White Paper

A Case for Real-Time Monitoring of Vehicular Operations at Signalized Intersections

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Introduction

This white paper makes the case for real-time monitoring of vehicular operations at signalized intersections. There are roughly 250,000 traffic signals in the United States, approximately one traffic signal for every 1000 persons. These traffic signals have been built over the years costing tens of billions of tax-payer dollars with several millions spent each year for maintaining them. Every trip we make using our automobile is certain to involve going through several traffic signals on a daily basis. A major component of the travel time of any typical trip is the time we spend waiting at a traffic signal. Yet only a small fraction of signalized intersections within the US have any real-time monitoring capability. There are significant benefits to monitoring traffic operations at signalized intersections, some of which are discussed in this paper. When the low cost of deploying such a system is compared against even modest assumptions on anticipated benefits, the benefits-cost advantage is staggering. Most infrastructure including communication networks, water, power, etc, have some level of continuous monitoring of the network. The freeway infrastructure has varying levels of real-time monitoring as part of Intelligent Transportation System (ITS) deployment around the United States. However, one major component of our infrastructure, namely traffic signals has almost no monitoring. This white paper presents the benefits, costs and potential implementation strategy for a real-time monitoring system at signalized intersections.

Context

Trips within a metropolitan area can be broken down into three types. Home-based work (HBW) trips which involve commute from/to home and the place of work. Home-based non-work (HBNW) trip which are trips related to shopping, going to school or a trip to the local library. Finally, Non home-based (NHB) trips include other trips such as from the place of work to the local restaurant, or business to business deliveries, etc. Based upon data collected within a metropolitan area by the Federal Highway Administration as part of the National Personal Transportation Study, roughly 25% of all trips are HBW, 50% of the trips are HBNW and the remaining 25% are NHB.

Each of these types of trips involves traveling on different types of roads. In general, roads are classified into various functional classes such freeways and expressways, arterials and collectors, and local streets. Each trip involves traveling on any and all of these road types. Within a typical metropolitan region, a greater portion of a HBW trip occurs on freeways than the other road types. However, the other two trip types, the HBNW and NHW trips which account for 75% of all trips, typically involve greater usage of the arterials/collectors. In other words, the arterials/collectors and local streets are utilized to a much greater extent. What is ubiquitous on arterials/collectors and local streets? It is traffic signals.

The Texas Transportation Institute (TTI) publishes the Urban Mobility Report which describes the level of congestion within 85 metropolitan areas within the United States. This document is widely referred to by national and state law-makers and public agency officials. Based upon an analysis of data for four typical major metropolitan regions (Boston, Denver, Houston, and San Jose), the number of miles of the arterials/collectors and local streets is more then 2 to 3 times the freeway miles. Furthermore, it was estimated that the average daily hours of delay per person on the arterials is roughly twice that on the freeway system. If one were to include

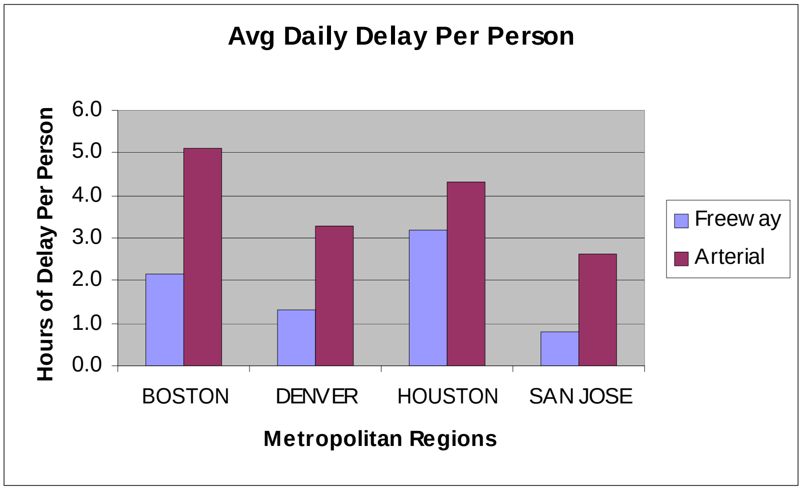

Figure 1 - Average Daily Delay Per Person

collectors and local streets, then the average delay experienced by a person on non-freeways would be more than twice the average delay per person on the freeways. This is not to say that delays on freeways are insignificant. Yet, if one were to consider the delay experienced by motorists at each of the approximately 250,000 signals in the United States, it would be a significant amount.

