. Advanced practice substitutes greater computerized control of the facility, which enables more rapid response to changing conditions. The full-spectrum strategy is still ATM, as long as there is regular monitoring of the facility and controls are regularly updated in response to changing conditions. Conventional practice and advanced practice overlap.

Dynamic control and response to changing conditions can range from "low" (fully scheduled, with regular updates of the schedules), to "medium" (partially scheduled on daily to monthly basis or in response to an intermittent field condition, such as a turn restriction because of light rail trains or other recurring event), to "high" (very responsive to current conditions on a daily or finer time period basis).

PRIOR ACTIVE TRAFFIC MANAGEMENT SYNTHESES

There currently are two major resources summarizing U.S. and European experience implementing ATM strategies. One is the report *Implementing Active Traffic Management Strategies*

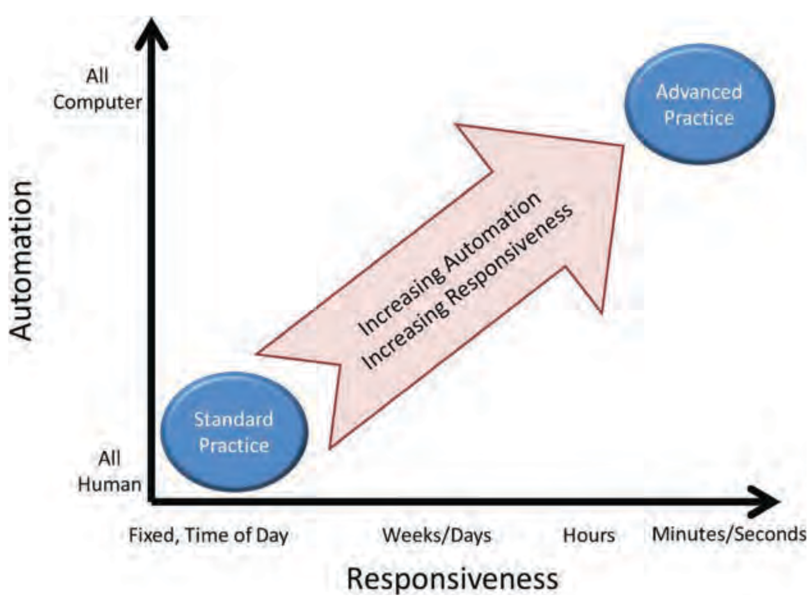

FIGURE 2 The continuum of ATM automation and responsiveness.

in the U.S. (Sisiopiku 2009). The other is the report *Synthesis of Active Traffic Management Experiences in Europe and the United States* (Fuhs 2010). Although both focus primarily on freeway applications of ATM with some discussion of urban street applications, they are of interest to this synthesis for their definitions of ATM and in their conclusions that are relevant to ATM on arterials practice.

Implementing Active Traffic Management Strategies in the U.S.

Implementing Active Traffic Management Strategies in the U.S. (Sisiopiku 2009) provides a literature review of ATM measures, case studies, and a state-of-the-practice review of four state departments of transportation (DOTs).

For the purposes of the study, the author defined ATM as follows:

> ATM includes the frequent adjustment or alteration of the traffic control and regulatory features of the road network in response to changing traffic conditions. ATM is the practice of dynamically managing both recurrent and non-recurrent congestion based on prevailing and future traffic conditions. In practice, ATM seeks to provide reliable travel times for all users, reduce both recurrent and non-recurrent congestion, and provide enhanced information to drivers.

The author specifically looked at speed harmonization, high occupancy vehicle toll lanes, junction control, temporary shoulder lane use, and dynamic signing and rerouting. The focus was exclusively on freeway applications in the literature review and in case studies of European practice, so the author's observations are not directly relevant to this synthesis; however, some of the author's observations and conclusions also apply to ATM on arterials, particularly when considering the joint operation of ATM measures on an integrated freeway/arterial corridor system.

The author's state-of-the-practice review looked at four state DOTs: Virginia, Minnesota, Washington State, and California (Caltrans). With the exception of Caltrans, the ATM programs the author described focused exclusively on freeway operations. The Caltrans overview mentions that the state was in the planning stages for the I-80 Corridor project, which involved both freeway and arterial ATM, but no details are provided in the author's review on the arterial aspects.

The author's conclusions from the literature review, case studies, and interviews of state DOTs are relevant to ATM on arterials in that they find that:

1. ATM is still in an initial development stage in the United States, so there are few ATM projects in operation and very little data available.
2. The primary implementation issues are:
   - Funding (lack thereof and need for supporting infrastructure investments);
   - Legal (public safety aspects of some ATM measures, such as shoulder use); and
   - Public education (educating drivers as to proper use of ATM measures).
3. There do not appear to be major technical or technology hurdles to the implementation of ATM.

The author also concludes that the most likely initial applications of ATM technologies are primarily freeway related: shoulder lane use, speed harmonization, adaptive lane controls, and high-occupancy/toll (HOT) lanes. However, these conclusions overlook available or soon-to-be-available arterial ATM technologies and measures.

Synthesis of Active Traffic Management Experiences in Europe and the United States

Chuck Fuhs' (2010) *Synthesis of Active Traffic Management Experiences in Europe and the United States* focuses primarily on European and U.S. experience with speed harmonization (including advanced queue warning), shoulder management, lane management (occupancy and pricing controls), junction control (ramp metering), traveler information, and dynamic rerouting.

The author defines ATM as follows:

> Active Traffic Management is generally regarded as an approach for dynamically managing and controlling traffic demand and available capacity of transportation facilities, based on prevailing traffic conditions, using one or a combination of real-time and predictive operational strategies. When implemented together with traditional traffic demand management strategies, these operational strategies can help to maximize the effectiveness and efficiency of a roadway and result in improved safety, trip reliability and throughput.

The report focuses on controlled access facility applications, and even when discussing dynamic rerouting, traveler information, or corridor/system management, the report focuses exclusively on controlled access facilities within the corridor or system.

Several state DOT implementations (or planning studies) of ATM are identified (Colorado, Florida, California, and North Carolina), but the descriptions focus exclusively on controlled access facilities.

Several recommendations are made to facilitate ATM implementation in the United States, many of which apply to agencies considering joint freeway/arterial ATM and exclusively arterial ATM strategies:

1. Provide for continuous (24-hour) operations of ATM measures so that the measures can be activated any time they are needed.
2. Reach out to stakeholders, public, and government officials to educate, inform, and obtain their continuing support for ATM measures.

3. Coordinate with law enforcement and key partnering agencies.
4. Create a Concept of Operations Plan to provide clarity to all parties on the ATM operation.
5. Integrate with intelligent transportation system (ITS) infrastructure.
6. Improve analysis and review.
7. Obtain approval for experimental traffic control devices.
8. Coordinate with other states and partnering agencies.
9. Coordinate ATM measures with traffic demand management (TDM) efforts.

MONITORING ARTERIAL OPERATIONS

Freeway-based performance data, such as vehicle counts, occupancy, speed, and travel time, have been collected for a while in places such as California, through their Performance Monitoring System (PeMS) (Choe et al. 2002), and Portland, Oregon, through the Portland Oregon Regional Transportation Archive Listing (PORTAL) (Intelligent Transportation Systems Lab, Portland State University 2006). In recent years, agencies have begun to see the value in collecting performance data on arterial roadways. There are many applications of historical and current data on what is happening on local arterials. Potential uses for archived and real-time data include:

- Real-time data can be used to quickly spot abnormal conditions on the arterial;
- Data can be used to calibrate travel demand models;
- Archived data and current data can be used to see the effects of signal timing changes or other modifications to arterial traffic operations;
- The data provide the ability to calculate travel time on key corridors for disseminating to the general public;
- Archived vehicle counts can be reviewed for historical trends to better predict future conditions and develop better timing plans; and
- The data can be used in a fully adaptive signal system to control all signals for current conditions rather than using time-of-day plans based on average days.

Conventional and advanced arterial monitoring technologies can be divided into those technologies that count volumes or measure performance at specific spots of the facility, and technologies that measure performance over the length of the facility (Middleton et al. 2003).

Spot performance measurement technologies include inductive loop detectors, magnetometers, radar detectors, and video cameras. These devices detect vehicle presence through various methods and can use this information to count traffic volumes and estimate spot speeds over the limited detection ranges of these devices.

Probe technologies include Bluetooth detectors, Wi-Fi detectors, cell phones, toll tags, and other global positioning system (GPS) tracking devices, and license plate readers. These devices match vehicles observed at different points on the facility and measure the elapsed time or track the position of GPS units within the vehicles over a broad geographic area.

In the *National Traffic Signal Report Card* (ITE 2012), 241 agencies representing slightly less than 40% of the traffic signals in the United States rated themselves with a grade of failing (F) for traffic monitoring and data collection. Almost half of the responding agencies reported that they did not have a satisfactory ongoing program for performance monitoring. Two-thirds did not have some process to archive traffic data.

CONTROL TACTICS

State and local agencies traditionally have focused their arterial management efforts on signal control. Signalized intersections are the critical bottlenecks of arterial operation, and it is logical for an agency to focus the majority of its efforts on those bottlenecks.

In the *National Traffic Signal Report Card* (ITE 2012), public agencies rated themselves with grades of C/D for traffic signal management, operation, and signal timing practices. Close to three-quarters of respondents reported that they have strong or outstanding procedures for timing traffic actuated controllers. The Report Card does not report separately on the use of traffic responsive and adaptive control.

Signal Control Options

Because there is extensive literature on actuated, responsive, and adaptive signal control [see FHWA's *Traffic Signal Timing Manual* (Koonce 2008)], this report briefly covers general signal control tactics here before devoting more attention in the following subsections to specialized signal timing plans and signal priority.

The first efforts at signal control focused on developing different signal timing and coordination plans for recurrent congestion during the peak periods of the day.

Later, traffic actuated control was established, which allows signal controllers to vary green times and yield points depending on side street and main street detected demands and pedestrian calls. The controller may vary the cycle length (within the constraints of maximum green times set by the operator) if the system is operating in uncoordinated mode; however, if coordination mode is activated, the controller is not allowed to vary the cycle length.

Traffic responsive control uses a library of prepared signal timing plans that have been developed for specific situations. Individual plans are activated when the system detects the appropriate condition in the field.

Traffic adaptive control is the technique by which the system controller is given maximum flexibility to identify appropriate green times and offsets on the fly, in real-time mode. According to *NCHRP Synthesis 403* (Stevanovic 2010), there are more than 25 adaptive traffic control systems operating in the United States. For more details on ATM strategies related to signal control, the reader can consult *NCHRP Synthesis 403.*

Specialized Signal Timing Plans

Specialized signal timing plans are developed by agencies to deal with special events, including major sporting events [see FHWA's *Traffic Signal Timing Manual* (Koonce 2008)]. In some installations, the specialized plans can be called up only by time of day (or manually by maintenance personnel). With more controllers with communications capabilities, it is now possible for the agency to more quickly command specialized timing plans in response to conditions that may not be readily apparent to the local controller, without having to dispatch maintenance personnel to the site.

One example application of special signal timing plans is in Salt Lake Valley, Utah. The Utah DOT implements a specialized signal timing plan for inclement weather because the agency found saturation flow rates, speeds, and start-up lost times decrease by 20%, 30%, and 23%, respectively, when snow and slush accumulate on the roadway surface (Perrin et al. 2010). These specialized signal timing plans account for the performance impacts of weather and readjust to maintain arterial signal coordination in the Salt Lake Valley. The decision to implement the plans is based on storm severity, projected duration, area of influence, and projected running speeds.

Signal Priority/Queue Jump

Signal priority is an intermediate step between normal signal operations and full preemption of the traffic signal, as occurs at railroad/highway at-grade crossings (Koonce 2008). Unlike preemption, signal priority does not override the signal controller to force an immediate phase change to allow the vehicle with preemption to quickly get through an intersection. Signal priority works within the existing signal control plan to provide improved operations for certain vehicles, such as transit vehicles. This typically is done by extension of the green time when a vehicle with signal priority is detected or beginning the green phase earlier in anticipation of the arrival of one of these vehicles. There are other options as well.

With Queue Jump, separate signal heads are provided for the transit lanes and the other lanes of an approach. The signal displays a green to the transit lanes before it does the same for the other lanes of an approach. The effect is to let the transit vehicle move to the head of the platoon discharged by the signal.

Signal preemption, although providing reduced delays to priority vehicles, does have adverse effects on all other traffic until the signal controller recovers to its original plan, which can take several cycles. By working within the signal timing plan, signal priority is able to provide reduced delay while affecting other traffic no more than necessary. The traditional use of signal priority has been by transit vehicles and often is called transit signal priority (TSP). In addition to TSP, there is emerging use of signal priority, rather than signal preemption, for emergency vehicles. Both of these uses will be discussed in this section.

Some benefits, as reported in *Transit Signal Priority (TSP): A Planning and Implementation Handbook* (Smith et al. 2005), include:

- In Tacoma, Washington, the combination of TSP and signal optimization reduced transit signal delay approximately 40% in two corridors.
- TriMet (Portland, Oregon) was able to avoid adding one more bus by using TSP and experienced a 10% improvement in travel time and as much as a 19% reduction in travel time variability. Because of increased reliability, TriMet has been able to reduce scheduled recovery time.
- In Chicago, PACE buses realized an average 15% reduction (3 minutes) in running time. Actual running time reductions varied from 7% to 20%, depending on the time of day.
- With the implementation of TSP and through more efficient run cutting, PACE (Chicago) was able to realize a savings of one weekday bus while maintaining the same frequency of service.
- Los Angeles experienced as much as a 25% reduction in bus travel times with TSP.

An article (Rinkerton 2005) on TSP implementation in San Francisco's East Bay included an interview with the transportation manager for the local transit service, who said, "A 17 per cent reduction in actual travel time is a significant improvement in system efficiency that was produced within the existing infrastructure."

There are two main pieces to a TSP system. The first is the detection system that lets the controller know that a transit vehicle is requesting priority. Typical detection systems include infrared devices, inductive loops, radio, strobe lights, and video detection. Infrared devices place an infrared emitter on the transit vehicle and an infrared detector at the signal. As the vehicle with the infrared transmitter gets within range, it alerts the signal to the presence of the vehicle (and for more advanced systems gives vehicle identifying information that enables the system to determine the "need" for priority). Inductive loops are used mainly on streetcar/light rail systems. The inductive loop is placed on the track near the signal, and when the train activates it, the signal is alerted to the train's presence. Video detection is similar to the inductive loop but uses video to detect a transit vehicle either on the track or in the bus-only lane. The final technology is radio based and is one of the newer methods. A short-range radio is coupled with a GPS device onboard the vehicle to transmit its location, allowing the system to know the presence of the vehicle and the need for priority.

The second part of a TSP system determines the need for priority and how to grant priority based on the programmed priority control plans (Smith et al. 2005).

The TSP handbook contains interviews with 24 agencies performing TSP. One of the interview questions concerned lessons learned. The responses include:

- Early stakeholder involvement is critical.
- Good communication among the stakeholders is important.
- One or more champions are needed to move the project forward.
- Demonstrations and pilot projects help test the TSP and build trust for full implementations.
- Good before and after studies can produce convincing evidence of benefits.
- Pitching the right ideas from the beginning can help ensure success.
- Interjurisdictional partnerships will help with coordination and implementation.
- It is important to keep the momentum going even when problems surface.
- Standardizing equipment will save time and money in the long run.
- Keep the project simple, especially in the beginning.
- It helps to remember to keep TSP objectives simple and build incrementally.

Although emergency vehicle preemption is employed frequently, an emerging application of signal priority is for emergency medical services (EMS) vehicles. Rather than going to full preemption, agencies such as that of Harris County, Texas, where Houston is located, are experimenting with emergency vehicle priority. This operates much the same way as TSP but relies mainly on radio transmitters and GPS. Emergency vehicles are equipped with a module for tracking and transmitting vehicle data to the signal controller. The module notifies the signal of an approaching EMS vehicle, allowing the signal to adjust the phase to allow the emergency vehicle to get through the signal on a green light.

GEOMETRIC CONFIGURATION TACTICS

Arterial geometric configuration tactics for actively managing arterial operations include dynamic lane assignments, dynamic turn restrictions, and reversible lanes.

Dynamic Lane Assignments

Generally, lane use at intersections is determined based on peak-hour traffic volumes and is designated by pavement markings and static signage. However, travel demand can change significantly between the morning and afternoon peak or at any other time of the day. Dynamic lane assignment is a tool that can be used by agencies to meet variable demand, or it can be used in areas experiencing heavy congestion owing to incidents or special events.

Dynamic lane assignment works by allowing agencies to change lane assignments to meet different traffic demands. For example, an approach with heavy left-turn movements in the morning peak can operate with dual left-turn lanes during that peak period. Later, the second left-turn lane can be changed to a through movement once the left-turn demand has abated. These lane assignment changes usually are implemented through the use of changeable overhead signs, such as those shown in Figure 3.

A survey of AASHTO (Hardt 2009) found that 11 of 33 states responding to the survey had tried dynamic turn lane installations. Six of those were still operating at the time of the survey in June 2009. Specific comments received from state DOTs regarding dynamic turn lane assignment included the following:

- One agency found that a significant improvement in level of service (LOS) was achieved. The LOS grade would have been "F" without the lane use change.
- Another agency found that there was no negative impact to traffic when lane use control was utilized.
- Another agency noted that the use of the variable lane was supported locally because it eliminated the need for

FIGURE 3 Example of dynamic turn lanes installation. *Source*: FHWA-HRT-06-095 (Urbanik et al. *Coordinated Freeway and Arterial Operations Handbook,* 2006).

a police officer to manually control the signal operation. The agency reported no complaints regarding motorist confusion.

- Another agency noted that no changes in accident data were observed or reported.
- One agency commented that complaints developed in the neighborhood about lane control creating a "speedway" for out-of-town commuters. There were also some instances of wrong-way driving.
- Another agency found that during special events, such as a concert, the dynamic lane use was very effective in moving the heavy left-turn volume.
- In another instance, an agency reported that the lane use changes during the afternoon commuter period could cause excessive through volume delay and queues.
- When implementing left-turn and right-turn dynamic lane assignment, one agency found that the dynamic right-turn lane showed no statistical improvement, whereas the dynamic left-turn lane showed some improvement. The findings were not consistent, varying for different geometric and traffic configurations.
- One agency found some negative reaction at first. They recommended that traffic signal timing should be considered during the reduction of through lanes to make sure traffic does not back up appreciably. In addition, property owners with shops and gas stations near intersections reported negative impacts.
- Although one agency did not perform an LOS analysis, the agency reported that there was a significant improvement realized for the modified movement (from left-turn to through).
- One agency found that there was a lot of confusion for the first 6 months or so as drivers figured out which lane they could/should use. The agency did not receive much in the way of complaints or support. However, the lanes were in use for only about a year and a half until the permanent dual-left/dual-through configuration was built.
- One agency found an increase in rear-end collisions after implementation.

The Texas Transportation Institute (TTI) performed a study (Voight and Goolsby 1999) on dynamic lane assignments at three intersections along the frontage roads of US-290. Their general conclusions were:

- The benefits of dynamic lane assignments were mixed. Some locations showed reduced delays, queues, and lane balance. However, some locations showed that improved lane balance led to increased delays, especially for right-turn applications.
- The anticipated statistically significant approach delay reductions were not observed at the three locations studied.

However, a later study by the same authors (Voight and Goolsby 2000) found significant benefits (as much as 25% reduction in delays) at the same locations when dynamic turn lane assignments were used as part of an incident management program.

Dynamic Turn Restrictions

Intersection turn restrictions, such as no right turn on red or no U-turn, generally are implemented at an intersection through static signage that leaves the restriction in place at all times. Left turns may be prohibited during peak hours. Dynamic signing enables agencies to impose these restrictions only when needed, not by time of day.

