TRAFFIC SIGNAL MAINTENANCE AND OPERATIONS IN PENNSYLVANIA

pennsylvania
DEPARTMENT OF TRANSPORTATION

Highway Administration Deputate

There are hyperlinks throughout this document that should provide network connections to other publications, regulations, Vehicle Code, etc. There are also hyperlinks that reference other sections, exhibits, or appendices within the same chapter, and these should assist you in navigating within the manual.

Although not obvious by their color, the Table of Contents and the List of Exhibits within the individual chapters also work as hyperlinks. Simply left click on the section or exhibit number, title, or page number and your computer should take you to the proper page.

You may also find the bookmarks on the left side of the screen helpful.

This training course was developed in partnership with the Pennsylvania Department of Transportation's Business Leadership and Administrative Services Office and the Highway Safety and Traffic Operations Division, and Albeck + Associates, Inc. It is offered as part of the Pennsylvania Department of Transportation's Highway Administration Comprehensive Training Plan exclusively through the Technical Training and Development Section.

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CHAPTER 1. INTRODUCTION

1.1 Introduction

No other device has such a daily impact on virtually every citizen as does the common, ever-present traffic signal. The trip to work is punctuated by stops at traffic signals, even on uncongested routes. Drivers place their physical safety and that of their passengers confidently in the signal's ability to give them the right-of-way.

A signal's necessity is accepted by the citizen, and in fact demanded in some cases, to assure safety and mobility. The same citizen quietly assumes that the operating agency knows how to best operate the signals, and reluctantly reports only the most obvious failures. Inefficient signal operation, even though such operation is silently stealing dollars from the user's pocket in increased fuel costs, longer trip time, etcetera (etc)., is rarely reported or noticed by the user. In the user's view, the signals are working and if they are sub-optimal, it becomes a concern but not a crisis.

The overall objective of signal control is to provide for the safe and efficient traffic flow at intersections, along routes and in street networks. A well maintained and timed signal system can reduce fuel consumption, eliminate unnecessary stops and delays, improve safety and enhance the environment.

This course and manual are design to assist in maintaining and operating the traffic signals within the commonwealth.

1.2 Goals of the Course

At the end of this Traffic Signal Maintenance and Operations course, you will be able to:

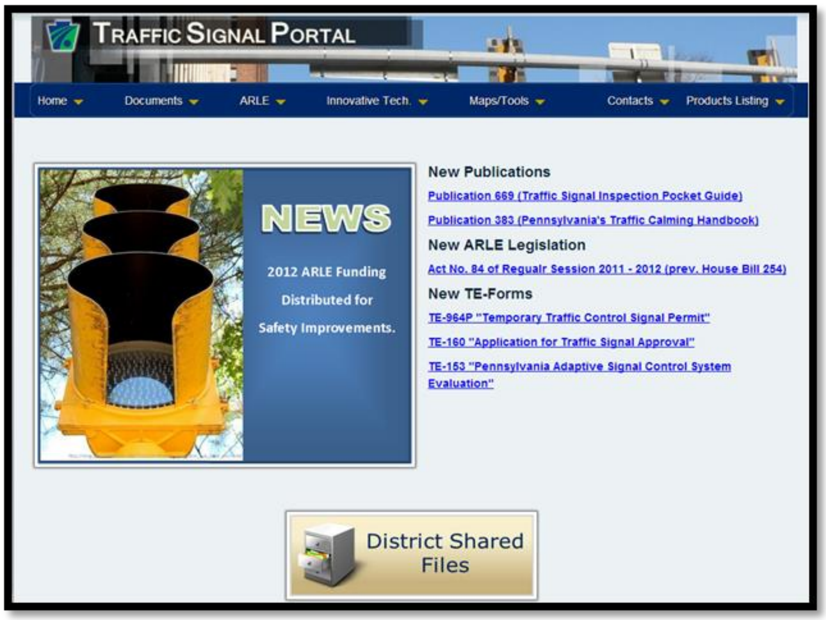
- ✓ List the types of traffic signal maintenance classifications
- ✓ Create the types of documents required for maintenance
- ✓ Describe typical maintenance activities
- ✓ Develop a traffic signal maintenance agreement
- ✓ Design basic phasing of the intersection
- ✓ Devise an appropriate data collection plan operating a signalized intersection
- ✓ Calculate signal timing for both actuated and coordinated operational strategies, including pedestrian clearance intervals
- ✓ Implement traffic signal timing and phasing plans

1.3 Traffic Signal Portal Website

The Department's Traffic Signal Portal can be found at:

www.dot.state.pa.us/Portal%20Information/Traffic%20Signal%20Portal/Index.html

Exhibit 1-1 PennDOT Traffic Signal Resource Portal



The portal serves as a central location for information on traffic signals in Pennsylvania. It includes, but is not limited to, the following sources:

- ✓ Publications, policies, forms, and other documents
- ✓ Approved products listing
- ✓ Frequently asked questions
- ✓ Traffic signal processes and procedures
- ✓ Automated red light enforcement (ARLE)
- ✓ Mapping and spreadsheets
- ✓ Training updates
- ✓ Traffic signal performance measures
- ✓ Recent news

1.4 PennDOT Traffic Signal Publications

The portal referenced in **Exhibit 1-1** includes a page related to publications (refer to the website for these documents). **Exhibit 1-2** illustrates how these publications are used in design, construction and maintenance.

Exhibit 1-2 Primary and Secondary Publications for Design, Construction and Maintenance

Design

Pub. 149
Design criteria and step-by-step guidance on developing a traffic signal plan

MUTCD
Part 4 is the "bible" on traffic signals, and includes warrants and design criteria.

Pub. 10
This Design Manual Part 1, Transportation Project Development Process explains the Department's project development process.

Pub. 46
Internal traffic engineering policy. Chapter 4 discusses responsibilities, proprietary equipment, removal, etc.

Pub. 13M
This Highway Design Manual, Part 2, is for highways, but Chapter 6 addresses design of pedestrian facilities.

PA Vehicle Code
Law that addresses the installation of traffic control devices and required driver responses.

Pub. 14M
This Design Manual Part 3, Plans Presentation, provides the general format and detail for the development of plan sheets – specifically, Chap. 4 addresses traffic control in work zones and Chap. 10 addresses traffic signal plans.

Chapter 212
PA regulations on traffic control devices. Subchapter D addresses a few traffic signal items, including a PA warrant.

Pub. 236
Identifies all approved signs for use within Pennsylvania and includes layout details for manufacturing.

Construction

Pub. 408
Provides detailed material and construction specs for traffic signal equipment, and field testing procedures

Pub. 35
Lists manufacturers of approved materials that can be used for construction.

Pub. 72M
Standard drawings for road construction. RC67M provides details for curbs, sidewalks, ADA, etc.

Pub. 148
Standard drawings showing design details, e.g., mast arm clearances, pole foundations , junction boxes, etc.

Pub. 647
Civil and Structural Standards for Intelligent Transportation Systems, ITS-1000M Series. Graphically illustrates the design and construction details for supports (poles and other structures), CCTV mountings, cabinet, trenches, fiber optics, etc., for ITS.

Pub. 213
Provides schematics defining the minimum acceptable traffic control within various types of work areas.

Pub. 111M
Standard drawings for the installation of signs and pavement markings.

Pub. 8
Construction Manual. Supplements Pub. 408 by providing some helpful information for inspectors, containing information generally not found in other manuals. It uses the same section numbering as Pub. 408.

Maintenance

Pub. 191
Guidance on maintenance and operation of traffic control signals and periodic review

ITE's Traffic Signal Maintenance
Provides a summary of best and suggested maintenance practices.

Pub. 669
Traffic Signal Inspection Guide.

FHWA's Traffic Signal Timing Manual
Comprehensive guide to the traffic signal timing engineer and technician on traffic signal control logic principles, practices, and procedures.

1.5 Traffic Signal Advantages and Disadvantages

When signals are installed in accordance with the warrants listed in the Manual on Uniform Traffic Control Devices (MUTCD), they can provide specific advantages in traffic control and safety. They can, however, also have certain negative impacts that may or may not apply at a particular location.

Some of the advantages (goals) of signal installations include:

- ✓ Providing for the orderly movement of traffic;
- ✓ Reducing the frequency of certain types of accidents (i.e., right-angle and pedestrian);
- ✓ Increasing the traffic handling capacity of the intersection;
- ✓ Providing a means of interrupting heavy traffic to allow other traffic, both vehicular and pedestrian, to enter or cross;
- ✓ Providing for nearly continuous movement of traffic at a desired speed along a given route by coordination;
- ✓ Affording considerable economy over manual control at intersections where alternate assignment of right-of-way is required; and,
- ✓ Promoting driver confidence by assigning right-of-way.

Some disadvantages to signal installations include:

- ✓ Increasing total intersection delay and fuel consumption at most installations, especially during off peak periods.
- ✓ Increasing certain types of accidents (e.g., rear end collisions).
- ✓ When improperly located, causing unnecessary delay and promote disrespect for this type of control.
- ✓ When improperly timed causing excessive delay, increasing driver irritation.

1.5.1 Review of Signal Timing

The operation of the traffic signal should be observed at least once a year. A complete signal timing analysis and operation check of the traffic signal should be made every three to five years.

1.6 Glossary of Terms and Abbreviations

Not all of the terms shown on the following table are used in this manual but are included as a resource to the holder of the manual.

Term	Definition
85^{th} Percentile Speed	This is the speed at which 85% of the traffic is travelling at or below.
AASHTO	The American Association of State Highway and Transportation Officials.
Actuated Operation	A type of traffic control signal operation in which some or all signal phases are operated on the basis of actuation (vehicle detection, pushbutton, etc.).
Actuation	The presence of a vehicle or pedestrian as indicated by an input to the controller from a detector. The action of a vehicle or pedestrian which causes a detector to generate a call to the signal controller.
ADA	Americans with Disabilities Act (1990).
Adaptive Traffic Control	A software program that is designed to adjust the signal timing to accommodate changing traffic patterns and ease traffic congestion. By receiving and processing data from sensors to optimize and update signal timing settings, adaptive signal control technologies can determine when and how long lights should be green.
All-Red	An interval during which all signal indications at an intersection display red indications.
Approach	All lanes of traffic that enter the intersection from the same direction.
As-Built (or Record) Plans	A modified traffic signal plan showing the roadway geometrics and the traffic signals after completion of the construction project, showing any field adjustments due to structural shifts of signal supports, unanticipated corner radius changes, etc.
Annual Average Daily Traffic (AADT)	The total volume of vehicle traffic of a highway or road for a year divided by 365 days. AADT is a useful and simple measurement of how busy the road is.
Average Daily Traffic (ADT)	The total volume of vehicle traffic of a highway or road for a period of time less than 1-year divided by the number of days of the count.
Call	A demand for service registered in a controller. A call indicates a vehicle or pedestrian is waiting for a green light or walk indication.
Clearance Interval(s)	The interval(s) from the end of the right-of-way of one phase to the beginning of a conflicting phase. This is usually the yellow plus any all red phase.

Term	Definition
Conflict Monitor	A device housed in the controller cabinet which continuously checks for the presence of conflicting signal indications such as simultaneous green signal indications on both the mainline and side road approaches. If a conflict is detected, the monitor places the signals into a flashing operation.
Controller	The electronic device that controls the sequence and duration of traffic signal indications.
Cycle Length	The time taken for a complete sequence of all phases at an intersection. This time is counted from a given point on any phase (usually main street end of green) until that same point occurs again. Pretimed cycle lengths do not vary, but actuated cycle lengths do because of phases skipped, extensions, etc.
Delay	Time lost while traffic impeded in its movement by some element over which it has no control. Usually expressed in seconds per vehicle.
Department	Term used to reference the Pennsylvania Department of Transportation.
Design Modifications	A proposed change to the approved design and operation of an existing traffic signal or signal system to accommodate changes in prevailing traffic or physical conditions, or update the installation to current state-of-the-art design. Typical modifications include addition or removal of signal phases or special functions; changes in signal displays, configurations, or locations; detector modifications; upgrading of equipment and communication systems; and revisions to related signs and pavement markings. These changes can be initiated by any involved party, but cannot be physically implemented until the signal permit is updated.
Detector	A device that provides an input to the controller to indicate that a vehicle or pedestrian is present.
Documentation	The information for the traffic signal or signal system, including the traffic signal permit, equipment manuals and warrantees, summary and detailed listing of all signal maintenance, and design modifications, etc.
Free Flow	Traffic flow which is not impeded.
Full Traffic-Actuated Controller Unit	A type of traffic-actuated controller unit which accommodates for traffic actuation on all approaches to the intersection.
Gap (Time Gap)	The interval in time or distance from the back of one vehicle to the front of the following vehicle.
Green Interval	The right-of-way portion of a traffic phase.

Term	Definition
Headway	The distance or (usually) time between vehicles measured from the front of one vehicle to the front of the next.
HDPE	High-Density Polyethylene Conduit
HOP	Highway Occupancy Permit.
Incandescent indications	Vehicular or pedestrian signals, or a blank-out sign, that are illuminated with a traditional light bulb having a thin tungsten filament.
Infrared Detection	An overhead mounted device that illuminates a select area with low-power infrared energy supplied by light-emitting diodes (LEDs) or laser diodes, and then converts the reflected energy into an electrical signal to indicate the presence of a vehicle or person. Infrared detectors may have special applications for detecting pedestrians and bicyclists.
Intersection	The area embraced between the prolongation and connection of the lateral curb lines, or if none, the lateral boundary lines of the roadways (i.e., the traveled portion) of two or more streets or highways.
Intersection Leg	The roadways entering or leaving one side of the intersection.
Interval	Any one of the several divisions of the cycle during which signal indications do not change.
Interval Sequence	The order of appearance of signal indications during successive intervals of a cycle.
Isolated Controller Unit Operation	The operation of a controller unit at an intersection without master controller supervision dial-up communication.
Isolated Intersection	A signalized intersection that is located far enough from other signalized intersections so that the signal timing at the other intersections does not influence the traffic flow at this intersection.
Local Authorities	Definition from Section 212.1 of Title 67 of the Pennsylvania Code. i. County, municipal and other local boards or bodies having authority to enact regulations relating to traffic. ii. The term also includes airport authorities except where those authorities are within counties of the first class or counties of the second class. iii. The term also includes state agencies, boards and commissions other than the Department, and governing bodies of colleges, universities, public and private schools and public and historical parks.

Term	Definition
Local Controller	The controller located at an intersection and which operates the traffic signals only at that intersection, and does not control or directly influence any other intersection.
Loop Detectors	A commonly used device to monitor traffic on the approach to a traffic control signal, consisting of multiple circles of wire in a basic square or rectangular shape that is buried within the roadway and which detects changes in their magnetic field caused by the metal in passing vehicles.
Maintenance Service Manuals	The document provided by the manufacturer of a piece of equipment that specifies how to adjust, clean, lubricate, calibrate, and otherwise maintain the equipment to ensure its proper operation and its longevity.
Maintenance Service Records	An accumulation of paperwork that captures all service performed to the traffic signals at a specific intersection. This paperwork identifies all inspections, cleaning, tightening, calibrations, adjustments, replacements, lubrications, etc., that were performed from either a preventative view point, or repairs due to crashes or equipment failure.
Malfunction Management Unit (MMU)	The malfunction management unit (MMU) can be configured to check for conflicting signal indications and various other malfunctions including absence of an OK status output from the controller (watchdog output), short or missing clearance intervals, and out-of-range operating voltages. If a malfunction is detected, the MMU automatically places the signal in an all-red flashing state, overriding the outputs of the controller.
Master Controller	The controller that supervises and directs the timing patterns for all local controllers within a traffic control signal system for the purpose of coordinating the operation of the signal system to improve traffic flow and safety.
Maximum Green	A longest period of green time allowed when there is a demand on an opposing phase.
Median Refuge	Raised islands or medians of sufficient width that are placed in the center area of a street or highway to serve as a place of refuge for pedestrians who are attempting to cross. Center islands or medians allow pedestrians to find an adequate gap in one direction of traffic at a time, as the pedestrians are able to stop, if necessary, in the center island or median area and wait for an adequate gap in the other direction of traffic before crossing the second half of the street or highway.

Term	Definition
Microwave Detection	Equipment that transmits an electromagnetic signal and compares the reflected signal from all objects in the protected area by use of the Doppler Effect. Based on a selected sensitivity level, it determines if the detection criteria are met; and if so, advises the controller of the presence of traffic.
Minimum Green	The shortest green time allowed a phase.
MUTCD	Manual on Uniform Traffic Control Devices
Offset	The relationship in time between a point in the cycle at a particular intersection and a similar point in the cycle at another intersection or reference.
NTCIP	National Transportation Communications for ITS Protocol
Operations	As it relates to traffic, this is the day-to-day control of traffic systems, including the analysis of the systems, detection of problems and deficiencies, setting of priorities, assignment of resources, and development of improvements through geometric design, traffic control, or other means. Frequently referred to as "traffic operations."
Passage Period	The time allowed for a vehicle to travel at a selected speed from the detector to the nearest point of conflicting traffic, i.e., from the detector into the intersection.
Pedestrian "WALK" Interval	The controller interval during which the "WALK", symbolized by the "WALKING PERSON", indications of the pedestrian signals are illuminated.
Pedestrian Clearance Interval	The first clearance interval following the pedestrian walk interval, normally symbolized by the flashing "HAND." The pedestrian clearance interval shall allow a pedestrian, who has already begun to cross, time to reach the far side of the roadway or a safe refuge. A pedestrian shall not begin to cross during this interval.
Pedestrian Detection	Hardware used to notify the traffic controller of the presence of a pedestrian, typically via a pushbutton.
Pedestrian Phase	A traffic phase allocated exclusively to pedestrian traffic.
Pedestrian Signal Indication	The illumination of a pedestrian signal lens or equivalent device.
Phase	The part of a cycle allocated to any combination of traffic movements receiving the right-of-way simultaneously during one or more intervals, i.e., for example a left turn phase.
Preemption	The transfer of the normal control of signals to a special signal control mode, i.e., to accommodate emergency vehicles.

Term	Definition
Pre-Timed Controller Operation	A method for operating traffic signals where the cycle length, phases, green times, and change intervals are all preset.
Preventative (Routine) Maintenance	Maintenance scheduled on a regular basis to minimize future maintenance and to maximize the life of the equipment. It includes inspection, calibration, cleaning, testing, sealing, painting, etc., in accordance with a predefined schedule. This maintenance is similar to the maintenance schedule for a vehicle.
Publication 111M	The Department's Traffic Control Pavement Markings and Signing Standards – TC-8600 and 8700 Series.
Publication 13M	The Department's Design Manual Part 2: Highway Design.
Publication 148	The Department's Traffic Standards (TC-8800 Series Signals).
Publication 149	The Department's Traffic Signal Design Handbook.
Publication 212	The Department's Official Traffic Control Devices, that contains the regulation, Chapter 212 of Title 67 of the Pennsylvania Code (67 Pa. Code Chap. 212). The Chapter 212 regulation adopts and supplements FHWA's Manual on Uniform Traffic Control Devices (MUTCD)
Publication 213	The Department's Temporary Traffic Control Guidelines.
Publication 236M	The Department's Handbook of Approved Signs.
Publication 287	The Department's publication showing the unit cost bid prices for construction projects during recent years.
Publication 35	The Department's listing of Approved Construction Materials, commonly referred to as Bulletin 15.
Publication 408	The Department's Highway Specifications.
Publication 441	The Department's regulation entitled "Access to and Occupancy of Highways by Driveways and Local Roads."
Publication 46	The Department's Traffic Engineering Manual.
Publication 70M	The Department's Guidelines for the Design of Local Roads and Streets.
Publication 72M	The Department's Roadway Construction Standards.
Push Button Detection	A mechanical switch that, when pushed or activated, tells the controller of the presence of a pedestrian.
Radar detection	A detector that uses radar waves to track vehicles as they approach and leave an intersection.

Term	Definition
Red Clearance Interval	An interval which follows the yellow change interval during which no green indication is shown on any conflicting phase.
Response Maintenance	Emergency repair performed on an as-needed basis due to either equipment failure or a crash. Upon notification, the maintenance service team is dispatched to secure the site, diagnose the problem, perform the repairs, and record its activities as quickly as possible.
Rest	The state in which a controller unit rests until called out of the phase.
Semi-Traffic-Actuated Controller Operation	A type of traffic operation in which means are provided for traffic actuation on one or more, but not all, approaches to the intersection.
Signal Face	That part of a signal head provided for controlling traffic in a single direction. Turning indications may be included in a signal face.
Signal Head	An assembly containing one or more signal faces which may be designated accordingly as one-way, two-way, etc.
Signal Indication	The illumination of a traffic signal lens or equivalent device or a combination of several lenses or equivalent devices at the same time. (Note: This term usually means indications to vehicular traffic; however, pedestrians may be using these indications if no Pedestrian Signal Indications are present.)
Source of Power (SOP)	The location of the electrical service equipment associated with a traffic signal, or the location where electrical connection is made to the power company distribution system.
Split Time	A division of the Cycle allocated to each of the various phases green, yellow, and all-red time.
Title 67 of the PA Code	The “Transportation Title” of the Pennsylvania Code which contains regulations of the Department, typically in response to a legislative mandate.
Traffic Control Signal	The specific type of traffic signal that provides alternating stop-and-go traffic control with red-yellow-green (R-Y-G) signal indications.
Traffic Signal	The broad category of highway lights including traffic control signals (provide alternating stop and go), pedestrian signals, flashing beacons, lane-use control signals, ramp metering, and in-roadway lights.
Traffic Signal Housing	The outer part of a traffic signal section that protects the light and other required components from the elements.

Term	Definition
Traffic Signal Permit	The document approved by the Department to authorize the installation and operation of the traffic signal. The traffic signal permit is for a traffic signal at a specific intersection. It includes the Traffic Engineering Form TE-964, and traffic signal plans showing the intersection plan sheets with the locations of the traffic signals, traffic signal supports, controller cabinet, junction boxes, detectors, stop lines, street names, approach grades, distance to nearest signals, etc., plus the traffic signal phasing diagram.
Traffic Signal Support	The physical means whereby signal heads, signs, and luminaires are supported in a particular location. Structural supports are to be designed to carry the loads induced by attached signal heads, signs, luminaires, and related appurtenances.
Traffic Signal System	Two or more traffic control signals operating in coordination with each other.
Traffic Signal Timing	The analysis of intersection geometrics, speeds, and historical traffic volumes used to identify the specific duration in seconds for the green, yellow, red, Walk, and Don't Walk intervals of each phase. For traffic actuated signals, the traffic signal timing also includes information on the incremental extensions of the green intervals due to the continued presence of approaching vehicles.
Uninterrupted Power Supply (UPS)	A battery backup system designed to instantly provide electrical power for the operation of the controller and traffic signals during a power outage.
Video Detection	The process of using a video imaging system to analyze the feed from a video camera mounted above the roadway to determine the presence or passage of vehicles in one or more specific travel lanes on an approach to the intersection.
Walk Interval	The portion of a traffic phase that permits pedestrians to leave the curb.
Wireless Detection	The use of equipment coupled with a radio transmitter that informs a receiver in the controller cabinet of the presence or passage of vehicles in one or more specific travel lanes. The type of detection may vary, but the radio transmission is used in lieu of wire or coaxial cable.
Yellow Change Interval	The first interval following the green right-of-way interval in which the signal indication for that phase is yellow, indicating that the right-of-way for that phase is about to terminate.

CHAPTER 2. TRAFFIC SIGNAL MAINTENANCE

2.1 Chapter References

The information in this chapter is based on Publication 191, Guidelines for the Maintenance and Operation of Traffic Signals.

2.2 Overview

Good maintenance is one of the keys to effective traffic signal operations. Poorly operating traffic signals are highly visible and provide an unsafe environment to the traveling public. Malfunctioning detectors and inappropriate traffic signal timing waste time and fuel, increase the release of pollutants from vehicles, and frustrate drivers. It is for these reasons that a municipality should be fully aware of their liabilities and their duty to provide safe and efficient travel to highway users in a way that minimizes the release of pollutants while reducing driver delay and fuel use. Only with a well-run maintenance program can this be achieved.

Section 6122 of The Pennsylvania Vehicle Code (75 Pa. C.S. §6122) requires local authorities to obtain approval from the Department prior to erecting any traffic signal within their boundaries except where Department regulations provide otherwise. The Department's regulation on this issue is titled "Municipal Traffic Engineering Certification", Chapter 205 of Title 67 of the Pennsylvania Code (67 Pa. Code Chapter 205), and this regulation only allows the following local authorities to install, modify or remove traffic signals without specific Department approval:

- ✓ In cities of the first and second class (i.e., Philadelphia and Pittsburgh, respectively) providing they have a qualified traffic engineer possessing a current professional engineer's license issued by the Pennsylvania state Registration Board for Professional Engineers.
- ✓ In any other municipality with **current** "Municipal Traffic Engineering Certification" as provided in Chapter 205.
- ✓ When otherwise provided in an agreement with the Department.

Additionally, Section 212.5(b)(v)(A) of Title 67 of the PA Code (67 Pa. Code §212.5(b)(v)(A)) assigns the installation, maintenance and operational responsibilities of traffic signals to the municipalities. Therefore, municipalities own the traffic signals in their jurisdiction, and assume the maintenance and operational responsibilities. These roles and responsibilities are summarized in **Exhibit 2-1**.

Inadequate maintenance can lead to inaccurate operation and/or deficiencies of traffic signals. These potential problems lead to safety issues, which is why it is essential that both preventative and emergency response maintenance be provided. Ensuring that proper maintenance responsibilities are administered allows municipalities to have the necessary documentation if a crash occurs at the intersection. Public benefits of proper maintenance and operation of traffic signals are the reduction in fuel consumption, greenhouse gas emissions and driver delay. For the municipality another benefit potential cost savings can result from less frequent response maintenance activities, a potential reduction in tort claims, and a longer service life of the traffic signals.

Exhibit 2-1 Summary of Agency Roles and Responsibilities

Action	Responsibility
Approve all signals, except those municipalities with "Municipal Traffic Engineering Certification."	Department
Pay for the construction to install traffic signals.	Local authorities; except the Department does sometimes help underwrite the costs of traffic signals within Department construction projects.
Pay for maintenance and operation of the traffic signals, including the signs pavement markings, and other items on the approved traffic signal permit.	Local authorities, except as indicated on the traffic signal permit.
Approve the revision of a traffic signal permit or the complete removal of a traffic signal.	Department
Implement design modifications.	Local authorities

It is important to note that prior to making any changes in the operation of a traffic signal, the municipality should always contact the appropriate Department Engineering District to request approval.

It is also important to note that the Department generally will not revise a traffic signal permit at the request of municipality if it is determined that the traffic signal was never in compliance with the previously-approved permit. Therefore, it is very important for the municipality to ensure compliance with the traffic signal permit.

2.2.1 Traffic Signal Ownership in Pennsylvania

Based on the Pennsylvania Transportation Advisory Committee (TAC) January 27, 2005 report (Pennsylvania Traffic Signal Systems; A Review of Policies and Practices), only about 46 percent of the municipalities within the Commonwealth have traffic signals, and of those almost two-thirds have five or fewer traffic signals as illustrated in **Exhibit 2-2**.

Exhibit 2-2 Municipal Traffic Signal Ownership Breakdown

Number of Signals	Number of Municipalities
0	1373
1	335
2-5	433
6-10	190
11-25	141
26-50	65
51 to 150	24
151 or more	4
TOTAL	**2665**

2.2.2 Traffic Signal Permit

The traffic signal permit is an important document for evaluating whether a traffic signal is operating and being properly maintained. This official document is typically issued by the Department to the municipalities for each traffic signal, and it identifies the approved design and operation of the traffic signal. An original traffic signal permit (including all revisions) should be kept up-to-date and be properly stored at the municipal building, and a copy should be kept inside the appropriate traffic signal cabinet.

The traffic signal permit contains information regarding the operation of the traffic signal and the placement of signal equipment, signing, and markings. Sheet 2 of the traffic signal permit is typically a signal plan sheet showing a scaled drawing of the intersection with the approved traffic control signal and other associated traffic control devices (e.g., signal structures, vehicular and pedestrian signal heads, controller, traffic detectors, traffic signs and any sign structures, pavement markings, pedestrian curb ramps, etc.).

Additional information on the signal permit plan can be found in the Introduction to Traffic Signals in Pennsylvania course and Publication 149, the official signal design manual.

2.2.3 Traffic Signal Forms

In addition to the traffic signal plan, the cover sheet is the Department's TE-964 "Traffic Signal Permit" form (ftp://ftp.dot.state.pa.us/public/PubsForms/Forms/TE-964.pdf) which is the official document that captures the Department's approval of the traffic signal. This form also captures some basic information such as who the permit is issued to, the hours that the signal will be on flash, the type of controller mounting, the permittee's responsibilities, etc.

The TE-964 "Traffic Signal Permit" form and other standard Department forms relating to traffic signals are identified in **Exhibit 2-3**. Each of these is available for download from the Department's "Traffic Signal Portal Page" (see www.dot.state.pa.us/Portal%20Information/Traffic%20Signal%20Portal%20(9-14-2009).htm).

Exhibit 2-3 Standard Department Forms

Form	Title and Importance
TE-699	Traffic Signal Description. This one-page form captures key features of the traffic signal and is the start of an asset management system. Items of interest include type of controller, type and model no. of the detectors, etc. ftp://ftp.dot.state.pa.us/public/PubsForms/Forms/TE-699.pdf
TE-160	Application for Traffic Signal Approval. Form TE-160 is the form used as an application for traffic signal approvals. See Section **2.2.4** in this training manual.
TE-964	Traffic Signal Permit. This is technically Sheet 1 of the traffic signal permit, and contains the department's approval and approval date. The traffic signal plan sheets comprise the balance of the actual "traffic signal permit." ftp://ftp.dot.state.pa.us/public/PubsForms/Forms/TE-964.pdf
TE-971	Master Signal Maintenance Log. A suggested paper format for manually tracking maintenance activities from a macroscopic point of view. Twenty different events can be summarized on each sheet. ftp://ftp.dot.state.pa.us/public/PubsForms/Forms/TE-971.pdf
TE-972	Response Maintenance Record. A suggested paper format for tracking detailed response activities in an organized one-page format. One sheet is used for each maintenance callout. ftp://ftp.dot.state.pa.us/public/PubsForms/Forms/TE-972.pdf
TE-973	Preventative Maintenance Record. A suggested paper format for tracking detailed preventative maintenance activities in an organized one-page format. One sheet is used for the preventative maintenance reviews of each traffic control signal. ftp://ftp.dot.state.pa.us/public/PubsForms/Forms/TE-973.pdf
TE-974	Design Modification Checklist. A two-page checklist designed to encourage a thorough review of recurring maintenance problems, state-of-the-art technologies, etc. ftp://ftp.dot.state.pa.us/public/PubsForms/Forms/TE-974.pdf

2.2.4 TE-160 Application for Traffic Signal Approval

Form TE-160 is used as an application for traffic signal approvals. This form replaces the following existing documents:

- ✓ Traffic Signal Maintenance Agreement (Preapproved Form # 18-K-392), which was required for all state and federally-funded traffic signal installations by PennDOT that were then transferred to the municipality to own, maintain and operate
- ✓ TE-952 (Application for Permit to Install and Operate Traffic Signals)
- ✓ TE-669 (Application for Permit to Install and Operate Flashing Warning Devices)

2.2.5 TE-160 Handout

The information in the Appendix (see Section **10.9**) is a handout of form TE-160. The most current version of the form can be downloaded from the PennDOT traffic signal portal:

www.dot.state.pa.us/Portal%20Information/Traffic%20Signal%20Portal/Index.html.

2.2.6 Insurance Guidelines

Municipalities should ensure that they have adequate insurance to cover property damage and liability issues. For example property insurance should cover traffic signal knockdowns and other damage from hit-and-run crashes, and at least temporarily cover costs to repair traffic signals until vehicle insurance claims are settled. In addition, liability insurance should cover any third party actions alleging bodily injury, property damage or personal injury resulting from the operations of the municipality such as traffic signal design errors or signal failures.

Also of concern is the potential for damage from a lightning strike. For example, if lightning were to strike the traffic signals and destroy the controller or the wiring, and during the outage a serious crash occurred, a municipality could be legally challenged concerning the timeliness of the traffic signal repair. In this situation, a settlement could be large.

Similarly, if the municipality receives a safety complaint about the traffic signals and they do not address the concern, or at least not in a timely manner in the eyes of the court, a subsequent crash related to the concern could pose a large liability problem. (See Section 5.1.1 of the *Traffic Signal Maintenance Handbook* for some other issues.)

Therefore, a municipality needs to ensure that they are adequately covered to reduce exposure to tort claims.

2.3 Establishing a Traffic Signal Maintenance and Operation Program

2.3.1 Overview

In their *2007 National Traffic Signal Report Card*, the National Transportation Operations Coalition (NTOC) documented their most recent findings regarding traffic signal operation in the United states, and gave the industry an overall score of “D” and traffic signal maintenance a score of “C-.”

Their report documents results provided by traffic signal owners throughout the country and determined that the following five key components make up an excellent maintenance program:

- ✓ Adequate policies and staffing (municipal or contract staffing) to provide for timely response within 1 hour during normal business hours and 2 hours outside of regular business hours after a critical malfunction is reported.
- ✓ Regular preventative maintenance and operational reviews, including a comprehensive semi-annual maintenance review, quarterly operational reviews and annual conflict monitor testing.
- ✓ An inventory of all traffic signal control equipment and management information (e.g., schematics, interconnection information and software documentation).
- ✓ Continuous malfunction monitoring and notification of critical components that provide reports to maintenance personnel within 5 minutes after detection of a failure.
- ✓ At least 90 percent of all detection devices working properly.

Nationally, agencies with a small number of signals had poorer maintenance scores than those with a larger number of traffic signals. Therefore, considering the high number of municipal subdivisions in Pennsylvania, and the fact that most of the municipal subdivisions that have traffic signals have less than five traffic signals, it is highly probable that traffic signal maintenance in Pennsylvania is worse than in the balance of the nation.

It is important to note that there are three distinct types of traffic signal maintenance that will be frequently referenced throughout this chapter, two which are planned activities and the other type which is responsive:

1. Preventative maintenance. This type of maintenance is the periodic scheduled maintenance to minimize future problems. It includes inspection, calibration, cleaning, testing, sealing, painting, etc., in accordance with a predefined schedule to minimize the probability of unexpected failure and to maximize the life of the equipment. This maintenance is similar to the scheduled maintenance for an automobile.
2. Response maintenance. This maintenance is emergency repair because of either equipment failure or a crash, and the goal is to make the traffic signal fully functional as soon as possible. Since response maintenance is frequently necessary at the most inopportune time, the objective is to minimize this type of maintenance.
3. Operational maintenance. This type of maintenance is the periodic scheduled operational maintenance to minimize existing and future congestion problems. This maintenance includes the analysis of traffic signal timings and other operational activities that can potentially improve safety and mobility at the traffic signal.

2.3.2 Budgeting

The cost for installing traffic signals at an intersection frequently exceeds $100,000 (in 2010 dollars). After a traffic signal is installed and tested, the appropriate municipality becomes responsible for the cost of maintenance and operation of the traffic signal. Since the municipality assumes liability, it is important that appropriate budgeting for insurance, preventative maintenance, and response maintenance associated with crashes and equipment failure be provided.

Preventative maintenance costs will escalate over time as equipment wears out and requires being replaced. More costly emergency repair costs will increase if proper preventative maintenance care is not provided. Typical annual maintenance costs per intersection may range from $1,500 to $6,000, and depends on several factors such as the age and complexity of the traffic signal. However, most municipalities base their traffic signal operations and maintenance budget on the previous year's budget.

Traffic signal unit prices for new/replacement products or operational improvements are included in **Exhibit 2-4**. However, in addition to the unit costs in **Exhibit 2-4**, the cost for work zone traffic control is typically an additional 15 to 20 percent.

For budgeting purposes, it is also helpful to be aware of the typical service life of various traffic signal assets. Although unscientific, **Exhibit 2-5** shows the average estimated life expectancy by several state Departments of Transportation based on responses to a 45-page questionnaire for the Transportation Research Board in 2006 (see NCHRP Synthesis 371 online at http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_371.pdf). However, the actual life of these traffic signal assets should be based on routine inspections, and may vary as a function of the manufacturer, location, loading, etc.

Traffic Signals are an important part of the Long Range Transportation Plan Asset Management effort. Municipalities should request to their planning partners that traffic signal improvement line item be placed onto the transportation improvement program (TIP). As long as it is on a regional TIP (even if locally funded for minimal amount), the funding stream can be adjusted. The purpose for a TIP line item like, "traffic signal improvements region-wide: traffic signal infrastructure, timing, and operational modifications at: Location #1, Location #2, and at other locations to be determined" allows the possibility of federal funding for maintenance and operations to occur.

Exhibit 2-4 Installed Unit Prices, in 2010 Dollars

Element	Unit Prices*
Mast arms	$6,000 to $9,000/each typically. Could be up to $20,000 for special or large mast arm
New controller	$9,000/each
3-section, 12-inch LED signal head	$800/each
5-section, 12-inch LED signal head	$1,300/each
LED pedestrian signal head	$600/each
LED replacement bulb	$150
Pedestrian pushbutton	$250/each
Loop detector	$1,200 to $1,800/each
Video detector	$4,000/approach $16,000 intersection
Junction box	$1,000/each
Emergency vehicle preemption (EVP)	$3,000/ approach, $10,000/intersection
Signs, misc	$35/square foot
Uninterruptible power supply (UPS), i.e., battery backup for LED signals	$3,000 to $6,000/intersection
External generator panel (hook-up to accommodate a small generator)	$500
Traffic Signal Retiming & Analysis (recommended every 3 to 5 years for every traffic signal)	$1,000 to $8,000/intersection

* Most of the unit prices were derived from recent Department construction projects (Publication 287, i.e., Construction Cost Catalog), inflated to 2010 prices, but a few of the unit prices came from the traffic signal industry.

Exhibit 2-5 Estimated Service Life

Component or Material	Average Life (years)
Tubular steel mast arms	24.6
Steel pole and span wire	22.8
Loop detector	8.6
Non-invasive detector	10.4
Traffic controller	13.5
Controller cabinet	17.5
Twisted copper interconnect cable	17.7
Fiber optic cable	23.6
Incandescent lamps	1.4
LED lamps	7.2
Signal heads	18.8
Signs	11
Thermoplastic pavement markings	4.2

* Values from Tables 6, 13, and 19 of *Managing Selected Transportation Assets: Signals, Lighting, Signs, Pavement Markings, Culverts, and Sidewalks*, NCHRP Synthesis 371, Transportation Research board of the National Academies, Washington, DC, 2007

2.3.3 Scheduling

As will be discussed in Section **2.4**, preventative maintenance should be normally scheduled by the municipality every 6 months, and it can be completed at any time during the year. However, response (emergency) maintenance can occur at any time, so the municipality needs to have adequate personnel in place to respond to these situations.

