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Signalization Design

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I. Introduction

Traffic signals are electronically controlled traffic control devices that control the movement of traffic at intersections. Traffic signals have been in use since the 1930's when the concept of the three-section signal head (red/yellow/green) was established.

Traffic signals are one of the most restrictive forms of traffic control that can be used at an intersection. In order to control the placement of traffic signals, the Manual on Uniform Traffic Control Devices (MUTCD) was developed providing a series of warrants to justify the installation of a traffic signal.

Traffic signals are common traffic control devices at major intersections. This is because they can handle high volumes of traffic at complex intersections.

The number of right-angle crashes is generally reduced by the installation of a signal. Left turn crashes are also reduced when there is a separate left turn phase. Pedestrian crossing movements are also safer under signal control. It should be noted that the installation of a signal may increase the number of rear-end crashes. However, generally these crashes are less severe than other types of crashes.

Signal installation is much costlier than other forms of intersection control. A complete signal installation including design, construction and inspection can cost from \$100,000 to \$250,000 depending on the type of signal design. Signing and pavement marking modifications can be used to improve the function of an intersection and can cost less than \$5,000.

It should be noted that the installation of a signal is not a “cure all” for all traffic problems at intersections. Geometric modifications or signing and pavement marking changes may provide suitable results. Less invasive measures should be attempted before installing a signal.

It is important to weigh the advantages and disadvantages of a signal prior to proceeding with the design.

Advantages	Disadvantages
<ul style="list-style-type: none"> • Provide orderly movement of traffic • Increase traffic-handling capacity of the intersection • Reduction in right-angle and left-turn crashes • Can be coordinated to provide continuous movement of traffic • Used to interrupt heavy traffic at intervals to permit other traffic to cross 	<ul style="list-style-type: none"> • Cost • Aesthetics • Increase in rear-end crashes • Excessive delay • Excessive disobedience of signal indications

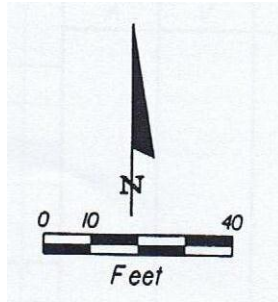
A. Field Survey Information

A signalization plan sheet requires an accurate base plan on which the signalization details are placed. This base must include right-of-way lines since the signalization equipment must be placed within the existing right-of-way. If insufficient right-of-way is available a permanent easement agreement or purchase of right-of-way must be obtained prior to construction. In addition to the right-of-way lines, the survey should include all geometric features of the proposed/existing intersection. These items may include sidewalks, curbs, medians, driveways, etc. Utility locates should also be performed to ensure that there are no conflicts between the signalization equipment and existing utilities. It is important to note that utilities may run overhead or underground, so a thorough survey should be completed. It is also crucial to coordinate with the local power company to establish the locations of the power drop for the electrical service.



B. Plans Preparation

A signalization plan will need to be plotted “to scale.” “To scale” means that a measurement on the plan sheet corresponds to a dimension in the field. For example, a 1:20 scale means 1 inch equals 20 feet. Typical signalization plans can be drawn at 1:20, 1:40 or 1:50 scale. The following illustration shows the North arrow and 1:40 scale that would be placed in a corner of each plan sheet.



II. Traffic Signal Warrants

The MUTCD states that “an engineering study of traffic conditions, pedestrian characteristics, and physical characteristics of the location shall be performed to determine whether installation of a traffic control signal is justified at a particular location.”

It expanded this requirement to include the investigation of the need for a traffic control signal. The investigation shall include the analysis of factors related to the existing operation and safety at the study location and the potential to improve these conditions.

The MUTCD requires the satisfaction of at least one of the signal warrants. The following are the MUTCD signal warrants.

- Warrant 1 – Eight-Hour Vehicular Volume
- Warrant 2 – Four-Hour Vehicular Volume
- Warrant 3 – Peak Hour
- Warrant 4 – Pedestrian Volume
- Warrant 5 – School Crossing
- Warrant 6 – Coordinated Signal System
- Warrant 7 – Crash Experience
- Warrant 8 – Roadway Network
- Warrant 9 – Intersection Near a Grade Crossing

III. Traffic Signal Control Type

There are three different signal control types:

A. Pre-Timed

Pre-timed signals operate with fixed cycle lengths and green split. Most pre-timed controls feature multiple timing plans, with different cycle, split and offset values for different periods of the day.

B. Semi-Actuated

Semi-actuated signals operate with varied green time for the main street left turn phases and side street phases. These times can vary by time of day or cycle to cycle. The major street thru movement green time can only vary by time of day.

C. Actuated

Actuated signals vary the amount of green time allocated to each phase based on traffic demand. Actuated control does not rely on a fixed cycle length unless the intersection is in a coordinated system or under adaptive control. It provides variable lengths of green timing for phases that are equipped with detectors. The time for each movement depends on the characteristics of the intersection and timing parameters.

IV. Traffic Signal Heads

A. Vehicle Displays

The location of signal heads should be evaluated based on visibility requirements and type of signal display. While signal head placement is governed by MUTCD requirements for signal displays, the specific placement of signal heads is typically determined by local policies. When designing the placement of signal heads, the following should be considered in addition to the minimum requirements in the MUTCD:

- Consistency with other intersections in the area
- A geometric design issue that could confuse a driver
- A large percentage of vehicles on one or more approaches that block lines of sight including trucks and vans
- The width of the intersection
- The turning paths of the vehicles.