Dynamic turn restrictions provide the ability to restrict certain turning movements only when necessary to improve the safety and operations of the intersection. Rather than restricting right turns for the entire day, a dynamic no-right-turn-on-red sign can illuminate during the left-turn phase, providing improved safety without affecting intersection operations more than necessary. Some other possible applications of dynamic turn restrictions from the FHWA report *Innovative Intersection Safety Improvement Strategies and Management Practices* (Hughes et al. 2006) include:

- Prohibit right turn on red only during the cross street's left-turn phase to help accommodate heavy U-turn volumes. The restriction would not be in effect when the cross street through movements are running.
- Improve safety by prohibiting right turn on red only when the opposing left turn is running a lagging left-turn phase. One example of this is in Livingston County, Michigan. The sign illuminates only when the opposing left turn has a green arrow (see Figure 4), thus reducing conflicts between right turns on red and the opposing left turn.
- Dynamic turn restrictions at intersections where pedestrians have their own phase (pedestrian exclusive phase) or there are heavy pedestrian volumes. Right turn on red is restricted during this exclusive pedestrian phase to reduce conflicts but can be allowed during the cross street through movement. Figure 5 shows an installation with a pedestrian scramble phase. Right turn on red is prohibited from 7 a.m. to 7 p.m.
- Dynamic turn restrictions at intersections with transit trains running through them. An arterial roadway with a light rail running down the center can allow permitted left turns across the tracks at intersections except when a train is nearby. When this happens, a blank-out sign can illuminate with the left turn restriction until the light rail train has passed (see Figure 6). This removes the threat of vehicles turning in front of the train.

Dynamic turn restrictions are particularly implemented in the vicinity of signalized intersection railroad grade crossings. According to Section 8B.08 of the *Manual of Uniform Traffic Control Devices* (FHWA 2009), "At a signalized intersection that is located within 200 feet of a highway-rail grade crossing, measured from the edge of the track to the edge of the

FIGURE 4 Example of a dynamic right-turn-on-red restriction, at intersection of Ninth and Franklin Street, Oakland, California (2012). *Source*: Kittelson & Associates.

roadway, where the intersection traffic control signals are preempted by the approach of a train, all existing turning movements toward the highway-rail grade crossing should be prohibited during the signal preemption sequences." As an option, "A blank-out or changeable message sign and/or appropriate highway traffic signal indication or other similar type sign may be used to prohibit turning movements toward the highway-rail grade crossing during preemption" (see Figure 6).

Another version of dynamic turn restrictions was found in Portland, Oregon, at the intersection of two one-way streets, where one street has a trolley line (Hughes et al. 2006). Two blank-out fiber-optic signs are displayed. One says "No Turn on Red" and the other says "Train." When a trolley is present,

FIGURE 5 Dynamic turn restriction signs for rail crossings.

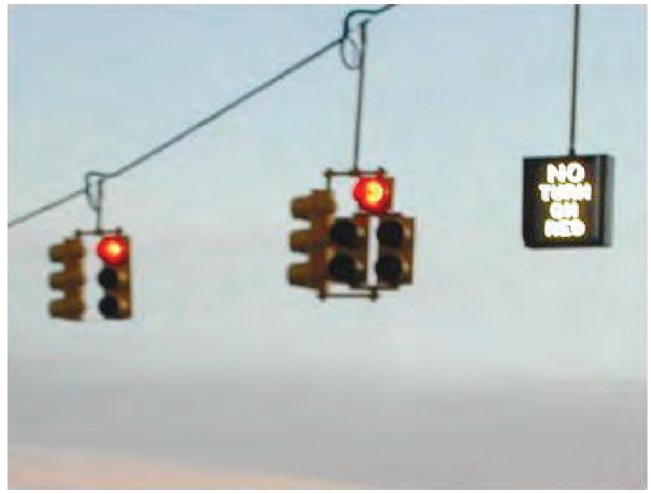

FIGURE 6 Dynamic no-turn-on-red installation in Livingston County, Michigan. *Source*: Hughes et al. 2006.

right turns on red are prohibited (see Figure 7). When no trolley is present, right turns on red are allowed. This extra protection is required because the trolley is turning right from a left hand lane while the signal is red. Right turning drivers would not be expecting this, so the dynamic turn restriction signs are needed.

Reversible Lanes

Many arterials have significant volume differences between the peak and off-peak directions. This usually results in one direction becoming oversaturated and congested while the other is far below capacity. One solution to addressing this imbalance is to implement reversible lanes on the arterial.

Reversible lanes allow for increased capacity in the peak direction by changing the directional flow of certain lanes. For example, a three-lane facility can have a center reversible lane that is always flowing in the peak direction. A morning commute with heavy eastbound demand can have two lanes headed eastbound and one headed westbound. This can then be reversed for the afternoon commute, with two lanes westbound and one eastbound. These reversible lanes usually are

FIGURE 7 Train-related dynamic turn restriction, Portland, Oregon. *Source*: Hughes et al. 2006.

FIGURE 8 Example of reversible arterial lane in Charlotte, North Carolina. *Source*: *NCHRP Synthesis 340* (Wolshon and Lambert 2004).

designated with overhead signs and special pavement markings, as shown in Figure 8.

NCHRP Synthesis 340 (Wolshon and Lambert 2004) concluded that practitioners and researchers generally have agreed on five criteria to determine if a reversible lane is warranted. These criteria include:

1. Volumes at or in excess of capacity;
2. Predictable patterns of high demand and/or congestion;
3. Limited right-of-way (or ability to acquire it) to construct additional lanes;
4. Ratios of major street volume to minor street volume of about 2:1 or greater; and
5. Lack of capacity or mobility on adjacent parallel streets.

NCHRP Synthesis 340 (Wolshon and Lambert 2004) also established four general requirements for making effective use of reversible lanes:

1. Segment entry and departure conditions that permit a high utilization of additional lanes;
2. Ability to maintain at least two lanes (or at least one through and one turning lane) in the minor-flow direction;
3. Predominantly through traffic; and
4. Relatively low percentage of heavy vehicles in the minor-flow direction.

Almost all agencies surveyed in *NCHRP Synthesis 340* reported no significant safety issues or driver confusion related to the reversible lanes. Overall driver response was positive, and the responding agencies found reversible lanes were not as complicated, controversial, or dangerous as may have been thought before implementation of the lanes. Table 1 lists the still active reversible lane installations on arterials that were identified in the *NCHRP Synthesis 340.*

Another study (TransCore 2005) on reversible lanes was performed in Tucson, Arizona, where a before and after study was done on the demand and safety impacts of removing the reversible lane. With regard to traffic demand, the study found that traffic volumes before the reversible lane was removed were significantly higher than after. The authors were unable to explain why the volumes dropped. They also found no trends in the traffic volumes to suggest a major redistribution of corridor traffic resulting from the reversible lane's removal.

The safety part of this study found the following:

- The number of crashes and the crash rates declined slightly after removal of the reversible lanes. Crashes declined by approximately 14%, while the crash rate (crashes per million vehicle miles of travel) decreased by about 10%. However, the authors note that the rates would have been similar had drivers not disregarded the no-left-turn prohibition that was in place while the reversible lanes were operating.
- Crash reductions were not uniform across the whole corridor. Some intersections had significant reductions, whereas others actually had an increased number of crashes with the removal of the reversible lane.
- Crash severity did not appear to change after the removal of the reversible lane.

DEMAND MODIFICATION TACTICS

Demand modification tactics for arterials include simple arterial travel speed information dissemination, dynamic route guidance (a more proactive form of information dissemination), and dynamic parking information/pricing.

An areawide dynamic entry toll, such as is employed in downtown London, England (Department of Transport 2010; Transport for London 2012), is another tactic for modifying arterial street demand. No U.S. examples of such a tactic were identified in the literature review, so the tactic is not discussed further here.

Arterial Travel Information Dissemination

Arterial travel information is disseminated to the public in the hopes that a better-informed traveling public will shift its demand to other hours, other routes, and other modes of travel to better balance congestion on the street network. The primary means used by agencies today to distribute data are dynamic message signs (DMSs) on the arterials, web pages, and mobile devices.

Some agencies make raw arterial travel time data available to resellers, which distribute the information to their subscribers. With raw data feeds, an agency makes available in electronic form simple tabular data listing the street, direction, segment, and average speed by time of day. The data are not mapped by the agency.

The city of Bellevue, Washington, for example, uploads arterial data to a file transfer protocol (FTP) site that is

TABLE 1
EXAMPLE ARTERIAL REVERSIBLE LANE INSTALLATIONS IN THE UNITED STATES

City, State	Name	Length (mi)	Control	Use
San Diego, California	State Route 75	2.3	Moveable barrier	Weekday peak periods
Washington, DC	Canal Road	3.0	Roadside signs/signals	Weekday peak periods
Washington, DC	Connecticut Avenue	2.5	Roadside signs/pavement markings	Weekday peak periods
Washington, DC	Rock Creek Parkway	4.0	Roadside signs and traffic enforcement police	Weekday peak periods
Lexington, Kentucky	Nicholasville Rd.	2.6	Overhead signs/signals	Weekday peak periods
Baton Rouge, Louisiana	Highland Rd.	1.5	Traffic enforcement police	LSU football games
Ocean City to U.S. 50 Maryland	MD-90	11.0	Traffic enforcement police	Hurricane evacuation
Washington, DC Metro Area, Maryland	MD-97 Georgia Ave.	0.5	Pavement markings	Weekday peak periods
Washington, DC Metro Area, Maryland	US-29 Colesville Rd.	1.0	Overhead signs/signals and pavement markings	Weekday peak periods
Anne Arundel County, Maryland	MD-77 Mountain Rd.	1.5	Overhead signs/ signals and pavement markings	Weekday peak periods
Baltimore, Maryland	Erdman Ave.	1.0	Overhead signals and pavement markings	Weekday peak periods
Baltimore, Maryland	Hanover St. Bridge	0.5	Overhead signals and pavement markings	Weekday peak periods
Washington, DC Metro Area, Maryland	US-29	4.0	Transit bus on shoulders, none	Weekday peak periods
Washington, DC Metro Area, Maryland	Brightside Rd.	0.75	Overhead signs/signals	NFL football games
Charlotte, North Carolina	7th St.	1.0	Overhead signs/signals	Weekday peak periods
Dennis Twp. to Maurice River Twp., New Jersey	NJ-47/NJ-347	19.0	Traffic enforcement police	Hurricane evacuation
Ship Bottom Borough to Southampton, New Jersey	NJ-72/NJ-70	29.5	Traffic enforcement police	Hurricane evacuation
Mantoloking Borough to Pt. Pleasant Beach, New Jersey	NJ-35	3.5	Traffic enforcement police	Hurricane evacuation

Adapted from Wolshon and Lambert (2004), Table 1. Note that there have been additional installations and removals of reversible lanes since the date of that study.

available to all. Using this kind of information, developers can create their own traffic mobile applications (apps) or use the data for other applications, such as traffic avoidance technology for GPS systems. This type of information dissemination requires little from the agency other than the hosting of an FTP site for data access.

DMSs have been widely used on freeways for many years. They often provide travel times to specific destinations and alerts to special traffic-related events, such as incidents and road closures. DMSs on arterial streets work in much the same way, with travel times to key destinations posted when available along with information on any impacts to arterial travel (see Figure 9). These devices keep drivers informed of current conditions and can suggest alternatives in the case of road closures.

San Francisco Muni (NextBus, Inc. 2012) and Portland Metro (NextBus, Inc. 2012) are examples of transit systems using arterial travel times to report when the next bus or light rail vehicle will arrive at the transit stop, either through the web or by means of electronic signs installed at major bus stops.

Web and Mobile Devices

Web pages are one of the primary ways agencies are disseminating travel time information along arterials to the public. These web pages usually contain a map of specific areas with a color-coded overlay of arterial conditions along

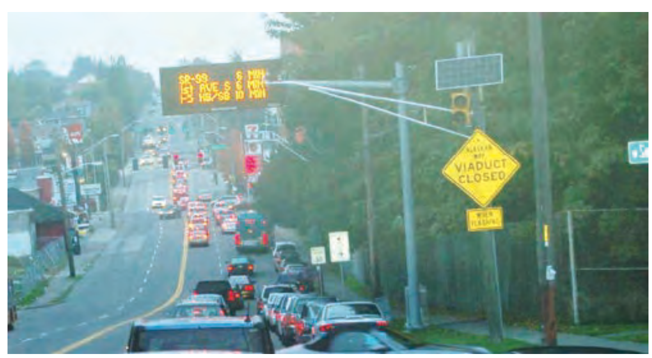

FIGURE 9 Example DMS travel time display; point-to-point travel times at 35th Avenue SW and SW Snoqualmie Street, Seattle, Washington. *Source*: Seattle DOT, http://sdotblog.seattle.gov/2010/10/page/2/.

major arterials. The color codes usually are green, yellow, and red, with green being free-flow conditions and red indicating heavy congestion. Some agencies also use other color codes to indicate traffic moving faster than the indicated speed limit (blue, for example) or a color code for severe congestion with extremely long delays (alternating red/black, for example).

The Los Angeles DOT makes arterial speed data available to the public by means of the web (Los Angeles DOT 2012). Arterial speeds are computed from the occupancies of the Automated Traffic Surveillance and Control (ATSAC) system's midblock, advanced loop detectors. The loop detector speeds are assigned to signalized intersection approach links. Speeds are indicated as high, medium, or low using a green (20+ mph), yellow (10–20 mph), and red (0–10 mph) color code (see Figure 10). The display also indicates road construction, filming sites, special events, and natural disasters. Traffic advisories and road closures also are posted. The city is split into 22 community maps for display purposes. The website is http://trafficinfo.lacity.org/.

Mobile Devices

One form of information dissemination using mobile phones requires the user to call an automated telephone number to find out local travel conditions. Many areas have a service such as 511 that can be called to receive roadway information (see the San Francisco Bay Area's website http://511.org, for example) (San Francisco Metropolitan Transportation Commission 2012).

The advent of smartphones has allowed agencies to develop mobile applications that allow users to check local arterial travel data. These mobile apps are similar in concept to the web pages but optimized for the smaller screen of a smartphone. They generally provide the color codes described previously and can have links to other items of interest, such as live traffic cameras. Washington State DOT, for example, developed such an application, and a screenshot is shown in Figure 11.

Dynamic Route Guidance

Dynamic route guidance is a proactive approach to information dissemination and ultimately demand management. It is an ITS technology that is designed to be of most help in the event of nonrecurring congestion. Most drivers will have sufficient knowledge from their own experience to make their route choice decision. However, an incident or weather can rapidly change the situation.

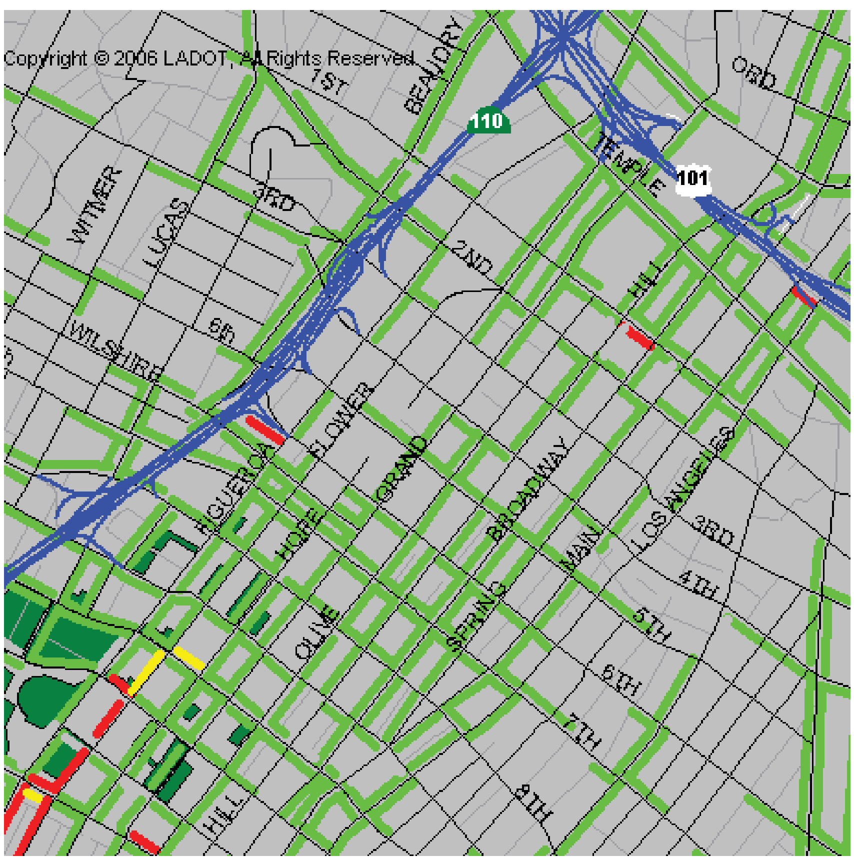

FIGURE 10 Example display of arterial travel speeds. *Source*: City of Los Angeles, http://trafficinfo.lacity.org/ (accessed July 2, 2012).

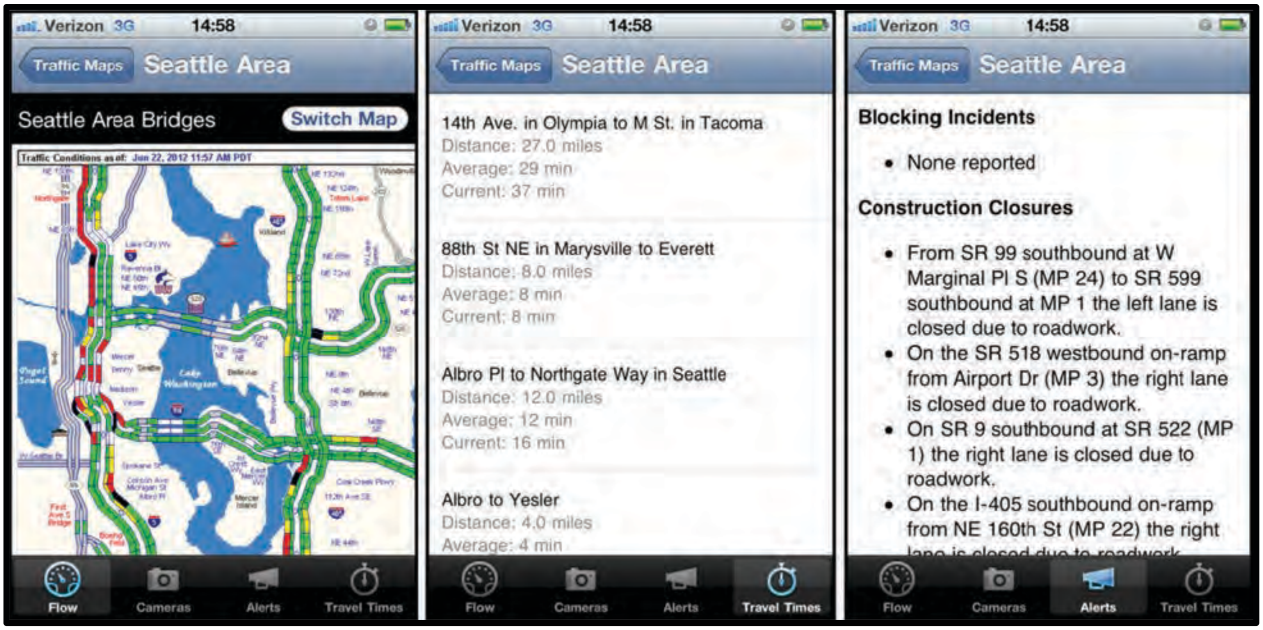

FIGURE 11 Screenshots of mobile app developed by Washington State Department of Transportation. *Source*: Washington DOT Smartphone application.

Dynamic route guidance has been used on arterials to direct traffic that has been detoured off the freeway for reasons such as an incident or special event. An example is the use of DMSs deployed at key intersections near the I-4 and I-95 interchange in Florida. These signs are used to direct traffic that has detoured off of these two freeways because of an incident or to provide path guidance for events occurring at the Daytona International Speedway.