2.3.4 Personnel/Resources

A municipality needs to determine the number of technically-proficient staff members that can maintain their traffic signals to the guidelines established within this document. When sufficient municipal resources are not available, consider having a traffic signal contractor perform municipal maintenance functions. Other considerations a municipality may consider include making a developer fund a municipal maintenance contract when determining the appropriate traffic signal maintenance budget.

In either case, the municipality should have a professional engineer either on staff or available to assist in overseeing the traffic signal maintenance. This individual should have experience in traffic flow theory and in the operation of traffic signals.

If traffic signals are being maintained by municipal staff, it is recommended that this individual(s) be in a supervisory role. This person would be responsible for directing the work activities pertaining to the municipalities traffic engineering and operations. Work activities would include the installation, monitoring, modification, maintenance and administration of all traffic signals and signal systems. This individual(s) should ensure that traffic signal-related maintenance activities are adequately planned and executed and that there is an adequate inventory of replacement parts. The municipal engineer is responsible for investigating and preparing specific recommendations for all traffic-related inquiries from both the public and governmental agencies and for providing overall traffic engineering expertise. This person plans, administers and supervises the installation, alteration, maintenance and repair of all types of traffic control devices, including the development and administration of contracts for the installation or modification of traffic signals.

Technicians

In order to adequately maintain traffic signals, a general rule-of-thumb is that a municipality should have one qualified technician for every 40 signalized intersections. However, additional technicians are required if the municipality has more than 150 traffic signals, a variety of different types of traffic signal equipment, larger intersections, or older traffic signal equipment.

The qualifications of technicians are included in **Exhibit 2-6**, and they should apply to both municipal and contractor employees:

Exhibit 2-6 Recommended Qualifications for Maintenance Personnel

Requirement	Technician 1	Technician 2	Maintenance Supervisor
General Tasks	Replacement and repair of controllers, traffic signals, wiring and other field equipment. Works under direction, usually provided by a Technician 2.	Skills include programming of traffic controllers, troubleshooting controllers and ancillary equipment. Requires minimal direction. Provides direction and training to Technician 1 level.	Full supervisory responsibility. Supervises Technician 1 and Technician 2 levels. Greater technical knowledge than Technician 2 is required. Administrative duties include ordering spares and supplies, contract administration, budgets and provision for training.
Education and Experience	High school (minimum). Knowledge of electrical standards, codes, practices and repair techniques. Certification to IMSA Traffic Signal Level I within one year of employment.	Certification to IMSA Traffic Signal Level II. Minimum of 2 years' experience as Technician 1.	Combination of training, education and experience for a total minimum of 5 years. Certification to IMSA Traffic Signal Level II. Additional training beyond IMSA Traffic Signal Level II.
Physical Requirements	Must be able to work for long periods in inclement weather. May be required to lift heavy objects, work from bucket trucks	Same as Technician 1.	

Using municipal personnel to perform maintenance on traffic signals that are located in two or more municipalities, or that are part of an interconnected traffic signal system, can be challenging. At a minimum, a multi-municipal agreement should exist in these cases to minimize potential maintenance issues.

Exhibit “C” in the Commonwealth and Municipal Traffic Signal Maintenance Agreement contains additional detail for the type of work activities required.

In addition to performing routine maintenance (preventative and emergency response), research indicates that operational maintenance (traffic signal timing) should be reevaluated every 3 to 5 years to determine if the traffic signal retiming is necessary. The research also indicated reevaluation even more often if development or traffic volumes change significantly. In FHWA’s report entitled *Traffic Signal Operations and Maintenance Staffing Guidelines* (Report No. FHWA-HOP-09-006, dated March 2009), this additional manpower needed for retiming is estimated at 43 hours per intersection, as included in **Exhibit 2-7**.

If a municipality determines, through evaluation of the current traffic signal operations, that the timing should be modified, an official request with traffic analysis documentation should be submitted to the Department’s appropriate District Traffic Engineer for approval and for revision of the traffic signal permit.

Specialized Equipment and Inventory

If a municipality elects to perform their own traffic signal maintenance, they should either have the following equipment and supplies, or at a minimum have ready access to them via a rental agency or contractor:

- ✓ Vehicles, including bucket trucks
- ✓ Test equipment and tools
- ✓ Digital multimeter
- ✓ Controller and conflict monitor test equipment
- ✓ Detector sensor test equipment
- ✓ Small tools
- ✓ Vacuum cleaner
- ✓ Small generator for backup power for signals at major intersections during power outages
- ✓ A field laptop with appropriate traffic signal controller and detection software (if applicable)
- ✓ A small video monitor when using video detection systems (if applicable)
- ✓ Replacement parts: controllers, CMU or MMU units, cabinets, cabinet fans and bulbs, signal heads, mast arms and poles, pushbuttons, detectors, bulbs or LED modules, filters, emergency vehicle preemption equipment, conduit, signal cables, detector cables, communication cables, signs, etc.

- ✓ Work zone traffic control devices (including work zone attire and equipment as defined in PennDOT Publications 46 “Traffic Engineering Manual” and 213 “Temporary Traffic Control Guidelines”).

Exhibit 2-7 Person Hours for Key Signal Timing Activities

Task	Person-Hours per Intersection
Project management	0.8
Weekday turning movement counts	19.8
Saturday turning movement counts	4.6
Field intersection inventory	1.5
Qualitative assessment	1.5
Signal timing analysis	7.5
Fine tuning	6.0
Final delivery	1.3

2.3.5 Measures of Effectiveness

Two typical measures of effectiveness (MOEs) used to evaluate the overall quality of the traffic signal operation are: (1) average delay per vehicle per intersection; and (2) average number of stops per day per intersection. These MOEs are good indicators of the quality of the design and/or the signals suitability with respect to current traffic volumes. Although it can be argued that a poorly maintained traffic signal will have negative effects on these MOEs, it is not true that poor MOEs are caused solely by the lack of proper maintenance – they may be in large part due to heavy traffic volumes and inadequate roadway capacity.

A large number of emergency repair calls involving equipment failure is an indication that there is a need for better preventative maintenance. In fact, a good preventative maintenance program will practically eliminate the need for emergency maintenance, with some agencies reporting after hour calls being reduced by as much as 90 percent. For this reason major emphasis should be placed on preventative maintenance, since safety and liability would also be related to the number of emergency repair calls.

Possible MOEs include:

1. Annual number of emergency calls per intersection.
2. Number of burnout/non-functioning lights replaced per year.
3. Average response time for emergency calls.
4. Average time to complete an emergency repair.
5. Percent of response calls that were fixed with all new parts from inventory.

6. Percent of loop detectors online.
7. Maintenance records showing all maintenance performed at each signal, including the technician and the date.
8. Number of traffic signal operational improvements to existing traffic signals.

The importance of using MOEs is to determine if the current maintenance program is working properly, and if changes are needed. If the MOEs are going in the wrong direction, it may be justification for increasing the traffic signal budget, changing maintenance contractors, etc.

To gauge how well you are doing currently, a municipality should know how well they have performed in the past. To be able to do so, baseline MOEs should be established so that trends can be established.

2.3.6 Training

As indicated in **Exhibit 2-6**, all traffic signal technicians should receive training and certification by the International Municipal Signal Association (IMSA). This is true whether the technicians are municipal employees or contractor employees. Traffic signal technicians should also be familiar with work zone traffic control requirements as defined in Publication 213 (Temporary Traffic Control Guidelines).

2.3.7 Documentation

Whenever preventative maintenance or response maintenance is performed, a record of the work must be documented in accordance with Section **2.5**.

2.3.8 Coordination

Coordination of maintenance and repair activities is important for any municipality with traffic signals. It increases in importance as the number of signals a municipality must maintain increases. Maintenance activities must be coordinated among municipal staff and/or with the contractor who conducts the maintenance such that it is performed in a timely and cost-effective manner. Coordination with other agencies and the review of proposed projects is essential since their projects could affect the traffic signal current operations. This includes utility work, road work, or a design by a land developer. For example a municipality may plan to replace traffic signal indications but if that traffic signal is being replaced by a land developer as part of a site plan in the near future, replacement of the signal indications may waste maintenance funds.

2.3.9 Contracts and Municipal Contractors

Municipalities are responsible for the costs associated with the installation and maintenance of all traffic signals within their jurisdiction. On state and/or federal funded projects, and any municipality with current municipal traffic engineering certification issued in accordance with 67 Pa. Code Chap. 205, municipalities are required to enter into a *Traffic Signal Maintenance Agreement* with the Department as discussed in Section **2.8**. The cities of Philadelphia and Pittsburg are excluded from this requirement. This traffic signal maintenance agreement defines the municipality’s responsibilities to the maintenance of the traffic signal.

This traffic signal maintenance agreement also requires a municipality to document whether they will use municipal personnel or contract services for maintenance. If a municipality elects to use contract services for either preventative or response maintenance, a municipality further agrees to submit a copy of the contract or agreement between them and the contractor to the Department. An example of this type of document is referenced in Section **2.8** and is included in the Appendix (See Section **10.1**).

2.4 Traffic Signal Maintenance Classifications

The Department recognizes the following four different traffic signal maintenance classifications:

- ✓ Response (emergency) maintenance
- ✓ Preventative (routine) maintenance
- ✓ Operational maintenance (See Section **2.7**)
- ✓ Design modifications (See Section **2.11**)

A municipality is responsible for evaluating their program requirements and determining the acceptable level of traffic signal maintenance and operation actions to meet the guidelines established in this chapter and Publication 191. A municipality will need to determine whether maintenance and operations responsibilities will be provided by either municipal personnel or by a private maintenance contractor. The following questions should be considered for a maintenance and operations program:

- ✓ What level of staffing is required?
- ✓ Does the agency wish to purchase and operate the equipment required for maintenance?
- ✓ What skill level is available from in-house staff, and what level can the agency afford to employ?
- ✓ If outsourced, does the agency have personnel with the skills to manage a contractor?
- ✓ How many similar maintenance contracts has the agency done?
- ✓ How many years has the agency done similar maintenance contracts?

If considering outsourcing maintenance of traffic signals, various options are available. This may range from a contractor providing all labor and materials, to other combinations where a contractor would provide a specific segment of labor and/or materials with the remaining functions provided by the municipality.

It is important to ensure that the municipal staff and/or municipal contractor have the appropriate training so that they are up-to-date with current traffic signal technologies and maintenance and operation procedures. In addition to being adequately trained, traffic signal maintenance personnel (contractor or municipal), should satisfactorily complete a certification program sponsored by a nationally recognized organization such as the International Municipal Signal Association (IMSA).

Before any "on street" maintenance or operation activities are performed, the applicable traffic control shall be in place as indicated in Publication 213 (i.e., Temporary Traffic Control Guidelines). Traffic control adjacent to the traffic signal could conflict with the signal operation causing a crash to occur.

2.4.1 Response (Emergency) Maintenance

Response Maintenance, also as known as Emergency Maintenance, is the immediate repair of operational deficiencies and/or physical malfunctions that may occur. Response Maintenance duration is dependent on the following elements:

- ✓ Receive notification – Point in time the contractor or municipality is notified that there is an issue requiring attention.
- ✓ Arrive at site/diagnose problem – The time it takes the contractor to diagnose the issue.
- ✓ Perform repairs – The time it takes the contractor to perform repairs.
- ✓ Log activity - This includes formally logging the activity into the maintenance log.

The goal of providing response maintenance is to restore the traffic signal to normal operation as indicated on the current, approved Traffic Signal Permit. Response Maintenance repairs can be either Final Repair or Temporary Repair as described below.

- ✓ Final Repair – Restore the traffic signal to operate in accordance with the approved Traffic Signal Permit.
- ✓ Temporary Repair – Use alternate means to restore the traffic signal to safe operation until final repair can be made. As a minimum, traffic signals should be set to operate in flashing mode, and not be left in an unlighted condition. For long-term traffic signal outages where even flashing mode is not possible, alternative traffic control methods need to be coordinated with the appropriate Engineering District.

  Examples of typical response maintenance problems are included in **Exhibit 2-8** and on the suggested Response Maintenance Record (TE-972) as included in the Appendix (See section **10.4**).

Exhibit 2-8 Typical Response Maintenance Items

Signal Heads
Restore unlighted traffic signal (includes pedestrian signals)
Correct misaligned traffic signal (includes pedestrian signals)
Repair or replace mounting hardware
Repair or replace damaged signal head or parts thereof (e.g., visor, lens, backplates, and reflector)
Clean any obstructed indications including, but not limited to, dirt or snow
Controller Assembly
Restore correct phasing and time setting in controller unit
Replace a malfunctioning controller unit
Replace a malfunctioning conflict monitor
Repair or replace malfunctioning flasher
Repair or replace malfunctioning load switch
Repair or replace malfunctioning time clock
Repair or replace malfunctioning relay
Traffic Signal Supports
Repair or replace defective poles or other supporting hardware
Replacement of any damaged traffic signal supports
Base Plate cracks
Pole cracks
Cracks in any weld metal or base metal
Anchor bolt connection failures, or other nut and bolt failures
Gaps between base plate connection and foundation
Foundation cracks
Restore required clearance between the roadway and bottom of signals and/or signs located over the roadway
Detection (Vehicular)
Repair or replace malfunctioning detector amplifier
Repair or replace malfunctioning detector sensor
Repair or replace malfunctioning video detection equipment
Repair or replace malfunctioning preemption system equipment
Tune or adjust detection amplifier
Redirection or re-establishment of detection equipment
Detection (Pedestrian Push Button)
Repair or replace malfunctioning push buttons
Repair of accessible pedestrian signal messages or indications
Removal of obstructions preventing pedestrian push button accessibility, e.g., piles of snow
Signs (As indicated on the Traffic Signal Permit)
Correct misaligned signs
Repair or replace damaged or missing signs
Pavement Markings
Restore pavement markings that are the responsibility of the permittee as indicated on the Traffic Signal Permit (e.g. stop lines, crosswalks, legends, etc.)

Response to a knockdown or equipment failure may require an emergency repair using temporary measures. Some repairs are not permitted to be performed using emergency (temporary) measures and require final repairs instead, e.g., signal heads or span wire. **Exhibit 2-9** identifies the types of repairs permitted and not permitted for various knockdowns and failures.

Exhibit 2-9 Response Maintenance Schedule

Knockdowns	**Type of Repair Permitted**
Support - Mast Arm	Emergency or Final
Support - Strain pole	Emergency or Final
Span Wire/Tether Wire	Final Only
Pedestal	Emergency or Final
Push Button Support	Emergency or Final
Cabinet	Emergency or Final
Signal Heads	Final Only
Equipment Failure	**Type of Repair Permitted**
Lamp Burnout (Vehicular & Pedestrian)	Final Only
Local Controller	Emergency or Final
Master Controller	Emergency or Final
Detector Sensor—	
Loop	Emergency or Final
Magnetometer	Emergency or Final
Wireless	Emergency or Final
Magnetic	Emergency or Final
Microwave	Emergency or Final
Video	Emergency or Final
Radar	Emergency or Final
Pushbutton	Emergency or Final
Preemption System	Emergency or Final
Detector Amplifier	Emergency or Final
Conflict Monitor	Final Only
Flasher	Final Only
Time Clock	Emergency or Final
Load Switch/Relay	Final Only
Coordination Unit	Emergency or Final
Communication Interface, Modem	Emergency or Final
Signal Cable	Final Only
Blank-Out Sign	Emergency or Final

2.4.2 Preventative (Routine) Maintenance

Preventative Maintenance, also known as Routine Maintenance, is the establishment of a pre-developed program of periodic inspections and procedures to minimize the probability of a failure which would require future response (emergency) maintenance. It also includes the repair or replacement of components, as necessary, to maintain the signal as it is intended to operate on the Traffic Signal Permit.

Preventative maintenance can be completed anytime during the year. It is especially important to perform the reviews after severe weather to ensure that the traffic signal has not been damaged. For example:

- ✓ High winds can twist or misalign signal heads and video cameras (misalignment is especially problematic for optically programmed signals).
- ✓ High winds can damage signs.
- ✓ Rain, snow or water in signal heads could create an electrical short.

Specific preventative (routine) maintenance considerations to be evaluated could include:

Operations

- ✓ Are intersection phases appropriate for observed conditions?
- ✓ Are intersection timings appropriate for observed conditions?
- ✓ Is the intersection on the appropriate “recall” mode?
- ✓ Is “dual entry” used for the appropriate phases?
- ✓ Is there suitable progression between intersections?

Maintenance

- ✓ Are detectors functioning properly?
- ✓ Are individual signals interconnected and communicating properly?
- ✓ Are all grounds solidly connected and in working order?
- ✓ Are battery(s) fully charged and holding the correct voltage?

Other

- ✓ Could lane reassignment or minor geometric enhancements improve operations?
- ✓ Could basic, low-cost access management practices improve operations?
- ✓ Do emergency services need addressed?
- ✓ Are pedestrians accommodated?
- ✓ Are timing changes necessary?

2.5 Documentation

Documentation is important for several reasons:

- ✓ Maintenance records are critical to ensure that traffic signal maintenance is performed at regular intervals.
- ✓ Up to date documentation of a traffic signal's equipment and operation may make future upgrades to the signal much easier and allows for sharing of information. Other public agencies may occasionally request this documentation, especially for nearby projects involving traffic signal installations or upgrades to ensure compatibility between traffic signals.
- ✓ Historical measures of effectiveness (MOEs) can help justify appropriate changes in the traffic signal budget.

2.5.1 Documentation Types

Regardless of the appropriate traffic signal maintenance and operations classification and/or how it's performed, one important but often neglected requirement of traffic signal maintenance is keeping relevant and up-to-date documentation. The records necessary for effective traffic signal maintenance fall into four basic categories: Maintenance Service Records, Signal Timing Charts, Traffic Signal Permit, and Maintenance Manuals/As-Built Plans. Some examples of traffic signal documentation include, but are not limited to, wiring schematics, controller time settings, software, conflict monitor programming sheet, manuals, technical publications, and maintenance records.

Maintaining up-to-date traffic signal maintenance records can help provide efficient service, detect and correct recurring problems, develop future maintenance schedules and strategies, and may protect a municipality from a tort liability claim. The following are types of traffic signal records that should be kept when managing maintenance activities:

- ✓ Master Record – master log of all service calls that includes the date, type of maintenance performed, and signatures of personnel performing the work.
- ✓ Preventive Maintenance Record – a log for each preventive maintenance service that includes the date, tasks performed, and signatures of personnel performing the work.
- ✓ Preventive Maintenance Problem Record – a record of potential problems identified, corrective action taken, and information about a follow-up inspection.
- ✓ Response Maintenance Record (See **Exhibit 2-10**) – a log recording the location, date, time, caller, receiver and complaint received, maintenance personnel, time dispatched, trouble found, and time cleared.

Exhibit 2-10 Sample Response Maintenance Documentation Form

RESPONSE MAINTENANCE RECORD

INTERSECTION: ______________________________

Call From	Date	Time Rec'd (AM or PM?)	Location	Trouble as Reported	Taken By	Person Assigned	Time Dispatched (AM or PM?)	Trouble Found	Time Cleared (AM or PM?)

2.5.2 Documentation Methods

Form TE-699 "Traffic Signal Description" includes basic information on a traffic signal's equipment and operation. This is important when performing repairs where the traffic signal must be restored in compliance with the approved traffic signal permit. Some of the information contained in this form includes:

- ✓ Type of mounting
- ✓ Number and size of signal indications
- ✓ Controller, conflict monitor, and detector manufacturer and model number
- ✓ Type of controller operation

Form TE-699 "Traffic Signal Description" (copy included in the Appendix – Section **10.2**) becomes more critical when developing a municipal traffic signal equipment asset management system since information would then be readily available for entry. Up-to-date and accurate information can benefit all parties in making informed decisions.

A further explanation of Form TE-699 is included in Publication 149 the "Traffic Signal Design Handbook." If a municipality has any questions concerning the proper traffic signal documentation, they should contact the appropriate Engineering District Traffic Signal Unit.

A copy of all maintenance records should be kept within the appropriate traffic signal cabinet and in a centralized municipal location with easy access. Suggested forms for maintenance records are identified below and included in the Appendix:

- ✓ TE-971 – Master Signal Maintenance Log (section **10.3**)
- ✓ TE-972 – Response Maintenance Record (section **10.4**)
- ✓ TE-973 – Preventative Maintenance Record (section **10.5**)
- ✓ TE-974 – Signal Modification Checklist (section **10.6**)

2.6 Maintenance Activities

Various components all work together to provide a fully functional traffic signal. Neglecting any one of these components can be detrimental to the safe and efficient operation of the entire traffic signal; therefore, it is important to maintain each and every one of these components. The following traffic signal components are detailed in the following sections:

- ✓ Supports (Section **2.6.1**)
- ✓ Indications (Section **2.6.2**)
- ✓ Detection (Section **2.6.3**)
- ✓ Controller (Section **2.6.4**)
- ✓ Communications (Section **2.6.5**)
- ✓ Emergency Preemption (Section **2.6.6**)
- ✓ Electrical Distribution (Section **2.6.7**)
- ✓ Signing and Marking (Section **2.6.8** and **2.6.9**)
- ✓ Sidewalks and ADA Curb Ramps (Section **2.6.10**)

2.6.1 Traffic Signal Supports

Overhead traffic signals are supported by either mast arms connected to signal support poles or span-wire that is tethered to strain poles. Mast arm installations are typical except where the intersection is too wide and proper signal placement cannot be accomplished with a suitable mast arm length (typically less than 60 feet).

Traffic Signal Support Installation

Post-Installation Procedures

When inspecting or evaluating traffic signal supports, it is essential that Publication 148 (i.e., "Traffic Standards – Signals, TC-8800 Series") and Publication 149 (i.e., "Traffic Signal Design Handbook") are reviewed.

Inspections of the welded and bolted connection apply in the following situations:

- ✓ When inspecting new traffic signal installations.

- ✓ When inspecting traffic signal installations in conjunction with the initial signal turn-on and the 30-day testing period.
- ✓ When municipalities conduct the recommended annual preventative traffic signal maintenance and inspection activities.

(a) Welded Connections:

Inspect 100 percent of all welds for visual evidence of any cracking.

Document and **immediately** report any evidence of weld metal or base metal cracking of the traffic signal installation for further investigation. If cracks are observed, schedule response (emergency) maintenance as soon as possible.

(b) Bolted Connections

- ✓ Ensure that a washer is used between the connection or flange plate and each nut.
- ✓ Visually examine the connection. The connection should be tight with no visible gap between the connection or flange plates, bolts, nuts, or washers.
- ✓ Galvanized nuts, bolts, and washers should not show any significant signs of corrosion.
- ✓ Document and immediately report any adverse findings to the appropriate official for further investigation. Immediate action shall be taken by the local authorities if adverse findings are observed.
- ✓ Where bolted connections require remedial corrective action, new bolts, washers, and nuts must be used.
- ✓ Inspect the foundation and base plate connection.
- ✓ Remove the grout or rodent screening under the base plate if there is evidence of anchor bolt weathering. Remove any debris, and examine the anchor bolts under the base plate, for signs of bending, cracking, etc.
- ✓ Ensure that leveling nuts are in a snug-tight condition with the bottom of the base plate. Snug-tight is defined as the full force of a man on a 12-inch wrench.
- ✓ For pole replacement, ensure that the distance between the bottom of each leveling nut and the concrete foundation is less than the bolt diameter, unless indicated otherwise on the approved design drawings for the traffic signal support. Note that, if the distance is not less than the bolt diameter, the American Association of State Highway and Transportation Officials' (AASHTO) "Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals" requires that the bending stresses in the anchor bolts be considered when determining the structural adequacy of the installation.
- ✓ Replace the grout or rodent screen if it has been removed.

- ✓ Ensure that a washer meeting Section 1104.02 of Publication 408 (i.e., "Highway Specifications") is present under each top nut to provide full bearing and to seal bolt hole gaps.
- ✓ Verify that the top nuts are tight. Remove, lubricate, and retighten any loose nuts using the method described for overhead sign structures in Section 948 of Publication 408 or the method described in AASHTO's "Standard Specification for Structural Supports for Highway Signs, Luminaires, and Traffic Signals," Section 5.17.6.2 'Anchor Pretensioning.' Both methods are similar turn-of-the-nut procedures. (Contact the Department for more specific assistance.)
- ✓ Where sufficient anchor bolt projection exists, install an additional top nut if a single nut exists.
- ✓ Verify that the threads have been burred above the top nut to prevent loosening.

Mast Arms

Maintenance and Inspection

(a) Bolted Connections:

Inspect arm to column connections.

(b) Welded Connections:

Inspect 100 percent of all welds for visual evidence of cracking.

- ✓ Cracks on traffic signal supports with mast arms may occur in the vertical column to base plate connection and generally initiate opposite the arm-to-shaft connection (about 180° from the centerline of the arm for single-arm structures).
- ✓ Cracks in the welded connection between the arm or column connection plates usually initiate at the uppermost (12-o'clock) or lowermost (6-o'clock) positions of the connections due to the dead load and oscillation (galloping) caused by wind loads.

Document and **immediately** report any evidence of weld metal or base metal cracking to the proper officials for further investigation. Appropriate response (emergency) maintenance should be scheduled as soon as possible if such cracks are observed.

Strain Poles

Maintenance and Inspection

(a) Bolted Connections:

Inspect connections.

(b) Welded Connections:

Inspect 100 percent of all welds for visual evidence of cracking.

- ✓ Cracks in the shaft or column to base plate connection usually initiate opposite the span wire connections.
- ✓ Document and **immediately** report any evidence of weld metal or base metal cracking to the appropriate officials for further investigation. Schedule the appropriate response (emergency) maintenance as soon as possible if such cracks are observed.

Pedestal Poles

See Section **2.6.1** for pre- and post-installation procedures. In addition, ensure a round top cap is in place to minimize injuries.

Appurtenances Unrelated to Traffic Control

With the use of technology becoming more widespread, appurtenances are sometimes installed on traffic signal supports even though they are not for the purpose of controlling traffic. These installations are discouraged on signal supports; however, if installed, a structural analysis should be performed to ensure the signal support can handle the additional load(s) and a modification of the traffic signal permit.

2.6.2 Traffic Signal Indications

Traffic signal indications provide the driver or pedestrian with a visual sign as to when they can proceed through an intersection. It is essential that drivers and pedestrians have a clear view of the traffic signal indications. Therefore, the traffic signal indications should be routinely inspected to ensure that advance signs, foliage, or snow does not impair a driver, and/or, pedestrian visibility.

Vehicular indications include red, yellow, green circular or arrow indications. Pedestrian indications typically include a Portland orange “hand” symbol and a white “person” symbol as well as a numeric countdown. This section explains these indications and the traffic signal housing in which the indications are installed.

Traffic Signal Housing

As indicated in the *Manual on Uniform Traffic Control Devices (MUTCD)*, a Traffic Signal Housing is the part of the traffic signal section that protects the light source and other required components. There are two primary types of Traffic Signal Housing:

Vehicular Housing

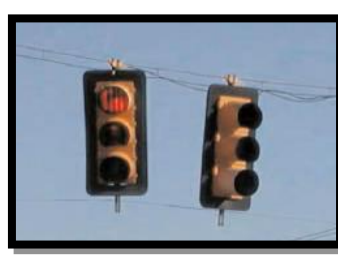
Pedestrian Housing

Traffic signal housings should be inspected routinely using the guidance materials provided in the TE-972 and TE-973 Forms (see the Appendix – section **10.4** and **10.5**). These documents will provide the necessary details to consider when providing both response and preventative maintenance. Additionally, the Traffic Signal Permit, Publication 408 (i.e., "Highway Specifications"), and Publication 148 (i.e., "Traffic Standards – Signals, TC-8800 Series") are key materials that should be used to evaluate the pedestrian housing. The importance of the traffic signal housing is critical to ensuring that the indications are protected.

If a traffic signal housing needs to be replaced, please refer to Publication 35 (i.e., "Approved Construction Materials," also referenced as Bulletin 15) to determine what manufacturers and model numbers are approved to the Department's specifications. All installations shall follow Publication 408 (i.e., "Highway Specifications") and Publication 148 (i.e., "Traffic Standards – Signals, TC-8800 Series").

(a) Vehicular Traffic Signal Housing

Vehicular traffic signal housings supplement the indications through the use of appurtenances such as backplates, visors, and louvers.



Backplates are used to provide a dark contrast to the traffic signal housing and indications to improve visibility. FHWA encourages their use on all approaches with a speed limit of 45 mph and above, and where sun glare, bright sky, and/or complex or confusing backgrounds indicate a need for enhanced traffic signal face target value. FHWA also permits the use of a yellow retroreflective strip with a width of 1 to 3 inches placed around the perimeter of the backplates with PennDOT Central Office approval.

Visors attach to the traffic signal housing and shield the indications from sun glare and the elements, also improving visibility. Visors should be flat black in color on the side toward the indication. Visors are typically cut-away where the bottom is open, but tunnel visors and full circle visors may be considered to make it more difficult for drivers in adjacent approaches to view traffic signals not intended for their approach. Louvers may be installed over the indications to further restrict indications' view from directions of travel for which they do not control.

Traffic signal heads on mast arms should be mounted using fixed-mounts as opposed to free-swing mounts unless there is a compelling reason. Hardware assemblies differ depending on whether the heads are mounted mid-span or end-span.

(b) Pedestrian Traffic Signal Housing

The pedestrian traffic signal housing, like vehicular traffic signal housings, use visors to protect and increase visibility of the indications. Screen visors can be used to protect the Light Emitting Diode (LED) indications from the weather.

For both vehicular and pedestrian traffic signal housings, it is essential that drivers and pedestrians have a clear view of the traffic signal indications. Therefore, traffic signal indications should be routinely inspected to ensure that advance signs, foliage, or snow does not impair their visibility.

Light Emitting Diode (LED) Indications

The Energy Policy Act of 2005 (EPACT 2005) effectively eliminates the use of incandescent traffic signal modules on new installations, and also encourages the upgrading of existing incandescent modules to more energy efficient LED technology.

The Department has created the following four categories to place LED products and has developed detailed specifications that take into account national practices, updated testing parameters, materials validation, and a 5-year warranty:

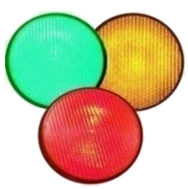
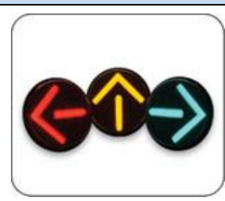
- ✓ Circular LED Vehicle Traffic Signal Module.
- ✓ 12-Inch LED Vehicle Arrow Traffic Signal Module.
- ✓ LED Pedestrian Signal Module. (Note, in accordance with Publication No. 149, all new pedestrian signal heads shall be countdown pedestrian signals, except at locations where the crossing is so short that the duration of the pedestrian change interval is 3 seconds or less.)
- ✓ LED Countdown Pedestrian Signal Module.

LED traffic signals can benefit a municipality since they use 80 to 90 percent less energy than incandescent bulbs, resulting in significant energy cost reductions. In addition, they typically last about 5 to 7 years so maintenance cost reductions can also be realized with their use. One benefit to LEDs is that the individual module slowly burns as opposed to an incandescent bulb which will fail immediately. LEDs should be periodically monitored for brightness level to ensure replacement prior to complete failure.

One drawback to LEDs is that they do not generate heat (thereby saving energy), which may lead to issues with snow captured in the traffic signal housing. Under unique snow and wind combinations the lens visibility can actually become restricted. This problem has occurred with incandescent bulbs, but not to the extent that it occurs with LEDs due to the lack of heat provided by LED modules. If snow buildup becomes a significant problem, a municipality should contact the appropriate PennDOT Engineering District to determine the proper course of action. Currently, the Department is evaluating and testing industry solutions at known problem locations, but will not allow the widespread use of these solutions until valid testing is performed to ensure that municipalities are receiving credible products. In the interim, if snow buildups restrict the signal indication, the municipality should have the snow removed immediately to ensure public safety.

Exhibit 2-11 provides examples of several common LED traffic signal module types.

Exhibit 2-11 Common LED Traffic Signal Module Types

Circular LED Modules	12-Inch LED Vehicle Arrow Modules	LED Pedestrian Signal	LED Countdown Pedestrian Signal
 Most commonly used vehicular indication	 Arrow modules typically used for an exclusive turn phase Use of red arrow now permitted in some cases but requires approval from appropriate District.	 Hand/person pedestrian crossing signal Should no longer be used for new installations except where crossing so short only 3 sec change interval used	 Enhances safety over conventional pedestrian signal by providing pedestrians a visual on how long they have to cross the street

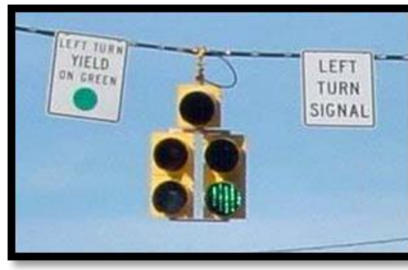
In accordance with PennDOT Publication 149 "Traffic Signal Design Handbook" countdown pedestrian signals are now preferred and should be used in lieu of hand/person pedestrian traffic signals. It is recommended that a municipality upgrade to these pedestrian traffic signals and adjust the Traffic Signal Permit accordingly.

Optically Programmed Traffic Signals

Optically programmed traffic signals are sometimes used at the downstream signal of two closely-spaced traffic signals. They are designed not to be visible from the first traffic signals so that drivers do not get confused by two conflicting traffic signal indications. They are also used at intersections where roads intersect at acute angles.

Please refer to Publication 149 (i.e., the "Traffic Signal Design Handbook") for additional guidance to ensure that the optically programmed signals are functioning properly.

Louvers



Louvers are full-circle inserts with one or more built-in fins or vanes that restrict the viewing angle of the signal. When used they should be installed with tunnel or full-circle visors.

Although they serve the same basic purpose as the optically programmed traffic signals, they are not as easily aligned and they also reduce the signal's light output.

Incandescent Indications

When incandescent indications have reached the end of their useful life and need to be replaced, Department-approved LED products in Publication 35 (i.e., "Approved Construction Materials," also referenced as Bulletin 15), Section 1104.06 should be used as a replacement. Incandescent replacement indications are no longer to be used. It should be noted that some manufacturers provide incandescent-look LED indications that have a similar appearance to a bright incandescent indication, whereas earlier LED indications had many bright LEDs, making it easy to distinguish them from incandescent indications.

Preemption Fail Safe Lights

Emergency Vehicle Preemption (EVP) is used to override a traffic signal's standard phasing such that priority is given to an emergency vehicle. This can work through detecting a siren sound or by a vehicle's transmitter being picked up by a receiver thereby preempting the traffic signal to provide a green indication in the direction the emergency vehicle is moving. Such a system can improve traffic safety and reduce emergency response time.

Fail Safe, or confirmation lights, provide indication to the emergency vehicle driver whether the approach is being preempted. The lights shall be mounted on traffic signal mast arms or strain wire, facing the direction of approaching traffic. The confirmation light shall remain off/dark when emergency vehicle preemption (EVP) is not active. When EVP is in operation, the confirmation light shall flash for the preempted approach. Maintenance responsibilities include ensuring the lights are properly aligned with each corresponding approach and testing for confirmation light off/dark operation using the appropriate transmission signal for the particular area (acoustical, optical, etc.).

Strobe Lights

Some municipalities have used white strobe lights within red signal indications for the purpose of calling attention to the red indication, especially at locations where this was the first traffic control signal on the highway for a mile or more. However, studies indicate that the strobe lights did not improve safety and FHWA has issued a final rule that prohibits the use of strobe lights (the prohibition is now included in Section 4D.06 of the *MUTCD 2009 Edition*). Therefore, these strobe lights should be removed as part of routine maintenance and replace with other traffic signal red indications approved in Publication 35 (i.e., “Approved Construction Materials,” also referenced as Bulletin 15).

2.6.3 Traffic Signal Detection

Many types of detection systems exist, most available as a means of detecting vehicles. The detection of pedestrians typically used by the Department is push button technology only.

Publication 149 (Traffic Signal Design Handbook) provides key guidance when selecting the proper detection system at an intersection. To ensure maximum effectiveness of each device, it is recommended, where possible, that manufacturer’s recommendations are followed.

Detection systems should be inspected routinely using the guidance materials provided in the TE-972 and TE-973 Forms (see the Appendix). These documents will provide the necessary details to consider when providing both response and preventative maintenance. The Traffic Signal Permit, Publication 408 (i.e., “Highway Specifications”) and Publication 149 (i.e., “Traffic Signal Design Handbook”) are key materials that should be used when evaluating detection systems.

Vehicle Detection

Detection is critical to an intersection’s safe and efficient operation. When a traffic signal is properly timed with detection fully functional, its operation is generally efficient. If an intersection lacks detection, unnecessary delay will occur resulting in wasted fuel and increased emissions. An example of a common occurrence with malfunctioning detection is a failed loop detector for a left-turn lane. Upon failure the signal controller is sent a signal to call the left-turn phase each cycle. This occurs whether vehicles are present or not, holding opposing traffic at a red indication. This again results in increased emissions and delays.

(a) Loop Detection

Loop detection uses electrically charged cables to detect traffic that is located in the detection zone. For small intersections loop detection is very cost effective. Drawbacks of loops, however, include disruption to traffic during installation since they are an intrusive type of technology in which saw-cuts are made into the pavement. Loops require regular replacement as a result of pavement failure due to heavy truck traffic and freeze-thaw cycles. Also, future milling and resurfacing generally requires that loops be re-installed. Loops preclude one from modifying the detection zone once installed.

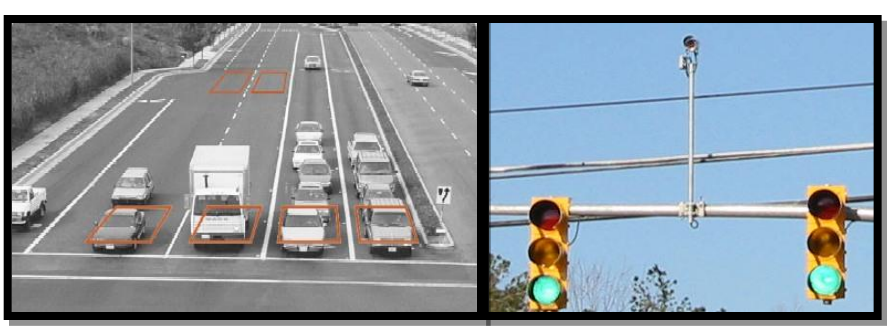
When loops fail it is for a number of reasons. These can include, but are not limited to:

- ✓ Loop sensitivity of the detector card is set too low and in need of adjustment.
- ✓ Pavement cracking and shifting.
- ✓ Breakdown of wire insulation.
- ✓ Poor sealants or inadequate sealant application.
- ✓ Inadequate splices or electrical connections due to installation methods, moisture, or corrosion.
- ✓ Damage caused by construction activities.
- ✓ Lightning/electrical surges
- ✓ "Stuck" loop in which case the loop detector can be reset by depressing loop detector reset button, or if an older detector, turning a knob to retune and then reset.

Corrective actions can range from simply repairing splices or applying new sealant to full-depth pavement repair and new loop installation.

