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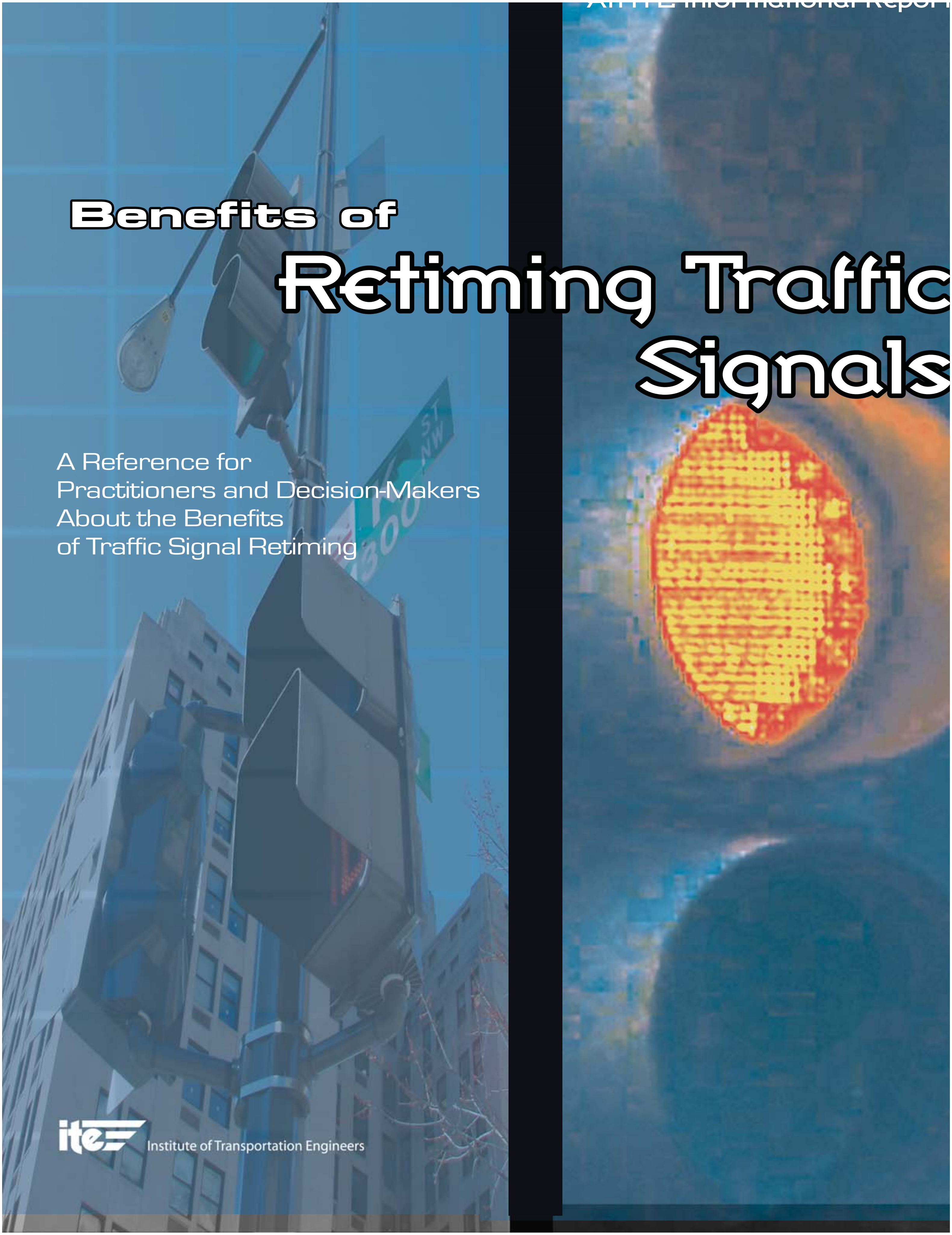


# Benefits of Retiming Traffic Signals

A Reference for Practitioners and Decision-Makers About the Benefits of Traffic Signal Retiming