Real-time Monitoring of Signalized Intersection

Real-time monitoring of signalized intersection is the collection of information related to vehicular operations on an on-going basis in real-time. There are two main methods of monitoring vehicular delay at signalized intersections:

- Infrastructure based
- Vehicle based

In the infrastructure based monitoring system, the vehicular delay is computed (or estimated) based upon information gathered from equipment installed at the intersection. The vehicle based monitoring system involves using vehicles are probes to directly collect information on delay. This paper focuses solely on the Infrastructure-based method.

Real-time monitoring of signalized intersections requires the following three components:

- A “count-capable” detection system at each signalized intersection able to provide accurate counts by lane[1].
- A field device at each intersection to continuously extract count data from the detection system as well as signal timing information from equipment within the cabinet in real-time and transmit to a central server for processing.
- A central server that processes the information transmitted by the field devices to estimate vehicular delay at each intersection, and that provides users easy access to the delay information.

[1] Most new traffic signal installations have “count-capable” detection systems. Detection systems at older intersections may need to be upgraded to make them count-capable.

It would be extremely beneficial to monitor vehicular delay at signalized intersections on a continuous basis and in real-time. The real-time vehicular delay information would have significant application in the following areas:

- Real-time traveler information
- Signal retiming and validation
- Highway performance monitoring

The following section discusses the analysis of the benefits that could be derived from and the justification for real-time monitoring of signalized intersections.

Analysis and Justification

Traveler Information

A significant benefit of real-time monitoring of vehicular operations at signalized intersection would be in the area of traveler information. Based upon the delay information at signalized intersections, we could obtain travel time information on the arterials and streets whose level of traffic operations are almost entirely determined by traffic signals.

If one were to look at market studies for Intelligent Transportation Systems (ITS) in general and traveler information in particular conducted in the early to mid 1990s, the expectation was to have a large and viable traveler information market by the year 2000. The traveler information market that currently exists is still relatively small. Most traveler information sources, whether from private or public sources, provide real-time traffic information predominately limited to major freeway systems around metropolitan areas. Why is it that the traveler information market did not grow as expected? Given the increasing congestion on our highways and streets, shouldn't the hunger for real-time traffic information by commuters be greater than ever? Especially by businesses involved in logistics and delivery, who might be willing to pay for information that might help them do a more efficient job?

The answers to the above questions lie in the coverage of our ITS devices on the highway system. As mentioned before, most of the real-time traffic information collected is almost entirely on freeways. Unless we collect real-time information on the other arterials and major streets as well, it is unlikely that the traveler information market will grow. As mentioned earlier, every trip a person makes includes travel on, to varying degrees, freeways as well as on other arterials and streets. Unless there is complete end-to-end real-time traffic information on the entire route of a person's trip, people are unlikely to find useful the information on only certain sections of their route.

Providing real-time traffic information on arterials and streets will create the greatest potential for a truly viable traveler information market for the following reasons. One, in combination with the already existing freeway real-time traffic information, the arterial and local street traffic information will enable a comprehensive coverage of the entire highway system. Two, the arterials and local streets have a much higher "network density" than the freeway system. In other words, there are a lot more network connections on the arterials and local street system. For example, each of us can identify multiple routes from our home to the nearest freeway interchange or from the freeway interchange to our place of work. Similarly, most of us have multiple ways of going between our home to the local grocery store or our kids' schools.

