pennsylvania
DEPARTMENT OF TRANSPORTATION
494-25-06

DATE: May 20, 2025

SUBJECT: PennDOT Traffic Signal System Solution Toolbox

TO: District Executives

FROM: Daniel Farley, P.E., Director
Bureau of Operations

for Doug Tomlinson, P.E.

This time and resource neutral Strike-off Letter (SOL) replaces Strike-Off-Letter 494-19-04 and further develops policy for evaluating potential deployments of Traffic Signal Systems. Form TE-153 streamlines the Systems Engineering Process for Adaptive Control Systems and has been enhanced to assess not only Adaptive Traffic Signal Control, but other types of Signal System Solutions. The goal is to determine appropriateness based on the context of the proposed installation.

The purpose of the new toolbox is to evaluate the feasibility of various traffic signal system solutions (e.g., coordinated, traffic responsive, adaptive, ATSPM) based on corridor needs, agency objectives, and agency capabilities. This toolbox facilitates the systems engineering process to ensure that final products and selected solutions can achieve appropriate objectives and agency needs. Such a process is required to assist planners in scoping projects before approving funding (e.g. Congestion Mitigation and Air Quality Improvement Program, Green Light-Go).

The revised Form TE-153 is available on the PennDOT Traffic Signal Portal here:
https://docs.penndot.pa.gov/Public/Bureaus/BOO/Forms/TE-153.xlsm

PennDOT Publications 46 (Traffic Engineering Manual) and 149 (Traffic Signal Design Handbook) have been revised to accommodate the enhanced TE-153 tool and supporting guidance. Descriptions of the proposed changes to these publications are as follows:

- Publication 46, Chapter 4, Section 4.6 (Design) – Adds a new subsection, "Traffic Signal System Selection," which describes how Form TE-153 can be used to aid in the traffic signal system selection process, the content covered within the revised TE-153 form, applications where use of the form is required, and the typical agencies/parties expected to complete the form. Applicable guidance provided previously under SOL 494-19-04 has also been incorporated into this section.

- Publication 46, Chapter 4, Section 4.12 (Adaptive Traffic Control Systems) – Removes this section due to its redundancy with Section 4.6.

- Publication 149, Chapter 3, Section 3.3 (Control Types) – Adds a new subsection, "Central Traffic Signal Systems" which defines central traffic signal systems and references Publication 46, Section 4.6 for information on control type selection guidelines.

- Publication 149, Chapter 11 (Systems) – Clarifies that this chapter can be referenced for physical design considerations related to traffic signal systems, but Chapter 3 as well as

- Publication 46, Section 4.6 should be referenced for information on signal coordination; as well as for determing the most appropriate type of traffic signal system solutions. Section 11.1 (Types) was removed due to its redundancy with Publication 46, Section 4.6.

The revised content has been attached to this SOL and will be incorporated into future updates to the referenced publications.

Projects which have already submitted Form TE-153 using the 11-12 version are not required to use the new version.

Should you have any questions, please contact Stephen Gault, P.E., PTOE, Chief, TSMO Arterials and Planning Section at (717) 787-6988 or sgault@pa.gov.

4940/SAG/acp

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Assistant District Executives – Design
Assistant District Executives – Construction
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District Traffic Signal Supervisors
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4.6 Design

Traffic Signal Systems

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.)

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

Generally a small system with a master-local 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). 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.

Closed Loop System

In this system, second-by-second commands are transmitted from local masters to the intersection controllers. The masters communicate with the central processor only when failure occurs, or when commanded to do so by the central processor. The connection between the masters and local controllers is usually made via communication cable (or other means of interconnect). The connection between the masters and the central computer is often made via dial-up telephone. In this way, it is possible to minimize the cost between remote groups of intersections and a central site. For this reason, closed-loop systems are popular with State and county agencies responsible for control of intersections dispersed over a wide geographic area.

~~Traffic~~ Adaptive ~~System~~Traffic Control Systems

~~Traffic adaptive~~Adaptive traffic control 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. For additional information on the selection and design of adaptive traffic control systems, refer to "Traffic Signal System Selection" later in this section of the Publication.