The MUTCD requires that each signal head have at least 3 but no more than five indications. Indications can either be 8 inches or 12 inches in diameter. Most municipalities require 12-inch indications for increased visibility.



Indications can have incandescent bulbs or LED's (Light Emitting Diodes). Most municipalities require LED indications which use less power and have a longer life. The following illustration shows an aluminum signal head with LED indications.



Signal heads are constructed with aluminum or polycarbonate. Polycarbonate heads weigh less and resist corrosion. However, polycarbonate heads may deteriorate from ultraviolet (UV) radiation. The following illustration shows a polycarbonate head.



A signal head can have multiple “faces.” A “face” is provided for each direction of traffic. For example, a signal head with 4 faces is referred to as a 4-way signal. The following illustration shows a 4-way signal head.

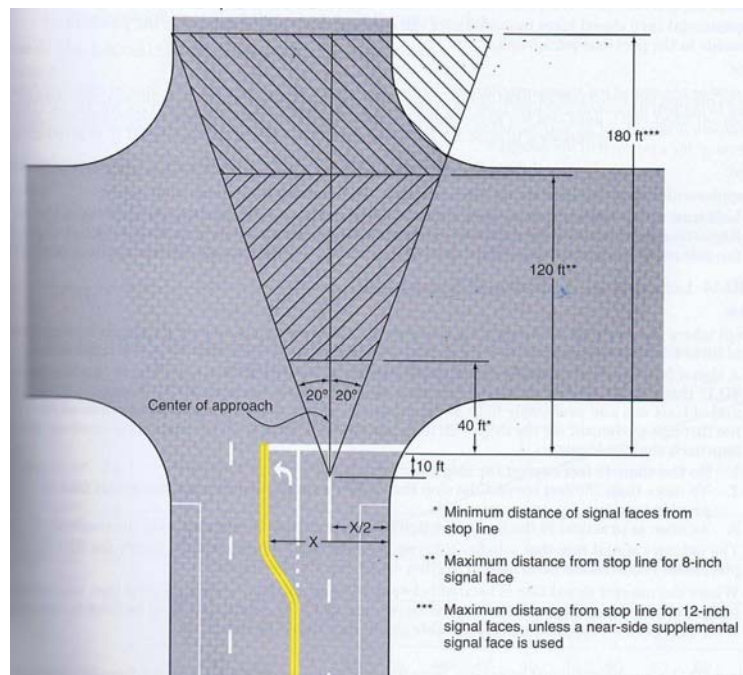


B. Lateral Positioning of Signals

The MUTCD requires a minimum of 2 signal faces for thru movements. Two faces are required to ensure that motorists have an indication present at all times, even if one burns out. For turn lanes, only 1 signal face is required. In addition, the MUTCD requires a minimum spacing of 8 feet between 2 signal faces controlling the thru movement.

C. Longitudinal Positioning of Signals

Signal heads shall be placed no less than 40 feet beyond the stop line and no more than 180 feet beyond the stop line unless a supplemental near-side signal face is provided. The following illustration shows the longitudinal positioning of signals.



V. Signal Head Auxiliaries

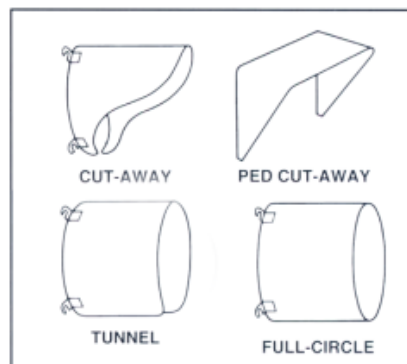
There are a number of signal head auxiliary devices available for installation. Two of the most common auxiliaries include back plates and tunnel visors.

A. Back Plates

A back plate can be constructed from aluminum or polycarbonate. They extend outward from all sides of the signal head. The finishes can be black or yellow. They can be used to enhance the visibility of the signal head for approaching vehicles. However, it should be noted that the installation of back plates increases the wind loading and may affect the structural capacity.

B. Tunnel Visors

Aluminum and polycarbonate visors are available in several styles for vehicle and pedestrian signals. The cutaway type is the standard. Tunnel and full-circle styles reduce or eliminate signal visibility from other approach directions.



The following illustration shows a mast arm installation with signal heads utilizing yellow back plates and tunnel visors.



C. Pedestrian Displays

According to the MUTCD, pedestrian signal heads must be used in conjunction with vehicular traffic control signals under any of the following conditions:

- If a traffic control signal is justified by an engineering study and meets either Warrant 4, Pedestrian Volume, or Warrant 5, School Crossing
- If an exclusive signal phase is provided or made available for pedestrian movements in one or more directions, with all conflicting vehicular movements being stopped.
- At an established school crossing at any signalized location.
- Where engineering judgment determines that multiphase signal indications (as with split-phase timing) would tend to confuse or cause conflicts with pedestrians using a crosswalk guided only by vehicular signal indications.