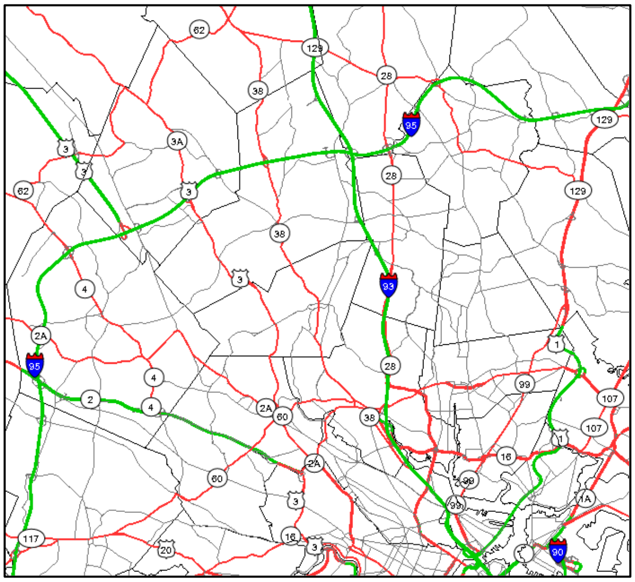

Figure 2 - Boston Metropolitan Highway Network

Figure 2 shows a portion of the highway network around the Boston Metropolitan region. The freeways are show in green and arterials in red and other streets in black. It is quite evident that the network density of the arterials and other streets are much higher than that of the freeways.

A higher density of the highway network promotes greater value to real-time traffic information and dynamic route guidance. People are likely to value real-time traffic information more on the arterials and local streets with a greater network density than on freeways that have a much lower level of network density. Given that the average daily delay per person on arterials and local streets are roughly twice than that on freeways, and given that there is greater choice of routes on the arterials and local street system, the greater value of real-time information and dynamic route guidance on the arterials and local streets is more than obvious.

Real-time traffic information on arterials in combination with existing freeway information will provide a truly comprehensive traveler information system and further promote the dynamic route guidance market. Benefits from real-time traveler information in general and dynamic route guidance in particular in terms of travel time savings, have been well-documented by studies throughout the United States.

Signal Re-timing and Validation

Collecting vehicular operations in terms of delay at signalized intersections on an on-going basis provides an obvious value-added: signal retiming. Traffic engineers would know more precisely at what times of the day delays on approaches at signalized intersections exceed acceptable thresholds. It would also help prioritize signal retiming efforts among the hundreds of signalized intersections typically within any jurisdiction. Such a system would also allow monitoring traffic operations along a major highway under coordinated set of traffic signals.

A key advantage of continuous monitoring of vehicular operations at traffic signals is that it provides a method to verify the effectiveness of signal retiming made by the public agency to improve traffic operations. Based upon the delay information if the public agency decides to retime the signals, now they have a way to see if in fact the retimed signals improved traffic operations or not. Further adjustments to the signal timing can be made and monitored for effectiveness.

Typically, traffic signals throughout the country are programmed with specific signal timing plans for the morning and evening peak hour periods. In many instances, these same timing plans are utilized for the rest of the day as well. If one were to look at the delay throughout a 24-hour period, roughly 15-20% of the daily delay at a signalized intersection occurs during each of the peak morning and evening peak periods. This means that the remaining 60-70% of the delay occurs outside of the peak periods during the rest of the day (not including the hours with extremely low traffic say between 10PM and 5AM). With the need to address traffic conditions during the Noon (lunch time) peak as well as increased travel during the “shoulder” hours of the peak periods, having vehicular delay information on a 24/7 basis will greatly assist the traffic engineers in creating additional timing plans. The existing traffic signal controller technology has substantially more capabilities than what is typically utilized. Having additional signal timing plans to specifically account for noon peak and off-peak periods as well as weekends, holidays and special events will greatly improve traffic operations on the arterials and local street system.

The benefits derived from optimizing signal timing in general and signal retiming during the peak periods are beyond dispute. The Institute of Transportation Engineers (ITE) has long been pointing to many benefits such as reduction in delay and travel time by 10-20%, reduction in gasoline consumption by 10% and similar reduction in vehicle emissions.

Performance Measurement

Vehicular delay information at signalized intersection would be an extremely important component of the overall performance measurement of the highway system. It would significantly improve the quality of travel and delay information on the non-freeway system.

Real-time vehicular delay information at signalized intersections would be crucial for homeland security during an emergency and greatly assist in any evacuation procedures. Based upon real-time information, police and other emergency personnel and resources could be deployed to specific points in the network with higher levels of delay. Police details could be placed at specific signalized intersections on an as-needed basis to further improve traffic operations during an emergency event.

