Did You Know?

Poor signal timing causes 5 percent of traffic congestion according to the Federal Highway Administration (FHWA). Some people think that when a traffic signal cycles between red, yellow, and green, it is working fine. In reality, traffic signals need routine maintenance and overhauls for proper operations. This can take several different forms such as replacing incandescent bulbs with light emitting diode (LED) modules, or replacing actuation loops with video detection. Another critical form of maintenance is retiming of the controller to change the timing of the traffic signal indicators to improve overall traffic flow and minimize delays or interruptions. While some maintenance needs are readily visible, without analysis it may not be immediately obvious that signal timing may need to be improved and optimized to reduce overall delay for vehicles at the intersection.

In December 2008, a bulletin on “Traffic Signals” was prepared and distributed. This bulletin covered when a traffic signal is needed, how a signal is warranted (per Chapter 4C of the Manual on Uniform Traffic Control Devices [MUTCD]), basic design elements, as well as signal timing and operations. This bulletin and others are available from our web page (www.tea.army.mil); look for bulletins under Publications and Studies, DoD Programs for National Defense.

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When is Retiming Needed?
Traffic signals with incorrect timings are a common problem on military bases. Timings are often correctly implemented when a signal is constructed, but over time, timing needs change. Factors that influence the timings include:

✓ Employment levels change, or new buildings are constructed which influence traffic demand resulting in changes to turning movement volumes through intersections.
✓ An entry control facility may be built which adds considerably more traffic to the roadway or changes demand patterns.
✓ Pedestrian demand.

Benefits of Traffic Signal Retiming
Of all of the recurring congestion sources shown above, upgrading traffic signal timings is one of the most cost-effective solutions.

Signal Retiming Gets a “C-” Grade
In 2006 the National Transportation Operations Coalition sent questionnaires to U.S. municipalities to obtain a self assessment of their traffic signal operations. The National Traffic Signal Report Card report summarizes the findings, which includes a “C-” grade for signal retiming practices.

It is believed that military bases would probably give themselves a similar grade.

Studies around the country have shown that the benefit of area-wide signal retiming outweighs the costs 40:1 (or more). In an economy where new roadway construction is much more limited, it is more critical to maximize operations on existing facilities. The benefits of up-to-date signal timing include shorter commute times, improved air quality, reduction in certain types and severity of crashes, and reduced driver frustration. Specifically, the FHWA Traffic Signal Timing Manual indicates that improved traffic signal operations can reduce:

✓ Traffic delay by 15-40 percent
✓ Travel time by up to 25 percent
✓ Stops by 10-40 percent
✓ Fuel consumption by up to 10 percent
✓ Emissions by up to 22 percent.

Equipment upgrades can also improve safety and efficiency of the traffic signal. These equipment upgrades may also reduce the number of crashes and therefore increase the safety and reliability at the intersection. For example:

✓ Light Emitting Diodes (LEDs) can reduce energy consumption by almost 80 percent.
✓ Video detection could reduce maintenance costs associated with replacing inductive loops.
✓ Spread spectrum radio interconnection can eliminate monthly utility attachment costs associated with physical interconnection.
✓ Emergency vehicle preemption can reduce response times by 16-23 percent.
✓ Countdown pedestrian signal heads can reduce confusion for pedestrians.

SDDCTEA performed a study at a large Army installation and found that by simply retiming the 50 traffic signals and adding detection where it was lacking yielded the following annual measures of effectiveness:

<table>
<thead>
<tr>
<th>Measure of Effectiveness</th>
<th>Annual Savings</th>
<th>Financial Savings*</th>
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<tr>
<td>Total Delay</td>
<td>4,374,000 hr</td>
<td>$64,243,125.00(^1)</td>
</tr>
<tr>
<td>Fuel Consumed</td>
<td>3,396,600 gal</td>
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<td>CO Emissions</td>
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<td>NOx Emissions</td>
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<td>VOC Emissions</td>
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* Note:
1. Delay savings were equated to monetary value using $14.6875 per hour identified in Engineering News Record and NCHRP Report 133
2. $3 per gallon was used for fuel savings.
If your military installation has specific questions or desires assistance in retiming traffic signals, feel free to contact SDDCTEA. See page 7 for contact information.