Institute of Transportation Engineers

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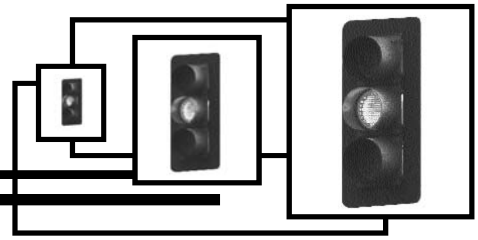
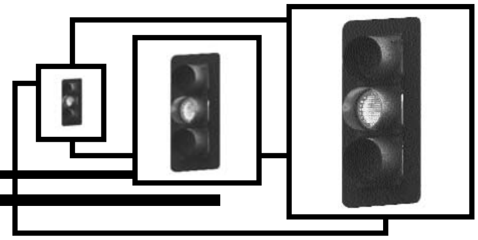


# Introduction

Signal retiming is a beneficial method for maintaining efficient traffic signal operations. Improving signal operations improves traffic conditions and enhances the driving experience in a signalized corridor. Signal retiming is the most cost-effective technique to reduce congestion, improve air quality and potentially reduce accidents; past projects have demonstrated benefit-to-cost ratios of 40:1 or more.

Retiming signals on a regular basis ensures maximum benefits. Unfortunately, signal retiming is often not a priority and frequently traffic engineers are not provided enough resources to develop, implement and maintain efficient signal timings. Traffic engineers often respond to citizen complaints by fine-tuning signal timing for individual intersections, but they lack the budget or time necessary to develop or maintain a comprehensive signal retiming process. Over time, these “spot” retiming efforts will not solve traffic congestion problems—they will only shift or delay the onset of congestion.

The overall objective of this report is to illustrate the importance of signal retiming. While this report illustrates the technical process of signal retiming, its primary objective is detailing the benefits of signal retiming. This report will assist traffic engineers in illustrating the importance and benefits of signal retiming to the policy- and decision-makers in their agencies.



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# What is Signal Timing?

Signal retiming is a process to optimize the operation of signalized intersections through a variety of low-cost improvements, including the development and implementation of new signal timing parameters, phasing sequences, improved control strategies and, occasionally, minor roadway improvements. In addition, the signal retiming process often requires the training of engineering and maintenance staff to more efficiently use existing signal control equipment and support new technologies as they become available for implementation.

Each traffic signal operates under a unique set of timing parameters. This includes minimum and maximum green durations, pedestrian indication requirements, gap and extension times, overlaps and phase change intervals (yellow change plus red clearance). A pretimed signal must also have fixed cycle and split lengths that accurately balance the average demand during a period of time.

When signals are operated within a coordinated system, additional parameters are used—cycle length (the time needed to serve all phases), offset (the time from a reference point, such as the start of green or yellow of the coordinated phase at one intersection to the same reference point at other intersections) and split (time allowed for each movement or phase—the total is the cycle length). The offset is used to allow vehicles moving at the proper speed to travel through a group of intersections without stopping. This process is called progressive movement.

As traffic characteristics change throughout the day, week and time of the year (including holidays), it is appropriate to modify signal-timing parameters to reflect the needs of these unique traffic characteristics. Often, this includes the development of different timing parameters for the morning and evening peak periods, the mid-day off-peak periods, nights and weekends.

Signal retiming is oriented toward the optimization of the controller unit's response to the demands of roadway users, including all types of motor vehicles, bicycles and pedestrians. Signal retiming strategies include the minimization of stops, delay, fuel consumption and air pollution emissions, and the maximization of progressive movement through the system.

Occasionally, the signal retiming process includes the reconfiguration of a signal's operation. This can include a change in the sequence of the movements used in the intersection, or the addition of signal displays and intervals (phases) to accommodate specific demands or movements, such as left turns. Left-turn movements are sometimes programmed to follow the opposing through movement to accommodate the different arrival times of through movements along a coordinated arterial.

As technology continues to change in the traffic control field, it is often important to upgrade existing traffic signal control hardware and software to accommodate enhanced signal operations. Upgraded equipment allows greater flexibility in timing pattern implementation by time-of-day and traffic responsive means. In addition, newer controller equipment allows for an improved interface with area-wide traffic signal control systems, which provides monitoring and control functions from a central location. Field technology upgrades may extend to the construction of new signals at an intersection, including enhanced signal displays, detectors and detection strategies and control equipment.