The *iFlorida Model Deployment Final Evaluation Report* (Haas et al. 2009) provides an example of the usefulness of these arterial route guidance signs when a police incident closed the Interstate after the Daytona 500 race at the Daytona International Speedway. The presence of these signs allowed the Florida DOT to identify diversion routes and post information on the arterial signs to redirect travelers along the diversion routes. Florida DOT received many compliments on the usefulness of these signs from those attending the event.

An example of dynamic route guidance implemented on a freeway facility that could also be relevant to arterial dynamic route guidance can be found in Florida. State Route 417 is a toll facility that bypasses downtown Orlando, whereas Interstate 4 runs directly through the downtown area. SR-417 is longer by about 15 miles but is often much less congested than I-4. When the automated system detects significant congestion on I-4 and calculates that travel times will be faster on SR-417, a DMS will notify drivers near the I-4/SR-417 interchanges that SR-417 will result in a faster travel time if traveling through downtown Orlando. Figure 12 provides an example of what this DMS displays at different times of day.

Dynamic Parking Management

Perhaps one of the newest ATM strategies used on arterials, dynamic parking management tries to manage the demand for parking spaces through variable parking rates and the dissemination of real-time parking availability. The goal of these programs often is to maintain at least one open parking space per block. Neighborhoods with high parking demand will have their parking rates increased, whereas neighborhoods with smaller demands will have decreased parking rates. The expected added benefits of managing parking using dynamic pricing are:

- *A better balance of on-street parking.* Streets with lower use will be cheaper and attract more vehicles. Streets with higher use will be more expensive and push some demand to the lower-priced streets.
- *Improved ability to find parking.* With a goal of at least one open space per block, parking will always be available on each block.
- *Reductions in greenhouse gases and delay.* With a goal of having open spaces on every block, vehicles will no longer need to circle the block, which will reduce greenhouse gas emissions and improve intersection delay.
- *Better access to local businesses.* Higher parking rates encourage more turnover, allowing more people to park closer to local businesses.

When it comes to setting the parking rates, there are two major ways of collecting and implementing these data, as illustrated by parking management programs in Seattle and San Francisco. Seattle uses a more traditional way of imple-

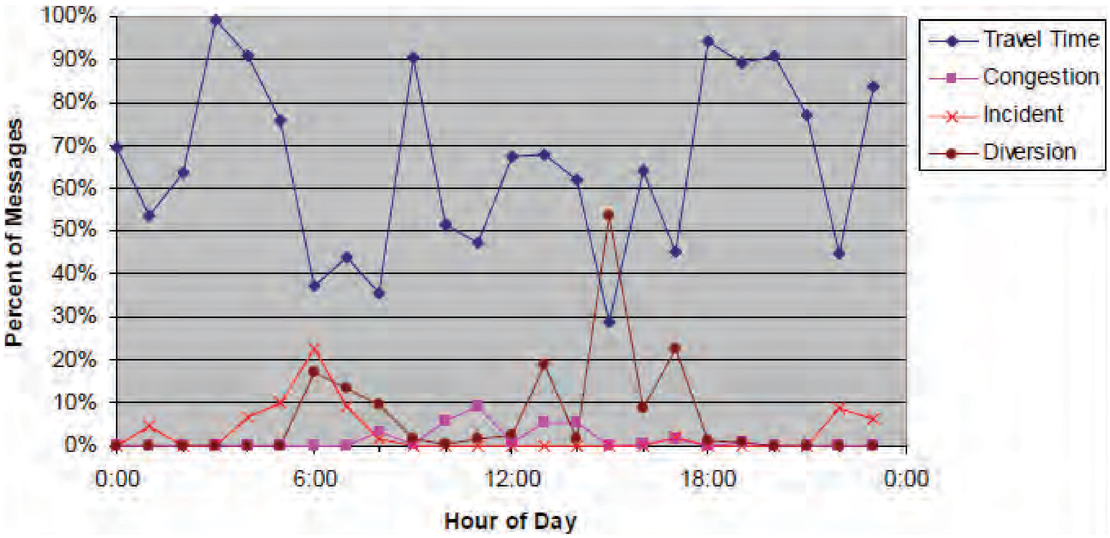

FIGURE 12 Displayed messages on a dynamic message sign. *Source*: *iFlorida Model Deployment Final Evaluation Report* (Haas et al. 2009).

mentation by manually collecting occupancy data about once per year. Seattle analyzes the occupancy data and then adjusts the rates either up or down if they are not meeting their desired occupancy thresholds. After the last round of studies, for example, Seattle increased rates in 18% of neighborhoods, left rates the same in 32%, and decreased rates in 50%. Rate changes are done on a yearly basis (http://www.seattle.gov/transportation/parking/performancepricing.htm).

San Francisco has implemented a dynamic parking strategy that heavily relies on automated data collection efforts. San Francisco's parking program, SF*park*, uses sensors in the pavement to automatically detect the occupancy of each parking space. The occupancy data are reviewed on a monthly basis, and the parking rates are either left alone if the occupancy is at the desired threshold or increased/decreased until the desired occupancy is met.

In addition to changing parking rates on a monthly basis, San Francisco can change parking rates by time of day. Parking rates during a morning period can be different than those in the afternoon. This recognizes that demand can fluctuate, not only block by block, but also hour by hour. Given the high level of technology implemented by San Francisco, the city is able to provide real-time parking information by means of a website and mobile application. Figure 13 shows an example

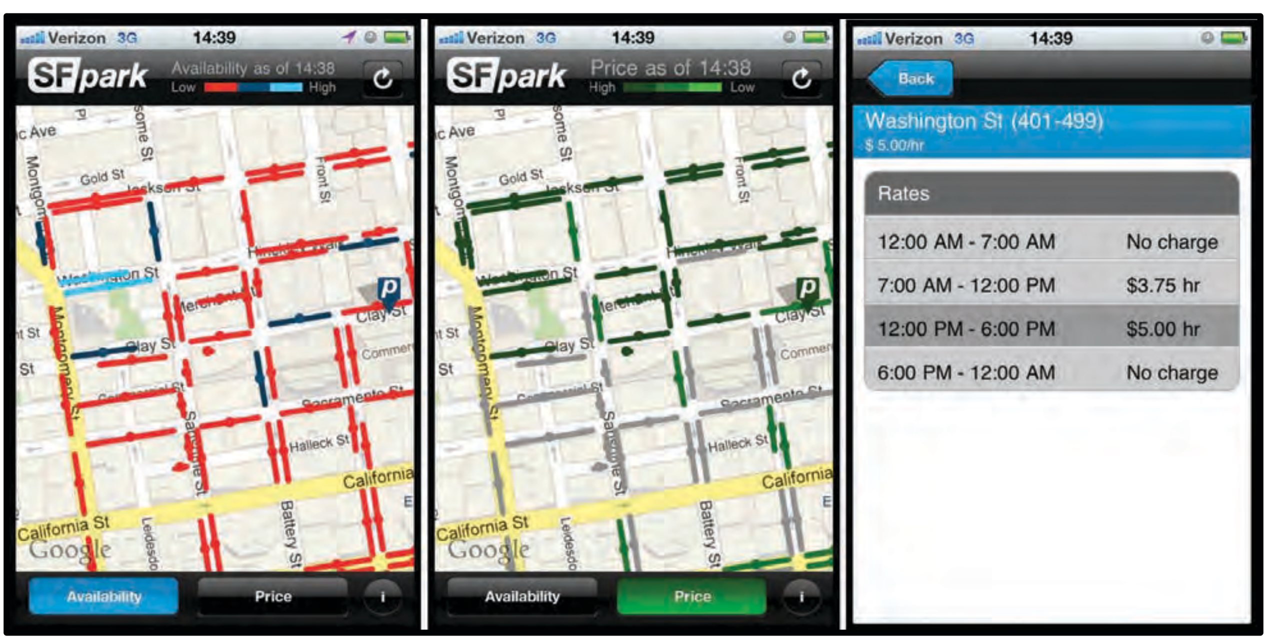

FIGURE 13 Screenshots of mobile app for SF*park.*

of the mobile app developed by SF*park*. As the figure shows, parking availability and price can be easily obtained by the public with the use of a smart phone.

COMBINING TACTICS INTO AN OVERALL ACTIVE TRAFFIC MANAGEMENT STRATEGY

ATM on urban arterials is a combination of measures and tactics combined into an overall management strategy for maximizing the productivity of urban streets under incident, weather, work zone, and special event conditions. One example of a city ATM strategy combining several measures and tactics is New York City's Midtown in Motion program (FHWA 2012).

The New York City Midtown in Motion program uses the tactics of monitoring, control, and traveler information. The first phase of the program was installed in July 2011. It consisted of 100 microwave sensors, 32 traffic video cameras, and E-ZPass readers at 23 intersections to measure traffic speeds. The city's Traffic Management Center (TMC) monitored congestion over the course of a year and used networked advanced solid state traffic controllers to remotely adjust Midtown traffic signal timings. Communication to the traffic controllers is wireless. The project also included the installation of exclusive turn lanes and turn arrows at 53 intersections. Measurements from the monitoring system plus monitoring of the movements of GPS-equipped taxicabs indicated that the improvements resulted in a 10% increase in average travel speeds on the avenues within the Midtown area. Traveler information is distributed by means of a web map and live camera feeds to the web (New York City DOT 2012).

FREEWAY CORRIDOR ARTERIAL TRAFFIC MANAGEMENT STRATEGY

The *Coordinated Freeway and Arterial Operations Handbook* (Urbanik et al. 2006) provides a planning/operations framework and identifies supporting ITS technologies for coordinating an arterial/freeway system. The handbook:

- Discusses the benefits of coordinating freeway and arterial operations.
- Explains how to develop a regional corridor management plan.
- Describes a planning framework and methods for overcoming institutional challenges.
- Defines a range of possible operations strategies, including traveler information, traffic management and control, and information/resource sharing by agencies.
- Discusses the ITS technologies that support coordinated operation.

The handbook presents strategies for incident management, work zone management, special event management, and day-to-day operation.

The handbook identified the following technologies for disseminating traveler information:

- Web pages
- Pagers/personal data assistants
- Telephones/511 services
- DMSs (fixed and portable)
- Commercial radio broadcast
- Commercial television broadcasts
- Highway advisory radio
- Citizens' band radios
- Dynamic route guidance signs (sometimes referred to as trailblazer signs)
- Kiosks

For traffic management and control, the handbook grouped measures into three categories: coordinated traffic signal timings, lane-use adjustments, and access control.

For the category of coordinated traffic signal timings, the handbook recommends extension of signal coordination across institutional boundaries and between freeway ramp meters and urban streets. Four different signal coordination strategies are identified: local traffic responsive coordination between ramp meters and adjacent signals, areawide integrated responsive coordination setting system ramp metering rates and signal timing, a diversion strategy for dealing with incidents, and a congestion strategy when traffic demand exceeds capacity on a portion of the corridor.

For the category of lane-use adjustments, the handbook recommends dynamic lane assignments on freeway frontage roads.

Finally, access control includes turning restrictions at signals, ramp metering, and ramp closure.

The shared information and resources strategy involves the sharing of agency resources and information between agencies. Information sharing can include text messages, e-mails, or video feeds.

FHWA Integrated Corridor Management Program is designed to encourage the coordinated management and operations of arterial streets and freeways within a corridor.

Examples of Coordinated Freeway/Arterial Operation

Minnesota DOT's Minneapolis Regional Transportation Management Center (Minnesota DOT 2012) and the Las Vegas Regional Transportation Commission FAST (Regional Transportation Commission of Southern Nevada) are two examples of regional transportation management centers with partial integration of arterial and freeway operations in a metropolitan area setting.

Minnesota DOT

The Regional Transportation Management Center (RTMC) provides a unified communications center for Minnesota DOT's Metro District Maintenance Dispatch and Traffic Operations with the Minnesota Department of Public Safety's State Patrol Dispatch. The center operates 450 CCTV cameras and 4,500 loop detectors posted along 340 miles of metro-area freeway. The center provides travelers and local reporters with information on incident location, speeds, and backups by means of 85 freeway electronic message signs, traffic radio, traffic TV, various Internet sites, and a telephone service. The FIRST service, in cooperation with the state patrol, locates, assists, and removes stalled vehicles.

The Minnesota DOT Metro District's Signal Operations unit is responsible for the operation and timing of the DOT's 635 traffic signals on the trunk highway system within the Twin Cities metropolitan area.

The RTMC acts as a central clearinghouse for arterial and freeway incident and operations information. Coordination between freeway and arterial systems primarily is through the communication of this information between the operators responsible for each system.

Las Vegas Regional Transportation Commission Freeway Arterial System of Transportation

The Regional Transportation Commission (RTC) of Southern Nevada's Freeway and Arterial System of Transportation (FAST) system both monitors and controls traffic in the Las Vegas metropolitan area. The transportation strategies of FAST are determined monthly by the Operations Management Committee, composed of the RTC, Clark County, Nevada DOT, and the cities of Henderson, Las Vegas, and North Las Vegas.

A combination of freeway sensors, Bluetooth detectors, and cameras is used to monitor freeway conditions. Ramp meters are used to control freeway operations. Real-time information on freeway speeds and incidents is displayed on the web. DMSs are used to communicate conditions in the field.

Traffic cameras are available primarily on the freeways, with about a dozen cameras monitoring key arterial intersections.

Coordination between freeway and arterial operations is achieved on a real-time basis through the exchange of information at the FAST center. Monthly meetings of the Operations Management Committee set the strategies for coordinating operations.

CHAPTER THREE

CASE EXAMPLES OF ARTERIAL ACTIVE TRAFFIC MANAGEMENT TACTICS

The previous chapter gave an overview of the literature on U.S. agency experience with and research into ATM tactics for arterials. This chapter provides more in-depth example cases of some of the more experienced agencies' applications of ATM measures on arterials.

SELECTION OF CASE EXAMPLES

A web-based screening survey sent to members of the ITE Traffic Engineers Council, the ITE Public Agency Council, the AASHTO Subcommittee on Traffic Engineering, the TRB ATM Joint Subcommittee, and the TRB Signal Systems Committee yielded 121 responses indicating varying degrees of experience with ATM implementations on arterials (see Table 2).

Entries are number of respondents according to their indicated degree of experience. Respondents to the screening survey were grouped according to their self-indicated degree of knowledge with each of nine possible categories of ATM measures on urban streets (see Table 2). Two or more agencies in each category (unless a lower response was received from the screening survey) who had indicated a high degree of experience with each ATM measure type were then selected for an in-depth phone interview regarding their lessons learned for that ATM measure. For categories in which more than two respondents indicated a high level of experience, the two agencies selected for interviews were selected based on cost-effectiveness (one agency interviewed for more than one category) and geographic diversity, when feasible. All candidates were contacted repeatedly until they responded. The interview was then conducted with that person or with an alternate person suggested by the candidate. Table 3 shows the 10 agencies interviewed by ATM measures.

Each agency was interviewed following a script based on the following seven questions:

1. Please describe how you are implementing this ATM strategy and where it is being applied.
2. What were the design considerations you looked at prior to implementation?
3. What types of technologies were implemented to facilitate this ATM strategy?
4. Were there any constraints (institutional, budget, technical, geographical) to implementing this ATM strategy?
5. What are the performance measures you use to gauge its effectiveness?
6. What were the outcomes of implementing this ATM strategy?
7. What were the primary lessons learned?

These seven questions are organized into three common categories for each of the agencies interviewed. The first category is background on the ATM strategy being used and corresponds to the first question asked. The second category covers design considerations, including technology and constraints, and correlates roughly to questions two through five. The final category is the outcomes and lessons learned for each ATM strategy, corresponding roughly to questions six and seven.

MONITORING TACTICS

Cobb County, Georgia, and the city of Bellevue, Washington, were selected for in-depth interviews regarding their experience with arterial travel time data collection.

Cobb County, Georgia

Overview

Cobb County uses Bluetooth technology to collect arterial travel time data. Currently, the county has 19 devices collecting data on three corridors within the county. One corridor is 6 miles long, and the other two are approximately 2 miles long. The county's Bluetooth vendor hosts a web page that the county staff can access to see the level of congestion on these three arterial roadways. The map uses a green, yellow, and red color scheme to report the level of congestion. In addition, Cobb County has a blue color code programmed to designate areas in which travel times indicate the speed limit is being exceeded.

The interviewee reported that the county has the ability to send information to the public and is currently using this feature on its website.

The project was funded by the Georgia DOT and was done as a pilot project for the state. Eventually, the agency wants to integrate Bluetooth and the CCTV cameras into

TABLE 2
SCREENING SURVEY RESPONDENTS' EXPERIENCE WITH ARTERIAL ATM MEASURES

ATM Tactics/Measures	None	Low	Medium	High
Arterial monitoring tactics				
Arterial travel data collection	24	35	37	25
Signal/Speed control tactics				
Specialized signal timing plans	30	36	31	24
Transit signal priority	63	29	20	9
Geometric modification tactics				
Dynamic lane assignments	96	12	10	3
Reversible lanes	87	12	12	10
Dynamic turn restrictions	77	23	18	3
Demand modification tactics				
Arterial travel information dissemination	54	38	19	10
Dynamic route guidance	77	26	12	6
Dynamic on-street parking	91	24	5	1

Entries are number of respondents according to their indicated degree of experience.

the Georgia NaviGAtor website (http://www.511ga.org/real timetraffic.html), which provides real-time traffic data for dissemination to the public. A screen capture of this website is shown in Figure 14.

Additional information can be found at the website http://dot.cobbcountyga.gov/.

Design Considerations

The main design consideration considered by Cobb County when implementing these Bluetooth readers was to have equipment in the signal controller that can send the data back to Cobb County and the county's Bluetooth equipment provider who manages their internal web page. To accomplish this, some of the controllers had to be updated to enable Ethernet connectivity.

In addition to the upgraded Ethernet connectivity, the primary technology implemented was the Bluetooth readers. These Bluetooth readers use the Ethernet connectivity of the signal controllers to send the travel time data back to Cobb County's Bluetooth vendor, which compiles the data and provides it to the county through a web page.