(b) Video Detection System

Video detection systems are those that use video cameras for the detection of vehicles by sending a video image from the camera to a video processor in the controller cabinet. These systems, in unique cases, can be part of a closed circuit television (CCTV) system where the video feed is transmitted to monitors at the municipality or to a PennDOT Traffic Operations Center. The detection zones which are created for the camera(s) are typically viewed by plugging a laptop into the traffic signal controller. A benefit to video detection is that detection zones may be removed, replaced, or redrawn at any time. Other benefits include the detection of bicycles and motorcycles as well as a single camera being capable of detecting an entire approach.



A major benefit of video detection is that it is a non-intrusive technology. When used at intersections with multi-lane approaches it can become more cost-effective when compared to using loop detection. Video detection can be installed with little impact to moving traffic and when the pavement deteriorates and/or is resurfaced, the camera still functions. Cameras must be mounted at a required height over the roadway in order to effectively detect vehicles. It should be noted that with those traffic signals where volume-density (advanced) detection is used, video cameras mounted on mast arms generally cannot adequately perform volume-density detection. They must be either mounted close to the point of detection or at a much greater height.

Disadvantages of video image detection are the initial capital costs and that they are adversely affected by camera motion from the wind. In addition, light level and sun glare can cause problems. Other weather elements such as fog, rain and snow can affect its operations and result in false calls. Since the introduction of this technology, dramatic improvements have minimized these problems with today's cameras. Even so, preventative maintenance must be performed by qualified personnel.

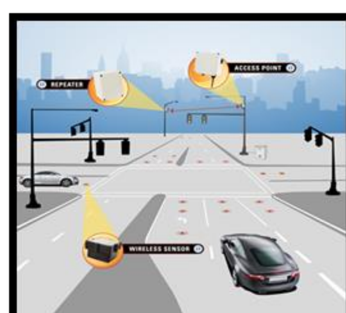
(c) Microwave Detection System

Microwave detection is mounted above the roadway to detect moving vehicles using microwave energy which is analyzed by a microprocessor. Like video detection this technology is non-intrusive. A disadvantage to this system is that it cannot detect stopped vehicles. Once the vehicle is detected, the call to the controller is locked, and if the vehicle moves the call is still in place. This detection would not work well where turn-on-red is permitted or where left turns are permitted and not always need the protected phase called upon. Benefits of microwave detection is that it is relatively unaffected by inclement weather and requires minimal maintenance.

(d) Infrared Detection System

Infrared detection is another nonintrusive type of detection that is highly reliable and allows for detection by lane. It works by detecting thermal radiation of vehicles. Infrared detection is independent of weather and can be used to detect both moving and stationary vehicles. They require very little maintenance.

(e) Wireless Detection System



Wireless detection uses a magnetometer and radio in a hardened casing which is installed within the pavement in the center of a travel lane. Both stationary and moving vehicles can be detected, and sensors transmit data to an access point which then relays the information to the traffic signal controller. The benefit of wireless detection is that it does not require costly trenching and wiring. It is lane intrusive, however, disrupting traffic flow, but installation is relatively quick. Sensors operate on battery power which can last up to 10 years. These sensors are virtually maintenance free.

(f) Digital Wave Radar

Digital Wave Radar is a non-intrusive radar technology used for advance/dilemma zone detection. Systems are capable of detecting vehicle presence and speed in order to identify vehicles within the dilemma zone, the zone in which a driver would find it difficult to safely stop as the light changes from green to yellow. Gaps within the dilemma zone shall then be identified such that the corresponding phase call will be dropped and the phase safely terminated. Maintenance includes ensuring that gaps are being properly identified by the system, the sensor is mounted securely, vehicles are being detected in only one direction, and that all cables and connections are properly secured.

Pedestrian Detection "Push Button" Detection

Push-button sensors activate a pedestrian signal for crossing a particular leg of an intersection. A circuit closure, created when a pedestrian pushes the button, causes a low-voltage current to flow to the controller, activating the call for the pedestrian phase.

Maintenance includes ensuring the button moves freely and activates the appropriate pedestrian phase. If two buttons for crossing in different directions are located on the same support, the appropriate signing should be in place to ensure that it is clear and easily understood which button applies to which approach. Signs should be securely mounted and aligned with the appropriate crosswalk. In addition, any noticeably short timing for safe pedestrian crossing of the street should be reported and addressed.

Accessible pedestrian signal (APS) use is becoming more widespread in the U.S. after having been used for quite some time in Europe and Japan. This is a device for the visually impaired that communicates information to pedestrians in a non-visual format using audible tones, verbal messages, and/or vibrating surfaces. The speaker that emits the sound is integrated into the push button housing. It emits a tone so that the user can locate the button. In addition, the button has a tactile device in the form of a raised arrow which helps the pedestrian to identify for which direction the button is intended to activate the traffic signal.

Maintenance of an APS includes ensuring none of the following has occurred or is occuring:

- ✓ No response to ambient sound
- ✓ Weak or no vibration
- ✓ Malfunction of audible message or tone

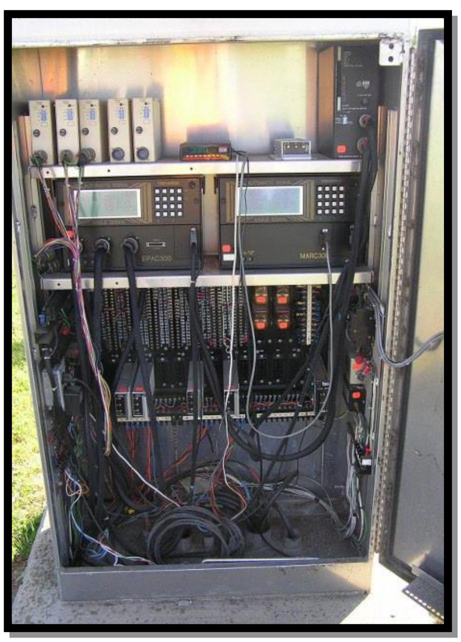
- ✓ Delay between onset of walk interval and start of speech message
- ✓ Failure due to wire short going to the vibrator cover/pushbutton.
- ✓ Mechanical failure of pushbutton magnetic switch
- ✓ Failure of control board
- ✓ Faulty pedestrian driver

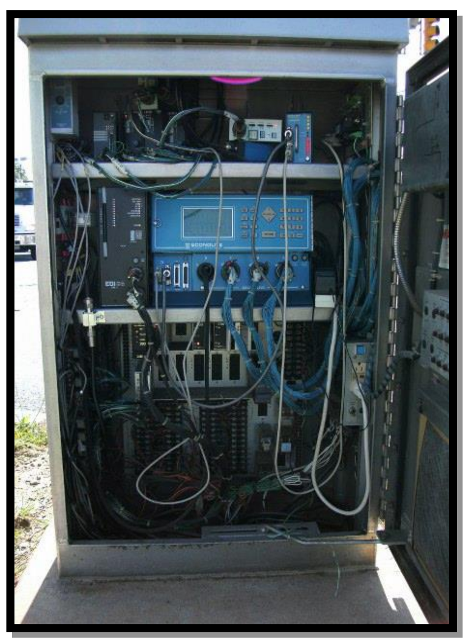
2.6.4 Traffic Signal Controllers

Several types of traffic signal controllers are used in Pennsylvania. The most common are NEMA controllers. These controllers used function-based standards. The first was the NEMA TS1 standard in 1976 which was developed as the first industry-wide signal controller standard allowing for interchangeability between manufacturers. NEMA TS2 replaced the TS1 standard. It allows for high-speed communication between equipment and for future expandability. There is a NEMA TS2 Type 1 which allows for this high speed communications and a Type 2 which retains TS1 type connectors to allow for a degree of downward capability.

Type 2070 Controllers are an advanced type of controller, modular in design, and use an open architecture allowing compatibility with off-the-shelf products. They allow for communications and are configurable for use with traffic management applications. Type 2070 Controllers are most often used in the cities of Pittsburgh and Philadelphia.

Type 170 Controllers are most often used in the City of Pittsburgh and Philadelphia. Standards for these controllers were developed by New York and California and are hardware-based. The purpose of hardware-based standards is to provide flexibility with interchanging components and to facilitate replacing components when the 170 controllers are in need of repair.





Controller Function

(a) Local Controller

The local controller resides at the intersection in which it controls and its function is to control a single intersection. The exception is when it is operating two closely spaced offset traffic signals and has adequate phase capability.

(b) Master Controller

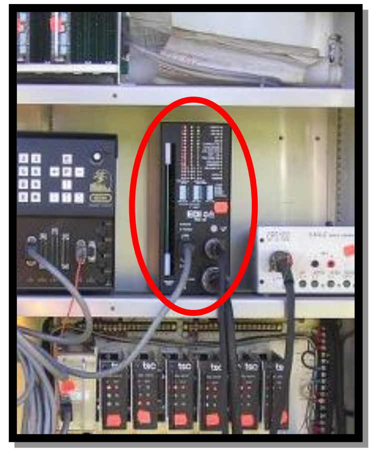
A master controller resides at what is typically referred to as the "master intersection" for a series of signals that are interconnected as part of a coordinated signal system. It is at this intersection where all other intersection phases are referenced, typically referred to as "offset." This is the time before or after the reference phase, for example beginning of the major street green, that another signal's same phase would begin.

Controller Maintenance

Controllers should be evaluated considering the following:

- ✓ When were signal timings last revised? Both the Department and FHWA recommend reviewing the timings every 3 to 5 years or if traffic volumes have significantly changed such that operation is inefficient.
- ✓ Is phasing appropriate? Are additions, deletions, or modifications of phasing necessary?
- ✓ Does controller operation need an update from pretimed to actuated?
- ✓ Are the yellow and red clearance change intervals appropriate?
- ✓ If a master controller, is it operating appropriately? Are signals running coordinated?
- ✓ Master controllers, where present, shall be disconnected to ensure the signal goes into backup or "free" operation
- ✓ Check controller cabinet condition. Is it necessary to relocate so the controller is not damaged by vehicle impacts?
- ✓ Check indicator lamps and replace if burned out.
- ✓ Check that phases are being appropriately called and extended by loop amplifiers.
- ✓ The Department strongly suggests that all electromechanical controllers be replaced with NEMA traffic signal controllers.

Conflict Monitor



A conflict monitor, or the more sophisticated malfunction management unit (MMU), continuously checks for the presence of conflicting signal indications. This monitor is hardwired into the output side of each load switch. If two conflicting phases are called, load switch failure occurs and the conflict monitor will place the signal into flashing operation. This is a significant problem if two green phases are simultaneously displayed on conflicting approaches. All traffic signal controllers require conflict monitors for this reason. Any municipality that determines a signal solid state signal controller is in operation without a conflict monitor should immediately contact their local engineering district for guidance on how to address the issue.

The most common occurrence when a conflict monitor fails is switch to flashing yellow/red operation. Less commonly steady red or yellow could occur, or the worst condition, steady green on conflicting approaches. One of the following test procedures should be conducted to ensure proper conflict monitor operation:

- ✓ Test conflict monitor yearly by a computerized conflict monitor tester. To assure the reliability of the computerized monitor tester, a calibration of the unit is to be done annually. The units need to be returned to the appropriate manufacturer in order for this calibration to be done properly.
- ✓ Perform conflict monitor test by removing the monitor and running a complete test with the conflict monitor tester unit. A spare monitor should be installed temporarily while the test is being performed or monitors may be shop-tested by rotating pre-tested monitors to the field. Documentation of the tested monitor should include the following:
    - Date
    - Name of Technician
    - Location - includes intersection name, city and/or county
    - Serial number of conflict monitor
    - Comments regarding fail or pass conditions, i.e. which streets were yellow/red during the test
- ✓ Failed monitors should be either repaired so that they pass the above-described monitor test or replaced with a monitor that passes the test.

Although extremely thorough, the computerized testing tests only the unit itself and is not connected to the cabinet. Using a jumper wire and pulling the load switch also tests the cabinet wiring and harnesses (and is a quick test of the unit). This is an important test to perform if cabinets are frequented by rodents that chew on electrical wires/cables.

Time Clock Flashing Warning Devices

Flashing warning devices that are to be activated during certain time periods shall include a controller with time clock. It is important that these devices operate only when intended. For example, school zone speed limit sign flashers are activated only when school is in session. This enhances the meaning of the school zone speed limit. If the devices flash during non-school hours the device may generate motorist disrespect which in turn could affect the usefulness of other flasher installations and jeopardize pedestrian safety.

Basic maintenance responsibilities include setting clocks, programming a calendar (school, holidays, and specific dates) and disabling the device. When school is not in session (unexpected school closure for reason such as winter weather) school zone flashers shall be disabled.

2.6.5 Traffic Signal Communications

Hardwire

Hardwire communications options include phone line, fiber optic, or direct wiring. Maintenance includes checking that communications between all system components that are part of the system are functioning. It is not possible to inspect underground hardwire; however, where communications are overhead, ensure that any trees or vegetation nearby has been trimmed away from the aerial lines.

Radio Spread Spectrum

Test all radio communications at each intersection to ensure no faults are detected in the radio diagnostics and the received signal strength indicator (RSSI) is within the acceptable fade margin. Adjustments shall be made to correct any deficiencies found in the communications system. If the radio or associated equipment needs to be replaced it shall be done in accordance with Section 957 of Publication 408 (i.e., “Highway Specifications”) and the manufacturer’s recommendations.

Time-Based

Ensure time clock is checked regularly for accuracy and that it is adjusted for daylight savings time. Where GPS clocks are used, periodically inspect to ensure they are operational; otherwise such clocks are virtually maintenance-free.

TMC-Activated/Closed-Loop Systems

Closed-loop systems consist of a number of local intersection controllers that all connect to a master controller and then tie into a central computer. This central computer can be located at a municipal building or a Transportation Management Center. Closed-loop systems sometimes include video cameras not only for detection of vehicle as it relates to a signal’s operation and for the detection of vehicle queuing or incidents.

Maintenance of the closed-loop system is really covered through maintenance of all the individual components. The primary maintenance for closed-loop systems, however, is to ensure that communication between all components is functioning properly. Closed-loop systems are expensive and even a failure of one of its low-cost components can render the closed-loop system useless.

Traffic Signal Software and Firmware Upgrades

Regular updates to traffic signal software or firmware are important to avoid problems that manufacturers become aware of and address with the upgrades. Ensure that the municipality is on the manufacturers' mailing or email list so that they are notified of software or firmware upgrades.

2.6.6 Vehicle Preemption Systems

Vehicle preemption systems give priority to those vehicles considered a priority such as fire engines, ambulance, and police cars, or even mass transit vehicles. These priority vehicles preempt the right-of-way by interrupting the normal phase sequence of a signal or signals along a route to allow for their safe and rapid passage. After a preset time period, the signal returns to normal operation.

Each preemption system should be inspected routinely using the guidance materials provided in Forms TE-972 and TE-973. These documents will provide the necessary details to consider when providing both response and preventative maintenance. The Traffic Signal Permit, Publication 408 (i.e., "Highway Specifications"), and Publication 149 (i.e., "Traffic Signal Design Handbook") are key materials that should be used when evaluating emergency vehicle preemption systems.

If the preemption system needs to be replaced, please refer to Publication 35 (i.e., "Approved Construction Materials," also referenced as Bulletin 15) to determine what manufacturers and model numbers are approved to the Department's specifications. All installations shall follow Publication 408 (i.e., "Highway Specifications") and the manufacturer-recommended procedures.

Optical and Acoustical Emergency Vehicle Preemption

As discussed in Section **2.6.2**, optical emergency vehicle preemption (EVP) uses fail safe, or confirmation lights, to provide indication to the driver whether the approach is being preempted. When EVP is in operation, the confirmation light flashes for the preempted approach and is dark for the conflicting approaches. Maintenance responsibilities include ensuring the lights are properly aligned with each corresponding approach and testing for confirmation light off/dark operation using the appropriate transmission signal for the particular area (acoustical, optical, etc.).

For sound-based systems, periodically test the emergency vehicle sirens for compliance with Class A siren specifications.

GPS Emergency Vehicle Preemption

With global position system (GPS) EVP, vehicles are equipped with a driver's console, computer, global positioning system (GPS), and data radio. A driver enters pertinent details about the current trip and the console notifies the driver of the time remaining to the destination. Priority request information is transmitted by the vehicle to a centrally located base station when the vehicle crosses a report line. Communication techniques include transmission of priority requests from emergency vehicle to a control center by digital channels and transmission of the signal priority command from the control center to the intersection using spread spectrum radio or optical links. There is little preventative maintenance for GPS EVP. Problems with communication links are identified during normal use.

Button Activated

Button activated emergency preemption operates typically from within a building such as a fire company/emergency building. Verify button operation and repair, replace, or clean as necessary.

Queue and Ramp Preemption

Queue and ramp preemption are used to clear a ramp or queue from the point of detection to clear a traffic signal. Typically this includes the off-ramp signal from a limited access route. This type of detection turns the signal green to clear traffic from a ramp or other roadway so that it does not back up onto a freeway or other major area of conflict.

Where adjacent traffic signals are within close proximity to the off-ramp traffic signal with ramp preemption, it may also be necessary to preempt these signals so that queuing does not occur from these locations such that it blocks the ramp signal should the ramp preemption be activated.

Maintenance is simply verifying that detection is functioning properly as discussed in Section **2.6**.

Railroad Preemption

Railroad preemption is typically used when a highway-rail grade crossing is so close to a signalized intersection that queuing (i.e., traffic back-ups) from the intersection could encroach or extend beyond the rail crossing. The objective of standard railroad preemption is to detect the presence of an approaching train and then to have the traffic signal quickly provide a green signal indication to traffic on the approach with the rail crossing so that no vehicles will be standing on the grade crossing.

Another variation is the use of a pre-signal, i.e., a regular R-Y-G set of traffic control signals in advance of the highway-rail grade crossing that turns red before the traffic control signal at the nearby signalized intersection so that no traffic is ever stopped in the immediate grade crossing area. In order to ensure that traffic is not queued in the vicinity of the grade crossing, standard vehicular detection is used on this section of highway. Refer to Section **2.6** for maintenance of these detection devices.

Transit Signal Priority

The objective of Transit Signal Priority (TSP) is maintaining schedules and improving transit travel time efficiency while at the same time minimizing impacts to normal traffic operations. A detection system lets the TSP system know where the vehicle requesting signal priority is located. This detection system communicates with a priority request generator which alerts the traffic control system that the vehicle would like to receive priority. Software processes the request and decides whether and how to grant priority based on the programmed priority control strategies. Software is used to manage the system, collect data, and generate reports. Maintenance is primarily related to software and hardware operation. It is recommended that maintenance be performed by an experienced technician.

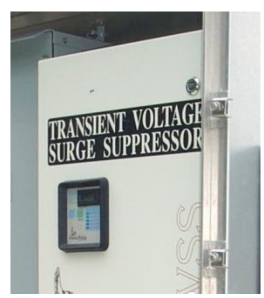
2.6.7 Electrical Distribution

Electrical distribution consists of all the electrical components that power and operate a traffic signal. Without a properly maintained and functioning electrical distribution, the most state-of-the-art traffic signal could operate ineffectively. This section provides a general overview of what to look for when performing maintenanPce and inspection. Refer to the Appendix (section **10.5**), TE-973, for more detailed preventative maintenance procedures. The Traffic Signal Permit, Publication 408 (i.e., "Highway Specifications"), and Publication 148 (i.e., "Traffic Standards – Signals, TC-8800 Series") are also key materials that should be used when evaluating electrical distribution.

When replacing electrical distribution components, please refer to Publication 35 (i.e., "Approved Construction Materials," also referenced as Bulletin 15) to determine what manufacturers and model numbers are approved to the Department's specifications. All installations shall follow Publication 408 (i.e., "Highway Specifications") and manufacturer recommended procedures.

Various electrical distribution components are summarized in the following table.

Junction Boxes Junction boxes should be inspected to ensure they remain sealed from water with the cover securely in place. Replace any cracked covers. Any junction boxes visibly cracked should be sealed or replaced. Ensure the junction box is flush with the ground elevation and that no erosion is occurring that could draw water. Also inspect inside the junction box and the inside of pole shafts for abnormal amounts of water or water damage. If water is present take measures to drain by installing weep holes.	
Conduit Ensure that any penetrations of conduit from equipment are sealed using electrical duct seal. Any exposed conduit should be buried. Any visible conduit that is crushed or cracked should be replaced.	

Emergency Generator Connection An emergency generator can be used when the controller provides switchover capability through the use of a generator adaptor kit. It is essential that the plug on the controller is compatible with the receptacle on the generator. Maintenance includes inspection of the disconnect enclosure, transfer switch, surge protection, and connector cable assembly.	
Controller Test for grounding, corrosion, and loose connections. Ensure fuses or power breakers are functioning. Clean or replace air filter as necessary.	
Service Disconnect Ensure power service disconnect box is properly locked and free of rust.	
Backup Power For Uninterrupted Power Supply (UPS) or Battery Backup Unit (BBU), inspect to ensure no faults are present and that the unit is in proper working order. If any problems are identified, the unit shall be replaced in accordance with Section 954 of Publication 408 (i.e., "Highway Specifications) and manufacturer recommendations.	
Surge Protection Devices (SPDs) The use of SPDs will protect against damages caused by lightning or other electrical disturbances. The National Fire Protection Association's NFPA 780 (installation of Lightning Protection Systems) is the standard, and critical applications include inductive loops, video cameras, pedestrian pushbutton loops, service loops for controls or signals that exit or enter the cabinet, and the AC that supplies the power.	
Splices Inspect all splices to ensure they are all solidly connected and not degraded. If deterioration is identified, splices shall be replaced in accordance with Section 954 of Publication 408 (i.e., "Highway Specifications").	

2.6.8 Traffic Signal Signing

At traffic signals, signing is used to regulate traffic flows, designate the use of approach lanes, restrict certain movements, and guide motorists. Missing signs could confuse motorists or cause a conflict that may otherwise not occur if the appropriate regulatory signs were in place.

Each sign should be inspected routinely using the guidance materials provided in Forms TE-972 and TE-973 (see the Appendix – section **10.4** and **10.5**). These documents will provide the necessary details to consider when providing both response and preventative maintenance. The Traffic Signal Permit, Publication 408 (i.e., "Highway Specifications"), Publication 111M (i.e., "Traffic Control Pavement Markings and Signing Standards," TC-8600 and TC-8700 Series), Publication 236M (i.e., "Handbook of Approved Signs"), and Publication 148 (i.e., "Traffic Standards – Signals, TC-8800 Series") are key materials that should be used when inspecting signs.

Transition from one to four lanes with no overhead lane use control signs

If signs need to be replaced, please refer to Publication 35 (i.e., "Approved Construction Materials," also referenced as Bulletin 15) to determine what manufacturers are approved to the Department's specifications. All installations shall follow Publication 408 (i.e., Highway Specifications") and manufacturer recommended procedures.

As a final item, signs must conform to the minimum sign retroreflectivity values in Section 2A.08 of the *MUTCD* 2009 Edition.

Overhead Signs

Overhead signing generally consists of signs mounted on mast arms or span wire. Most often these signs are mounted adjacent to the traffic signals. Examples include LEFT TURN SIGNAL, NO TURN ON RED, or street name signing. Signing is also mounted overhead in advance of a multilane intersection approach. This type of signing is referred to as lane use control signing and is important to direct motorists into the appropriate lanes to minimize the potential for sideswipe crashes. These signs become especially important when snow covers the pavement and the markings which supplement these signs. It is important that all signs pertaining to operation of the traffic signal be included on the permit and verified in the field during inspections. Mounting should

Appropriate overhead lane use control

follow the recommendations provided in Publication 148 (i.e., "Traffic Standards – Signals, TC-8800 Series").

Prior to adding additional signs or replacing existing signs with larger sizes, it is important to:

- ✓ Ensure that the sign structure is capable of accommodating the additional loading (see Publication 149).
- ✓ Obtain a required revision of the traffic signal permit.

Ground Mounted Signs

Ground mounted signs also consist of turn restrictions and lane use control, as well as numerous other regulatory signing. Signs should be securely mounted with no evidence of damage. This signing should also be included on the traffic signal permit if it pertains to traffic signal operation. Field inspections should confirm there are no missing signs.

Signs on Traffic Signal Pedestal Supports

Signs on traffic signal supports include NO PEDESTRIAN CROSSING, push button signing, and sometimes RIGHT TURN SIGNAL signs. Signs should be securely fastened to supports using banding material.

Internally Illuminated Signs

Perform the following activities:

- ✓ Ensure that mast arm bracket connections are secure.
- ✓ Inspect wiring from Internally Illuminated Sign to service disconnect box.
- ✓ Ensure drain holes in the bottom of the sign are unobstructed and that no corrosion is present.
- ✓ Ensure the transparent reflective sheeting is internally illuminated and retroreflective when not energized.
- ✓ Inspect entrance junction box to ensure a weather-tight seal is still provided to the sign assembly.
- ✓ Inspect photocell and LEDs and replace as necessary.
- ✓ Ensure that any swing brackets allow the sign to swing freely.

Unlike retroreflective signs that gradually deteriorate, when an internally illuminated sign stops working the message is not legible. In the past, this has been a specific problem with Signal Ahead (W3-3) signs, but it could also be an issue with signs used in conjunction with railroad preemption.

When used as a blank-out sign, problems are compounded because in order to review the functionality of the sign, the sign must be energized.

2.6.9 Traffic Signal Pavement Markings

Pavement markings provide the motorist with guidance so that they remain in the appropriate lane as they approach and travel through an intersection. Typical markings at intersections include lane lines, word and arrow markings, stop and yield lines, and crosswalks.

Markings should be inspected routinely using the guidance materials provided in Forms TE-972 and TE-973 (see the Appendix – section **10.4** and **10.5**) when providing response and preventative maintenance. The Traffic Signal Permit, Publication 408 (i.e., "Highway Specifications"), and Publication 111M (i.e., "Traffic Control Pavement Markings and Signing Standards," TC-8600 and TC-8700 Series) are key materials that should be used when reviewing pavement markings.

All pavement markings are required to be retroreflective. The Federal Highway Administration (FHWA) is also in the process of "raising the bar" on quality control by establishing minimum retroreflectivity values.

If pavement markings need to be replaced, refer to Publication 35 (i.e., "Approved Construction Materials," also referenced as Bulletin 15) to determine what manufacturers are approved to the Department's specifications. All installations shall follow Publication 408 (i.e., "Highway Specifications") and manufacturer recommended procedures.

Longitudinal Pavement Markings

These include markings that run in the direction of travel. Currently on state highways, the Department maintains longitudinal pavement markings.

Poorly maintained pavement markings

Transverse Markings

Transverse markings are those which run perpendicular to direction of travel. They include stop and yield lines, and crosswalks. Maintenance of these markings is the responsibility of the municipality even if the traffic signal is on a state road at a traffic signal.

These markings need to be replaced frequently since they are driven over constantly. Municipalities are encouraged to specify preformed thermoplastic markings to reduce the frequency of replacing these markings.

Legend Markings

Legend markings are used to designate the use of a lane. At signalized intersections, they frequently include "arrows" and "ONLY" legends.

Example of pavement markings in good condition

Maintenance of these markings is the responsibility of the municipality, even if on a state road at a traffic signal. These markings need replaced frequently since, like transverse markings, they are driven over frequently. Therefore, municipalities are encouraged to use preformed thermoplastic material.

Pavement marking legends need to conform to the plan sheet in the traffic signal permit. However, the word "ONLY" is currently required only on through lanes that become mandatory turn lanes. For example, ONLY is no longer required where it is obvious to motorists that a left-turn or right-turn lane is an added lane at an intersection. Therefore, if these words are included on the traffic signal permit for turn lanes, consider requesting a change in the permit to eliminate them.

2.6.10 Sidewalks and ADA Curb Ramps

Municipalities are responsible for pedestrian accommodations, including sidewalks and curb ramps. Moreover, whenever an existing pedestrian facility is replaced, it must either be brought into compliance with PennDOT's standards or have an approved Technically Infeasible Form for any element that does not meet full compliance.

Publication 149 contains additional guidance on when the revisions must be made and what provisions must be followed (see Publication 149).

2.7 Traffic Signal Retiming and Equipment Upgrade Activities

2.7.1 General

After traffic signals are installed, traffic volumes change and new technologies are developed. Therefore, the Department encourages municipalities to reexamine the traffic signal timing and the equipment about every 3 to 5 years to see if changes would be helpful to improve traffic flow and safety. The "retiming" of a traffic signal should reduce delays, and reduce emissions and motorist fuel costs.

When traffic signal retiming activities are to occur, the Department recommends referring to the Federal Highway Administration's (FHWA) Traffic Signal Timing Manual. This manual is a comprehensive guide of traffic signal timing concepts, analytical procedures, and applications based on current practices.

Traffic signal equipment upgrades, and phasing and timing changes usually require modification of the traffic signal permit.

The remaining chapters in the training manual focus on traffic signal timing activities.

2.7.2 Regionalization

Sometimes it is best to pursue retiming of traffic signals from a regional approach because it is desirable to coordinate cycle lengths and offsets at all traffic signals on the same corridor. It is also more economical to perform reviews on a regional basis due to economies-of-scale and the possible elimination of performing new traffic counts due to redundancies within a region. In addition, expediting traffic flow at one intersection may not produce the desired results if other bottlenecks remain.

Regionalization also helps to encourage consistencies within a region. A coordinated traffic signal system is in the best interest of the traveling public, and municipal boundaries mean nothing to the motorist. For example, a three mile corridor with multiple traffic signals may involve several municipalities. Motorist delay should be minimized along the corridor by coordinating and retiming all traffic signals no matter where the traffic signals reside. Another example relates to equipment consistency. Instead of upgrading equipment to provide emergency vehicle preemption equipment or countdown pedestrian signals at random intersections, from a user standpoint there is merit in doing so at all intersections within a region.

Therefore, "regionalization" is an important component when considering the impacts of multiple traffic signals and the unnecessary congestion created by them not operating as a system. The congestion caused by their operation as fragmented systems or isolated intersections results in increased fuel consumption, driver delay, and emissions.

Regionalization can also bring the benefits of obtaining more affordable contracts, obtaining relationships with neighboring municipalities, and becoming more knowledgeable of proper and best practice timing and upgrading techniques. Regionalization requires multi-municipal maintenance and/or operational agreements as outlined in Chapter 11. Regional planning partners can assist with multi-municipal agreements.

2.7.3 Retiming Efforts

Traffic signal timing can range from the very simple (e.g., pretimed operation at an isolated intersection) to very complex (e.g., interconnected traffic signal system with adaptive traffic control system). In any case, it is important to maintain effective traffic signal timing plans. By providing motorists with efficient traffic signal timings, delay is reduced and complaints to the municipality relative to traffic signal operation are reduced.

The Federal Highway Administration (FHWA) has indicated that traffic signal retiming does not necessarily require a significant amount of effort. They have suggested that it takes approximately 40 hours of labor, at a cost of approximately $2,000 to $5,000 per intersection, which would include collecting the traffic volume data, evaluating those volumes to develop three timing plans (typically the peak traffic periods), and then implementing those timings in the field.

Additionally, FHWA has published a document entitled, "Signal Timing on a Shoestring," in which they note that the biggest cost for traffic signal retiming is for data collection. Therefore, FHWA has suggested a "short-count method" using the following steps:

1. Determine the beginning and ending time of the period for which the count is intended to represent.
2. Within this time window identified above, start a stop watch when the yellow ends for the through movement on the approach being observed.

3. Record the number of vehicles turning left, through, and right during the cycle measured from the end of yellow to the end of yellow during each cycle.
4. Continue recording the counts at the end of each cycle until at least 15 minutes have elapsed and at least eight cycles are recorded.
5. For the last cycle, add the number of vehicles in queue (if any) to the count for the last cycle.
6. Record the time on the stop watch (10 minutes or more).
7. Convert the counts to an hourly flow rate for each movement.

By using the above “short-count method,” it is estimated that the cost of data collection is about one-half of the typical full peak-hour counts with tube automatic counts during the full day.

The need for traffic signal retiming is generally a result of changes in traffic demand since the intersection was last timed. This change in traffic demand could be related to land-use changes, general population growth, special event impacts, or other factors.

While the need for retiming can be identified in several different ways, calls from the public are one of the most common reasons for reviewing intersection operations. It is not possible for municipal officials to be present at every intersection each hour of the day to evaluate operations so motorist complaints are one of the best ways to identify problems. Most complaints involve motorists being annoyed by waiting at a red signal indication when there are no vehicles present on any other approach (which may be due to lack of or a malfunctioning detection), or when they have to stop at successive traffic signals in a corridor (coordination not present or operational). Motorists could be frustrated by having to wait several cycles at an intersection when they see other approaches to a traffic signal clearing in one cycle. These are all valid complaints that should not be ignored. Simple timing adjustments can result in significant benefits.

As congestion increases, traffic signal retiming can be the only effective way to increase capacity other than high-priced capacity-adding projects.

For that reason, both FHWA and the Department recommend retiming traffic signals every 3 to 5 years.

Keep in mind that in some cases public complaints cannot be resolved because they are not aware of the other traffic signal operations constraints (involving pedestrian clearance times, progression, or other factors). When evaluating and responding to citizen calls or other correspondence, capture the following information to ensure that the issue is investigated appropriately:

- ✓ Name and contact information
- ✓ Location information
- ✓ Time-of-day of problem
- ✓ Description of problem

Ideally, all complaints should be entered into a spreadsheet or database that catalogues the date the complaint was received, the information outlined above, the date of the evaluation, and the date of the response to the citizen (if necessary).

A Best Practice. It is good to keep a digital backup of all signal timings to ensure that the appropriate timings can be quickly restored if needed. In fact, Engineering Districts may request municipalities do this as part of an agreement.

Signal timing maintenance occurs not only due to motorist complaints but for other reasons as well:

- ✓ Land use changes
- ✓ Population growth
- ✓ Change in flow profiles (volume and classification)
- ✓ Incident management
- ✓ Special Events
- ✓ Construction work zone or a temporary traffic signal
- ✓ Traffic signal equipment change
- ✓ Scheduled or periodic traffic signal retiming
- ✓ High frequency or rate of crashes

Once the need for traffic signal retiming has been identified, follow the procedure in **Exhibit 2-12** and document using Forms TE-972 and TE-973 (see the Appendix – section **10.4 and 10.5**).

Exhibit 2-12 Signal Retiming Flowchart

Schedule a field visit for the type and time of day in which the problem was identified

↓

Assemble the traffic signal permit and the traffic volume information if available

↓

Observe the physical condition of traffic signal hardware and perform a physical inspection of controller cabinet components

↓

Check operability of all cabinet components either through observation or diagnostics

↓

Compare controller timing settings with timing documentation on the traffic signal permit

↓

Qualitatively compare traffic conditions with the traffic count data to determine if demands have changed

↓

Identify whether the adjustments are intended for congested or under-saturated conditions, depending on time of day in which problems are known

↓

Determine the procedure to be followed for the traffic signal retiming (not a field item)

↓

Evaluate the impact of the timing changes by observing the intersection for a minimum of one hour during morning, midday, and evening peak (and off-peak if necessary)

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 (HCS), Synchro and SimTraffic, and others. Since new software packages are being developed, municipalities are encouraged to review Chapter 12 of Publication 46 or contact the local PennDOT District to identify the appropriate analysis tool to be used. All traffic signal timing modifications should be developed by an engineer and implemented by a traffic signal specialist or technician.

The Department is currently developing a traffic signal retiming program; therefore, a municipality may wish to contact their Engineering District Office for any updates.

2.7.4 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, the following potential upgrades should be identified, any modifications should be indicated to the appropriate District office.

- ✓ Replace incandescent bulbs with Light Emitting Diodes (LEDs)
- ✓ Replace inductive loop detectors with video detection
- ✓ Replace physical interconnection with spread-spectrum radio or other wireless applications
- ✓ Install emergency vehicle preemption (EVP)
- ✓ Install countdown pedestrian signals (now required in most situations in Publication 149) to improve safety for pedestrians or where no pedestrian accommodations present install countdown signals and push buttons
- ✓ Install adaptive traffic signal control that responds to changes in traffic demands
- ✓ Add an uninterruptible power supply (UPS) or battery backup Unit (BBU)
- ✓ Add surge protection devices to reduce the threat of lightning damage
- ✓ Safety-related upgrades such as the addition of a protected left-turn phase or the addition of a near-side traffic signal where, for example, truck traffic restricts view of primary traffic signals

2.7.5 Benefits of Upgrades

Studies around the country have shown that the benefits of area-wide signal timing outweigh the costs 40:1 (or more). 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 Traffic Signal Timing Manual indicates that improved traffic signal operations can:

- ✓ Reduce traffic delay 15-40%
- ✓ Reduce travel time up to 25%
- ✓ Reduce stops 10-40%
- ✓ Reduce fuel consumption up to 10%
- ✓ Reduce harmful emissions up to 22%, resulting in cleaner air.

For example, traffic signal timing upgrades would result in a savings of almost 17 billion gallons of fuel per year on a nationwide basis.

Numerous programs exist in the state which have proven the benefit of traffic signal upgrades as shown in **Exhibit 2-13**.

Exhibit 2-13 Signal Upgrade Programs

Program	Description/Benefits
PennDOT Congested Corridor Improvement Program (CCIP)	Program which identifies immediate, short-term, and long-term improvements on a signalized corridor to reduce fuel consumption, emissions, and delay. Includes recommendations for traffic signal retiming as well as infrastructure upgrades. Goal of CCIP program is a 20 percent reduction in corridor delay.
PennDOT Traffic Signal Enhancement Initiative (TSEI)	Program which evaluates traffic signal timings and the need for upgrades. May include coordination, upgrade of detection, and the use of new traffic signal technologies. Goal of TSEI program is a 10 percent reduction in corridor delay.
Southwestern Pennsylvania Commission (SPC) Signals In Coordination with Upgrades (SINC-UP) program	SPC has developed a regional traffic signal program that includes technical assistance to municipalities as well as potential funding to assist in upgrading signal systems in the region. Travel time and delay studies performed as part of the program identified 5-year savings for one project at just over $800,000 with a benefit-cost ratio of 43:1.

Equipment upgrades can also result in benefits by providing additional efficiency and safety components to 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%
- ✓ Implementing video detection would reduce the maintenance costs associated with replacing inductive loops which have a higher failure rate
- ✓ Spread spectrum radio interconnection can eliminate monthly utility attachment costs associated with physical interconnection
- ✓ Emergency vehicle preemption can reduce response times by 16-23%
- ✓ Countdown pedestrian signal heads can reduce confusion for pedestrians crossing the street

Adaptive traffic control signal systems can reduce delay up to 22% over typical time-of-day timing.

2.8 Traffic Signal Maintenance Agreements

Traffic signals are owned and maintained by the municipalities. Moreover, when the Department issues a Traffic Signal Permit (PennDOT Form TE-964), the Department clearly indicates that it is the responsibility of the municipality to maintain the traffic signal in a safe condition at all times.