It is also possible to associate minor roadway or lane striping improvements with the signal retiming effort to improve traffic operations. For example, the provision for an additional left-turn lane, the extension of a right-turn lane, or the addition of right-turn overlap to accommodate additional vehicle demand is often important.

Finally, training activities can be included as part of the signal timing effort. Advancements in control technology, signal optimization programs and other traffic engineering tools are important to allow the maximum usage of available resources.

# Why is Signal Retiming Performed?

Traffic signal retiming is one of the most cost-effective ways to improve traffic movement and make our streets safer. Vehicles operate most efficiently when moving with minimal stops and delays. With optimized signal timing and progressive movement through groups of signals, fuel consumption and emissions are minimized. The cost-effectiveness of signal retiming has been repeatedly confirmed by studies showing that the benefits of investment outweigh the costs by 40:1 or more. Signal retiming is needed as much as patching potholes, restriping pavement markings and removing snow. Various reasons why signal retiming is performed include:

- Improving traffic flow through a series or group of signals. By coordinating or sequencing the signals in relation to each other, groups of vehicles can travel through the series of signals with minimal or no stopping.
- Reducing overall intersection delay time at an intersection by balancing the green time. Even within a signal system, splits at individual intersections can be analyzed to see if reallocation of existing cycle time may reduce delay at that intersection.
- Adjusting for changes in traffic characteristics. With developments such as the addition of new homes or stores, traffic will increase or be redistributed to different roads or turning movements and create the need to adjust the timing of affected traffic signals.
- Accommodating diversion of traffic off a freeway or interstate due to an incident (accident or event), associated with a computerized signal system.
- Reducing motorist frustration caused by excessive delay or stops by adjusting timing to provide coordinated flow through groups of signals.
- Reducing emissions and fuel consumption by optimizing signal timing and coordinated traffic flow.
- Saving time for emergency vehicles, buses and commercial vehicles.
- Reducing the number of collisions on city streets by producing smoother traffic flow and fewer stops.
- Postponing or eliminating the need for costly reconstruction by providing improved flow using existing resources in a more efficient manner, or with minor equipment and/or roadway improvements.
- Adapting to changes in traffic flow for different times of the day or days of the week by developing and implementing signal timing plans to match predictable periods of traffic flow, such as the “rush hours” to and from work and holiday/seasonal demands.

- Accommodating moderate- and long-term construction. Signal retiming performed during a reconstruction project where a lane closure or a traffic detour causes a significant change in demand or capacity will alleviate traffic congestion.

# How is Signal Timing Performed?

Signal timing analysis is a method to determine the timing to be entered in the controller utilizing a series of calculations performed by a traffic engineer. The calculations are usually performed in the office based on current field data and a traffic engineer's knowledge of traffic operations based on field observations. The analysis method usually includes computer software for traffic signal timing optimization. A summary of the process typically used to conduct signal timing studies is as follows:

- Create or verify an inventory of the signal system to determine geometric conditions, record and verify the type and placement of field signal hardware, and record other pertinent information that, along with field observations, documents the status of the signal system and current traffic conditions during peak and off-peak traffic periods.
- Collect vehicular and pedestrian volume data. Traffic counts include all turning and through movements, including vehicle classification information and the number of pedestrians using each crosswalk for each 15 minutes of the study period. Travel time data are also collected for travel from one end of the system to the other to identify current operating conditions.
- Check collision history and perform a crash analysis by obtaining the crash records for the past 3 years and preparing a collision diagram. Pertinent factors include causation, collision types and remedy tables to determine if a change in signal operation is likely to provide safer operation.
- Process and analyze the collected data using capacity analysis, traffic signal timing optimization and simulation software programs. Where appropriate, models should be calibrated using existing signal timing and performance data before final analytical runs are performed.
- Optimize intersections located in a signal system by using manual techniques or signal system analysis software (such as SYNCHRO or PASSER II) to improve coordination and offsets. Results may be tested using simulation software such as CORSIM, SimTraffic, or VISSIM.
- Implement optimized timing at intersection(s).
- Evaluate new timing in the field during various critical time periods and make final fine-tuning adjustments.
- Conduct travel time and delay studies when the final timing plans are in place. These studies are typically formatted as "before and after" to determine if there was an improvement in the traffic flow and a reduction in stops or delay.
- Repeat the signal retiming process every 3 to 5 years (or more frequently based on changing conditions) to ensure continued optimum flow of traffic.