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:

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- 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

~~Adaptive~~ Traffic ~~Control~~ Signal System Selection

In August 2019, FHWA released a guidance document for procuring Central Traffic Signal Systems (CTSS) such as adaptive systems, to ensure a procured and deployed CTSS will successfully meet stakeholder needs. CTSS is defined as “a system that manages traffic signal databases and monitors the operation of traffic signal controllers. The software communicates with the traffic signals in the field from a central location such as a TMC.” The guidance document can be accessed online at the following link:
https://ops.fhwa.dot.gov/publications/fhwahop19019/fhwahop19019.pdf

~~Traffic~~While adaptive and other centralized systems ~~perform “real-time” adjustments to the cycle length, splits and offsets in response to~~ can significantly improve traffic ~~demand. Traffic adaptive~~ operations in specific contexts, they are not always the most appropriate design choice. Such systems ~~require extensive detection inputs. Complete~~can have large up-front hardware and ~~accurate~~software costs, as well as recurring maintenance costs and needs when compared to other signal system solutions.

To aid project stakeholders in determining whether an adaptive or other CTSS system is the most appropriate solution, PennDOT has developed Form TE-153, the Pennsylvania Traffic Signal System Solution Toolbox. The purpose of the toolbox is to evaluate the feasibility of various traffic ~~flow data must be gathered, processed and communicated~~signal system solutions (e.g., coordinated, traffic responsive, adaptive, ATSPM) based on corridor needs, agency objectives, and agency capabilities. This toolbox facilitates the systems engineering process to ~~the~~ ensure that final products and selected solutions can achieve appropriate objectives and agency needs.

For evaluation of potential signal systems, application of the tool is recommended as follows:

- Brand-new CTSS deployments to operate and manage traffic signals using commercial off-the-shelf software: Tool required; see below.
- Expansion of an existing CTSS system to operate and manage traffic signals (includes adding signals to Unified Command and Control (UCC) and Automated Traffic Signal Performance Measures (ATSPM)): Tool

required (Stages 1 and 2 only, as system requirements were already established when the system was first deployed).

- Brand-new deployment or expansion of a system to operate and manage traffic signals using custom-developed software: Project-specific systems engineering required.
- Isolated signal without any central system: No systems engineering required.

Form TE-153 is separated into four progressive stages: Pre-TIP (Stage 1), Preliminary Engineering (Stage 2), Final Design (Stage 3), and System Test (Stage 4).

The following table describes the four stages associated with the evaluation process:

Stage 1 (Pre-TIP)	-Eliminate systems unlikely to provide desirable results -Readily available information for screening (no data collection)
Stage 2 (Preliminary Engineering)	-More detailed screening -Simplified if only one alternative was advanced from Stage 1
Stage 3 (Final Design if CTSS)	-Systems engineering -Concept of operations -System requirements -Recommendations
Stage 4 (System Test)	-Verification -Validation

Stage 1 of the form (pre-TIP) requires the designer to input key network parameters, including the network characteristics, roadway functional class, AADT, lane configurations, peak hours, and D-factor. When the characteristics change within the network, the form should be completed with data for the critical intersection. The critical intersection is likely to govern control decisions for the signal system because it has the least green time available based on its combination of volume, geometry, and signal phasing. For example, the critical intersection may have the highest minor street traffic volume, longest pedestrian crossings, more left-turn phases, or more phases because of additional approach legs. It also asks the designer to input how frequently the signal owner performs preventative maintenance. If an adaptive system is not appropriate given these inputs, the workbook will recommend potential alternative signal system treatments or solutions and advise the designer that Stage 2 analysis is not required. If an adaptive system should still receive consideration, the designer advances to Stage 2.

Stage 2 (Preliminary Engineering) asks the designer a series of questions about the context of the project location, including the owner's maintenance and funding capabilities, operational objective of the study corridor, whether the corridor receives diverted traffic from a freeway, use of the corridor by traffic generated by special events, Level of Travel Time Reliability (LOTTR), other intersection complexities, and the level of pedestrian activity. At the completion of Stage 2, the workbook will confirm whether an adaptive system could be considered. If the designer selects adaptive as the end solution, they can manually advance to Stage 3.

Stage 3 (Final Design) covers the initial Systems Engineering, Adaptive System Comparison and Signature Documentation processes. This includes the corridor's needs and constraints; project's specific needs; and operational, administrative and maintenance requirements. Once the form is completed, the designer generates a PDF that can be signed and dated to be maintained with the project's documentation.

Once the adaptive system has been constructed and is operational, Stage 4 (System Test must be completed. The analysis cannot be completed by the system designer to eliminate potential conflicts of interest. The person(s) completing the form confirms whether the needs and requirements of the system meet expectations, documents the results of the before and after evaluation of the project, and uses the workbook to generate a PDF for signature to be added to the project documentation.