However, if the intention is to use any state or federal funds to construct the traffic signal, the Department also requires that the municipality enter into a Traffic Signal Maintenance Agreement with the Department prior to the design and construction of the signal. The purpose of this agreement is to fulfill the state's fiduciary responsibility to the citizens of the Commonwealth by ensuring that the limited state and federal funds are not wasted and the traffic signal equipment is transferred properly. After all, it would be an embarrassment to the Department and local residents if, after the traffic signal was installed, it was not properly energized or maintained.

The purpose of this section is to discuss the Traffic Signal Maintenance Agreement.

If the District determines that a traffic signal is not being properly maintained and safety is being compromised, the Department will immediately notify the municipal traffic signal owner to take appropriate corrective action.

2.8.1 General Provisions

The *"Commonwealth and Municipal Traffic Signal Maintenance Agreement"* is between the Department and the municipality, and it addresses the required maintenance and operation of the traffic signal installation. This traffic signal maintenance agreement can be for a single intersection, or for multiple signalized intersections within the municipality. This document is a standard statewide agreement that contains very detailed maintenance responsibilities of the municipality, and requires the municipality to attach a copy of the municipal resolution that authorized the execution and attestation of the traffic signal maintenance agreement. A copy of the template for the traffic signal maintenance agreement is included in the Appendix (section **10.1**). Additionally, the traffic signal maintenance agreement should not be altered from the already approved language from the Department's Office of Chief Counsel.

The traffic signal maintenance agreement requires the municipality to also note if maintenance will be done with municipal personnel or via contract, and if by contract, it requires a municipality to provide the name of the contractor and a copy of the traffic signal maintenance agreement or contract that the municipality has with the contractor.

The "traffic signal maintenance agreement" includes the following exhibits which are further clarified below:

1. Preventive and Response Maintenance
2. Recordkeeping
3. Signal Maintenance Organization
4. Contractor Integrity Provisions
5. The Americans With Disabilities Act
6. Contract Provisions – Right to Know Law 8-K-1532

2.8.2 Exhibits

Exhibit A, Preventative and Response Maintenance

This exhibit defines the level of preventative maintenance and response maintenance that is required by the municipality as discussed in Section **2.4** of this training manual.

Exhibit B, Recordkeeping

Because accurate maintenance records are essential to document the preventative maintenance schedule and to be better able to estimate the need for spare hardware, each municipality that enters into the Traffic Signal Maintenance Agreement is required to use the same basic recordkeeping forms unless first authorized by the Department. The following three forms are identified in Exhibit B:

- ✓ TE-971 – Master Signal Maintenance Log
- ✓ TE-972 – Response Maintenance Record
- ✓ TE-973 – Preventative Maintenance Record

Since municipalities sometimes contract with different maintenance contractors, the importance of maintaining good records cannot be overemphasized. Moreover, the forms should reside in separate intersection folders in the municipal building, signal maintenance shop, or some other weather-protected building.

Exhibit C, Maintenance Organization

This exhibit addresses the personnel classifications that the municipality needs to maintain if they perform their own traffic signal maintenance. There is also a place for the Department and the municipality to mutually agree to specific training requirements, which would generally come into play when the municipality is exposed to new types of equipment or a higher level of complexity is involved.

Exhibit D, Contractor Integrity Provisions.

This exhibit establishes contractor integrity provisions that apply for any traffic signal maintenance contractor.

Exhibit E, Provisions Concerning the Americans with Disabilities Act.

This exhibit defines the requirements to comply with the Americans with Disability Act, to avoid discriminating against any person with a disability, and to absolve the Commonwealth of Pennsylvania of all actions due to failure to comply with the Act.

Specifically, a municipality should be aware of the requirements of the Department's Standard Drawing No. RC-67, which is in Publication 72M (i.e., "Standards for Road Construction"). These standard drawings define the details required for curb ramps and sidewalk features in order to satisfy the ADA requirements (see ftp://ftp.dot.state.pa.us/public/Bureaus/design/PUB72M/RC-67M_c3.pdf).

2.9 Municipal Service Purchase Contracts

Most municipalities do not have the in-house expertise, staffing, equipment, or inventory of parts necessary to service and maintain traffic signal equipment. Therefore, the preferred method of maintaining traffic signals is by a traffic signal contractor.

A number of options are available to select a traffic signal contractor:

- ✓ low-bid;
- ✓ qualifications-based selection;
- ✓ two-step process (first low-bid, then request qualifications from say the two lowest bidders)

Using a low bid may be fairly simple for preventative maintenance elements, but a municipality generally needs to estimate a certain number of hours and replacement parts to consider the response maintenance side of the equation. Similarly, basing everything on qualifications (e.g., experience, expertise, personnel, project management, and the distance between the contractor's home base and the traffic signals) is subjective. Therefore, perhaps the best criteria is to make it a two-step process – request qualifications from the two or three lowest bidders and then make the final selection based on perceived qualifications. It is also a good idea to request references.

If the municipality uses a contractor to perform the maintenance of the signals, Chapter 4 of the agreement between the Department and the municipality requires that the municipality provides the Department with a copy of the document they use to obtain these services. Unlike the above traffic signal maintenance agreement between the Department and the municipality, there is no standard format for the document, which allows municipality and a maintenance contractor some creativity and flexibility. For example, municipalities can call it a contract or an agreement; they can establish hourly labor and equipment charges; very detailed unit prices for almost countless types of equipment; etc.

In general, a municipality is responsible for the maintenance of everything on the traffic signal permit plan including the traffic signal and all appurtenances (pavement markings, signs, and any advance warning signs).

It is important to note that even if a municipality uses a maintenance contractor, the municipality is still ultimately responsible for traffic signal ownership, maintenance, and operations. For this reason, the Department will only communicate with the municipality if they observe any deficiencies, and not with the contractor.

2.9.1 Typical Provisions

Municipalities are encouraged to ensure that contracts or agreements between the municipality and the contractor address, as a minimum, the following issues to minimize potential legal battles:

- ✓ A minimum duration of the contract or agreement needs to be established (e.g., a 3-year contract with an option for renewal).
- ✓ What materials need to be stockpiled by the contractor?
- ✓ Define the schedule for annual preventative maintenance and the on-call response time.
- ✓ Establish any charges and the periods of time they apply. For example, specify hourly charges for service personnel, flaggers, crane trucks, auger trucks, backhoes, etc., for both regular business hours and non-business hours (emergency call outs).
- ✓ What additional charges are necessary for late payment?
- ✓ The applicable publications listed in Section **1.4**.

2.9.2 Accreditation – Department / IMSA

As noted earlier, the contractor and the municipal personnel should be provided with the appropriate training to assure that they have a thorough understanding of current traffic signal technologies and proper maintenance procedures. The Department also encourages municipalities to require their traffic signal maintenance contractor to satisfactorily complete a certification program sponsored by a nationally recognized organization such as the International Municipal Signal Association (IMSA).

At a minimum, the Department recommends IMSA Work Zone Traffic Control Safety Certification (or LTAP's Temporary Traffic Control Training) and the IMSA Traffic Signal Level 1 Training to effectively understand traffic signal maintenance activities. IMSA Traffic Signal Level 2, IMSA Traffic Signal Level 3, IMSA Traffic Signal Inspection, and other traffic signal courses may be desirable to obtain a full understanding of traffic signal maintenance and operations. (See http://www.imsasafety.org/ for additional training details.)

2.9.3 Estimating Prices

Exhibit 2-4 includes some of the most common unit prices related to traffic signals. However, municipalities are encouraged to use the unit prices from recent Department-administered projects to get a sense of current costs (see Publication 287). Although these costs include typical labor costs, maintenance costs tend to be higher than new construction costs because old components frequently need to be removed before new components can be installed. In addition, maintenance normally involves smaller quantities than construction projects.

The primary benefit of understanding future costs is to avoid sticker shock and to help a municipality plan and budget for future upgrades.

2.9.4 Specifications

When available, municipalities should use Publication 408 (i.e., "Highway Specifications") for all replacement components for the following reasons:

- ✓ The original construction plans would have used PennDOT's standards and all replacement items should follow the same criteria so that the traffic signal continues to conform to the traffic signal permit.
- ✓ Uniform, standardized specifications simplifies installation and maintenance for contractors and makes it less likely that compatibility issues will evolve.
- ✓ Sole source items tend to be significantly higher in cost

In the event that PennDOT does not have a specification, municipalities are encouraged to keep their special provisions as generic as possible to avoid proprietary items. Only items critical to the interconnection of traffic signals should be considered as proprietary. However, municipalities are encouraged to use similar equipment from one intersection to the next because this simplifies the formation of some traffic signal systems and reduces the necessary number of spare parts.

2.9.5 Maintenance Contracts/Agreements

As a final item, if a municipality is not prepared to maintain their own traffic signals, it is very important that they have a legal document in place to ensure that they can obtain maintenance repairs on a timely basis. Without a contract or agreement, it is very likely that repairs will not be completed in a timely manner, which in turn increases:

- ✓ Costs for temporary traffic control during outages.
- ✓ Liability in the event of a crash due to improper operation.

2.10 Design Modifications

Modifications to a traffic signal installation are sometimes necessary to accommodate changes in traffic, to improve a safety problem, or for a number of other reasons. Except during emergency traffic control or when otherwise authorized by the Department, proposed design modification must first be approved by the Department and the Traffic Signal Permit must be updated to reflect this modification.

2.10.1 Introduction

A design modification is a change to the approved design and operation of an existing traffic signal or traffic signal system. Changes can be initiated by the Department, the municipality, a developer, or the contractor to correct a recurring problem, accommodate changes in prevailing traffic or physical conditions, update the installation to current state-of-the-art design, or address a safety problem. For any change a traffic engineering study in accordance with Publication 46 is required. Typical modifications include: addition or removal of signal phases or special functions; changes in signal displays, configurations, or locations; detector modifications; upgrading of Intelligent Transportation Systems (ITS) equipment and communication systems; and sign revisions such as No Turn on Red restrictions and marking revisions due to lane configuration changes. However, a design modification cannot occur until the signal permit is revised.

This chapter discusses how to identify the need for design modifications and the typical solutions to resolve design deficiencies commonly occur. A checklist is included in the TE-974 form (see the Appendix – section **10.6**) to facilitate the design modification process.

Problems with the design or operation of traffic signals and traffic signal systems sometimes develop or become apparent after the traffic signal is operational. Those performing preventive and response maintenance should continuously be alert for recurring maintenance issues that can be corrected or minimized through a design modification to the existing location. Maintenance personnel are in the best position to detect recurring problems or design deficiencies and to develop the most appropriate design solutions for the specific location. These problems may be detected through the follow-up inspections. This feedback assists designers in reviewing and making suggested improvements to the safety and operation of the traffic signals.

For example, traffic signal technicians should be aware if call-outs occur to correct damage from crashes and should be informed should missed phase calls exist. Some recurring but correctable problems include:

- ✓ Traffic signal head visor damage
- ✓ Traffic signal head visibility issues
- ✓ Obstructions to pedestrian push buttons (i.e. snow)
- ✓ Traffic signal hardware knockdowns
- ✓ Detector alignment
- ✓ CCTV alignment

In addition, technicians should also be aware of new technology and practices that ideally should be implemented and proposed to the municipality as a possible design modification. Examples include:

- ✓ Pedestrian countdown timers
- ✓ Video detection
- ✓ 12-inch traffic signals instead of 8-inch
- ✓ Backplates and/or the addition of retroreflective borders

- ✓ Emergency vehicle preemption
- ✓ Adaptive traffic control system
- ✓ Adding overhead street name signs
- ✓ ADA curb ramps and accessible pedestrian signals
- ✓ Adding positive offset between opposing left-turn lanes

2.10.2 Suggested Procedures for Future Design Modifications

Although many design deficiencies can be identified and corrected through effective feedback from field personnel, a comprehensive review process is also required to ensure that necessary design modifications are detected. The design and operation of each signalized intersection and system should be reviewed on a regular schedule (e.g., every 2 to 3 years) for conformance with the approved plan, conformance with state-of-the-art design standards and features, and compatibility with prevailing traffic demands and physical conditions of the approved traffic signal permit. A safety review should also be conducted. There may be a hidden problem requiring a comprehensive review which makes evident a required change, for example, increasing a phase's split timing, or conversion of a protected/permitted left-turn phase to a protected-only phase.

Additional reviews should be conducted when major changes in land use or roadway systems have occurred at nearby locations. Maintenance records for all components should also be routinely reviewed to determine if problems exist that have not been detected and corrected through direct feedback from appropriate field personnel.

To facilitate the design modification review, use a checklist like the one provided below and provided in the Appendix. Each reviewer should conduct appropriate field investigations, records and data research, and technical studies to answer, at a minimum, the following questions for each of the operation and design features of the traffic signal below:

1. Do the maintenance records reveal recurring problems that a design modification could potentially correct?
2. Are the operation and design in conformance with the approved traffic signal permit?
3. Is the signal in conformance with current design standards and design features? Have changes to the design standards occurred since the approved traffic signal permit? Are new or improved equipment or products available that would consider a design modification? (For example, improved equipment could result in a reduction in life-cycle costs.)
4. Have changes in traffic patterns, volumes, speeds, or physical conditions at the intersection occurred that warrant a design modification?

Where appropriate, recommended improvements or improvement alternatives should be formulated and reviewed with the municipality to determine if it should be presented to the Department. For example, prior to adding items (signs, additional signal heads, etc.) on existing traffic signal span wire or mast arm structural support, further analysis may be necessary, in which the Department should be contacted for assistance.

2.10.3 Department Assistance and Approval

The Department is willing to assist a municipality with the review of any suggested changes, including an on-site field view with them and the maintenance contractor.

All design modifications must be approved by the Department, unless the Department has granted current municipal traffic engineering certification to the municipality as indicated in Chapter 205 of Title 67 of the Pennsylvania Code (67 Pa. Code Chapter 205). However, prior to the Department approving any design modification, the municipality must submit a written request to the Department, recommending the change and agreeing to fund and maintain the modifications.

2.11 Maintenance Contracts/Agreements

Traffic signal maintenance is critical to effectively ensure the safety and mobility of the traveling public through the intersection controlled by a traffic signal. Qualified personnel, maintenance equipment and an inventory of traffic signal equipment allow a municipality to obtain a better understanding of their current practices.

The Department can provide technical assistance and ensure that the contracts are written properly. If there are any questions concerning their proposed contracts, municipalities should contact the appropriate Engineering District (see the Traffic Signal Portal, http://www.dot.state.pa.us/Portal%20Information/Traffic%20Signal%20Portal/Index.html#).

2.11.1 Department Maintenance Agreement

The understanding of maintenance responsibilities is important for a municipality when it first accepts a traffic signal. Although it may seem very simple and practical, effectively managing safety and operations at a traffic signal may become a difficult task. The Department reaffirms the maintenance responsibilities with a municipality before approving any new or revising any existing traffic signals. An official document reaffirms the local authority's maintenance responsibilities, as specified in Chapter 212 of Title 67 of the PA Code (67, Pa. Code Chap. 212). This document must be prepared and accepted by the municipality for every traffic signal.

The basic "Commonwealth and Municipal Traffic Signal Maintenance Agreement" document is included in the Appendix (section **10.1**). Exhibit C of the document requests specific information about the personnel that will be performing the maintenance. This agreement evaluates the maintenance capability of a municipality contemplating an agreement to maintain traffic signals which are to be constructed with the aid of federal or state funds.

The Preventative Maintenance Record (Form TE-973), contains a checklist that should be used to ensure that the signal maintenance personnel performs the proper maintenance responsibilities.

2.11.2 Highway Occupancy Permit Agreement with The Department

Section 441.3 of Title 67 of the Pennsylvania Code (67 Pa. Code, Chapter 441) stipulates that a highway occupancy permit is required from the Department prior to:

- ✓ The construction or alteration of any driveway, local road, drainage facility, or structure within state highway right-of-way.
- ✓ Connection to or alteration of a Department drainage facility.

Department regulations also require that the owner, which would be a municipality for traffic signals, is the party responsible for submitting the application (Form M-945A), and that the application must be submitted to either the Department's District or County office.

This application should be submitted whenever new signal supports, curb radii, new loop detectors, or anything else alters the grade or things below grade within the right-of-way of any state highway. Additional requirements and guidance are defined within Publication 441 (see Chapter 441, i.e., "Access to and Occupancy of Highways by Driveways and Local Roads"). Moreover, the application should be submitted as soon as possible to avoid last-minute changes that may be required by the Department.

Since the Department has the oversight responsibility to maintain its roads, municipalities need to be fully aware of this requirement.

2.12 Multi-Municipal Agreements

In the following two situations, it is necessary to have an agreement between the involved municipalities so that each municipality is aware of their fiscal and maintenance responsibilities:

- ✓ A traffic signal installed at an intersection that is in two or more municipalities.
- ✓ An interconnected traffic signal system that involves more than one municipality.

In both situations, it is very important that each municipality works with each another in a systematic manner in order to ensure that the traffic signal system works as designed. Also, there are certain maintenance elements that are shared in both of the above situations; and without a pre-established cost basis, local authorities could end up thinking that they paid too high for their portion of the bill.

To ensure cooperation, each municipality needs to enter into a *"Cooperative Memorandum of Agreement"* for the multi-jurisdictional signal or signal system. A sample agreement designed for an interconnected signal system is included in the Appendix (section **10.8**).

To ensure system uniformity, one agency should be assigned an oversight responsibility, and identified as Party #1 in the multi municipal agreement. For a single intersection, the oversight agency should typically be the municipality with the controller. However, for interconnected signal systems, the municipality with the oversight responsibility could be determined by any of the following considerations:

- ✓ The municipality with the master controller
- ✓ Either the largest municipality or the one with the highest number of traffic signals in the system
- ✓ The municipality that houses the traffic signal system controller

Additionally, the multi-municipal agreement should identify the following (a sample agreement is included in the Appendix):

- ✓ The costs shared between the respective municipalities or identify the components of local traffic signals that each municipality is responsible for, and those components that are borne by an oversight organization. If costs are shared between the municipalities, the rationale for the sharing should be defined. For example, the costs could be defined by percentages, or based on the prorated number of the intersections within each of the respective municipalities to help address future expansion.
- ✓ The location of the system computer and any adaptive controller (see Paragraph 3 in the sample agreement).
- ✓ A willingness to support future additions to the system (see Paragraphs 5 and 6 in the sample agreement).
- ✓ How to resolve conflicts (see Paragraph 8 in the sample agreement).

The remainder of this training manual focuses traffic signal timing.

CHAPTER 3. DATA COLLECTION

Data collection is a vital element of the traffic signal timing process, therefore it is important to develop a data collection plan. The plan should outline the data to be collected, the parties responsible for collecting the data, and the schedule for collecting the data.

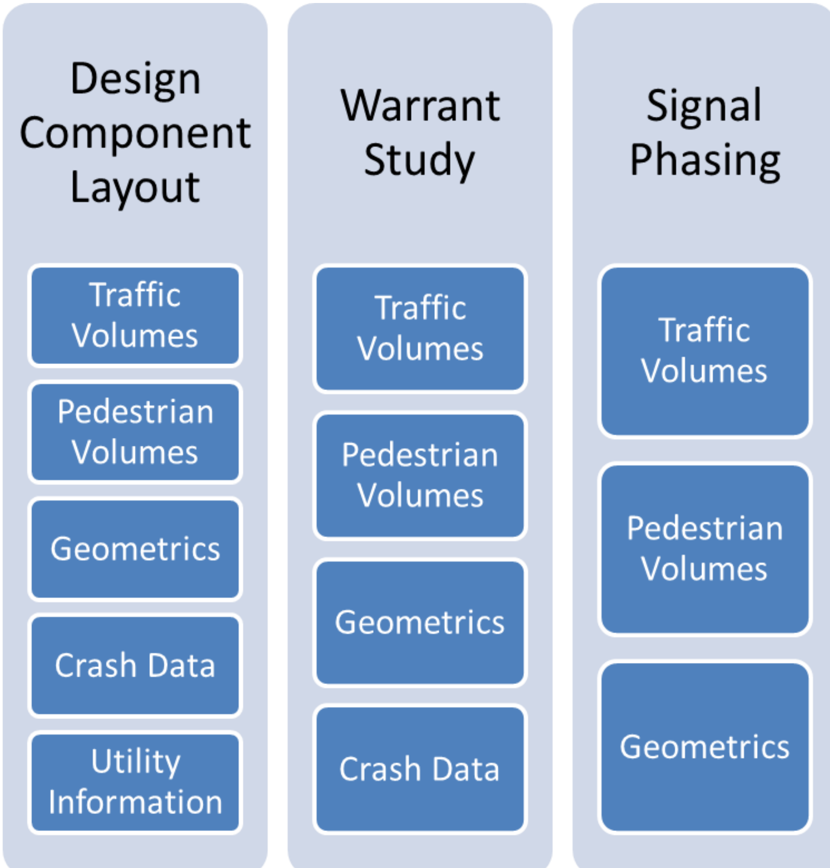
The data should include, but is not limited to:

- ✓ Intersection geometry, including lane usage and link distances.
- ✓ Existing Intersection Turning Movement Counts
- ✓ AM peak hour (minimum 2 hours - 15 minute periods)
- ✓ PM peak hour (minimum 2 hours - 15 minute periods)
- ✓ Off peak period or any other special traffic period
- ✓ Count vehicles and pedestrians (Seasonal counts if required)
- ✓ 24 hour approach counts (preferably over a 7 day period)
- ✓ Posted speed on each approach
- ✓ Crash reports or preferably collision diagrams representing past 3 years for urban locations (consider 5 years in rural locations)
- ✓ Percent of heavy vehicles
- ✓ Field Studies, including travel time runs and approach delay studies. This data will be used in the calibration of the computer models and for comparison to similar data collected in the "after" condition.
- ✓ Signal Timing and Phasing Data
- ✓ Existing Traffic Signal Hardware. This information should include controller equipment, communications details, vehicle detectors and traffic signal heads. This information can be used to determine the phasing/timing capabilities at each intersection. For example, could a protected left-turn phase be added?
- ✓ Additional Data. These may include items such as pedestrian counts, traffic counts of mid-block generators, early-release studies, etc.

All data should be current and representative of the intersection. Turning movement counts used should be within one year of implementing the timing plan or recent enough to reflect current conditions.

Other uses for data is to determine the appropriate signal phasing for an intersection and how that operation effects the design, classify vehicles and determine how that vehicle mix affects placement of elements, etc. **Exhibit 3-1** illustrates typical uses of traffic data.

Exhibit 3-1 Traffic Data Uses



3.1 Traffic Volume Data

Traffic counts are the most basic type of data collected in the field of traffic engineering. Quite simply, traffic counts involve counting vehicles passing a point for varying intervals of time. They can range from 24 hours per day, 365 days per year, to five minutes of a peak period.

Volume counts play a major role in traffic signal design. Their uses include:

1. Determining the need for traffic control devices (warrants)
2. Obtaining various factors (hourly, daily, weekly, etc.)
3. Determining peak periods and peak hours
4. Signal phasing and timing
5. Determining trends
6. Determining the need for channelization
7. Simulation studies
8. Vehicle classifications
9. Calculating crash rates

Discuss with the District staff the traffic volume requirements for the particular study.

3.1.1 Turn Movement Count Example

TURNING MOVMENT VOLUME DATA

Start Time	Southbound				Westbound				Northbound				Eastbound				
	Peds	Rght	Thru	Left	Peds	Rght	Thru	Left	Peds	Rght	Thru	Left	Peds	Rght	Thru	Left	
Movement	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
7:00	0	17	8	34	0	16	65	5	0	4	4	2	0	8	103	5	271
7:15	0	14	12	23	0	20	76	10	0	9	9	5	0	10	111	8	307
7:30	0	14	8	52	0	17	70	7	0	11	5	5	0	9	151	9	358
7:45	0	14	9	34	0	16	94	18	0	10	3	10	0	11	130	12	361
Hr. Tot.	0	59	37	143	0	69	305	40	0	34	21	22	0	38	495	34	1297
8:00	0	17	5	26	0	19	92	9	0	11	12	8	0	11	99	7	316
8:15	0	22	7	30	0	23	96	10	0	9	3	8	0	9	93	9	319
8:30	0	15	7	36	0	17	96	9	0	8	5	6	0	13	113	11	336
8:45	0	23	13	29	0	13	94	22	0	9	4	12	0	4	102	9	334
Hour Total	0	77	32	121	0	72	378	50	0	37	24	34	0	37	407	36	1305

Peak Hour Analysis

	Southbound				Westbound				Northbound				Eastbound				
	Peds	Rght	Thru	Left	Peds	Rght	Thru	Left	Peds	Rght	Thru	Left	Peds	Rght	Thru	Left	Total
1. Peak Hour of Intersection	0	67	29	142	0	75	352	44	0	41	23	31	0	40	473	37	1354
St. Time	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30	7:30
2. Peak 15 min x 4	0	88	36	208	0	92	384	72	0	44	48	40	0	44	604	48	1708

Peak Hour Factor

Method 1.		0.76	0.81	0.68		0.82	0.92	0.61		0.93	0.48	0.78		0.91	0.78	0.77	0.79
Method 2.		1.00	1.00	1.00		1.00	1.00	1.00		1.00	1.00	1.00		1.00	1.00	1.00	1.00

Peak Hour of Intersection Method

1. Determine the highest total intersection hourly volume. This can be any four consecutive 15-minute periods in the count duration. For the example, it is as follows:

Total	
271	
307	
358	
361	Highest four consecutive 15 minute counts = 1,354 vph.
316	
319	
336	
334	

2. Calculate the hourly volume for each movement. Use the same four consecutive 15 minute periods as used in the step above. For example, the peak hour volume for the westbound through movement is calculated as follows (start at 7:30):

   70 + 94 + 92 + 96 = 352 vph.

3. Calculate the movement and intersection Peak Hour Factors (PHF). The Peak Hour Factor is used to determine the traffic flow rate during the busiest 15-minute period. To determine the PHF, divide the peak hour volume computed in step 2 by the highest 15 minute count in the peak interval multiplied by four. For example, the PHF for the westbound through movement is:

   Hourly Flow Rate = 352 vph

   Peak 15 minute count = 96 vph

   PHF = 352 / (96 x 4) = 0.92

3.2 Pedestrian Volume Information

When collecting data, it is important to collect pedestrian counts when pedestrians are present. This information is needed for studies and signal timing. This data will also aid in the decision to add pedestrian facilities including Accessible Pedestrian Systems (APS) to the intersection.

Refer to **Exhibit 3-1** for additional information on pedestrian data requirements.

3.3 Crash Data

A list of all the crashes that have occurred at the intersection should be obtained from the district. Only those crashes that have occurred during the most recent 12-month period (in which data are available) should be used in analyzing the Crash Experience Warrant.

3.4 Geometrics

Existing Geometrics

The existing geometrics of the intersection being considered for design improvements must be documented. The geometry of the intersection can affect the efficiency of the traffic signal. It is preferable to provide a layout or graphical display of the intersections showing lane configurations with existing striping, lane widths, parking lanes, shoulders and/or curb treatments, medians, pedestrian and bicycle facilities, right of way limits and access driveways or adjacent roadways for all approaches. The posted speed limit and the current traffic control of each roadway should also be shown or stated. Adjacent structures, overhead utilities, and vaults should also be outlined such as buildings, bridges, box culverts, power poles, etc.

The locations of schools or other significant land uses, which may require more specialized treatment for pedestrians or vehicles, should be documented, if applicable.

Geographic features must be shown if they will influence the selection of an alternative, such as severe grades, wetlands, parkland, etc.

Proposed Geometrics/Traffic Control Alternative

A layout or conceptual plan showing the proposed geometrics for the recommended traffic control alternative must be included. An electronic copy of the design is preferred and may be required depending on the intersection alternative. The plan should document all changes from the existing conditions.

3.4.1 Utility Information

Coordination with utilities is essential for traffic signal construction projects. Aerial (overhead) utilities, such as electric, telephone, and cable lines, are typically attached to wooden utility poles. Underground utilities, such as gas, sewer, and water lines, can vary greatly in depth. Any time traffic signal equipment is installed under a crossing or attached to an overpass owned by a railroad, the PA Public Utilities Commission (PUC) must be contacted.

3.5 Travel Time & Delay Studies

3.5.1 Definitions

- ✓ Travel Time Study. A study conducted to determine the amount of time required to traverse a specific route or section of a street or highway. The data obtained provide travel time and travel speed information but not necessarily delay. This term is often used to include speed and delay studies.
- ✓ Delay Study. A study made to provide information concerning the amount, cause, location, duration, and frequency of delays as well as travel time and similar values.

- ✓ Travel Time. The total elapsed time of travel, including stops and delay, necessary for a vehicle to travel from one point to another over a specified route under existing traffic conditions.
- ✓ Running Time. That portion of the travel time that the vehicle is actually in motion. Running time is equal to travel time minus stopped-time delay.
- ✓ Travel Speed. The over-all average speed along a specified route of a street or highway. Travel speed is computed by dividing the total distance by the travel time.
- ✓ Running Speed. The average speed along the specified route when the stopped time is removed from the computations. Running speed is distance divided by running time.
- ✓ Delay. The time lost by traffic due to traffic friction and traffic control devices.
- ✓ Fixed Delay. The delay to which a vehicle is subjected regardless of the amount of traffic volume and interference present.
- ✓ Operational Delay. The delay caused by interference from other components of the traffic stream. Examples include time lost while waiting for a gap in a conflicting traffic stream, or resulting from congestion, parking maneuvers, pedestrians, and turning movements.
- ✓ Stopped Delay. The time a vehicle is not moving.
- ✓ Travel Time Delay. The difference between the actual time required to traverse a section of street or highway and the time corresponding to the average speed of traffic under uncongested conditions. It includes acceleration and deceleration delay in addition to stopped delay.
- ✓ Approach Delay. Travel time delay encountered at the approach to an intersection.
- ✓ Total Vehicle Delay. The total time lost, in vehicle-minutes per mile, by vehicles in a traffic stream because the street or section does not meet the suggested minimum standards. It is obtained by multiplying the peak-hour one-direction volumes by the delay rate.

3.5.2 Need for Travel Time or Delay Data

Congestion can be evaluated by means of speed and delay studies. Data is obtained on the amount, location, and cause of delay; the delay data also indicates locations where other studies are needed to determine the proper remedy.

Traffic signal timing studies often require travel time data at periodic intervals.

Before-and-after studies may utilize these data to determine the effectiveness of a change in signal timings, etc.

3.5.3 Causes of Delay

Fixed Delay occurs primarily at intersections. This delay is not a result of the flow characteristics of the traffic stream and could occur with only one vehicle traveling the section. It may be caused for example, by traffic signals, stop signs, yield signs, or railroad crossings.

Operational Delay is the result of influences by other traffic.

- ✓ One type of operational delay is caused by other traffic movements that interfere with their stream flow (side friction), e.g., parking or unparking vehicles, turning vehicles, pedestrians, stalled vehicles, double parking, or cross traffic.
- ✓ The second type of operational delay is caused by internal frictions within the stream flow.

3.5.4 Methods for Obtaining Travel Time or Delay Data

Test Car Technique

The Test Car Technique utilizes a test vehicle which is driven over the street section in a series of runs.

- ✓ *The Floating Car Method*. In this method the driver tries to "float" in the traffic stream passing as many vehicles as pass the test car.
- ✓ *The Average Speed Method*. In this method the driver is instructed to travel at a speed that is judged to be representative of the speed of all traffic at the time.
- ✓ *Data Obtained* from the test car technique frequently includes delay information.
- ✓ *Equipment Used* in recording the data varies.
- ✓ An observer with one or two stopwatches was a common method but has generally been replaced by new technology. The observer starts the first watch at the beginning of each run, and records the time at various control points along the route. The second watch (if used) measures the length of individual stopped-time delays. The time, location, and cause of these delays are recorded either on data forms or by voice recording equipment.
- ✓ Various recording devices have been developed to eliminate the necessity of using two persons on test runs. These include recording speedometers, tachometers, and the Traffic Stream Analyzer.
- ✓ State-of-the-practice techniques involve using a GPS and will be discussed in Chapter 5.
- ✓ *Analysis*. The mean, standard deviation, and standard error of the mean of a series of test car runs and the significance of differences of the means of "before" and "after" studies are calculated.

License Plate Technique

The License Plate Technique is used when only travel-time information is desired.

Bluetooth Technologies

The tracking of Media Access Control (MAC) addresses via Bluetooth signals has emerged as a promising technology that offers space mean speed (segment detection) metrics. Many devices such as smartphones, headsets, and in-vehicle navigation systems are Bluetooth enabled and can be read by roadside readers. The MAC address of a device resembles a "license plate" for the particular device. Several vendors have developed platforms that can detect and record these addresses with timestamps in real-time. This information is then used to determine the travel time and delay along the route.

3.6 Intersection Delay Studies

Delay at intersections is a major problem in the analysis of congestion. Delay studies at individual intersections are valuable in evaluating the efficiency or effectiveness of a traffic control method. Other factors include accidents, cost of operation, and motorists' desires.

Factors which affect delay at intersections include:

- ✓ Physical factors such as number of lanes, grades, widths, access control, turning provisions, transit stops, etc.
- ✓ Traffic factors such as volume on each approach, driver characteristics, turning movements, pedestrians, parking, approach speeds, etc.

Methods for Measurement of Intersection Delay

- ✓ There are three measures of prime importance for describing intersection performance.
- ✓ Approach delay per vehicle is considered to be the best single measure. However, it must be derived indirectly from the stopped delay field study.
- ✓ Stopped delay per vehicle results directly from the field study. A multiplier factor is applied to the raw data to bring the estimate closer to the true value.
- ✓ Percent of vehicles stopping is a third performance measure. Again, a multiplication factor is applied to the raw field data to achieve a better estimate of the true value.
- ✓ Past and current procedures used to estimate or measure intersection delay fall into one of four basic categories.
- ✓ Point sample is based on a systematic sample of some factor (such as the number of stopped vehicles).
- ✓ Input-output uses an interval sample to measure some factor at both its point or time of beginning and ending.
- ✓ Path trace procedures track individual vehicles while noting their actions. The use of test cars as in travel time studies is a type of path trace.

- ✓ Models take into account the arrival and departure characteristics of vehicles, and many models incorporate some field measurements and data in the delay estimates.
- ✓ Field data collection consists of two items.
- ✓ Stopped delay obtained by a point sample procedure was found to be the most practical method for measuring intersection delay in the field. A minimum sample of 60 measurements of the number of vehicles in the approach

3.7 HCM Method for Direct Measurement of Prevailing Saturation Flow Rates

[Source: Highway Capacity Manual]

The Highway Capacity Manual (HCM) describes a technique for quantifying the base saturation flow rate for local conditions. In this manner, it provides a means of calibrating the saturation flow rate calculation procedure to reflect driver behavior at a local level. The technique is based on a comparison of field-measured saturation flow rate with the calculated saturation flow rate for a common set of lane groups at intersections in a given area.

Concepts

The default ideal saturation flow rate used in the methodology of Chapter 16 of the HCM is 1900 pc/h/ln. This value must be adjusted for prevailing traffic conditions such as lane width, left turns, right turns, heavy vehicles, grades, parking, parking blockage, area type, bus blockage, and left turn blockage. As an alternative to this adjustment to the "assumed" ideal saturation flow rate, the prevailing saturation flow rate may be measured in the field.

Saturation flow rate is the maximum discharge rate during the green time. It is usually achieved after about 10 to 14 seconds of green, which corresponds to the front axle of the fourth to sixth passenger car crossing the stop line after the beginning of green.

The base saturation flow rate is defined as the discharge rate from a standing queue in a 12 foot wide lane that carries only through passenger cars and is otherwise unaffected by conditions such as grade, parking, and turning vehicles.

The base saturation flow rate is usually stable over a period of time for similar traffic conditions in a given community. Values measured in the same lane during repetitive weekday traffic conditions normally exhibit relatively narrow distributions. On the other hand, saturation flow rates for different communities or different traffic conditions and compositions, even at the same location, may vary significantly.

Measurement Technique (Two People)

1. **Recorder**
   a) Note the last vehicle in the stopped queue when the signal turns green.
   b) Describe the last vehicle to the Timer.
   c) Note which are heavy vehicles and/or turning vehicles.
   d) Record the time called out by the Timer.
2. **Timer**
   a) Start stop watch at the beginning of the green and notify the Recorder.
   b) Count aloud each vehicle in the queue as its rear axle crosses the stop line.
   c) Call out the time for the fourth, tenth, and the last vehicle in the queue.
   d) Notify the Recorder, if queued vehicles are still entering the intersection at the end of the green.

Example

a) Take the difference in time between the 4th and last vehicle and divide by the number of vehicles served (seconds/veh).
b) The prevailing saturation flow rate is:

3600/ seconds/veh in a = veh/h/ln

	run #																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
time between 4th and last veh in queue	26	27	36	36	21	22	50	46	21	24	27	11	28	44	30		
# of veh between 4th and last in queue	12	13	16	21	11	9	24	27	10	12	8	9	14	26	15		
	2.17	2.08	2.25	1.71	1.91	2.44	2.08	1.70	2.10	2.00	3.38	1.22	2.00	1.69	2.00	2.05	s/veh
																1757	veh/h/ln
what if the recorder was 1 sec high	27	28	37	37	22	23	51	47	22	25	28	12	29	45	31		
	12	13	16	21	11	9	24	27	10	12	8	9	14	26	15		
	2.25	2.15	2.31	1.76	2.00	2.56	2.13	1.74	2.20	2.08	3.50	1.33	2.07	1.73	2.07	2.13	s/veh
																1694	veh/h/ln
what if the recorder was 1 sec low	25	26	35	35	20	21	49	45	20	23	26	10	27	43	29		
	12	13	16	21	11	9	24	27	10	12	8	9	14	26	15		
	2.08	2.00	2.19	1.67	1.82	2.33	2.04	1.67	2.00	1.92	3.25	1.11	1.93	1.65	1.93	1.97	s/veh
																1825	veh/h/ln

CHAPTER 4. LOCAL INTERSECTION CONCEPTS

4.1 Signal Timing Theory

Signalized intersections play a critical role in the safe and efficient movement of vehicular and pedestrian traffic. The objective of traffic signal timing is to assign the right-of-way to alternating traffic movements in such a manner to minimize the average delay to any group of vehicles or pedestrians and reduce the probability of accident producing conflicts. Some of the guiding standards to accomplish this objective are as follows:

- ✓ Minimize the number of phases that are used. Each additional phase increases the amount of lost time due to starting delays and clearance intervals.
- ✓ Short cycle lengths typically yield the best performance in terms of providing the lowest overall average delay, provided the capacity of the cycle to pass vehicles is not exceeded. ***The cycle length, however, must allow adequate time for vehicular and pedestrian movements***. Longer cycles are used during peak periods to provide more green time for the major street, to permit larger platoons in the peak direction, and/or to reduce the number of starting delays.

4.2 Controller Timing

A traffic signal controls traffic by assigning right-of-way to one traffic movement or several non-conflicting traffic movements at a time. Right-of-way is assigned by turning on a green signal for a certain length of time or an interval. Right-of-way is ended by a yellow change interval during which a yellow signal is displayed, followed by the display of a red signal. The device that times these intervals and switches the signal lamps is called a controller unit. This section will cover the operation of controller units and the various features and characteristics of the types currently available.

