Traffic Signal Operations Manual

Prepared by the Division of Traffic Operations

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1/9/2019	HQ	Updated Appendix M added CTSCP Railroad Guidance
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CALTRANS TRAFFIC SIGNAL OPERATIONS MANUAL

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Chapter 1
INTRODUCTION

This manual establishes engineering guidelines, policies and procedures for traffic signal operations of the California Department of Transportation (Caltrans). Many of the instructions given herein are subject to amendment as conditions and experience warrant. Special situations may call for variation subject to sound engineering judgment. This manual is not intended to be a substitute for engineering knowledge, experience or judgment. It contains material that is intended to serve as an aid in the solution of various traffic situations. It is not intended that any standard of conduct or duty toward the public shall be created or imposed by the publication of this manual.

This manual contains current highway traffic signal standards, criteria and policies. Traffic signal standards have evolved over a period of many years; consequently, many existing roads or intersections do not fully conform to current standards. It is not economically feasible to upgrade all roads to current design standards; however, certain roadway features may be upgraded where it is cost-effective to do so.

This document is to assist engineers with the best practices for processes and procedures for traffic signal operations and supplements other documentation, such as the Model 2070 Controller Traffic Signal Control Program (TSCP) User's Manual; C8 Operations Manual; Traffic Signal Management and Surveillance System (TSMSS) Users Guide; the Signal, Lighting and Electrical Systems Design Guide; the TRAC Users Guide and the California Manual on Uniform Traffic Control Devices (CA MUTCD). This is consistent with the Traffic Signal Operations Business Plan's goals.

1.1.1 Purpose of Traffic Signals

The CA MUTCD defines a traffic control signal as any highway traffic signal by which traffic is alternatively directed to stop and permitted to proceed. Traffic is defined as pedestrians, bicyclists, ridden or herded animals, vehicles, streetcars, and other conveyances either singularly or together while using any highway for purposes of travel (1). Refer to Section 4B.03 of the CA MUTCD regarding "Advantages and Disadvantages of Traffic Control Signals."

It is the need to assign the right of way that we consider the dual purpose of traffic signals — efficiency and safety. Judgment must be exercised to balance both the need for safety and efficiency to achieve improvements and meet increasing demands. Traffic signals can serve both operational efficiency and safety, based on the conditions.

A traffic signal that is properly designed and timed can be expected to provide one or more of the following benefits:

- Provide for the orderly and efficient movement of people (all modes of transportation).
- Effectively maximize the volume movements (throughput) served at the intersection.
- Reduce the frequency and severity of certain types of crashes.
- Provide appropriate levels of accessibility for pedestrians and side street traffic.

The degree to which these benefits are realized is based partly on the design and partly on the appropriate need for a signal. Traffic signals are not always the optimal solution to reducing crashes at intersections (2). Traffic control signals that are ill designed, ineffectively placed, improperly operated, or poorly maintained, may result in excessive delay, disobedience of the indication, avoidance, and increased frequency of collisions.

1.1.2 Objectives of Basic Signal Timing Parameters and Settings

The CA MUTCD Section 4B.03 describes the advantages and disadvantages of Traffic Control Signals:

> When properly used, traffic control signals are valuable devices for the control of vehicular and pedestrian traffic. They assign the right-of-way to the various traffic movements and thereby profoundly influence traffic flow.
>
> Traffic control signals that are properly designed, located, operated, and maintained will have one or more of the following advantages:
>
> A. They provide for the orderly movement of traffic.
> B. They increase the traffic-handling capacity of the intersection if:
>   1) Proper physical layouts and control measures are used, and
>   2) The signal operational parameters are reviewed and updated (if needed) on a regular basis (as engineering judgment determines that significant traffic flow and/or land use changes have occurred) to maximize the ability of the traffic control signal to satisfy current traffic demands.
> C. They reduce the frequency and severity of certain types of crashes, especially right-angle collisions.
> D. They are coordinated to provide for continuous or nearly continuous movement of traffic at a definite speed along a given route under favorable conditions.
>
> E. They are used to interrupt heavy traffic at intervals to permit other traffic, vehicular or pedestrian, to cross. Traffic control signals are often considered a panacea for all traffic problems at intersections. This belief has led to traffic control signals being installed at many locations where they are not needed, adversely affecting the safety and efficiency of vehicular, bicycle, and pedestrian traffic.
>
> Traffic control signals, even when justified by traffic and roadway conditions, can be ill designed, ineffectively placed, improperly operated, or poorly maintained. Improper or unjustified traffic control signals can result in one or more of the following disadvantages:
>
> A. Excessive delay
> B. Excessive disobedience of the signal indications
> C. Increased use of less adequate routes as road users attempt to avoid the traffic control signals
> D. Significant increases in the frequency of collisions (especially rear-end collisions)

A primary objective of signal timing settings is to move people through an intersection efficiently. Achieving this objective requires a plan that allocates right-of-way to the various users. This plan should accommodate fluctuations in demand over the course of each day, week, and year. Because travel demand patterns change over time, the signal timing plan should be periodically updated to maintain intersection efficiency.

There are many traffic signal timing parameters that affect intersection efficiency, including the cycle length (the time needed to serve all movements (signal phases)), movement green time, and clearance intervals. Increasing a traffic movement's green time may reduce its delay and the number of vehicles that stop. However, an increase in one movement's green time generally comes at the expense of increased delay and stops to another movement. A good signal timing plan is one that allocates time appropriately based on the demand at the intersection and keeps cycle lengths to a minimum.

The relationship between signal timing and safety is also addressed with specific timing parameters and the design of the intersection. For instance, the intent of the yellow change interval is to facilitate safe transfer of right-of-way from one movement to another. The safety benefit of this interval is most likely to be realized when its duration is consistent with the needs of drivers approaching the intersection at the onset of the yellow indication. This need relates to the driver's ability to perceive the yellow indication and gauge their ability to either stop before the limit line, or travel through the intersection more safely. Their decision to stop, or continue, is influenced by several factors, most notably speed. Appropriately timed yellow change intervals can reduce driver confusion. Signal timing plans that reduce the number of stops and minimize delays may also provide some additional safety benefits. Traffic signal timing must consider pedestrians, vehicular traffic conditions, change and clearance intervals, and if actuated, detection layout. These signal timing parameter settings may be influenced by adjacent intersections (the concept of coordination is more fully explored in Chapter 3), but are applicable for each intersection considered as an isolated unit.

1.1.3 Establishing the Need for Retiming

Traffic professionals have long recognized the value of designing effective signal timing to meet changing travel patterns and characteristics. In 1995, the U.S. General Accounting Office (GAO) reported, "Properly designed, operated and maintained traffic control signal systems yield significant benefits along the corridors and road networks on which they are installed. They mitigate congestion and reduce accidents, fuel consumption, air pollutants and travel times. Resource constraints have prevented the use of traffic signals to their full potential. The Traffic Signal Report Card Technical Report states (3):

> *"It became clear that for safety and liability reasons, agencies must ensure a basic level of operation of the traffic signal system so that signals continue to turn green, yellow and red. The signals may not function efficiently for traffic or pedestrians, but, technically, the signals are working and that is what people see. However, the uniformly low scores (on the National Report Card) indicate that, for the most part, people consistently experience poor traffic signal performance and, as a consequence, their expectations are low. The pattern, once again, is one where agencies are forced to use their resources to deal with critical maintenance issues when they arise rather than proactively. Signal systems are managed to simply ensure base levels of performance."*

The National Transportation Operations Coalition (NTOC) and the Federal Highway Administration (FHWA) continue to work to make the case that additional resources are needed to develop signal timing plans and to modernize equipment. The use of 20-year-old technology and infrastructure may satisfy the requirement for the signal to display green, yellow, and red, but it may not offer the opportunity to efficiently operate the system or provide preferential treatment for a certain type of user to meet the policies and desires of the community. In most cases, upgraded equipment improves the efficiency for staff to manage the system, assuming the staff is properly trained to operate the upgraded equipment. Balancing technology upgrades as funds become available is important.

Efficiencies are observed with updating traffic signal timing plans, developing new strategies to improve transportation, and improving customer service. There have been some great technological advances in the past five years, such as the development of transit signal priority, which seeks to provide preferential treatment to buses as they approach the traffic signal. This new technology allows the engineer to allocate green time that more closely reflects the community's transportation policies.

1.1.4 Benefits of Up-to-Date Timing

Studies around the country have shown that the benefits of area-wide signal timing outweigh the costs 40:1 (or more) (4). 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.

The NTOC recently surveyed the quality of traffic signal operations in the United States. The NTOC concluded that the nation scored a D in terms of the overall quality of traffic signal operation. "If the nation supported its signals at an 'A' level, we would see:

- Reductions in traffic delay ranging from 15-40%; reductions in travel time up to 25%; and reductions in stops ranging from 10-40%. For example, if you spent two hours in your car commuting to and from work and running errands, you'd save 50 hours per year (or more than a work week) because of improved signal timing.
- Reductions in fuel consumption of up to 10%. Nationwide this would amount to a savings of almost 170 billion gallons of motor fuels per year.
- Reduction in harmful emissions (carbon monoxide, nitrogen oxides, volatile organic compounds) up to 22%. According to the Surface Transportation Policy Project, motor vehicles are the largest source of urban air pollution. In addition, the EPA estimates that vehicles generate 3 billion pounds of air pollutants yearly.

Beyond the benefits to vehicular traffic, there are opportunities to improve performance for transit, pedestrians, and freight movement.

1.1.5 Organization of Manual

This manual is divided into three parts and is organized as follows:

Part 1 - *Introduction*

Part 2 - *Signal Timing Concepts, Guidelines, and Application and Coordination Plan Development* (Chapters 2 and 3). This part describes traffic signal timing from the concepts to application. It provides guidelines where appropriate based on industry practice. This chapter provides several examples that represent good practice.

Part 3 - *Appendix.* This part presents an overview of a number of advanced topics related to improving signal timing operations that will be especially relevant to sophisticated timing engineers that are implementing innovative strategies and specific process for documenting work performed.

2.1 TERMINOLOGY AND KEY DEFINITIONS

This section identifies and describes basic terminology used within this chapter. Additional terms can be found in the Glossary section of this Manual.

Actuated Signal Control - A type of signal control where time for each phase is at least partially controlled by vehicle detector actuations.

Call - An indication within a controller that a vehicle or pedestrian is awaiting service from a particular phase or that a recall has been placed on the phase.

Extend - A detector parameter that increases the duration of a detector actuation by a defined fixed amount of time.

Gap Out - A type of actuated operation for a given phase where the phase terminates, due to a lack of vehicle calls, within a specific period of time (passage time).

Interval - The duration of time during which the indications do not change their state (active or off). Typically, one or more timing parameters control the duration of an interval. The pedestrian clearance interval is determined by the pedestrian clearance time. The green interval duration is controlled by a number of parameters including minimum time, maximum time, gap time, etc.

Isolated Intersection - An intersection located outside the influence of and not coordinated with other signalized intersections, commonly one mile or more from other signalized intersections.

Minimum Gap - A volume density parameter that specifies the minimum green extension when gap reduction is used.

Minimum Green - A parameter that defines the shortest allowable duration of the green interval.

Minimum Recall - A parameter that results in a phase being called and timed for at least its minimum green time, whether or not a vehicle is present.