The ultimate responsibility for signal timing typically falls to the agency responsible for the operation of the roadways where signals are located.

# Who Times Traffic Signals?

On state highways, the state department of transportation (DOT) usually has the responsibility for the timing and operation of signal equipment. State DOTs are usually tasked with the goal of providing optimal traffic flow along the state highway system. In their timing efforts, the state highway system usually has priority. State DOTs sometimes assign the responsibility of operating and maintaining state highway system signals to local government agencies who may be more closely attuned to local conditions affecting signal timings.

The local counties and municipalities that have responsibility for the operation of signals within their jurisdictions may also time traffic signals. Usually this is performed within the agency's public works or traffic engineering department, depending on the experience level and time availability of the agency's staff.

In today's environment of limited public resources and reduced staffing, many agencies use the services of consulting engineers to perform signal-timing projects. This is particularly applicable to periodic timing applications funded by grants or special funding opportunities.

Unfortunately, in many jurisdictions, there is no strategic signal timing effort. Spot adjustments to signal timing are performed only when a request is received from the public.

Indirectly, political bodies, planning organizations and other advisory committees help to drive the signal timing process by authorizing funding for signal timing studies and related improvements. In addition, the public is involved both as a user and as an impacted party. Signal timing complaints and requests are often received from the public with requests to update studies or make signal-timing improvements. Occasionally, a traffic engineer enters the public meeting process to gather citizen commentary and provide information through the public involvement process.

Traffic engineering personnel accomplish the actual process of signal timing. The first stages of the process, system inventory and traffic data collection, are usually performed by traffic engineering technicians that either install automated count equipment or manually count and tabulate the movements at each intersection (and potentially at mid-block locations) along an arterial. These count data are then put into a usable form by engineers or technicians.

A traffic engineer typically performs the analysis portion of the signal timing process. This phase of the analysis includes an examination of crash history and an assessment of potential countermeasures if safety concerns are present. Computerized optimization and simulation tools are often used to update and evaluate signal-timing patterns. Revised signal timing parameters are then developed in the office for peak and off-peak traffic conditions for typical days of the week and special events.

The final steps in signal retiming are implementation and fine-tuning. The signal-timing patterns are entered into the field equipment or master traffic control system. Signal operation is observed and monitored under real traffic conditions. The fine-tuning process is critical to the success of the signal timing effort, and minor adjustments to computer-generated timings are made to provide optimal operation considering variations in traffic flow that were encountered in the field.

# What Constraints Are Faced When Optimizing and Operating Traffic Signals?

Many factors limit the extent to which intersection efficiency can be improved with the optimization of signal timing. Though interrelated, these factors, or constraints, can be broken down into three general categories: institutional, physical and temporal.

Institutional constraints on signal timing optimization pertain to the allocation of resources within an organization or agency, and to the relationship that agencies have across jurisdictional boundaries. Competing budget demands within an agency may mean that insufficient resources, in terms of staff time and/or outsourcing contracts, are available to perform the necessary data collection, analysis and implementation for proper signal operation, timing and maintenance. Budget and programming constraints may also limit the amount of funding that is available for physical intersection improvements, such as lane additions, turn bay installation, signal equipment enhancements, or traffic detector installation. In environments where multiple agencies are involved, the lack of cooperative working arrangements may produce inconsistent operation. Separate agencies may also place different priorities on signal control or may face equipment incompatibilities that limit the extent to which signal interconnection can be accomplished. Across and within agencies, a local political climate may exist that does not favor optimal signal and arterial operation. For instance, an agency may be willing to accept non-optimal signal operation in order to increase the real and/or perceived safety along an arterial corridor.