4.2.1 Signal Phasing

Definition of a Traffic Signal “Phase”:

> *That part of the cycle length allocated to a traffic movement receiving the right of way, or to any combination of movements receiving the right of way simultaneously.*

4.2.2 Ring and Barrier Structure

Ring

A ring is a term that is used to describe a series of conflicting phases that occur in an established order. A ring may be a single ring, dual ring, or multi-ring and is described in detail below. A good understanding of the ring structure is a good way to understand the operation of multiphase controllers.

Barrier

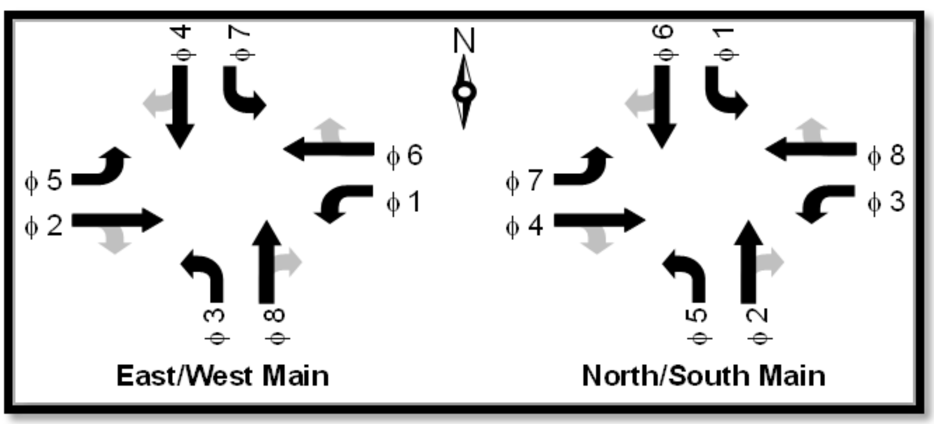
A barrier (compatibility line) is a reference point in the preferred sequence of a multi-ring controller unit at which all rings are interlocked. Barriers assure there will be no concurrent selection and timing of conflicting phases for traffic movements in different rings. All rings cross the barrier simultaneously to select and time phases on the other side.

Phase Numbers

Phase numbers are the labels assigned to the individual movements around the intersection. For an eight phase dual ring controller (see definition of dual ring below), it is common to assign the main street through movements as phases 2 and 6. In addition, it is common to use odd numbers for left turn signals and the even numbers for through signals. A rule of thumb is that the sum of the through movement and the adjacent left turn is equal to seven or eleven.

Exhibit 4-1 illustrates a typical phase numbering scheme for an East/West arterial and a North/South arterial.

Exhibit 4-1 Typical Phase Numbering Convention

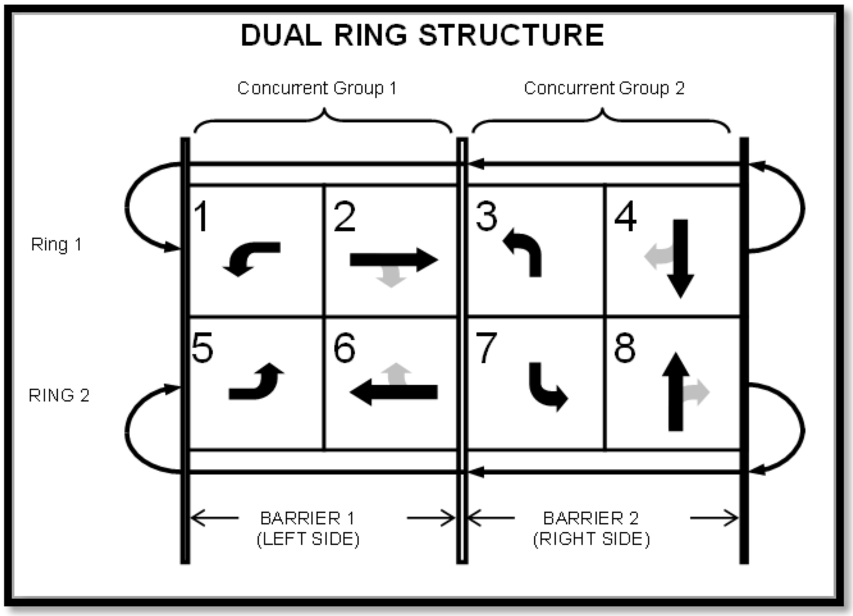


Local standards may have the phases mirrored from that shown in **Exhibit 4-1**. In addition, **Exhibit 4-1** is for dual ring control. Depending on the situation, unique phasing combinations may be required and the phase numbers shown in the figure are not applicable.

Dual Ring Control

The traffic actuated controller usually employs a "dual ring concurrent" timing process. The NEMA, dual ring concept with the major route in the east/west direction is illustrated in **Exhibit 4-2**.

Exhibit 4-2 Ring and Barrier Structure



The dual-ring controller uses a maximum of eight phase modules, each of which controls a single traffic movement with red, yellow and green display. The eight phases are required to accommodate the eight movements (four through and four left turns) at the intersection. Phases 1 through 4 are included in ring 1, and phases 5 through 8 are included in ring 2. The two rings operate independently, except that their control must cross the barrier (see definition of barrier above) at the same time.

If the movements to be controlled by these eight phases are assigned properly, the controller will operate without giving the right-of-way simultaneously to conflicting movements. All of the movements from one street (usually the major street) must be assigned to the left side of the barrier. Similarly, all movements from the other street must be assigned to the right side.

Exhibit 4-2 shows how the phases are arranged. At any given time, the controller will display one phase from Ring A and one phase from the Ring B. Both phases must be either from the left side of the barrier or from the right side of the barrier. Phase 1 can be displayed with phase 5 or 6 for example, but not with any other phase.

4.3 Cycle Length

The cycle length is the total time to complete one sequence of signalization around an intersection. In an actuated controller unit, a complete cycle is dependent on the presence of calls on all phases. In a pre-timed controller unit, it is a complete sequence of signal indications.

4.4 Types of Operation

Traffic control concepts for isolated intersections fall into two basic categories, pre-timed and traffic-actuated.

4.4.1 Pretimed Control

The signal assigns right-of-way at an intersection according to a predetermined schedule. The sequence of right-of-way (phases) and the length of the time interval for each signal indication in the cycle is fixed. No recognition is given to the current traffic demand on the intersection approaches unless detectors are used. The major elements of pre-timed control are (1) fixed cycle length, (2) fixed phase length, and (3) number and sequence of phases.

Advantages to pre-timed control include:

- ✓ Simplicity of equipment provides relatively easy servicing and maintenance.
- ✓ Can be coordinated to provide continuous flow of traffic at a given speed along a particular route, thus providing positive speed control.
- ✓ Timing is easily adjusted in the field.
- ✓ Under certain conditions can be programmed to handle peak conditions.

Disadvantages to pre-timed control include:

- ✓ Do not recognize or accommodate short-term fluctuations in traffic.
- ✓ Can cause excessive delay to vehicles and pedestrians during off-peak periods.

4.4.2 Traffic Actuated Control Operations

Traffic-actuated control attempts to adjust green time continuously, and, in some cases, the sequence of phasing. These adjustments occur in accordance with real-time measures of traffic demand obtained from vehicle detectors placed on one or more of the approaches to the intersection. The full range of actuated control capabilities depends on the type of equipment employed and the operational requirements.

Advantages to actuated signals include:

- ✓ Usually reduce delay (if properly timed).
- ✓ Adaptable to short-term fluctuations in traffic flow.
- ✓ Usually increase capacity (by continually reapportioning green time).

- ✓ Provide continuous operation under low volume conditions as an added safety feature, when pre-timed signals may be put on flashing operation to prevent excessive delay.
- ✓ Especially effective at multiple phase intersections.

Disadvantages to actuated control include:

- ✓ The cost of an actuated installation is higher than the cost of a pre-timed installation.
- ✓ Actuated controllers and detectors are much more complicated than pre-timed signal controllers, increasing maintenance and inspection skill requirements and costs.
- ✓ Detectors are costly to install and require careful inspection and maintenance to ensure proper operations.

Traffic actuated signal control can further be divided into the following categories:

Semi-Actuated Control. In semi-actuated control, the major movement receives green unless there is a conflicting call on a minor movement phase. The minor phases include any protected left-turn phases or side street through phases. Detectors are needed for each minor movement. Detectors may be used on the major movement if dilemma zone protection is desired.

In semi-actuated coordinated systems, the major movement is the “sync” phase. Minor movement phases are served only after the sync phase yield point and are terminated on or before their respective force off points. These points occur at the same point in time during the background signal cycle and ensure that the major road phase will be coordinated with adjacent signal controllers.

In semi-actuated non-coordinated systems, the major movement phase is placed on minimum (or maximum) recall. The major movement rests in green until a conflicting call is placed. The conflicting phase is serviced as soon as a gap-out or max-out occurs on the major phase. Immediately after the yellow is presented to the major phase, a call is placed by the controller for the major phase, regardless of whether or not a major phase vehicle is present.

Full Actuated Control. In full actuated control, all signal phases are actuated and all signalized movements require detection. This is generally used at isolated intersections; however, it can also be used at high-demand intersections in coordinated systems.

Volume-density operation can be considered to be a more advanced form of full actuated control. It has the ability to calculate the duration of minimum green based on actual demand (calls on red) and the ability to reduce the maximum allowable time between calls from passage time down to minimum gap. Reducing the allowable time between calls below the passage time will improve efficiency by being better able to detect the end of queued flow.

4.4.3 Isolated Intersection Operation

An isolated intersection is a signalized intersection that is located far enough from other signalized intersections so that the signal timing at the other intersections does not influence the traffic flow at this intersection. Often, this intersection will operate with actuated operation.

4.4.4 Coordinated Signal Operation

Green intervals of certain phases at adjacent intersections are controlled to provide a relationship between them such that groups of vehicles can proceed through the intersections at a planned speed without stopping. Additional details can be found in **Chapter 6**.

4.4.5 Vehicle Change and Clearance Intervals

In general, the vehicle change and clearance intervals should be dependent upon the approach speeds at the intersection and other factors. They should be sufficient to allow a motorist to safely bring his/her vehicle to a stop under normal conditions, or if he/she is too close to stop, then to proceed safely through the intersection.

Use the procedures contained in this section, along with engineering judgment, to determine the vehicle change and clearance intervals for each approach to a signalized intersection.

The Department uses the recommended Institute of Transportation Engineers (ITE) formulas for yellow and all-red clearance intervals to ensure compliance with the 2009 MUTCD requirement of using established engineering practices. If engineering judgment is used to vary from the established ITE formulas, then this should be documented in the traffic signal file.

Yellow Change Interval

A yellow change interval should have a duration of approximately three to six seconds. The longer intervals should be reserved for use on approaches with higher speeds. Excessively long change intervals may result in abnormal running of the change and clearance intervals.

The yellow change interval should be calculated using the following equation:

$$Y = t + \frac{1.47V}{2a \pm 64.4g}$$

Where:

Y = Yellow change interval; s (typically 3 to 6 seconds)

t = Perception-reaction time; s (typically 1 second)

v = Approach speed of the roadway; mph

a = Deceleration rate; [typically 10 ft/s2]

g = Grade of approach; %/100

Exhibit 4-3 provides yellow change intervals using the required information. (Refer to the following charts for informational purposes; document all calculations.)

Exhibit 4-3 Yellow Change Interval

	V (Approach Speed, mph)	*g* (Grade of Approach)												
		Uphill						Level	Downhill					
		6%	5%	4%	3%	2%	1%	0%	-1%	-2%	-3%	-4%	-5%	-6%
$t + \frac{1.47V}{2a \pm 64.4g}$	25	2.5	2.6	2.6	2.7	2.7	2.8	2.8	2.9	3.0	3.0	3.1	3.2	3.3
	30	2.8	2.9	3.0	3.0	3.1	3.1	3.2	3.3	3.4	3.4	3.5	3.6	3.7
	35	3.2	3.2	3.3	3.3	3.4	3.5	3.6	3.7	3.7	3.8	4.0	4.1	4.2
	40	3.5	3.5	3.6	3.7	3.8	3.8	3.9	4.0	4.1	4.3	4.4	4.5	4.6
	45	3.8	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.7	4.8	4.9	5.1
	50	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.1	5.2	5.4	5.6
	55	4.4	4.5	4.6	4.7	4.8	4.9	5.0	5.2	5.3	5.5	5.6	5.8	6.0
	60	4.7	4.8	4.9	5.0	5.1	5.3	5.4	5.6	5.7	5.9	6.1	6.3	6.5
	65	5.0	5.1	5.2	5.4	5.5	5.6	5.8	5.9	6.1	6.3	6.5	6.7	6.9

The perception-reaction time (*t*) was assumed to be 1 second, and a deceleration rate (*a*) of 10 ft/s^2 was assumed.

All-Red Clearance Interval

The yellow change interval should be followed by an all-red clearance interval to provide additional time before conflicting traffic movements, including pedestrians, are released.

The all-red clearance interval should be calculated using the following equation:

$$AR = \frac{(W + L)}{1.47V}$$

Where:

AR = All-red clearance interval; s

V = Approach speed of the roadway; mph

W = Width of intersection (from the stop bar to the end of the farthest traveled lane); (ft)

L = Length of vehicle, [typically 20 ft]

Refer to **Exhibit 4-4** for a graphical definition of the terms used in the all-red interval calculation.

Exhibit 4-4 Definition of Terms for All-Red Clearance Intervals

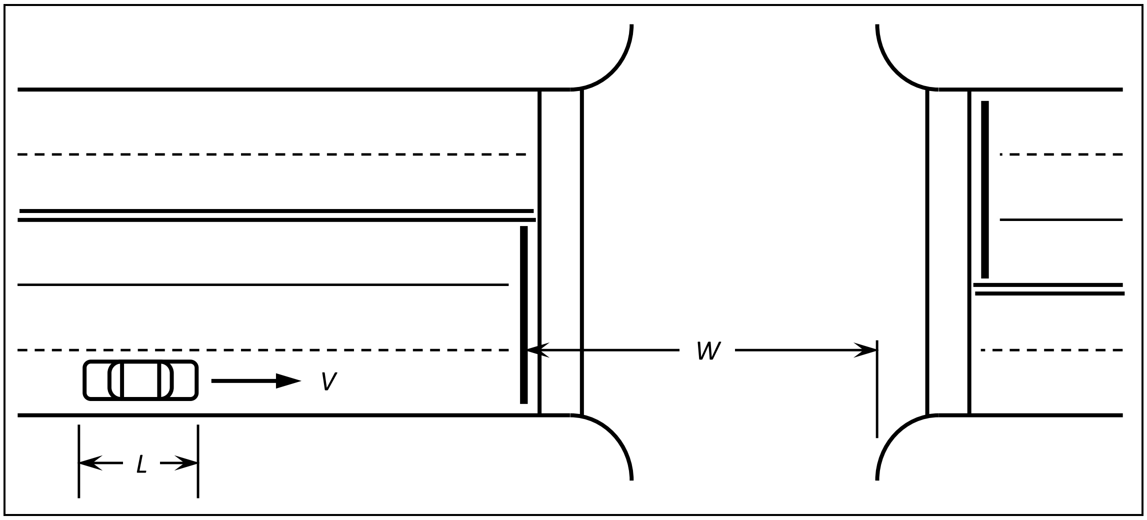


Exhibit 4-5 provides all-red clearance intervals using the required information. (Refer to the following charts for informational purposes; document all calculations.)

Exhibit 4-5 All-Red Clearance Interval

	V (Approach Speed, mph)	*W* (Width of Intersection), ft										
		20	30	40	50	60	70	80	90	100	110	120
$\frac{W+L}{1.47V}$	25	1.1	1.4	1.6	1.9	2.2	2.4	2.7	3.0	3.3	3.5	3.8
	30	0.9	1.1	1.4	1.6	1.8	2.0	2.3	2.5	2.7	2.9	3.2
	35	0.8	1.0	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.5	2.7
	40	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4
	45	0.6	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2.0	2.1
	50	0.5	0.7	0.8	1.0	1.1	1.2	1.4	1.5	1.6	1.8	1.9
	55	0.5	0.6	0.7	0.9	1.0	1.1	1.2	1.4	1.5	1.6	1.7
	60	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.4	1.5	1.6
	65	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.3	1.4	1.5

The length of vehicle was assumed to be 20 feet.

4.4.6 Pedestrian Timing

Refer to the MUTCD 2009 Edition Section 4E.06 Pedestrian Intervals and Signal Phases and Section 4E.07 Countdown Pedestrian Signals.

When pedestrian signal heads are used, a WALKING PERSON (symbolizing WALK) signal indication shall be displayed only when pedestrians are permitted to leave the curb or shoulder.

A pedestrian clearance time shall begin immediately following the WALKING PERSON (symbolizing WALK) signal indication. The first portion of the pedestrian clearance time shall consist of a pedestrian change interval during which a flashing UPRAISED HAND (symbolizing DONT WALK) signal indication shall be displayed. The remaining portions shall consist of the yellow change interval and any all-red clearance interval (prior to a conflicting green being displayed), during which a flashing or steady UPRAISED HAND (symbolizing DONT WALK) signal indication shall be displayed.

The pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or shoulder during the WALKING PERSON (symbolizing WALK) signal indication to travel at a walking speed of 3.5 ft per second, to at least the far side of the traveled way or to a median of sufficient width for pedestrians to wait. The distance is typically measured in the middle of the crosswalk. Where pedestrians who walk slower than 3.5 ft per second, or pedestrians who use wheelchairs, routinely use the crosswalk, a walking speed of 3 ft per second should be considered in determining the pedestrian clearance time. A slower walking speed should be considered when near elementary schools and elderly facilities.

When countdown pedestrian signals are used, the numeric countdown signal indication shall be displayed only during the pedestrian change interval (flashing DONT WALK interval) and no numeric indication shall be visible during a steady upraised hand indication or walking person indication.

WALK Interval

The WALK interval allows pedestrians to access the intersection and provides enough time for pedestrians to enter the crosswalk before the pedestrian change interval (flashing DONT Walk interval) commences. The walk interval should be at least 7 seconds in length so that pedestrians will have adequate opportunity to leave the curb or shoulder before the pedestrian clearance time begins. If pedestrian volumes and characteristics do not require a 7-second walk interval, walk intervals as short as 4 seconds may be used. Longer walk intervals are often used when the duration of the vehicular green phase associated with the pedestrian crossing is long enough to allow them.

Pedestrian Change Interval (FLASHING DONT WALK)

The pedestrian change interval (flashing DONT WALK) allows pedestrians to clear the intersection approach, alerts pedestrians of an upcoming changing phase, and provides time for pedestrians to cross the intersection approach completely upon termination of the WALK interval.

Use the following equation to calculate the length of the pedestrian change (flashing DON'T WALK) interval:

$$T_{pc} = \frac{L}{S_w}$$

Where:

T_{pc} = Pedestrian change (flashing DON'T WALK) interval; s

L = Pedestrian walking distance from the curb or edge of shoulder to the far edge of the traveled way; ft

S_w = Walking speed; s [typically 3.5 ft/s]

Total Duration of Walk Interval and Pedestrian Clearance Time

The total of the walk interval and pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the pedestrian detector [or, if no pedestrian detector is present, a location 6 ft from the face of the curb or from the edge of the pavement] at the beginning of the WALKING PERSON (symbolizing WALK) signal indication to travel at a walking speed of 3 ft per second to the far side of the traveled way being crossed. Any additional time that is required to satisfy the conditions of this paragraph should be added to the walk interval.

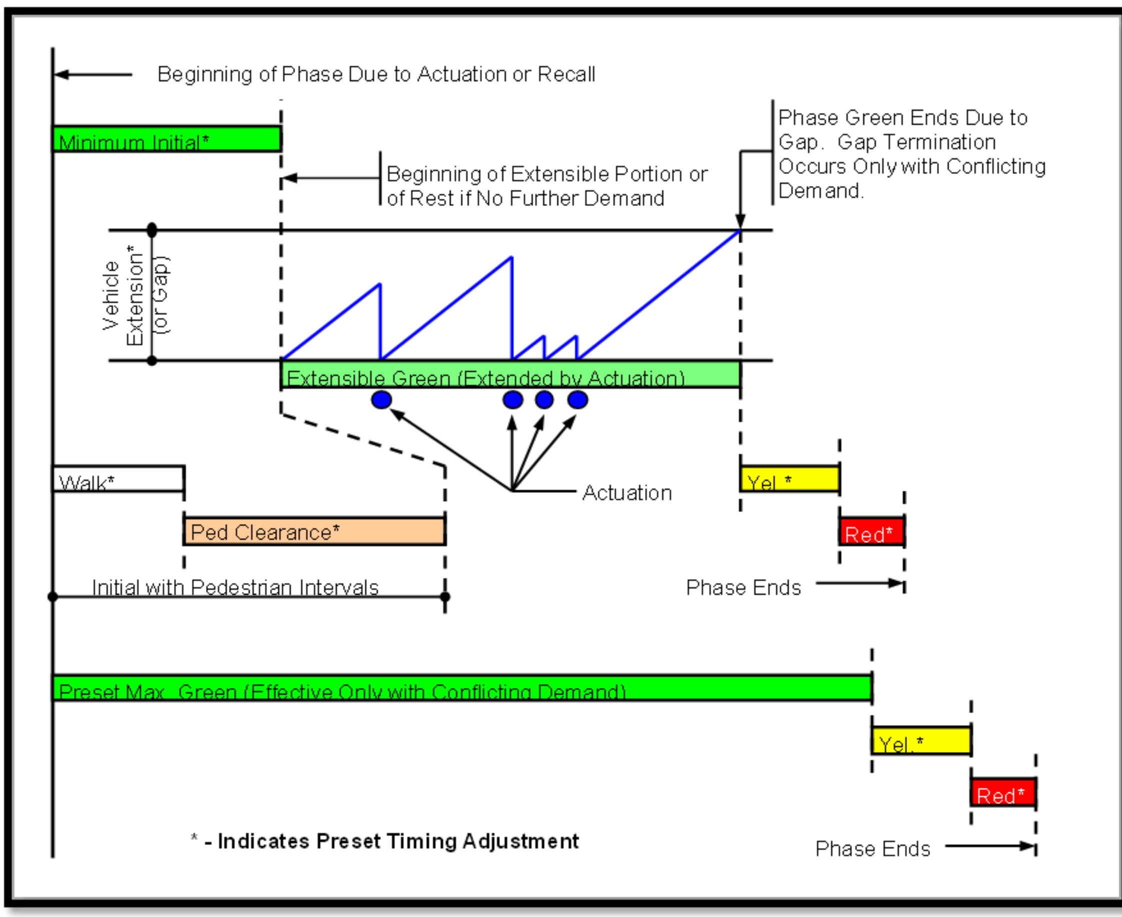
4.5 Actuated Phasing Parameters

Some of the basic principles of timing the green interval in a traffic actuated controller unit is as follows:

- ✓ There must be a minimum green time so that a stopped vehicle that receives a green indication has enough time to get started and partially cross the intersection before the yellow signal appears. This time is termed the minimum green (or minimum initial) portion of the green interval.
- ✓ Each following vehicle requires green time. This is called vehicle extension or gap. Gap refers to the distance between vehicles as well as the time between vehicles.
- ✓ There must be a maximum time that the green interval can be extended if opposing cars are waiting – this is called the maximum or extension limit.

Exhibit 4-6 shows a timing diagram for one traffic-actuated phase. The other phases in the controller operate in the same manner.

Exhibit 4-6 Actuated Phase Timing Diagram



4.5.1 Minimum Green

There must be a minimum green time so that stopped vehicles have enough time to get started and partially cross the intersection before the clearance interval appears. This time is often termed the minimum initial portion of the green interval. A typical value would be 4 seconds and could range from 2 to 30 seconds. This value is also called minimum green by some controllers.

4.5.2 Vehicle Extension Time

The vehicle extension (also known as passage time or gap time) is the unit time extension for each vehicle actuation during the extensible portion as shown in **Exhibit 4-6**. The extensible green portion is that portion of the green interval of an actuated phase following the initial portion that may be extended, for example, by traffic actuation. Each detector actuation resets the vehicle extension timer. The green interval of the phase may terminate on expiration of the extension time.

With no opposing calls for other phases, the phase will rest in green. The vehicle extension will continue to time but will have no effect on the green interval. Upon receipt of an actuation on an opposing phase, the vehicle extension will check to see if the time between actuations is greater than the vehicle extension time. If so, the green will be terminated, the yellow interval will show, and the next phase in sequence with demand will be serviced. This is commonly referred to as "gap-out." These vehicle actuations (calls) can be received at the detector in either a locking or non-locking mode.

The vehicle extension time is typically set to allow an average speed vehicle to move from the detector to and through the intersection. This time can be reset by continuous vehicle actuation up to the maximum green time. Typical values of vehicle extension range from 0 seconds to 9 seconds.

4.5.3 Maximum Green

The maximum green time is the maximum limit to which the green time can be extended on a phase in the presence of a call on a conflicting phase. The maximum green is illustrated in **Exhibit 4-6**.

The maximum green time begins timing at the start of the green interval when there is a serviceable vehicle demand on a conflicting phase. The phase is allowed to "max-out" if the preset time is reached even if actuations are close enough in time to prevent gap termination. If the phase terminates due to reaching the maximum, a recall is placed on the phase and it is returned to at the earliest opportunity.

The maximum green time typically ranges in values from 0 to 99 seconds (or more in some cases).

4.5.4 Recall

In the absence of an actuation, a controller unit will normally rest on the current phase being serviced. A recall will force the controller to return to a particular phase's green interval, even with no demand.

Every phase has the capability of operation with the following types of recall:

Minimum Recall

When active and in the absence of a vehicle call on the phase, a temporary call to service the minimum initial time will be placed on the phase. If a vehicle call is received prior to the phase being serviced the temporary call will be removed. Once the phase is serviced, it can be extended based on normal vehicle demand.

Maximum Recall

With the maximum vehicle recall active a constant vehicle call will be placed on the phase. This constant call will force the controller to time the maximum green. Maximum recall is generally used to call a phase when local detection is not present or inoperative.

Pedestrian Recall

This feature provides vehicle green and pedestrian walk and clearance intervals. After that, normal green timing is in effect except that pedestrian calls will not recycle pedestrian intervals until opposing phases are serviced.

4.6 Traffic Signal Systems

If the intersection is to be included in a system, it will factor into the design regarding communication (interconnect, communications, etc.). Refer to **Chapter 6** for details on traffic signal systems.

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CHAPTER 5. LOCAL INTERSECTION TIMING

5.1 Timing Practices

Assuming that the traffic control signal has been designed and installed in accordance with good technical practices, proper timing is the final ingredient to create an efficiently operating traffic control signal. The objective of signal timing is to alternate the right of way between traffic streams so that average total delay to all vehicles and pedestrians, and the possibility of accident-producing conflicts is minimized.

The purpose of this chapter is to establish uniform guidelines for signal timing personnel to time traffic control signals. It is intended to set forth accepted practices, procedures and guidelines. It should be noted that there are no legal requirements for the use of these practices, procedures and guidelines. The legal considerations are set forth in the state law and the Manual on Uniform Traffic Control Devices (MUTCD).

It should also be noted that these guidelines, procedures and practices are general and should be used only as a general guide. Many other factors at each individual intersection must be considered and good engineering judgment must be utilized in applying these guidelines. Field observations and timing adjustments must be done to maximize the efficiency and safety of the traffic control signal operation. A series of timing adjustments may be necessary.

The timing values developed through these procedures may not in all cases be directly set on all traffic control signal controllers. Each manufacturer may have a different way of timing each timing function. Care must be taken in knowing the theory of operation of each traffic control signal controller and setting values in the traffic signal controller.

There are basically two types of traffic signal controllers; pre-timed (fixed timed) and traffic actuated (variably timed). The guidelines, procedures and practices apply more directly to traffic actuated controllers, because the majority of the modern controllers are the traffic actuated type.

Traffic control signal controllers can be operated in a free (isolated) or a coordinated (system) mode of operation.

In timing a traffic signal, a good understanding of the meaning of the signal indications is necessary. The meaning of signal and pedestrian indications can be found in the MUTCD in Section 4D.

5.2 Full Traffic Actuated Timing Controls

The following are basic timing parameters that are necessary for a traffic signal controller to operate. These guidelines, procedures and practices are based on them. There are additional functions and parameters that need to be installed on each particular manufacturer controllers. Each manufacturer's traffic controller manual should be reviewed and understood before operating the controller in a field application. Any questions as to using these other functions or parameters should be directed to the Traffic Signal Engineer and the controller vendor.

1. WALK - Establishes the length of the WALK interval.
2. PEDESTRIAN CLEARANCE (CHANGE) - Establishes the length of flashing DON'T WALK interval.
3. MINIMUM GREEN - Establishes the length of initial state of green interval.
4. ADDED INITIAL - Density feature. Establishes number of seconds by which each vehicle (actuation) builds added initial state of green during non-green time on phase.
5. PASSAGE TIME - Establishes the increment of right of way (green) time extension for each vehicle actuation during the green interval.
6. TIME BEFORE REDUCTION - Density feature. Establishes a preset time before allowed gap begins to reduce.
7. TIME TO REDUCE - Density feature. Establishes time in which the allowed gap is reduced from passage time to minimum gap, after the time before reduction has expired.
8. MINIMUM GAP - Density feature. Establishes minimum value to which allowed gap between actuations on phase with green can be reduced upon expiration of time to reduce.
9. MAXIMUM GREEN - Establishes the maximum limit to which the green interval can be extended on a phase in the present of a serviceable demand on a conflicting phase.
10. YELLOW - Establishes the length of yellow interval following the green interval.
11. RED - Establishes the length of red interval following the yellow interval.
12. MEMORY MODES - Establishes whether the controller will remember (lock) or drop (non-lock) vehicle actuation.
13. RECALL MODES - Establishes whether the controller automatically returns to and provides right-of-way (green) on the selected phase once each traffic signal cycle, without the need for vehicle demand for service. There are pedestrian, minimum vehicle and maximum vehicle recall modes.

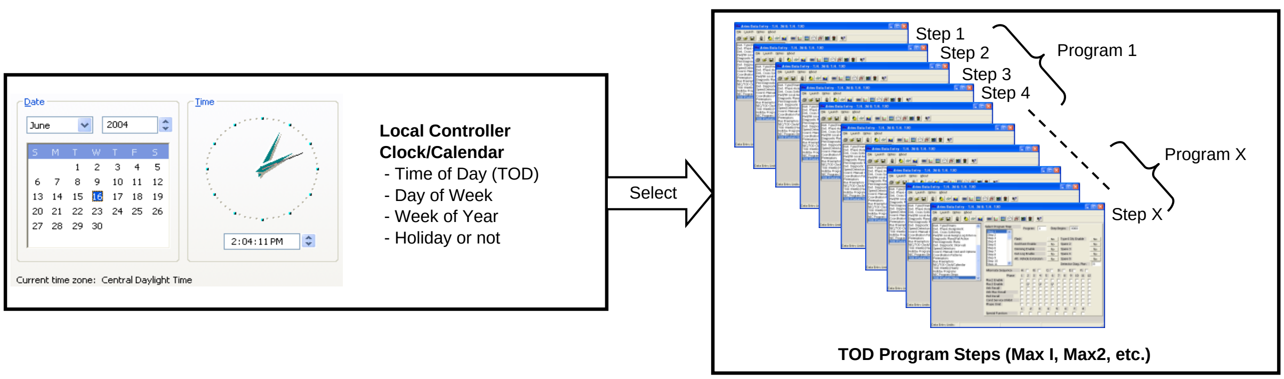
5.3 Local Free By TOD

The previous section lists some of the settings required for a local intersection controller. Some of these values can vary based on a time of day (TOD), day of week, week of year and special holiday program. Some of the parameters that can be changed include:

- ✓ Maximum time setting (Max I, Max II, Max III)
- ✓ Dynamic Max
- ✓ Phase omit
- ✓ Conditional service inhibit
- ✓ Flash
- ✓ Red Rest
- ✓ Alternate vehicle extension
- ✓ Alternate sequence
- ✓ Vehicle recall
- ✓ Vehicle max recall
- ✓ Pedestrian recall

Exhibit 5-1 illustrates that the local controller will use the clock and day information to choose the appropriate program and step.

Exhibit 5-1 Local Controller TOD Program Step



This above image does not address intersections running in a coordinated system. The intent is for an intersection running in free mode operation. Coordinated systems are discussed in Chapter **6**.

5.4 Local Intersection Start-up Process

Start-up of a local intersection is the sequence of operation following a dark or flash condition.

Below is information from the 2009 MUTCD.

Section 4D.31 Flashing Operation – Transition Out of Flashing Mode

Standard:

01 **All changes from flashing mode to steady (stop-and-go) mode shall be made under one of the following procedures:**

- **A. Yellow-red flashing mode: Changes from flashing mode to steady (stop-and-go) mode shall be made at the beginning of the major-street green interval (when a green signal indication is displayed to through traffic in both directions on the major street), or if there is no common major-street green interval, at the beginning of the green interval for the major traffic movement on the major street.**
- **B. Red-red flashing mode: Changes from flashing mode to steady (stop-and-go) mode shall be made by changing the flashing red indications to steady red indications followed by appropriate green indications to begin the steady mode cycle. These green indications shall be the beginning of the major-street green interval (when a green signal indication is displayed to through traffic in both directions on the major street) or if there is no common major-street green interval, at the beginning of the green interval for the major traffic movement on the major street.**

Guidance:

02 *The steady red clearance interval provided during the change from red-red flashing mode to steady (stop-and-go) mode should have a duration of 6 seconds.*

03 *When changing from the yellow-red flashing mode to steady (stop-and-go) mode, if there is no common major-street green interval, the provision of a steady red clearance interval for the other approaches before changing from a flashing yellow or a flashing red signal indication to a green signal indication on the major approach should be considered.*

Standard:

04 **During programmed changes out of flashing mode, no flashing yellow signal indication shall be terminated and immediately followed by a steady red or flashing red signal indication without first displaying the steady yellow signal indication.**

Option:

05 Because special midblock signals that rest in flashing circular yellow in the position normally occupied by the green signal indication do not have a green signal indication in the signal face, these signals may go directly from flashing circular yellow (in the position normally occupied by the green signal indication) to steady yellow without going first to a green signal indication.

[Source: Federal MUTCD, 2009 Edition]

5.5 Pedestrian Timing Requirements

This section will cover the WALK and PEDESTRIAN CLEARANCE (*flashing* DON'T WALK) parameters.

The MUTCD requires that pedestrians should be assured of sufficient time to cross the roadway at a signalized intersection. This must be shown with the vehicle and/or pedestrian indications. In the absence of pedestrian indications, the minimum green + yellow + all red time must be equal to pedestrian timing (walk + pedestrian clearance).

The MUTCD meaning of pedestrian signal indications are summarized as follows:

- ✓ WALK indication, means that pedestrians may begin to cross the roadway in the direction of the indication.

- ✓ *flashing* DON'T WALK indication, means that a pedestrian shall not start to cross the roadway in the direction of the indication, but that any pedestrian who has partly completed their crossing shall continue to a sidewalk, or to a safety island.
- ✓ steady DON'T WALK indication, means that a pedestrian shall not enter the roadway in the direction of the indication.

5.5.1 Walk

The MUTCD states, "Under normal conditions, the WALK interval should be at least 4 to 7 seconds in length so that pedestrians will have adequate opportunity to leave the curb before the clearance interval is shown." Research indicates that queues (more than 24 people) requiring more than 7 seconds to discharge occur very rarely and will usually be found only in certain sections of large metropolitan areas. The minimum WALK interval under low volume (less than 10 pedestrians per cycle) conditions could possibly be lowered to 4 - 5 seconds but the importance of the inattentiveness factor should be also weighted in this decision.

5.5.2 Flashing Don't Walk

The duration of the pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or shoulder at the end of the WALKING PERSON (symbolizing WALK) signal indication to travel at a walking speed of 3.5 feet per second to at least the far side of the traveled way or to a median of sufficient width for pedestrians to wait.

The *flashing* DON'T WALK interval is determined by the following formula:

flashing DON'T WALK = D/R

D = Distance from the near curb or shoulder to at least the far side of the traveled way or to a median of greater than 6 feet.

R = Walking rate of 3.5 feet per second assumed walking rate unless special conditions (school kids, elderly or handicapped) require a slower walking rate.

When determining the distance, consideration should be given to the pedestrian's normal walking path. Pedestrian timing should consider the pedestrian walking to the nearest pedestrian and/or vehicle indication following a marked or unmarked crosswalk.

On median divided roadways, consideration should be given to providing sufficient time to the pedestrians to cross both roadways. A pedestrian's goal is to cross the total roadway and does not expect to stop at the dividing median and wait till the next cycle. If the median is less than 6 feet wide the pedestrian should be provided sufficient time to cross both roadways as a median less than 6 feet wide is not considered a safe refuge island.

Normal walking speed is assumed to be 3.5 feet per second. In selecting a walking rate, consideration must be given to the type of pedestrians, volume of pedestrians, intersection location and geometrics and overall signal operation.

Some controllers do not time the yellow vehicle indication concurrent with the flashing DON'T WALK. This is assuming minimum vehicle green time. The steady DON'T WALK is displayed at the onset of yellow to encourage any pedestrians still in the street to complete the crossing without delay. Because of this and a MUTCD Ruling No. IV-35, Pedestrian Clearance Interval Calculation, the yellow interval may be included in the pedestrian clearance time (i.e., the pedestrian clearance time is equal to flashing DON'T WALK interval plus the yellow interval). The *flashing* DON'T WALK interval could then be determined by the following formula:

flashing DON'T WALK = (D/R) - Yellow

However, the ruling also states, "Discretion should be used in utilizing the latitude afforded by Section 4E." Therefore, as a general practice, this should not be followed unless it is necessary to minimize the pedestrian timing. By subtracting the yellow interval, pedestrians may receive the steady DON'T WALK before they reach the far side of the farthest traveled lane. Engineering studies and judgment should be exercised in determining walking rates, distances and utilizing the yellow interval as part of the pedestrian clearance interval.

5.6 Pedestrian Timing (2009 Federal MUTCD)

The following information is from the 2009 Federal 2009 MUTCD. The latest information can be found by visiting http://mutcd.fhwa.dot.gov/.