Movement - Movements reflect the user perspective. Movements can also be broken down into classes (car, pedestrians, buses, LRT, etc.). Typical movements are left, through and right. Movement is an activity in response to a "go" (green ball, green arrow, walk, white vertical transit bar) indication.

Max Out - A type of actuated operation for a given phase where the phase terminates due to reaching the designated maximum green time for the phase.

Passage Time (Vehicle Interval, Gap, Passage Gap, Unit Extension) - A parameter that specifies the maximum allowable duration of time between vehicle calls on a phase, before the phase is terminated.

Pedestrian Change Interval (Flash "Don't Walk" (FDW) + Yellow + All Red) - An indication warning pedestrians that the walk interval has ended and the flashing UPRAISED HAND (symbolizing don't walk) indication will begin, at the end of the pedestrian change interval. Caltrans typically includes yellow and includes the red clearance intervals in the calculation. (See CA MUTCD 2014 Figure 4E-2)

Phase – A controller timing parameter associated with the control of one or more movements. *The MUTCD defines a signal phase as the right-of-way, yellow change, and red clearance intervals in a cycle that are assigned to an independent traffic movement.*

Phase Sequence– The order of a series of phases in a ring.

Queue - A line of vehicles, bicycles, or persons waiting to be served by a phase in which the flow rate from the front of the queue determines the average speed within the queue. Slowly moving vehicles or people joining the rear of the queue are usually considered part of the queue. The internal queue dynamics can involve starts and stops. A faster-moving line of vehicles is often referred to as a moving queue or a platoon.

Ring – An array of independent timing sequences. For example, with a dual-ring controller, opposing left-turn arrows may turn red independently, depending on the amount of traffic. A typical controller is an "8-phase, dual ring control."

Ring-Barrier Diagram – A graphical representation of phases within a set of rings and phases within a set of barriers. An example ring diagram is shown in Figure 2-1a. The sequence of phases is shown as they occur in time, proceeding from left to right. The figure illustrates a phase sequence with left-turn movements leading the opposing through movements on both the major and minor streets. The diagram shows phase 1 and 5 ending at the same time, but they operate independently and can end at different times. The subsequent phase (phases 2 and 6, respectively) may begin once the previous phase has used its time. Once the barrier is crossed, phases 3 and 7 operate followed by phases 4 and 8. The cycle ends with the completion of phases 4 and 8. Figure 2-1b shows the corresponding signalized intersection, with the numbered traffic movements.

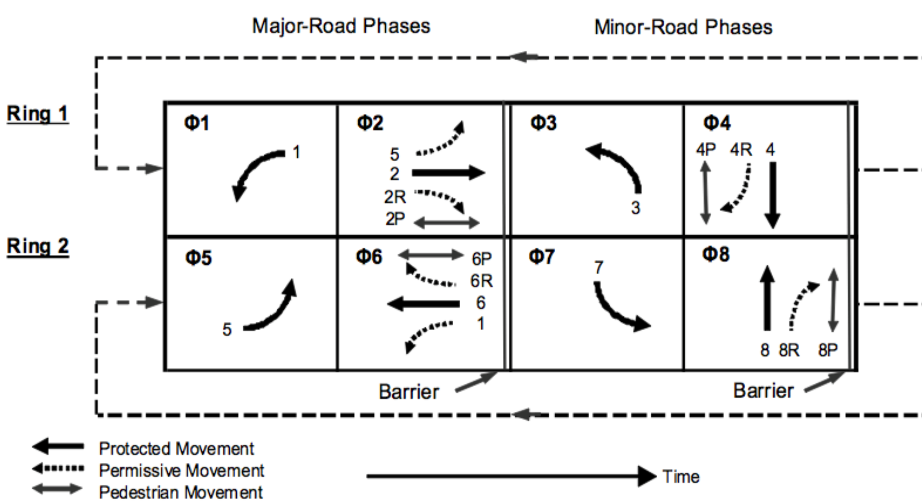

Figure 2-1a – Standard Ring-Barrier Diagram

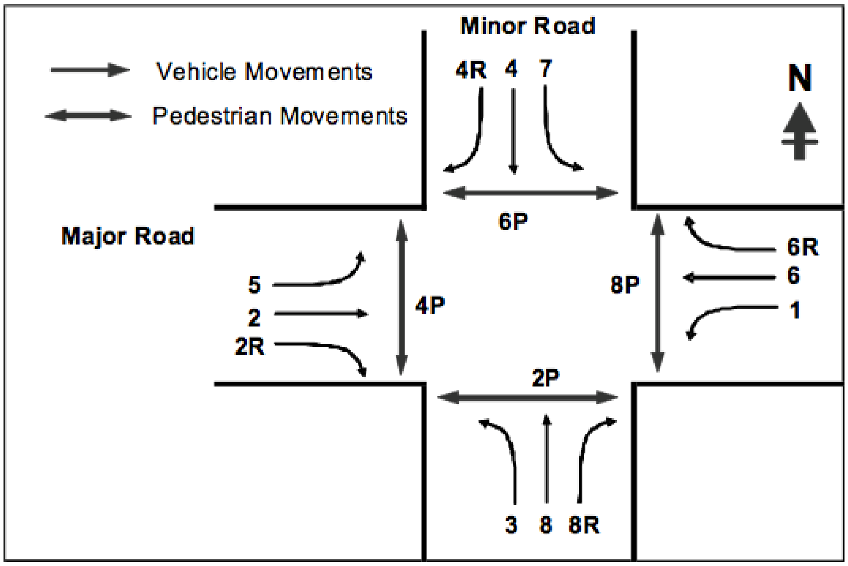

Figure 2-1b – Intersection Traffic Movements and Numbering Scheme (showing 8 phases)

Recall - A call is placed for a specified phase each time the controller is servicing a conflicting phase. This will ensure that the specified phase will be serviced again. Types of recall include minimum, maximum, pedestrian and bicycle recall (bicycle recall is an option in the Traffic Signal Control Program, TSCP, for the Model 2070 controller).

Reference Midnight - When the master cycle timer is referencing midnight, it means the master cycle timer is ZERO at midnight.

"Signal" Indication – the illumination of a signal lens or equivalent device.

Semi-Actuated Control - A type of signal control where detection is provided for some of the movements, typically the minor movements (such as side street traffic).

Volume-Density - A phase timing technique that uses a series of parameters (variable initial, minimum gap, maximum gap, time before reduction, time to reduce) to provide alternative, variable settings for the otherwise fixed parameters of minimum green and passage time.

2.2 MODES OF TRAFFIC SIGNAL OPERATION AND THEIR USE

Traffic signals operate in either pre-timed or actuated mode or some combination of the two. Pre-timed control consists of a series of intervals that are fixed in duration. Collectively, the preset green, yellow, and red intervals result in a deterministic sequence and fixed cycle length for the intersection. In contrast to pre-timed control, actuated control consists of intervals that are called and extended in response to vehicle detectors. Detection is used to provide information about traffic demand to the controller. The duration of each phase is determined by detector input and corresponding controller parameters. Actuated control can be characterized as fully-actuated or semi-actuated, depending on the number of traffic movements that are detected. Table 2-1 summarizes the general attributes of each mode of operation to aid in the determination of the most appropriate type of traffic signal control for an intersection. The attributes of the various modes of operation are discussed in additional detail in the following subsections.

	Type of Operation:	**Isolated**	**Coordinated**	**Semi-Actuated**	**Key Benefit**
PRE-TIMED	***Fixed Cycle Length***	***Conditions Where Applicable***	***Example Application***	***Fully-Actuated***	***Coordinated***
	Yes	Yes	No	No	Yes
ACTUATED	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
	Work zones	Central business districts, interchanges	Highway operations	Locations without nearby signals; rural, high speed locations; intersection of two arterials	Suburban arterial
	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

Table 2-1 – Relationship between Intersection Operation and Control Type

2.2.1 Pre-timed Control

Pre-timed control is ideally suited to closely spaced intersections where traffic volumes and patterns are consistent on a daily or day-of-week basis. Such conditions are often found in downtown areas. They are also better suited to intersections where three or fewer phases are needed (5). Pre-timed control has several advantages. For example, it can be used to provide efficient coordination with adjacent pre-timed signals, since both the start and end of green are predictable. Also, it does not require detectors, thus making its operation immune to problems associated with detector failure. Finally, it requires a minimum amount of training to set up and maintain. However, pre-timed control cannot compensate for unplanned fluctuations in traffic flows, and it tends to be inefficient at isolated intersections were traffic arrivals are random.

The Model 2070 controllers, as well as the Model 170 controller are designed to accommodate actuated operation so its advantages are not realized when using pre-timed operation. Nevertheless, pre-timed operations can be achieved by specifying a maximum green setting that is equal to the desired pre-timed green interval and invoking the maximum vehicle recall parameter described below.

2.2.2 Semi-Actuated Control

Semi-actuated control uses detection only for some of the movements at an intersection, typically the minor movements. The phases associated with the major-road through movements are operated as "non-actuated." That is, these phases are not provided detection information. In this type of operation, the controller is programmed to dwell in the non-actuated phases and, thereby, sustain a green indication for the highest flow movements (normally the major street through movement). Minor movement phases are serviced after a call (demand) for their service is received.

Semi-actuated control is most suitable for application at intersections that are part of a coordinated arterial street system. Coordinated-actuated operation is discussed in more detail in Chapter 3.

Semi-actuated control may also be suitable for isolated intersections with a low-speed major road and lighter crossroad volume.

Semi-actuated control has several advantages. Its primary advantage is that it can be used effectively in a coordinated signal system. Also, relative to pre-timed control, it reduces the delay incurred by the major-road through movements (i.e., the movements associated with the non-actuated phases) during periods of light traffic. Finally, it does not require detectors for the major-road through movement phases and hence, its operation is not compromised by the failure of these detectors.

The major disadvantage of semi-actuated operation is that continuous demand on the phases associated with one or more minor movements can cause excessive delay to the major road through movements if the maximum green and passage time parameters are not appropriately set. Alternatively, because the major street has no detection and is thus guaranteed a minimum green time regardless of the presence of traffic, there can be unnecessary delay to the minor movement traffic in off-peak hours. Another drawback is that detectors must be used on the minor approaches, thus requiring installation and ongoing maintenance.

2.2.3 Fully-Actuated Control

Fully-actuated control refers to intersections for which all phases are actuated and hence, it requires detection for all traffic movements. Fully-actuated control is ideally suited to isolated intersections where the traffic demands and patterns vary widely during the course of the day. Both the Model 2070 and Model 170 controllers can be programmed in coordinated signal systems to operate in a fully-actuated mode during low-volume periods where the system is operating in a "***free***" (or non-coordinated) mode. Free operations mode may be an intersection operating with "Recall" or "Fixed Time." Fully-actuated control can also improve performance at intersections with lower volumes that are located at the boundary of a coordinated system and do not impact progression of the system.

There are several advantages of fully-actuated control. First, it reduces delay relative to pre-timed control by being highly responsive to traffic demand and to changes in traffic pattern. In addition, detection information allows the cycle time to be efficiently allocated on a cycle-by-cycle basis. Finally, it allows phases to be skipped if there is no call for service, thereby allowing the controller to reallocate the unused time to a subsequent phase. The fully-actuated control requires initial and maintenance costs.