Physical constraints are geometric barriers to more efficient signal operation. The more obvious examples of such barriers are turn lanes of insufficient length, lack of necessary turn lanes or too few primary lanes for servicing traffic demand (lack of capacity). In such cases, green time allocation at the signal may attempt to compensate for the limiting geometric feature(s). Irregular and/or close signal spacing also has a detrimental effect on signal efficiency, in that poor spacing places artificial restrictions on the amount of green time available for a platoon of vehicles to move from one intersection to the next without stopping, or precludes the use of progression strategies. Mid-block access points may contribute enough traffic to the arterial to interfere with progression between intersections. In the grid systems found in many downtown areas, it may not be possible to simultaneously service competing north/south and east/west traffic demands.

Temporal, or time, constraints are related to the signal’s inability to consistently provide adequate green time for traffic demand, given competing simultaneous demands from vehicles and pedestrians. This situation occurs when there is too much traffic for the intersection to physically process, when demand patterns vary to the extent that the signal equipment cannot be realistically programmed to accommodate the broad range of hourly/daily/weekly/monthly traffic fluctuations, or where too many conflicting movements require excessive green time (For example, heavy left-turn movements and through movements from multiple approaches at one intersection). Time constraints can also be imposed by pedestrian signal demands that, with their relatively long clearance intervals, may be more demanding of intersection green time than vehicular approaches to the intersection. Also, the increasing use of emergency vehicle and transit priority and the high-level demand of railroad preemption may mean that green time must be diverted for priority and safety reasons, regardless of capacity conditions at the intersection. Vehicles leaving factories, schools, or other large traffic generators all at the same time can also severely impact traffic at a nearby signal.

# What Is The Effective "Life Span" of a Signal Retiming Project?

Signal timing is effective only as long as the traffic characteristics that were used to generate the signal timing are reasonably constant. Realistically, however, traffic characteristics change over time. Development in the surrounding area or overall regional growth can cause significant changes in traffic volumes and conditions, and existing signal timing may not be able to efficiently accommodate these changes. Signal timing can be fine-tuned to operate better, but to efficiently operate traffic signals in a system, a complete retiming of a traffic signal or system is often necessary.

# What Is The Cost of Retiming Traffic Signals?

A continuous review of traffic signal and system performance is desirable. Ideally a yearly review by the traffic engineer ensures the effectiveness of signal timing. An operating agency with a budget to retime traffic signals every 3 years, especially in developing areas and/or areas with sustained growth, will maintain a high quality of traffic operations. Signal retiming is often postponed or ignored due to an agency's financial and staff constraints. Given the need for field data collection, data analysis, signal timing optimization and testing and implementation, the overall signal timing process can be expensive and time consuming. However, as mentioned earlier, retiming traffic signals is necessary to maintain efficient traffic operations and is the most effective way to improve traffic operations. The signal retiming process starts with data collection when either agency staff or a consultant inventories the system and measures traffic flows at each location during peak and off-peak periods. Inventory of the system includes documentation of the intersection geometry, arterial geometry, arterial speeds, intersection signal hardware and other details. Traffic flows comprise turning movement and mid-block counts, pedestrian counts and truck/bus counts. Data collection is very time consuming and is usually performed by a consultant.

After completion of the data collection process, an engineering study is performed by the agency or consultant. The engineering study involves using various traffic optimization software programs such as SYNCHRO, PASSER II and TRANSYT-7F to generate signal timing plans. This is the crucial stage in the signal timing process where the optimum solution is determined. The end product of the engineering study is a recommended set of timing plans for implementation. The agency employees or a consultant then inputs these timing plans in the field. After the retiming, the essential stage of fine-tuning the new timing is performed. It is ONLY by effective fine-tuning that all benefits of the new signal timing can be realized. The agency employees, along with the consultant (if any) who generated the signal timing plans usually perform the fine-tuning.

Estimates for the time required vary according to available expertise and equipment. On average it is estimated to take 25 to 30 hours per intersection to generate four timing plans (a.m. peak, noon peak, p.m. peak and off-peak conditions). The cost of signal retiming is usually less than $3,000 per intersection.