For adaptive and other CTSS deployments, the tool is **required** for the following:

- Federally funded projects;
- State-funded projects, including projects with state grant funding such as Green Light-Go, ARLE, Multimodal;
- Municipal Projects;
- Developer projects, including Highway Occupancy Permits (HOP).

For Department Projects, Stages 1-3 need to be completed and submitted to the Bureau of Operations (BOO) Arterial Operations Unit (AOU) for approval prior to beginning of preliminary engineering. For municipal and developer projects, Stages 1-3 need to be completed and submitted to AOU as part of the first traffic signal submission.

Stage 4 needs to be completed and submitted to AOU after the system is functional. INRIX speed data may be used to reduce or eliminate field data collection using the RITIS Probe Data Analytics Suite (https://pda.ritis.org/suite/~~computer~~).

The following table identifies the party responsible for completing Form TE-153 through Stage 3B:

Project Type	Typical Agency/Party to Complete Form TE-153 through Stage 3
PennDOT projects	PennDOT staff or their consultants
PennDOT projects with municipal lead	Municipal staff or their consultants, with assistance from PennDOT
Municipal projects	Municipal staff or their consultants
Highway Occupancy Permit (HOP)	HOP Applicant or their consultants

Detailed instructions on completion of Form TE-153 can be found with the form. The form can be accessed at XXXX.

Additional information on Adaptive Traffic Control Systems can be found in NCHRP 403 found at:

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_403.pdf

Additional details and information can be found on the Traffic Signal Portal:

http://www.dot.state.pa.us/signals

3.3 Control Types

The type of traffic signal control is very important when determining signal timing. It is also essential to understand the pros and cons of each type of operation so that the safest and most efficient type is selected for the given conditions. The following are some typical traffic signal control operations that are presently used throughout the Commonwealth.

a) Pre-timed traffic signal control is a set of phases with fixed green, yellow, and red intervals that make up the cycle length that does not vary. Typically, pre-timed traffic control is most effective when used in an area where traffic patterns are predictable by time of day.

b) Semi-actuated traffic signal control generally has detection on the minor approaches to provide green time for the minor street phases based upon minor street traffic demand. Typically,
semi-actuated traffic control operation is most efficient when the minor street has low volumes during the off-peak traffic periods.

c) Fully-actuated traffic signal control has detection on all approaches to allow the green times to vary and non-actuated phases to be skipped based on the traffic demand. Typically, fully- actuated traffic signal control is the most responsive operation to traffic demands.

d) Coordinated traffic signal control allows multiple signalized intersections to work together to optimize traffic flow along a corridor.

The type of control used can have a profound effect on the operational efficiency of any signal and, if incorrectly chosen, can defeat the purpose for which the signals were installed. The selection of the best form of control for any location can be made only with a full knowledge of local conditions.

The following Exhibit may be used as a guide for the selection of the type of controller at an isolated intersection, subject to variations in local conditions:

Exhibit 3-15 Isolated intersection controller selection

Factor	Fixed-Time	Fully-Actuated	Volume-Density
Main street average to peak value	Any	More than 20%	More than 30%
Main street average hour variation	Less than 20%	More than 20%	More than 30%
Cross street average hour variation	Less than 20%	More than 20%	More than 30%
Cross street volume	More than 25%	Any	More than 30%

The following Exhibit may be used as a guide for the selection of the type of controller subject to variations in local conditions.

Exhibit 3-16 Relationship between intersection operation and control type *(from FHWA Signal Timing Manual)*

	Pre-timed		Actuated		
Type of Operation	**Isolated**	**Coordinated**	**Semi-Actuated**	**Fully-Actuated**	**Coordinated**
Fixed Cycle Length	Yes	Yes	No	No	Yes
Conditions Where Applicable	Where detection is not available	Where traffic is consistent, closely spaced intersections, and where cross street is consistent	Where defaulting to one movement is desirable, major road is posted <40 mph and cross road carries light traffic demand	Where detection is provided on all approaches, isolated locations where posted speed is >40 mph	Arterial where traffic is heavy and adjacent intersections are nearby
Example Application	Work Zones	Central business districts, interchanges	Highway operations	Locations without nearby signals; rural, high speed locations; intersection of two arterials	Suburban arterial
Key Benefit	Temporary application keeps signals operational	Predictable operations, lowest cost of equipment and maintenance	Lower cost for highway maintenance	Responsive to changing traffic patterns, efficient allocation of green time, reduced delay and improved safety	Lower arterial delay, potential reduction in delay for the system, depending on the settings

The pre-timed control type, if selected, shall be capable of providing multiple timing patterns to better accommodate directional shifts or volume variations in traffic during different portions of the day.