Having continuous delay information would help identify problematic signalized intersections. Currently, agencies identify signalized intersections for improvement either based upon the crash history or on the amount of citizen complaints. These methods are “reactive” in nature. Instead, the transportation agencies can be more “proactive” with continuous vehicular delay information at signalized intersections. As soon as any signalized intersection begins to operate at below industry-accepted standards, it could be reviewed for any operational improvements through signal retiming or programmed into the Transportation Improvement Program (TIP) for funding. Delay information for intersections along a signalized arterial could be used to determine the need for signal coordination or improvements along the arterial.

Implementation

Architecture

The overall architecture of a real-time monitoring system of vehicular delays at signalized intersection could be as shown in Figure 3. Information collected from the signalized intersection is continually transmitted to a central server by a transceiver. The server software would process the information received to estimate vehicular delay. Further it would enable access to this information over the Internet by transportation agencies as well as traveler information service providers. The architecture envisions a communication link between the remote signalized intersection and the user to also allow the transportation agency owning the signalized intersection to communicate with the signal controller for remote update/fine-tuning of the signal timings.

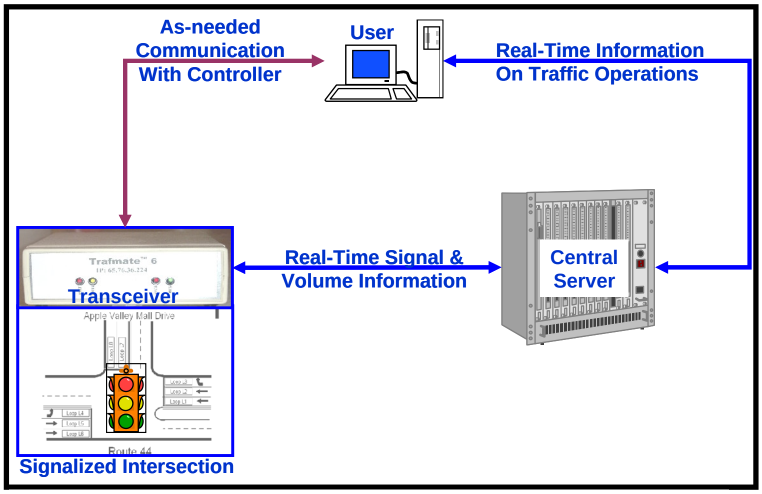

Figure 3 - Architecture for Signalized Intersection Monitoring

From the signalized intersection, data on traffic volume and signal timing would be transmitted to a central server in real-time. Using mathematical algorithms, the server software would estimate the vehicular delay based upon the traffic volume and signal timing information.

This method of real-time monitoring of signalized intersections can be immediately implemented using equipment already available at existing traffic signals. Traffic signals are constructed with detection systems that can provide traffic volume data. The traffic signal cabinet’s internal wiring allows for monitoring the voltages of individual signal displays and thereby obtaining signal timing information. Combining the traffic volume with the signal timing information to estimate vehicular delay can be done using well-established empherical equations such as those described in the Highway Capacity Manual’s (HCM) procedure for analyzing signalized intersections.

NCHRP 3-79 “Measuring and Predicting the Performance of Automobile Traffic on Urban Streets” research project being conducted by Texas Transportation Institute (TTI) and Purdue University is looking at methods for monitoring traffic operations at signalized intersections.

TrafInfo is working on algorithms based upon modifications to the HCM empherical equations and prior research to estimate vehicular delay that, based upon initial study, appear to be significantly closer to the actual delay than using the HCM equations *per se*. Further research and fine-tuning of the estimation algorithm are underway by others.

Cost

A major component of a real-time traffic monitoring system at signalized intersection is a transceiver to extract traffic volume information from the intersection's detection system and to extract signal timing information. If an existing signalized intersection has a fully-functional count-capable detection system, then the cost to implement a real-time system for monitoring vehicular delays would be in the order of $3000-$5000.

To realize the benefits from real-time monitoring at signalized intersections mentioned previously in this paper, to begin with, it would be prudent to deploy the system at major and critical signalized intersections within a typical metropolitan area. Major and critical intersections could amount to about 15-20% of the total signalized intersections, about a 1000 signalized intersections within a typical metropolitan region. Monitoring every intersection at the outset would be cost-prohibitive. However, as intersections undergo signal upgrade and/or replacement, then the real-time monitoring system could be deployed at more signalized intersections on an incremental basis to further expand the coverage. Using a cost of $5000 per intersection, the total cost of real-time monitoring of traffic signals at about 1000 intersections covering a typical metropolitan region would be about $5 million.