The following is an example of a countdown pedestrian signal display.



Pedestrian signals should be used under the following conditions:

- If it is necessary to assist pedestrians in making a reasonable safe crossing or if engineering judgment determines that pedestrian signal heads are justified to minimize vehicle-pedestrian conflicts.
- If pedestrians are permitted to cross a portion of a street, such as to or from a median or sufficient width for pedestrians to wait, during a particular interval but are not permitted to cross the remainder of the street during any part of the same interval.
- If no vehicular signal indications are visible to pedestrians, or if the vehicular signal indications that are visible to pedestrians starting or continuing a crossing provide insufficient guidance for them to decide when it is reasonably safe to cross, such as on on-way streets, at T-intersections or at multiphase signal operations.

VI. Conduit

The design of a traffic signal system should provide adequate capacity, both in wire size and conduit size, for the proper operation of the complete system. In addition, it is important to

include adequate capacity in the electrical system to allow maintenance to make repairs safely and promptly. One example of this is the spare conductors that are provided in major conduit runs for a traffic signal.



Installation of a conduit shall conform to the requirements of the municipalities' standard specifications.

A conduit can be installed in a number of ways including:

- Aboveground
- Underground
- Underpavement Sawcut
- Underground – Jacked
- Bridge Mount

Underground is the most typical installation with new construction because excavation for the roadway has already occurred.

Signal installation at an existing intersection may require the use of underground – jacked installation. In this case, a jack-and-bore machine places the conduit under existing pavement. The following illustration shows a jacked installation.



It is important that a spare conduit be placed in each of the underground runs for ease of future maintenance.

The wiring placed inside the conduit provides the power and communication for the signal system. The National Electric Code (NEC) provides the wiring specifications. The “high voltage” (120 volts AC) signal wiring and “low voltage” (24 volts DC) loop wiring are generally run in separate conduits.



VII. Traffic Signal Phasing

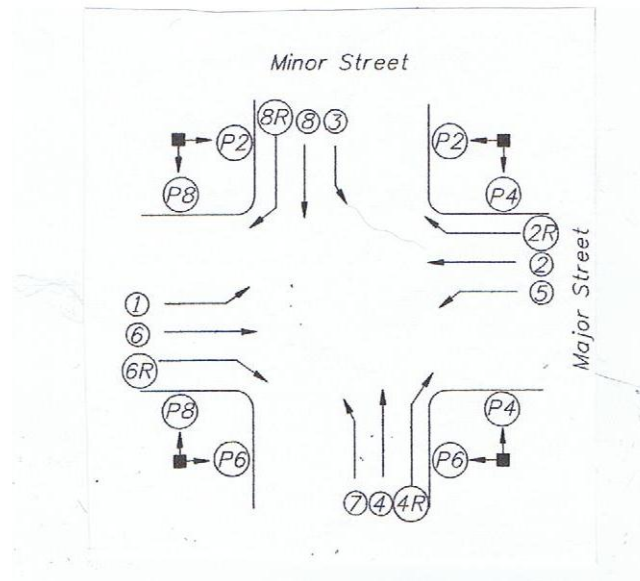
The Manual on Uniform Traffic Control Devices (MUTCD) defines signal phase as the right-of-way, yellow change and red clearance intervals in a cycle that are assigned to an independent traffic movement or combination of traffic movements. Signal phasing is the sequence of individual signal phases or combinations of signal phases within a cycle that define the order in which various pedestrian and vehicular movements are assigned the right-of-way. The MUTCD rules for determining controller phasing, selecting allowable signal indication combinations for displays on an approach to a traffic control signs and determining the order in which signal indications can be displayed.

Depending on the complexity of the intersection, 2 to 8 phases are typically used, although some controllers can provide up to 40 phases to serve complex intersections or sets of intersections. Pedestrian movements are typically assigned to parallel vehicle movements.

Provision of a separate left-turn lane may alleviate the problems somewhat by providing storage space where vehicles can await an adequate gap without blocking other traffic movements at the intersections. In most cases, the development of a signal phasing plan should involve an analytical analysis of the intersection. Several software packages are suitable for selecting an optimal phasing plan for a given set of geometric and traffic conditions for both individual intersections and for system optimization.

Pedestrian movements must be considered during the development of a phasing plan. For example, on wide roadways pedestrian timing may require timing longer than what is required for vehicular traffic, which may have an effect on the operation analysis.

The following illustration shows a sample intersection layout with signal head movement numbers. Vehicle movements and signal head number assignments are not directionally oriented but shall maintain their relative orientation about the intersection. Note that movements 2 and 6 are reserved for the main street thru movements. Movements 1 and 5 are reserved for the main street left turn movements. The pedestrian indications (“P”) follow the same numbering system, but are used for the pedestrian movements. The right turn movements that are controlled by a signal head are given designations with an “R.”



The following illustration shows a timing table for the signal indications.