Often, it is found that certain movements (such as left turns or movements from a minor approach) cannot be accommodated adequately without the provision of special phases such as advance or exclusive phases. The demand for such special phases varies from cycle to cycle. In such cases, an actuated control type shall be selected. This would enable the special phases to be extended, skipped, or maintained as demand warrants without causing unnecessary delays to the major movements.

In order to allow for future expansion, the controller should be capable of providing additional phases of operation and timing patterns regardless of the number of phases and timing patterns required in the initial design.

Central Traffic Signal Systems

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.

Central Traffic Signal Systems (CTSS) are tools which remotely manage traffic signal databases and monitor the operation of traffic signal controllers. The software communicates with the traffic signals in the field from a central location such as a TMC. Such systems can have large up-front hardware and software costs, as well as recurring maintenance costs and needs when compared to other signal system solutions. As a result, selection and design of such systems requires more complex analysis prior to implementation.

PennDOT has developed guidance and a form, TE-153, to aid designers with traffic signal system selection. For control type selection guidelines when proposed signals are operating together in a system, please reference Publication 46, Section 4.6.

CHAPTER 11 - SYSTEMS

The 2001 Traffic Control Devices Handbook published by the Institute of Transportation Engineers states:

"A traffic signal control system exists whenever two or more signals operate in a synchronous manner. The objective of a traffic signal control system is to improve the flow of traffic along a major street or throughout a network of streets. A traffic signal control major system consists of an appropriate signal-timing plan and the hardware components to implement that signal-timing plan. The signal-timing plan must satisfy traffic demand, traffic flow patterns and the geometrics that exist at each intersection and in the network as a whole.

Traffic signal control systems may be relatively small and simple or fairly large and complex. A system may merely consist of a series of intersections along a major street whose controller units are interconnected.

Such a system's purpose is to move platoons of traffic without interruption along the major street. On the other hand, a system may consist of a network of streets whose intersection controller units are centrally controlled by a digital computer with two-way communication between the computer and the intersection controllers. The purpose of this type of system is to reduce the total amount of delay and the total number of stops occurring to all traffic in the network."

~~Refer to Chapter 3, Operational Requirements and for information regarding traffic signal coordination, proper timing, and progression analysis procedures.~~ Where the proximity between signalized intersections is such that traffic signal coordination is deemed appropriate and necessary, a system of traffic signals may be implemented. Historically, and currently, a reliable coordinated system can be achieved using a physical method of interconnection via some type of wiring or cable. More recently, technologies have become available that allow for the implementation of a system without physical means. The provision of traffic signals into a system is the focus of this chapter. Each type of system has its advantages and disadvantages that should be weighed by the designer while factoring in reliability, cost, and functionality.

~~11.1 Types~~

~~Time-Based Coordination (TBC)~~

~~The simplest form of coordination is the use of time-based coordination. The controller at each traffic signal must be equipped with an internal or external time clock to provide a point of reference (controller brands do not need to match). The primary disadvantage of TBC is that the time clocks may "drift" if not properly maintained. Over time small changes at each controller accumulate. Periodic resynchronization will be necessary. The use of GPS time clocks will generally eliminate this drift.~~

~~Interconnect~~

~~A communication link between two or more intersections has more long-term reliability for maintaining the coordination and efficiency of a system than TBC. Interconnect typically requires the use of a master controller, which can either act as a time clock synchronizer for all of the traffic signals in a system or send time-of-day patterns to each local controller. Methods of communication are discussed in Section 11.3.~~

~~Centralized/Closed Loop System~~

~~There are various types of centralized traffic signal systems that may be implemented. Types may range from large scale city grid systems that have proprietary customized software to smaller scale "off-the-shelf" PC-based arterial systems. A centralized system offers the capability to remotely monitor the individual intersection controllers, or groups of controllers. These systems are capable of communicating through a land line telephone drop or direct connection via fiber optic cable or wireless methods. The software is typically capable of viewing and editing timing patterns, viewing and storing traffic volumes, monitoring communication status, receiving maintenance alarms, etc.~~