# What Are the Benefits of Retiming Traffic Signals?

Signal retiming offers significant benefits to the traveling public. One of the direct benefits is reduced delay. Delay savings is more apparent for motorists traveling along coordinated signalized arterials because they will experience fewer stops. Apart from direct benefits, there will be a general public perception of reduced delay during travel. A side benefit may be a reduction of motorist frustration and improved safety. Improving signal timing can also reduce fuel consumption, reduce emissions and improve air quality. Efficient signal timing minimizes diversion of traffic to local and residential neighborhoods, potentially improving safety and traffic conditions in those areas. Improved traffic flow also reduces pavement wear and tear, minimizing the maintenance requirements of the public works department. Finally, signal retiming efforts are opportunities for the operating agencies to conduct a quality control check on controller settings for pedestrian, preemption and priority requirements.

Figure 1 illustrates the typical savings in user costs if signals are retimed. The figure demonstrates that retiming traffic signals at periodic intervals provides significant savings in user costs in the form of reduced delay, stops, fuel consumption and other measures of effectiveness. According to the Institute of Transportation Engineers (ITE), traffic signal improvements typically reduce travel time between 8 to 25 percent.

No retiming

Retiming at end of 3rd year

Retiming at end of 3rd and 6th years

Figure 1. Typical Savings in User Costs Due to Signal Retiming.

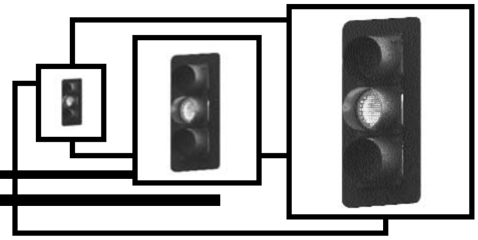
# Examples of Successful Retiming Projects

- ***Washington, DC suburbs, Maryland:*** Since the summer of 2002, the Maryland Department of Transportation has re-timed about 215 signals in the Washington suburbs and an additional 30 signals on the Route 650 (New Hampshire Avenue) corridor between Montgomery County and the District of Columbia. An analysis showed that delays on those roads decreased by about 13 percent and vehicles made 10 percent fewer stops. Fuel consumption also dropped by about 2 percent.
- ***Lexington, Kentucky:*** Adjusting signal timings by responding to real-time traffic data reduced delay by about 40 percent and reduced crashes by 31 percent.
- ***SURF-2000:*** This traffic control system in Paris, France reduced travel times by 20 percent, stops by 30 percent and fuel consumption by 10 percent.
- ***Kitchener-Waterloo, Canada (1996):*** 89 signals that included arterials along commuter and commercial routes and in central business district areas were retimed. The project demonstrated savings of 10 percent in travel time, 27 percent in delay and 20 percent in stops.
- ***Toronto, Canada (1987):*** 62 signals in six arterial sections were retimed. The project achieved a savings of 15 percent in travel time, 46 percent in delay, 42 percent in stops and 15 percent in fuel consumption.
- ***Burlington, Canada (2001):*** 62 signals were retimed, resulting in a savings of 7 percent in travel time, 11 percent in stops and 6 percent in fuel consumption. This project demonstrated an annual savings of $1.06 million in delay and fuel costs alone. Based on total savings, the payback period for this project was just 13 days.
- ***US 1 in St. Augustine, Florida (2001):*** Retiming traffic signals along an 11-intersection arterial reduced average arterial delay by 36 percent, arterial stops by 49 percent and arterial travel time by 10 percent, resulting in an estimated annual fuel savings of 26,000 gallons and overall annual cost savings of $1.1 million.
- ***SR 26 in Gainesville, Florida (2001):*** Retiming traffic signals along an eight-intersection arterial reduced average delay by 94 percent and arterial stops by 77 percent, resulting in an estimated annual fuel savings of 3,300 gallons and overall annual cost savings of $93,000.
- ***San Jose Blvd. in Jacksonville, Florida (2001):*** Retiming traffic signals along a 25-intersection section reduced average delay by 35 percent, arterial stops by 39 percent and arterial travel time by 7 percent, resulting in an estimated annual fuel savings of 65,000 gallons and an overall annual cost savings of $2.5 million.
- ***Blanding Blvd. in Jacksonville, Florida (2001):*** Retiming traffic signals along a 26-intersection section reduced average delay by 24 percent, stops by 26 percent and arterial travel time by 7 percent, resulting in an overall annual cost savings of $1.9 million.
- ***Martin County, Florida (2001):*** Retiming traffic signals at 52 intersections in 10 sections reduced average arterial delay by 48 percent and arterial stops by 60 percent, resulting in an estimated annual fuel savings of 37,000 gallons and an overall annual cost savings of $1.4 million.
- ***Portland, Oregon (1996):*** 35 traffic signals were retimed on two major city arterials. The resulting timing reduced fuel consumption on the streets by more than 175,000 gallons of fuel per year, while the total project cost was only $70,000.