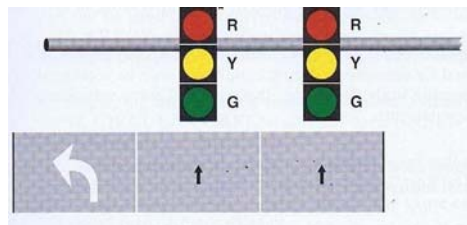
From To		SIGNAL INDICATIONS						
		R	←	G	↔	↑	WALK	DONT WALK
SIGNAL INDICATIONS	R			Y	↔	Y		
	←			Y	↔	Y		
	G				↔			
	↔							
	↑							
	WALK							
	DONT WALK							Flash DONT WALK

A. Permissive-Only Phasing

Permissive-only (also known as permitted-only) phasing allows two opposing approaches to time concurrently, with left turns allowed after yielding to conflicting traffic and pedestrians. One possible implementation of this phasing pattern is illustrated in the following figure:

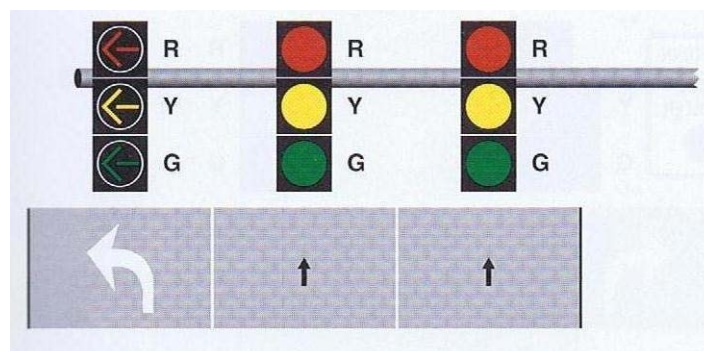
For most high-volume intersections, permissive-only left-turn is generally not practical for major street movements given the high number of movements at the intersections. Minor side street movements, however, may function acceptably using permissive-only left-turn phasing, provided that traffic volumes are low enough to operate adequately and safely without additional left-turn protection.

Permissive-only displays are signified by a green ball indication. In this case, no regulatory sign is required, but the MUTCD allows the option of using the “Left Turn Yield on Green” regulatory sign. As traffic volumes increase at the intersection, the number of adequate gaps to accommodate left-turning vehicles on the permissive indication may result in safety concerns at the intersection.



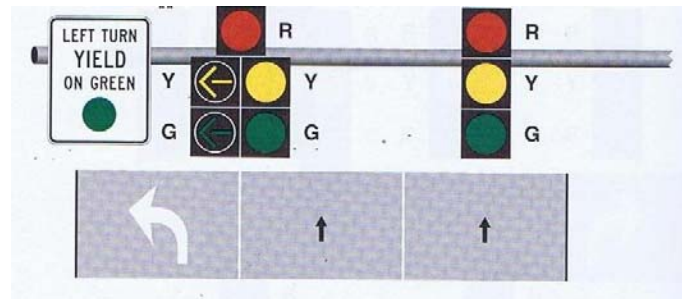
B. Protected-Only Left-Turn Phasing

Protected-only phasing consists of providing a separate phase for left-turning traffic and allowing left turns to be made only on a green left arrow signal indication, with no pedestrian movement or vehicular traffic conflicting with the left turn. As a result, left-turn movements with protected-only phasing have a higher capacity than those with permissive-only phasing due to fewer conflicts.



C. Protected-Permissive Left-Turn Phasing

A combination of protected and permissive left-turn phasing is referred to as protected-permissive left-turn (PPLT) operation. A typical signal head and associated signing arrangement that implements protected-permissive phasing is shown in the following illustration. Note a 3-section signal head is centered over the far thru lane. A 5-section signal head is centered over the lane line between the near thru lane and the left turn lane since it controls both lane movements. A supplemental “LEFT TURN YIELD ON GREEN” sign is used to remind the driver that the left turn is not a protected movement.

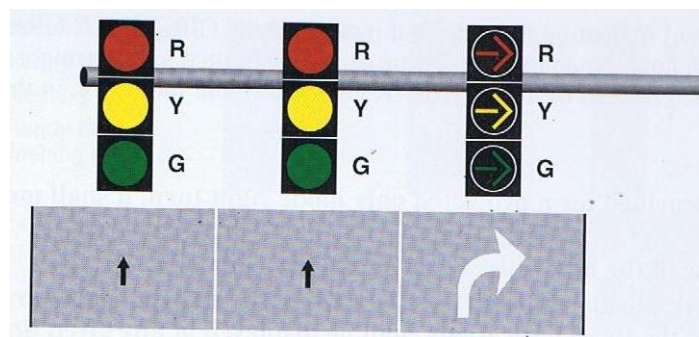


D. Split Phasing

Split phasing consists of having two opposing approaches time consecutively rather than concurrently (i.e., all movements originating from the west followed by all movements from the east). Split phase can be implemented in a variety of ways depending on signal controller capabilities and how pedestrian movements are treated.

E. Right-Turn Phasing

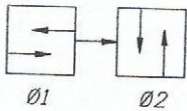
Right-turn phasing may be controlled in a permissive or protected manner with different configurations depending on the presence of pedestrians and lane configurations at the intersections.



VIII. Signal Operating Plan (SOP)

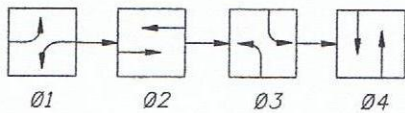
A signal operating plan (SOP) is a plan in which the timings are implemented into the movements at the intersections. There are over a dozen different signal operating plans for different movement configurations.