~~Certain systems may offer traffic responsive program selections based on traffic demand. A group of predetermined timing patterns may be stored in the system which can be selected based on traffic volume and occupancy thresholds.~~

~~**Adaptive Signal Control**~~

~~Adaptive signal control (ASC) is a type of traffic signal system that continually adjusts based on real-time traffic data in an attempt to provide the optimal traffic signal operation. Parameters, such as splits, permissives, and force-offs are adaptable within common controller brands; however, more advanced controllers are available. The use of ASC requires an extensive amount of detection to measure volume, occupancy, and/or queue lengths.~~

~~**11.2**~~This chapter focuses on physical design considerations for traffic signal systems. Refer to Chapter 3, Operational Requirements for information regarding traffic signal coordination. Refer to Publication 46, Section 4.6 for a background on types of traffic signal systems, as well as guidance for determining the most appropriate type of traffic signal system solution.

11.1 Design Considerations

Several factors should be considered when determining which type of system to use, including but not limited to:

a) Cost
b) Desired Functions
c) Operation and Maintenance
d) Corridor classification

TBC or a simple interconnect may be sufficient for isolated corridors with predictable traffic patterns. A centralized or closed loop system should be considered for major arterials and densely-populated areas that experience heavy volumes and daily volume fluctuations that may occur due to non-recurring congestion.

Interconnected systems need to be monitored periodically to ensure that communications are operational. ASC should be considered as well for areas that experience major fluctuations in traffic demand, such as near interstates, shopping malls, sporting venues, etc. Buy-in and a financial commitment of operations and maintenance from the lead municipality must be obtained before proposing any type of system that requires periodic operations and maintenance.

11.~~3~~2 Communications

Three modes of communications are typically used to interconnect signals within a system. Refer to

Section 953 (Traffic Signal Systems and Communications) of Publication 408 for specifics on the materials and construction methods.

Hard-wire Interconnect

Twisted-pair cable is generally installed in conduit between intersections.

a) **Advantages**

Least expensive method of physical interconnection, no additional equipment is required beyond the controller unit

b) **Disadvantages**

Conducts electricity which may cause lightning or power surge damage at multiple signal controllers

Fiber Optic Cable

Fiber optic cable can be installed aerially or in conduit between intersections. Care must be taken during design to specify the correct accompanying equipment as different types of fiber optic cable are available, i.e., single-mode vs. multi-mode, loose tube vs. tight buffered.

a) Advantages

Non-conductive (not susceptible to lightning strike travel), able to carry large amounts of data

b) Disadvantages

Cable difficult and exspensive to repair, accompanying equipment, and installation more expensive

Spread Spectrum Radio (SSR)

Communications between intersections is provided by a wide bandwidth frequency signal. Two frequency ranges are allowed, 902-928 MHz and 2.4 GHz, which do not require FCC licensing. An implementation survey will be required during design to determine if obstructions and/or roadway curvatures would require repeaters.

a) Advantages

No physical connection between intersections, lower cost

b) Disadvantages

Limited bandwidth compared to fiber, repeaters may be necessary.

Methods may be mixed within a system. For example, three intersections can be interconnected by fiber optic cable but a fourth may be interconnected by SSR due to an obstruction, such as a railroad overpass.

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Basis of Selecting Timing Plans

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Closed Loop System

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- Real time preemption log retrieval

Traffic Signal System Selection

In August 2019, FHWA released a guidance document for procuring Central Traffic Signal Systems (CTSS) such as adaptive systems, to ensure a procured and deployed CTSS will successfully meet stakeholder needs. CTSS is defined as “a system that manages traffic signal databases and monitors the operation of traffic signal controllers. The software communicates with the traffic signals in the field from a central location such as a TMC.” The guidance document can be accessed online at the following link: https://ops.fhwa.dot.gov/publications/fhwahop19019/fhwahop19019.pdf

While adaptive and other centralized systems can significantly improve traffic operations in specific contexts, they are not always the most appropriate design choice. Such systems can have large up-front hardware and software costs, as well as recurring maintenance costs and needs when compared to other signal system solutions.

To aid project stakeholders in determining whether an adaptive or other CTSS system is the most appropriate solution, PennDOT has developed Form TE-153, the Pennsylvania Traffic Signal System Solution Toolbox. The purpose of the toolbox is to evaluate the feasibility of various traffic signal system solutions (e.g., coordinated, traffic responsive, adaptive, ATSPM) based on corridor needs, agency objectives, and agency capabilities. This toolbox facilitates the systems engineering process to ensure that final products and selected solutions can achieve appropriate objectives and agency needs.