TABLE 3
AGENCIES INTERVIEWED FOR ATM MEASURES EXPERIENCE

ATM Tactics and Measures	Agency Interviewed
Performance monitoring	
Arterial travel data collection	Cobb County, Georgia City of Bellevue, Washington
Signal control tactics	
Specialized signal timing plans	City of Gainesville, Florida City of Anaheim, California
Transit signal priority	Harris County, Texas San Francisco Municipal Transportation Agency, California Utah DOT
Geometric tactics	
Dynamic lane assignments	Harris County, Texas
Reversible lanes	Utah DOT City of Roswell, Georgia
Dynamic turn restrictions	City of Overland Park, Kansas City of Bellevue, Washington
Demand modification tactics	
Arterial travel information dissemination, route guidance	City of Bellevue, Washington City of Seattle, Washington
Dynamic on-street parking	City of Seattle, Washington San Francisco Municipal Transportation Agency, California

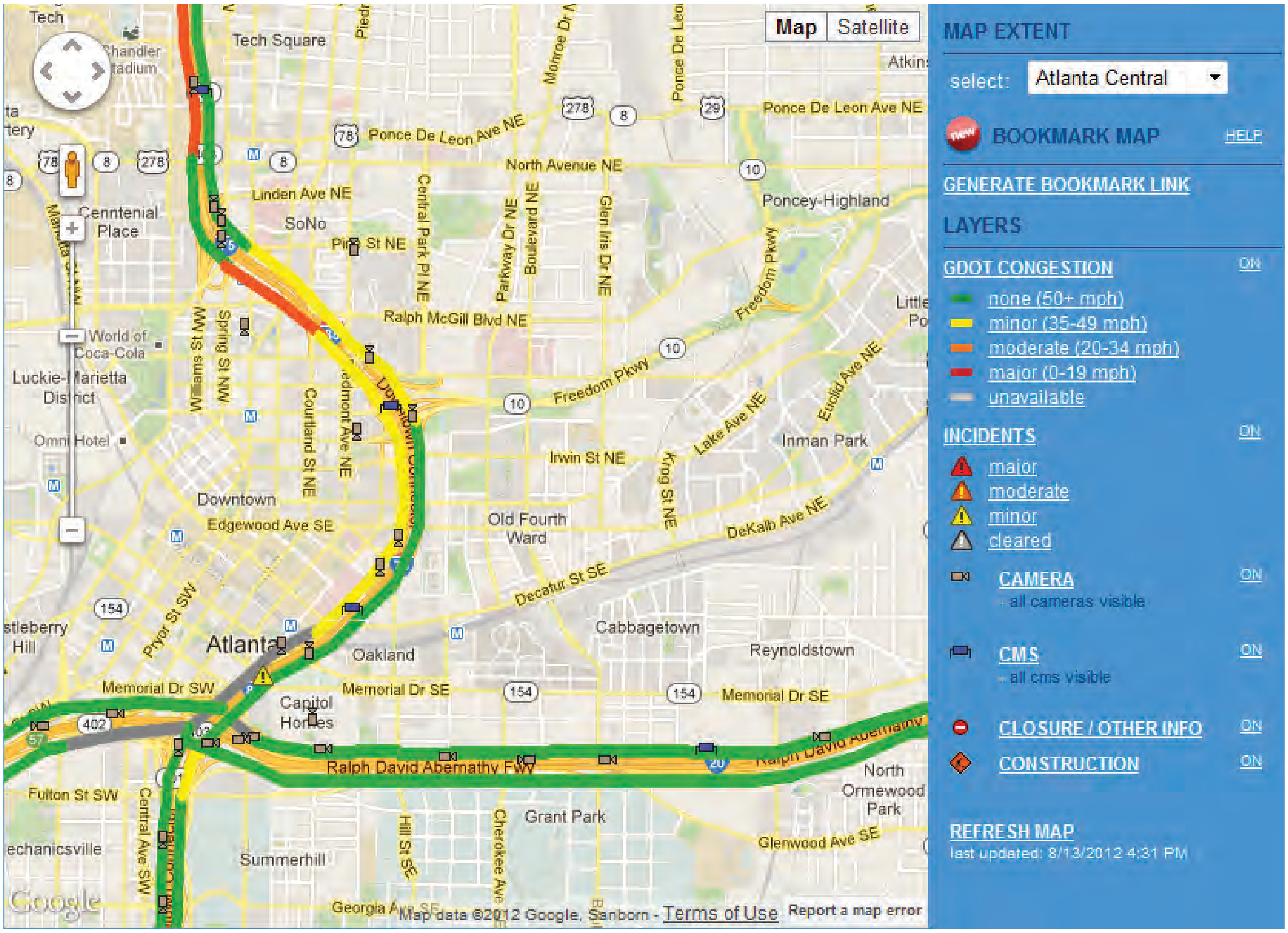

FIGURE 14 Screen capture of Georgia's NaviGAtor website. *Source*: Georgia 511, http://www.511ga.org/realtimetraffic.html (accessed August 13, 2012).

Cobb County reported that one of the biggest constraints in implementing its Bluetooth devices is having new signal controllers that can accommodate the Internet connectivity of the Bluetooth devices. However, only a small number of their signal controllers lacked Internet connectivity, minimizing the upgrade costs that would otherwise have been necessary.

Outcomes and Lessons Learned

Cobb County reports that the accuracy of the Bluetooth travel time devices is gauged by performing floating car travel time surveys on the corridor. During the phone interview, the Cobb County respondent reported that these travel time surveys for the Bluetooth devices and floating car runs have been similar. Given this similarity, the respondent indicated no reservations about the accuracy of the data reported by the new system.

The Cobb County respondent stated that the outcomes of the Bluetooth project have all been positive because now the county has the ability to do before and after analyses of signal retiming projects. This ability has already been used on several retiming adjustments. In addition, data provided by the Bluetooth devices is useful in getting real-time information on current traffic conditions. This allows the county to see issues and resolve them more quickly. The final outcome reported by Cobb County is an increased awareness by emergency services. This is because of the Bluetooth travel time data being sent to the 911 operations center, which can monitor traffic and locate potential incident locations more quickly.

One of the primary lessons learned from implementing this arterial travel data collection effort, as reported by the Cobb County respondent, was that it is important to size the system appropriately to the needs. On the 6-mile corridor, Cobb County has 11 devices, which are now deemed too many devices for the corridor. Sizing the system more appropriately would have saved money or allowed the setup of another arterial corridor with Bluetooth devices.

The second lesson learned is that it is important to be able to work with the Bluetooth vendors to custom tailor what is needed. Cobb County was able to work with the vendor to develop reports that would be most relevant to the data of most interest to the county.

City of Bellevue, Washington

Overview

The city of Bellevue uses for data collection more than 500 inductive system loop detectors around the city. These data are published to an FTP site that is used by a number of others, including the University of Washington for research purposes. Bellevue also recently went to a new adaptive signal control system that allows them to collect counts from every lane approaching the intersection.

The city of Bellevue reports one of the major benefits of this data collection capability is the ability to collect data at all times of the day and year. The city no longer has to guess at seasonal variations in traffic because they keep the collected data in a database. Bellevue reports one of the city's more recent uses for the collected data was to track diversion from SR-520, which was recently converted to a toll facility.

Bellevue's next step with regard to using the data being collected is to improve the accessibility of the data. The city recently hired an intern to write software to improve the accessibility of the data outputs. Once this is done, the city will begin phasing out some of the manual data collection efforts that have been ongoing for years. These manual data collection efforts include things such as publishing a traffic count book every year that contains afternoon peak hour volumes for the year. Bellevue also collected manual morning and midday counts every 3 years. The city's goal is to replace these manual data collection efforts with an automated system using the inductive loop sensors.

The city has also been collecting manual screen line counts using pneumatic tubes at various locations to validate travel demand models. Bellevue is beginning to replace these manual count locations with the automated ones. Every time a signal system is rebuilt near one of these screen line locations, the city makes sure the data collection system can replicate the manual tube counts.

The city has 110 intersections using advanced signal systems and plans to have 40 more by the end of 2013.

Additional information can be found at the city's website: http://www.ci.bellevue.wa.us/transportation.htm.

Design Considerations

The main design consideration reported by Bellevue was how to make use of all the data the city was receiving from the signal controllers with automated data collection. The ability to mine the data in a more user friendly way was the primary reason for hiring an intern, who could take all the data coming in from 110 signalized intersections and turn them into something useful for the city.

Bellevue reported that the city has experimented with a number of technologies, including inductive loops, video, and radar devices, to find one that best suits their needs. Of these three technologies, inductive loops were found to be the most reliable. However, the city reports new forms of video and radar, such as Forward Looking Infrared (FLIR) cameras and Wavetronix radar devices, are being studied. These devices are showing promise in meeting or exceeding the accuracy of the inductive loop technology currently used by Bellevue, the city reports.

The Bellevue respondents indicated during the interview that they contended with both technical and institutional constraints in implementing their arterial data collection network. Technical constraints were based primarily around having an older system that needed to be upgraded. The original system was able to report only eight loops of data for the whole intersection, which was not enough for full intersection coverage. The new adaptive system implemented by Bellevue can report as many as 24 loops of data. This allows the city to have lane-by-lane information for each intersection approach, giving them turn movement counts.

One of the main institutional constraints reported by Bellevue was a misunderstood technological issue near the beginning of the project implementation. This misunderstanding slowed acceptance of the new data within the organization. Initial testing found that the loop data and manual counts did not yield the same results. This problem eventually was tracked down to the lag between when loop data were collected and the time period for which the data were reported. For example, the controller does not report data until about 1 minute after it performed the count. This initially led people within the organization to think the new automated loops were not as accurate as they are because the lag time was unknown. Because it took time to determine this issue, there initially was quite a bit of pushback from within the city with regard to using the automated data. However, the lag is now better understood and accepted by people using the data.

Outcomes and Lessons Learned

The Bellevue respondents report that there were a number of positive outcomes from implementing arterial travel data collection efforts. First, it allowed the city to collect better data and be more responsive to complaints about intersection operations. For example, the city recently had a complaint from a driver who reported a long delay on a side street approach without any cars on the major street. Bellevue was able to quickly look up the data to see that vehicles were being served on the major street.

Another benefit reported by Bellevue with this system was that the nearby University of Washington was able to use a lot of the data in research. This led to Bellevue getting a lot of research done on their arterials at no cost to the city.

The primary lesson Bellevue respondents report they learned from the experience with the automated data collection was to really know how the controllers are reporting data. They were well into the program before they learned that the controller was not always reporting data exactly on schedule with when it was collected. This led to many people initially not trusting the data because they did not know about this, which resulted in comparisons with manual counts being different. Once the lag time was understood, the system was shown to be quite accurate. Getting past the initial negative results was a major hurdle to overcome.

Another lesson the Bellevue respondents learned is that they were able to identify two peaks in some locations from the information they received from the detectors. Microsoft, for example, has a more flexible start time than do other companies, so the corporation's employees contribute to a mini peak hour from 9 a.m. to 10 a.m. that is after the traditional morning peak. The data collected through the automated system allowed the city to see this second peak and make sure they accommodated it rather than starting to transition to a midday signal timing plan earlier in the morning.

SIGNAL CONTROL TACTICS

Agencies were interviewed about specialized signal timing plans and transit priority measures they have undertaken. *NCHRP Synthesis 403* (Stevanovic 2010) should be consulted for agency experience with adaptive signal control.

Specialized Signal Timing Plans

Two agencies were interviewed to discuss how they are using signal timing plans to better manage certain events. The first agency is the city of Gainesville, Florida, which is home to a major university (University of Florida). Gainesville's specialized signal timing plans are to handle heavy congestion that occurs as a result of university functions, such as football and basketball games. The other agency interviewed is the city of Anaheim, California. Anaheim has a large number of special events that cause heavy congestion around the city. Their strategy is to actively manage the signal timing plans using operators in the TMC to improve traffic operations. The details of the in-depth interviews with these agencies are presented in this section.

Additional information can be found at the following websites:

- Gainesville, Florida: http://gac-smarttraffic.com/
- Anaheim, California: http://www.anaheim.net/section.asp?id=142

City of Gainesville, Florida

Overview

The city of Gainesville has special timing plans for different traffic events: football pregame inbound, football postgame outbound, basketball arena outbound, performing arts center outbound, and a plan to accommodate the closure of University Avenue as the result of the event called Gatorwalk. Plans are implemented by scheduled pattern time-of-day overrides, on-the-fly pattern time-of-day overrides, or by a trigger in the field. Football patterns, including postgame and pregame ones, affect more than 40 intersections throughout the urban area. Other event special patterns are more localized.

For Gainesville's system to work, all traffic controllers must be online to the central server, or they have no control to implement these patterns based on actual demand. Football inbound patterns are designed to keep the Interstate 75 off-ramps from queuing back into the travel lanes and to reduce the number of stops and the delay in getting to the University of Florida campus. Football outbound timing plans are designed to get as many vehicles back to I-75 or away from the stadium as quickly as possible. The Gatorwalk special pattern is designed so that no cars can get access to the closed-off portions of University Avenue; this is accomplished by initiating an all-red phase at the adjacent and affected intersections. Plans for the basketball arena and the performing arts center seek to get vehicles away from events at these locations quickly with minimal disruption to normal traffic.

Additional information can be found at the following website: http://gac-smarttraffic.com/.

Design Considerations

To implement these specialized signal timing plans, Gainesville respondents stated they had to update some of the city's traffic controller technology. This involved changing out controllers to advanced fully featured Ethernet NEMA TS2 controllers. The city also had to create a large metro-area fiber Ethernet network for communications with each intersection. Traffic surveillance cameras were then placed at every intersection location around the University of Florida campus for monitoring the special events. All of this was then tied back into the permanent TMC with a large monitor wall (see Figure 15) with satellite connections to a smaller facility at the football stadium. The primary constraints identified by the city in accomplishing this dealt with coordinating the utilities with the construction efforts.

The city of Gainesville measures the performance of these specialized timing plans in two ways. The first is queue length, especially as it affects the off-ramps from I-75. How well the timing plans perform in this respect is determined visually through the traffic monitoring cameras. The second

FIGURE 15 Large traffic monitoring wall. *Source*: http://gac-smartraffic.com/about (accessed August 12, 2012).

performance measure is how long it takes to flush traffic out when special events have ended. This is also observed visually.

Outcomes and Lessons Learned

The main outcomes of this integrated system and specialized signal timing plans as reported by Gainesville were faster travel times inbound and outbound from the special events occurring at the university. Traffic that previously would have taken 3 to 4 hours to clear from the university now takes about 90 minutes or less. The new system has also greatly reduced the queue spillback onto I-75 from the arterials. This is now an issue only when the University of Florida plays another in-state team in football. The final outcomes of this system are reduced police overtime costs, improved safety, and reduced driver frustration.

Respondents for the city of Gainesville report they learned a number of lessons in implementing these specialized signal timing plans. The first lesson is that special timing patterns take several iterations to tweak. Even after the tweaks were completed, different events have different characteristics. This forced planners to develop special patterns within the special patterns to favor different directions, depending on the game or other event. The second lesson learned is that turning movement and tube counts are helpful in only a limited way because the queues become so large it is hard to grasp actual demand. This is why the city relies on performance measures that are broad, such as whether queues are backing up onto the freeway and the total time it takes to clear traffic after a special event. The final lesson learned is that a lot can be done with law enforcement to close or prohibit certain turn lanes to fully utilize the existing infrastructure and prevent spillback and demand starvation with the larger queues.

City of Anaheim, California

Overview

The city of Anaheim, California, has a large number of venues that generate high levels of traffic, including

- The Honda Center, a multipurpose indoor arena;
- Angel Stadium, an outdoor stadium and home of the Los Angeles Angels;
- Disneyland, a theme park; and
- Anaheim Convention Center, which plays host to conventions and Anaheim Bolts soccer team home matches.

These venues have many events throughout the year that are actively managed by the city of Anaheim. The first step to actively managing these events is active traffic planning. This is accomplished through meetings held every Wednesday at 2:30 p.m. Traffic engineers, police, representatives from the key venues, and construction contractors all get together to discuss upcoming events that will affect local traffic.

These weekly discussions involve what is expected, such as number of people and how they most likely will arrive (carpool, single occupant vehicle, bus, and so forth). Another aspect discussed during these meetings is the best way to handle the parking requirements of the coming events. The group decides which parking lots will be open during certain hours; DMSs route people to the open parking lots.

The final piece of active traffic planning is a monthly calendar given to the participants in the weekly traffic planning meetings. These calendars detail which events will have the TMC staffed. In addition, days without planned events are shaded in the calendar so that the construction contractors know when road closures for construction or maintenance will have the least effect on traffic.

Although some cities have begun using adaptive signal systems to manage their traffic congestion, Anaheim uses human operators at the TMC to modify signal timings during events. The city has a staff of seven part-time employees who work in the TMC during events. This group relies on video received from CCTV cameras, the police, and other city staff to determine traffic conditions and make adjustments to nearby signal controllers, if needed.

In addition to actively managing the signal controllers using operators at the TMC, Anaheim also employs DMSs and reversible lanes. The DMSs are used in a variety of ways to inform motorists of traffic issues. Some examples of how these DMSs are used include informing local residents of major upcoming events as much as a week in advance, or informing motorists which parking lots are open for events and how to get there. Reversible lanes are beginning to be used near Angel Stadium and the Honda Center. These reversible lanes are manually operated by police but assist in better managing the traffic in areas near the events.

Additional information can be found at the following website: http://www.anaheim.net/section.asp?id=142.

Design Considerations

The primary design consideration faced by the city of Anaheim was whether to use automated traffic systems such as adaptive controllers or use human operators at the TMC to adjust signal timings for events. After looking into the issues, Anaheim respondents stated, they chose human operators. They found adaptive controllers were reactionary, whereas they needed an approach that could be more proactive. An operator at a TMC is better able to anticipate when and how traffic will arrive and can therefore be more proactive at managing it than can an adaptive system. However, Anaheim recognizes that technology is always evolving, so the city has been putting in the structure to support adaptive signal systems in the event the city ever wants to make the switch.

The primary technology being used by the city of Anaheim for ATM is CCTV cameras. City respondents stated that unless what is happening can be visualized, it is difficult to manage it. They found loop detectors and other devices were good but had limitations in revealing what is truly happening on the arterial street network.

The Anaheim respondents say their primary constraint is maintenance of the systems they have. This constraint is related to both budget and technical concerns. The budget is a constraint because of the number of events in the city, and unlike the police resources used for special events, the TMC staff is paid for through the city's budget. This expense can be an issue during budget review, when the transportation staff is asked why they spend so much on special events. However, most of the city's management understands that no fees are being collected from the events to fund better management of traffic, so the special events budget will be higher.

The technical constraint is ensuring that the city has a technical staff willing to embrace the technologies being implemented and that their expertise is up to the task. Staff who do not embrace the technology will not have the will to understand it and keep it operating. In addition, Anaheim has only three full-time and seven part-time staff members, whose services are used only for events. The city has found it can be difficult to keep the part-time staff involved when they sometimes can go 3 or more weeks without having a shift in the TMC.

Institutional constraints have not been much of a problem for Anaheim because everybody involved at the city level appears to be onboard with the ATM measures. The one area of difficulty the transportation staff runs into is convincing some that the initial capital expenditure on these systems is not the end of the costs. If the system is not maintained, it will not be functional.

The city respondents state that some performance measures have been collected in the past but collection is difficult to do on a continuous basis owing to the cost and labor required. Without the resources to continuously monitor performance measures, they set loose and high-level performance measures. Their empirical observation is that their ATM is making a difference.

Outcomes and Lessons Learned

The Anaheim respondents say the outcome of their ATM arterials experience has been a positive one. They say it is improving traffic congestion during events, and they cannot think of a better way to manage their traffic issues than what they are doing now.

The Anaheim respondents say one of the primary lessons they learned is that having a way to measure performance of the ATM systems would be useful. This would allow them to quantitatively show that what they are doing has a positive effect on the transportation network. In addition, they would have a definable set of performance measures for setting objectives.

There were two other lessons learned by the Anaheim respondents. First, it is important for the staff who will be using and maintaining the ATM programs to buy into them. Without the staff support, these systems will not be used or maintained properly. The second lesson is to be up-front about continued maintenance costs. Anaheim gets questions about why more money is needed after the large capital costs were provided to implement the system. If the maintenance budget is accounted for in the beginning, fewer questions are raised when the system is implemented.

Signal Priority/Queue Jumping

Another signal control tactic is signal priority and queue jumping. Three different agencies were interviewed to determine how they are implementing signal priority. Two of the agencies are implementing the more traditional transit signal priority, whereas a third is implementing emergency services priority.

Harris County, Texas

Overview

Harris County initiated a pilot project to install an emergency services priority signal system at 50 intersections in the Houston area. The pilot study took place on Louetta Road, between State Highway 249 and Interstate 45. A module was placed inside the signal controller cabinet that monitors the signal phase and allows preemption in real time for emergency vehicles. In addition, DMSs were mounted above each approach lane to the intersection that indicate the direction and location of approaching emergency vehicles.

Within the emergency vehicles is a module for tracking and transmitting vehicle data to the signal controller. This notifies the signal of an approaching EMS vehicle, allowing the signal to adjust the phase to allow the emergency vehicle to get through the signal on a green light.

Additional information can be found at the website http://www.houstontranstar.org/.

Design Considerations

There were no real design considerations for implementing this system. The agency only needed to make sure that the existing controllers could handle the components and software needed, which they could. The two primary technologies implemented were the components and software needed for the emergency priority system and a 2070 controller.