- ***The Fuel Efficient Traffic Signal Management (FETSIM) Program (1988):*** Demonstrated a benefit to cost ratio of 58:1 in California. The program retimed 3,172 signals resulting in savings of 15 percent in delay, 8.6 percent in fuel consumption, 16 percent in stops and 7.2 percent in travel time.
- ***The Traffic Light Synchronization (TLS) Program (1992):*** Showed a benefit to cost ratio of 62:1 in Texas. In the TLS program, the City of Abilene experienced a reduction of 14 percent in travel time and 37 percent in delay by retiming the traffic signals. Overall the program resulted in a 24.6 percent reduction in delay, 9.1 percent reduction in fuel consumption and a 14.2 percent reduction in stops.

# Conclusions

Effective signal retiming can reduce delay experienced by motorists and ease motorists' frustration, reduce fuel consumption and emissions, improve safety, and most importantly reduce the need for costly roadway improvements. It is imperative that traffic engineers provide appropriate information to decision-makers so they may provide necessary funds for maintaining and operating the traffic signals in their jurisdictions.



# Definitions

**Adaptive operation**—The operation of generating signal timing plans dynamically based on information from system detectors. This can include adding and removing traffic signals from a coordinated system and changing offsets and cycle lengths. The timing plans are generated dynamically and not selected from a predetermined list.

**Approach**—Physical roadway as it nears an intersection, also known as a leg. It is all the lanes that approach the intersection from a given direction.

**Arterial**—A roadway that allows traffic to move from one portion of town to another, generally designed to provide mobility rather than access. A series of traffic signals can be coordinated to create progression along an arterial.

**Average control delay**—Average control delay is typically measured at a signalized intersection along an arterial and is the delay experienced by a motorist due to the presence of a traffic signal. It includes delay associated with deceleration for a yellow or red indication or the end of a queue waiting at a signal, the delay time spent stopped for a red signal indication and the time spent accelerating away from the intersection as motorists attempt to re-establish normal operating speed.

**Average stopped delay**—The total time vehicles are stopped in an intersection approach during a specified time interval divided by the volume departing the approach during the same time interval. It is a measure of the average time of duration that vehicles are stopped on an approach and is measured in seconds per vehicle. Higher average stopped delay is associated with higher traffic volumes and/or signal timings that are not appropriate for current demand levels.

**Controller unit**—A device at a signalized intersection that controls the sequence and timing of various phases. It works within the controller assembly to provide the displays to the signal heads.

**Cycle length**—Amount of time for all movements or phases at an intersection to receive green, yellow and red indications. It is a fixed duration in coordinated operation along arterials where progression is necessary. It normally ranges between 70 seconds and 180 seconds. Higher cycle lengths cause excessive delays for drivers on side streets, as the motorists may have to wait for a longer time to receive a green indication. However, higher cycle lengths may be necessary during congested conditions.

**Detector**—A device for determining the presence or passage of vehicles and pedestrians. This general term is usually supplemented with a modifier, for example a loop detector, pedestrian pushbutton detector, video detector, etc.

**Display/Signal head/Signal indication**—An arrangement of signal faces that conveys the status of the right-of-way for a given phase.

**Emissions**—Pollutants such as nitrous oxide (NOx), carbon monoxide (CO) and hydrocarbons (HC) that are produced as a result of fuel combustion in a motor vehicle. Emissions are higher in congested areas where there is stop-and-go traffic.

**Fuel consumption**—Rate that fuel is consumed by a motor vehicle, typically expressed in gallons of fuel consumed per mile of travel. While the efficiency of the automobile engine has a predominant influence on fuel consumption, traffic conditions also have a significant impact. Improved and efficient signal operation will keep traffic moving without idling and reduce fuel consumption.