For evaluation of potential signal systems, application of the tool is recommended as follows:

- Brand-new CTSS deployments to operate and manage traffic signals using commercial off-the-shelf software: Tool required; see below.
- Expansion of an existing CTSS system to operate and manage traffic signals (includes adding signals to Unified Command and Control (UCC) and Automated Traffic Signal Performance Measures (ATSPM)): Tool required (Stages 1 and 2 only, as system requirements were already established when the system was first deployed).

- Brand-new deployment or expansion of a system to operate and manage traffic signals using custom-developed software: Project-specific systems engineering required.
- Isolated signal without any central system: No systems engineering required.

Form TE-153 is separated into four progressive stages: Pre-TIP (Stage 1), Preliminary Engineering (Stage 2), Final Design (Stage 3), and System Test (Stage 4).

The following table describes the four stages associated with the evaluation process:

Stage 1 (Pre-TIP)	-Eliminate systems unlikely to provide desirable results -Readily available information for screening (no data collection)
Stage 2 (Preliminary Engineering)	-More detailed screening -Simplified if only one alternative was advanced from Stage 1
Stage 3 (Final Design if CTSS)	-Systems engineering -Concept of operations -System requirements -Recommendations
Stage 4 (System Test)	-Verification -Validation

Stage 1 of the form (pre-TIP) requires the designer to input key network parameters, including the network characteristics, roadway functional class, AADT, lane configurations, peak hours, and D-factor. When the characteristics change within the network, the form should be completed with data for the critical intersection. The critical intersection is likely to govern control decisions for the signal system because it has the least green time available based on its combination of volume, geometry, and signal phasing. For example, the critical intersection may have the highest minor street traffic volume, longest pedestrian crossings, more left-turn phases, or more phases because of additional approach legs. It also asks the designer to input how frequently the signal owner performs preventative maintenance. If an adaptive system is not appropriate given these inputs, the workbook will recommend potential alternative signal system treatments or solutions and advise the designer that Stage 2 analysis is not required. If an adaptive system should still receive consideration, the designer advances to Stage 2.

Stage 2 (Preliminary Engineering) asks the designer a series of questions about the context of the project location, including the owner’s maintenance and funding capabilities, operational objective of the study corridor, whether the corridor receives diverted traffic from a freeway, use of the corridor by traffic generated by special events, Level of Travel Time Reliability (LOTTR), other intersection complexities, and the level of pedestrian activity. At the completion of Stage 2, the workbook will confirm whether an adaptive system could be considered. If the designer selects adaptive as the end solution, they can manually advance to Stage 3.

Stage 3 (Final Design) covers the initial Systems Engineering, Adaptive System Comparison and Signature Documentation processes. This includes the corridor’s needs and constraints; project’s specific needs; and operational, administrative and maintenance requirements. Once the form is completed, the designer generates a PDF that can be signed and dated to be maintained with the project's documentation.

Once the adaptive system has been constructed and is operational, Stage 4 (System Test must be completed. The analysis cannot be completed by the system designer to eliminate potential conflicts of interest. The person(s) completing the form confirms whether the needs and requirements of the system meet expectations, documents the results of the before and after evaluation of the project, and uses the workbook to generate a PDF for signature to be added to the project documentation.

For adaptive and other CTSS deployments, the tool is **required** for the following:

- Federally funded projects;
- State-funded projects, including projects with state grant funding such as Green Light-Go, ARLE, Multimodal;
- Municipal Projects;
- Developer projects, including Highway Occupancy Permits (HOP).

For Department Projects, Stages 1-3 need to be completed and submitted to the Bureau of Operations (BOO) Arterial Operations Unit (AOU) for approval prior to beginning of preliminary engineering. For municipal and developer projects, Stages 1-3 need to be completed and submitted to AOU as part of the first traffic signal submission.

Stage 4 needs to be completed and submitted to AOU after the system is functional. INRIX speed data may be used to reduce or eliminate field data collection using the RITIS Probe Data Analytics Suite (https://pda.ritis.org/suite/).