The Harris County respondents indicated the primary constraint they had to overcome was technical in nature. The EMS signal priority was fairly new at the time of implementation, and Harris County was putting in one of the largest systems to date. Being on the cutting edge often leads to technical challenges in getting the systems to work as desired.

Outcomes and Lessons Learned

Harris County has gauged the effectiveness of the system using two criteria. The first is whether the emergency services personnel are happy with the system, and the second is the LOS at the intersections where the system was installed. The emergency services personnel have been happy with the system, and the agency has not found it to be detrimental to normal intersection operations. Harris County respondents did state that they plan to study the impacts on intersection LOS more thoroughly in the future. Overall, Harris County respondents report the system has been a success.

Harris County has decided to continue expanding the original pilot study of 50 intersections to approximately 220 intersections in the northwest part of the county in the next 3 years.

The Harris County respondents reported one of the primary lessons they learned from implementation of this ATM tactic is that it is important to communicate with the emergency services personnel from the beginning. Emergency services personnel have a different set of objectives than do transportation professionals, and including EMS from the beginning will allow for understanding and acceptance that a signal system with EMS priority is better than the typical preemption devices that use line of sight. Obstructing vehicles can be cleared from intersections before an EMS vehicle arrives. This allows the EMS vehicle to never hit congested traffic.

San Francisco Municipal Transportation Agency

Overview

San Francisco Municipal Transportation Agency (SFMTA) has been using the more traditional TSP for decades and has developed a policy to be a transit-first city. Both light rail and buses use TSP technology at many intersections within the city. Given the long time the city has been using TSP, a number of different types of systems have been used. These systems include video-based detection, inductive loop technology, and infrared emitters/detectors. The video-based technology usually is used at transit-only lanes and detects the presence of buses. Inductive loops are used on the light rail tracks to detect the presence of trains, whereas infrared emitters are used for buses. These are the main systems that have been used in the past.

In the next 2 to 3 years, San Francisco will be switching to a wireless radio communications-based system. The new system will be GPS based and fully integrated with the signal controller, NextBus, and the transit management center for rerouting buses when there are problems. This new system uses radio communications for a variety of functions, such as real-time tracking of transit vehicles by SFMTA, communication with signal controllers for TSP, and communication with riders for when the next bus will arrive.

The new system most likely will operate in the 5.9-GHz range because this frequency range is designated for this type of use by the Federal Communications Commission (FCC). SFMTA is currently working on pilot programs to see how this frequency range will work within the city because there may be interference from other communications devices. The new wireless system will know if a bus is behind schedule, ahead of schedule, loaded, and other factors, which will then be used intelligently by the signal controllers to prioritize the signals on the transit vehicles route.

SFMTA is also setting up a peer-to-peer communication system that will operate mostly wirelessly so that the traffic signal controllers can communicate with each other. When a transit vehicle arrives at one signal, it will communicate this to other signals so that timing can begin to be adjusted downstream for the bus's arrival. The initial focus will be getting the system up and running for 14 to 15 primary corridors that carry 80% of all transit riders in San Francisco. Additional information can be found at the website http://www.sfmta.com/.

Design Considerations

The primary design consideration San Francisco had to contend with before implementation was making sure the traffic signal controllers in the cabinets could handle the new wireless technology. San Francisco has approximately 1,200 signals in total, and 600 of them are located on these high-priority transit routes that carry a majority of the transit passengers. Currently, 350 have been upgraded to type 2070 controllers, and the other 250 are in the process of being upgraded.

Technology implemented by SFMTA to facilitate transit signal priority has included:

- Inductive loops, which detect the presence of trains at intersections;
- Infrared detection, which is used by both buses and trains to indicate their arrival at the signal;
- Video, which detects the longer transit vehicles at the intersection and notifies the signal controller of the presence of a transit vehicle; and
- Radio-based GPS communications, a new technology that will be used on transit vehicles to identify current location and arrival time at downstream signals.

The main issues in implementing TSP have been institutional and budget related. SFMTA had difficulty in getting the funding for the new radios that will make the buses operate on the new integrated system. The agency also had institutional issues with the FCC and the requirement for 5.9 GHz for vehicle-to-traffic signal communications. This standard is so new that it is not fully vetted. There are also not a lot of vendors making radio equipment at this frequency range.

The main measure of effectiveness SFMTA uses to determine the effectiveness of TSP is reliability of the transit service. The agency hopes the upgraded TSP system will improve reliability and make SFMTA a transit service the city can be proud of because it is extremely reliable.

Outcomes and Lessons Learned

The increase in reliability of transit service using current TSP systems has been a positive outcome. It is hoped the conversion to the new 5.9-GHz system will increase reliability even more. Another benefit of the new system will be better information for transit riders because the system will know where the bus is at all times and be able to provide this information to transit passengers.

SFMTA states that one of the lessons they learned in implementing TSP was to remain patient with the infrastructure. All systems have flaws, and it is important to understand the system. It was also important not to forget about the maintenance associated with such a system. There is more than the initial capital cost of the system. If a system is not maintained, it will not work. The final piece of advice is to make sure everyone is "on board" with everything that is trying to be accomplished. This means including all stakeholders from the beginning to alleviate many concerns and decrease pushback as the process advances.

Utah Department of Transportation

Overview

Utah DOT is implementing TSP on two corridors around Salt Lake City. In one corridor, TSP is being used for bus rapid transit (BRT). The BRT corridor has approximately 10 to 15 intersections, with TSP implemented using a built-in feature on the signal controllers. Each BRT bus has an infrared transmitter that broadcasts to the signal controllers. When the infrared transmitter gets within range of the signal, the signal controller extends the length of the green to accommodate the bus.

The second corridor where Utah is using TSP is in the Salt Lake City Region, on a corridor running a light rail system. This corridor uses inductive loops on the track bed at almost all the intersections along the light rail's route. The exceptions are major intersections where the disruption to operations was too great. The light rail TSP detects the train at the signal and can perform a number of different functions, depending on where the signal is in the cycle. If the train is approaching near the end of the cycle, it will extend the green as it did for BRT. If the train is waiting for the signal, the signal controller will give the train a green indication before the auto green indication. This allows the train to begin moving first (queue jump) so that vehicles do not try to turn in front of the train.

Another feature of the light rail system TSP is its use of special software to communicate the presence of a train between one to two signals downstream. This allows the downstream signals to know there will soon be a train approaching so that it can improve its progression through modes such as phase rotation. Additional information can be found at the website http://www.udot.utah.gov/.

Design Considerations

There were no major design considerations for the BRT corridor because the signal controllers already had a special feature to handle TSP. However, if this system had not been in place, upgraded controllers would have been needed.

The light rail TSP system required a number of design considerations. Because the light rail had been in place for a number of years without TSP, the signal controllers were not set up to handle it. Thus, they had to be replaced with special controllers that could handle the TSP inputs at those intersections where TSP was going to be allowed. This was done approximately 12 to 13 years ago.

The constraints for these TSP projects were not as difficult for Utah DOT as were some of their other projects. Upgrades for the BRT corridor were all paid for by the local transit agency, so any budget constraints were handled by that agency. The TSP system for the light rail corridor was not very noticeable to the general public and was mostly paid for by the local transit agency.

Utah DOT is not actively measuring the effectiveness of these two TSP systems. Their main feedback is complaints they get from local drivers.

Outcomes and Lessons Learned

The local transit agency received beneficial improvements to travel time, whereas motorists experienced a noticeable negative effect on their travel time performance. Utah DOT reports the agency continues to receive a lot of complaints about these two systems from motorists. Utah DOT reported that TSP affected vehicles running parallel to the train.

One lesson learned by Utah DOT was to be careful with the placement location for the activation detector for the TSP. At first, Utah DOT used inductive loops placed at the light rail station that were activated when the train arrived. The agency then made assumptions about dwell time and planned the activation for priority around those assumptions. However, the agency found the loading and unloading process is always different, leading to different timings, especially for handicapped patrons. A train could activate the TSP system but still be waiting for the loading process to finish when the downstream signal executed the priority. By the time the train was moving again, the TSP had timed out, causing additional delay. To correct this problem, Utah DOT moved the inductive loops out of the stations.

The next lesson learned was that all signals do not need the same amount of priority. The agency originally set up every intersection with the same amount of priority. This caused problems at major intersections with a lot of demand because of transit getting the priority. The agency found a more balanced approach for all users was to allow less priority at major intersections and more at minor intersections. The theory was that a little more delay for the transit vehicle at major intersections is fine if they will move faster through the minor ones. This is less disruptive to vehicle traffic.

Utah DOT's next phase is to work with transit agencies to use more GPS-based systems for priority. These types of systems will be able to determine if a vehicle is ahead or behind schedule and the occupancy of a vehicle. If the transit vehicle is ahead, it will not get priority. If the vehicle is behind schedule, it will be given the priority needed to get it back on schedule. This will allow for a more finely tuned balance between quickly serving the transit vehicles while maintaining auto LOS.

GEOMETRIC CONFIGURATION TACTICS

Agencies were interviewed to obtain their experience with dynamic lane assignments, dynamic turn restrictions, and reversible lanes.

Dynamic Lane Assignments

Dynamic lane assignment on arterial facilities is not a common ATM strategy in the United States. However, one agency was found that is about to implement this strategy. This agency is Harris County, Texas, which includes the Houston area.

Harris County, Texas

Overview

Harris County is about to implement dynamic lane assignments at the intersection of Kuykendahl Road and Louetta Road in Spring, Texas. A recent project improved a bottleneck at an intersection located about 3 miles to the south of this intersection by making it grade separated. Although grade separation improved the other intersection, it essentially moved the bottleneck to the intersection of Kuykendahl Road and Louetta Road. This site is unable to be improved by grade separation; therefore, Harris County decided to place a dynamic lane assignment system (changeable lane assignment system or CLAS) (see Figure 16). CLAS provides the ability to integrate operations between the traffic signal control system and the CLAS application, allowing lane assignments to change with the traffic patterns for better intersection

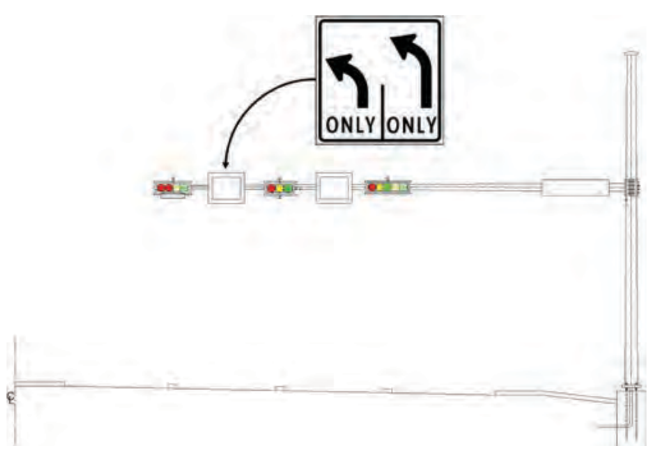

FIGURE 16 Planned dynamic turn lane installation—intersection of Louetta Road and Kuykendahl Road. *Source*: Andrew Mao, Harris County, Texas.

management. This is a joint participation project between Harris County and the Texas DOT. This project allows the lane assignments to be altered based on demand for certain movements. For example, a northbound dual left turn can be run to accommodate the morning peak, whereas an eastbound dual right turn can be used during the afternoon peak for the reverse direction.

One factor Harris County had to determine was what to do in the case of a logical conflict between the lane assignment controller, which operates the color LED signs, and the traffic signal controller. The agency originally planned for the signal to go into an all-flash mode, as a signal normally would. However, the agency realized this would be a major traffic problem. Therefore, if a conflict is detected between the signal controller and the dynamic lane assignment system, the lane assignment system simply shuts off, and the intersection reverts to operating as it did before it had dynamic lane assignments.

Design Considerations

The primary design consideration Harris County considered before implementation was how to get the dynamic lane assignment controller to communicate with the signal controller. In addition, it was important to determine how transitions between lane assignments would take place. Meeting this challenge required a lot of strategizing about how the system should work and a lot of logic coding being done to the controllers to make the system work as desired.

To facilitate the implementation of this arterial ATM strategy, Harris County installed color LED signs above the approach lanes. These LED signs were then paired with a 2070 signal controller.

Harris County's main constraint in implementing this system was technical. These types of systems are not ready-to-go out of the box. Harris County had to acquire the dynamic lane assignment system and then figure out how to make it work with their signal controller. The county developed a number of items to get the two systems to communicate with each other; these involved additional hardware and software coding.

Although the system has not been installed completely, Harris County has decided to use intersection delay as a performance measure in gauging the effectiveness of the new dynamic lanes. The Texas Transportation Institute has already performed the "before" study, and they will also perform the "after" study once the system is in place, which is expected in September or October 2012.

Outcomes and Lessons Learned

There have been no outcomes yet for this system because it will not be implemented until the fall of 2012. However, the agency plans to embark on a public outreach campaign during the summer of 2012 to familiarize the public with the changes and what to expect.

Harris County respondents report the primary lesson they learned in planning this project was that a lot of planning is necessary to get a system like this to work. The work must be thought out well in advance of any implementation, so that as many issues as possible are addressed ahead of time. Some of the planning steps the agency suggests include:

- Figuring out how to get the signal controller and the lane assignment controller to communicate.
- Working with the manufacturer of the lane assignment controller to provide feedback for conflict monitoring.
- Determining how to transition from one set of lane assignments to another.
- Determining what to do when a conflict is detected between the signal and lane assignment controllers.

Dynamic Turn Restrictions

Many agencies are using some form of dynamic turn restrictions. The most common application probably is the prohibition of right turn on red during certain conditions, such as when running a left-turn phase with a high U-turn volume or when an intersection has a more complicated geometric layout. There is also another turn restriction methodology in which certain movements are prohibited during certain conditions. An example of this is restricting right turns when there is heavy pedestrian volume.

Overland Park, Kansas

Overview

The city of Overland Park currently is using dynamic turn restrictions for right turns at approximately six locations. There are three major reasons this is being done.

1. Some locations used to have a right-turn overlap that was removed to favor U-turns from the left-turn lane. A no-right-turn-on-red message now appears on an LED sign when the left-turn phase is active to reinforce that right turns are now prohibited and reduce conflicts with U-turns.
2. The second application is at an intersection near a firehouse. When the fire department responds to a call, the no-right-turn-on-red sign will illuminate so that the fire trucks do not have any conflicts from right-turning vehicles at the intersection.
3. The final application is at the intersection of 61st Street and Metcalf Avenue. The westbound approach allows left and right turns only, whereas the eastbound approach allows only right turns. Eastbound right turns on red are restricted during the westbound left-turn phase to

reduce conflicts. During all other phases, right turns on red are allowed. The right-turn-on-red sign provided increased safety owing to the unusual layout of this intersection.

4. Overland Park has found dynamic no-right-turn-on-red signs to provide increased safety by making the right-turn-on-red restrictions more visible to drivers. The agency also reports the dynamic signs provide improved operations because they do not have to restrict right turns at all times. Restrictions are in effect only when they are most needed. Additional information can be found at http://www.opkansas.org/.

Design Considerations

The primary design consideration reviewed by Overland Park before implementation was determining the best locations for these dynamic turn restriction signs. The agency decided the best uses of these signs were at intersections with recently removed right-turn overlaps, intersections that had unconventional layouts, and locations with fire truck conflict concerns.

The main technology being implemented to deploy dynamic turn restrictions is blank-out signs that illuminate when the right turn on red is prohibited. Overland Park uses blank-out signs with built-in LED lights. The signs are straightforward to install. They need only to be placed in the correct location and then connected to the proper terminals within the signal control cabinet. The sign at the fire station is an older design that has been in place for at least 15 years. However, the operations concept is basically the same.

Overland Park did not report any major constraints with getting these signs installed. The signs cost more than do static no-right-turn-on-red signs, but the agency reported the operational and safety improvements of these signs justified the additional cost. The agency met with representatives of the police department ahead of time to make sure there would be no issues with a right-turn-on-red prohibition that is dynamic. However, the police approved of the use of the signs, and there were no issues with the city's municipal code. The agency respondents noted in the phone interview was that after these signs were put into use, the agency received requests from residents to have such signs installed at other locations.

Although the city is not actively assessing the effectiveness of dynamic turn restrictions through performance measures, they have observed one location to check compliance. The location is at 135th Street and Switzer Road, near a high school. A commercial area on the northeast corner causes a number of U-turns to be made on the southbound approach. The city wanted to see how the younger drivers heading westbound at the intersection responded to the dynamic right-turn-on-red prohibition. They found no compliance issues at this location and reported the students quickly recognized the new signs and their meaning.

Outcomes and Lessons Learned

The city has found these signs to be effective in eliminating the right-turn conflicts for the three situations for which the signs were placed. Safety improved at these intersections, and the signs allowed improved efficiency of the intersection because the prohibition was in effect only during conflicting left-turn phases.

The lesson learned by Overland Park from the experience of implementing dynamic lane restrictions was to spend time investigating how the different signs work and operate. There are a number of different manufacturers making signs, some of which are more complex than others. Overland Park respondents reported it is important to fully understand what the sign needs to do and then investigate different models until one is found that matches the need.

City of Bellevue, Washington

Bellevue has implemented a variable turn restriction that controls two signs that restrict the eastbound right turn movement at NE 8th Street and Bellevue Way. The eastbound movement at this location has dual left-turn lanes, a through lane, and a shared through and right lane and is the main exit route from the Bellevue Square (a regional shopping mall). The Bellevue Square mall has grown to occupy property adjacent to three quadrants of this intersection. The mall developer and the city of Bellevue established agreements to allow pedestrian bridges between the buildings and the underground parking garages on the east side of Bellevue. However, even with these improvements, pedestrian traffic is intense across all legs of this intersection. Because of the high pedestrian traffic essentially blocking any EBRT vehicles, the eastbound capacity can be reduced by 50%.

To help alleviate the congestion caused by heavy pedestrian activity, Bellevue has implemented a right-turn restriction for the eastbound movement. This turn restriction is based on occupancy data received from an upstream loop detector on the eastbound movement. At higher occupancies, the right turn restriction will activate to reduce congestion at the intersection caused by drivers waiting to make a right turn. Additional information can be found at http://www.ci.bellevue.wa.us/Prv_Cont_Traf_map.htm.

Design Considerations

Bellevue respondents stated that they had originally set the turn restriction to run on an older UTCS style signal system using its scripting logic. However, this intersection was converted to an adaptive signal system. Thus, Bellevue had to redesign the logic in the new controller to be able to collect the data needed to implement the turn restriction.

A blank-out sign at the intersection is used to illuminate the traditional R3-1 sign. There is also an advance sign (R3-6 style) over the curb lane that can display two states. The first state is a through/right arrow, and the second state is for the turn restriction when the sign displays only a through arrow.

The adaptive signal system's variation routines are used to test for cycle length and the degree of saturation/occupancy on the eastbound advanced loop detector. In addition, timers have been implemented to ensure the turn restriction stays in the same state for at least 10 minutes to avoid the potential for on/off cycling.

There is also a manual switch so police officers can manually turn the restriction on or off. Police are often used at this location for nearby festivals or big events, and the manual switch is useful to them.

The only constraint faced by the city of Bellevue in implementing the dynamic turn restriction was the ability to work within the signal system's script capabilities for the older UTCS style signal system or variation routine logic of the newer adaptive system.

With the new adaptive signal system installed, Bellevue does not have a specific performance measure for just this strategy. In the past, mall staff often would call to request more time for eastbound traffic to exit their parking garages onto NE 8th Street. With the new adaptive system with the automated turn restriction, the number of such calls received by the city has dropped from approximately four to six per month to approximately four calls per year.

Outcomes and Lessons Learned

Bellevue respondents state that the performance of the turn restriction strategy has increased capacity during most times but that the compliance rate is low. The agency thinks that during heavy pedestrian volumes, the compliance rate is higher. As with most strategies, a prolonged police enforcement period increased compliance, which quickly decreased again after the enforcement period ended.