Section 4E.05 Location and Height of Pedestrian Signal Heads

Standard:

01 **Pedestrian signal heads shall be mounted with the bottom of the signal housing including brackets not less than 7 feet or more than 10 feet above sidewalk level, and shall be positioned and adjusted to provide maximum visibility at the beginning of the controlled crosswalk.**

02 **If pedestrian signal heads are mounted on the same support as vehicular signal heads, there shall be a physical separation between them.**

Section 4E.06 Pedestrian Intervals and Signal Phases

Standard:

01 **At intersections equipped with pedestrian signal heads, the pedestrian signal indications shall be displayed except when the vehicular traffic control signal is being operated in the flashing mode. At those times, the pedestrian signal indications shall not be displayed.**

02 **When the pedestrian signal heads associated with a crosswalk are displaying either a steady WALKING PERSON (symbolizing WALK) or a flashing UPRAISED HAND (symbolizing DONT WALK) signal indication, a steady or a flashing red signal indication shall be shown to any conflicting vehicular movement that is approaching the intersection or midblock location perpendicular or nearly perpendicular to the crosswalk.**

03 **When pedestrian signal heads are used, a WALKING PERSON (symbolizing WALK) signal indication shall be displayed only when pedestrians are permitted to leave the curb or shoulder.**

04 **A pedestrian change interval consisting of a flashing UPRAISED HAND (symbolizing DONT WALK) signal indication shall begin immediately following the WALKING PERSON (symbolizing WALK) signal indication. Following the pedestrian change interval, a buffer interval consisting of a steady UPRAISED HAND (symbolizing DONT WALK) signal indication shall be displayed for at least 3 seconds prior to the release of any conflicting vehicular movement. The sum of the time of the pedestrian change interval and the buffer interval shall not be less than the calculated pedestrian clearance time (see Paragraphs 7 through 16). The buffer interval shall not begin later than the beginning of the red clearance interval, if used.**

Option:

05 During the yellow change interval, the UPRAISED HAND (symbolizing DON'T WALK) signal indication may be displayed as either a flashing indication, a steady indication, or a flashing indication for an initial portion of the yellow change interval and a steady indication for the remainder of the interval.

Support:

06 Figure 4E-2 illustrates the pedestrian intervals and their possible relationships with associated vehicular signal phase intervals.

Guidance:

07 *Except as provided in Paragraph 8, the pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or shoulder at the end of the WALKING PERSON (symbolizing WALK) signal indication to travel at a walking speed of 3.5 feet per second to at least the far side of the traveled way or to a median of sufficient width for pedestrians to wait.*

Option:

08 A walking speed of up to 4 feet per second may be used to evaluate the sufficiency of the pedestrian clearance time at locations where an extended pushbutton press function has been installed to provide slower pedestrians an opportunity to request and receive a longer pedestrian clearance time. Passive pedestrian detection may also be used to automatically adjust the pedestrian clearance time based on the pedestrian's actual walking speed or actual clearance of the crosswalk.

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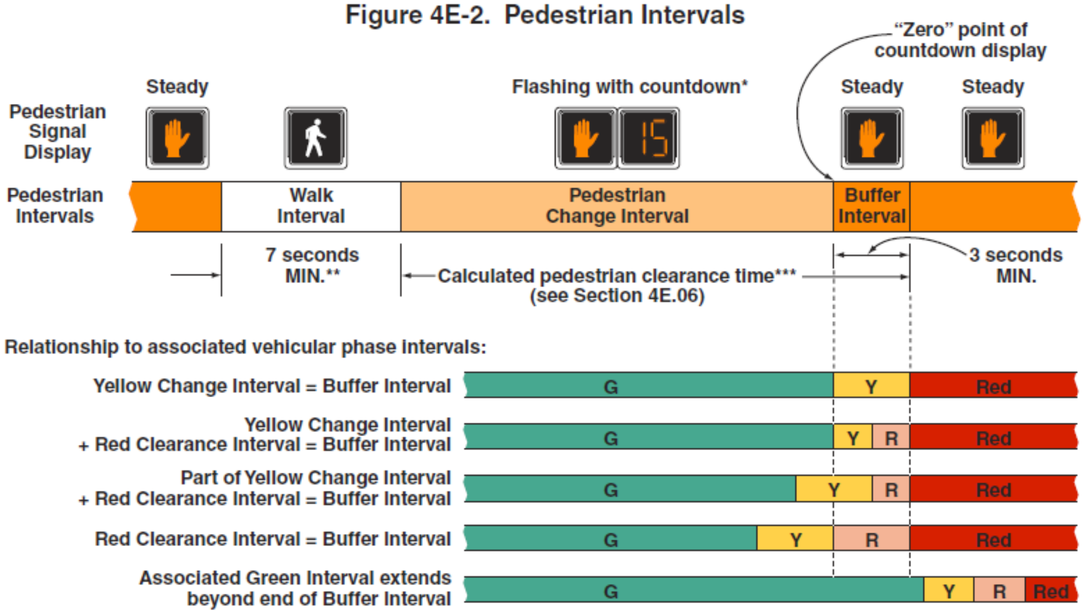
Figure 4E-2. Pedestrian Intervals



* The countdown display is optional for Pedestrian Change Intervals of 7 seconds or less.

** The Walk Interval may be reduced under some conditions (see Section 4E.06).

*** The Buffer Interval, which shall always be provided and displayed, may be used to help satisfy the calculated pedestrian clearance time, or may begin after the calculated pedestrian clearance time has ended.

Legend

G = Green Interval
Y = Yellow Change Interval (of at least 3 seconds)
R = Red Clearance Interval
Red = Red because conflicting traffic has been released

09 The additional time provided by an extended pushbutton press to satisfy pedestrian clearance time needs may be added to either the walk interval or the pedestrian change interval.

Guidance:

10 *Where pedestrians who walk slower than 3.5 feet per second, or pedestrians who use wheelchairs, routinely use the crosswalk, a walking speed of less than 3.5 feet per second should be considered in determining the pedestrian clearance time.*

11 *Except as provided in Paragraph 12, the walk interval should be at least 7 seconds in length so that pedestrians will have adequate opportunity to leave the curb or shoulder before the pedestrian clearance time begins.*

Option:

12 If pedestrian volumes and characteristics do not require a 7-second walk interval, walk intervals as short as 4 seconds may be used.

Support:

13 The walk interval is intended for pedestrians to start their crossing. The pedestrian clearance time is intended to allow pedestrians who started crossing during the walk interval to complete their crossing. Longer walk intervals are often used when the duration of the vehicular green phase associated with the pedestrian crossing is long enough to allow it.

Guidance:

14 *The total of the walk interval and pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the pedestrian detector (or, if no pedestrian detector is present, a location 6 feet from the face of the curb or from the edge of the pavement) at the beginning of the WALKING PERSON (symbolizing WALK) signal indication to travel at a walking speed of 3 feet per second to the far side of the traveled way being crossed or to the median if a two-stage pedestrian crossing sequence is used. Any additional time that is required to satisfy the conditions of this paragraph should be added to the walk interval.*

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Option:

15 On a street with a median of sufficient width for pedestrians to wait, a pedestrian clearance time that allows the pedestrian to cross only from the curb or shoulder to the median may be provided.

Standard:

16 **Where the pedestrian clearance time is sufficient only for crossing from the curb or shoulder to a median of sufficient width for pedestrians to wait, median-mounted pedestrian signals (with pedestrian detectors if actuated operation is used) shall be provided (see Sections 4E.08 and 4E.09) and signing such as the R10-3d sign (see Section 2B.52) shall be provided to notify pedestrians to cross only to the median to await the next WALKING PERSON (symbolizing WALK) signal indication.**

Guidance:

17 *Where median-mounted pedestrian signals and detectors are provided, the use of accessible pedestrian signals (see Sections 4E.09 through 4E.13) should be considered.*

Option:

18 During the transition into preemption, the walk interval and the pedestrian change interval may be shortened or omitted as described in Section 4D.27.

19 At intersections with high pedestrian volumes and high conflicting turning vehicle volumes, a brief leading pedestrian interval, during which an advance WALKING PERSON (symbolizing WALK) indication is displayed for the crosswalk while red indications continue to be displayed to parallel through and/or turning traffic, may be used to reduce conflicts between pedestrians and turning vehicles.

Guidance:

20 *If a leading pedestrian interval is used, the use of accessible pedestrian signals (see Sections 4E.09 through 4E.13) should be considered.*

Support:

21 If a leading pedestrian interval is used without accessible features, pedestrians who are visually impaired can be expected to begin crossing at the onset of the vehicular movement when drivers are not expecting them to begin crossing.

Guidance:

22 *If a leading pedestrian interval is used, it should be at least 3 seconds in duration and should be timed to allow pedestrians to cross at least one lane of traffic or, in the case of a large corner radius, to travel far enough for pedestrians to establish their position ahead of the turning traffic before the turning traffic is released.*

23 *If a leading pedestrian interval is used, consideration should be given to prohibiting turns across the crosswalk during the leading pedestrian interval.*

Support:

24 At intersections with pedestrian volumes that are so high that drivers have difficulty finding an opportunity to turn across the crosswalk, the duration of the green interval for a parallel concurrent vehicular movement is sometimes intentionally set to extend beyond the pedestrian clearance time to provide turning drivers additional green time to make their turns while the pedestrian signal head is displaying a steady UPRAISED HAND (symbolizing DONT WALK) signal indication after pedestrians have had time to complete their crossings.

Section 4E.07 Countdown Pedestrian Signals

Standard:

01 **All pedestrian signal heads used at crosswalks where the pedestrian change interval is more than 7 seconds shall include a pedestrian change interval countdown display in order to inform pedestrians of the number of seconds remaining in the pedestrian change interval.**

Option:

02 Pedestrian signal heads used at crosswalks where the pedestrian change interval is 7 seconds or less may include a pedestrian change interval countdown display in order to inform pedestrians of the number of seconds remaining in the pedestrian change interval.

Standard:

03 **Where countdown pedestrian signals are used, the countdown shall always be displayed simultaneously with the flashing UPRAISED HAND (symbolizing DONT WALK) signal indication displayed for that crosswalk.**

04 **Countdown pedestrian signals shall consist of Portland orange numbers that are at least 6 inches in height on a black opaque background. The countdown pedestrian signal shall be located immediately adjacent to the associated UPRAISED HAND (symbolizing DONT WALK) pedestrian signal head indication (see Figure 4E-1).**

05 **The display of the number of remaining seconds shall begin only at the beginning of the pedestrian change interval (flashing UPRAISED HAND). After the countdown displays zero, the display shall remain dark until the beginning of the next countdown.**

06 **The countdown pedestrian signal shall display the number of seconds remaining until the termination of the pedestrian change interval (flashing UPRAISED HAND). Countdown displays shall not be used during the walk interval or during the red clearance interval of a concurrent vehicular phase.**

Guidance:

07 *If used with a pedestrian signal head that does not have a concurrent vehicular phase, the pedestrian change interval (flashing UPRAISED HAND) should be set to be approximately 4 seconds less than the required pedestrian clearance time (see Section 4E.06) and an additional clearance interval (during which a steady UPRAISED HAND is displayed) should be provided prior to the start of the conflicting vehicular phase.*

08 *For crosswalks where the pedestrian enters the crosswalk more than 100 feet from the countdown pedestrian signal display, the numbers should be at least 9 inches in height.*

09 *Because some technology includes the countdown pedestrian signal logic in a separate timing device that is independent of the timing in the traffic signal controller, care should be exercised by the engineer when timing changes are made to pedestrian change intervals.*

10 *If the pedestrian change interval is interrupted or shortened as a part of a transition into a preemption sequence (see Section 4E.06), the countdown pedestrian signal display should be discontinued and go dark immediately upon activation of the preemption transition.*

Section 4E.08 Pedestrian Detectors

Option:

01 Pedestrian detectors may be pushbuttons or passive detection devices.

Support:

02 Passive detection devices register the presence of a pedestrian in a position indicative of a desire to cross, without requiring the pedestrian to push a button. Some passive detection devices are capable of tracking the progress of a pedestrian as the pedestrian crosses the roadway for the purpose of extending or shortening the duration of certain pedestrian timing intervals.

03 The provisions in this Section place pedestrian pushbuttons within easy reach of pedestrians who are intending to cross each crosswalk and make it obvious which pushbutton is associated with each crosswalk. These provisions also position pushbutton poles in optimal locations for installation of accessible pedestrian signals (see Sections 4E.09 through 4E.13). Information regarding reach ranges can be found in the "Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG)" (see Section 1A.11).

Guidance:

04 *If pedestrian pushbuttons are used, they should be capable of easy activation and conveniently located near each end of the crosswalks. Except as provided in Paragraphs 5 and 6, pedestrian pushbuttons should be located to meet all of the following criteria (see Figure 4E-3):*

- *A. Unobstructed and adjacent to a level all-weather surface to provide access from a wheelchair;*
- *B. Where there is an all-weather surface, a wheelchair accessible route from the pushbutton to the ramp;*
- *C. Between the edge of the crosswalk line (extended) farthest from the center of the intersection and the side of a curb ramp (if present), but not greater than 5 feet from said crosswalk line;*
- *D. Between 1.5 and 6 feet from the edge of the curb, shoulder, or pavement;*
- *E. With the face of the pushbutton parallel to the crosswalk to be used; and*
- *F. At a mounting height of approximately 3.5 feet, but no more than 4 feet, above the sidewalk.*

05 *Where there are physical constraints that make it impractical to place the pedestrian pushbutton adjacent to a level all-weather surface, the surface should be as level as feasible.*

06 *Where there are physical constraints that make it impractical to place the pedestrian pushbutton between 1.5 and 6 feet from the edge of the curb, shoulder, or pavement, it should not be farther than 10 feet from the edge of curb, shoulder, or pavement.*

07 *Except as provided in Paragraph 8, where two pedestrian pushbuttons are provided on the same corner of a signalized location, the pushbuttons should be separated by a distance of at least 10 feet.*

Option:

08 Where there are physical constraints on a particular corner that make it impractical to provide the 10-foot separation between the two pedestrian pushbuttons, the pushbuttons may be placed closer together or on the same pole.

5.7 Initial Timing

5.7.1 Minimum Initial

The minimum initial time is the minimum assured green that is displayed. It is established to allow vehicles stopped between the detector on the approach and the stop line to get started and move into the intersection. Therefore, timing of this interval depends on the location of the detector and the number of vehicles that can be stored between the detector and the stop line. Consideration must be given to pedestrian timing, density operations, controller type and detection design when determining this setting. When there are no pedestrian provisions (indications or pushbuttons), the minimum assured green must be equal to the minimum pedestrian timing (walk + pedestrian clearance).

Density operation. In density operation the minimum initial green should be set low to clear a minimum of vehicles expected during light volume. Density operation has another timed interval that adds initial time per vehicle arriving on red for that approach. The initial green should not be set to low as to display an unexpected short green.

Non-density operation. In non-density operation the minimum initial green must be long enough to guarantee that vehicles stored between the detector and the stop line will clear the intersection before the clearance intervals terminate the movement. If stop line extending detection is used, the minimum initial green time should be set as for a density operation.

Minimum Initial (Density operation)

Major approach = 15 seconds

20 seconds (45 mph or above)

Minor approach = 7-10 seconds (consider the lower values when split phasing is used)

Protected Left turn = 7 seconds

Protected/Permissive = 5 seconds

(Non-density operation)

Minimum initial green = 3 + 2n

n = Number of vehicles that can be stored between the stop line and the far detector in one lane. This is determined by dividing the distance between the stop line and the detector by 25. 25 is the average vehicle length plus headway in feet.

5.8 Density Features

5.8.1 Added Initial

Added initial is sometimes referred to as variable initial. This feature increases the minimum assured green time (minimum initial) so it will be long enough to serve the actual number of vehicles waiting for the green between the stop line and the detector.

This interval is generally used on phases for higher speed approaches where the detectors are placed quite a distance from the stop line (resulting in unacceptably long minimum initial requirements). This feature allows the minimum initial to be set low for light volumes. Vehicles crossing the detector when the phase is red will add time to the minimum assured green, so that when the phase is served, the minimum assured green will be long enough to serve the actual number of vehicles waiting for the green.

Consideration should be given to the number of lanes and detectors, distance from the stop line to detector, number of right turn vehicles, approach grades, type of controller, etc.

Field observation is very important in determining this setting.

This is calculated by the following:

D/25 x 2.1 + 3

Example: If detector is 400’ from stop line, then

400’/25’ x 2.1 + 3 = 16 x 2.1 + 3 = 36.6 seconds

Actuations Before Added Initial is the number of vehicles which can be adequately served by the time set on the minimum initial

	One Lane	Two Lanes
15 second Minimum Initial	6	10
20 second Minimum Initial	8	14

This is determined by: (minimum initial - 3) / 2

Two lane is 1.75 of one lane.

Added Initial Per Actuation is the amount of time that each vehicle crossing the detector on red should add to the minimum assured green.

One Lane: 2.0 seconds per actuation

Two Lane: 1.5 seconds per actuation

5.8.2 Passage Time

This function setting is the same for non-density and density operation. This setting should be the number of seconds required for a vehicle moving at the approach speed to travel from the detector to the stop line. The passage time serves two purposes. It is the passage time from the detector to the stop line and the allowable time gap between actuations that will cause the green to remain on that approach. As long as vehicle detections come at shorter intervals than the passage time (allowable gap), the green will be retained on that phase. In the density operation, the allowable gap is reduce by another timing feature.

If the passage interval is too short, quick stops may result as well as terminating the green before the vehicular movement has been adequately served. If the passage interval is set too long, excessive delays will result as well as safety problems due to improperly timed last vehicle intervals.

- ✓ Passage Time = $^{D}/_{1.47S}$ (general range is 2.0 - 8.0 seconds)
- ✓ D = Distance from the stop line to back detector, if single point detection. Distance (greatest distance) between stop line and/or detectors, if multiple detection.
- ✓ S = Posted speed limit in mph

Gap Reduction - Density Feature

This feature reduces the passage time and as a result reduces the allowable time gap between actuations that will cause the green to remain on that approach.

When a phase is green the time between vehicles to terminate that phase starts out at amount of time set for the passage time (i.e., successive actuations must be closer together than the passage time to extend the green). After the phase has been green for some time, it becomes desirable to terminate the phase on smaller distances between vehicles. This is done to reduce the probability of the phase being terminated at the maximum time. **When a phase terminates at maximum time there is no decision zone protection**. This feature is generally used on phases for higher speed approaches where the detectors are placed quite a distance from the stop line (resulting in long passage timing).

Time Before Reduction establishes the time before the passage time (allowable gap) begins to reduce.

Time To Reduce establishes the time in which the allowable gap is reduced from the passage time to the minimum gap, after the time before reduction has expired.

Minimum Gap establishes the minimum value to which the allowable gap between actuations can be reduced upon expiration of the time to reduce.

Generally, the minimum gap should not be set lower than 2 seconds. This is the average headway between vehicles and is approximately the time it takes a vehicle to travel from the detector through the decision zone. The amount of time into the green to reduce to the minimum gap should be set at about 2/3 of the maximum time. The allowable gap will gradually reduce in that time frame. Therefore, the last 1/3 of the maximum green would be extended only by tightly spaced vehicles.

5.8.3 Time Before Reduction

This is normally set for 1/3 maximum time.

5.8.4 Time To Reduce

This is normally set for 1/3 maximum time.

5.8.5 Minimum Gap

Minimum Gap = Passage time minus the time in seconds between the stop line and the end of the dilemma zone (generally considered 2.0 seconds)

Note: Gap reduction is normally not used when stop bar detectors exist. Gap reduction with stop bar detectors require special detector functions and timings.

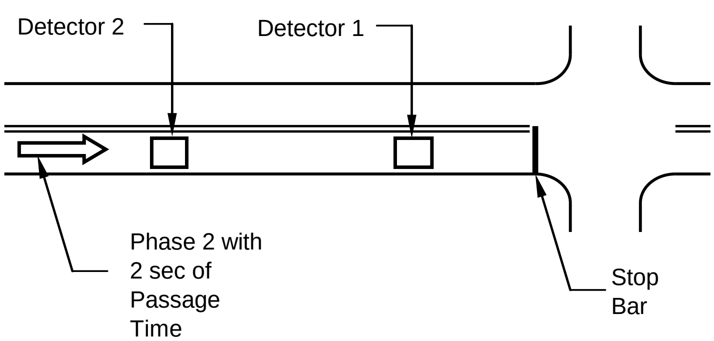
During moderate flow conditions a well-timed actuated signal should terminate due to gap-out rather than due to max-out. The goal of good green timing should be to terminate the green indication on gap out and to max out only under heavy traffic conditions (tightly spaced vehicles).

5.8.6 Detector Extend

The previous sections discuss per phase controller settings. That is, the setting in the controller applies to the given movement/phase. There are additional functions that allow this to be extended with the detectors. Some users will use a “per phase” extension and an additional extension “by detector.”

Refer to **Exhibit 5-2**. In this example, the passage time is set to 2 seconds. This 2 seconds may be adequate to get a vehicle from Detector 1 through or to the intersection. However, the 2 seconds of time may not be enough to get a vehicle from Detector 2 to Detector 1. Instead of increasing the Passage Time, which would be used by both detectors, a special extension of X seconds could be added to Detector 2.

Exhibit 5-2 Detector Extend Example



5.9 Maximum Green

Careful capacity analysis must be made to control peak hour cycle lengths and phase green times. The critical movement analysis (CMA) procedures can be used to establish these maximum green time settings.

> The CMA is a traditional (legacy) method for determining the maximum green time. However, traffic signal programs such as the HCS and Synchro are typically used to determine the optimal maximum green times.

Many controllers can have two or more maximum green times programmed. The second maximum time can put into effect by time clock.

Outlined below is a basic procedure to determine maximum green time per phase if not using signal timing software. An analysis should be done for both AM and PM peak hours or other peak time.

- ✓ From the AM and PM peak hour turning movement counts, take the 15 minute peak and multiply it by 4 to get the adjusted peak hour volume. If only hourly volumes are available, divide the hourly volume by the peak hour factor. If a peak hour factor is not available, use a 0.9 factor.
- ✓ Select the critical phase volume and sum them for a total intersection critical phase volume. All phase volumes should be per lane volumes.
- ✓ Use this volume to select the first approximation for cycle length from the tables on the following page.
- ✓ Once the cycle length has been determined, determine cycles per hour which is equal to 3600/cycle length.
- ✓ Calculate the number of vehicles that are required to handle per cycle per phase. No. of vehicles = volume/cycles per hour
- ✓ Apply 3 + 2.1n formula to get the required phase green time to handle vehicles. n - number of vehicles arrived at in step 5. The 3 factor is the start up delay (2.5 seconds is recommended by ITE) and the 2.1 is for a 2.1 second headway per vehicle.
- ✓ Take the calculated phase green time and multiple by 1.5 and round to the nearest 5 seconds. This factor is applied because these calculation apply basically to fixed time controllers and this factor increases the time to allow for fluctuations in vehicle demand that an actuated controller is designed to handle. This should allow the phase to terminate on a gap in traffic at 2/3 of maximum time as discussed earlier rather than maxing out.
- ✓ Review these phase green times and adjust for intersection characteristics and how intersection should operate to arrive at the maximum green timing per phase. If green

time demand is more than a 180 second cycle length, cycle length and phase green times should be reduced proportionately.

During moderate flow conditions a well-timed actuated signal will seldom terminate the green because the maximum green has timed out; it should terminate on gap out.

Optional check on cycle length:

The cycle length should also be compared to the Webster equation for calculation of cycle length. This equation for optimum cycle length that minimizes delay is as follows:

$C = {}^{(1.5L + 5)} / {}_{(1.0 - Y)}$

C = optimum cycle length, seconds

L = unusable time per cycle, seconds = nl + R

n = number of phases

l = average lost time per phase, seconds

R = Total all-red time per cycle, seconds = assumed to be the yellow and all-red

Y = sum of critical approach volume/saturation flow in each phase, assume saturation flow rate as 1600 vehicles per hour

The calculated cycle should fall within range of .75C and 1.5C as determined by the Webster formula. It has been determined that cycle lengths within this range do not significantly affect delay.

Consideration should be given to utilizing software in determining maximum green times.

Approximation for Cycle Length

5.9.1 Typical Maximum Green Interval

Left turn phase	10 - 45 seconds
Minor approach phase	20 - 75 seconds
Density operation	30 - 75 seconds
Major approach phase	30 - 120 seconds
Density operation under 45 mph	45 - 120 seconds
45 mph and over	60 - 120 seconds

5.9.2 Typical Minimum Cycle Length

2 phase signal	45 seconds
5 phase signal	60 seconds
8 phase signal	75 seconds

5.9.3 Typical Maximum Cycle Length = 180 seconds

SUM OF CRITICAL VOLUME	2 PHASE	5 PHASE	8 PHASE
700	45	60	90
800	60	75	105
900	60	75	105
1000	75	90	105
1100	75	90	105
1200	90	105	120
1300	105	120	135
1400	120	135	150
1500	135	150	165
1600	150	165	180
1700	165	180	180
1800	180	180	180

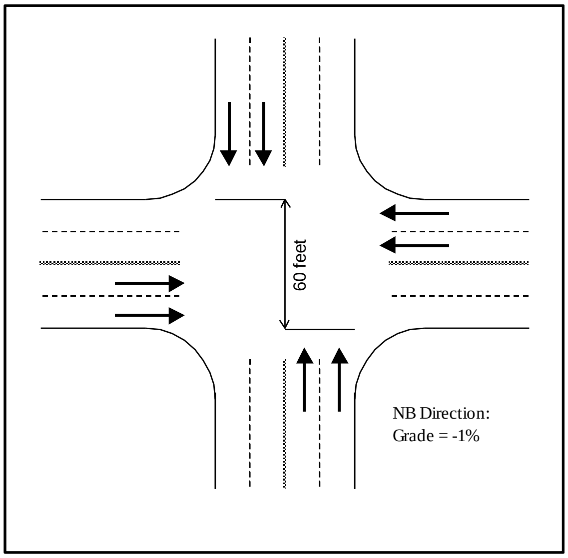
5.9.4 Vehicle Change and Clearance Intervals

In general, the vehicle change and clearance intervals should be dependent upon the approach speeds at the intersection and other factors. They should be sufficient to allow a motorist to safely bring his/her vehicle to a stop under normal conditions, or if he/she is too close to stop, then to proceed safely through the intersection.

Use the procedures contained in Chapter 4, Section **4.4.5**, along with engineering judgment, to determine the vehicle change and clearance intervals for each approach to a signalized intersection.

The Department uses the recommended Institute of Transportation Engineers (ITE) formulas for yellow and all-red clearance intervals to ensure compliance with the 2009 MUTCD requirement of using established engineering practices. If engineering judgment is used to vary from the established ITE formulas, then this should be documented in the traffic signal file.

Example: Consider the intersection shown in the figure below.



Assume the following:

t = 1.0 seconds

v = 45 mph

a = 10 feet per second

l = 20 feet

g = -1 percent

Y + R = 1.0 + 1.467 (45) + 60 + 20

2(10 + 32.2(-0.01)) 1.467 (45)

Y + AR = 1.0 + 3.41 + 1.21 = 5.62 seconds

Use,

Yellow = 4.4 seconds and All Red = 1.2 seconds

5.10 Vehicle Detection

One of the advantages of actuated control is the ability to adjust timing parameters based on actual vehicle or pedestrian demand. Since this vehicle or pedestrian demand varies at different times of the day, a detector is placed in the path of approaching vehicles or at a convenient location for the use of pedestrians.

The actual operation of the signal is highly dependent on the operation of these detectors. The following sections identify some of the more common detector types and the various modes of operation employed.

5.10.1 Types of Detectors

Loop Detector

This is the most common detector type. It is a loop of wire imbedded in the pavement carrying a small electrical current. When a large mass of metal passes over the loop, it senses a change in inductance of its inductive loop sensor by the passage or presence of a vehicle near the sensor.

Microwave Radar Detector

A detector that is capable of sensing the passage of a vehicle through its field of emitted microwave energy. The principles of operation involve microwave energy being beamed on an area of roadway from an overhead antenna, and the vehicle's effect on the energy detected.

Video Detection

The process of using a video imaging system to analyze the feed from a video camera mounted above the roadway to determine the presence or passage of vehicles in one or more specific travel lanes on an approach to the intersection.

Infrared Detector

A detector that senses radiation in the infrared spectrum.

Ultrasonic Detector

A detector that is capable of sensing the passage or presence of a vehicle through its field of emitted ultrasonic energy.

5.11 Detector Definitions

Some of the more common detector definitions are defined below.

- ✓ **Actuation**: The operative response of any type of detector (call).
- ✓ **Call**: A registration of a demand for the right-of-way by traffic at a controller unit.
- ✓ **Calling Detector**: A registration of a demand during red interval for right-of-way by traffic (vehicles or pedestrians) to a controller unit.
- ✓ **Check**: An output from a controller unit that indicates the existence of unanswered call(s).
- ✓ **Continuous-Presence Mode**: This is a mode of operation where the detector output continues if any vehicle (first or last remaining) remains in the zone of detection.
- ✓ **Controlled Output**: This is the mode of operation where the detector has the ability to produce a pulse that has a predetermined duration regardless of the length of time a vehicle is in the zone of detection.
- ✓ **Detector**: A device for indicating the presence or passage of vehicles.
- ✓ **Extension Detector**: A detector that is arranged to register an actuation at the controller unit only during the green interval for that approach so as to extend the green time of the actuating vehicles.
- ✓ **Limited-Presence Mode**: This is a mode of operation where the detector output continues for a limited period of time if vehicles remain in zone of detection.
- ✓ **Locking and Non-Locking Mode of Operation**: Vehicle actuations (calls) can be received at the detector in either a locking or non-locking mode. For the locking mode, the call is retained until the phase receives its green interval. For non-locking mode, the call is retained only while vehicles are in the zone of detection.
- ✓ **Passage Detection**: The ability of a vehicle detector to detect the passage of a vehicle moving through the zone of detection and to ignore the presence of a vehicle stopped within the zone of detection.
- ✓ **Presence Detection**: The ability of a vehicle detector to sense that a vehicle, whether moving or stopped, has appeared in its zone of detection.
- ✓ **Pulse Mode**: This is a mode of operation where the detector produces a short output pulse when detection occurs.
- ✓ **Zone of Detection**: The area or zone that a vehicle detector can detect a vehicle.

5.12 Detector Operations

Some of the more common detector operations are defined below.

- ✓ **Call and Extend**: Upon actuation the detector immediately places a call on its associated phases at all times. The detector shall also immediately cause the controller unit to extend the green time for the actuating vehicle only during the green interval of that phase. The controller unit may be in Lock or Non-Lock mode.
- ✓ **Extend Only**: The detector immediately registers actuation at the Controller unit only during the green interval for that phase thus extending the green time before the actuating vehicles. The controller unit may be in Lock or Non-Lock mode.
- ✓ **Call Only**: Upon actuation the detector immediately places a call on its associated phase only during the red interval of that phase. This call remains active as long as the detector is actuated. The controller unit may be in Lock or Non-Lock mode.
- ✓ **Call Only Density**: Upon actuation the detector immediately places a call on its associated phase only during the red interval of that phase. This call is inactivated when the controller unit outputs a check. This allows the use of density functions on this phase but necessitates the use of detector memory (lock) on the controller unit.
- ✓ **Delay Call Density Only**: When actuated during the red interval of its associated phase, the detector delays its output call for a pre-determined length of time during the extended actuation. This call is inactivated when the controller unit outputs a check and the time delay unit is not reset until after that phase has been served. This allows the use of density functions on this phase but necessitates the use of detector memory (lock).
- ✓ **Carry-Over Call and Extend**: Upon actuation the detector immediately places a call on its associated phase at all times and continues to output the call for a pre-determined length of time. The detector shall also immediately cause the controller unit to extend the green time for the actuating vehicle during the green interval of that phase and shall continue its output for a pre-determined length of time following an actuation. The controller unit may be in Lock or Non-Lock mode.
- ✓ **Delay Call Only**: When actuated during the red interval of its associated phase, the detector delays its output call for a pre-determined length of time during the extended actuation. After the time delay expires, the call remains active at the controller unit as long as the detector remains actuated. The controller unit may be in Lock or Non-Lock mode.
- ✓ **Type-3**: These are detectors at the stop bar that place a call while the phase is red. These type-3 detectors also place extension calls for the first 4 to 10 seconds of green time. After this initial green time, the type-3 detectors are disabled.

5.13 Pedestrian Detection

Pedestrian detectors are devices that notify the controller of the presence of pedestrians.

5.13.1 Push Buttons

The pedestrian push button is the typical detection device used for actuation of pedestrian timings. The device consists of a housing of high visibility with a 2-inch minimum diameter button. Optional features can include a latching LED confirmation light and confirmation tone. Push buttons should be located horizontally and vertical on a traffic signal support nearest to the crosswalk in accordance with the MUTCD Chapter 4E, and TC-8803 of Publication 148. If a history of visually impaired pedestrians is documented, the use of Accessible Pedestrian Systems (APS) should be provided. An APS can include locator tones, spoken WALK messages, and/or vibrotactile indications to assist the impaired pedestrians in safely traversing the intersection. Consult the MUTCD sections 4E.09 to 4E.13 for guidance on APS.

5.13.2 Passive Pedestrian Detection

Detection systems that passively sense the presence and walking speed of pedestrians may be considered. Ensure that these systems have been approved by PennDOT before proceeding with their use.

CHAPTER 6. COORDINATION CONCEPTS

6.1 Cycle Length

The cycle length is the total time to complete one sequence of signalization around an intersection. In an actuated controller unit, a complete cycle is dependent on the presence of calls on all phases. In a pre-timed controller unit it is a complete sequence of signal indications.

A detailed network analysis should be performed using a software package such as Synchro or TRANSYT for cycle length determination in a coordinated system. The use of computer models allows for multiple iterations of varying cycle combinations to determine the optimum signal timing parameters.

6.2 Signal Timing Intervals and Splits

The sum of the green, yellow, and all red intervals typically defines an individual phase **split**. A split is then the segment of the cycle length allocated to each phase that may occur (expressed in percent or seconds).

The primary considerations that must be given to vehicle split times are as follows:

- ✓ The phase duration must be no shorter than some absolute **minimum time**, such as five to seven seconds of green plus the required clearance interval. If pedestrians may be crossing with this phase, their crossing time must also be considered and included in the minimum phase length.
- ✓ A phase must be long enough to avoid over saturating any approach associated with it. Too short a time will cause frequent **cycle failures** where some traffic fails to clear during its phase.
- ✓ A phase length must not be so long that green time is wasted and vehicles on other approaches are delayed needlessly.
- ✓ Phase lengths should be properly designed to efficiently balance the cycle time available among the several phases, not just “equitably” between, say, north-south and east-west.

6.3 Offset

The **offset** is the time relationship, expressed in seconds or percent of cycle length, determined by the difference between a fixed point in the cycle length and a system reference point.

Proper determination and application of intersection offsets provide for the efficient movement of platoons through multiple intersections during the green indication. Properly timed offsets can significantly reduce delay and improve driver satisfaction with the system timing.

6.4 Progression Measures

All of the coordinated system analysis models have some MOEs associated with the green bands in the Time-Space Diagram (TSD). In fact some of the models utilize progression MOEs as a component of the optimization objective function. The more common of these MOEs are introduced below.

6.4.1 Bandwidth Efficiency

PASSER II uses this measure as its objective function. This is simply the proportion of the cycle that is included in through green bands, extending the entire length of the system. A simple TSD showing perfect time-space progression illustrates the concept. Mathematically, efficiency is calculated as:

where,

E = bandwidth efficiency,

B_f, B_r = bandwidths in the forward (f) and reverse (r) directions with respect to the arterial orientation, and

C = cycle length.

Example*:* Bandwidth Efficiency

Number of Signalized Intersections = 5

Bandwidth (forward) = 40 seconds

Bandwidth (reverse) = 40 seconds

Cycle Length = 90 seconds

Then,

$E = (B_f + B_r) / 2C$

= (40 sec + 40 sec) / (2 x 90 sec)

= 0.44 or 44%

6.4.2 Bandwidth Attainability

The attainability is the ratio of the total bandwidths to critical phase lengths for each of the directions on the arterial. Attainability is a measure of how much of the maximum available green is used for through progression, and is computed as:

where,

A = attainability

G_f, G_r = the critical (or minimum) green periods (including change periods) in the two directions, and

C = cycle length as before

***Example**:* Bandwidth Attainability

Number of Signalized Intersections = 5

Bandwidth (forward) = 40 seconds

Bandwidth (reverse) = 40 seconds

Cycle Length = 90 seconds

Intersection 1 $G_f = G_r$ = 60 seconds

Intersection 2 $G_f = G_r$ = 55 seconds

Intersection 3 $G_f = G_r$ = 55 seconds

Intersection 4 $G_f = G_r$ = 45 seconds

Intersection 5 $G_f = G_r$ = 50 seconds

Then,

$A = (B_f + B_r) / (G_f + G_r)$

= (40 sec + 40 sec) / (45 sec + 45 sec)

= 0.89 or 89%

This MOE is only reported by PASSER II. You can easily see that if attainability on a two-way street is less than 0.5, you can almost certainly improve the overall progression, including efficiency, by providing “perfect” one-way progression in the peak direction. PASSER II will not do this automatically, but you can instruct it to.

6.5 System Measures

Several other MOEs of interest are produced by most traffic operations models.

6.5.1 Total Travel

This value will be constant for any given network and demand distribution. This is simply the agreement of the product of link volumes and link lengths:

$TT_i = v_i L_i$

where,

TT_i = total travel on link i in veh-mi (veh-km) per hour;

v_i = traffic volume on link i, vph; and

L_i = length of link i in miles (km).

This MOE will not change in any given optimization, since the basic values (flow rates and link lengths) do not change.

6.5.2 Total Travel Time

Similar to the total travel, this system MOE is the product of link volumes and total time spent on the links, including delay or:

$TTT_i = v_i (L_i/V_i + d_i)$

where,

TTT_i = total travel time in veh-hr per hour on link i;

v_i = traffic volume on link i in vph;

V_i = average cruise speed on link i in mph (km/hr);

L_i = length of link i in miles (km);

d_i = total delay on link i in veh-hr per hour.

This measure should obviously decrease as the network signal timing is improved to reduce delay.

6.5.3 Average System Speed

The average speed in the system is an indication of the overall quality of flow in the network. It is simply the ratio of total travel (TT) to total travel time (TTT), and is thus expressed as veh-mi/veh-hr = mph (or similarly, km/hr). Links with zero distance (e.g. external links) or links that have been assigned zero delay and stop weights (e.g. non-vehicular links) should be excluded from the calculation of network average speed, as they are in TRANSYT-7F.

6.6 Computer Timing Tools

Computer models for developing optimized traffic signal timing plans have been available for over 25 years. The earliest versions of these programs were originally developed for mainframe computers and were often difficult to use. Over the years, these programs have evolved to take advantage of advances in microcomputer technology. In addition, the models themselves have been improved to better simulate the flow of traffic and make them more compatible with modern traffic control equipment. Of course, computer models cannot replace good engineering practice, including field observation and hardware understanding.

Today there are more than 30 models that users can choose from for signal timing and analysis applications. A brief description of five widely utilized programs is provided below.

Synchro/SimTraffic. Synchro is a complete software package for modeling and optimizing traffic signal timings. The key features of Synchro include:

- ✓ ***Capacity Analysis***. Synchro provides a complete implementation of the 2000 Highway Capacity Manual, Chapter 16.
- ✓ ***Coordination***: Synchro allows you to quickly generate optimum timing plans.
- ✓ ***Actuated Signals****:* Synchro is the only interactive software package to model actuated signals. Synchro can model skipping and gap-out behavior and apply this information to delay modeling.
- ✓ ***Time-Space Diagram****:* Synchro has colorful, informative Time-Space Diagrams. Splits and offsets can be changed directly on the diagram.
- ✓ ***Integration with SimTraffic, CORSIM, and HCS****:* Synchro features preprocessor to these software analysis packages. Enter data once with easy-to-use Synchro, and then perform analyses with these software packages.