The following table identifies the party responsible for completing Form TE-153 through Stage 3B:

Project Type	Typical Agency/Party to Complete Form TE-153 through Stage 3
PennDOT projects	PennDOT staff or their consultants
PennDOT projects with municipal lead	Municipal staff or their consultants, with assistance from PennDOT
Municipal projects	Municipal staff or their consultants
Highway Occupancy Permit (HOP)	HOP Applicant or their consultants

Detailed instructions on completion of Form TE-153 can be found with the form. The form can be accessed at XXXX.

Additional information on Adaptive Traffic Control Systems can be found in NCHRP 403 found at:

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_403.pdf

Additional details and information can be found on the Traffic Signal Portal:

http://www.dot.state.pa.us/signals

3.3 Control Types

The type of traffic signal control is very important when determining signal timing. It is also essential to understand the pros and cons of each type of operation so that the safest and most efficient type is selected for the given conditions. The following are some typical traffic signal control operations that are presently used throughout the Commonwealth.

a) Pre-timed traffic signal control is a set of phases with fixed green, yellow, and red intervals that make up the cycle length that does not vary. Typically, pre-timed traffic control is most effective when used in an area where traffic patterns are predictable by time of day.

b) Semi-actuated traffic signal control generally has detection on the minor approaches to provide green time for the minor street phases based upon minor street traffic demand. Typically,
semi-actuated traffic control operation is most efficient when the minor street has low volumes during the off-peak traffic periods.

c) Fully-actuated traffic signal control has detection on all approaches to allow the green times to vary and non-actuated phases to be skipped based on the traffic demand. Typically, fully- actuated traffic signal control is the most responsive operation to traffic demands.

d) Coordinated traffic signal control allows multiple signalized intersections to work together to optimize traffic flow along a corridor.

The type of control used can have a profound effect on the operational efficiency of any signal and, if incorrectly chosen, can defeat the purpose for which the signals were installed. The selection of the best form of control for any location can be made only with a full knowledge of local conditions.

The following Exhibit may be used as a guide for the selection of the type of controller at an isolated intersection, subject to variations in local conditions:

Exhibit 3-15 Isolated intersection controller selection

Factor	Fixed-Time	Fully-Actuated	Volume-Density
Main street average to peak value	Any	More than 20%	More than 30%
Main street average hour variation	Less than 20%	More than 20%	More than 30%
Cross street average hour variation	Less than 20%	More than 20%	More than 30%
Cross street volume	More than 25%	Any	More than 30%

The following Exhibit may be used as a guide for the selection of the type of controller subject to variations in local conditions.

Exhibit 3-16 Relationship between intersection operation and control type *(from FHWA Signal Timing Manual)*

	Pre-timed		Actuated		
Type of Operation	**Isolated**	**Coordinated**	**Semi-Actuated**	**Fully-Actuated**	**Coordinated**
Fixed Cycle Length	Yes	Yes	No	No	Yes
Conditions Where Applicable	Where detection is not available	Where traffic is consistent, closely spaced intersections, and where cross street is consistent	Where defaulting to one movement is desirable, major road is posted <40 mph and cross road carries light traffic demand	Where detection is provided on all approaches, isolated locations where posted speed is >40 mph	Arterial where traffic is heavy and adjacent intersections are nearby
Example Application	Work Zones	Central business districts, interchanges	Highway operations	Locations without nearby signals; rural, high speed locations; intersection of two arterials	Suburban arterial
Key Benefit	Temporary application keeps signals operational	Predictable operations, lowest cost of equipment and maintenance	Lower cost for highway maintenance	Responsive to changing traffic patterns, efficient allocation of green time, reduced delay and improved safety	Lower arterial delay, potential reduction in delay for the system, depending on the settings

The pre-timed control type, if selected, shall be capable of providing multiple timing patterns to better accommodate directional shifts or volume variations in traffic during different portions of the day.

Often, it is found that certain movements (such as left turns or movements from a minor approach) cannot be accommodated adequately without the provision of special phases such as advance or exclusive phases. The demand for such special phases varies from cycle to cycle. In such cases, an actuated control type shall be selected. This would enable the special phases to be extended, skipped, or maintained as demand warrants without causing unnecessary delays to the major movements.

In order to allow for future expansion, the controller should be capable of providing additional phases of operation and timing patterns regardless of the number of phases and timing patterns required in the initial design.

Central Traffic Signal Systems

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.

Central Traffic Signal Systems (CTSS) are tools which remotely manage traffic signal databases and monitor the operation of traffic signal controllers. The software communicates with the traffic signals in the field from a central location such as a TMC. Such systems can have large up-front hardware and software costs, as well as recurring maintenance costs and needs when compared to other signal system solutions. As a result, selection and design of such systems requires more complex analysis prior to implementation.