Although the turn restriction strategy can be implemented, Bellevue believes its success depends on three things. The first is whether drivers see a need for the restriction. The presence of reasonable alternative routes is also a key consideration for the effectives. Finally, periodic police enforcement is needed for successful implementation.

Bellevue respondents also reported that visual clutter in an urban area can be a concern because many ticketed drivers said they never saw the signs. Other drivers requested the operational logs because they said the sign was permissive when they received the ticket. The city reported these requests were heavy for about a year but have dropped off to negligible amounts since then.

Reversible Lanes

Reversible lanes have been in use in the United States in some locations for many years. Two agencies were identified for in-depth interviews about this type of ATM strategy. One agency, Utah DOT in Salt Lake City, is about to implement them for the first time. The other agency, the city of Roswell, Georgia, has been using such lanes for more than 30 years and is considering removing them.

City of Roswell, Georgia

Overview

The city of Roswell has been using reversible lanes on South Atlanta Street (State Route 9) for more than 30 years. The corridor extends from around Marietta Highway on the northern end to Riverside Road to the south for a distance of approximately 1 mile. This corridor currently operates as a three-lane facility, with the center lane being the reversible one.

South Atlanta Street (State Route 9) and US-19 are the major routes crossing the Chattahoochee River connecting the northern Atlanta communities with downtown Atlanta. Given the importance of the State Route 9 corridor, it is mainly a four-lane arterial facility. The one exception is the corridor with the reversible lane. A number of historic places along the road made it difficult to widen the road to four lanes, so 30 years ago traffic engineers implemented reversible lanes within the existing three-lane section.

This corridor operates its reversible lanes in three different patterns. From 6 a.m. to 11 a.m., the corridor maintains two lanes in the southbound direction toward Atlanta. At all other times of the day, except 1 a.m. to 5 a.m., it maintains two lanes headed northbound. The time between 1 a.m. and 5 a.m. has only one lane in each direction, with the reversible lane closed off in both directions. This was done to improve safety.

The system changes the direction of the reversible lane by giving a 5-minute clearance interval. When the next direction for the center lane is about to go into effect, the system closes the reversible lanes for all directions of travel. After allowing 5 minutes to clear the 1-mile length, the system reopens the lane for the reverse direction. Additional information can be found at http://www.roswellgov.com/.

Design Considerations

The design considerations Roswell considered 30 years ago, before implementing the reversible lane, were the restrictions on right-of-way caused by adjacent historical buildings. There was no room to widen the roadway given these restrictions, and significant directional distribution of traffic existed in the morning and afternoon peaks.

Reversible lanes were implemented on this corridor through overhead illuminated signs. There is a sign above each lane with the outside lanes showing a static arrow so drivers know it is always available for the direction they are traveling. The center lane that is reversible shows a red X or a green arrow, depending on the time of day and which direction is using the reversible lane.

In addition to the overhead signs designating whether traffic can use certain lanes, the northbound approach to the segment has two signs. The first sign gives a warning that the lane ends in 1,000 feet, and the second says the lane ends in 250 feet. These are blank when there is no lane drop but illuminated when there is. The southbound approach has one sign warning of a lane drop but no reference to distance.

Because this project was implemented 30 years ago, not much is known about the constraints experienced when the city implemented the reversible lanes. The only major known constraint faced by the city was inadequate right-of-way to expand to four lanes of traffic. This forced traffic engineers to think of alternatives regarding what they could do with three lanes, which led to the implementation of the reversible lanes.

The city of Roswell is not using any performance measures related to the reversible lanes. It is more empirical based in that they know there are only two major routes across the Chattahoochee River, and limiting the number of lanes on SR-9 will cause major backups. The city has also experienced major backups when the reversible lane system is down for repair.

Outcomes and Lessons Learned

Roswell reported two primary outcomes of implementing reversible lanes. The first was the improvement to capacity in the peak direction. The ability to keep at least two lanes open in the peak direction given the limited right-of-way for the reversible lane section has been a major benefit of the reversible lanes. Without such lanes, there would be a major bottleneck in the direction that did not have the additional lane during the peak period commute for that direction.

The second outcome was the higher collision rates along the reversible lane section of SR-9. This section has a quite a bit of horizontal curvature, and the city of Roswell found that the collision rates were higher than for other similar facilities.

The age of the system is another factor affecting the performance of the facility. At more than 30 years old, the system has problems once or twice a year that lead to closure of the reversible lanes during peak conditions for maintenance. This causes major traffic congestion in the area.

The primary lesson learned by the city of Roswell from this reversible lane system is that although it does make the best use of the existing right-of-way for moving heavy traffic volumes, the reversible lane section has a higher collision rate. Given the decreased safety of the reversible lanes section and the ever-growing amount of traffic in the Atlanta area, Roswell is in the design phase of a project to eliminate the reversible lanes and convert to a four-lane facility. They decided the expansion to four lanes was better than looking at ways to improve the reversible lane, mainly owing to the increased traffic growth. With this traffic growth, it is becoming difficult to manage the off-peak direction with only one lane, which necessitates moving to a four-lane cross section.

Utah DOT in Salt Lake City

Overview

The Utah DOT is implementing reversible lanes along 5400 South in West Valley City, Utah. The reversible lane corridor will extend approximately 2.25 miles, with the boundaries being Bangerter Highway on the west and Redwood Road on the east. The reversible lanes began operating in November 2012.

The current roadway has a cross-sectional width of approximately 82 feet accommodating three lanes in each direction and a center two-way left-turn lane, for a total of seven lanes. The Utah DOT has found that three travel lanes are insufficient to handle demand during the morning and afternoon peak hours. The agency has been working on implementing reversible lanes for about 3 years to accommodate the demand within the existing right-of-way.

The reversible lanes will operate in the morning, with four travel lanes in the eastbound direction, a center two-way left-turn lane, and two lanes in the westbound direction. The afternoon peak will be the reverse of this, with four lanes westbound, a two-way left-turn lane, and two lanes eastbound. The midday lane assignments will revert to the current lane assignments with three lanes in each direction and a two-way left-turn lane in the middle.

This corridor also has four signalized intersections that must be accounted for when the reversible lanes are in operation or during transition periods. Each signal has extra signal heads that have a bimodal lens incorporating both a ball and an arrow. The signal controller receives an input from the reversible lane controller so that the signal knows what the current lane assignments are. When it becomes time to alter the lane assignments, the controller goes through a complex sequence of events at the intersection to clear the lanes that will have altered lane assignments. These events include:

1. First, the east-west through movement comes up to clear out the through lanes. At the same time, the lane indications on lanes to be closed change from the green arrow to a yellow X. After a period of time, the yellow X changes to a red X.
2. Then, after a delay, the major street left turns come up to clear out those lanes.
3. As soon as the side street becomes active, the lane assignments are altered at the intersections only (lanes between intersections remain closed).
4. After the side street has been serviced, the east-west left turns are serviced again to give one remaining chance for anyone still waiting to make a left turn from the old lane. After the east-west left turns are serviced and the detectors are clear from the old lane, the lane control system opens all of the new lanes while the signals resume their normal cycle.

Additional information can be found at http://www.udot.utah.gov/flexlanes/.

Design Considerations

Utah DOT looked at two major design considerations before implementing reversible lanes. The first was to determine volume splits for the peak periods. Plans for the reversible lanes could be considered only if the off-peak direction would not experience significant delays.

The second consideration was the ability to keep the existing two-way left-turn lane. Many reversible lane projects tend to restrict left-turn movements because of the added complexity of handling left turns from shifting lanes. Given the large number of access points off of 5400 South, restricting left turns would have caused significant access issues for local streets and businesses. Therefore, Utah DOT had to design the reversible lanes system to handle the two-way left-turn lane shifting to different lanes throughout the day.

The reversible lane system is implemented through a variety of different technologies. Overhead electronic signs will be the main technology noticed by the general public. These signs were supplied by USA Signal Technology and will designate the current assignment for the lane. The next technology is the controller for the overhead signs. This device is a programmable logic controller supplied by ICX, and its main functions are to control what the overhead signs display and to handle the transitions between the different lane assignment plans. The final piece to implementing the reversible lanes is the signal controllers at the four signalized intersections along the route. These controllers are Econolite ASC 3 controllers, and they will work in coordination with the reversible lane controllers to make sure there are no conflicts at the intersections.

This reversible lane project for Utah DOT was subject to a combination of constraints. There were a lot of political constraints with getting the new system approved by local politicians; doing so involved outreach. Budget is always a constraint in the current economy. On the technical side, these systems are fairly new, and trying to keep the center two-way left-turn lane turned out to be a major obstacle. There were also a large number of utility conflicts that required fitting in the new equipment around existing utilities.

The primary performance measures the agency will use to determine the effectiveness of this system are travel time and delay at the intersection. The ideal outcome would be improved travel time along the corridor in the peak direction with minimal impact to the off-peak direction. Delay at the intersections will also be measured to see how the intersections themselves operate under the new reversible lane system.

Outcomes and Lessons Learned

Although the system had not been implemented at the time of the interview, the Utah DOT respondents state their goal is to maximize the lanes without causing major capacity issues in the off-peak direction. A successful reversible lane system for Utah DOT would be one that has:

1. No major capacity constraint for the off-peak direction;
2. Decreased travel time for the peak direction; and
3. No decrease in the safety of the road.

The primary lesson Utah DOT respondents say they learned from reversible lanes was how difficult it would be to maintain the two-way left-turn lane through the different configurations. In addition to learning how difficult it was to maintain the turn lane, the Utah DOT respondents provided some suggestions for any agency thinking about this type of system. They suggest carefully thinking through what is trying to be achieved before issuing the documents for bid. Once the objective has been fully thought through, be sure to have good specifications before going out for bid, and make sure the equipment is capable of doing what it needs to do.

DEMAND MODIFICATION TACTICS

The demand modification in-depth interviews focused on travel information dissemination and parking management. The survey did not identify a public agency with a high level of expertise in dynamic route guidance.

Arterial Travel Information Dissemination

Today's technology provides the sophistication and automation to deliver data on arterial traffic operations to the general public using applications such as smart phones. Agencies with advanced data collection abilities, such as those described in the previous discussion of ATM strategy on arterial travel data collection, are looking to disseminate the data to the general public in a useful way. Two agencies with experience in getting arterial travel information to the public were interviewed. These were the cities of Bellevue and Seattle, Washington.

City of Bellevue, Washington

Overview

As described in the discussion of arterial travel data collection, Bellevue obtains a great deal of data from their arterial data collection activities. Thus, the agency wanted to determine a way of providing this information to people so they were aware of congestion within the city. Bellevue found that most people really only want to know travel time from A to B, but the current system is not easily able to extract this information. Therefore, the agency decided to give the public something that might be useful for now. The agency settled on reporting the level of congestion at intersections using green, yellow, red, and black color codes (Figure 17). Colors are determined through detector occupancy. Results are reported through the city's website with a traffic map. In addition, people can sign up for e-mail communications that give them traffic information.

Bellevue hosts a real-time travel information map, and data collected from the sensors is published to an FTP site. These data can then be accessed by developers, such as mobile app developers and big-name travel time information providers, such as Inrix. The idea is that these individuals and companies will be provided the necessary data to create their own applications to assist in route guidance.

In addition to the traffic map, Bellevue currently has 55 cameras around the city showing local conditions. Ten of these cameras are uploaded to the DOT camera site with still shots taken every 1.5 minutes. The DOT is working on a regional camera system that will tie in live streaming traffic cameras from 23 cities in the region. This project is called

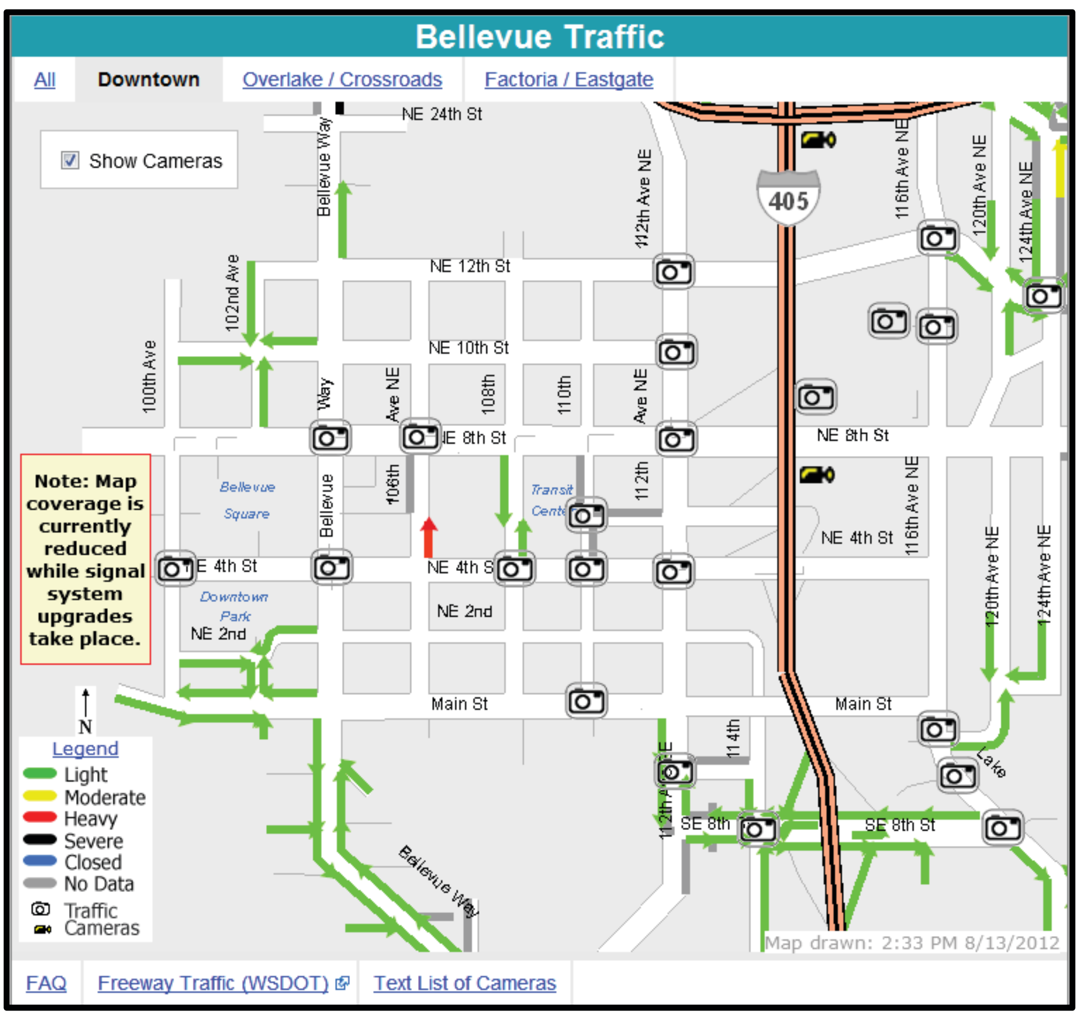

FIGURE 17 Example of Bellevue's traffic map web interface. *Source*: City of Bellevue, http://trafficmap.cityofbellevue.net/ (accessed August 13, 2012).

"Traffic Busters," and when it is complete, all 55 cameras in Bellevue will be streaming video on the consolidated traffic camera website. More information can be found at http://www.ci.bellevue.wa.us/Prv_Cont_Traf_map.htm.

Design Considerations

Some design considerations Bellevue did not take into account when developing the traffic map web page was that it was not geographic information system (GIS) based. This made it functional for large computer screens but not ideal for mobile devices. The agency is now converting the system into a GIS-based system, which will make overlays possible so companies such as Google can overlay Bellevue's traffic data on their traffic maps. This overlay will also be put up on the city's FTP site for other developers to use. The city plans to let the developers disseminate traffic data to travelers in a convenient form for their mobile devices. They will therefore concentrate their efforts on their web page.

In addition to the systems currently in place, Bellevue is starting to look at setups such as Bluetooth and Wi-Fi detectors to do more travel time data collection. Access to Inrix (a supplier of traffic information) data is available to them because the State of Washington has a statewide license for access. Bellevue is now looking into this data source to see what they can use.

Bellevue had their vendor modify their existing data collection reports to have a field that allowed for them to set color codes for various occupancies. The city found that one-lane, two-lane, and three-lane approaches would have different thresholds for the various color codes indicating congestion. Once the adjustments for the number of lanes on the approach had been made, they could be implemented with only slight adjustments in assigning the color code on the map.

Color codes on their map represent (web version only):

- Green—free-flowing traffic;
- Yellow—vehicles may miss a cycle;
- Red—vehicles will definitely miss a cycle or two; and
- Black—indicates stop-and-go traffic.

Bellevue reports the biggest issue with these color codes is how to tie them back into color codes used on freeways. Red on a freeway indicates traffic is congested but drivers are generally always moving at 25 mph or less. Red on an arterial street generally means drivers will be sitting for a long period of time.

The main constraint for implementing traveler information was getting the data to disseminate to the public. In addition, the city had no defined budget, so the funds were being pulled together from maintenance funds and using in-house information technology staff.

In terms of measuring the effectiveness of how useful traveler information is to the public, the number of hits to the traffic map website is used as a performance measure. Bellevue has found that the traffic map is consistently in the top five of all viewed city web pages, usually following right behind the employment page. The city also has noticed that the number of unique visitors jumps dramatically for severe weather events or incidents.

Outcomes and Lessons Learned

As far as outcomes of disseminating this information, the city respondents indicate there is no good way to measure such outcomes. Their hope is that the information will cause drivers to better spread the congestion among different routes and time throughout the day. They also hope to convert the system from link speed to origin-destination travel time based because they think this is what people really want.

The biggest thing Bellevue respondents report they learned in implementing arterial travel information dissemination was that the system is popular with the public. It originally was intended as an internal task that had no defined budget or staff. Once it became popular, any issues with this internal project had to take precedence because of its popularity.

Another thing they learned is that the traffic information being disseminated was being used not only by the public but also by local traffic engineers, who found it to be a useful tool. The map is always up in the city's TMC, and engineers know what it's supposed to look like at any given time of the day. When something unusual pops up on the map, they look into the problem. This gives them a lot of real-time information about how well the traffic system is working.

City of Seattle, Washington

Overview

Traveler information is provided in a number of ways in the city of Seattle, which has a web-based traveler information map that is color coded for green, yellow, red, and black. This application is also currently available as a mobile app for iPhone and is coming soon to phones using the Android operating system. These map color codes are based on occupancy data collected by magnetometers in many locations throughout the city. The locations are carefully selected so that they are not affected by traffic signals. Each of these locations required a lot of fine-tuning to interpret and assign values that reflect the appropriate color codes.

In addition to the color coded maps, Seattle has 22 DMSs throughout the city. These signs warn drivers of significant transportation-related events, such as incidents, construction, and local movable bridges allowing ships to pass. Although these types of messages are the primary purpose of DMSs, some signs also provide travel time information to key points in the city. Travel times are determined through license plate readers (LPRs). As a vehicle passes an LPR at the DMS, it is recorded by the system. It is eventually paired with another capture of the same license plate at another destination location, thereby giving the travel time between the two points.

The web portal for the traffic map (www.seattle.gov/travelers) also has links to 130 traffic cameras available to the general public. Most of these cameras are still shots updated every couple of minutes. However, Seattle is trying to upgrade this to live streaming traffic cameras. The initial upgrading of 25 cameras to live streaming is complete and available on the website. More information can be found at http://web5.seattle.gov/travelers/.

Design Considerations

The main design considerations Seattle had to contend with dealt primarily with how to set up their equipment in the most useful places. Traffic cameras had to be set up in places where they could have good views up and down the corridors. Occupancy sensors had to be in isolated locations that were unaffected by nearby signals but still needed to be placed in areas where people are interested in finding out the traffic conditions. DMSs had to be placed near LPRs to get useful travel times. Finally, Seattle wanted to figure out a way to tie the DMSs into the traffic map so that if something went red, the DMSs would automatically post the information.