Synchro is a macroscopic traffic software program that replicates the signalized intersection capacity analysis as specified in the 2000 Highway Capacity Manual (HCM). Macroscopic level models represent traffic in terms of aggregate measures for each movement at the intersections. Equations are used to determine measures of effectiveness such as delay and queue length. These models do not account for "bottleneck" situations where upstream traffic deficiencies reduce the amount of traffic reaching downstream intersections. This would be a situation where Synchro may show a delay that is worse than SimTraffic since all of the volume is not reaching the intersection in SimTraffic.

A unique analysis methodology to Synchro is the “Percentile Method.” To account for variations in traffic, Synchro models traffic flow under five percentile scenarios. They are the 90th, 70th, 50th, 30th, and 10th percentile scenarios based on a Poisson distribution. If 100 cycles are observed, the 90th percentile cycle will represent the 10 busiest cycles. Each of these scenarios will represent 20% of the cycles actually occurring. This feature is discussed in more detail in Chapter 6.

When it comes to SimTraffic, this is a microscopic simulation model. SimTraffic has the capability to simulate a wide variety of traffic controls, including a network with traffic signals operating on different cycle lengths or operating under fully-actuated conditions. Most other traffic analysis software packages do not allow for a direct evaluation of traffic conditions operating under varying cycle lengths and traffic control.

Each vehicle in the traffic system is individually tracked through the model and comprehensive operational measures of effectiveness are collected on every vehicle during each 0.1-second of the simulation. Driver behavior characteristics (ranging from passive to aggressive) are assigned to each vehicle by the model, affecting the vehicle's free-flow speed, queue discharge headways, and other behavioral attributes. The variation of each vehicle's behavior is simulated in a manner reflecting real-world operations.

Since SimTraffic is a microscopic model, the full impact of queuing and blocking would be measured by the model. This is a situation where SimTraffic could show more delay when compared to Synchro.

The intention is to use Synchro and SimTraffic as companion models. Use Synchro to determine macro level LOS and delays (similar to the 2000 HCM), and use SimTraffic to simulate and animate to determine the 'problems' that may not be fully realized with a macro-level model.

Within Windows, Synchro is capable of drawing street layouts and networks onto a map background which can be imported as a DXF file, JPG image, or BMP image which can result in powerful animation graphics for public viewing. Synchro also serves as a preprocessor to the CORSIM, and the HCS programs. This means that users are required to enter data just once for subsequent analysis is multiple software packages. Synchro can also illustrate time-space diagrams. Chapter 6 of this manual contains detailed information about Synchro 6.

TRANSYT-7F. TRANSYT-7F (Traffic Network Study Tool) is a macroscopic traffic signal model originally developed in the United Kingdom by the Transportation and Road Research Laboratory and later modified by the University of Florida Transportation Research Center for the Federal Highway Administration (FHWA). The basic premise of the analysis procedures used in TRANSYT-7F is the macroscopic, step-wise modeling of platoon progression and dispersion as it travels through a series of adjacent intersections. The TRANSYT-7F software has been designed to serve two primary functions. The first of these is the simulation of traffic as it flows through an arterial or network. The second is the development of optimized traffic signal timing plans. In both cases, it is required that all signals operate with consistent cycle lengths, though double cycling can be incorporated.

When using TRANSYT-7F to simulate traffic operations, input data requirements are similar to those required for the analysis detailed in the HCM methodology. User input includes volumes and turning percentages, cycle and phase durations, and roadway geometries. Unlike the HCM analysis methods, saturation flow rates for various lane groups must also be entered by the user, rather than intrinsically calculated within the model. Therefore, it is essential that an accurate estimate of saturation flow rates be obtained, through either field measurements or some other analytical means.

When using TRANSYT-7F for system optimization, much of the input data requirements are the same as those discussed above. Specifically, TRANSYT-7F requires that the user input phase sequences and minimum splits. It has the ability to optimize other signal settings, such as cycle length, phase lengths, and offsets. These values are optimized through either minimization or maximization of a user selected objective function, or performance index (PI). Options for this PI include minimization of a disutility index (DI) which is a linear combination of delays, stops, fuel consumption, and, optionally, excessive queuing; minimization of excess operating cost; or optimization of “forward progression opportunities”, which may also be done in combination with the disutility function.

Output reports produced by TRANSYT-7F, like the HCM, indicate both degree of saturation and delay for each lane group. TRANSYT-7F delay, like delay calculated with the HCM methodology, is a combination of uniform delay and random plus saturation delay. To calculate uniform delay, TRANSYT-7F simulates traffic flow, step by step throughout the cycle, to develop queue lengths. TRANSYT-7F then uses an algorithm to estimate uniform delay from these simulated queue lengths. When conducting the simulation, TRANSYT-7F accounts for the arrival pattern, due to upstream intersections and platoon dispersion, as well as lane group start-up lost time and extension of effective green. Thus, unlike the HCM methodology, TRANSYT-7F calculates uniform delay based on simulation of the traffic flow. Therefore, no delay factor is necessary to account for the impacts of progression, since it is intrinsic in the flow profiles.

The second portion of delay, random plus saturation delay, is computed using the same algorithm found in the HCM for d_2. The delay calculated by TRANSYT-7F is total delay, rather than stopped delay. To equate TRANSYT-7F delay to HCM level of service, HCM level of service thresholds should be increased by a factor of 1.3.

Where the HCM methodology computes these measures of effectiveness based on a peak 15 minute flow period, TRANSYT-7F simulates only one cycle. Therefore, the MOEs should be viewed as an average for the analysis period. Thus, TRANSYT-7F, like the HCM methodology cannot account for effects of queues which develop over time during periods of oversaturated flows. For lane groups whose V/C exceed 0.95, calculated delays should be used cautiously. TRANSYT-7F, unlike the HCM, does have the ability to determine another MOE, maximum back of queues (MBQ). This MBQ is based on arrivals on red, also incorporating vehicles that may join the back of the queue as the queue dissipates during the allotted green time. While TRANSYT-7F cannot model the effects of spillback, this value provides a good indication of whether it is occurring.

TRANSYT-7F produces various other measures of effectiveness that are useful in evaluating intersection performance. These include total travel and total travel time, stops, and fuel consumption. In addition to these intersection MOEs, TRANSYT-7F output also provides route and system MOEs. These include total travel and travel time; uniform, random, total, average, and passenger delays; stops; speeds; fuel consumption; operating costs; and performance index.

Refer to http://mctrans.ce.ufl.edu/featured/TRANSYT-7F/ for additional details.

PASSER II. PASSER II-90, or Progression Analysis and Signal System Evaluation Routine, is not a simulation model like TRANSYT-7F or NETSIM, but rather utilizes a discrete, macroscopic, deterministic traffic analysis and signal timing model. (Although a simulation mode has been added as part of this version for analyzing uncoordinated operation.) This program is capable of handling isolated intersections or arterials only; it does not model signal grid networks.

In general, PASSER II-90 combines algorithms developed for this, and other, model(s) with HCM methodologies to analyze and optimize signals along an arterial. In particular, PASSER II-90 utilizes Webster's method as part of the optimization of cycle length and splits. Instead of simulation, PASSER II-90 uses algorithms to determine probability of queue clearance, percent green within the band, and all MOEs. PASSER II-90 is designed to select an arterial wide cycle length (it does not consider double cycling), intersection phase sequences which best serve progression, phase length, and offsets. One issue that many users may need to consider is that this version utilizes methodologies from the 1985 HCM, not the 1994 update to the HCM. MOEs estimated by PASSER include degree of saturation (v/c ratio), delay, stops, maximum queue length, fuel consumption, minimum delay cycle, bandwidth efficiency and attainability, and Levels of Service.

The main thrust of PASSER II-90 is to optimize a series of signals, allowing for the greatest possible bandwidth, for either one- or two-way flow, depending on the user's specifications. This goal differs from that of Synchro and TRANSYT-7F, which develop their optimization procedures around delay. The best cycle determined by PASSER II-90 is chosen to give the highest bandwidth efficiency, which may or may not correspond to the lowest delay. Unlike TRANSYT-7F, PASSER II-90 does consider different possible lead/lag and overlap phasing when optimizing.

PASSER II-90 calculates delay using variations of the uniform and random delay terms found in the 1985 HCM. Calculation of uniform delay is fundamentally the same as the HCM equation for dl, with an adjustment made to account for progression allowing platoon arrivals during green, and queue formation and dissipation. Random delay is calculated as in the 1985 HCM, with the exception that the calculation may be performed for either a one hour or fifteen minute period. Random delay, as calculated in the HCM, is for a fifteen minute period only. The PASSER II-90 delay model calculates the total, or approach, delay, not stopped delay as defined in HCM level of service. HCM level of service threshold values are increased by a factor of 1.3 to account for this difference between stopped and approach delay.

PASSER II-90 also incorporates other areas and factors of the 1985 HCM. One such item is an assistant function which aids the user in calculating saturation flows based on HCM adjustment factors. Also, PASSER II-90 contains an algorithm that roughly models shared lanes. This includes whether the lane will operate as a "de facto" left turn lane, as in the HCM. There are also various methods in which PASSER II-90 may model permitted movement. The user is allowed to use the HCM (1985) model, their own, or several other developed models. If the user wishes to stay as close to HCM methodologies as possible, he/she should be aware that the default method used is not the HCM model, but the TEXAS A&M model.

PASSER II-90 also calculates the volume to capacity (v/c) ratio in the same manner found in the HCM. While saturation flow may be calculated using HCM methodologies, the importance of accuracy in this value cannot be overstated. As with the other models discussed, an incorrect saturation flow can have a measurable effect on the quality of results and recommended timing and offsets. Saturation flow in one crucial area where engineering judgment must be keenly used, through field studies or other methods, to assure accurate reflection of local, existing conditions. Users must also be cautious in saturated conditions, since spillback is not directly modeled and will not be taken into account.

Refer to http://ttisoftware.tamu.edu/fraPasserII_02.htm for additional details.

TSIS-CORSIM. The CORSIM (TRAF-NETSIM) model, originally named UTCS-1S, was developed in the early 1970's under the direction of FHWA. Originally designed for mainframe usage, TRAF-NETSIM was later converted to a microcomputer version and became part of the TRAF-family of models. The TRAF family of models is a set of simulation models, each representing a particular traffic environment that, when combined, may represent an entire traffic system. NETSIM'S role in the TRAF family is to model the urban traffic environment (i.e. intersections), including signalization, stop signs, yield signs, buses, pedestrians, etc. In general, NETSIM is a surface street network (urban traffic) microscopic stochastic simulation model. NETSIM has no direct optimization feature.

Briefly, a microscopic model is one which models each vehicle as a separate entity, contrasted to the macroscopic models discussed which model groups or platoons of vehicles. Microscopic models tend, by their nature, to provide a more detailed model of the traffic environment and vehicle interaction. Stochastic, according to Webster's Dictionary of the English Language, is defined as "pertaining to chance or conjecture..., random." Therefore, NETSIM accounts for the randomness of the traffic, the mix of car and driver types, in an attempt to reflect the "real world."

An understanding of the stochastic nature of NETSIM is crucial in gaining insight into the nature, operation, and methodology of the model and how it relates to the HCM. First, recall that the HCM provides a set of equations where a specific set of traffic, roadway, and signal conditions will always result in the same capacities and delays. In NETSIM, the same traffic conditions will not always result in the same MOE values. By utilizing the randomness of the model, the traffic stream may be "re-mixed." NETSIM stochastically assigns turn movements, free-flow speeds, queue discharge headways, and vehicle and driver attributes, allowing for the same "traffic" to yield varying MOES. To account for this randomness of the model, it may be necessary to perform a statistically sufficient number of runs, averaging the results, to better reflect real world variation. It is readily realized that an arterial will not operate identically on any two days. One Friday is different from the next, which is different from the next, etc.

Vehicle movement in the model is based on car following and lane changing logic, and response to traffic control devices and other demands. NETSIM accounts for "driver behavior characteristics" (i.e., passive or aggressive), vehicle characteristics (up to 16 different vehicle types with different operating and performance characteristics), vehicle interactions, traffic control devices (pre-timed and actuated signals, stop and yield signs), street system geometry, buses, pedestrians, etc. NETSIM also allows for the traffic environment characteristics to change over time, such as changes in signal timings and traffic volumes.

Unlike the other models discussed, NETSIM does not utilize the HCM delay or critical degree of saturation equations. Whereas HCS is an attempt to use traffic attributes (volumes, signal timing, geometries, etc.) to predict the capacities, delays, queues, etc. with a set of equations and factors, NETSIM uses these traffic attributes to generate a simulation of the traffic flow, from which the MOEs are directly measured. That is, the amount of delay experienced by each car is physically measured, from which an average is determined (both stopped and approach). The MOEs of the simulation may be thought of as being measured in much the same manner as field measurements would be performed.

As stated, NETSIM has been in use since the early stages of transportation modeling, and has been used by many people to successfully and accurately reflect traffic flow. While NETSIM uses direct measurements, rather than predictions, to determine MOEs, any measurements are only as accurate as the simulation from which they are based. Therefore, calibration and validation of the simulation are crucial in the creation of an accurate model. This cannot be overstated for this or any other model. Items such as queue discharge characteristics, driver types, length of entry links, etc., may require study and engineering judgment when developing a model.

Refer to http://mctrans.ce.ufl.edu/featured/TSIS/ for additional details.

Highway Capacity Software (HCS). The HCS implements the procedures defined in the 2000 Update to the Highway Capacity Manual (HCM) from the Transportation Research Board (TRB). The software includes analysis modules on (1) Basic Freeway segments, (2) Weaving areas, (3) Ramps, (4) Multilane Highways, (5) Two-Lane facilities, (6) Signalized intersections, (7) Unsignalized intersections, (8) Arterials segments, (9) Transit, and (10) Freeway facilities analysis.

HCS-2000 and HCS+ were developed by the McTrans Center at the University of Florida as a typical Windows (all operating systems versions) installation.

The HCS **Signalized** Intersection module entry screen has been organized to consolidate data entry with the factors affected in the analysis. In this arrangement, the results of changing input data are readily apparent. The Report Pane will produce output similar to the HCM and previous versions of HCS which follow the Volume, Saturation Flow, Capacity and Level of Service worksheets.

Operational analyses will typically solve for Level of Service (LOS) for a given set of operational and geometric conditions. This type of analysis is oriented toward the evaluation of an existing facility or specific design proposal. The methodology uses the HCM Chapter 16 procedures.

Tru-Traffic (formerly TS/PP-Draft) is a worksheet for drafting time-space or platoon-progression diagrams. It allows the user to see the entire diagram in colorful, high resolution on the screen. Although Tru-Traffic offers some automatic optimization options, it was developed with the idea that some decisions in signal timing are based on factors that cannot be quantified easily or accurately for a computer (e.g., driver perception, citizen complaints, queue length, local policies, etc.) and therefore must be made by a human.

Tru-Traffic allows the user to see one or more diagrams, easily modify any parameter (phase sequence, offset, cycle length, splits, etc.) for any intersection, and instantly see the effects of the change. Thus, the user can quickly optimize the parameters. On time-space and time-location diagrams, it automatically adjusts the green bands to show the traffic flow. On platoon-progression diagrams, it shows the flow density and queue lengths, much like the diagrams of PPD, the TRANSYT-7F post processor (except that the parameters may be changed interactively with the mouse or cursor keys, and the diagrams are displayed on the screen rather than just on the printer).

Tru-Traffic handles signalized networks or intersecting arteries by allowing multiple diagrams, each in its own diagram window, and each representing a different artery. The common intersections are "linked" across diagram windows so that the user may edit the parameters in any diagram window, and Tru-Traffic ensures that the common parameters between linked intersections stay concurrent.

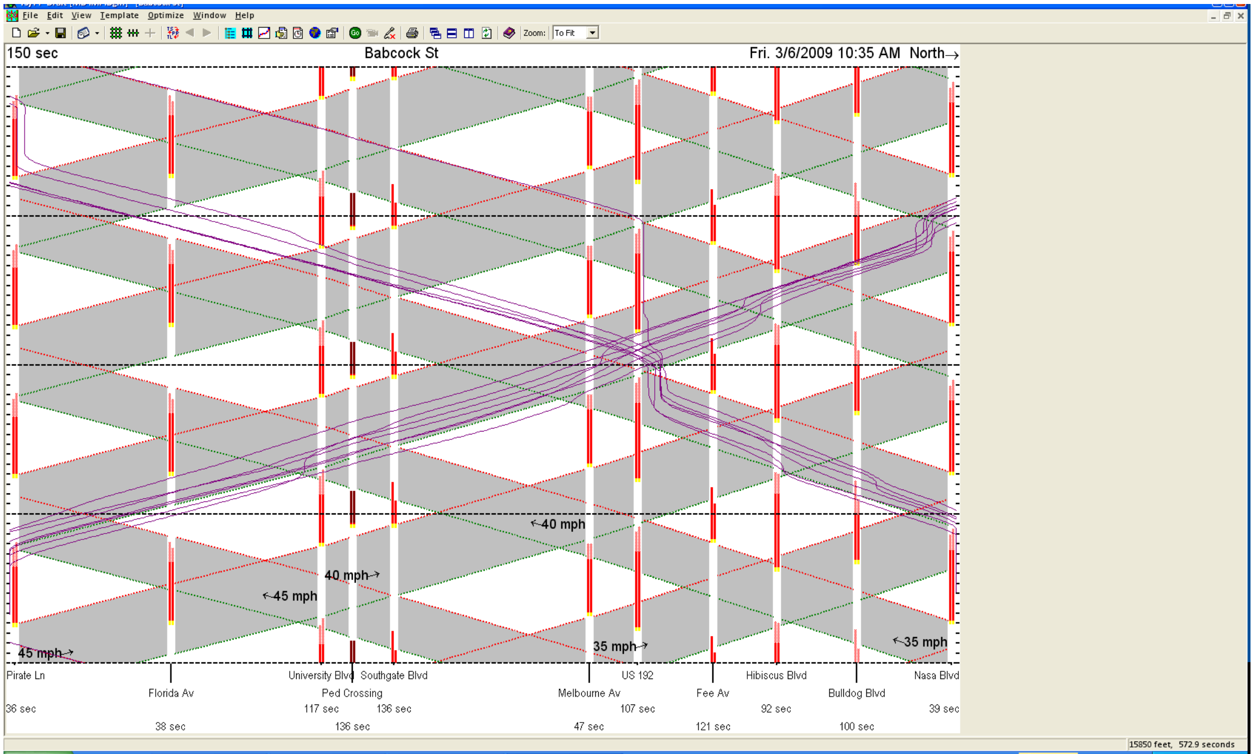
Using a GPS Receiver connected to your computer will allow Tru-Traffic to track position and speed. The collected information may be used to:

- ✓ Calculate the distance between intersections.
- ✓ Lay out the Network View with high accuracy.
- ✓ Display your current location in time and space on the diagram window and in the Network View.
- ✓ Predict whether you will arrive at the next signal during the green time.

Record Trip Logs of travel along the artery. Trip Logs can be:

- ✓ Plotted as trajectories on the diagram windows, graphically showing where delay occurs, which signals you're stopped at, and where you enter or leave the green bands. Before and after trip logs may be recorded in the same diagram data file, and you may select which ones are visible at any moment.
- ✓ Used to prepare comparative Travel Time and Delay Reports (before vs. after runs), which can easily be copied and pasted into word-processing documents or spreadsheets for detailed analysis. These can be very powerful tools of analysis for determining the effectiveness of a timing plan.
- ✓ Plotted as Speed vs. Distance or as Time vs. Distance plots.
- ✓ Used to measure the actual travel distance between intersections.
- ✓ Used to calculate the "optimal" relative offset between intersections for a given direction of travel.
- ✓ Used to calculate the actual average speed between intersections.

Exhibit 6-1 Travel Time Runs in Tru-Traffic



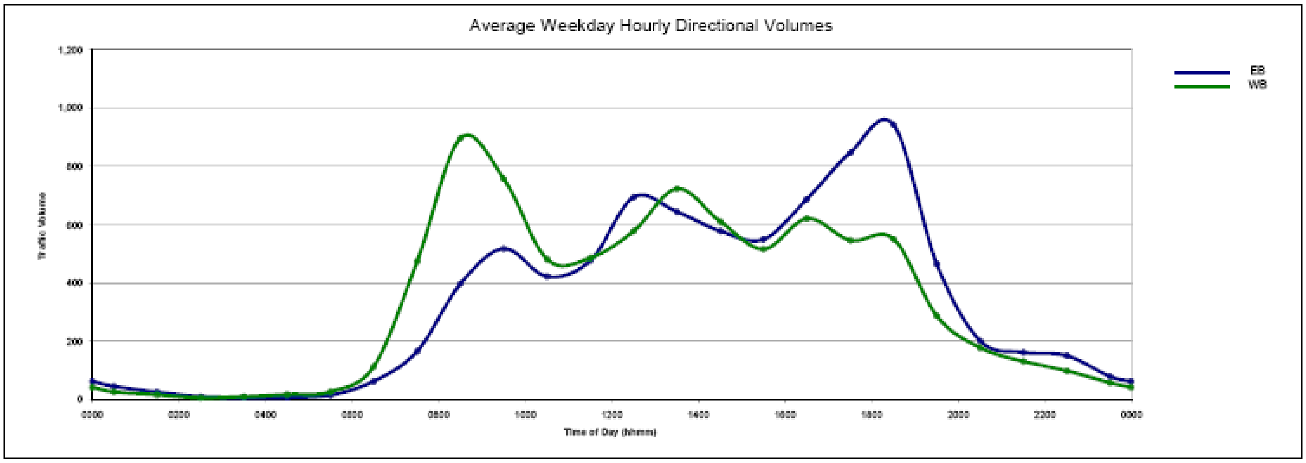
6.7 Timing Plan Needs

In order for a traffic signal system to operate under coordinated traffic responsive (TR) or time of day (TOD) control, it is necessary to develop various signal timing plans. For traffic responsive operation, the traffic control plan is selected based on the actual traffic demand along the corridor. System detectors transmit volume and occupancy data to the master controller which then selects the timing plan based on predetermined threshold values for various volume levels and directional preferences.

For TOD operation, the timing plan for varying volume levels and directional preferences is selected based on the time of day, day of week, and week of year. Traffic responsive operation has the advantage in that it can change the timing plan to account for varying conditions if the traffic demand is different from that predicted for use in the TOD plan. More details on these operational modes is covered in later sections.

The number of timing plans required is influenced by a number of factors but largely depends on the traffic variability throughout the year, week and day. The following graphic illustrates traffic variability averaged over 7 days and is used to determine how many timing plans are needed and when to conduct the pattern changes.

Exhibit 6-2 Sample Average Weekday Hourly Directional Volumes



When the resources are available, the following timing plans should be investigated for three different volume levels with three different directional preferences, as follows:

Exhibit 6-3 Sample Directional Coordinated Timing Plans

Volume Level (TR)	Plan Number	Time of Day (TOD)	Directional Preference
Low	1	Low AM Peak	Inbound Flow
	2	Low Off Peak	Balanced
	3	Low PM Peak	Outbound Flow
Medium	4	Medium AM Peak	Inbound Flow
	5	Medium Off Peak	Balanced
	6	Medium PM Peak	Outbound Flow
High (Peak)	7	High AM Peak	Inbound Flow
	8	High Off Peak	Balanced
	9	High PM Peak	Outbound Flow

Implementation

The initial timing plans should be implemented and fine-tuned. This implementation should include, as a minimum, the following three steps:

- ✓ Field verification of the initial timings of each plan should be performed. This will include verification of cycle lengths, splits and offsets.
- ✓ Field assessment of traffic operations resulting from each plan. This will include observations of intersection operations for several cycles during peak hours and trial runs along both directions of arterials (at the prevailing speed) to ascertain progression. Changes to splits and/or offsets should be implemented as necessary.
- ✓ Reassessment of traffic operations resulting from revisions to the timing plans.

An accurate record of all field revisions to the timing plans should be prepared.

"After" Conditions

An "after" study of the new timing plans for comparison to the "before" study results should be performed. This effort should occur after a "stabilizing period."

Comparisons between "before" and "after" data should be performed for:

- ✓ System-wide measures-of-effectiveness output from the simulation models, and
- ✓ Field-collected measures such as travel time.

Also, refer to Chapter 4 for procedures to time a traffic control signal.

6.8 Traffic Signal Control Systems

6.8.1 System Concept

A system may be defined as an arrangement or combination of interacting or interdependent parts which form a unified whole serving a common purpose. The system concept as related to traffic signal control includes the methods, equipment, and techniques required to coordinate traffic flow along an arterial or throughout an area.

System Objective

The major objective of a traffic control system is to permit continuous movement and/or minimize delay along an arterial or throughout a network of major streets. This involves the selection, implementation, and monitoring of the most appropriate operational plan. Basically, a traffic signal system provides the appropriate and necessary timing plans for each intersection in terms of individual needs as well as the combined needs of a series of intersections.

Relationship of Timing Plans to Traffic Control

In the system concept a timing plan is defined by a combination of control parameters for one or more intersections based upon an analysis of demand. Timing plans can be provided as a function of equipment at the local intersection, the central control point, or both. Timing plans consist of:

1. *A system Cycle*. A specific cycle length is imposed throughout the system covered by the timing plan.
2. *Split*. All intersections in the system have defined splits which are the apportionment of the cycle to the various phases present at that intersection.
3. *Offset*. Each intersection has a unique offset. The offset is the relationship of the beginning of the main street green at this intersection to a master system base time. Offsets are generally expressed in seconds. Properly established offsets along a street can potentially provide for smooth traffic flow without stopping.

Basis of Selecting Timing Plans

The selection parameters which define timing plans include:

1. *Historic Data* Time of Day information compiled from traffic counts to reflect traffic volumes for specified time of day (morning peak, midday, afternoon peak, etc.) and day of week.
2. *Current Data* Real time on-street volumes from traffic detection equipment.
3. *Special Data* Special events, emergency route assignment, special right-of-way preemption (fire equipment, ambulances, buses, etc.)

6.8.2 Types of Traffic Signal Control Systems

Many combinations of methods, equipment, and techniques can comprise a traffic signal control system. Generally, these systems fall into the following basic types.

Time Based Coordinated (TBC) System

This form of coordination utilizes non-interconnected controllers with auxiliary devices called time based coordinators. These devices use the power company supplied frequency to keep time very accurately. Various timing plans can be established with time of day and day of week plan changes. Since all intersections use the same power source, the time-based coordinators provide coordination without physical interconnection.

Global Positioning System (GPS) receivers have been used for several years to provide a clock sync to ensure TBC is maintained.

Interconnected Pre-timed System

This type of system was originally developed for electromechanical controllers, but can also be used with some of the newer controllers. Local intersections are physically interconnected (usually by a 7-wire cable) to ensure coordinated operation. The system provides automatic re-synchronization should a signal go “out of step.” The number of timing plans is a function of the number of dials and the number of offsets and splits per dial; the most common system consists of a three-dial, three-offset, one-split combination. Timing plans are normally selected by a time clock or time dependent programming device. The local controller for one intersection may act as master controller for the system.

Traffic Responsive System

Basically, this is an interconnected system utilizing a master controller for pattern (cycle/offset/splits) selection. Traffic detectors are used to sample directional volumes and detector occupancy. Volume and occupancy metrics determine which of the available patterns is selected (i.e., inbound, outbound, or average) based on predetermined thresholds. The master controller may be an analog or a digital computer.

Interconnected Actuated Systems

This is generally a small system with a master-slave relationship (i.e., two or more fully-or semi-actuated local controllers with one acting as system master and controlling cycle length for the other controllers). Offset capability is limited. A variation of this system uses a system master, coordinating units, and local actuated controllers. The master may be traffic responsive or combination of time clocks.

Traffic Adaptive System

Traffic adaptive systems perform "real-time" adjustments to the cycle length, splits and offsets in response to traffic demand. Traffic adaptive systems require extensive detection inputs. Complete and accurate traffic flow data must be gathered, processed and communicated to the central computer.

Advanced Traffic Management Systems (ATMS)

ATMS are capable of monitoring and controlling thousands of intersection controllers using state-of-the-art architecture like TCP/IP and NTCIP. ATMS offer complete traffic and data management including real time field reporting for multiple users over distributed local and wide area networks and remote access.

ATMS offer scalable software solutions that support a range of users including:

- ✓ School zone flashers
- ✓ Freeway management
- ✓ CMS, VMS, DMS
- ✓ CCTV surveillance
- ✓ HOV lane control
- ✓ Reversible lane control signals
- ✓ Real-time split monitoring and time space reporting
- ✓ Incident detection
- ✓ Light rail control systems
- ✓ Transit priority systems
- ✓ 1.5 generation timing plan development using Synchro or PASSER
- ✓ 2.0 Generation control (Traffic Responsive and Traffic Adaptive)
- ✓ Integrated video detection
- ✓ Real time preemption log retrieval

6.8.3 Time-Space Diagrams

These are prepared to determine the offsets on individual intersections.

A time-space diagram is a chart on which distance is plotted against time. The location of each signalized intersection is plotted along one axis. At each such point the signal color sequence and split are plotted in such a manner that through bands are available for each direction of traffic flow. The slope of the through band (distance divided by time) is the speed of progression, and width indicates the time available for a platoon traveling through systems.

For two-way streets, the diagram is usually prepared to give equal consideration to each direction of travel. Where appropriate types of program controllers are available, separate peak-hour diagrams are prepared for streets carrying heavy directional peak volumes; these will favor travel in the peak direction. The cycle length may be changed (for the entire system) and the offsets are changed through the use of time clocks in the master controller. A sample time-space diagrams for off-peak and evening peak periods are shown in the Exhibit 6-4 and **Exhibit 6-5**, respectively.

When a coordinated system is established for a certain speed during all periods of the day, supplemental signs may be erected which inform the driver of that speed.

Exhibit 6-4 Sample Off-Peak Time Space Diagram

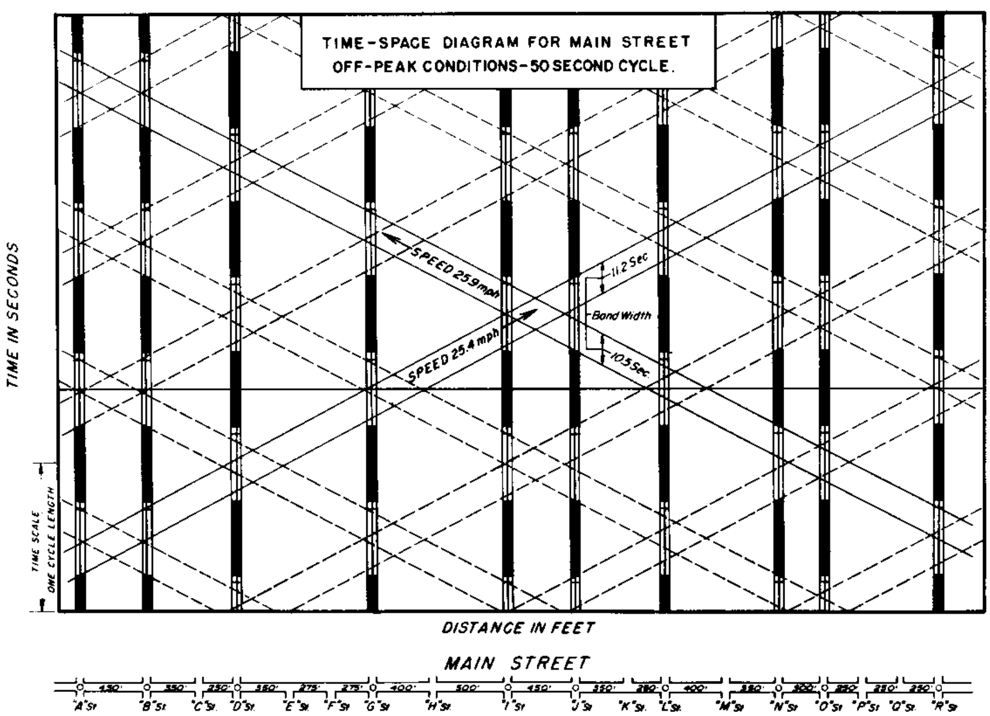
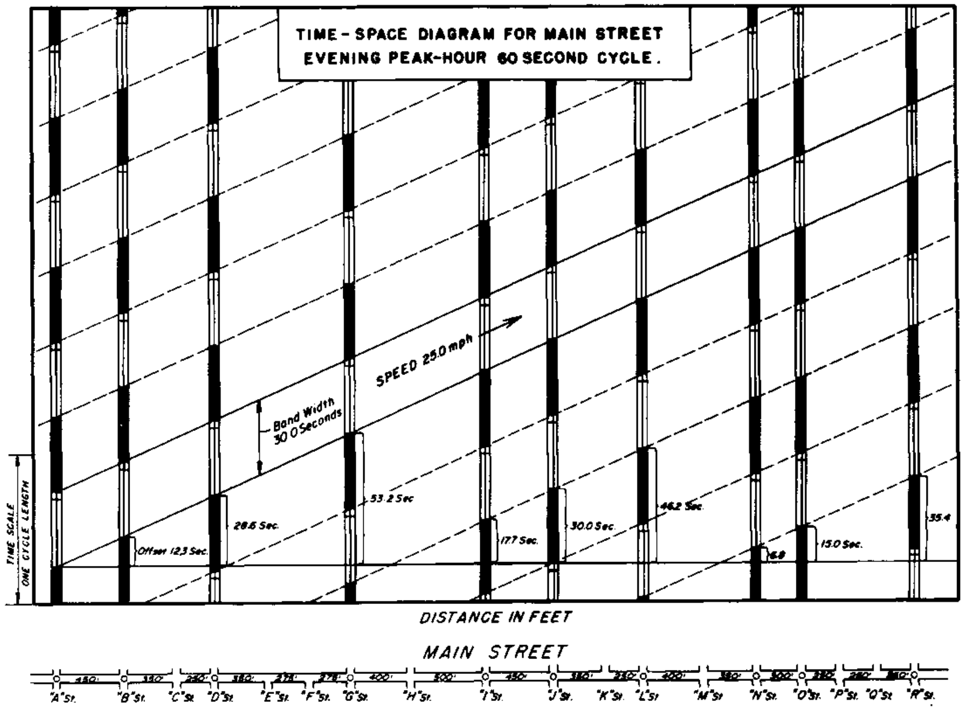


Exhibit 6-5 Sample Evening Peak Time Space Diagram



Complex Timing Systems. Development of timing parameters and programs for the more sophisticated signal systems is very specialized and depends greatly on the specific system components and configuration. Timing techniques, methodology, and philosophy are receiving considerable attention. Extensive research in these areas is continuing. Computer programs such as Synchro have been developed for timing networks.

6.8.4 Control Philosophies for Computerized Traffic Signal Systems

The progress of the state of the art in traffic signal control systems is a function of the technological development of computer applications and control philosophies. Generally, control philosophies may be categorized as follows:

First Generation

These programs are basically of the table look-up type. A number of essentially fixed timing patterns have been precomputed and stored. Control plans are selected based on time of day or on sensing certain demand parameters at strategically located detectors. As threshold positions are reached, alternative predeveloped and stored control plans are implemented. This procedure is used in most of the presently operational digital computer controlled systems.

Second Generation

This type of control program is still based on a background cycle, but provides for on-line, real time computation of control plans and strategies. It utilizes a prediction model to predict near-term (e.g., 15-minute) changes in traffic demand. Current conditions and these predictions are then used in an on-line optimization program to compute splits and offsets.

1.5 Generation Control (GC)

1.5 GC utilizes on-line data collection and predetermined algorithms to generate input data to the TRANSYT-7F timing program. A new timing plan is computed and compared to the existing timing plan. Currently, the operator must decide whether the improvement is worth implementing on either a temporary or permanent basis.

Comparison

The FHWA sponsored extensive research in evaluating the first and second generations of control under the Urban Traffic Control System (UTCS) program. The abstract of the Executive Summary of the Evaluation Study states:

“The First Generation...was found to be operationally effective, was the least expensive to apply, and should be given primary consideration for implementation. Second Generation proved effective on arterials, was only slightly more costly to implement than [first generation], and should be given consideration for areas with substantial arterial development.”

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CHAPTER 7. PREEMPTION AND PRIORITY CONTROL

In addition to the materials indicated throughout this chapter, please consult the MUTCD, Section 4D.27.

Systems in which traffic control signals are preempted by an approaching emergency vehicle shall be designed and installed to provide a fail-safe indication to the driver of the approaching emergency vehicle when the equipment has preempted the traffic signal at that intersection. The fail-safe indication shall be a flashing white light on the street or approach on which the emergency vehicle is approaching.

Traffic signals operating during preemption conditions should be operated in a manner designed to keep traffic moving. The stopping of all traffic by the display of a steady All-Red is prohibited, except during normal clearance intervals.

7.1 Emergency Vehicle Preemption (EVP)

7.1.1 Types

Currently, emergency vehicle preemption systems use either optical, acoustic, or radio with global positioning system (GPS) technologies. When considering emergency vehicle preemption systems, it is important to evaluate the pros and cons of the various types of PennDOT-approved systems. Since emergency vehicles may cross municipal borders, it is also important to determine the type of preemption systems that adjacent municipalities use or plan to use in order to ensure the desired regional interoperability.

Optical Preemption Systems

Optical preemption systems have three basic components: 1) emitters that send the signal from the emergency vehicle to request the preemption; 2) detectors that receive the signal and send it to the controller; and 3) controller cards that process the signal, determine its validity, and initiate the preemption of all other signal functions. The emitters used in optical systems use light to inform the detector that a call has been placed at the signalized intersection.

Acoustic Preemption Systems

Acoustic preemption systems detect the sound from the siren of an emergency vehicle. Acoustic preemption systems do not require an optical emitter on the emergency vehicle, but it is desirable that all the types of sirens used by emergency vehicles be tested and the system be calibrated to help ensure that the desired performance is achieved.

Radio with Global Positioning System (GPS) Preemption Systems

Radio with GPS preemption systems have three basic components: 1) emitters that send the signal via radio from the emergency vehicle to request the preemption; 2) detectors that receive the signal and send it to the controller; and 3) controller cards that process the signal, determine its validity, and initiate the preemption of all other signal functions. The GPS feature monitors the movement of the approaching emergency vehicle and initiates the preemption phasing accordingly.

7.1.2 Operation

Emergency vehicle preemption may occur during any interval of the normal controller operation. Depending upon the direction of travel of the emergency vehicle, one of the following phases (using NEMA phases) will be displayed: Phase 1+6, 2+5, 3+8, or 4+7. The system shall provide service on a first-come, first-serve basis. Once the first priority vehicle calls the system, it shall prevent other preemptive vehicles from entering calls until the first emergency vehicle releases control and clears the intersection.