**Network**—A system of intersecting streets that work together to form a roadway or signal system.

**Offset**—The relative difference in time between the start or end of a green signal of a coordinated phase (usually the major street through movements) at different traffic signals along a roadway.

**Optimization programs**—Computer programs used to calculate and evaluate the effects of various sets of signal timings on vehicular flow within a given network. These programs determine optimum timing plans or evaluate a given timing plan. Examples of signal optimization programs are SYNCHRO, PASSER II and TRANSYT-7F.

**Pedestrian clearance interval**—A warning to arriving pedestrians that the protected walking portion of the phase has ended. Generally set to get the last pedestrian that leaves on the walk indication out of the roadway before opposing vehicles are given a green. The interval is typically based on a walking speed of 4 feet per second, though slower walking speeds may be used where appropriate.

**Pedestrian pushbuttons**—A button to activate pedestrian timing for the pedestrian's intended direction of travel.

**Pedestrian signal**—A signal that contains the lunar white WALKING PERSON (symbolizing WALK) and the Portland orange UPRAISED HAND (symbolizing DON'T WALK) symbols that are installed to direct pedestrian traffic at a signalized intersection or midblock crossing.

**Phase**—An individual movement or a series of movements at an intersection that receive its own distinct display. A signal phase is comprised of green, yellow change and red clearance intervals. These displays can be in the form of arrows or circular indications.

**Phase sequence**—The order of service for the various movements (phases) at an intersection.

**Preemption**—The transfer of normal operation of a traffic signal to a special signal control mode. This special mode provides railroad preemption to accommodate a railroad grade crossing or it may be used to provide priority operation for emergency or transit vehicles.

**Red clearance interval**—An optional interval after a yellow indication in which all directions are shown a red indication, and precedes a green indication for a conflicting phase or movement. It is intended to allow a vehicle that entered the intersection during the yellow change interval to clear the intersection before the onset of an opposing traffic phase. It is typically between 1 and 2 seconds with a maximum value of 6 seconds and depends on the size of the intersection and the size and speed of the typical vehicle.

**Simulation programs**—Traffic analysis software designed to model a real world or proposed traffic system. These programs provide measures of effectiveness based on the model of the system but do not provide optimal solutions in terms of signal timings or intersection geometry.

**Split**— Amount of time allocated to an individual movement or a phase including green, yellow change and red clearance intervals. The sum of all splits equals the cycle length.

**Traffic responsive control**—The feature of an open or closed loop master controller that selects signal timing plans based on information from system detectors. Signal timing plans are selected from a list of established timing plans based on anticipated traffic patterns.

**Travel time**—Amount of time required to travel from one point in the network to another. Travel time is a prime indicator of the quality of traffic flow along a roadway.

**Turn pocket/Turn lane**—An individual lane that is present at the intersection allowing turning vehicles to get out of the way of vehicles going straight through the intersection.

**WALK interval**—The time that the WALK indication is shown. Nominally set to 7 seconds as per current standards, but can be as low as 4 seconds to maximize green time for opposing phases or as high as the associated vehicular green minus the pedestrian clearance time. It is intended to allow waiting pedestrians to start crossing the street.

**Yellow change interval**—The interval following the green indication. It is intended to warn the motorists of an impending red signal indication. It is typically between 3 and 6 seconds with longer durations for high-speed approaches and/or on down-grades.

## Actuated Operations

**Semi-actuated**—Signal operation where at least one but not all signal phases are operated on the basis of vehicle actuations. A background cycle is maintained to provide coordination along the arterial.

**Fully actuated**—Signal operation in which all signal phases are operated on the basis of vehicle actuations; no background cycle exists.

## Modes of Operation

**Isolated operation**—Mode of operation where the controller unit is allowed to time and cycle as needed to service demand on the various approaches to the intersection.

**Fixed time/Pretimed**—Signal operation where a fixed time is allotted to each signal phase regardless of the level of traffic demand for that signal phase.

**Coordinated operation**—Mode of operation where the controller unit is constrained to a cycle length and specific times within the cycle to service selected phases. Allows the engineer to offset the arterial green from one intersection to the next, providing the motorist the opportunity to go through multiple signals along an arterial while minimizing stopping.