SOP 1



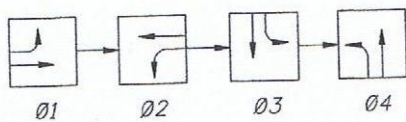
SOP 1 is the most basic signal operation plan. It provides two phases – one for the major street movements and the other for the minor street movements.

SOP 4



SOP 4 is a protected-only signal operating plan. It provides four phases. Each street receives protected left turn movement phases and thru/right movement phases.

SOP 5



SOP 5 is a permissive signal operating plan. It provides four phases. Each leg of the intersection receives a shared left/thru phase.

The numerous standard signal operating plans cover intersections with basic through movements to intersections within diamond interchanges. Standard SOPs also include pedestrian movements and railroad crossings. In addition, special signal operation plans can be developed for any non-standard situation.

IX. Traffic Signal Pole Layout

There are three primary types of signal configurations which display vehicle signal indications:

- Pedestal or post-mounted signal assemblies
- Span wire signal assemblies
- Mast arm signal assemblies

Advantages	Disadvantages
Pedestal (post-mounted) signal assembly	
<ul style="list-style-type: none"> • Low cost • Lower maintenance costs • Aesthetics 	<ul style="list-style-type: none"> • Difficult to meet MUTCD visibility requirements, particularly at large signalized intersections
Span wire signal assembly	
<ul style="list-style-type: none"> • Can accommodate large intersections • Flexibility in signal head placement • Lower cost than mast arms 	<ul style="list-style-type: none"> • Higher maintenance costs • Wind and ice can cause problems • May be considered non-aesthetic
Mast arm signal assembly	
<ul style="list-style-type: none"> • Provides good signal head placement • Lower maintenance costs • Many pole aesthetic design options 	<ul style="list-style-type: none"> • Costlier than span wire • Mast arm lengths can limit use and be extremely costly for some large intersections



A pedestal (post-mounted) signal may be used in areas with right-of-way constraints or vertical clearance concerns. Due to driver expectancy, span wire or mast arm assemblies are preferred over pedestal assemblies.



The number of poles required for a span wire assembly is determined by the number of signal heads to be placed on the span wire. A single diagonal span with two poles may suffice for a small intersection. A box span assembly (as seen in the illustration above) or a dual diagonal span assembly using 4 poles may be necessary for larger intersections with more signal heads. Span wire assemblies are supported by strain poles. Strain poles can be made of wood, aluminum or steel. The size and type of strain poles depends upon the loading (number of signal heads, signal head auxiliaries, etc.) on the span wires.

Most coastal communities now require mast arm assemblies due to the possibility of high winds during a storm event. As seen in the illustration below, mast arm supports can also accommodate signs and roadway lighting fixtures. Mast arm supports are also capable of accommodating more than one mast arm.



Heavy duty bolts are used to secure the mast arm to the foundation as seen in the illustration below. The size of the bolts and foundation are dependent upon the loading of the mast arm and the soil conditions.



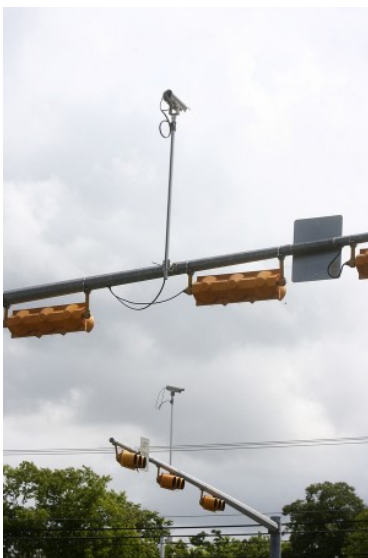
X. Detection

A. Vehicle Detection

Vehicle detection is the mechanism that allows the controller to detect the presence of vehicles.

Different municipalities require different types of detection. There are two main types of detection:

1. Overhead
2. In/Under the Pavement



Many municipalities now require video detection for their signal systems. The video cameras are placed on the mast arm assembly as seen in the illustration. This method is often preferable because it is not affected by roadway resurfacing projects that would destroy in pavement loops.

In pavement loop detectors are the norm for many municipalities. Different municipalities have different requirements for the size and placement of loops. Generally, loops are placed at or slightly upstream of the stop bar in order to transmit the presence of vehicles stopped at the intersection. In addition, advance loops may be placed to transmit the presence of approaching vehicles. The length of detection zones may vary.



B. Pedestrian Detection

Pedestrian detection actuated signals are typically accomplished through the use of pedestrian push buttons. Accessible pedestrian signal detectors, or devices to help pedestrians with visual or mobility impairments which activate the pedestrian phase, may be push buttons or other passive detection devices. For pushbuttons to be accessible, they should be placed in accordance with the guidance in the MUTCD and located as follows:

- Adjacent to a level all-weather surface to provide access from a wheelchair with a wheelchair-accessible route to the ramp
- Within 5 ft of the crosswalk extended
- Within 10 ft of the edge of curb, shoulder or pavement
- Parallel to the crosswalk to be used
- Separated from other pushbuttons by a distance of at least 10 ft
- Mounted at a height of approximately 3.5 ft above the sidewalk



XI. Controller



The traffic signal controller uses information programmed into it to control the movements of vehicles and pedestrians at the intersection. It receives information from the vehicle and pedestrian detector systems and determines the priority of the right-of-way. The controller also determines the way the power is supplied to the signal equipment. It determines which indications will be illuminated for each movement. The traffic signal controller and signal equipment are powered by 120-volt AC current.

