Reducing Carbon Emissions and Congestion by Coordinating Traffic Signals

THIS FEATURE SUMMARIZES CURRENT TRAFFIC SIGNAL OPERATIONS IN THE UNITED STATES AND THE POTENTIAL TO COORDINATE TRAFFIC SIGNALS TO REDUCE CONGESTION AND CARBON EMISSIONS. THE TIME COULD NOT BE BETTER FOR THIS INVESTMENT GIVEN THE RAPID ESCALATION IN CONSTRUCTION COSTS OF LARGE TRANSPORTATION PROJECTS.

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WHAT IS THE PROBLEM?

According to the Surface Transportation Policy Project, motor vehicles are the largest source of urban air pollution.[1] The U.S. Environmental Protection Agency estimates that vehicles generate 3 billion pounds of air pollutants yearly.[2] Inefficient traffic signals account for a significant portion of the carbon emissions in urban areas. Vehicles stop at red lights and subsequently accelerate, resulting in excess fuel consumption that produces additional carbon emissions.

The United States has not been adequately funding traffic signal timing improvement projects, and this has resulted in an overall poor rating for traffic signal operations based on the *2007 National Traffic Signal Report Card.*[3] Improper traffic signal timing accounts for 5 to 10 percent of all traffic delay, or 295 million vehicle-hours of delay on major roadways alone.[4] The stop and start activity and low travel speeds caused by poorly timed signals and congestion have the greatest impact on carbon emissions.[5]

The *National Traffic Signal Report Card* indicates that at a cost of less than 1 percent of the total national expenditure on highway transportation, traffic signal operations could be improved to achieve an excellent rating in traffic signal management, with annual savings of almost 17 billion gallons of motor fuel nationwide. This equates to nearly 150 million metric tons of carbon dioxide (CO_2) saved per year.

WHY ARE TRAFFIC SIGNALS NOT BEING COORDINATED TODAY?

Some investment is being made in signal system operations in the United States today, but on the whole, the vast majority of signal systems have potential for greatly improved performance.[6] Investment in signal timing is lacking because agencies must prioritize limited budgets with competing construction, maintenance and operations needs. Because construction and maintenance costs continue to increase, available funds for operating and coordinating traffic signals have become scarcer over time. This is not a surprise; public agencies often focus these funds on maintenance of the existing roadway network first to ensure safe conditions for transportation users.

As evidenced in the *National Traffic Signal Report Card,* not nearly enough is done to stem the tide of excess greenhouse gas emissions generated by poorly timed signals. More important, the lack of investment is nationwide. Strategically applied carbon offset funds would make a meaningful impact on carbon reduction well beyond current funding programs. Performance criteria should be developed to target the agencies and corridors where signal timing can provide the biggest carbon benefits and would not be updated without funding from carbon credits. Examples of the performance criteria for targeting carbon offset funds include:

- corridors where traffic signal timings are more than 10 years old;
- jurisdictions with staff that have no signal timing expertise or support and/or have limited resources;
- corridors where multiple agencies operate traffic signals and coordination across agency boundaries is lacking;
- locations that are lacking communication systems for effective signal coordination; and
- corridors that have variable volumes and would benefit from adaptive signal systems.

WHAT IS THE OPPORTUNITY?

Nationally, if traffic signals were operated at an "A" level, it would be possible to save almost 17 billion gallons of fuel per year and reduce harmful emissions by up to 22 percent.[7] Coordinated traffic signal

timing can reduce congestion, improve air quality and reduce fuel consumed along urban roadway corridors. It is proven as one of the most cost-effective techniques for improving traffic operations, producing benefit-to-cost ratios of 40:1 or more.[8]

These improvements can be achieved without the large costs of increasing the physical capacity of the roadway system. Study after study has shown that signal timing can reduce harmful emissions by 5 to 10 percent. This increment may appear minor, but when thousands of traffic signals are included and the effect on hundreds of thousands of vehicles is considered, the result equates to millions of gallons of fuel saved each year. This has a secondary benefit of reducing costs to consumers.

There are more than 270,000 traffic signals in the United States, according to the Institute of Transportation Engineers (ITE). Two-thirds of all miles driven each year are on roadways controlled by traffic signals.[9] However, in 2007, the United States received an overall poor rating for traffic signal operations. This can be improved with a minimal investment in better traffic signal timing.

The time could not be better for this investment given the rapid escalation in construction costs of large transportation projects. The cost to implement new signal timing averages approximately $3,500 per intersection and produces substantial benefits including:

- reductions in fuel consumption up to 10 percent;[10]
- reductions in traffic delay ranging from 15 to 40 percent;
- reductions in travel time up to 25 percent;
- reductions in stops ranging from 10 to 14 percent; and
- reductions in harmful emissions up to 22 percent.

These substantial benefits can be delivered to the public at modest cost. The greatest opportunity will be found in locations where signal timing is not done routinely due to budget constraints or where multiple agencies operate a corridor without coordination across agency boundaries. In some cases, municipalities have not retimed their signals in more than 10 years even though ITE recommends signals be retimed every 2 to 3 years to stay current with constantly changing travel demand patterns.

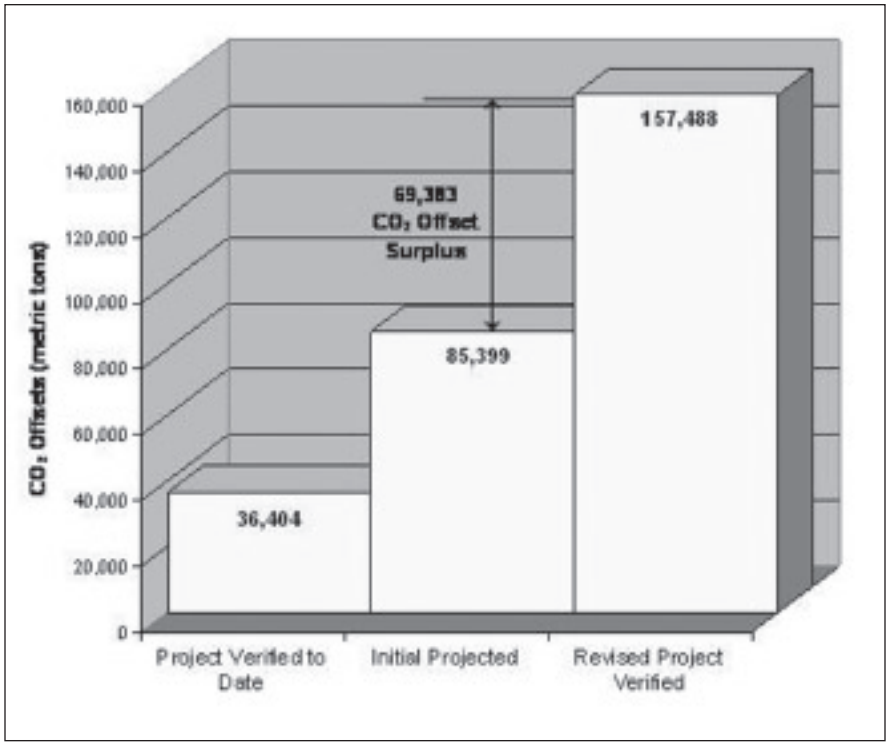

Figure 1. CO_2 emissions reductions from the City of Portland's signal timing project in 2003.

What Are the Potential Carbon Savings for a Typical Jurisdiction?

Results from the joint City of Portland, OR, USA/Climate Trust project produced savings of approximately 50 metric tons of CO_2 per year per traffic signal. Over the lifespan of the City of Portland signal timing project (phase 1), an estimated 15,000 metric tons of CO_2 will be offset per year. The revised project verified CO_2 offsets for all corridors will reach a total of 157,488 metric tons at the end of the project.

In Oregon, there are approximately 3,300 traffic signals. Approximately 70 percent of these traffic signals are on corridors that could benefit from signal timing (2,310). If new timings were installed at all 2,310 intersections, the potential CO_2 savings in 1 year would be 115,000 metric tons per year.

IS THERE PRECEDENT FOR FUNDING SIGNAL TIMING TO REDUCE EMISSIONS?

In 2003, the City of Portland Offices of Sustainable Development and Transportation entered into an agreement with the Climate Trust to develop new coordinated signal timings at 135 traffic signals on 17 corridors in the City of Portland and in surrounding areas (City of Gresham and Oregon Department of Transportation roadways). The project was a success and produced annual savings in carbon emissions of over 15,000 metric tons of CO_2 per year at a cost of $530,000. The project has since been extended to another 132 traffic signals on 16 corridors and is projected to reduce CO_2 emissions by another 6,600 metric tons per year at a cost of $235,000.

In Portland, the Climate Trust and the City considered the right to ownership of the credits. The traffic signals are owned, operated and maintained by the City of Portland, and the signal timings are developed and implemented by City staff. Consequently, both parties agreed that the City was the owner of the offsets. The City of Portland/Climate Trust agreement transfers ownership of the CO_2 offsets from the City of Portland to the Climate Trust. No third party has asserted or threatened to assert any right to ownership in the CO_2 offsets described in the City of Portland/Climate Trust project.

HOW ARE CHANGES IN EMISSIONS CALCULATED?

The most effective tools to measure changes in emissions that result from traffic operations improvements are microsimulation models of traffic conditions. Engineers use traffic simulation models to develop coordinated traffic signal timings and typically enter a significant amount of corridor condition data to calibrate the model to represent existing conditions. The data inputs required for a traffic simulation model include four categories of information that allow the engineer to configure the model to match field conditions:

- **geometric data** (lanes, bus stop locations, grades, parking maneuvers, etc.);
- **traffic data** (volumes, pedestrians and bikes, saturation flow rates, etc.);
- **traffic signal timing** (green times, cycle lengths, vehicle detector settings, pedestrian times, etc.); and
- **vehicle characteristics** (vehicle mix, acceleration rates, speeds, etc.).

Using an accurately calibrated traffic simulation model, an engineer can test alternate signal timing methods and use the model to calculate the impacts on vehicle speeds, travel times, stops, delay and emissions.

Two types of traffic simulation models exist: macroscopic and microscopic. Macroscopic models are based on deterministic relationships between roadway and intersection characteristics and traffic flow. Microscopic models simulate the movement of individual vehicles through the network being modeled.[11] Either type of model measures changes in emissions based on vehicle speed and acceleration characteristics; however, microsimulation models can account for a variety of vehicle acceleration rates. Because traffic engineers already develop coordinated signal timing using microsimulation models, it is logical to use these same models to measure changes in emissions associated with signal timing improvements.

The detailed emissions calculation methodology developed by the City of Portland for the Climate Trust project uses a detailed traffic simulation model[12] of the actual corridor to measure changes in emissions. The traffic simulation model is calibrated to actual field data including detailed vehicle counts, vehicle speeds, number of stops, signal timing operations and detailed vehicle characteristics. This allows for comparison of the system performance with and without the coordinated signal operations. The model provides the following benefits that ensure relatively accurate assessments of impacts:

- models individual vehicles through the network;
- capable of a network level analysis;
- uses reliable formulas for estimation of emissions and fuel consumption;
- accurately models field operating conditions;
- incorporates vehicle acceleration characteristics;
- includes vehicle types that can be adjusted to represent the vehicle fleet mix within a particular corridor;
- can be validated using actual floating car travel time surveys, field measurements and traffic count data from the field to "ground truth" the assessment; and
- external models could be used to interface the signal timing model to new energy and emissions values determined in an emissions lab.

IN 2007, THE UNITED STATES RECEIVED AN OVERALL POOR RATING FOR TRAFFIC SIGNAL OPERATIONS. THIS CAN BE IMPROVED WITH A MINIMAL INVESTMENT IN BETTER TRAFFIC SIGNAL TIMING.

Although the microsimulation model provides substantial capability to model current conditions, there is no existing provision to model a comparison of alternative fuel types.

WHAT SHOULD BE DONE?

As noted earlier, most public agencies lack the necessary funds and staff resources to maintain adequate signal timings. Public agency budgets have historically focused on capital improvements (new roads, roadway widening, new traffic signals, etc.). A significant shift in public agency budgeting and culture must take place to implement a new focus on operating the transportation network in response to changing conditions.

Coordinating traffic signals is a "can-do" solution for public agencies interested in reducing congestion, responding to changing traffic conditions and reducing fuel consumption and greenhouse gas emissions. Key steps include the following:

- Develop a master plan that considers the needs for signal timing, agency resources, the communication systems that allow signals to talk to one another and priority corridors. Many times a key aspect of traffic signal timing is the communication systems that tie signals to a centralized traffic control system. Lack of this "system" level approach can limit efficient signal timing strategies.
- Develop, implement and fine-tune new coordinated signal timings on corridors regionally. Coordinated signal timings are not restricted to a single public agency. This is a solution that can be duplicated at any agency that operates traffic signals on major arterials.
- Develop an ongoing program to ensure the coordinated signal timings are maintained and updated at least every 5 years and preferably every 2 to 3 years.
- Develop an ongoing maintenance program to quickly repair vehicle detection and maintain efficient traffic signal operations.

WILL TIMING SIGNALS INDUCE DEMAND AND CANCEL THE CARBON SAVINGS?

The Climate Trust and the City of Portland considered this question and conducted an analysis to assess whether the new signal timings resulted in additional traffic volumes on the corridor due to the improved signal timings. The research conducted in Portland monitored volumes on a corridor with new signal timings and a parallel corridor with no traffic signal coordination. Results of this analysis have to date been inconclusive.

The two corridors in the analysis both showed an increase in traffic volumes at a rate equal to the land use growth in the area (indicating regional issues such as economic development being more likely factors in vehicle trip growth). For comparison, the analysis monitored volumes on other corridors where signal timings were implemented, and in some cases the vehicle volumes actually decreased on corridors with new signal timing. If signal timing induced demand, this should not be possible.

The Federal Highway Administration (FHWA) documents the influences of induced demand and generally has found that it is extremely difficult to separate the minor growth in motor vehicle traffic as a result of corridor operational enhancements such as traffic signal timing as compared to the traffic growth resulting from land use actions and economic development in an area. Absent land use increases and economic growth, it would be unlikely to document a significant overall net increase in new travel as a result of traffic signal timing enhancements.

However, there is ample research and evidence of the reduced fuel consumption and emissions as a result of traffic signal timing enhancements. The ability of periodic signal timing refinements to sustain and refresh these gains even with traffic volume growth caused by changing land use activity and economic development has been proven in numerous communities that have timed traffic signals.

CAN SIGNAL TIMING BE USED TO MANAGE NON-RECURRING EVENTS?

Over half of all congestion is caused by non-recurring events such as weather, incidents and special events. Modifying traffic signal timings in response to a non-recurring event can reduce travel times, stops, delays, fuel consumed and emissions during an event such as a traffic incident that closes an interstate. Research has demonstrated the negative impacts to air quality when vehicle speeds drop below 30 miles per hour on regional freeway systems.[13] Surface street systems that have special event or corridor traffic signal timing strategies in place can act to reduce the congestion and emission impacts. To actively manage and implement traffic signal response strategies in response to a non-recurring event, these options exist:

1. Install communications to traffic signals that do not already have it so agency personnel can remotely implement the necessary response strategy. Develop pre-planned response plans including modifications to signal timings that can be called in by an operator in a traffic management center.
2. Install adaptive signal control systems at appropriate intersections. Adaptive systems measure the level of congestion on the roadway and the computer system responds to the changes in congestion by automatically adjusting the signal timings on a corridor.

SURFACE STREET SYSTEMS THAT HAVE SPECIAL EVENT OR CORRIDOR TRAFFIC SIGNAL TIMING STRATEGIES IN PLACE CAN ACT TO REDUCE THE CONGESTION AND EMISSION IMPACTS.

WHAT DOES IT TAKE TO COORDINATE TRAFFIC SIGNALS?

Traffic signal timing projects consist of several steps. First, an inventory of the existing field conditions is conducted. Traffic count data are collected and field observations are made to determine the current geometric and operating conditions and to identify problem areas. Next, the data are entered into a traffic signal timing optimization and simulation software program, such as Synchro, and the model is calibrated to determine the optimum signal timing that provides vehicle progression along the major roadway and minimizes delay to vehicles on side streets.

Typically, a number of signal timing models are developed for one corridor for various times of day, such as morning and evening peak hours, to adjust for volume fluctuations. Finally, the signal timing plans are implemented and evaluated in the field during key time periods and final adjustments are made by experts in the field to fine-tune the traffic signal operations. Typical details of a signal timing project include:

- costs approximately $3,500 per intersection;
- should be updated on average every 3 to 5 years; and
- an adaptive system would cost approximately $50,000 per intersection. ■

References

1. Surface Transportation Policy Project. Accessible via www.transact.org/library/factsheets/environment.asp.

2. National Toxics Inventory, 1996. Accessible via www.epa.gov/otaq/regs/toxics/d00003.pdf.

3. "National Traffic Signal Report Card, Executive Summary," National Transportation Operations Coalition, 2007.

4. "Temporary Losses of Highway Capacity and Impacts on Performance: Phase 2." Report No. ORNL/TM-2004/209. Oak Ridge, TN, USA: U.S. Department of Transportation (U.S. DOT), Oak Ridge National Laboratory, November 2004.

5. Barth, M. and K. Boriboonsomsin. TRB

08-2860. "Real World CO_2 Impacts of Traffic Congestion." Transportation Research Board, 2008.

6. National Transportation Operations Coalition 2007, note 3 above.

7. Bureau of Transportation Statistics. "Table 4-5: Transportation Expenditures by Mode and Level of Government from Own Funds, Fiscal Year." Accessible via www.bts.gov/publications/national_transportation_statistics/2006/html/table_04_05.html.

8. National Transportation Operations Coalition 2007, note 3 above.

9. "Managing Traffic Flow Through Signal Timing." *Public Roads* (January/February 2002).

10. A typical signal timing project in Portland has produced savings between 5,000 and 20,000 metric tons of CO_2 over the life of the project.

11. *Emissions Analysis Techniques for Transportation Control Measures, Final Report.* Prepared for the Federal Highway Administration by Cambridge Systematics Inc., October 2000.

12. Synchro/SimTraffic Version 6.0 by Trafficware Corp.

13. Transportation Research Board 2008, note 5 above.

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