A number of different technologies are in place to facilitate travel information dissemination to the general public. Technologies that are used to distribute information include:

- Traffic map website;
- Traffic application for iPhone and Android phones;
- Traffic alerts by means of tweets; and
- DMSs at 22 locations.

Technologies used to collect information include:

- Magnetometers for collection of vehicle occupancy data;
- LPRs for collecting travel time between two points; and
- Traffic cameras for monitoring traffic conditions.

Although budget is always a constraint for any project, the nice thing about ITS technologies are that they can be adjusted to match the budget by simply changing the number of devices installed. As the design proceeded, and estimates of costs were made, Seattle was able to add and subtract devices based on available funding.

There were also some geographical constraints that required some devices being moved from their original locations. Some of the wireless equipment used for connecting the system needed to be line of sight, and trees frequently were a problem. There was also a lot of coordination with the Washington State DOT to get the license plate readers working for travel time. This system required access to the state DOT server, which was not always online because it was a lower priority use for the state. Because Seattle needed it to do the matching, they had to coordinate with the State DOT to make the server always being operational a higher priority.

The city of Seattle uses two main performance measures for determining the effectiveness of the agency's information dissemination. The first is tracking the number of hits on the traffic website and live traffic cameras, which allows the city to see what events drive usage of the website. The second performance measure is public feedback. Most reactions have been positive, but there have been a few negatives, especially at the beginning when the system was first being implemented. At that time, many features were not fully connected, so message signs were blank most of the time, which led some to wonder why Seattle spent money on a system that never appeared to be working. However, the system is now interconnected, and the message signs are almost continually used.

Outcomes and Lessons Learned

One of the primary reasons for implementing this traveler information system was to support major construction efforts in Seattle. The system has been successful in informing motorists about detours and other construction-related information. It has also been good from a media relations standpoint. When something major happens, the city can show the problem is being actively managed using the new system. Public officials are pleased with the system and the results. They are also getting a number of requests to use the system from various project managers in support of road closures.

The city found travel time to be a real positive and extra benefit of the system. The ability to show travel times on the DMSs was not a planned part of the project; only the website was planned. Consequently, not all message signs have LPRs, which means travel times cannot be shown at the locations without LPRs. In hindsight, Seattle would like to have installed LPRs at all the DMSs so travel times could be provided. The city has more projects in the pipeline and will be installing LPRs and DMSs at the same locations to provide the travel time data.

The other lesson Seattle learned is that it takes experience to properly place wireless devices. There has been a lot of trial and error on their part in placing these systems. The more experience the better because wireless systems are starting to be used for a lot of things, such as bus priority, which is an application Seattle is undertaking.

TABLE 4
SAMPLE OF METERING RATE PERIODS USED FOR SF*PARK*

Meter Active	Rate Periods	Meter Active	Rate Periods
9 a.m.–6 p.m.	9 a.m.–Noon Noon–3 p.m. 3 p.m.–6 p.m.	7 a.m.–7 p.m.	7 a.m.–Noon Noon–3 p.m. 3 p.m.–7 p.m.
7 a.m.–6 p.m.	7 a.m.–Noon Noon–3 p.m. 3 p.m.–6 p.m.	7 a.m.–11 p.m.	7 a.m.–Noon Noon–3 p.m. 3 p.m.–7 p.m. 7 p.m.–11 p.m.

Dynamic Route Guidance

Chapter two describes Florida DOT's iFlorida program, for which agencies provide route guidance through a 511-type program. Many agencies support private developers by providing data collected by the agencies on arterial performance so that developers can incorporate the data into their products. This has the benefit of eliminating software development costs for the agencies and allowing developers to use the information for dynamically adjusting people's routes to balance the transportation network. Because this type of data collection and dissemination was covered in the literature review and in the previous section, no in-depth interview for this strategy was performed.

Dynamic Parking Management

Dynamic on-street parking is perhaps one of the newest concepts in arterial ATM strategies. Although there are not too many agencies currently implementing this type of strategy, many are considering it. Two agencies were selected for in-depth interviews regarding dynamic parking management. One agency, SFMTA, was able to obtain federal funding for its project, which allowed extensive use of the latest technology. The agency calls its parking management program SF*park*. The second agency, the city of Seattle, received no federal money and is implementing an arterial ATM strategy on a "shoestring" budget paid for by city funds only.

San Francisco Municipal Transportation Agency, San Francisco, California

Overview

SF*park*'s goal is to make it easy to find a parking space. It does this by adjusting the parking pricing until a street reaches the right level of parking availability. This demand-responsive pricing is gradual, with periodic changing at no less than 30-day intervals until it achieves a target of around 80% occupancy on all city blocks. The program was rolled out through a pilot project, which included:

- Eight pilot areas with new policies, technology, and significant data collection;
- Three control areas that remained the same but had extensive data collection; and
- 7,000 metered on-street spaces and 12,250 off-street spaces.

To accommodate different parking demands for various times of the day, the SF*park* meters can change the parking rate based on the time of day. Each SF*park* meter can have between two and four rate periods. This allows for parking to be more expensive at times of high demand (morning peak) but lower when parking demand is less (early afternoon). Samples of the different rate periods that can be found at meters are shown in Table 4.

Because of these different hourly rates, a vehicle parking from 2 to 4 p.m. would pay one rate for 2 to 3 p.m. and another rate for 3 to 4 p.m. The rates within these designated periods are demand responsive and based on previous occupancies. The SF*park* system will analyze historical parking occupancy on the block for each rate period and make adjustments to that rate on a monthly basis, if necessary, to meet its occupancy goal of 80%. The rate adjustments are made according to the schedule shown in Table 5.

Rates in San Francisco can be as low as $0.25 and as high as $6.00 per hour under normal conditions. During special events, rates can be as high as $18.00 per hour.

The general public must be made aware of these price changes at least 7 calendar days before the prices change. This is in accordance with the legislation approving SF*park*. Rate changes are made public through the SFMTA and SF*park* websites.

The first rate adjustments made in July and August 2011 showed rate increases at 32% of the meters, rate decreases at

TABLE 5
PRICE ADJUSTMENTS BASED ON OCCUPANCY

Occupancy	Rate
80%–100%	Raise by $0.25
60%–80%	No change
30%–60%	Lower by $0.25
<30%	Lower by $0.50

Note: These changes are made no more than once per month.

31% of the meters, with the remaining 37% of meters maintaining the same pricing.

Design Considerations

SFMTA stated that the biggest design consideration of all in implementing a program such as SF*park* is the ability to have the information technology to implement the program. There are many sensors collecting data to dynamically change the parking rates on a month-to-month basis. Having the hardware and software to manage the massive amount of data is critical to a successful program.

A number of different types of technologies were implemented to get SF*park* working. New parking meters were a large part of the investment in getting SF*park* operational, requiring many new parking meters to be installed. The new parking meters accept credit card payments, transmit credit card data to the central server, and allow San Francisco to set new rates and display information remotely.

The second technology implemented for the SF*park* program was parking sensors. Sensors were installed at roughly 8,000 spaces. These sensors are small magnetometers that measure small changes in the Earth's electromagnetic field. When a vehicle with a mass of metal is parked over the sensor, the Earth's electromagnetic field is disrupted, which is detected by the sensor, which reads the information as an occupied parking space. These sensors are the primary way SF*park* collects occupancy data for determining the appropriate metering rate to achieve 80% occupancy rates on all blocks.

Another large piece of technology implemented for this project includes all the information technology for real-time data acquisition and data warehousing. SF*park* collects data from many different places to analyze and operate San Francisco's dynamic on-street parking management. SFMTA needed to develop ways to efficiently gather these data and make them useful for the agency's purposes. The stated purpose of the agency's data warehousing and business intelligence tool includes:

- Convert incoming data into useful numbers for managing parking;
- Store historical data to better implement SF*park* in the future;
- Error check incoming data for any errors; and
- Be able to support an Internet interface that can be used by the public for finding parking or for other researchers using the compiled data.

The final pieces of technology implemented are related to disseminating parking information to the public, which SF*park* does in a number of ways. There is a web application (http://SFpark.org/) that provides a graphical depiction of

FIGURE 18 SF*park's* mobile application. *Source*: SF*park's* Mobile Application for iOS Operating Systems.

parking space availability and the parking rates. In addition, iPhone users have access to an app that provides the same parking information. An example of this application is shown in Figure 18. This app will soon be available for Android-based phones. The final parking information dissemination tool is text messaging, which provides availability information by means of text message to people who request it. Additional information can be found at http://sfpark.org/.

SFMTA states the primary constraint for this program was political. Getting the city council to accept the idea of variable parking pricing and then working to receive the federal funding to implement it was a real challenge. There were also many technical constraints in collecting, organizing, and using the data collected by all the sensors, manual counts, and other data sources that feed into the SF*park* system.

San Francisco uses a variety of performance measures to fully capture the effect of SF*park*, including

- Sensor/parking meter downtime;
- Occupancy (vehicle and motorcycle);
- Number of parking citations;
- Public transit ridership (fitted on about 30% of the bus fleet);
- Safety;

- Roadway data at 60 locations, such as counts, speed, and density; and
- Manual surveys of double parking, disabled placard use, parking search time, and intercept surveys.

Outcomes and Lessons Learned

San Francisco is a pilot project for this type of ATM strategy. Thus, the project has extensive data collection efforts that will be used by the city of San Francisco, the U.S. DOT, researchers, and other cities to determine how well a dynamic on-street parking management system works.

A comprehensive after study has not yet been completed by the time of this synthesis project. However, San Francisco expects SF*park* to increase parking availability, lower parking search times and variability, decrease double parking, and reduce long-term on-street parking.

SFMTA has identified the following items as the primary lessons learned in implementing the SF*park* program:

1. It is easy to underestimate the magnitude, scope, and technology needed to perform dynamic parking management.
2. The project required a lot of custom technology and programming to get all the systems to work and then to work together.
3. The accuracy and reliability of parking sensors are not perfect, which can be limiting in how the data are used. For example, the sensors use low power to communicate occupancy data, and electromagnetic interference can make it difficult sometimes to get accurate data. In addition, the data are routed through cell towers, which are not always working well, leading to gaps in some of the received data.
4. The pilot program was a good approach to rolling out the program, rather than converting the whole city at one time.
5. The technology to implement dynamic parking management is complex. It is important to include a technology professional on the team when writing the request for proposals.
6. The request for the proposal should include specific performance standards in the contract and how they will be measured.
7. It is best to design a system that is as vendor neutral as possible. This allows more flexibility in the future for changing vendors.

City of Seattle, Washington

Overview

In 2010 the city council for Seattle agreed to implement performance-based parking. The city council established an annual budget to perform parking studies to set parking rates in 22 distinct neighborhoods in Seattle. These annual studies are used to set the parking rates in the neighborhoods for the coming year and to provide a solid base of historical parking data to help set parking rates in the future. Seattle's performance parking initiative is funded completely by the city with no federal tax dollars.

The goal of this performance-based parking initiative was to encourage more parking turnover and maintain one to two empty parking spaces per block; the goal was not to fill budget shortfalls with parking fines. The yearly data collection assists in setting the parking rates for the next year. There are approximately 13,000 parking spaces in the city, and these data collection efforts cover at least half of them. Once the occupancy data are collected, parking rates are set anywhere between $1.00 and $4.00 per hour. If the occupancy is higher than desired, the parking rate is increased, and if it is lower, the parking rate is decreased.

For example, the 2012 parking rates were determined based on the study performed in 2011. That study showed parking occupancy was too high in four neighborhoods, so the parking rate in those neighborhoods was increased. Seven neighborhoods were right on target for empty spaces, so the rates were left the same. In the final 11 neighborhoods, rates decreased owing to lack of demand.

One interesting thing that Seattle found in the 3 years since implementing the program is that although increasing parking rates decreases parking occupancy, decreasing the rate does not always increase parking occupancy. Some neighborhoods are just not significant attractors to fill occupancy targets, no matter how inexpensive the parking rates.

This year, Seattle is trying additional refinements with this performance-based parking initiative. In the first 2 years, identical parking rates were set throughout each of the 22 neighborhoods into which the city had been divided. However, further subdivision was needed because some streets are more popular than others within a neighborhood.

The University neighborhood is a good example of uneven parking use within a neighborhood. University Avenue within the University neighborhood has a very large parking demand. Seattle's parking studies showed there was little parking availability along University Avenue but a lot of availability along the side streets. The original parking strategy would have both University Avenue and the side streets with the same parking rate. However, Seattle will experiment with having "value blocks" on the side streets. The idea is to better balance parking throughout the whole neighborhood. University Avenue will be more expensive, but if a driver is willing to walk a bit further, cheaper parking will be available.

Seattle will also experiment with a program called "after 5" in eight neighborhoods. Paid parking rates have traditionally ended at 6 p.m. in Seattle, but some neighborhoods have very high demands after work. Many employees of these neighborhoods arrive for work at 5 p.m., pay for an hour of parking, and then their cars remain on the street the rest of the night. This makes parking difficult for customers of the neighborhoods' businesses. The after 5 p.m. program will extend the paid parking hours until 8 p.m. and remove the 2-hour parking restriction. Seattle hopes this will encourage more parking turnover and provide better access for business customers. Additional information can be found at http://www.seattle.gov/transportation/parking/performancepricing.htm.

Design Considerations

The main design consideration for Seattle's performance-based parking initiative was to have policy guidance in implementing the program. Seattle had this guidance in their comprehensive plan along with having a policy of maintaining one to two open spaces per block. These policies allowed the agency to influence and direct how the performance-based parking was done within the city.

The types of technologies used by Seattle to implement the parking management program are the parking pay stations themselves. In 2004, the mayor of Seattle directed that all the old electronic meters in the city be replaced with pay stations. This was done between 2004 and 2007. Between 2007 and 2010, the city had a robust program to assess parking impacts and needs throughout the city, which led to the installation of an additional 5,000 paid spaces.

The pay stations implemented by the city are a major component of being able to change the parking rate annually, if needed. However, the pay stations are getting near the end of their 10-year life, and the city is starting to consider replacements. Seattle's city council is interested in perhaps going to time-of-day rates, which their current pay stations cannot accommodate. Pay stations that can accommodate time-of-day parking rates likely will be the next technological step.

The final piece of technology Seattle is working on for the near future is the ability to pay parking fees by cell phone. They believe this will be a major benefit to residents and will improve overall satisfaction with parking in Seattle.

Seattle's biggest constraint in implementing their dynamic parking management plan has been financial. The city budget is tight. However, the city council has been supportive of performance-based parking and has continued to approve the funding for the annual parking study for setting new parking rates.

Seattle's performance measure for how the parking management program is performing is the number of open spaces per block achieved by the variable pricing program. The agency seeks to have no more and no less than one to two open spaces per block, with a goal of meeting this target range in 60% of the neighborhoods. The agency also uses time as a performance measure in making sure rate changes are deployed in a timely manner.

Outcomes and Lessons Learned

One of the outcomes the Seattle respondents noted with regard to dynamic on-street parking was failure to see an increase in demand when the price was lowered. However, the opposite was seen, with higher prices decreasing parking demand. The main goal for the whole program was to improve access to parking near where people want to be. It is hoped people would have a more positive parking experience, without having to drive around for a long time to find a parking space, which would make life easier for getting things done in a timely manner.

Support from elected officials is critical to the success of any performance-based parking strategy, which is something Seattle learned from implementing this strategy. City officials in Seattle understand the idea of parking management and have been open to the concept.

Another primary lesson learned is to have good communications with the city budget office. The personnel in that office need to be on board and fully briefed on what it being done for parking. Parking is not a small budget issue. A city such as Seattle has parking revenues amounting to about $32 million annually.

Another item that Seattle believes is a good lesson is the importance of having a meeting to discuss the dynamic parking with a wide variety of stakeholders. Seattle had two such meetings and found the various perspectives to be helpful. The city also convened an expert panel, composed of a number of different interests, that was very helpful in implementing the program.

The final lesson learned was the investment in technology and infrastructure is not trivial. It is a major information technology task to take all the collected occupancy data and find a way to manipulate, read, and store it. The agency did not realize at the beginning what it would take to mine the data to tell the story. They needed to work with and compel the information technology personnel to take on the task.

CHAPTER FOUR

CONCLUSIONS

The purpose of this synthesis has been to document the state of the practice associated with designing, implementing, and operating active traffic management (ATM) on arterials. Of particular interest was information on:

- Strategies used to actively manage traffic and congestion on arterials;
- Situations and operating conditions in which ATM strategies have been successfully and unsuccessfully deployed on arterials; and
- System and technology requirements associated with implementing the strategies.

ATM measures involving adaptive signal control, congestion pricing, or speed harmonization on arterials were not included in this synthesis, either because they are already covered in another recent synthesis (in the case of adaptive signal control) or because there is a lack of U.S. installations of the measures on arterials for a synthesis of current practice.

FINDINGS

The findings of this synthesis are as follows:

- The literature review and screening survey identified the following strategies for actively managing traffic and congestion on arterials: monitoring arterial performance, dynamic signal control (special plans, signal priority, queue jump), dynamic geometric controls (reversible lanes, dynamic turn prohibitions, dynamic turn lanes), and traveler information.
- The literature review and screening survey indicated that ATM strategies have been deployed successfully on arterials when there was:
  - A need for dynamic management of arterial operations (recurring and nonrecurring traffic congestion coupled with limited capacity improvement options);
  - An operating agency with the maintenance and operation (M&O) resources to implement and fine-tune the ATM application; and
  - The active participation and coordination of multiple divisions within a single agency and multiple agencies in the ATM application.
- The literature review and screening survey found few ATM strategies that were sufficiently mature to enable a final determination that the strategies were unsuccessful. However, reversible lanes are one ATM strategy mature enough to identify situations in the literature in which the strategy has been retired because it is no longer needed and/or the costs outweigh the benefits. As traffic grows in both directions of travel, reversible lanes start to impose delays on the reverse direction that dilute the benefits of the strategies.
- The literature and survey found that system and technology requirements associated with implementing the strategies vary by strategy:
  - Continuous real-time monitoring of arterial performance requires permanent detectors in the field (a wide variety of technologies are available) and moderate capacity communications between the field and the central office. Storage of the information in the central office enables the data to be used for engineering studies as well as for real-time control.
  - Dynamic signal control requires sophisticated software at the control center and/or in the field.
  - Dynamic geometric control (dynamic turn lanes, prohibitions, and so forth) requires sophisticated software in the field and/or in the control center plus specialized display hardware in the field.
  - Depending on the technology selected, dynamic traveler information may require specialized display hardware in the field with communications between central office and the field, or it may require cell phone and website technology.
- Regarding issues of secondary interest to this study (institutional issues associated with implementation, M&O requirements, and the benefits and costs associated with implementing these strategies):
  - Interviewees considered institutional issues to be among the greatest challenge to implementing ATM on arterials.
  - Interviewees pointed out the need to budget for M&O costs of ATM on arterials but did not provide information on ATM M&O costs separate from other agency costs.
  - Although all interviewees considered ATM on arterials to be a positive benefit to the public, none were prepared to offer quantified computations or measurements of the benefits of ATM on arterials. Most interviewees considered themselves to still be in the developmental phase of their specific ATM

application and did not think their particular application was sufficiently mature at this point for a formal evaluation of the benefits.

The literature review identified numerous instances in the literature of ATM measures applied to better monitor arterial performance and control arterial operation. Efforts to disseminate freeway performance information to the public are well established and documented in the literature. Dissemination of arterial performance information to travelers is a more recent development with less documentation in the literature. Several references were found for dynamic turn-lane prohibitions and reversible lanes. Less common in the literature were instances in which agencies implemented dynamic turn lanes. Dynamic parking management also is a relatively recent innovation that is only beginning to be documented in the literature.