The electrical disconnect should be pole mounted separately from the controller so it is accessible if an incident were to destroy the cabinet. The electrical disconnect switch allows the power source to be turned off in the event of an emergency.

XII. Traffic Signal Signing

There are a number of signs associated with signalized intersections. The most common are illustrated below.



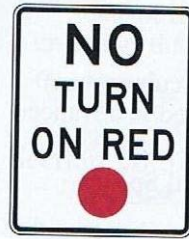
The “Signal Ahead” sign is placed in advance of a signalized intersection. It is a warning sign generally placed where there is a sight distance issue.



A “Stop Here on Red” sign is placed at the vehicle detector loop location. It ensures that the cabinet will receive the “call” for a waiting vehicle.



The “Pedestrian Crossing” sign is placed on the pedestal pole with the pedestrian signal display. The street name is optional. However, it ensures the pedestrian understands which push button operates a specific crossing.



There are numerous regulatory signs that control the movements at signalized intersections. For safety or capacity reasons, a “No U-Turn” sign may be provided. A “No Turn on Red” sign may be provided to prohibit right turn on red movements. A “Left on Green Arrow Only” sign may be provided in a protected left-only phasing.



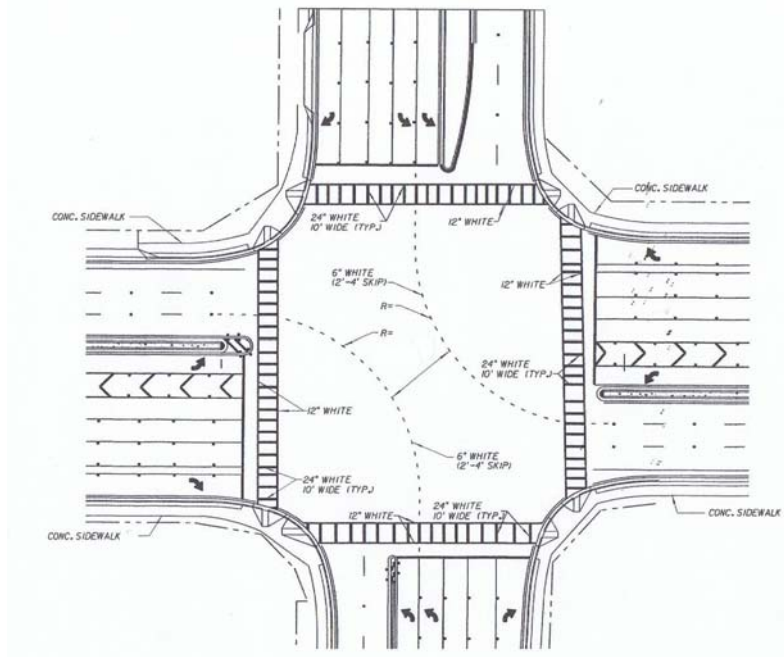
Lane assignment signs can be used as supplement pavement messages to direct the motorist to the proper lane.

XIII. Traffic Signal Pavement Markings

Stop bar lines (24” white) are located a minimum of 4 feet behind the crosswalk.

Crosswalk marking widths should match sidewalk widths. The typical crosswalk width is 10 feet. High emphasis crosswalk markings are desirable by many municipalities. They consist of 12” white outer lines with 24” white perpendicular lines at 10-foot spacing as depicted in the following sketch.

Dual left turn lanes require a 6” white stripe (2’ to 4’ skip) to guide the turning vehicles into the correct receiving lane. A commonly used distance between the turning guide lines is a minimum of 35 feet.



XIV. Basic Signal Timing Parameters

The development of a signal timing plan should address all user needs at a particular location including pedestrians, bicyclists, transit vehicles, emergency vehicles, automobiles and trucks.

A. Pedestrian Timing

Pedestrian timing requirements include a WALK interval and a flashing DON'T WALK interval. The WALK interval varies based upon local agency policy. The MUTCD recommends a minimum WALK time of 7 sec, although WALK times as low as 4 sec may be used if pedestrian volumes and characteristics do not require an interval of 7 sec. The WALK interval gives pedestrians adequate time to perceive the WALK indication and depart the curb before the clearance interval (flashing DON'T WALK) begins.

In downtown areas, longer WALK times are often appropriate to promote walking and serve pedestrian demand. School zones and areas with large numbers of elderly pedestrians also warrant consideration and the display of WALK time in excess of the minimum WALK time.