2.3 PHASE INTERVALS AND BASIC PARAMETERS

An interval is defined in the NTCIP 1202 standard as "a period of time during which signal indications do not change." Various parameters control the length of an interval depending on the interval type. For example, a pedestrian walk interval (the time period during which the Walking Person signal indication is displayed) is generally controlled by the single user-defined setting for the walk parameter. The vehicular green interval, on the other hand, is generally controlled by multiple parameters, including minimum green, maximum green, and passage time. This section describes guidelines for setting basic parameters that determine the duration of each interval associated with a signal phase. These intervals include:

- Vehicular Green Interval
- Vehicle Change and Clearance Intervals
- Pedestrian Intervals
- Bicycle Min Green

Parameters related to these intervals and discussed in this section include minimum green, maximum green, yellow-change, red clearance, pedestrian walk, and pedestrian flashing don't walk (FDW). Figure 2-2 depicts the relationship between these parameters and the user group associated with each interval that may time during a phase. These intervals time concurrently during a phase. Additional timing parameters related to actuated control (e.g., passage time) may also influence the duration of an interval and are discussed in Section 2.4.

Figure 2-2 – Users and the Actuated Signal Timing Parameters that Determine Phase Length

2.3.1 Vehicular Green Interval

The vehicular green interval is the time dedicated to serving vehicular traffic with a green indication. This interval is defined primarily by the minimum and maximum green parameters in the case of an isolated intersection. At an actuated controller, other parameters (e.g., passage time) also determine the length of this interval. Those parameters are discussed in Section 2.4. It is also possible that the duration of the vehicle green interval may be defined by the length of the associated pedestrian intervals.

Minimum Green

The minimum green parameter represents the least amount of time that a green signal indication will be displayed for a movement. Minimum green is used to allow drivers to perceive and react to the start of the green interval and provide time for a minimal queue of traffic to proceed through the intersection; this is considered "Driver Expectancy." Its duration may also be based on considerations of queue length or pedestrian timing in the absence of pedestrian call buttons and/or indications. A minimum green that is too long may result in wasted time at the intersection; one that is too short may terminate the move before queued traffic can proceed through the intersection.

The minimum green interval is shown in Figure 2-3, as it relates to other intervals and signal control parameters. Calls placed on the active phase during the minimum green have no bearing on the duration of the green interval since the interval will time at least as long as the minimum green timer.

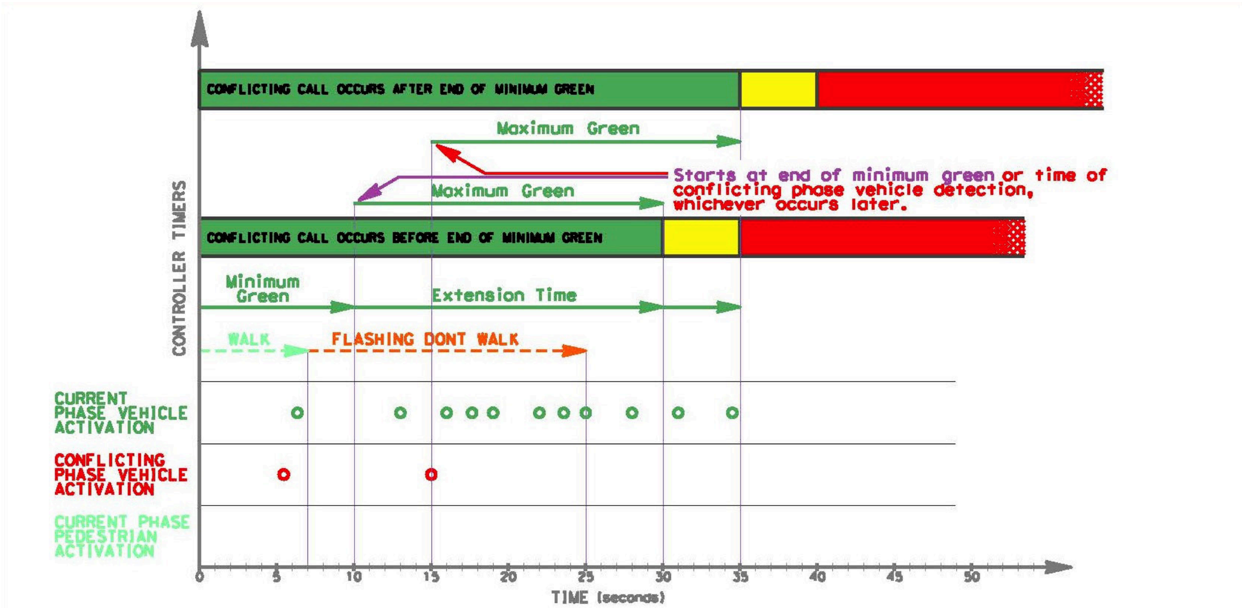

Figure 2-3 – Settings that Define the Duration of a Vehicle Phase

When limit line detection is restricted to call detection or is not provided, variable initial, a parameter that increases the minimum green as described in Section 2.5, should be used to allow vehicles queued between the limit line and the nearest detector at the start of green, to clear the intersection. In cases where separate pedestrian signal displays are not provided, the minimum green interval will also need to be long enough to accommodate pedestrians who desire to cross in a direction parallel to the traffic movement receiving the green indication.

Minimum Green for Pedestrian Crossing Time

The minimum green duration must satisfy pedestrian crossing needs for through phases that are not associated with a pedestrian push button *but have a pedestrian demand*. Under these conditions, the minimum green needed to satisfy pedestrian considerations can be computed using Equation 2-1. Methodology for computing walk and pedestrian clearance interval durations are provided in Section 2.3.3.

$$G_p = PW + PC \qquad \textbf{Equation 2-1}$$

Where: G_p is the minimum green interval duration needed to satisfy pedestrian crossing time
PW is the walk interval duration, and
PC is the pedestrian clearance interval duration, s (all values in seconds).

Minimum Green for Queue Clearance

The duration of minimum green can also be influenced by detector location and controller operation. This subsection addresses the situation where a phase has one or more advance detectors and no limit line detection. If this detection design is present, and the added initial parameter (as discussed later) is not used, then a minimum green interval is needed to clear the vehicles queued between the limit line and the advance detector. The duration of this interval is specified in Table 2-2.

Distance Between Limit Line and Nearest Upstream Detector (ft)	Minimum Green Needed to Satisfy Queue Clearance (G_q), (seconds)
0 to 25	5
26 to 50	7
51 to 75	9
76 to 100	11
101 to 125	13
126 to 150	15

Notes:

1. Minimum green values listed apply only to phases that have one or more advance detectors, no limit line detection, and the added initial parameter is not used.
2. Minimum green needed to satisfy queue clearance, $Gq = 3 + 2n$ (in seconds), where n = number of vehicles between limit line and nearest upstream detector in one lane. And, $n = Dd / 25$, where Dd = distance between the limit line and the downstream edge of the nearest upstream detector (in feet) and 25 is the average vehicle length (in feet), which could vary by area.

Table 2-2 – Typical Minimum Green Interval Duration Needed to Satisfy Queue Clearance

Maximum Green

The maximum green parameter represents the maximum amount of time that a green signal indication can be displayed in the presence of conflicting demand. Maximum green is used to limit the delay to any other movement at the intersection and to keep the cycle length to a maximum amount. It also guards against long green times due to continuous demand or broken detectors. Ideally, the maximum green will not be reached because the detection system will find a gap to end the phase, but if there are continuous calls for service and a call on one or more conflicting phases, the maximum green parameter will eventually terminate the phase. A maximum green that is too long may result in wasted time at the intersection. If its value is too short, then the phase capacity may be inadequate for the traffic demand, and some vehicles will remain *unserved* at the end of the green interval.

The Model 2070 and Model 170 controllers provide three maximum green parameters that can be invoked by a time-of-day plan or external input (i.e., Maximum Green 2). As shown in Figure 2-3, the maximum green extension timer begins timing upon the presence of a conflicting call. If there is demand on the phase that is currently timing and no conflicting calls, the maximum green timer will be reset until an opposing call occurs. The Max Green timer does not start until *after* the termination of the Min Green timer expires for TSCP; however, in the Model 170 software, the Max Green timer does run concurrently with the Min Green timer at the moment of conflicting call detection.

It should be noted that the normal failure mode of a detector is to place a continuous call for service. In this case, a failed detector on a phase will cause that phase's maximum green to time every cycle, whether there is a vehicle present or not.

The Model 2070 and Model 170 controllers also provide a feature that allows the maximum green time to be increased to a defined threshold after maxing out a phase a certain number of consecutive times (or alternatively to select among two or three maximum green values). The maximum green time may then be automatically decreased back to the original value after the phase has gapped out a certain number of times, this is called "Traffic Actuated Max 2."

The maximum green value should exceed the green duration needed to serve the average queue and, thereby, allow the phase to accommodate cycle-to-cycle peaks in demand. Frequent phase termination by gap out (as opposed to max out) during low-to-moderate volumes and by occasional max out during peak periods is commonly used as an indication of a properly timed maximum green duration. Example values are listed in Table 2-3.

Phase Type	*Facility Type*	*Maximum Green, seconds*
Through	Major Arterial (speed limit exceeds 40 mph)	50 to 70
	Major Arterial (speed limit is 40 mph or less)	40 to 60
	Minor Arterial	30 to 50
	Collector, Local, Driveway	20 to 40
Left Turn	Any	15 to 30

Table 2-3 – Example Values for Maximum Green Duration

Two methods are commonly used to establish the maximum green setting. Both estimate the green duration needed for average volume conditions and inflate this value to accommodate cycle-to-cycle peaks. Both of these methods assume that advance detection for indecision zone protection is not provided. If advance detection is provided for indecision zone protection, the maximum green setting obtained from either method may need to be increased slightly to allow the controller to find a "safer" time to terminate the phase by gap out.

One method used by some agencies is to establish the maximum green setting based on an 85th to 95th percentile probability of queue clearance. The procedure requires knowledge of the cycle length, or an estimate of its average value for actuated operation. If the cycle length is known, then the maximum green setting for a signal phase can be obtained from Table 2-4.

Phase Volume per Lane, veh/hr/ln	***Cycle Length (seconds)***							
	0	**60**	**70**	**80**	**90**	**100**	**110**	**120**
	Maximum Green (G_{max}), (seconds)							
100	15	15	15	15	15	15	15	15
200	15	15	15	15	16	18	19	21
300	15	16	19	21	24	26	29	31
400	18	21	24	28	31	34	38	41
500	22	26	30	34	39	43	47	51
600	26	31	36	41	46	51	56	61
700	30	36	42	48	54	59	65	71
800	34	41	48	54	61	68	74	81

Note: Values listed are computed as: $G_{max} = (V\,C)/(1200\,n) + 1$ where, V = design hourly volume served by subject phase (in vehicles per hour); n = number of lanes served by subject phase, and C = cycle length (in seconds). A 15 sec. minimum duration is imposed on the computed values.

Table 2-4 – Maximum Green Duration as a Function of Cycle Length and Volume

The values listed are based on the equation shown in the table footnote. Due to the approximate nature of this equation, the actual percentage probability of queue clearance varies between the 85th and 95th percentiles for the values listed.

A second method for establishing the maximum green setting is based on the equivalent optimal pre-timed timing plan. This method requires the development of a pre-timed signal timing plan based on delay minimization. The minimum-delay green interval durations are multiplied by a factor ranging from 1.25 to 1.50 to obtain an estimate of the maximum green setting.