The transition into and out of preemption as a result of a preemptive call being received during any interval of traffic signal operation shall be clearly defined in the Movement, Phasing, and Sequence Diagram; Emergency Preemption Phasing Diagram; and associated notes on the traffic signal permit. Care should be taken to avoid yellow traps, if practical. During the transition to preemption, the controller unit may stay in a normal sequence phase if that phase is also defined as a preemption phase. For example, if the traffic signal is in phase 1+6 green and that phase is the direction from which the preempting vehicle is approaching, the controller may stay in phase 1+6 without going through selective clearances.

Upon termination of the preemption phase, the controller goes to the pre-designated post preemption phase, then to normal "Phase Next" operation. Four options are available within most controllers in determining the post preemption phase:

(a) Go to Exit Phase: The preemption phase and the post preemption phase may be as follows:

Preemption Phase	Post Preemption Phase
1+6	2+6
2+5	2+6
4+8	2+6
2+6	4+8
3+8	4+8
4+7	4+8

As an alternative, the post preemption phase would be the major street green.

(b) Go to Next Demand: The post preemption phase may be the phase immediately after the preemption phase during normal operation.

(c) Resume Interrupted Sequence: The post preemption phase will be the phase that occurred before the preemption phase.

(d) Exit to Coordination: The post preemption phase will be the phase that would have occurred to keep the signal in coordination within the system.

7.2 Preemption Systems

7.2.1 Rail

Consult chapter 19 of Publication 149 and the MUTCD, Chapter 8.

Where the distance between a traffic signal and a highway-rail grade crossing is less than 300 feet, rail preemption should be utilized to help avoid a potential collision between a vehicle which is queued on the tracks and the rail utility. An interconnection between the rail utility and the controller cabinet will be necessary. Rail preemption shall supersede emergency preemption.

Design of the rail preemption system involves determining the amount of time a queue of vehicles needs to clear the tracks before transferring right-of-way to the rail. The "Guide for Determining Time Requirements for Traffic Signal Preemption at Highway-Rail Grade Crossings," adopted by PennDOT from the Texas Department of Transportation, should be utilized to calculate the proper clearances and to provide the rail utility with the correct distance for placing its actuators on its tracks. Typically, while the signalized intersection is preempted by the railroad, a non-conflicting phase is active. As provided within Publication 46, PUC coordination is required for all railroad preemption systems.

7.2.2 Transit

Transit priority preemption may be used for buses or light-rail services where the traffic signal can truncate opposing phases or extend phases concurrent with the bus/light-rail vehicle at a traffic signalized intersection. A predetermined amount of time, typically 5-15 seconds, shall be established. Transit priority shall not supersede emergency preemption. The effectiveness of transit priority should be evaluated and recommended in an engineering study and approved by the appropriate District Traffic Engineer prior to considering deployment.

7.2.3 Queue

Where queue spillback is a concern and deemed necessary to address with signal operations, queue preemption may be utilized. A detection zone should be utilized between the stop bar and the theoretical gore. If the detector is continuously occupied for a predetermined amount of time the signal may be preempted and the phase of concern will be activated. The detection zone location and occupancy actuation time should be approximated by factoring in the estimated queue discharge rate, vehicle headways, and average vehicle arrival rate so as to avoid the back of queue reaching the point of conflict.

Typically, queue preemption systems are used at the end of limited access ramp sections where a concern with queue vehicles affecting the limit access facility exists.

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CHAPTER 8. TRAFFIC MODEL CALIBRATION

Today, traffic engineers and other practitioners are generally in agreement that a properly timed traffic signal system will reduce travel time, delays, vehicle stops, and fuel consumption. Numerous research studies and successful timing projects in cities across the United States in the last twenty years have supported this theory. Based on “before-and-after” studies, many of these studies have reported reductions in travel time, stops, delays and fuel consumption in the range of 10 percent to 40 percent and benefit-to-cost ratios as high as 100-to-1. In recent years, air quality improvements have been added to the list of benefits.

The benefits of improved signal timing are especially desirable for several reasons. First, the benefits are realized directly by the motoring public (and their passengers) who use the transportation system. Second, there is no discrimination regarding the distribution of these benefits; all consumers reap the rewards of reduced traffic congestion, reduced fuel consumption, operating cost savings, and improved air quality. And finally, these benefits continue to be realized year after year.

However, to truly realize the benefits of a properly timed signal system, it is critical to evaluate the results of the signal timing project that was performed.

8.1 Computer Model Measures of Effectiveness (MOEs)

Computer modeling is one of the more important tools in traffic engineering. If a traffic system is modeled on a computer, it is possible to predict the effect of multiple traffic timing plans on the system’s operational performance, as expressed in terms of MOEs, which include average vehicle speed, vehicle stops, delays, vehicle-hours of travel, vehicle-miles of travel, fuel consumption, and pollutant emissions. The MOEs provide insight into the effects of the signal timing project, and they provide the basis for optimizing that strategy.

Computer modeling has the following advantages over a field experiment:

- ✓ It is less costly.
- ✓ Results are obtained quickly.
- ✓ The data generated by computer modeling include several MOEs that cannot be easily obtained from field studies.
- ✓ The disruption of traffic operations, which often accompanies a field experiment, is completely avoided.
- ✓ Many schemes require significant physical changes to the facility, which are not acceptable for experimental purposes.
- ✓ Evaluation of the operational impact of future traffic demand must be conducted by using simulation or an equivalent analytical tool.
- ✓ Many variables can be held constant.

The availability of traffic modeling and optimization programs greatly expands the opportunity for the development of new traffic signal timing plans. Since the results generated by the model can form the basis for selecting the most effective candidate among different timing plans, the eventual field implementation will have a high probability of success.

In Chapter 6, there was an introduction to Synchro 6 reporting. The following sections will highlight in more detail some of the computer model results that can be obtained from the Synchro 6 program.

8.2 Computer Model Calibration

Calibration is the process of adjusting input data and model parameters in order to ensure that the simulation results from the models match observed traffic performance in the field. Calibration is an important step in a signal timing project because the development of optimal timing plans depends on how closely the model represents the existing conditions. Calibration should be based on the knowledge of the existing conditions in the network and correct interpretation of the model outputs.

Calibration really serves two purposes:

- ✓ It is a "final" check on the quality of the general input data, and
- ✓ It involves the "fine-tuning" of the traffic parameters to ensure that their modeling is realistic.

The following general steps should be taken, at a minimum, once all base data have been coded in the model and initial runs have been made to clear up obvious coding problems:

- ✓ Before continuing any further, double check the base input data.
- ✓ Compare the following MOE's to ensure that the values are consistent with the way you know the system operates:
    - o Degrees of saturation
    - o Delay and average travel times
    - o Maximum queue length, or maximum back of queue, depending on the model.
- ✓ If you are not certain of the actual system operation, or if any of the above MOEs do not "measure up" as expected, conduct field studies to verify field conditions.
- ✓ For the more sophisticated models, conduct field studies for the significant advanced modeling features (e.g., such as the linked flow movements within CORSIM).
- ✓ Vary the appropriate model parameters to bring the simulated or estimated results into better agreement with the field data.
- ✓ Always continually look for overlooked data errors.

This process demands a thorough understanding of the results and outputs of the various models. Recall that the same MOE may be calculated differently by several programs, and may not even include the same basis of measure.

8.2.1 Data Verification

Verifying the accuracy of input data is both an important and continuous task. It is so critical to do this early in the process, because if a significant error is not discovered until, for example, the design process has been completed, a considerable amount of work and computer runs may have to be repeated. Nonetheless, do not conclude that all data are correct after this final check. You must be continuously on the alert for data errors throughout the calibration, design and evaluation stages.

The process at this step is relatively simple. Have a person who has not been intimately involved in the coding process carefully review all input data to ensure that they agree with the original sources. The key data item to check should include as a minimum:

- ✓ Traffic volumes, particularly if a data preprocessor was used to develop more detailed relationships.
- ✓ Capacity parameters (saturation flow rates and lost times) if these were based on field studies. If they are estimated, make sure that the values are reasonable for the conditions.
- ✓ Speeds and other related data.
- ✓ Signal timing.

8.2.2 Volume to Capacity Ratio

The Volume to Capacity Ratio is defined as:

v/c = vC / sg x 100 (%)

where,

v/c = Volume to Capacity Ratio here expressed as a percentage;

v = volume in vph,

C = cycle length in seconds,

s = adjusted saturation flow in vphg, and

g = effective green (split time - lost time).

g = G - SLT + EEG, or

g = G + Y + R - L

and, G = actual green time

SLT = start-up lost time

EEG = extension of effective green

Y,R = yellow and all-red time

L = total lost time.

The volume-to-capacity ratio (v/c), is an indicator of the level of congestion on the particular link. At high degrees of saturation, traffic on the link experiences substantial delays and frequent cycle failures. You should compare the degree of saturation for each link with what you know to be the existing conditions in the field. Significant differences between the predicted and actual intersection operations indicate that the input data may need adjustments. For example, if critical intersections are indicated as saturated in the program (X is approaching or exceeding 100%), check whether this is actually occurring.

8.2.3 Timing and Lost Time

If re-examining the volumes does not clear up the problem, check the timing and lost time. Of course, the cycle length should have been coded correctly, so the likely culprit is the phase length and/or lost time.

For pre-timed controllers, the timing is trivial to check, but this may also indicate the need for a field check of a particular controller.

Actuated control is a different story. Theoretically, minor (actuated) movements should be operating near saturation. If the models say they are not, the estimates of the green times are likely not correct (unless, of course, all phases are operating on recall, thus destroying the purpose of actuated control).

As with timing data, lost time can be a source of highly sensitive fluctuations in the intersection MOEs.

8.2.4 Maximum Queue Length (MQL) or Maximum Back of Queue (MBQ)

Compare the predicted MQL, or MBQ, with field observations for selected links. The following should be kept in mind when making the comparisons of model outputs and field data:

- ✓ The MQL estimated by most models is the maximum physical length of the queue, which occurs just after the beginning of the green.
- ✓ The MBQ is not the queue length at the beginning of the green, but the farthest point the queue extends upstream during the cycle, usually several seconds into the effective green.

If the estimated queue length is significantly different than observed in the field in an average cycle, then the volumes, saturation flows, or signal timing data should be checked.

8.2.5 Delay and Travel Time

The average delay (sec/veh) predicted by the models should be compared with field measurements for a number of representative links (through and left-turn movements). These comparisons should, however, be made with caution, since the definition of delay used in the models may not be the same as the definition used by the measurement technique. For example, TRANSYT estimates the total approach delay for a link. If the average stopped delay is measured in the field, it should be converted to the total delay for comparison with most model estimates.

Another source of error occurs when the link is saturated, since the estimate for random and saturation delay produced by the models may lead to a total estimate which is significantly greater than that measured in the field. For example, comparison of the field measurements with TRANSYT's uniform delay estimate may produce a better result in this case.

Travel time measurements also should be conducted and compared with model estimates (if available) to verify that the model reasonably represents existing condition. Travel times are obtained using floating cars on test routes representing the predominant traffic patterns in the study area. Travel time, including the delay and stops at signals, should be recorded for every link and then compared to the model outputs.

Substantial differences between measured and predicted travel times typically indicate input error in cruise speeds, link volumes, saturation flows and/or signal timing data. Again, travel time estimates may be unrealistic at saturated intersections. In this case, the degree of saturation and the maximum back of queue are better measures of performance for the purpose of model calibration.

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CHAPTER 9. TIMING PLAN IMPLEMENTATION AND EVALUATION

Proper implementation of the timing plans is crucial to a successful system retiming project. A major component to proper implementation involves a thorough understanding of field equipment, specifically detection and the controller. There is no replacement for experience so this section only touches on implementation.

9.1 Implementation and Field Verification

There are four basic steps in the implementation process as follows:

- ✓ The timing plan must be developed (i.e., output from Synchro)
- ✓ The timing plan must be converted into a form that is compatible with the traffic signal controller
- ✓ The timing plan must be transferred into the traffic signal controller in the field or remotely
- ✓ The timing plan must be fine-tuned in the field

Install timing plan into controller and put plan into operation during an off peak time. Check timing, observe operation and make any necessary changes.

The traffic signal operation should be observed for all time periods serviced by the new timing plans immediately following implementation. Seemingly small errors can have dramatic impact on traffic operations, so new timing plans must be observed in operation. If excessive stops and delays are observed, timing adjustments should be made. It may be necessary to observe the signal operation again after a period of time to allow traffic to stabilize. A series of timing adjustments may be necessary.

9.2 Traffic Controller Timing Inputs

A portion of an Econolite controller manual has been included at the end of this chapter.

Synchro reports many of the parameters required for implementing the timing data into the controller. These include:

- ✓ The controller cycle length
- ✓ The movement split in seconds or percent
- ✓ The reference phase offset

There are, however, certain checks and calculations that must be performed before implementation into a coordinated system controller unit. These include, but are not limited to:

- ✓ Can the cycle length handle all of the green, clearance, walk, and flashing don’t walk intervals?
- ✓ Do all splits satisfy their minimum requirement?
- ✓ Are the permissive periods set correctly (some controllers have the ability to automatically determine the permissive periods)?

- ✓ If coordinated phase split extension is used (see the definition in the Econolite literature), are the remaining phases allocated adequate time?

9.3 Post Implementation Evaluation

Field evaluation of new timing plans is substantially more complicated than the estimating of benefits from computer outputs, but it is more significant because it is physical "proof." Such field verification of benefits is often necessary to justify the cost of signal optimization projects.

Field evaluation is a complex task requiring careful planning, execution, and analysis. Evaluations are typically "before" vs. "after" in nature and are usually conducted through floating car techniques. Typical measures of effectiveness include travel time, or delay, and number of stops. Fuel consumption is also sometimes measured, although it is difficult to accurately measure fuel consumption in the field. A sufficient number of floating car runs must be made to be representative of the traffic movements in the system to assure that, if statistically improvements exist, they can be measured at a reasonable level of confidence. Measured benefits can be translated into monetary values, compared with the sum of capital costs and any recurring maintenance costs in order to determine cost-effectiveness.

9.3.1 Field Conditions

Since the objective of a field evaluation is to test the performance of the new timing plan, the conditions in the project area should be as identical as possible in the existing condition (i.e., "before" condition) and those expected after the new timing plans are implemented (i.e., "after" condition). Unrelated design changes in the system, such as adding a lane or a left-turn bay or traffic management schemes, should be avoided. These changes could affect the results obtained in the field, possibly leading to inconclusive statements about the performance of the implemented timing plan.

Since measurable improvements to the traffic operations could potentially result in the system attracting additional traffic from parallel congested systems, field measurements for the "after" condition should be conducted as soon as possible after the timing plans have been implemented and fine-tuned. That is, an acclimation period intended to allow traffic stabilize is not necessary and is not recommended. The data collection schedule should also be planned to avoid any activities that change the normal traffic patterns in the project area. Common examples include holidays, return to school, street blockages from construction work, etc.

9.3.2 Data Collection Periods

Field data on system performance should be collected at the same times of the day that were modeled. For example, if signal timing plans were developed for the AM peak, off-peak and PM peak, the test periods for field data collection should be identical so that the implemented timing plans correspond to the traffic patterns at those times. This requirement applies to field measurements for both the "before" and "after" conditions.

9.3.3 Duration of Data Collection

The time required for data collection varies with the number of signals in the system, the number of timing plans, available personnel and equipment, and other considerations particular to the specific system. Ideally, you should plan to collect data for two weeks, 3-5 days a week, for both the “before” and “after” conditions. This would ensure a minimum of 8-10 days of good data. An even longer period might be needed if unusual traffic conditions occur in the system, or if other circumstances degrade the quality of the data collected.

Resource constraints may necessitate cutting back the data collection period to one week before and one week after. This will naturally reduce the degree of confidence you will have in the evaluation.

9.3.4 Measures of Effectiveness

The specific MOEs recommended to be measured in the field evaluation are travel time and stops. Travel time is preferred to delay because it takes into account the improvements in mid-block travel due to improved progression. It is also easier to measure.

Manual field data should be recorded on log sheets. If computerized data collection methods are used, the MOEs will be automatically recorded by the system. For manually collected travel time data, only the “cumulative travel time” needs to completed in the field. The link travel times may then be computed in the office by subtracting the cumulative travel time at the beginning of the link from the corresponding value at the end of the link. The cumulative time in the system is also computed in the office by removing travel times on links that are outside of the system (i.e., exit/entry links). The total cumulative times in the system should be averaged and compared to give an assessment of the improvement.

9.3.5 Sample Size Requirements

Ideally, only the timing plan would vary between the “before” condition and the “after” condition. However, traffic measurements will generally vary by time of day, day of week, car type, driver, etc. Effort should be made to minimize this variation by using the same car and driver in each case and collecting data under similar conditions. To help overcome these variations, the sample size should be adequate and should be set to provide a level of confidence of not less than 80%. Note that different MOEs may require different sample sizes.

9.4 Econolite Controller Timing

Data source: Econolite Controller Manual

9.4.1 Offset Change by Smooth Transition

When changing offset by smooth transition, the coordination module establishes a new offset by moving the current offset toward the desired offset by the shortest percentage route possible. This movement will normally not be over 50 percent of the cycle length and will be accomplished by moving the actual offset 1 percent for each 6 percent of the local master cycle length.

Therefore, if the desired offset is changed, the actual offset will equal the desired offset within three local cycle lengths or less. The direction in which the offset is moved is determined by the coordination module by comparing the desired offset to the current offset. If the desired offset is greater than the current offset by no more than 50 percent, the module will move the offset point by adding to it. This procedure will lengthen the local cycle by a maximum of 20 percent until the desired offset is reached. If the desired offset is less than the current offset or greater by more than 50 percent of the current offset, the module will move the offset point by subtracting 1 percent from the offset for each 6 percent of the cycle length. This will shorten the cycle by a maximum of 16.6 percent until the desired offset is reached.

If the coordination module determines that the offset should be changed by subtracting, it will compare the controller minimum cycle length to the current cycle length in effect to determine if the cycle can be decreased. If decreasing the cycle will shorten the cycle below the controller minimum cycle, the coordination module will force the offset to be changed by adding. This may cause the offset change to take more than three cycle lengths to complete.

It is possible to program the coordination module to inhibit the smooth transition subtract operation. This will result in all offset changes being made by adding time.

9.4.2 Offset Change by Dwell

The coordination module can make offset changes by smooth transition or by dwelling. The option of offset changes by dwelling is selected by programming the dwell to a value other than zero (0). This will inhibit smooth transition and force all offset changes to be made by dwelling in the coordinated phase.

The coordination module will hold the controller in the coordinated phase while dwelling. The period of time that the module will dwell in the coordinated phases is from 1 to 99 percent of the cycle length. After the dwell period the coordinator, will release. the coordinated phases to serve calls. The dwelling operation will then be preempted until the desired offset is reached.

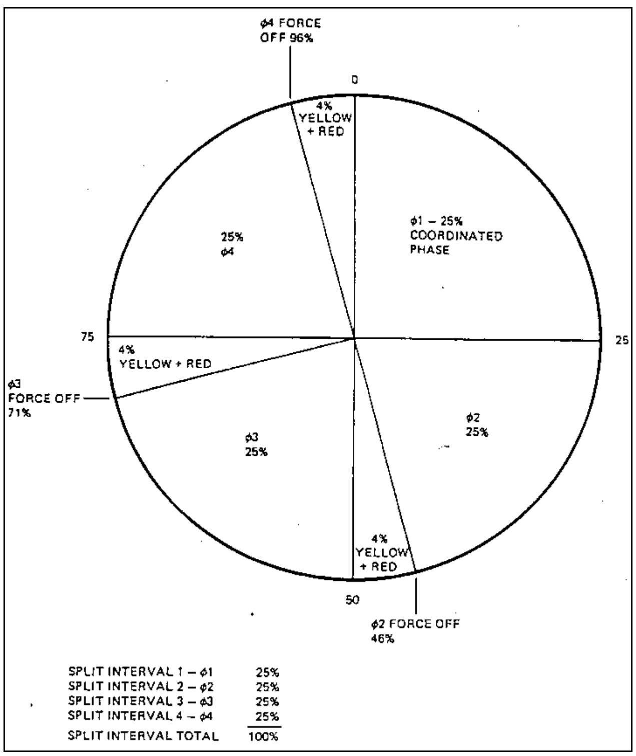
9.4.3 Split

Each of the six cycles of the coordination module will operate in any of four splits. A split is the division of the cycle time period into sections (split intervals) which establish the maximum amount of time that will be allocated to each timing phase (see the figure in Section **9.4.4 - Split**

Intervals). The maximum time allocated to a phase is controlled by the split interval setting for the phase. The coordinator provides a split interval for each phase, including the coordinated phase. The split intervals are numbered from 1 to 8, with the split interval number corresponding to the phase number. Each split interval is variable from 0 to 99 percent of the cycle length. However, the sum of the split intervals for each timing ring of the controller should not exceed 100 percent. In addition, the sum of the split interval for each timing ring of a concurrent group should normally be equal.

9.4.4 Split Intervals

The maximum time allocated to a phase is entered as a percentage of cycle length in the split interval corresponding to the phase. This percentage value should be the total maximum time that the phase will be allowed to time, including yellow and red clearance time. In the example shown in the figure on the following page, each of the four phases has been assigned an equal portion of the cycle. Thus, the split interval entry for each phase will be 25 percent.



The coordination module uses the controller's force-off capability to control the maximum time for each phase. Using the split interval value for the phase and the phase yellow and red clearance times, the coordination module establishes a point within the cycle when force off should be applied to terminate the phase, thus limiting the timing of the phase. The coordination module calculates the force-off point according to the following formula:

Force-Off Point = Coordinated phase split interval + phase timing split interval + sum of the split intervals prior to the phase timing - (phase timing yellow + red clearance percent).

Using the example of the figure in this section, the force-off points will be calculated as follows:

∅2 Force-Off Point = 25% (∅1) + 25% (∅2) - 4% (∅2 clearance)
= 46%

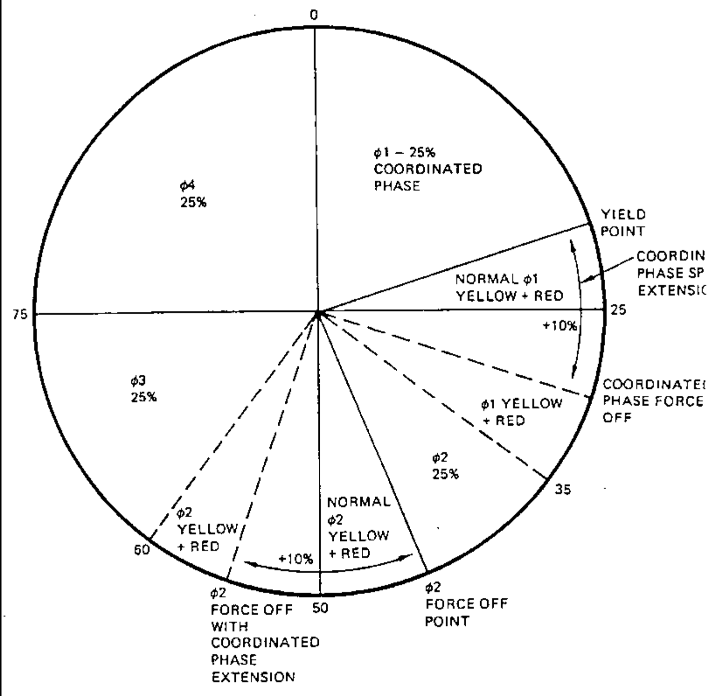
∅3 Force-Off Point = 25% (∅1) + 25% (∅3) + 25% (∅2) - 4% (∅3 clearance)
= 75%

∅4 Force-Off Point = 25% (∅1) + 25% (∅4) + 50% (∅2 + ∅3) - 4% (∅4 clearance)
= 75%

9.4.5 Coordinated Phase Split Extension

The coordination module normally sets the coordinated phases to operate in the nonactuated mode. However, it is possible to program the coordinated phases to operate in the actuated mode. In either mode, the controller is held in the coordinated phases by applying the hold command. This effectively inhibits actuated operation. At the yield point the coordinator removes the hold command, releasing the coordinated phase. If the coordinated phase is actuated, it then can begin extending. The amount of extension is controlled by the coordinated phase split extension interval (split interval 0). At the end of the extension period, the coordinator applies a force off to the coordinated phases, thus causing them to yield to calls on other phases. This operation allows the coordinated phase split to be increased based on traffic demand.

To ensure that the remaining phases are allocated a full split interval, the coordinator cycle is modified based on the amount of coordinated phase extension. This is shown in the following figure. In this example the coordinated phase is allowed to extend 10 percent. This makes the end of the coordinated phase from 25 percent to 35 percent. This would normally have been a portion of the phase 2-split interval. Without modifying the cycle, this implies that the phase 2 split would be reduced by 10 percent. To prevent this from occurring, the cycle is shifted by the coordinated phase extension. Thus, if there are continuous calls on phase 2 causing the phase to use its full split interval, the phase will now end at 60 percent instead of 50 percent. This same operation also occurs in phases 3 and 4. However, if each phase uses its maximum allotted split time, the split of the last sequential phase will be reduced. The coordinator will try to extend the split of the last phase. However, if it determines that the extension will require the phase to be terminated after local zero, the coordinator will apply force off to the phase at 99 percent. This will normally result in a coordination error causing an offset error. As soon as the controller reenters the coordinated phase, the coordinator will begin a smooth transition or dwell operation to correct the offset error.



The maximum amount that the coordinated phase can extend is controlled by the coordinated phase split extension interval. This can be set from 0 to 99 percent. If the coordinated phase gaps out before the maximum amount, the actual extension amount will be used in extending the split of the other phases.

If the phase following the coordinated phase (phase 2 in the example shown in the figure above) does not have a demand prior to the end of the coordinated phase split extension, the split of the remaining phases will not be extended. This is because the coordinated phase extension did not actually use any of the phase 2 split time, being there was no demand on the phase.

9.4.6 Free to Coordinated Transition

After initial power-on of the controller or after the coordination module has been returned to the remote or coordinated mode following a Free or Remote Flash command, the coordination module remains in the Free mode until a sync pulse is detected. This first sync pulse loads the current coordination commands and starts the local master cycle timer. This pulse also starts a coordination pick-up cycle. During this cycle one detector call is placed on all phases and the controller is allowed to continue running Free. The coordinator then monitors the controller checking for the start of the coordinated phase green interval. When both coordinated phases (if a dual ring intersection) have reached the beginning of the green interval, the coordinator places the controller into coordinated operation. This point is used as the first local zero point. The local cycle timer is started and the coordination module begins controlling the controller timing based on the current offset of the local cycle. This pick-up scheme provides a smooth and orderly transition of the intersection into the coordinated system. During the pick-up cycle, the cycle complete display is set to the message UP to indicate that the coordinator is in the pick-up cycle.

9.4.7 Permissive Periods

The coordination module provides two types of permissive period operations. The permissive period controls the time period during which the coordination module releases hold on the coordinated phases, allowing the controller to begin servicing calls on the remaining phases. If a call is not detected during the permissive period, hold is reapplied to the coordinated phases, causing the controller to rest in the coordinated phases until the next permissive period. Permissive period operation always starts at the coordinated phase yield point. This is defined as the point in the local cycle equal to the coordinated phase split interval minus clearance times.

The first type of permissive operation consists of standard single or dual permissive periods that are controlled by operator entries. The second type of permissive operation consists of automatically computed permissive periods for each sequential phase. This method does not require any permissive period data entries by the operator. All permissive periods consist of vehicle and pedestrian periods, with each timing together. The length of the pedestrian period is automatically determined by the walk plus pedestrian clearance timing of the phase being controlled by the period.

9.4.8 Yield Point

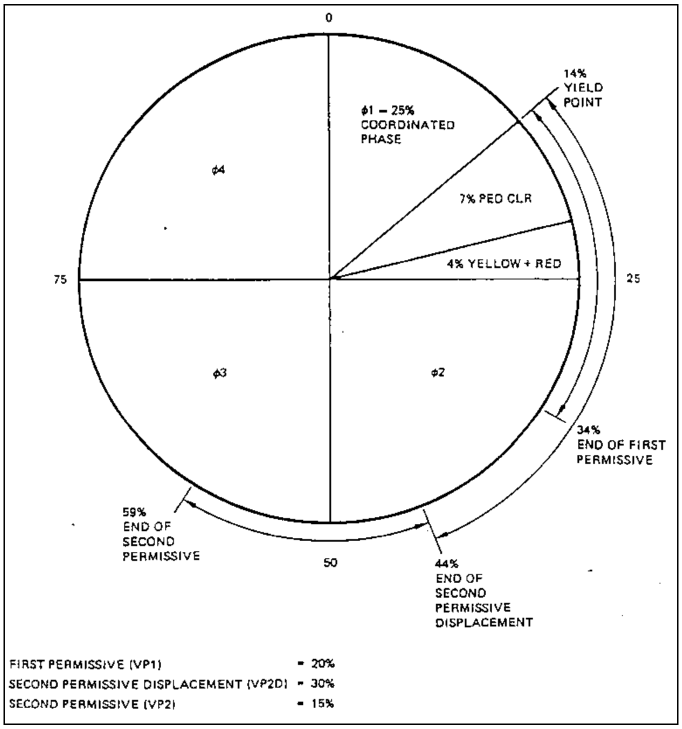
All permissive period timing begins at the yield point. This is the point within the cycle at which the coordination module releases hold on the coordinated phase and allows the controller to begin servicing calls. The yield point is automatically determined by the coordination module based on the coordinated phase split interval and pedestrian and vehicle clearance times. If the coordinated phase is operating as a standard nonactuated phase, the yield point is calculated according to the following formula:

Yield Point = Coordinated phase split interval - (Pedestrian + vehicle clearance time)

Using the example shown in the figure following, the uncoordinated phase 1, yield point is calculated as follows:

Yield Point = 25% - (7+4)%

= 14%



The yield point calculation changes if the coordinated phase is operating fully actuated. In this case, the coordinated phase pedestrian movement times normally and, thus, is not held at the end of the walk timing. In this case, the yield is calculated according to the following formula:

Yield Point = Coordinated phase split interval - vehicle clearance time

Thus, using the same example of the figure above, if the coordinated phase was actuated, the yield point would be 21 percent instead of 14 percent.

9.4.9 Operator Controller Permissive Periods

The operator controlled permissive periods are variable from 0 to 99 percent of the cycle length and are capable of either dual or single permissive operation.

9.4.10 Dual Permissive Operation

If dual permissive operation is used, the Vehicle Permissive Period 1 and its associated pedestrian permissive period time first. This period always begins timing at the coordinated phase yield point (see the figure above). During this first permissive period, the coordination module allows the controller to serve vehicle or pedestrian calls on only the first phase(s), or B phase, following the coordinated phase. The coordination module determines which phase(s) is the B phase based on the phase sequence programming of the controller configuration PROM and by checking which phases are set to the NO-PHASE mode.

The second permissive period, or Vehicle Permissive Period 2, begins timing at an adjustable time period after the yield point. This period is the Vehicle Permissive Period 2 Displacement and is adjustable from 0 to 99 percent of the cycle length. During the second permissive period, the coordination module allows the controller to serve calls on all remaining phases except the first permissive phase(s). The module applies Phase Omit to the first permissive phase(s) during the second permissive period. The pedestrian permissive period portion of the second permissive period controls the pedestrian calls on the second phase(s), C Phase, following the coordinated phase. The pedestrian calls on the remaining phase(s) of the controller are not controlled.

If the controller yields to a call during the first permissive period, the coordination module allows the controller to serve all remaining phase calls in normal sequence. Thus, if a yield occurs during the first permissive, the second permissive period is inhibited from starting because it is no longer required.

Single Permissive Operation

The second permissive period is capable of being eliminated to give a single permissive period operation. With single permissive operation, only the Vehicle Permissive Period 1 and its associated pedestrian permissive period are timed. Both permissive periods begin timing at the yield point. During the permissive period, the coordination module allows the controller to yield to a call on any phase. The pedestrian permissive period portion of the permissive period, however, only controls the pedestrian call on the first phase following the coordinated phase. Single permissive operation is selected by setting the Vehicle Permissive 2 displacement to zero. The Vehicle Permissive Period 2 setting is then ignored by the coordination module.

Two-Phase Controller Dual Permissive

The coordination module provides a special dual permissive operation in a two-phase controller. (A two-phase controller is any KMC-2/4/3 using only two phases.) During the first permissive period the coordinator checks for calls on the second phase and yields if a call is present. If a call is not present, then the coordinator holds the coordinated phase until the second permissive period starts. It then rechecks calls on the second phase and will allow the controller to yield if a call is present. If the controller yields during the first permissive, the coordinator will not time the second permissive. Thus, the coordinator will only allow the controller to yield once to the second phase.

Pedestrian Permissive

During single or dual permissive operation, the pedestrian permissive period is automatically calculated by the coordinator. The period is determined by the walk plus pedestrian clearance and split interval of the phase being controlled. If a pedestrian call is not detected during the pedestrian permissive, the coordinator inhibits pedestrian operation by applying pedestrian omit to the phase. This will be cleared at the next local zero. If the controller yields to a vehicle call during the pedestrian permissive period, pedestrian call will be answered up to the beginning of the phase.

Automatic Permissive Periods

The coordination module is capable of automatically computing permissive periods. In this operation the coordination module assigns each sequential phase a specific vehicle and pedestrian permissive period. The length of the vehicle permissive period is determined by the phase split interval and minimum time. The phase minimum time is equal to the auto permissive minimum green or the phase minimum green time, whichever is larger, plus the yellow and red clearance time. The auto permissive green time allows the phase minimum to be set to a low value but still ensures that the auto permissive period provides sufficient green time if the controller yields to the phase at the end of the permissive. This is especially useful on left-turn phases where the minimum is set to zero. An auto permissive green time is provided for each cycle. The pedestrian permissive is determined by split interval and walk, pedestrian clearance, and yellow plus red clearance timing. Automatic permissive operation is selected by setting the value of Vehicle Permissive 1 and Vehicle Permissive 2 Displacement to zero (0). This allows the automatic permissive operation to be selected on a cycle-by-cycle basis. It should be noted that the default permissive operation, after initial turn on of the coordinator, is automatic permissives.

During automatic permissive operation, the timing of a permissive period for a phase is determined by the controller's phase sequence (as determined by the configuration PROM and phases set to NO PHASE). The permissive period for the first phase(s) following the coordinated phase times first. If a call is not received within the permissive period, the coordinator applies phase omit to the phase and begins timing the permissive period for the next sequential active phase(s). This operation continues for each sequential phase(s). This allows a phase to be serviced only within its permissive period. However, if the coordination module yields the controller to a phase, the controller is allowed to service the remaining phases in the normal manner. The automatic permissive periods do, however, continue to time and will inhibit servicing a phase if there is not sufficient time remaining.

Calculating Automatic Vehicle Permissives

All automatic permissive periods begin timing at the yield point. The period of each vehicle permissive is determined by the phase split interval and minimum time. The coordinator calculates the end point of the permissive period according to the following formula:

Vehicle Permissive End Point = Coordinated phase split interval

+ Sum of the split intervals of the permissive phase and all phases prior to it

- Permissive phases minimum time

- Coordinated phase clearance time

+ Coordinated phase extension

Using the example shown in the figure on the following page, the end of phase 2 vehicle permissive will be calculated as follows:

∅2 Vehicle Permissive End Point = 25% (∅1) + 25% (∅2) - 9% - 4%

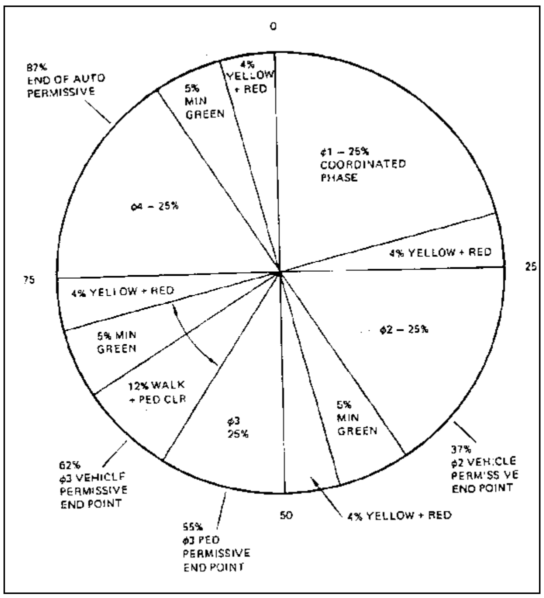
= 37%

Thus, if a phase 2 call is not received prior to the cycle reaching 37 percent, phase 2 will be omitted and the permissive period for phase 3 will start. The end point of the phase 3 vehicle permissive is calculated in a similar manner:

∅3 Vehicle Permissive End Point = 25% (∅1) + 50% (∅2 + ∅3) - 9% - 4%

= 62%

The coordinator continues the permissive timing until the cycle reaches the permissive end point of the last sequential phase or until the controller returns to the coordinated phases. Thus in the example in the figure following figure, the permissive timing would end when the cycle reached 87 percent.



Calculating Automatic Pedestrian Periods

Each vehicle permissive period has a separate pedestrian permissive period that times concurrently with it. The pedestrian permissive period is the time period during which the controller is allowed to answer pedestrian calls. This period is determined by the walk plus pedestrian clearance and split interval of the phase being controlled. However, the pedestrian permissive can never be longer than the vehicle permissive. If the vehicle permissive ends prior to the end of the pedestrian permissive, the pedestrian permissive is terminated.

If a pedestrian call is not detected during the pedestrian permissive period, the coordination module inhibits the controller from servicing any further pedestrian call by applying pedestrian omit to the phase. This is then cleared at the next local zero. However, if the controller yields to a vehicle call during the pedestrian permissive period, pedestrian calls will be answered up to the beginning of the Vehicle Phase Green.

The coordination module calculates the end point of the pedestrian permissive period according to the following formula:

Pedestrian Permissive End Point = Coordinated phase split interval

+ Sum of the split intervals of the permissive phase and all phases prior to it

- Permissive phases walk time + pedestrian clearance + yellow + red time

- Coordinated phase clearance time

Using the example of the figure above, the phase 3 pedestrian permissive end point is calculated as follows:

∅3 Pedestrian Permissive End Point = 25% (∅1) + 75% (∅2 + ∅3) - (12 + 4) - 4%

= 55%

Thus, when the cycle reaches 55 percent, pedestrian omit would be applied to phase 3 unless a pedestrian call was present.

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CHAPTER 10. APPENDIX

10.1 Commonwealth and Municipal Traffic Signal Maintenance Agreement

10.2 TE-699 Form – Traffic Signal Description

10.3 TE-971 Form – Master Signal Maintenance Log

10.4 TE-972 Form – Response Maintenance Record

10.5 TE-973 Form – Preventative Maintenance Record

10.6 TE-974 Form – Design Modification Checklist

10.7 Municipal Service Agreement for Maintenance of Traffic Control Signals (EXAMPLE)

10.8 Cooperative Memorandum of Agreement; SR ____ Multi-Jurisdictional Signal System

10.9 Form TE-160 - Application for Traffic Signal Approval

10.10 Form TE-964 - Traffic Signal Permit