Arterial performance monitoring is an ATM tactic with much literature and a wide selection of technologies available, yet public agencies rate themselves as failing when it comes to monitoring. From what can be discerned from the literature, this is not a problem with lack of available technology. Future research may be appropriate to identify the obstacles to greater arterial monitoring.

The dominant theme emerging from the sample case interviews was that the major requirements for a successful ATM implementation on arterial streets are much the same as for any major investment project undertaken by the agency.

1. Political support.
2. Funding.
3. Identification and engagement of stakeholders (within and across agencies).
4. Appropriate technological expertise (hired if not available in-house).
5. Detailed planning and design of the proposed investment, which includes
    a. An accurate inventory of the infrastructure necessary to support the new technology.
    b. Recognition that technology is not perfect and accounting for this in the planning.
    c. Consideration of the effect of the project on on-going maintenance costs.
    d. Recognition that is easy to underestimate the required investment costs and the costs for on-going maintenance.

The agencies interviewed each identified at least one and often many more of these points as their “lessons learned” when implementing ATM on their streets.

The interviews highlighted that the difference between major investments and an ATM investment is in the degree to which the involvement of multiple stakeholders and the use of new technology stand out as major challenges to ATM projects. To be successful, ATM projects must involve multiple agencies and multiple divisions within the same agency working together toward a common objective. The new technology involved in more advanced ATM applications is a challenge to agencies without that expertise in-house.

BARRIERS TO WIDESPREAD IMPLEMENTATION

Although the interviews uniformly pointed out the positive benefits experienced with ATM implementations on arterials, they also pointed out that the bottom line challenge to all future ATM investments is funding.

Although many of the agencies interviewed for this study reported that predicting and monitoring the benefits of ATM implementations can be key to securing initial and continuing political and stakeholder support, few agencies reported formal before and after studies. Although all ATM implementations involve monitoring of some kind, relatively few agency operators have conducted formal benefit cost assessments of their ATM installations. This appears to be primarily the result of the early stage of implementation of ATM for most agencies in the United States. The installations are still evolving and being fine-tuned. Therefore, performance has not stabilized sufficiently for a reliable before-and-after comparison.

Similarly, the interviewees generally did not have a clear concept of exactly which performance measures were appropriate for measuring the costs and benefits of ATM installations. They generally were unable to respond quantitatively to requests for information on the precise benefits of their respective ATM installations.

Although most ATM measures appeared in the interviews to be sufficiently along in their technological development to enable agencies to use readily available in-house or commercially available technical expertise to plan, design, construct, and operate most ATM measures, the dynamic turn lanes ATM measure appears to be the farthest back in its technological development. The agencies implementing dynamic turn lanes had to develop from scratch some of the software and hardware systems needed to implement the measure.

SUGGESTIONS FOR FURTHER RESEARCH

The knowledge gaps identified in this synthesis include:

- Lack of knowledge on the appropriate measures of effectiveness and appropriate analysis methods for evaluating ATM investments.
- Lack of sufficient expertise in the hardware, software, and operation of dynamic turn lanes.
- Lack of research into the benefits of and how to operationally implement dynamic route guidance on arterials.
- Guidelines on which ATM tactics to consider.

The SHRP2 Reliability program has developed performance measures and analysis methods for predicting travel time reliability. This information, all recently developed but not fully disseminated, likely will be useful to the community of agencies implementing or considering the implementation of ATM measures on their arterials.

With regard to predicting the benefits of ATM investments, research is needed to develop analytical tools for predicting how different ATM investments can affect travel time reliability and delay in an arterial system (either alone or integrated with a freeway).

Additional research is needed to develop more information and guidance on the appropriate application of dynamic geometric configuration changes (dynamic turn lanes, dynamic turn restrictions, and reversible lanes), including hardware and software system engineering needs.

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APPENDIX A

Screening Survey Instrument

A web-based screening survey was developed to help identify agencies in the United States with a high degree of knowledge and experience in the implementation and operation of ATM on arterial streets. Members of the Institute of Transportation Engineers (ITE) Traffic Engineers Council, the ITE Public Agency Council, the Association of American State Highway and Transportation Officials (AASHTO) Subcommittee on Traffic Engineering, the Transportation Research Board (TRB) ATM Joint Subcommittee, and the TRB Signal Systems Committee were recruited to participate in the screening survey. One hundred twenty-one complete responses were obtained from professionals in 39 states. The candidates for the phone interview surveys were selected from these respondents.

The following pages provide the screening survey questionnaire converted into an MS Word document from the web-based survey. As this is a converted web document, the formatting is different than the online edition.

NCHRP Synthesis 43-10: Active Traffic Management for Arterials

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Dear Transportation Professional:

The Transportation Research Board (TRB) is preparing a synthesis on Active Traffic Management for Arterials. This is being done for NCHRP, under the sponsorship of the American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration.

The purpose of this synthesis is to document the state of the practice associated with designing, implementing, and operating active traffic management on arterials. This study will benefit agencies that are seeking alternative operational strategies to better manage their arterials.

This three-question screening survey is being sent to states, counties, cities, and other local transportation agencies. Your cooperation in completing this screening survey will ensure the success of this effort. The link below can be used to preview the screening survey so you can determine if you are the appropriate person at your agency to complete it. If you determine you are not, please forward the survey's link to the correct person.

Preview Screening Survey: http://surveygizmolibrary.s3.amazonaws.com/library/64484/PDFversionofsurvey.pdf

Thank you very much for your time and expertise.

Please enter the date (MM/DD/YYYY). ______________________________

Please enter your contact information.

First Name*: ______________________________
Last Name*: ______________________________
Title*: ______________________________
Agency/Organization*: ______________________________
Street Address: ______________________________
Suite: ______________________________
City*: ______________________________
State*: ______________________________
Zip Code: ______________________________
Country: ______________________________
E-mail Address*: ______________________________
Phone Number*: ______________________________
Fax Number: ______________________________
Mobile Phone: ______________________________
URL: ______________________________

---

1) Please check the level of experience your agency has in implementing Active Traffic Management Strategies on arterials:*

	None	Low	Medium	High
Dynamic lane assignments	( )	( )	( )	( )
Dynamic turn restrictions	( )	( )	( )	( )
Dynamic route guidance (e.g., trailblazing signage)	( )	( )	( )	( )
Reversible lanes	( )	( )	( )	( )
Specialized signal timing plans (e.g., flushing and gating, tidal flow from special events and incidents)	( )	( )	( )	( )
Arterial travel data collection	( )	( )	( )	( )
Arterial travel information dissemination	( )	( )	( )	( )
Transit signal priority/queue jumping	( )	( )	( )	( )
Dynamic on-street parking management/parking removal	( )	( )	( )	( )

2) Are there any other active traffic management strategies for arterials not listed above that are implemented by your agency/company? If so, please provide a description of the strategy or strategies.

3) Would you be willing to participate in some follow-up questions via e-mail or telephone for us to better understand your experience with any arterial ATM strategy employed by your agency?*

( ) Yes
( ) No

Thank You!

Thank you for taking our survey. Your response is very important to us. If you have any questions or comments, please feel free to contact Richard Dowling at:

E-mail: rdowling@kittelson.com
Phone: 510-839-1742
Mailing Address: 180 Grand Avenue, Suite 250, Oakland, CA 94612

APPENDIX B

List of Agencies' Experience Performing ATM Strategies

This appendix presents a list of agencies responding to the screening survey and their self-selected experience with the various ATM arterial strategies. This information is organized in alphabetical order by state and is shown in Table B1.

TABLE B1
AGENCIES RESPONDING TO THE SCREENING SURVEY AND THEIR EXPERIENCE WITH EACH ATM STRATEGY

State	City	Agency	Arterial Travel Data Collection	Specialized Signal Timing Plans	Signal Priority	Dynamic Lane Assignments	Dynamic Turn Restrictions	Reversible Lanes	Travel Information Dissemination	Dynamic Route Guidance	Dynamic Parking Management
			N = None		L = Low		M = Medium			H = High	
AK	Anchorage	AKDOT&PF	L	L	L	N	N	N	L	N	N
AK	Juneau	Alaska DOT&PF	L	L	L	N	N	N	L	N	N
AL	Huntsville	Garver	M	M	L	L	M	L	L	L	L
AL	Huntsville	City of Huntsville Department of Traffic Engineering	M	M	L	N	M	M	N	N	N
AZ	Lake Havasu City	Lake Havasu City	N	N	N	N	N	N	N	N	N
AZ	Mesa	City of Mesa	M	L	M	N	N	N	L	N	N
AZ	Gilbert	Town of Gilbert	M	L	L	N	N	N	L	N	N
AZ	Queen Creek	Town of Queen Creek	M	N	N	N	N	N	N	N	N
AZ	Yuma	City of Yuma	N	L	N	N	N	N	N	N	N
CA	Campbell	City of Campbell	L	L	N	N	N	L	N	N	N
CA	Richmond	PATH, U.C. Berkeley	H	H	H	H	M	L	H	H	L
CA	San Ramon	Quality Counts LLC	H	N	M	N	N	N	L	N	M
CA	San Jose	City of San Jose	L	L	M	N	L	N	L	M	L
CA	Oakland	Alameda Contra Costa Transit District	L	N	H	N	N	N	N	N	N
CA	San Leandro	City of San Leandro	N	N	N	N	N	N	N	N	N
CA	Moreno Valley	City of Moreno Valley	N	N	N	N	N	N	N	N	N
CA	Santa Monica	City of Santa Monica	L	M	L	N	N	N	N	L	L
CA	Temecula	City of Temecula	M	H	N	L	M	N	N	N	L
CA	Oakland	California Department of Transportation	H	L	H	N	N	N	M	L	N
CO	Lakewood	City of Lakewood	M	L	N	N	N	N	L	L	N
CO	Fort Collins	City of Fort Collins Traffic Operations	L	L	N	N	N	N	L	N	N
CT	New Haven	CDM Smith	M	M	H	M	M	M	M	M	H
CT	Manchester	Town of Manchester	L	N	N	N	N	N	N	N	N

TABLE B1
(*continued*)

State	City	Agency	Arterial Travel Data Collection	Specialized Signal Timing Plans	Signal Priority	Dynamic Lane Assignments	Dynamic Turn Restrictions	Reversible Lanes	Travel Information Dissemination	Dynamic Route Guidance	Dynamic Parking Management
DE	Smyrna	Delaware DOT	M	H	N	N	N	N	M	N	N
FL	Miami	Miami–Dade County PWWM Traffic Signals & Signs Division	L	M	L	L	L	M	L	L	N
FL	Tampa	City of Tampa	M	H	N	M	M	H	L	M	N
FL	Fort Myers	Lee County Department of Transportation	N	N	N	N	N	N	N	N	N
FL	Bradenton	Manatee County Public Works	L	L	N	N	N	N	N	N	N
FL	Yulee	Nassau County Florida Engineering	L	L	N	N	N	N	L	N	N
FL	Ft. Lauderdale	FDOT District Four, Traffic Operations	L	N	L	N	L	N	L	N	L
GA	Marietta	City of Marietta	M	M	M	N	N	N	L	L	N
GA	Roswell	City of Roswell	M	N	N	H	H	H	L	N	N
GA	Atlanta	Pilkington Engineering	N	N	N	N	N	N	N	N	N
GA	Gainesville	City Of Gainesville	N	H	M	N	N	N	M	N	N
GA	Lawrenceville	Gwinnett County DOT	M	H	N	N	N	L	L	N	N
GA	Jonesboro	Clayton County Transportation and Development	H	H	L	N	N	L	L	N	N
GA	Alpharetta	City of Alpharetta	L	M	N	N	N	N	N	M	N
GA	Atlanta	Georgia DOT	M	H	M	N	L	H	L	N	N
GA	Marietta	Cobb County DOT	M	M	L	N	N	N	H	N	N
IA	Cedar Rapids	City of Cedar Rapids	M	L	N	N	N	N	N	N	N
IA	Des Moines	City of Des Moines	L	M	M	N	N	N	N	M	N
IA	Ames	Iowa DOT	N	N	N	N	N	N	N	N	N
ID	Boise	Ada County Highway District	L	H	N	N	N	N	L	N	N
IN	Indianapolis	Indiana DOT	H	M	N	N	L	L	N	N	N
KS	Overland Park	City Of Overland Park	H	M	L	N	M	N	H	M	N
KS	Olathe	City of Olathe	M	H	N	N	L	N	L	N	N
KY	Lexington	Lexington–Fayette Urban County Government	L	H	N	L	H	H	H	L	M
KY	Lexington	CDM Smith	H	L	M	N	N	M	L	L	L

(*continued on next page*)

TABLE B1
(*continued*)

State	City	Agency	Arterial Travel Data Collection	Specialized Signal Timing Plans	Signal Priority	Dynamic Lane Assignments	Dynamic Turn Restrictions	Reversible Lanes	Travel Information Dissemination	Dynamic Route Guidance	Dynamic Parking Management
MD	Hunt Valley	Century Engineering, Inc.	H	H	H	H	H	H	H	H	M
MD	Baltimore	STV Incorporated	H	N	L	N	M	M	L	N	L
MD	Towson	Division of Traffic Engineering	L	L	N	N	L	N	N	N	N
MI	Flint	ROWE Professional Services Company	N	N	N	N	N	N	N	N	N
MI	Battle Creek	Battle Creek Public Works Department	N	N	N	N	L	N	N	N	N
MI	Saginaw	City of Saginaw, Michigan	N	N	N	N	N	N	N	N	N
MI	Lansing	Michigan DOT	N	L	N	L	N	L	N	L	N
MN	Plymouth	SRF Consulting Group, Inc.	L	M	L	M	N	M	L	L	N
MN	Roseville	Minnesota DOT—Metro District	H	M	M	N	M	N	M	L	N
MN	Roseville	Minnesota DOT	H	L	L	L	L	N	L	L	N
MN	Roseville	Maryland DOT Metro District	H	M	M	N	M	N	M	L	N
MO	Grandview	City of Grandview	L	N	N	N	N	N	L	N	N
MO	Springfield	City of Springfield	N	M	N	N	N	N	N	N	N
MO	Chesterfield	Missouri DOT	M	M	L	N	M	H	H	M	M
MO	Lee’s Summit	City of Lee’s Summit	L	N	N	N	N	N	N	L	N
MS	Jackson	Mississippi DOT	M	L	N	N	N	N	H	N	N
NC	Cary	Road Safety & Transportation Solutions, Inc.	H	L	M	N	N	M	M	N	L
NC	Cary	Town of Cary	M	M	N	L	L	N	L	L	N
NC	Winston-Salem	City of Winston-Salem DOT	M	L	N	N	N	N	N	N	N
NE	Lincoln	Nebraska Department of Roads	N	L	N	N	N	N	N	N	N
NE	Omaha	City of Omaha, Nebraska	N	L	N	N	L	H	N	L	N
NH	Manchester	Hoyle Tanner and Associates, Inc.	H	L	L	N	L	N	L	N	L
NH	Concord	New Hampshire DOT	L	L	N	N	N	N	M	N	N
NJ	Lyndhurst	New Jersey Meadowlands Commission	H	H	N	N	N	N	N	N	N
NJ	Piscataway	AECOM Transportation USA	H	M	H	L	L	L	H	H	L
NM	Farmington	City of Farmington	L	N	N	N	N	N	N	N	N

TABLE B1
(*continued*)

State	City	Agency	Arterial Travel Data Collection	Specialized Signal Timing Plans	Signal Priority	Dynamic Lane Assignments	Dynamic Turn Restrictions	Reversible Lanes	Travel Information Dissemination	Dynamic Route Guidance	Dynamic Parking Management
NV	Carson City	Nevada DOT	L	M	L	N	N	N	L	L	N
NY	Watertown	NYSDOT Region 7	L	M	N	N	N	N	N	N	N
NY	Rochester	Monroe County DOT	H	H	L	N	N	N	L	N	L
NY	LIC	NYC DOT	H	H	M	L	L	H	M	H	L
OH	Columbus	EP Ferris & Assoc., Inc.	M	L	N	N	N	N	N	N	N
OH	Hilliard	City of Hilliard	L	L	N	N	N	N	N	N	N
OK	Edmond	City of Edmond	L	N	N	N	N	N	N	L	N
OK	Oklahoma City	SAIC	M	M	N	L	L	M	L	H	L
OR	Salem	Marion County	L	L	N	N	N	N	N	N	N
OR	Portland	City of Portland	H	H	H	N	M	N	M	M	N
OR	Portland	Oregon Department of Transportation	L	L	M	N	N	N	L	L	N
OR	Springfield	City of Springfield	L	L	M	N	L	N	N	N	N
PA	Exton	McMahon Associates, Inc.	M	H	L	N	M	N	N	N	N
PA	New Britain	Gilmore & Associates, Inc.	H	M	N	N	M	N	H	L	M
PA	State College	Ferguson Township	N	N	L	N	N	N	N	N	N
RI	Providence	Rhode Island Dept. Of Transportation	M	M	L	N	L	N	L	L	N
SC	Beaufort	Beaufort County	M	H	N	N	N	N	L	N	N
TN	Memphis	Kimley-Horn and Associates, Inc.	M	M	L	N	N	M	M	L	L
TX	Waco	City of Waco Traffic	M	N	N	N	N	N	L	N	N
TX	Frisco	City of Frisco	M	H	N	M	M	N	N	N	N
TX	Lubbock	City of Lubbock	M	H	N	N	N	N	N	N	N
TX	McKinney	City of McKinney	N	L	N	N	N	N	N	N	N
TX	Garland	Transportation Dept./City of Garland	N	N	N	N	N	N	N	N	N
TX	College Station	City of College Station	M	H	N	N	N	N	L	N	N
TX	Abilene	City of Abilene	L	N	N	N	N	N	N	N	N

(*continued on next page*)

TABLE B1
(*continued*)

State	City	Agency	Arterial Travel Data Collection	Specialized Signal Timing Plans	Signal Priority	Dynamic Lane Assignments	Dynamic Turn Restrictions	Reversible Lanes	Travel Information Dissemination	Dynamic Route Guidance	Dynamic Parking Management
UT	Orem	Utah DOT Region 3	M	H	M	M	L	M	L	M	N
UT	Salt Lake City	Utah DOT	L	H	H	M	L	H	L	M	N
VA	Alexandria	City of Alexandria, Virginia	N	N	L	N	N	N	N	N	N
VA	Arlington	Arlington County	M	M	M	M	N	L	M	L	L
WA	Federal Way	City of Federal Way	N	N	L	N	N	N	N	N	N
WA	Bellevue	City of Bellevue	H	M	M	N	L	N	H	N	N
WA	Seattle	Washington State DOT	H	M	M	M	M	H	M	M	L
WA	Spokane	City of Spokane	H	M	L	N	N	N	M	N	N
WI	Eau Claire	City of Eau Claire	M	N	N	N	N	N	N	N	N
WI	Milwaukee	HNTB	N	M	L	N	N	L	N	L	N
WI	Waukesha	Wisconsin DOT	H	M	N	L	N	M	M	M	N
WV	Charleston	West Virginia Division of Highways	M	M	M	N	N	N	M	L	L
WY	Cheyenne	WYDOT	N	N	N	N	N	N	N	N	L
INT	Markham	Hatch Mott MacDonald	N	N	N	N	N	N	N	N	N
INT	Regina	AECOM	L	L	N	M	L	L	N	L	N
INT	Jubail	BECHTEL	H	L	L	N	N	N	L	N	L
INT	Dhahran	Saudi Aramco	L	L	N	N	N	N	N	N	L
INT	Hawthorn East	O'Brien Traffic	L	L	M	N	M	N	M	N	N
INT	Coburg	Moreland City Council	M	L	L	N	L	N	M	N	L
INT	Dresden	Grahl—Transportation Engineer	M	H	H	M	M	M	M	H	L
INT	Kelowna	City of Kelowna	N	L	L	N	N	N	N	N	N
INT	Surrey	Baskin Associates Technical Services	L	N	N	L	L	L	N	N	L

N = None
L = Low
M = Medium
H = High
INT = International

Abbreviations used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation