

Improving Traffic Signal Operations

A PRIMER



U.S. Department
of Transportation
**Federal Highway
Administration**



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Traffic Signals--Tools for Improving Safety and Traffic Flow

Traffic signal operations can be substantially improved by implementing an aggressive, yet relatively low-cost, management system that will minimize traffic delay, pollution, and fuel consumption.

Traffic congestion is a major problem in cities of all sizes. People are taking more trips, and there are more vehicles on the road. The street system is often overtaxed, causing traffic to bog down. The resulting traffic congestion is costly--motorists' time is wasted, and the environment is harmed by pollutants emitted from idling engines. Even worse, the congestion often provokes motorists into dangerous behavior, such as running red lights, in an attempt to make up lost time.

Some relatively simple, low-cost adjustments to a traffic signal system can, however, significantly improve traffic flow. This report describes how adjusting your city's traffic signals can reduce congestion and lead to big payoffs in time savings, environmental benefits, and safety.

When the first traffic signal was installed at a Cleveland intersection in 1914, the objective was to prevent accidents by alternately assigning the right of way. Not much thought was given to minimizing traffic delay and fuel consumption. Over time, however, as traffic volumes have increased, the objective has broadened to include maximizing the capacity of the roadway system and improving traffic flow.

Today, there are more than 300,000 traffic signals in North America. They play an important role in the transportation network. Traffic signals at a busy intersection in a typical urban area might direct the movement of as many as 100,000 vehicles per day--as if the entire population of Albany, New York, drove through the intersection.

Two-thirds of all miles driven each year occur on roadways controlled by traffic signals. In the State of California alone, motorists drive more than 60 billion miles each year on streets controlled by traffic signals.

Despite their important role in traffic management, traffic signals, once installed, are often given short shrift. Maintenance activities are delayed or canceled, in reaction to shrinking budgets and staffs. More than half of the signals in North America are in need of repair, replacement, or upgrading. If signals are not properly designed, installed, operated, and maintained, motorists will likely

- Spend more time delayed in traffic,
- Increasingly disobey signal indications (for example, run red lights),
- Reroute themselves onto adjacent neighborhood streets, and
- Experience higher accident rates, especially involving rear-end collisions.

It doesn't have to be that way. Traffic signal operations can be substantially improved by implementing an aggressive, yet relatively low-cost, management system that will minimize traffic delay, pollution, and fuel consumption. Some relatively simple tasks, such as adjusting the timing of traffic signals, can bring dramatic benefits to a city and its citizens.



Simple Strategies with Big Payoffs

Traffic signal improvements rank as one of the most cost-effective energy conservation strategies in urban areas.

Much of the delay experienced by motorists during the day occurs at signalized intersections, as they wait for the light to turn green. Delays can be reduced, however, by optimizing the timing of the signals. Although more than 60 percent of the signalized intersections in the United States would benefit from equipment upgrades, nearly 1.5 percent of the intersections would benefit from signal timing adjustments alone—without any hardware changes.*

Traffic signal improvements rank as one of the most cost-effective energy conservation strategies in urban areas. An idling engine not only wastes fuel, but also emits pollutants into the air. The 1990 Clean Air Act Amendments require metropolitan areas to improve their air quality; one cost-effective, practical step toward that goal is to cut down the amount of time vehicles spend idling at traffic lights.

The annual costs for various signal system improvements are summarized in Table 1. Optimizing the timing of already interconnected traffic signals is the most cost-effective project, with an annual cost of \$300 to \$400 per signal. At today's gas prices, that is very cost effective— for less than a nickel, we can save a gallon of gas. Each dollar spent optimizing signal timing could yield a 15- to 20-gallon fuel savings. Alternately, interconnecting and optimizing noninterconnected signals costs any-

Table 1.
Summary of Annual Costs of Various Traffic Signal System Improvements*

Traffic Control Improvement	Implementation Cost per Signal (\$)	Approximate Annual Cost per Signal (\$)		
		Equivalent Capital Outlay [*]	Operations and Maintenance ^{**}	Total
Optimize Previously Interconnected Signals	—	—	300-400	300-400
Interconnect and Optimize	2,000-10,000	260-1,300	500-1,400	760-2,700
Advanced Computer-Based Master Control (including Interconnection and Optimization)	5,000-13,000	760-1,800	1,100-2,000	1,860-3,800
Approximate Marginal Cost of Advanced Computer-Based Master Control	9,000	500	600	1,100

* Equivalent annual capital outlay computed using 10 percent interest and 15-year life for interconnect, 10-year life for marginal costs of advanced master controls.

** Annual operations and maintenance cost = 10 percent of capital cost for interconnect plus 20 percent of marginal capital costs for advanced control. Optimization cost included in all cases.

where from \$760 to \$2,700 per signal per year, which equates to a very reasonable cost of 4-15 cents per gallon of fuel saved.^{2,3}

Less delay also means significant cost savings to the public. In York County, Virginia, for example, traffic signal improvements on a 1.5-mile stretch of U.S. 17 are estimated to save motorists \$65,000 per year (using a rate of \$5 per hour of wasted time and vehicle operation). Fuel consumption has decreased 11 gallons per 1,000 vehicles during some of the study periods.

A more dramatic example comes from California. In 1983, 41 cities retimed 1,535 signals at a cost of \$2 million. Field studies found that vehicle stops and delays were reduced by more than 14 percent, travel time was cut by 6.5 percent, and fuel use declined by 6 percent. The reductions resulted in annual savings of approximately 6.4 million gallons of fuel. At an average fuel cost of \$1.20 per gallon, the improved fuel efficiency saved California motorists nearly \$8 million. The improvements also brought a substantial decrease in air-polluting emissions.⁴

In contrast to many other roadway improvements, traffic signal improvements generally involve only minimal traffic disruption, relatively low costs, and little downside risk. And the public generally reacts very favorably to traffic signal retiming projects, making them win-win situations for both the public agency and the public it serves.

The Federal Highway Administration estimates that the benefit-to-cost ratio of traffic signal timing optimization projects approaches 40 to 1. That is, for every \$1 invested in optimizing the timing of traffic signals, \$40 is returned to the public in time and fuel savings. Several other important benefits have also been noted:⁵

- Basic traffic signal improvements can result in a 12 percent improvement in vehicle speed or travel time.
- More advanced improvements can increase speeds by 25 percent.
- Retimed traffic signals, with no changes in hardware, can generally save 12 percent in travel time. In some cases, the time savings reaches 22 percent.
- Improved traffic signal operations means less stop-and-go traffic, which in turn means fewer rear-end accidents.

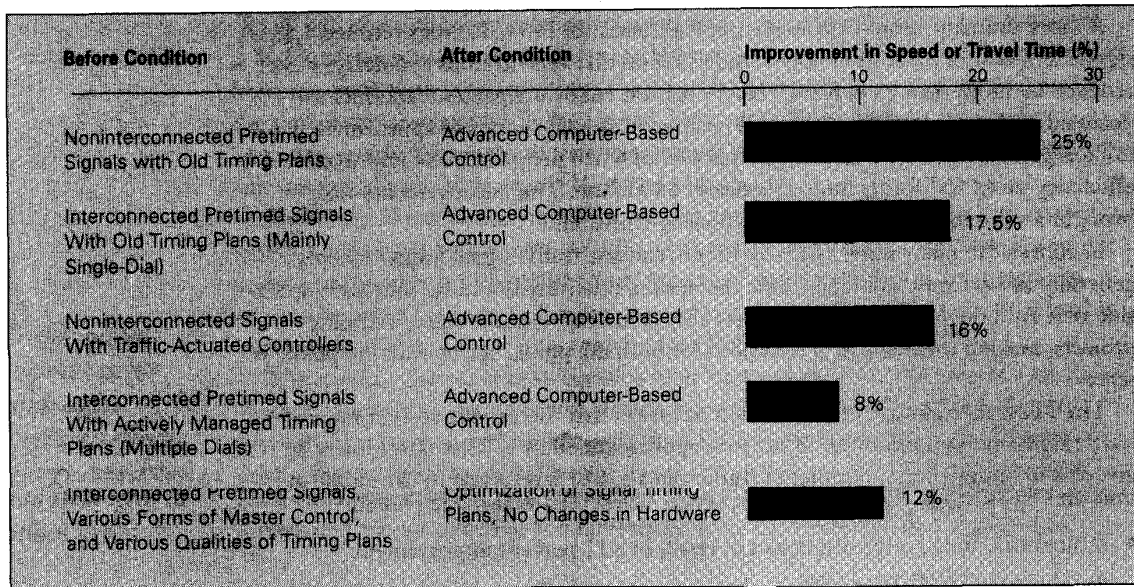
Impacts of Signal Operations Improvements

Obviously, the degree of improvement at a given project site depends on the "before" conditions. The more primitive the original condition, the greater the degree of improvement. Figure 1 shows overall travel time and speed improvements for typical before-and-after conditions at projects in the United States.

The most dramatic improvement (25 percent) is achieved by interconnecting and coordinating traffic signals and instituting timing plans and a central master control system to optimize traffic flow. Improving traffic signal timing plans for already interconnected signals produces a respectable 12 percent reduction in travel time—with no changes in hardware.³

Reducing the total vehicle hours of travel-that is, the number of hours motorists spend behind the wheel-by a mere 10 percent results in a 3.5 percent savings in areawide vehicle fuel consumption. That amounts to almost 12 million gallons saved annually in an urban area with a population of 1 million.²

Figure 1.
Comparative Impacts of Traffic Signal System Improvements (Project Level)²



How Traffic Signals Work

Traffic signals alternately assign the right of way to different traffic movements at an intersection. They provide a degree of control that is second only to physical barriers.

A controller is used to switch the signal displays. Two basic kinds of controllers are used: **Pretimed** (also known as fixed time) and **traffic actuated**.

Pretimed Controllers

Pretimed controllers represent traffic control in its most basic form. They operate on a predetermined, regularly repeated sequence of signal indications. For example, in one complete phase of the cycle, one street—the primary street—may be assigned 40 seconds of green time, and the other street may be assigned 15 seconds of green time. Several seconds per minute are assigned to the yellow, or clearance, interval. The signal rotates through this defined cycle in a constant fashion, as determined by the controller's settings. Pretimed controllers are best suited for intersections where traffic volumes are predictable, stable, and fairly constant. They may also be preferable where pedestrian volumes are large and fairly constant.

Depending on the equipment, several timing sequences may be preset to accommodate variations in traffic volume during the day. The timing of pretimed signals is typically determined from visual observations and traffic counts. Once the timing programs are set, they remain fixed until they are changed manually, in the field.

Generally, pretimed controllers are cheaper to purchase, install, and maintain than traffic-actuated controllers. Their repetitive nature facilitates coordination with adjacent signals, and they are useful where progression is desired. **Progression** refers to the nonstop movement of vehicles along a signalized street system. Properly timed signal systems facilitate progression.

Traffic-Actuated Controllers

Traffic-actuated controllers differ from pretimed controllers in that their signal indications are not of fixed length, but rather change in response to variations in the level and speed of traffic. Traffic-actuated controllers are typically used where traffic volumes fluctuate irregularly or where it is desirable to minimize interruptions to traffic flow on the street carrying the greater volume of traffic.

A simple traffic-actuated signal installation consists of four basic components: detectors, the controller unit, signal heads (the traffic lights), and connecting cables.

The detectors are usually placed in the pavement, but they are sometimes positioned on signal poles. Commonly used types include the inductive loop detector, magnetic detector, magnetometer, and microwave detector.

The inductive loop detector is by far the most common. A loop of metal wire is embedded in a saw-cut slot in the pavement and then covered with a protective epoxy sealant. As a vehicle travels over the detector, its metallic mass changes the inductance of the loop. The detector processes this change and notifies the controller unit of the presence of a vehicle.

There are three basic types of traffic-actuated controllers:

- Semiactuated controllers,
- Fully actuated controllers, and
- Volume-density controllers.

Semiactuated controllers assign a continuous green indication to the major street except when a detector signals that a vehicle on the minor street is waiting to enter the intersection. Traffic detectors are thus only needed on the minor street approaches.

Fully actuated controllers require detectors on all lanes approaching an intersection. They are most useful when vehicle volumes vary over the course of the day, making frequent timing changes necessary. Fully actuated controllers are often preferred because of their responsiveness to actual traffic conditions.

Volume-density controllers are a more advanced type of fully actuated controllers. They record and retain actual traffic information, such as volumes. Using the recorded information, they can calculate and recalculate as necessary the duration of the minimum green time based on actual traffic demand.

Both pretimed control and actuated control have application today. In Howard County, Maryland, for example, pretimed controllers are used to coordinate the flow of traffic on main streets during the day, with semiactuated control on minor streets. At night, when traffic volumes drop, fully actuated control is used on all streets.

The efficiency of a traffic-actuated signal installation depends on the programming of the unit and the location of the detectors.

Timing adjustments should be made by trained technicians and should be based on the traffic periods. When adjusting a controller, the technician should observe the effect on traffic and then fine-tune the settings as necessary. Intersections should be periodically monitored to ensure the signals are operating efficiently. As traffic volumes and other conditions change, the controller settings will need to be changed accordingly.

Another type of actuated control uses a computer to control, operate, and supervise a traffic control signal system. Computer-controlled systems basically consist of a central computer, communication media (cable, telephone, radio, etc.), and field equipment (local controllers, detectors, etc.).



When Is a Signal Needed?

Unwarranted signals often generate an increase in vehicle stops, traffic delay, fuel consumption, traffic accidents, and motorist disrespect for traffic signals.

When installed under conditions that justify its use, a traffic signal is an effective traffic control device. Conversely, an unwarranted or poorly designed signal is ineffective, inefficient, and a potential danger to motorists and pedestrians. For those reasons, it is essential that qualified personnel conduct traffic engineering studies to determine if a traffic signal is indeed warranted.

Many motorists and community leaders believe that traffic signals are the solution to all traffic problems at intersections. In that mistaken belief, communities have installed signals where no legitimate need exists, making the decision on the basis of public or political pressure, rather than professional traffic engineering judgment. Unwarranted signals, however, often generate an increase in vehicle stops, traffic delays, fuel consumption, traffic accidents, and motorist disrespect for traffic signals.

To help communities in the United States determine when and where signals might be necessary, the Federal Highway Administration has published the *form Traffic Control Devices* (MUTCD), which contains equipment and location specifications for signals, as well as guidelines (“warrants”) for determining when a signal is necessary. The MUTCD is the federal standard governing traffic control devices in the United States. Other countries have their own specifications and warrants.

To preclude the indiscriminate use of traffic signals, the MUTCD recommends that traffic signals be installed only when at least one of the signal warrants in the manual is met. But satisfying a warrant or warrants is not in itself justification for a signal, as stated in the MUTCD:

Information should be obtained by means of engineering studies and compared with the requirements set forth in the warrants. The engineering study should indicate the installation of a traffic signal will improve the overall safety and/or operation of the intersection. If these requirements are not met, a traffic signal should neither be put into operation nor continued in operation (if already installed).

The MUTCD states that an investigation of the need for traffic signal control should include, where applicable, at least an analysis of the factors contained in the 11 warrants (Table 2).⁶ (For more information on signal warrants, refer to the MUTCD.)

When Should a Traffic Signal Be Removed?

If a signal is no longer needed, because of changed traffic volumes or patterns, it should be removed. There are, however, three areas of concern when a signal is marked for removal—safety impacts; traffic flow impacts, such as delay and fuel consumption; and cost impacts.

A Federal Highway Administration study found that when 191 urban intersections were converted from signalized control to two-way stop control, neither the total

accident rate nor the rate of injury accidents (those accidents resulting@ personal injury) was significantly affected.⁷

Factors known to affect the accident rate at intersections where traffic signals have been removed include: (a) adequacy of the side-street sight distance, (b) traffic volumes, and (c) the average annual accident frequency at the intersection prior to signal removal.

When a signalized intersection is converted to two-way stop control, studies have found that the total delay per vehicle is reduced by 10 seconds, the idling delay per vehicle is reduced by 5-6 seconds, stops are reduced by half, and fuel consumption is slightly improved. In addition, by eliminating electrical costs and reducing maintenance costs, the switch to two-way stop control can save the highway agency money.

Before deciding to remove any signal, however, the highway agency must conduct a thorough review process. Engineering factors, such as impact on accidents, must be carefully evaluated, and other factors such as political barriers and public reaction, must also be considered.

Table 2. Warrants for Traffic Signal⁶

Warrant	Factor
1	Minimum vehicle volume. Intended for application where the volume of intersecting traffic is the principal reason for considering installing a traffic signal.
2	Interruption of continuous traffic. Applies to operating conditions where the traffic volume on a major street is so heavy that traffic on a minor intersecting street suffers excessive delay or hazard in entering or crossing the major street.
3	Minimum pedestrian volume. Applies only to those locations where the nearest traffic signal along the major street is greater than 300 feet and where a new traffic signal at the study location would not unduly restrict platooned flow of traffic.
4	School crossing.
5	Progressive movement. Appropriate when it is desirable to maintain proper grouping of vehicles and effectively regulate vehicle speed.
6	Accident experience. For intersections with high accident rates and where the signal installation will not seriously disrupt progressive traffic flow.
7	Systems. To encourage the concentration and organization of traffic flow networks.
8	Combination. When no single warrant is satisfied, but where Warrants 1 and 2 are at least 80 percent satisfied.
9	Four-hour volumes. For relatively high volume or high speed intersections.
10	Peak-hour delay. Intended for application where the minor street traffic suffers undue delay in entering or crossing the major street during at least 1 hour each day.
11	Peak-hour volume. Intended for application when the minor street traffic suffers undue traffic delay in entering or crossing the major street during at least 1 hour each day.

Traffic Signal Maintenance

Traffic signal timing must be a routine, ongoing activity involving regular review of timing plans in light of actual traffic volumes and patterns.

An effective maintenance management program, consisting of both preventive and remedial maintenance of traffic signal hardware and software, is essential to the successful performance of any traffic control system, whether computerized or not. A poorly maintained signal system can compromise travel efficiency and safety. And, as is the case with most equipment, signal systems that are neglected will likely perform inefficiently and experience premature failure, which in turn could lead to traffic delays and even accidents. Preventive maintenance really does pay off with traffic signals.

To ensure that a signal system is working properly and thus that traffic is flowing efficiently and safely, highway agencies should regularly monitor traffic at intersections and then update their traffic control strategies, including signal timing plans, in response. Unfortunately, because updating timing control strategies is labor intensive and thus costly, many jurisdictions fail to do this, with the result that the original traffic signal plan for an intersection often remains operational long after changing traffic volumes have made it outdated. Those jurisdictions instead choose to reevaluate their traffic control strategies only when forced to, such as when equipment fails, motorists complain, or congestion becomes unbearable. Traffic signal timing must be a routine, ongoing activity involving regular review of timing plans in light of actual traffic volumes and patterns.

Traffic signal maintenance can be divided into three categories: preventive maintenance, response maintenance, and design modification.

Preventive maintenance practices involve inspecting, cleaning, and adjusting signals at regular intervals and replacing components as necessary. The goal is to avoid signal failures through timely maintenance procedures. Examples include replacing signal lamps, cleaning signal lenses, aligning signal heads, tuning vehicle detectors, and inspecting and testing signal control equipment. Keeping detailed records of all these tasks is an important part of an effective preventive maintenance program.

Vehicle detectors are an all-too-often overlooked component of the signal system. They do, however, play a critical role in the efficient operation of a signal system. If a detector stops working properly, the actuated controller becomes useless; the signal system will no longer respond to actual traffic conditions.

The second category of maintenance—response maintenance—involves procedures that are undertaken when traffic signal and control equipment fails, either fully or partially. It also includes troubleshooting and record-keeping tasks. A highway agency can minimize the need for this type of maintenance services by implementing a well-planned preventive maintenance program.

The third category—design modification—involves changing the signal display, timing plans, or equipment to reflect changed traffic conditions.

The overall level of maintenance will vary, depending on a jurisdiction's commitment to safe and efficient traffic operations and available funding and staffing resources.

Legal Aspects

Improperly maintained and operated traffic signals can result in an increased number and frequency of traffic accidents. A liability judgment against the highway agency could result. Courts have held that state highway departments, for example, have a duty to use reasonable care in creating a safe highway environment. This involves, in essence, regularly inspecting the highway system, anticipating and correcting defects in the system, and conforming with applicable standards and practices, such as the ***Manual on Uniform Traffic Control Devices***.

Although driver error contributes to many accidents, the highway environment is also often culpable. The environment—which includes signs, signals, and markings—could cause motorists to err or to respond inappropriately at signalized intersections. For example, an improperly timed signal may not provide an adequate yellow interval, which could lead a driver to inadvertently run a red light and cause an accident.

Improperly timed and unnecessary signals can also lead to motorist disrespect for signals in general, with the result that they take more risks when approaching and entering intersections. The result could be an increase in accidents, with a corresponding increase in the highway agency's liability exposure.

A highway agency's failure to respond in a timely fashion to complaints about traffic signals may be interpreted as negligence on the agency's part. A series of accidents at the same intersection could be construed as notice of an existing hazard. Although the agency might be somewhat protected by a design immunity, a court might waive the immunity in cases where there is an apparent notice of a hazardous condition. Once an agency is aware of a dangerous condition, it must act reasonably to correct the hazard.

7.



Funding Traffic Signal Improvements

Funding sources for traffic signal improvements include a number of transportation improvement programs at the local, state, and federal level. In many jurisdictions, the cost of installing and improving traffic signals near new developments is funded by fees assessed on the land developers.

Federal funds are available to assist highway agencies in making optimum use of their signal systems so as to minimize delay and thus reduce the amount of pollutants emitted from idling vehicles. Two pieces of legislation—the 1990 Clean Air Act Amendments and the 1991 Intermodal Surface Transportation Efficiency Act—set the stage for funding transportation improvements. Both statutes emphasize improving traffic operations, rather than building more highways.

Federal funds for traffic signal improvements are now available as part of the National Highway Program, the Surface Transportation Program, and the Congestion Mitigation/Air Quality Program. In addition, for the first time, federal funds can now be used to help pay for the operation of traffic control systems.

Local highway agencies should work closely with their state department of transportation and their metropolitan planning organization to ensure that their traffic signal improvement projects and other needs are fully considered for funding as part of the transportation improvement program.



This report has described how some relatively simple, low-cost adjustments to a traffic signal system can reduce traffic congestion and lead to big payoffs in time savings, environmental benefits, and safety. To find out if your jurisdiction could benefit from these adjustments, talk to your traffic engineer or other staff person responsible for traffic operations on your streets.

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