There are about 300,000 traffic signals in the United States, and the FHWA estimates that as many as 75 percent of these traffic signals could be made to operate more efficiently by adjusting their timing plans, coordinating adjacent signals, or updating equipment. These efforts would also:

✓ Improve air quality and reduce fuel consumption.
✓ Reduce travel time.
✓ Reduce the number of serious accidents.
✓ Reduce aggressive driving behavior, including red-light running.
✓ Postpone the need to construct additional road capacity, provided the lanes are not currently over-capacity.

SDDCTEA encourages all military installations with traffic signals to reexamine the traffic signal timings and equipment at least every 3 to 5 years to see if changes would be helpful to improve both traffic flow and safety.

However, if new employment centers are constructed or if there are significant changes in the installation’s population or transportation infrastructure, the retiming should be scheduled when these changes occur.

**Retiming Efforts**

It is important to maintain effectively operating traffic signals to minimize motorist delays and complaints, and thereby improve safety and reduce fuel consumption. When retiming traffic signals, military installations should refer to the FHWA *Traffic Signal Timing Manual*. This manual is a comprehensive guide of traffic signal timing concepts, analytical procedures, and applications based on current practices.

Equipment upgrades, and phasing and timing changes should be fully documented. Each traffic signal should have a drawing of the intersection showing traffic signal equipment details and timing information. This drawing should be retained in a pouch in the controller cabinet, as well as in the Public Works or installation engineer’s office.

**Exhibit 2. Example of Synchro Network**
In accordance with the FHWA’s Traffic Signal Operations and Maintenance Staffing Guidelines (Mar 09), the typical intersection signal retiming requires an estimated 43 person-hours at a cost of $2,500 to $3,500. Of the 43 hours, turning movement counts typically consume about 25 hours and it is the single most costly element in the process.

While the need for retiming can be identified in several different ways, calls from employees and other road users are one of the most common motivation factors for reviewing intersection operations. Most complaints involve motorists being annoyed by waiting at a red signal indication when there are no vehicles on other approaches due to lack of or malfunctioning detection, or when they have to stop at successive signals in a corridor because coordination is not operational or incorrectly timed. Motorists could be frustrated by having to wait several cycles at an intersection when they see other approaches clearing in one

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**Reasons to Use a Regionalized Approach to Signal Retiming**

✓ Expediting traffic flow at one intersection will not produce the desired results if bottlenecks remain at nearby signals.
✓ If part of a coordinated signal system it is necessary to establish the best cycle length for all signals.
✓ It is more economical to perform reviews on a regional basis due to economies-of-scale and the fact that some traffic counts may be redundant.
✓ A systematic approach provides an opportunity for consistent upgrades, e.g., emergency vehicle preemption, countdown pedestrian signals, etc.

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Exhibit 3. Signal Retiming Flowchart

1. **Complaint and/or Scheduled Timing Evaluation.**
2. **Schedule a field visit to observe known problems.**
3. **Assemble the most recent traffic volume information. It may be necessary to perform new turning movement counts in the peak periods.**
4. **Observe the physical condition of traffic signal hardware and inspect the controller cabinet components.**
5. **Check operability of all cabinet components either through observation or diagnostics.**
6. **Determine current controller settings. Most of the time, it is easy to find settings through the controller interface. Ideally, these should be recorded on paper and stored in the controller cabinet.**
7. **Calculate and implement new timings.**
8. **Evaluate the timing changes by observing the intersection during morning, midday, and afternoon peak (and off-peak if necessary).**
9. **Fine-tune the adjustments.**
cycle. These are all valid complaints that should not be ignored since simple timing adjustments can provide significant benefits to the problems.

Keep in mind that some complaints cannot be resolved because the motorists may not be aware of other constraints such as poor signal spacing, lack of intersection capacity, the inability to program signal equipment to accommodate a broad range of traffic fluctuations, pedestrian clearance times, and too many conflicting movements which require excessive green time.

Once the need for traffic signal retiming has been identified, follow the general procedures in Exhibit 3.

The development of traffic signal timing plans can be accomplished through the use of a number of computer software packages including the Highway Capacity Software, Synchro and SimTraffic, and others. All traffic signal timing modifications should be developed by an engineer and implemented by a traffic signal specialist or technician.

**Basic Timing Parameters**

Signal operation and timing have a significant impact on intersection performance. Controllers have a lot of inputs which need to be tailored to the specific intersection.

The development of a basic signal timing plan should address all user needs at a particular location including pedestrians, bicyclists, transit vehicles, emergency vehicles, automobiles, motorcycles and trucks. The purpose of this section is not to identify details of performing the calculations, but to inform of the importance of different settings that should be considered. For more information on calculating and implementing actual timings, contact SDDCTEA. See page 7 for contact information.