The maximum green time used for a particular phase is calculated differently for low and high levels of saturation. During periods of low volume, when the green phase times rarely reach their maximum values, the maximum green time can be set fairly high (up to 1.7 times the calculated average time for the phase). This accommodates most fluctuations in vehicle arrival rates. During conditions at or near saturation, it is important to set the maximum green times as if they were fixed time, equitably allocating the green based on the critical lane volumes.

Application of the maximum green times show significant disparity in the techniques reported for determination of maximum phase time, which ultimately may result in a wide variation of cycle lengths at intersections. In many cases, maximum green times are set at one value throughout the day and don't reflect the needs of the intersection during various times of day. In some cases, these maximum green time values result in cycle lengths that are too long for efficient operations.

2.3.2 Vehicular Change and Clearance Intervals

The intent of the vehicle phase change and clearance intervals is to provide an orderly transition between two conflicting phases. It consists of a yellow change interval and, optionally, a red clearance interval. The intent of the yellow change interval is to warn drivers of the impending change in right-of-way assignment. *The red clearance interval may be used when there is some benefit to providing additional time before conflicting movements receive a green indication.*

Yellow Change

The duration of the yellow change interval is typically based upon driver perception-reaction time, plus the distance needed to more safely stop or to travel safely through the intersection.

A state's Uniform Vehicle Code directly affects yellow change interval timing, as it determines whether a permissive or restrictive yellow law is in place.

Permissive Yellow Law: In California, a driver can enter the intersection during the entire yellow interval and be in the intersection during the red indication as long as the vehicle entered the intersection during the yellow interval. This is consistent with California Vehicle Code 21452.

Red Clearance

The red clearance interval, referred to in some publications as an all-red interval, is an interval at the end of the yellow change interval during which the phase has a red-signal display before the display of green for the following phase. The purpose of this interval is to allow time for vehicles that entered the intersection during the yellow-change interval to clear the intersection prior to the next phase. Note that the use of the "all-red" nomenclature is generally incorrect, as the red clearance interval only applies to a single phase, not to all phases.

The duration of a red clearance interval is determined through good engineering judgment. A disadvantage of using the red clearance interval is that there is a reduction in available green time for other phases. At intersections where the timing for minor movements is restricted (e.g., to split times under coordinated operation), the extra time for a red clearance interval comes from the remaining phases at the intersection. In cases where major movements are already at or near saturation, the reduction in capacity associated with providing red clearance intervals should be accounted for in an operational analysis.

The California MUTCD (CA MUTCD) provides guidance on the application and duration of the yellow change and red clearance intervals. It recommends that the interval durations shall be predetermined based on individual intersection conditions, such as approach speed and intersection width. The CA MUTCD advises that the yellow change interval should last approximately 3 to 6 seconds, with the longer intervals being used on higher-speed approaches. It also advises that the red clearance interval should not exceed 6 seconds. Typical red clearance intervals range from 0.5 to 2.0 seconds.

The following equation may be used for computing the phase change period (yellow change plus red clearance intervals):

$$CP = \left[t + \frac{1.47v}{2(a + 32.2g)}\right] + \left[\frac{W + L_v}{1.47v}\right] \qquad \textbf{Equation 2-2}$$

where:
- CP = change period (yellow change plus red clearance intervals), s;
- t = perception-reaction time to the onset of a yellow indication, s;
- v = approach speed, mph;
- a = deceleration rate in response to the onset of a yellow indication;
- g = grade, with uphill positive and downhill negative (percent grade / 100), ft/ft;
- W = width of intersection, ft; and
- L_v = length of vehicle.

Equation 2-2 (6) is based on driver reaction time, approach speed, approach grade, and intersection width and consists of two terms. The first term (yellow change) represents the time required for a vehicle to travel one safe stopping distance, including driver perception-reaction time. This permits a driver to either stop at the intersection if the distance to the intersection is greater than one safe stopping distance or more safely enter the intersection (and clear the intersection under the restrictive yellow law) if the distance to the intersection is less than one safe stopping distance. The second term (red clearance) represents the time needed for a vehicle to traverse the intersection ($[W + L_v]/v$). Although values will vary by driver population and local conditions, the values of t = 1.0 second, a = 10 ft/s^2, and L_v = 20 ft. are often cited for use in Equation 2-2. *It is critical that engineering judgment be exercised to determine the appropriate clearance interval.*

When applying Equation 2-2 to through movement phases, the speed used is generally either the 85th-percentile speed or the posted regulatory speed limit as tabulated in CA MUTCD Table 102. When applying Equation 2-2 to turning movement phases, the speed used should reflect that of the drivers that intend to turn. This speed may equal that of the adjacent through movement but it can also be slower as left-turn drivers inherently slow down to a comfortable turning speed, approximately 20 mph. Regardless, if the turning phase terminates concurrently with the adjacent through phase, it will have the same total change and clearance interval durations as the through phase because the phases are interlocked by the ring-barrier operation.

Engineering judgment should be used when measuring the width of the intersection, W.
One approach is to measure from the near-side limit line to the far edge of the last conflicting traffic lane along the subject movement travel path. If crosswalks are present at the intersection, some

agencies have policies to measure from the near-side limit line to the far side of the pedestrian crosswalk on the far side of the intersection (for through-movement phases) or to the far side of the pedestrian crosswalk across the leg of the intersection which the left-turn is entering.

2.3.3 Pedestrian Timing Intervals

The pedestrian phase consists of three intervals:

1) Walk
2) Pedestrian clearance, commonly referred to as flashing don't walk (FDW)
3) Solid don't walk

The walk interval typically begins at the start of the green interval and is used to allow pedestrians to react to the change, to walk at the start of the phase and move into the crosswalk. This interval corresponds to the WALKING PERSON indication on the pedestrian signal. The pedestrian clearance interval follows the walk interval and informs pedestrians the phase is ending. During this interval, the UPRAISED HAND indication flashes on the pedestrian signal. The solid don't walk interval follows the pedestrian clearance interval and is indicated by a solid UPRAISED HAND indication. This interval is an indication to the pedestrian that they should have cleared the crosswalk and opposing vehicle movements could begin. The solid don't walk time is not a programmable parameter in the controller. The duration of the solid don't walk interval is simply the length of the cycle minus the walk and pedestrian clearance intervals.

Although the illustration in Figure 2-3 does not include pedestrian phase activation, it does show that the pedestrian timers (walk and FDW) would time concurrently with the vehicle intervals, if there were a pedestrian activation. In the case of Figure 2-3, the pedestrian intervals are shown as requiring less time than allowed by the maximum green timer. In this case, if there was continuing vehicle demand, the pedestrian indication would show a solid don't walk until the vehicle phase terminated due to lack of demand or the maximum green timer expired. However, if the pedestrian intervals required more time than permitted by the maximum green timer, the vehicle phase would continue to time until the pedestrian flashing don't walk interval finished timing.

For further information regarding pedestrian signal timing, refer to Appendix B.

2.3.4 Left-Turn Phase Selection

Left-turning traffic is controlled by one of five modes:

A. Permissive only Mode – turns made on a circular green signal indication, a flashing left-turn yellow arrow signal indication or a flashing left-turn red arrow signal indication
B. Protected only Mode – turns made only when a left-turn green arrow signal indication is displayed.
C. Protected/Permissive Mode – both modes can occur on an approach during the same cycle.
D. Permissive/Protected Mode – allows permissive mode first, before a protected turn
E. Variable Left-Turn Mode – the operating mode changes among the protected only mode and/or the protected/permissive mode and or the permissive only mode during different periods of the day or as traffic conditions change.

Left turn phasing options:

1. Dual Left-Turn Phasing (left turns time concurrently, not to be confused with the term dual left referring to two left turn lanes for the same phase).
2. Lead-lag Left-Turn Phasing – this can vary throughout the day. It's a good tool for use in traffic signal coordination as determined by the system time-space diagram.

3. Opposite or Opposing Phasing – works well when left turn volumes are high in either direction and is about equal to or greater than the companion thought movement. This method is especially useful when one of the through lanes must be used as an optional turning lane or where a separate left turn lane cannot be provided.
4. Permissive Left-Turn Phasing should not be used where the left turn crash warrant is satisfied. Both directions of through traffic should be terminated simultaneously except where opposing left turns or opposing U-turns are prohibited.

As stated in D above, 1, 2 and 4 can be utilized at the same intersection during different periods of the day or as traffic conditions change.

2.4 ACTUATED TIMING PARAMETERS

Actuated controllers operate most effectively when timed in a manner that permits them to respond rapidly to fluctuations in vehicle demand. This section describes several of the more commonly used settings and parameters that influence phase function or duration in an actuated controller, including phase recall, passage time, simultaneous gap, and dual entry. In addition, this section discusses the volume-density technique.

2.4.1 Dual Entry

The dual (double) entry parameter is used to call vehicle phases that can time concurrently even if only one of the phases is receiving an active call. For example, if dual entry is active for Phases 4 and 8 and Phase 4 receives a call but no call is placed on Phase 8, Phase 8 would still be displayed along with Phase 4. The most common use of dual entry is to activate the parameter for compatible through movements. If the dual entry parameter is not selected, a vehicle call on a phase will only result in the timing of that phase in the absence of a call on a compatible phase.

2.4.2 Phase Recalls

Recall causes the controller to place a call for a specified phase each time the controller is servicing a conflicting phase, regardless of the presence of any detector-actuated calls for the phase. There are three types of recalls: minimum recall (also known as vehicle recall), maximum recall, and pedestrian recall.

Minimum Recall (Vehicle Min)
The minimum recall parameter causes the controller to place a call for vehicle service on the phase. The phase is timed for its minimum green regardless of whether there is demand on the movement; any vehicle detector calls will extend the service. The call is cleared upon start of green for the affected phase and placed upon start of the yellow change interval.

Minimum recall is the most frequently used recall mode. It is most often used for the major road through-movement phases (commonly designated as phases 2 and 6). This use ensures that the controller will always return to the major road through phases regardless of demand, thus providing a green indication as early as possible in the cycle. The minimum recall may also be used where detection has failed.

Maximum Recall (Vehicle Max)
The maximum recall parameter causes the controller to place a continuous call for vehicle service on the phase. In TSCP, it results in the presentation of the green indication for its maximum duration every cycle as defined by the maximum green parameter plus the minimum green parameter for the phase in free operation. For the software in the Model 170 controller, the maximum recall is the maximum green time when in free operation. The max recall during coordination will result in the

presentation of green indication for the length of the force-off.

In TSCP, when the maximum recall parameter is selected for a phase in free operation, the maximum green timer begins timing at the end of the phase's minimum green interval, regardless of the presence of a conflicting call or lack thereof. In the Model 170, the maximum green timer begins timing at the beginning of the green phase. When the maximum recall parameter is selected for a phase in coordinated operation, the green phase is held to the force-off point (but at the force-off point for Model 170 controller), regardless of the presence of a conflicting call or lack thereof.