A key component of the real-time monitoring system is a fully-functional count-capable detection system at the signalized intersection. The recent NTOC's Traffic Signal Report Card was not every encouraging in terms of the current state of detection systems at signalized intersections. The report card highlighted the importance of having a functional detection system to ensure optimal traffic signal operation. Some communities have been able to tap into CMAQ (Congestion Mitigation and Air Quality) funding to replace and/or update the detection systems at their signalized intersections. If public sector investment is made towards fixing/upgrading existing detection system at traffic signals to make them fully-functional and count-capable, it would encourage implementation of the real-time monitoring system by a private sector partner.

Public-Private Partnership

Real-time monitoring of signalized intersections is especially suited to public-private partnerships. Given the value it can generate in terms of real-time traveler information, the private sector can be expected to participate in terms of implementation. In addition, given the ever-prevalent budgetary constraints at public agencies, participation by the private sector in contributing towards the initial capital expenditure would be welcome.

A likely scenario of implementation would be where a private company would install the transceivers and the central server and the public agency would undertake the upgrade of the detection system. In return for permitting the private company to install equipment in their signal cabinet, the public sector partner would receive the following in return: (a) access to the information on vehicular operations for off-line analysis; and (b) ability to remotely connect to their signal controller and potentially other equipment within the cabinet for troubleshooting, diagnostics or signal retiming.

Investment by the public sector towards the traffic signal detection system needed for the real-time monitoring system would deliver significant benefits to the public, if one were to account for savings in fuel consumption due to savings in travel time from comprehensive traveler information. A typical commuter in a metropolitan region consumes about 600 gallons of gasoline every year or spends about $1800 every year. If one were to assume a modest savings of around 3-5% in fuel consumption due to real-time traveler information and from signal retiming efforts, it would mean a savings of about $75 per commuter. Even if one were to consider a medium-sized metropolitan region with a population of about 1 million with roughly 300,000 commuters, the total annual savings in gasoline consumption would amount to $22 million!

Significant return-on-investment can also be expected by both the private and public sector partners with strong possibility of revenue-sharing. One only needs to consider the explosion of global positioning system (GPS) devices, personal digital assistants (PDA) and Smartphones. Each of these devices now provides navigational information, using static transportation network information without any dynamic real-time traffic information. With increases in gasoline prices, motorists will look towards navigational devices to avoid bottle-necks and help reduce their gasoline consumption by using the route with the least travel time.

Conclusion

Public agencies throughout the United States have made significant investment of ITS technology on freeways. There has been minimal investment of ITS technologies on arterials and local streets, even though an average driver utilizes these roads to a much greater extent and faces twice as much delay on an average on these roads than on the freeway system. Real-time traffic information on the arterials and local streets is a critical component of a comprehensive traveler information system. Without real-time information on the arterials and local streets, having purely freeway-related traffic information would be of limited value. If real-time traffic information were to be available for the arterial and local street system along with freeway information, it would allow traveler information service providers to begin providing a whole host of services to the traveling public. Given the explosion of in-vehicle navigation devices, and broadband wireless services providing access to the Internet, the demand for real-time traveler information would greatly expand if arterial and local street information were to be available along with the existing freeway information.

A strong case is made in this document for real-time monitoring of vehicular delays at signalized intersections. Benefits of such a system include real-time traveler information, signal retiming, and highway performance monitoring.

This paper discusses the infrastructure-based systems for real-time monitoring of signalized intersection, which estimate vehicular delays based upon traffic volumes and signal timing. Such systems can be immediately implemented for relatively low cost using equipment already available at traffic signals and provide a significant benefit to the traveling public.

Historically, ITS technologies at signalized intersections have focused almost entirely on adaptive traffic signal control. It is now time to deploy technologies for real-time monitoring of vehicular delays at signalized intersections that potentially would lay a strong foundation to even more sophisticated adaptive traffic signal control technologies in the future.