Exhibit 4 shows a typical phasing diagram that would be shown on a signal operation drawing. The arrows at the top show all of the allowable movements by lane of traffic during each phase. The numbers on the left column are different signal heads; the letters to the right of those numbers are each signal’s display indications during each phase. The numbers in the lower columns are the actual times in seconds for each interval of that phase.

**Exhibit 4. Traffic Signal Phasing Plan**

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**Exhibit 4. Traffic Signal Phasing Plan**

- Upon pedestrian actuation only, otherwise DW
  - W = Man symbol
  - DW = Flashing upraised hand symbol with countdown timer
  - DW = Steady upraised hand symbol
- 1: IF FOLLOWED BY PHASE 1+6
- 2: IF FOLLOWED BY PHASE 2+5
- 3: IF FOLLOWED BY PHASE 2+6
- 4: IF FOLLOWED BY PHASE 1+5 OR 1+6
Pedestrian Timing

Pedestrian timing requirements include a “walk interval” and a “pedestrian clearance interval.” The walk interval gives pedestrians adequate time to perceive the WALKING PERSON indication and depart the curb before the beginning of the pedestrian clearance interval, i.e., when the UPRaised hand starts to flash. The MUTCD generally recommends a minimum walk interval of 7 seconds. In areas with heavy pedestrian demand or within school zones, longer walk intervals are often appropriate to promote walking and to serve pedestrian demand, and also slower walking speeds.

The pedestrian clearance interval consists of two components:

✓ Pedestrian change interval, which must be sufficient to allow a pedestrian crossing in the crosswalk who has left the curb or shoulder at the end of the WALKING PERSON indication to travel at a walking speed of 3.5 feet per second to at least the far side of the traveled way. During this component, the flashing hand with countdown (if provided) is displayed.
✓ Buffer interval, which must be a minimum of 3 seconds between the end of the pedestrian change interval and the beginning of a phase for conflicting traffic. During this component, the solid hand symbol is displayed.

Vehicle Timing—Green Interval

The length of the green display should be sufficient to serve the demand present at the start of the green phase for each movement and should be able to move groups of vehicles, or platoons, in a coordinated system. At an actuated intersection, the length of the green interval varies based on inputs received from the detectors. Minimum and maximum green times for each phase provide a range of allowable green times. Detectors are used to sense the amount of traffic and thereby help determine the required time for each movement within the allowable range.

The minimum green time is the amount of time allocated to each phase so that queued vehicles at the stop bar are able to clear the intersection. The minimum initial green time is established by determining the time needed to clear the vehicles located between the stop bar and the detector nearest the stop bar.

The maximum green time is the maximum limit to which the green time can be extended for a phase in the presence of a call from another phase. Generally, this is based on traffic demand. Most controllers are capable of multiple timing plans to allow different maximum green times for different times of day.

Vehicle Timing—Passage Time

The term “passage” refers to the amount of time that the signal will remain green after there is no vehicle on a detector, after the minimum green time has been met, provided the maximum green time has not been met. The longer the passage time, the longer the signal will remain green to wait for a vehicle on that approach.

Longer passage times are needed when the detectors are short. Short passage times are acceptable with longer detectors (40 feet in length), because if there is a series of vehicles, there is a shorter time that there will be no vehicle on the detector. This is generally a more efficient operation.

Vehicle Timing—Clearance Intervals

The vehicle clearance interval consists of the yellow change and red clearance intervals.

The yellow interval provides warning that the signal will be changing. The length of time given to the yellow interval is based on the approach speed.

New Pedestrian Signals

In accordance with the MUTCD, new pedestrian signal heads must be capable of displaying a white WALKING PERSON symbol, and a Portland orange UPRaised HAND symbol. Although pedestrian symbols previously were allowed to consist of an outline, all new indications must consist of solid symbols. Except for very narrow street crossings, new pedestrian signal heads are required to include countdown displays showing the number of seconds remaining in the pedestrian change interval.
The red clearance interval provides time for a vehicle that entered the intersection late in the yellow interval to travel through the intersection at the prevailing speed. The length of this interval is based on speed and width of the intersection.

The topic of yellow and red clearance intervals has been much debated in the traffic engineering profession. At some locations, the yellow clearance interval is either too short or set improperly due to changes in posted speed limits or 85th-percentile speeds. This is a common problem and frequently causes drivers to brake hard or to run through the intersection during the red phase. On the other hand, studies suggest that longer clearance intervals will cause drivers to enter the intersection later and will breed disrespect for the traffic signal.