There are at least three common applications of maximum recall:

- *Fixed-time operation is desired:* Each phase is set for maximum recall. The maximum green setting used for this application should be equal to the green interval durations associated with an optimal fixed time plan.
- *Vehicle detection is not present or is out of service:* Maximum recall for a phase without detection ensures that the phase serves the associated movement. However, maximum recall can result in inefficient operation during light volume conditions (e.g., during night times and weekends) and should be used only when necessary. In some of these situations, a lower maximum green or MAX 2 (50 to 75% of the typical MAX GREEN value) may be desirable.
- *Gapping out is not desired:* Maximum recall can be used to prevent a phase from gapping out. An example application of this is under coordinated operations where a left turn phase is lagging. By setting the lagging left turn phase to maximum recall, the phase will time for its maximum duration, allowing the adjacent coordinated phase to also time for its intended maximum duration. This type of operation is typically only used on a time-of-day basis in conjunction with a particular coordinated plan (see Chapter 3).

Pedestrian Recall

The pedestrian recall parameter causes the controller to place a continuous call for pedestrian service on the phase, resulting in the controller timing its walk and flashing don't walk operation. Coordination plans may invoke pedestrian calls using a rest in walk command, which dwells in the pedestrian walk interval, while awaiting the yield point (see section 3.3.2).

There are at least two common applications of pedestrian recall:

- *Pedestrian detection is not present or is out of service:* Pedestrian recall for a phase without pedestrian detection ensures that the phase times pedestrian walk and clearance intervals each cycle.
- *High pedestrian demand:* Pedestrian recall is sometimes used to activate the Walk and Pedestrian clearance intervals for phases and time periods that are likely to have high pedestrian demand. This is a common application during periods of high pedestrian activity in downtown environments or at intersections near schools as students are arriving or leaving school for the day.

2.4.3 Passage Time

Passage time, sometimes called passage gap, vehicle extension, or unit extension, is used to extend the green interval based on the detector status once the phase is green. This parameter extends the Green Interval for each vehicle actuation up to the Maximum Green. It begins timing when the vehicle actuation is removed. This extension period is subject to termination by the Maximum Green timer or a Force Off.

Passage time is used to find a gap in traffic for which to terminate the phase, essentially it is the setting that results in a phase ending prior to its maximum green time during isolated operation. If the passage time is too short, the green may end prematurely, before the vehicular movement has been adequately served. If the passage interval is set too long, there will be delays to other movements caused by unnecessary extension of a phase, resulting in delay to the other movements at the intersection. The appropriate passage time used for a particular signal phase depends on many considerations, including: type and number of detection zones per lane, location of each detection zone, detection zone length, detection call memory (i.e., locking or non-locking), detection mode (i.e., pulse or presence), approach speed, and whether lane-by-lane or approach detection is used. Ideally, the detection design is established and the passage time determined to ensure that the "system" provides efficient queue service and minimizes abrupt phase termination for higher speed approaches.

The passage timer starts to time from the instant the detector actuation is removed. A subsequent actuation will reset the passage timer. Thus, the mode of the detector, pulse or presence, is extremely important in setting the passage time. The pulse mode essentially measures headways between vehicles and the passage time would be set accordingly. The speed of the vehicles crossing the detectors and the size of the detectors is an important consideration in determining passage time when using presence mode. Longer passage times are often used with shorter detectors, greater distance between the detectors and limit line, fewer lanes, and slower speeds.

When the passage timer reaches the passage time limit, and a call is waiting for service on a conflicting phase, the phase will terminate, as shown in Figure 2-4. When this occurs, it is commonly termed as a "gap out." In the figure, vehicle calls extend the green time until the gap in detector occupancy is greater than the passage time. In this example, presence detection is assumed. The vehicle extension interval is one of the most important actuated controller settings for maximizing traffic flow.

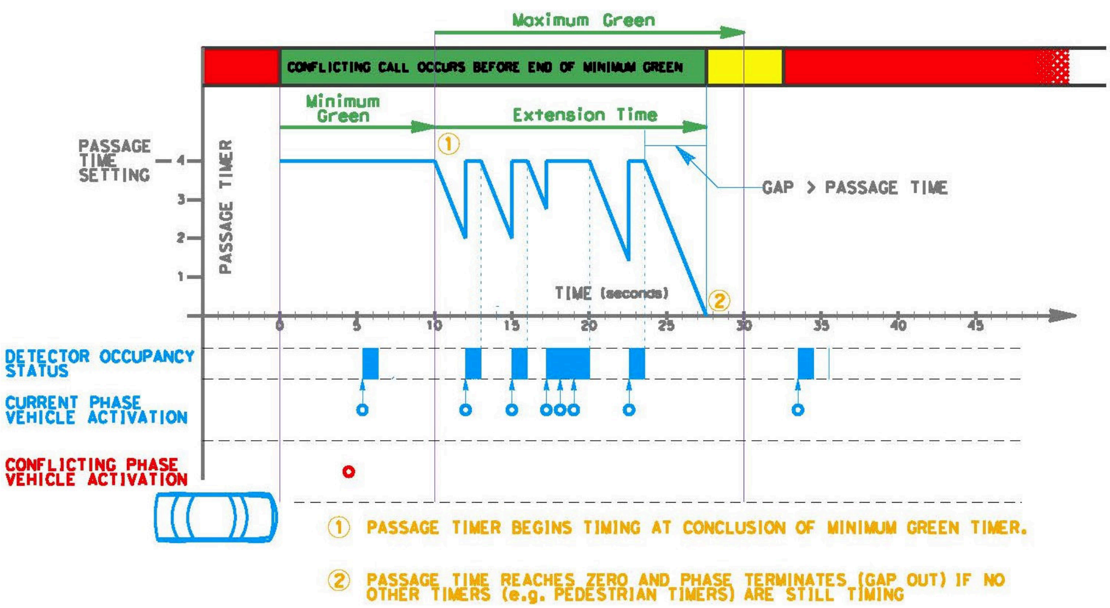

Figure 2-4 – Application of Passage Time

The objective when determining the passage time value is to make it large enough to ensure that all vehicles in a moving queue are served but to not make it so large that it extends the green for randomly arriving traffic. This objective is broadened on high-speed approaches to ensure the passage time is not so large that the abrupt termination of the phase cannot be avoided.

The guidelines provided in this section are based on the assumption that non-locking memory is used and that one source of detection is provided (per lane) for the subject signal phase. This source of detection could consist of one long detector loop at the limit line, or a Type D inductive loop detector that is spaced closely to adjacent Type A loop detectors and they operate together as one long zone of detection near the limit line or a single 6-foot loop located at a known distance upstream of the limit line (and the limit line detection if provided does not act as an extension loop). Passage time is a design parameter for detection designs that include multiple detectors for the purpose of minimizing abrupt termination (i.e. dilemma zone protection). The passage-time value for this application is inherently linked to the detection design and should not be changed from its design value.

Passage time defines the maximum time separation that can occur between vehicle calls without "gapping out" the phase. When only one traffic lane is served during the phase, this maximum time separation equals the Maximum Allowable Headway (MAH) between vehicles. Although the maximum time separation does not equal the maximum allowable headway when several lanes are being served, the term "MAH" is still used and it is understood that the "headway" represents the time interval between calls (and not necessarily the time between vehicles in the same lane).

Figure 2-5 illustrates the relationship between passage time, gap, and maximum allowable headway for a single-lane approach with one detector. This relationship can be used to derive the following equation for computing passage time for presence mode detection. Gap as shown in this figure is the amount of time that the detection zone is unoccupied.

$$PT = MAH - \frac{L_v + L_d}{1.47 v_a}$$ **Equation 2-5**

where,

PT = passage time, s;
MAH = maximum allowable headway, s;
v_a = average approach speed, mph;
L_v = length of vehicle (use 20 ft); and
L_d = length of detection zone, ft.

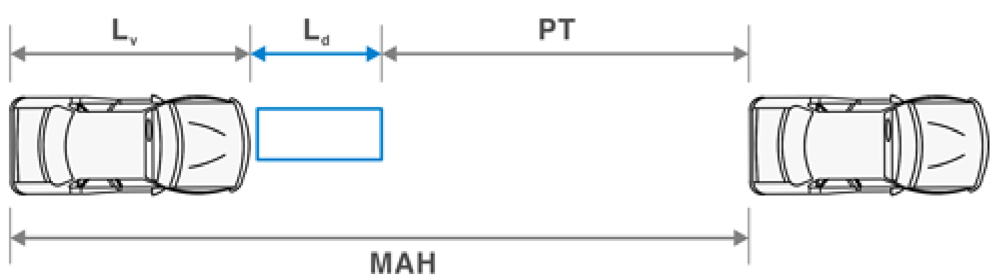

Figure 2-5 – Relationship between Passage Time, Gap and Maximum Allowable Headway

If Equation 2-5 (7) is used with pulse-mode detection, then the length of vehicle L_v and the length of detector L_d equal 0.0 ft, and the passage time is equal to the MAH. The duration of the passage time setting should be based on three goals:

- *Ensure queue clearance.* The passage time should not be so small that the resulting MAH causes the phase to have frequent premature gap-outs (i.e., a gap-out that occurs before the queue is fully served). A premature gap-out will leave a portion of the stopped queue *unserved* and, thereby, lead to increased delays and possible queue spillback. If the queue is extraordinarily long and cannot be accommodated without creating a cycle length that is longer than desirable, this goal may not apply.

- *Satisfy driver expectancy.* The passage time should not be so large that the green is extended unnecessarily after the queue has cleared. Waiting drivers in conflicting phases will become anxious and may come to disrespect the signal indication.
- *Reduce max-out frequency.* The passage time should not be so large that the resulting MAH causes the phase to have frequent max-outs. A long MAH would allow even light traffic volumes to extend the green to max-out. Waiting drivers in higher-volume conflicting phases may be unfairly delayed.

There is a range of passage times within efficient intersection operations. This range extends from about 1 to 4 seconds for presence mode detection, with lower values being more appropriate under higher volume conditions. Values outside this range tend to increase delay. These passage times correspond to MAH values in the range of 2.0 to 4.5 seconds, depending on detection zone length and location.

Based on the previous discussion, the following MAH values are recommended for use with Equation 2-5 to determine passage time:

- Gap reduction not used: MAH = 3.0 s
- Gap reduction used: MAH = 4.0 s

The recommended MAH values may be increased by 0.1 s if the approach is on a steep upgrade and by 1.0 seconds if there is a large percentage of heavy vehicles.

The passage time computed from the recommended MAH values for a range of speeds and detection zone lengths is provided in Table 2-5 for presence mode detection. It is critical that the relationship of passage time to vehicle speed, detector length, and detector location be considered.

Maximum Allowable Headway *(seconds)*	**Detection Zone Length (ft)**	**85th Percentile Approach Speed (mph)**				
		25	**30**	**35**	**40**	**45**
		Passage Time (PT), (seconds)				
3.0	6	2.2	2.3	2.4	2.5	2.6
	15	1.9	2.1	2.2	2.3	2.4
	25	1.6	1.8	2.0	2.1	2.2
	35	1.3	1.6	1.8	1.9	2.1
	45	1.0	1.3	1.6	1.7	1.9
	55	0.7	1.1	1.3	1.6	1.7
	65	0.4	0.8	1.1	1.4	1.5
	75	0.1	0.6	0.9	1.2	1.4
4.0	6	3.2	3.3	3.4	3.5	3.6
	15	2.9	3.1	3.2	3.3	3.4
	25	2.6	2.8	3.0	3.1	3.2
	35	2.3	2.6	2.8	2.9	3.1
	45	2.0	2.3	2.6	2.7	2.9
	55	1.7	2.1	2.3	2.6	2.7
	65	1.4	1.8	2.1	2.4	2.5
	75	1.1	1.6	1.9	2.2	2.4
Note: Average approach speed is computed as 88 percent of the 85th percentile approach speed.						