The MUTCD states that the pedestrian clearance time should allow a pedestrian crossing in the crosswalk to leave the curb and travel to at least the far side of the traveled way or to a median of sufficient width for pedestrians to wait before opposing vehicles receive a green indication. The MUTCD uses a walk speed of 4.0 ft/s for determining crossing times. Pedestrian clearance time is calculated using the following equation:

$$\text{Pedestrian Clearance Time} = \text{Crossing Distance} / \text{Walking Speed}$$

Pedestrian clearance Time – sec

Crossing Distance = distance from the near curb to at least the far side of the traveled way or to a median

Walking Speed = typically 4.0 ft/s

Example

What is the pedestrian clearance time for an intersection with a crossing distance of 48 feet and a typical walking speed of 4.0 ft/s?

$$\text{Pedestrian clearance time} = 48 \text{ ft} / (4 \text{ ft/s}) = 12 \text{ sec}$$

Pedestrian clearance time is accommodated during either a combination of flashing DON'T WALK time and yellow clearance time or by flashing DON'T WALK time alone. The recommended practice is for the pedestrian clearance time to be accommodated completely within the flashing DON'T WALK time. However, at high-volume locations, it may be necessary as a tradeoff for vehicular capacity to use the yellow change interval as part of satisfying the calculated pedestrian clearance time.

B. Vehicle Timing – Green Interval

Ideally, 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 are assigned by a controller to provide a range of allowable green times. Detectors are used to measure the amount of traffic and 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 vehicles in queue at the stop bar are able to start and 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. Where presence detection is installed at the stop bar, a minimum interval may be set to a value that is less than 1.0 sec.

Example

An intersection has the following characteristics: average vehicle spacing of 25 ft per vehicle, initial start-up time of 2 sec and vehicle headway of 2 sec per vehicle. What is the minimum green time for an approach with a detector location 100 ft from the stop bar?

$$2 + (100 \text{ ft}/25 \text{ ft} \times 2) = 10 \text{ sec}$$

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 a conflicting phase. The maximum green time begins when a call is placed on a conflicting phase. The phase is allowed to “max-out” if the maximum green time is reached even if actuations have been received that would typically extend the phase.

C. Vehicle Timing – Detector Timing

One advantage of actuated control is that it can adjust timing parameters based on vehicle or pedestrian demand. The detectors and the timing parameters allow the signal to respond to varied flow throughout the day. For pedestrians, detectors are located for convenient access; for vehicles, detector spacing is a function of travel speed and the characteristics of the street. The operation of the signal is highly dependent on detector timing.

One type of detection timing, known as volume-density timing, uses gap timers to reduce the allowable gap time the longer the signal is green. This type of timing makes the signal less likely to extend the green phase the longer the signal is green. A typical setting for a volume-density controller is to have the passage gap set to twice the calculated gap time to ensure the phase does not gap out too early. The minimum gap time might be set to less than the calculated gap time on multiple lane approaches, depending on the characteristics of the intersection.

Signal timing parameters provide an opportunity to maximize the efficiency of the intersection. Signal timing parameters control how quickly the phase ends once the traffic demand is no

longer present. The one phase that is the exception is the coordinated phase, which receives the unused or additional time.

D. Vehicle Timing – Vehicle Clearance

The vehicle clearance interval consists of the yellow change and red clearance intervals. The recommended practice for computing the vehicle clearance interval is in the following ITE formula:

$$CP = t + V/(2a + 64.4g) + (W+L)/V$$

CP = change periods (sec)

t = perception-reaction time for the motorist (assumption: 1 sec)

V = speed of the approaching vehicle (ft/s)

a = comfortable deceleration rate of the vehicles (ft/s²) (assumption: 10 ft/s²)

W = width of the intersection, curb to curb (ft)

L = length of vehicle (ft) (assumption: 20 ft)

g = grade of the intersection approach (%); positive for upgrade, negative for downgrade

For change periods longer than 5 sec, a red clearance interval is typically used. The MUTCD does not require specific yellow or red intervals but provides guidance that the yellow change interval should be approximately 5 to 6 sec and that the red clearance interval should not exceed 6 sec.

Example

What is the change period (CP) for a 48-foot wide intersection on a roadway with a posted speed limit of 45 mph with a grade of 1%?

$$CP = 1 + 66/[(2 \times 10) + (64.4 \times .01)] + (48+20)/66$$

$$CP = 1 + 66/20.64 + 1.03$$

$$CP = 5.2 \text{ sec}$$

E. Vehicle Timing – Cycle Length

For isolated, actuated intersections, cycle length varies from cycle to cycle based on traffic demand and signal timing parameters. For coordinated intersections a background cycle length is used to achieve consistent operation between consecutive intersections. In general, shorter cycle lengths are preferable to longer ones because they result in less delay and shorter queues. However, the need to accommodate multiple pedestrian movements across wide roadways, coupled with complex signal phasing and minimum green requirements to accommodate signal progression in multiple directions, may sometimes require the use of even longer cycle lengths. Wherever possible, such use should be limited to peak traffic periods only.

In general, it is preferred that the cycle lengths for conventional, four-legged intersections not exceed 120 sec, although larger intersections may require longer cycle lengths. Longer cycle lengths generally result in increased delay and queues to all users, particularly minor movements. There may also be connection between longer cycle lengths and increased incidence of red-light running, although this has not been documented in research.

XV. Basic Signal Operation Terms

Cycle Length (C) – the total time for the signal to go through one complete sequence of indications.

Phase – the part of a cycle allocated to any combination of traffic movements receiving the right of way simultaneously.