**Vehicle Timing—Cycle Length**

One signal cycle is the time for all traffic signal phases to occur once, and at their maximum time if the signal is actuated. Cycle lengths generally vary by traffic demand. Different cycle lengths should be used to accommodate different levels of traffic demand at different times of day. In general, an isolated signalized intersection or a network of signalized intersections will have an optimum cycle length that minimizes average vehicle delay.

For isolated, actuated intersections, the cycle length is only dependent on conditions at that intersection. For coordinated signal systems, the same cycle length is used for the entire corridor at any given time in order to achieve consistent operation for all signals within the system. Shorter cycle lengths, such as 60 seconds, are generally preferable to longer ones, such as 120 seconds or more, because they result in less delay and shorter queues; however longer cycles are generally needed as more phases are used. Also, as intersections become more and more congested, longer cycle lengths tend to be used to minimize lost time from the clearance intervals.

Longer cycle lengths generally result in increased delay and queues to all users, particularly minor movements. There may also be a connection between longer cycle lengths and increased incidence of red-light running, although this has not been documented in research. More drivers may be tempted to run the red light to avoid the extra delay caused by the longer cycle length.

**Vehicle Timing—Offset**

It is common practice to coordinate traffic signals at adjacent intersections along a corridor that are within 3/4 mile of each other. With coordinated signals, the green intervals for the major road should occur to minimize the need for platoons of traffic to stop at each intersection. The exact point in each cycle where the green interval for the major roadway occurs with respect to an adjacent signal is called the “offset”. An improper offset means that vehicles are required to stop more frequently at signals along a corridor.

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Web Site: [http://www.tea.army.mil](http://www.tea.army.mil) for pamphlets, bulletins, and studies
Controller Setting—Phase Recall

Although not technically a timing setting, phase recall is critical to the operation of a signal. The phase in recall is the phase that the signal will rest in when there is no traffic demand. This generally should be the green phase for the major roadway through movement, although there are cases where it is appropriate for another phase to be in recall. Normally, it is rare that there is no traffic demand at a signalized intersection, but there may be more frequent cases where a side street has no demand.

There are two settings for a recall phase, “Minimum Recall” and “Maximum Recall.” Minimum Recall means that the phase in recall will remain for at least the minimum time, and will be extended if there is demand detected. Maximum Recall means that the phase in recall will remain for at least the maximum time for that phase. Typically, this is only used where there is no detection for the major roadway.

Detector Setting—Locking

“Locking” refers to whether a phase that has placed a call by the detector will come up if there is no vehicle on that detector at the time that the phase would otherwise come up. Locking is appropriate when the detection is located in advance of the stop line, or for pedestrian phases. Non Locking is appropriate when there is detection located at the stop line. This is more efficient and preferred since if the vehicle proceeds, the phase can be skipped.

Controller Setting—Dual Entry

Dual entry ensures that two phases will always be on. For example, when one direction’s left-turn phase is on, the opposite direction’s left-turn phase will be on if there is demand; or, if there is no demand the adjacent direction’s through phase will be on. Without dual entry enabled, only the actual phase that had the detection call will be on at a point when another nonconflicting phase could be on.

Flashing Operations

With flashing operation, one or both roadways would be required to stop. Traditionally, intersections flashed at night for two primary reasons: to be more efficient with lower traffic demand, and to save power. With the use of LED indications, the signal uses much less power than traditional incandescent bulbs. Generally, there is less traffic demand at night, so signals can generally operate acceptably flashing. However, there are other factors to consider:

✓ At night, it may be more difficult to perceive gaps in traffic since it is dark and drivers are only able to judge based on seeing another vehicle’s headlights.
✓ Is there a sight distance limitation in one or more quadrants? If so, it would be safer to operate in steady operation.
✓ If all approaches are required to stop, there may be less overall delay if the signal operates in steady mode with low side street traffic demand.
✓ There may still be pedestrian demand, which would be safer with steady operation.

Signals at Entry Control Facilities

Traffic signals near entry control facilities (ECFs) have special considerations. Since ECFs are typically on major approach corridors, it is especially critical that traffic signals on these corridors operate efficiently. If these signals do not operate efficiently, it will adversely affect a significant proportion of an installation’s traffic. Special timings may be appropriate for certain periods if traffic queues extend through a signal.