Table 2-5 – Passage Time Duration for Presence Mode Detection

2.5 VOLUME-DENSITY FEATURES

Volume-density features can be categorized by two main features: gap reduction and variable initial. These features permit the user to provide variable alternatives to the otherwise fixed parameters of passage time (gap reduction) and minimum green (variable initial). Gap reduction provides a way to reduce the allowable gap over time, essentially becoming more aggressive in looking for an opportunity to end the phase. Variable initial provides an opportunity to utilize cycle-by-cycle traffic demand to vary the minimum time provided for a phase. These features increase the efficiency of the cycle with the fluctuations in demand, which can result in lower delay for users at the intersection.

2.5.1 Variable Initial

Variable initial is used in some cases to serve vehicles queued between the limit line and the nearest upstream detector. Variable initial uses detector activity to increase the effective minimum green. Vehicles arriving during the yellow and red intervals will be detected by the upstream detector and can extend the initial period of green by an amount sufficient to allow them to be served. This feature is applicable when there are one or more advance detectors and wide fluctuations in traffic volumes between peak and off-peak hours. Variable initial timing is achieved by programming the following controller parameters: Minimum Green, "Added per Vehicle" and Maximum Initial.

Minimum Green: The Minimum Green parameter represents the least amount of time that a green signal indication will be displayed for a movement.

Added Per Vehicle: This is a value of time (normally between 0.5 and 3.0 seconds) that gets multiplied by the number of vehicles crossing the advance detectors, during the yellow and red intervals of a vehicle phase. This product is stored in a register called the Variable Initial.

Variable Initial: A timing parameter that can replace the Minimum Green to allow a longer queue of traffic to clear the limit line without advance detectors extending the movement during the green interval. The Variable Initial is timed concurrently with the Minimum Green. The Variable Initial time is compared to the Minimum Green; the greater value is used.

Maximum Initial – This is the maximum period of time for which the "Added per Vehicle" can extend the initial green period. The Maximum Initial cannot be less than the Minimum Green (Figure 2-6).

In traffic signal operation, the controller compares the Variable Initial value and the Minimum Green value, and uses the larger of the two values for the initial green period. Their relations is shown in Figure 2-6.

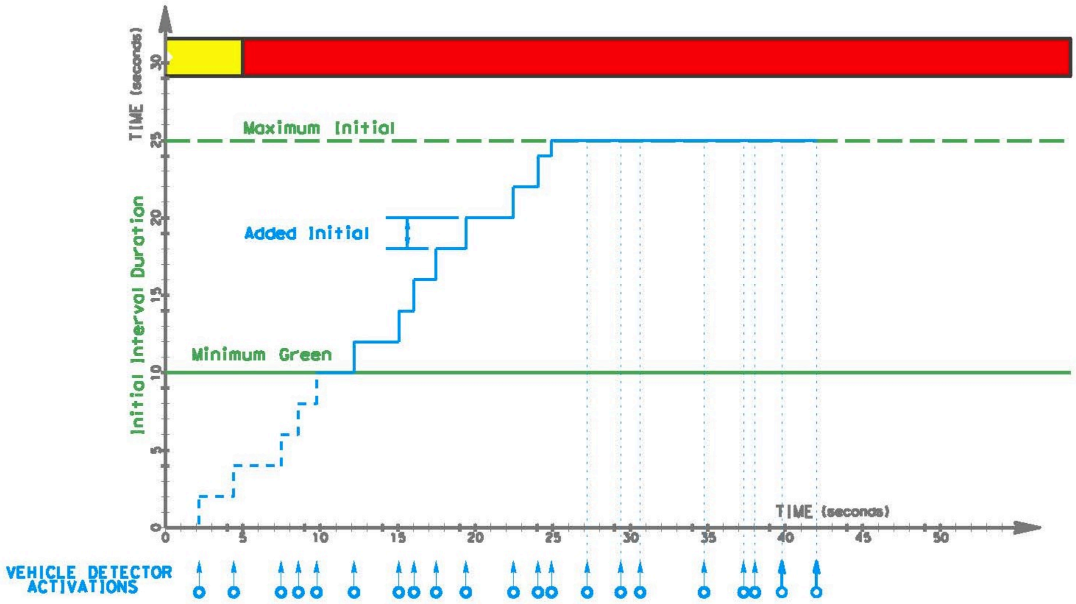

Figure 2-6 – Use of Added Initial to Modify Minimum Green

The top horizontal bar represents Yellow interval and Red interval. The blue dashed lines represent "Added Per Vehicle," during the Minimum Green.

As with other volume-density parameters, there are varying policies that may be employed in determining the values of maximum-initial and "Added Per Vehicle." Generally, the maximum initial setting should be determined using the calculation for minimum green for queue clearance shown in Section 2.3.1.

A common practice for selecting the "Added Per Vehicle" parameter is to set this value at approximately 2.0 seconds per actuation if the phase serves only one traffic lane, 1.5 seconds per actuation if it serves two traffic lanes, and 1.2 seconds per actuation if it serves three or more lanes. However, this is dependent on whether or not each lane has its own input channel in the controller cabinet. Slightly larger values can be used if the approach has a significant upgrade or a significant number of heavy trucks. Bicycle traffic may also warrant higher values depending on the intersection width.

2.5.2 Gap Reduction

The gap reduction feature reduces the passage time to a smaller value while the phase is green. Initially, the gap sought between actuations is the passage time value. Then, after the Minimum Green times out and in the presence of a conflicting vehicle call, the passage timer is reduced to a minimum gap using a gradual reduction over a specified time ("Time to Reduce"). This functionality is achieved by programming the following controller parameters: Minimum Green, Maximum Gap, Minimum Gap, Reduce Every and Reduce By values. Their relationship is shown in Figure 2-6. The "Time to Reduce" is actually accomplished by the settings of "Reduce By" and "Reduce Every" settings in the TSCP and Model 170 programs. This slope is determined by the step rate of these two timing parameters. For instance, if you have the program set to "Reduce By" 0.1 seconds and "Reduce Every" 2 seconds, it would have a "Time to Reduce" slope twice as long as if the program was set to "Reduce By" 0.1 seconds and "Reduce Every" 1 second. Figure 2-7 should show a stepped slope.

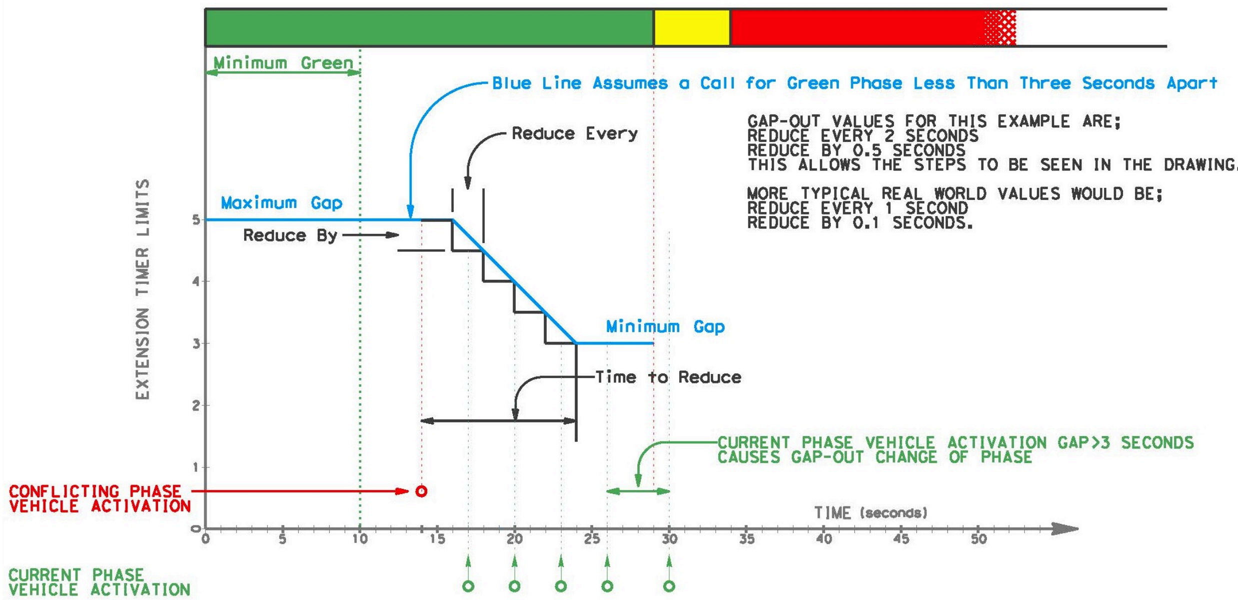

Figure 2-7 – Use of Volume-Density to Change the Extension Time

The Gap Reduction period begins when the phase is green, the Minimum Green time has expired and there is a serviceable call on a conflicting phase. Once the gap reduction period has begun, the extension timer limit is reduced in a linear manner until the time-to-reduce period expires. Thereafter, the extension timer limit is set equal to the minimum-gap parameter. Like the Passage Time, this parameter extends the green interval by up to the Minimum Gap time for each vehicle actuation up to the Maximum Green. It begins timing when the vehicle actuation is removed. This extension period is subject to termination by the Maximum Green or a Force Off.

The gap-reduction feature may be desirable when the phase volume is high and it is difficult to differentiate between the end of the initial queue and of the subsequent arrival of randomly formed platoons. This feature allows the user to specify a higher passage time at the beginning of a phase and then incrementally reduce the passage time as a phase gets longer and the delay to conflicting movements increases.

With gap reduction, a MAH of 2.0 seconds is recommended for use with Equation 2-5 to determine the minimum gap. This MAH may be increased by 0.1 second if the approach is on a steep upgrade, and by 1.0 second if there is a large percentage of heavy vehicles.

If Equation 2-3 is used with pulse-mode detection, then the length of vehicle L_v and the length of detector L_d equal 0.0 ft, and the minimum gap is equal to the MAH.

A sample of minimum gaps were computed and shown in Table 2-6 using the recommended MAH values for a range of speeds and detection zone lengths provided for presence mode detection.

Maximum Allowable Headway (sec)	Detection Zone Length, (ft)	85th Percentile Approach Speed (mph)				
		25	30	35	40	45
		Minimum Gap (sec)				
2.0	6	1.2	1.3	1.4	1.5	1.6
	15	0.9	1.1	1.2	1.3	1.4
	25	0.6	0.8	1.0	1.1	1.2
	35	0.3	0.6	0.8	0.9	1.1
	45	0.0	0.3	0.6	0.7	0.9
	55	0.0	0.1	0.3	0.6	0.7
	65	0.0	0.0	0.1	0.4	0.5
	75	0.0	0.0	0.0	0.2	0.4
Note: Average approach speed is computed as 88 percent of the 85th percentile approach speed.						

Table 2-6 – Minimum Gap Duration for Presence Mode Detection

A number of different policies may be employed in determining the value of time-to-reduce setting. An example policy is to make time-to-reduce setting equal to half the difference between the maximum and minimum green intervals. This guidance is illustrated in Table 2-7.