Green Time (G) – the amount of time within a given phase (usually mainline through) during which the green indication is present

Lost time – the amount of time during which the intersection is not used effectively due to start up of vehicles and clearance of intersections. Default is 4 seconds per phase.

Lost Time = Yellow (Y) + All Red (AR) times

Assumptions: Typically yellow (Y) is 3 seconds per phase. All Red (AR) is typically one second per phase. Therefore, the default for Lost Time is 4 seconds per phase.

Effective Green Time (g) – the time in a given phase (usually mainline through) that is available to permitted movements

$$g = G + Y + AR - L$$

Effective Green Ratio (g/C) – the ratio of the effective green time to the cycle length

There are three methods of obtaining g/C with varying accuracies.

1. Actual signal timings

This method is the most accurate. It is also consistent and verifiable.

2. Field measurement

This method has potentially high accuracy. However, it is less consistent and has a potential for misuse.

3. Signal timing plans

This method has outstanding consistency and is verifiable. However, they are less accurate due to field changes.

XVI. Signal Coordination

Drivers may have difficulty making permissive turning maneuvers at signalized intersections (e.g., permissive left turns, right turn on red after stop) because of lack of gaps in through traffic. This can contribute to both operational and safety problems. Left-turning vehicles waiting to turn can block thorough traffic, even if a left-turn lane is provided. This can lead to rear-end collisions between turning and through vehicles. Collisions may also occur when left-turning drivers become impatient and accept a gap that is smaller than needed to complete a safe maneuver. Such collisions could be minimized if longer gaps were made available.

One method of providing longer gaps is to coordinate adjacent traffic signals to promote platooning of vehicles. Signals within ½ mile of each other on a major route, or in a network of major routes, should be coordinated; signals spaced farther than ½ mile may be candidates for coordination if platooning can be maintained. Signal progression can help improve driver expectancy of changes in right-of-way assignment. Increase platooning of vehicles can create more defined gaps of increased length for permissive vehicle movements at intersections and can result in improved intersection operation. Increased platooning of vehicles may also result in a decrease in rear-end collisions. Effective coordination of signals should reduce the required number of stops for the higher priority movements.

Signal coordination may be applicable for intersections where:

- Rear-end collisions are occurring due to the higher probability of having to stop at each light
- Lack of coordination is causing unexpected and/or unnecessary stopping of traffic approaching from adjacent intersections
- Congestion between closely spaced intersections is causing queues from one intersection to interfere with the operation of another

A. Signal Preemption

Preemption is primarily related to the transfer of the normal control (operation) of traffic signals to a special signal control mode for the purpose of servicing railroad crossings, emergency vehicle passage, mass transit vehicle passage and other special tasks. This control requires terminating normal traffic control to provide the special task.

Priority is defined by the preferential treatment of one vehicle class (such as transit vehicle or emergency service vehicle) over another vehicle class at a signalized intersection without causing the traffic signal controllers to drop from coordinated operations. Priority may be accomplished by a number of methods, including changing the beginning and end times of greens on identified phase, changing the phase sequence or including special phases, all without interrupting the general timing relationship between specific green indications at adjacent intersections.

B. Emergency Vehicle Preemption

A specific vehicle often targeted for signal preemption is the emergency vehicle. Signal preemption allows emergency vehicles to disrupt a normal signal cycle to proceed through the intersection more quickly and under safer conditions. The preemption systems can extend the green on an emergency vehicle's approach or replace the phases and timing for the whole cycle.

The MUTCD discusses signal promotion, standards for the phases during preemption and priorities for different vehicle types that might have preemption capabilities.

Several types of emergency vehicle detection technologies are available and include the use of light, sound, pavement loops, radio transmission and push buttons to detect vehicles approaching an intersection:

- Light – an emitter mounted on emergency vehicles sends a strobe light toward a detector mounted at the traffic signal, which is wired into the signal controller
- Sound - a microphone mounted at the intersection detects sirens on approaching vehicle; the emergency vehicles do not need any additional equipment to implement signal priority systems
- Pavement loop – standard pavement loop connected to an amplifier detects a signal from a low frequency transponder mounted on the emergency vehicle.
- Push-button- a hardwire system is activated in the firehouse and is connected to the adjacent signal controller
- Radio – a radio transmitter is mounted on the vehicle and a receiver is mounted at the intersection



Summary

From this course, you should have a basic understanding of the design of a signalized intersection. You now understand the advantages and disadvantages of a signalization. The Manual on Uniform Traffic Control Devices (MUTCD) signal warrants were outlined. Pre-timed, semi-actuated and actuated signal control types were defined. Different types of signal heads were discussed along with the lateral and longitudinal positioning of the signal heads. Pedestrian displays for use at crosswalks were also covered.

Traffic signal phasing was outlined including the numbering of traffic movements at an intersection and the outline of the signal timing table. The commonly used Signal Operating Plans (SOP) were discussed. The advantages and disadvantages of signal pole layout were compared. Vehicle and pedestrian detectors were covered. There was also a detailed discussion of traffic signal signing & pavement marking for the roadway intersection.

Calculations for basic signal timing parameters such as pedestrian timing, vehicular green interval and vehicular clearance timings were provided. Definitions of basic signal operation terms were also provided.