If active vehicle barriers are located at an intersection, the signal system for the barriers should be integrated with the intersection traffic signal. In this case, there are certain timings that are governed by the operation of the barriers. When this occurs, contact SDDCTEA for guidance. Additionally, SDDCTEA Pamphlet 55-15, Traffic and Safety Engineering for Better Entry Control Facilities, has more information on the operation of these signals.
Upgrade Opportunities

In addition to retiming efforts, equipment upgrades can also contribute to the efficient operation of a traffic signal. As part of routine maintenance or operational audits, consider the following potential upgrades:

✓ Replace incandescent bulbs with LEDs since they are more energy efficient and require less maintenance than incandescent lamps.
✓ Replace inductive loop detectors with video detection since video detectors are permanent, and offer the flexibility to easily change zones if desired due to a work zone lane closure lane redesignation, or change in detection settings.
✓ Replace physical interconnection with spread-spectrum radio or other wireless applications.
✓ Install emergency vehicle preemption.
✓ Install countdown pedestrian signals to improve pedestrian safety.
✓ Add an uninterruptible power supply or battery backup unit to maintain signal operation during power outages.
✓ Add surge protection devices to reduce the threat of lightning damage.
✓ Safety-related upgrades such as adding a protected left-turn phase or a near-side signal to minimize the effects of a truck blocking the view of the primary signals.

Remember—Whenever traffic signal components and traffic control devices need to be replaced or revised, the new components must conform to the current edition of the MUTCD at a minimum. State and local jurisdictions may have additional requirements.

SDDCTEA Can Help!

One of SDDCTEA’s services is an Operational Audit for Traffic Signal Sustainability (OATSS) study. With this type of study, we will perform the following:

✓ Collect traffic data at four to six signalized locations
✓ Identify existing signal equipment and operational deficiencies
✓ Conduct traffic analyses to determine delay and levels of service
✓ Develop optimized traffic signal timings

Special Features

✓ Conduct traffic data collection, traffic analyses, and field implementation of new signal timings
✓ Record deficient signal equipment
✓ Enter new signal timing parameters into controllers.

This type of study can be completed in 1 week.

Exhibit 5. Video Detection Zones From A Single Camera

Video detection enables detection zones to be changed easily in the field with no change to hardware.
New Traffic Signal-Related Requirements in the 2009 MUTCD

The 2009 MUTCD added several new requirements relating to traffic signal design. Some of these include:

✓ Larger signs are now required for many signal-related regulatory signs, e.g., LEFT TURN SIGNAL, LEFT TURN YIELD ON GREEN, etc. (see Section 2B.03). There are also many new signal-related signs.

✓ Street name signs now required to use a combination of lower-case letters with initial upper-case letters as referenced in Section 2D.43.

✓ Larger 12-inch signal indications are generally required on all roads with a speed limit greater than 30 mph (see Section 4D.07).

✓ If there are two or more lanes for the through movement, a separate signal face is recommended for each through lane (see Section 4D.11).

✓ Backplates are recommended on all signals when the speed limit or the 85th-percentile speed is over 45 mph (see Section 4D.12).

✓ Flashing yellow arrows and flashing red arrows may be used for separate left-turn signal faces (see Section 4D.18).

✓ Protected-only separate left-turn lanes must use a red arrow instead of a circular red (see Section 4D-19).

✓ The duration of yellow change intervals and red clearance intervals must conform to engineering practices by December 31, 2014 or when changing any timings, whichever comes first (see Section 4D.26 and Table I-2).

✓ Expanding the use of flashing yellow arrow signals at some intersections to give a clearer indication that drivers can turn left after yielding to any opposing traffic (see Section 4D.26).

✓ Pedestrian change interval shall not extend into a red clearance interval and must be followed by a minimum 3-second buffer interval by December 31, 2014 or when changing any timings, whichever comes first (see Section 4E.06 and Table I-2).

✓ Pedestrian signal timing should be based on a walking speed of 3.5 feet per second instead of 4 feet per second (see Section 4E.06).

✓ Countdown pedestrian signals are now required whenever the pedestrian change interval is greater than 7 seconds (see Section 4E.07).

✓ The location of pedestrian pushbuttons must comply with Section 4E.08. Pushbuttons in the same quadrant are preferred to be located 10 feet apart for ADA considerations.
Reference List

✓ Traffic Control System Operations – Installation, Management, and Maintenance, Institute of Transportation Engineers, April 2000
✓ www.fhwa.dot.gov
✓ www.tea.army.mil
✓ www.ite.org

Training

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Prepared with the assistance of Gannett Fleming