Minimum Green Interval (sec.)	Maximum Green (sec.)										
	20	25	30	35	40	45	50	55	60	65	75
	Time To Reduce (sec.)										
5	8	10	13	15	18	20	23	25	28	30	33
10	5	8	10	13	15	18	20	23	25	28	30
15	N/A	5	8	10	13	15	18	20	23	25	28
20	N/A	N/A	5	8	10	13	15	18	20	23	25

Table 2-7 – Gap Reduction Parameter Values

2.6 DETECTION CONFIGURATION AND PARAMETERS

The Model 2070 and Model 170 traffic signal controllers have several settings that can be used to modify the vehicle detectors. Its implementation in the controller unit has streamlined the signal timing process and can duplicate functionality that may be in the detection unit.

The parameters discussed in this section include: delay, extend, call, and queue. The latter two parameters are actually elements of the detector options in NTCIP Document 1202.

2.6.1 Delay

A delay parameter can be used to postpone a vehicle actuation for a detector input on a phase. By using a delay timer, an actuation is not made available until the delay timer expires and the actuation channel input is still active (i.e., the detection zone is still occupied). Once an actuation is made available to the controller, it is continued for as long as the channel input is active. Application of the delay timer is illustrated in Figure 2-8.

1. Vehicle enters detection zone, delay timer begins timing, call status in controller remains inactive.
2. Vehicle departs detection zone, delay timer resets, call status in controller remains inactive.
3. Delay timer reaches zero, call status in controller becomes active.
4. Vehicle receives green.

Figure 2-8 – Application of Delay Timer

Common applications of a delay parameter on detection include the following:

- Delay is sometimes used with limit line, presence mode detection for turn movements from exclusive lanes. For right-turn-lane detection, delay should be considered when the capacity for right-turn-on-red (RTOR) exceeds the right-turn volume or a conflicting movement is on recall. If RTOR capacity is limited, then delay may only serve to degrade intersection efficiency by further delaying right-turn vehicles. The delay setting should range from 8 to 12 seconds, with the larger values used for higher crossroad volumes.
- If the left-turn movement is protected-permissive and the opposing through phase is on minimum recall, then delay should be considered for the detection in the left turn lane. The delay setting should range from 3 to 7 seconds, with the larger values used for higher opposing volumes. In this case, a minimum recall should also be placed on the adjacent through phase to ensure that a lack of demand on the adjacent through phase does not result in the left-turn movement receiving neither a permissive nor a protected left-turn indication.
- Delay may also be used to prevent an erroneous call from being registered in the controller if vehicles tend to traverse over another phase's detector zone. For example, left-turning vehicles often cut across the perpendicular left-turn lane at the end of their turning movement. A detector delay coupled with non-locking memory would prevent a call from being placed for the unoccupied detector.
- Delay also may be used on advance detectors to prevent unnecessary calls to service. For example, if there is no present call on mainline traffic (Phase 2 & 6) and off-ramp traffic from a freeway crosses the advance detectors just before a mainline platoon crosses their advance detector, the signal will terminate mainline and serve the off-ramp traffic (likely a single vehicle). However, the off-ramp traffic may have been turning right so would not have needed a service, thus mainline traffic was stopped unnecessarily. This is why including a delay is relevant.

2.6.2 Extend

The extend parameter is used to increase the duration of the actuation for a detector or phase. The extend timer begins the instant the actuation channel input is inactive. Thus, an actuation that is one second in duration at the channel input can be extended to three seconds, if the extend parameter is set to two seconds. This process is illustrated in Figure 2-9.

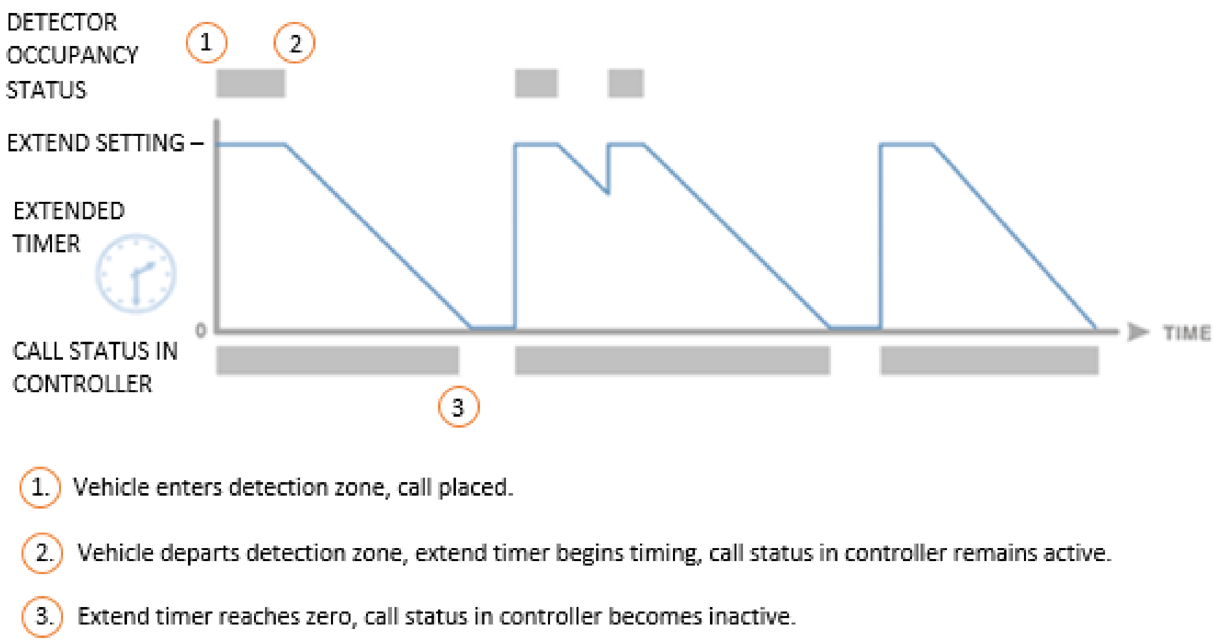

Figure 2-9 – Application of Extend Timer

Extend is typically used with detection designs that combine multiple advance detectors and limit line detection for phase termination of high-speed intersection approaches. Extend is used with specific upstream detectors to supplement the passage-time parameter, to ensure that these detectors can extend the green interval by an amount of time equal to the sum of the passage time and call extension. The magnitude of the extension interval is dependent on the passage time, approach speed, and the distance between the subject detector and the next downstream detector. Typical values range from 0.1 to 2.0 seconds.

The objective when used at high-speed approaches is to extend the green interval to ensure that a vehicle approaching the intersection has just enough time to reach the next downstream detector and place a new call for green extension. The procedure for identifying when call extension is needed and computing the amount of the extension time is specific to the detection design.

2.6.3 Carryover

Carryover is a term commonly used for the Extend setting in controller manuals. It is another way to describe the time provided for a vehicle to traverse from one detector to the next.

2.6.4 Call

The call parameter is used to allow actuations to be passed to the controller for the assigned phase when it is not timing a green interval. Actuations received during the green interval are ignored. The call parameter is sometimes used with detection designs that include one or more advance detectors and limit line detection. With this design, the call-only parameter is used with the limit line detectors to ignore the actuations these detectors receive during the green interval. The advance detectors are used to ensure safer and efficient service during the green interval. When an appropriate detection design is combined with this parameter, intersection efficiency can be improved by eliminating unnecessary green extension by the limit line detection.

2.6.5 Limited or Type 3 Disconnect to Serve Queue

A detector can be configured as a queue service detector to effectively extend the green interval until the queue is served, at which time it is deactivated until the start of the next conflicting phase. This functionality is offered as a parameter in Caltrans controllers. In the Model 2070 controller, the TSCP program feature is referred to as "limited" and in the Model 170 controller, the C8 program feature is referred to as "Type 3 Disconnect."

This functionality is sometimes used with detection designs that include one or more advance detectors and limit line detection. With this design, the queue service functionality is used to allow limit line detection during the early portion of the green interval until the queue has cleared. The limit line detectors are then deactivated and the advance detectors are used to ensure phase termination. When combined with an appropriate detection design, this functionality can improve intersection efficiency by eliminating unnecessary green extension by the limit line detection.

2.7 GUIDELINES FOR TIME-BASE CONTROLS

Caltrans controllers provide a means to apply signal timing parameters by time of day; typically these include maximum green, and minimum recall on a time-of-day basis. The approach specified by NTCIP 1202 for activating phase and ring controls invokes a timing pattern that can be selected on a time-of-day basis. In NTCIP protocol, a timing pattern consists of a cycle length, offset, set of minimum green and maximum green values, force off (determined by splits in some cases), and phase sequence. It also includes specification of phase parameters for minimum or maximum vehicle recall, or pedestrian recall. The most common time-based controls are time-of-day coordination, maximum green 2 (Max 2), and minimum recall. This will be further described in Chapter 3.

Minimum recall is used primarily on the major-road phase(s) of a fully-actuated, non-coordinated intersection. If the volume on the minor road is low only during certain times of the day, minimum recall for the major-road phases could be activated during these time periods.

Chapter 3
COORDINATION

3.0 COORDINATION

This chapter presents the concept of coordination of traffic signals. Coordination is a tool to provide the ability to synchronize multiple intersections to enhance the operation of one or more directional movements in a system. Examples include arterial streets, downtown networks, and closely spaced intersections such as diamond interchanges. This chapter identifies coordination concepts using examples from research and practice. It contains four sections. The first section provides an overview of coordination including a summary of objectives, the fundamental concepts, and expectations of coordination timing. The second section describes the concepts for coordination, its effect on time allocation, implementation issues, and time-space diagrams. The third section provides guidelines for developing coordination timing plans, and the fourth section describes complexities associated with coordinated operations. The intent of this chapter is to provide necessary background for the development of timing strategies.

3.1 TERMINOLOGY

This section identifies and describes basic terminology used within this chapter. Additional terms can be found in the Glossary section in Appendix L.

Coordination - The ability to synchronize multiple intersections to enhance the operation of one or more directional movements by decreasing the number of stops, delay, or both, experienced in a system.

Double Cycle – A multiplier that doubles the cycle length, at a specific intersection, which serves the non-coordinated phases once every other cycle of the Master cycle. Non-coordinated phases get served every other cycle. Coordinated phases get served every cycle.

Early Return to Green - A term used to describe the servicing of a coordinated phase in advance of its programmed begin time as a result of unused time from non-coordinated phases.

Force-off - A point within a cycle where a phase must end regardless of continued demand. These points in a coordinated cycle ensure that the coordinated phases are provided a minimum amount of green time.

Fixed Force-off – A force-off mode where force-off points cannot move. Under this mode, non-coordinated phases can use unused time of previous phases.

Green Factor – The amount of green time allocated to non-coordinated phase(s).

Half Cycle - A cycle length that allows phases to be serviced twice as often as the other intersections in the coordinated system. Both non-coordinated and coordinated phases get served twice every cycle.

Master Clock - The background timing mechanism within the controller logic to which each controller is referenced during coordinated operations.

Offset - The time relationship between coordinated phases defined reference point and a defined master reference (master clock or sync pulse). See Figure 3-8.

Offset Reference Point (Coordination Point) - The defined point that creates an association between the local clock at a given signalized intersection and the master clock.