PennDOT has developed guidance and a form, TE-153, to aid designers with traffic signal system selection. For control type selection guidelines when proposed signals are operating together in a system, please reference Publication 46, Section 4.6.

CHAPTER 11 - SYSTEMS

The 2001 Traffic Control Devices Handbook published by the Institute of Transportation Engineers states:

"A traffic signal control system exists whenever two or more signals operate in a synchronous manner. The objective of a traffic signal control system is to improve the flow of traffic along a major street or throughout a network of streets. A traffic signal control major system consists of an appropriate signal-timing plan and the hardware components to implement that signal-timing plan. The signal-timing plan must satisfy traffic demand, traffic flow patterns and the geometrics that exist at each intersection and in the network as a whole.

Traffic signal control systems may be relatively small and simple or fairly large and complex. A system may merely consist of a series of intersections along a major street whose controller units are interconnected.

Such a system's purpose is to move platoons of traffic without interruption along the major street. On the other hand, a system may consist of a network of streets whose intersection controller units are centrally controlled by a digital computer with two-way communication between the computer and the intersection controllers. The purpose of this type of system is to reduce the total amount of delay and the total number of stops occurring to all traffic in the network."

Where the proximity between signalized intersections is such that traffic signal coordination is deemed appropriate and necessary, a system of traffic signals may be implemented. Historically, and currently, a reliable coordinated system can be achieved using a physical method of interconnection via some type of wiring or cable. More recently, technologies have become available that allow for the implementation of a system without physical means. The provision of traffic signals into a system is the focus of this chapter. Each type of system has its advantages and disadvantages that should be weighed by the designer while factoring in reliability, cost, and functionality.

This chapter focuses on physical design considerations for traffic signal systems. Refer to Chapter 3, Operational Requirements for information regarding traffic signal coordination. Refer to Publication 46, Section 4.6 for a background on types of traffic signal systems, as well as guidance for determining the most appropriate type of traffic signal system solution.

11.1 Design Considerations

Several factors should be considered when determining which type of system to use, including but not limited to:

a) Cost
b) Desired Functions
c) Operation and Maintenance
d) Corridor classification

TBC or a simple interconnect may be sufficient for isolated corridors with predictable traffic patterns. A centralized or closed loop system should be considered for major arterials and densely-populated areas that experience heavy volumes and daily volume fluctuations that may occur due to non-recurring congestion.

Interconnected systems need to be monitored periodically to ensure that communications are operational. ASC should be considered as well for areas that experience major fluctuations in traffic demand, such as near interstates, shopping malls, sporting venues, etc. Buy-in and a financial commitment of operations and maintenance from the lead municipality must be obtained before proposing any type of system that requires periodic operations and maintenance.

11.2 Communications

Three modes of communications are typically used to interconnect signals within a system. Refer to *Section 953* (Traffic Signal Systems and Communications) of Publication 408 for specifics on the materials and construction methods.

Hard-wire Interconnect

Twisted-pair cable is generally installed in conduit between intersections.

a) **Advantages**

Least expensive method of physical interconnection, no additional equipment is required beyond the controller unit

b) **Disadvantages**

Conducts electricity which may cause lightning or power surge damage at multiple signal controllers

Fiber Optic Cable

Fiber optic cable can be installed aerially or in conduit between intersections. Care must be taken during design to specify the correct accompanying equipment as different types of fiber optic cable are available, i.e., single-mode vs. multi-mode, loose tube vs. tight buffered.

a) Advantages

Non-conductive (not susceptible to lightning strike travel), able to carry large amounts of data

b) Disadvantages

Cable difficult and expensive to repair, accompanying equipment, and installation more expensive

Spread Spectrum Radio (SSR)

Communications between intersections is provided by a wide bandwidth frequency signal. Two frequency ranges are allowed, 902-928 MHz and 2.4 GHz, which do not require FCC licensing. An implementation survey will be required during design to determine if obstructions and/or roadway curvatures would require repeaters.

a) Advantages

No physical connection between intersections, lower cost

b) <u>Disadvantages</u>

Limited bandwidth compared to fiber, repeaters may be necessary.

Methods may be mixed within a system. For example, three intersections can be interconnected by fiber optic cable but a fourth may be interconnected by SSR due to an obstruction, such as a railroad overpass.