Permissive Period - A period of time after the yield point where a call on a non-coordinated phase can be serviced without delaying the start of the coordinated phase. This is a calculated value by the controller program (TSCP (Traffic Signal Controller Program) or C8).

Split – In coordination, phase splits are calculated values by the controller program (TSCP or C8). These values are the sum of the phase green factor, yellow and red timing. Pedestrian timing should be considered when determining the green factor. The phase may not use the entire split allocated within the cycle. The coordinated phase is slightly different in this regard, in that it will always get its split time plus any unused time from the other phases.

Time-Space Diagram - A chart that plots the location of signalized intersections along the vertical axis and the signal timing along the horizontal axis. This is a visual tool that illustrates coordination relationships between intersections.

Yield Point - A point in a coordinated signal operation that defines where the controller decides to terminate the coordinated phase.

3.2 PRINCIPLES OF COORDINATED OPERATION

Establishing coordination is easiest to justify when the intersections are in close proximity and there is a large amount of traffic on the coordinated street. The CA MUTCD provides guidance that coordination should be considered where traffic signals are within 0.5 mile (2,640 feet) of each other along an arterial.

3.2.1 Coordination Objectives

Coordination is largely a strategic approach to synchronize signals together to meet specific objectives. While there are numerous objectives for the coordination of traffic signals, a common objective is stated succinctly in the National Report Card.

As stated in the U.S Department of Transportation, Federal Highway Administration (FHWA), Office of Operations' Traffic Signal Timing Manual,

> The intent of coordinating traffic signals is to provide smooth flow of traffic along streets and highways in order to reduce travel times, stops and delay. A well-timed, coordinated system permits continuous movement along an arterial or throughout a network of major streets with minimum stops and delays, which, reduces fuel consumption and improves air quality.

Figure 3-1 illustrates the concept of moving vehicles through a system of traffic signals using a graphical representation known as a time-space diagram.

The time-space diagram is a chart that plots ideal vehicle platoon trajectories through a series of signalized intersections. The locations of intersections are shown on the distance axis, and vehicles travel in both directions (in a two-way street). Signal timing sequence and splits for each signalized intersection are plotted along the time axis. It is very important these plots are to scale so that a consistency between units can be maintained. The time axis illustrates what motorists on the arterial will experience as they travel down the street. Left turns are shown as angled lines that either are operated with a concurrent green for the same direction or not (see Figure 3-1).

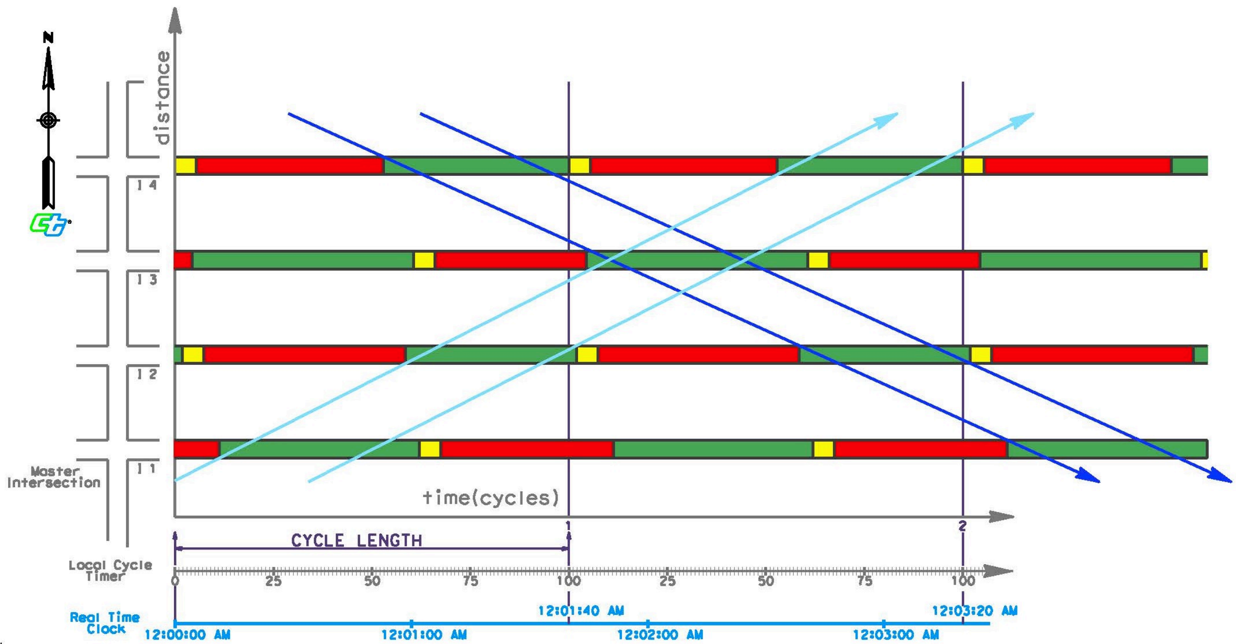

Figure 3-1 – Time-Space Diagram of a Coordinated Timing Plan

The result of signal coordination is illustrated on the time-space diagram above. The start and end of green time show the potential trajectories for vehicles on the street. It is these trajectories that determine the performance of the coordination plan. Performance measures include stops, vehicle delay, and arterial travel time; they can also include other measures such as changes in delay to transit vehicles or existence of spill back queuing between closely spaced intersections. While the effectiveness of the coordination timing plan is directly related to the performance measures, it is also determined by the user experience and their perception of signal displays. Successful coordinated signal timing plans are usually characterized by both the users and the measure:

- Maximizing traffic volume throughput on state highways;
- A neighborhood may seek reduced traffic and lower speeds;
- Downtown merchants may favor pedestrian traffic over vehicular traffic; and
- A transit agency may be concerned with signal delay to buses and/or light rail vehicles.

There are tools available to use to quantify the performance of a coordinated system, using the time-space diagram. These tools enable the signal operations engineer to record measured improvements, such as decrease in traffic stops (delays) and travel time. Subsequent performance measures of decreased carbon emissions, greenhouse gas, time savings and fuel costs can be reported.

3.2.2 When to Use Coordination

Establishing coordination is easiest to justify when the intersections are in close proximity to one another and when traffic volumes between the adjacent intersections are large. The need for coordination can be identified through observation of traffic flow arriving from upstream intersections. If arriving traffic includes platoons that have been formed by the release of vehicles from the upstream intersection, coordination should be implemented. If vehicle arrivals tend to be random and are unrelated to the upstream intersection operation, then coordination may provide little benefit to the system operation.

When intersections are close together (i.e. within half mile of each other) it may be advantageous to coordinate them. When the distance between intersections are greater than half a mile, the traffic volumes and potential for platoons should be reviewed to determine if coordination would be beneficial to the system operations. In both cases, traffic conditions should be considered.

Communications Infrastructure
In order to coordinate signalized intersections, it is critical that the traffic controller be able to communicate with another traffic controller or central system. This may be done in several ways: through a dedicated broadband wireless infrastructure, fiber optic infrastructure, or hardwired interconnect cables. The ability to communicate with a traffic signal controller allows coordination as well as the ability to collect valuable data for performance measurement.

3.2.3 Fundamentals of Coordination

With the Model 2070 and Model 170 signal controllers, coordination is accomplished by adding a layer of logic (that is, coordination logic compliments some basic features such as when a phase can begin or end) to the basic actuated logic used for isolated signal timing operations (discussed in Chapter 2). In previous chapters, the details of the controller settings were limited to those applied at isolated or independent intersections (maximum green, pedestrian timing, etc.). Signal coordination establishes an additional set of time constraints among a series of signalized intersections by establishing a background cycle length. This cycle length includes a series of timers for each phase and requires the designation of one phase as the coordination phase. This designation identifies the phase that will be the last one (or the first, depending on your reference point) to receive its allocation of green time. This coordinated phase is distinguished from other actuated phases because it always receives a minimum amount of assigned green time. While it is possible to have a portion of the coordinated phase be actuated, the important point is that there is a non-actuated interval for the designated coordinated phase(s) that is “guaranteed” every cycle for the purposes of coordination.

Figure 3-2 shows the intersection of two one-way streets, which results in a simple intersection with just two phases. It also shows the relationship between a phase diagram with movements assigned to the indications at the intersection, a ring-and-barrier diagram that illustrates the logic used in the controller for phase sequence and to establish the relationship between conflicting and complimentary movements, and the time-space diagram which would be used to display the relationship between this intersection and others along an arterial or within a street network (previously shown in Figure 3-1). This intersection has only one ring within the ring-and-barrier diagram and a simple time-space diagram. Phase 2 is identified as the coordinated phase. This intersection represents the most basic configuration for a signalized intersection.

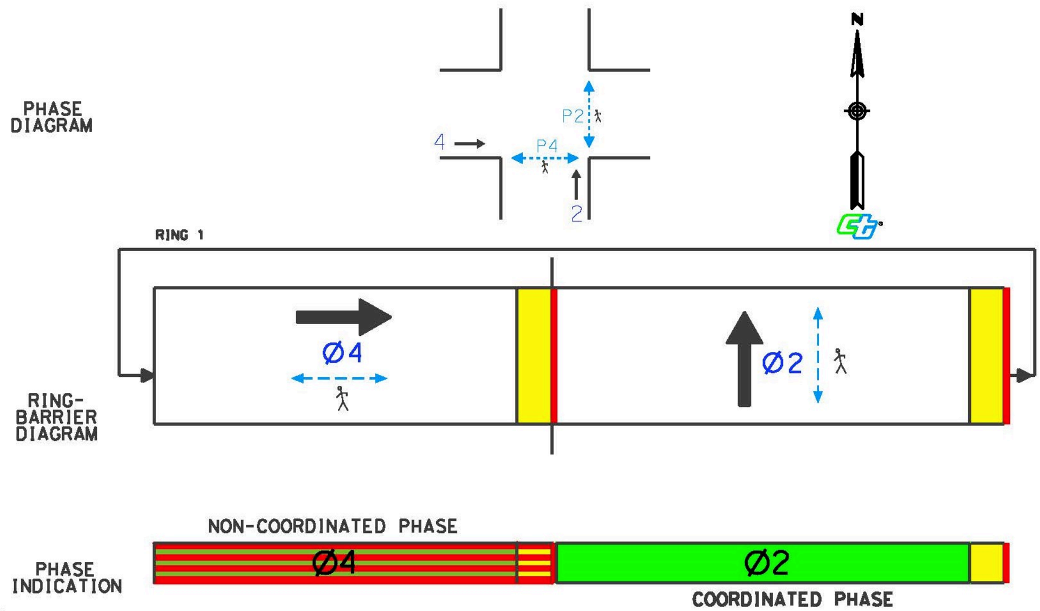

Figure 3-2 – Phase and Ring-and-Barrier Diagram Intersection of Two One-Way Streets

In an actuated-coordinated system, the first event in the cycle is one of the non-coordinated phases, which would serve the demand on that phase (in this case, just phase 4). If demand is less than the time allocated to that phase, it would gap out, and the remaining time for that movement would be reallocated to the coordinated phase (phase 2).

The ring-and-barrier diagram for a full-movement four-legged intersection has 2 rings, where Ring 1 consists of a sequence of phases and Ring 2 consists of the concurrent phases for the intersection, while the barrier separates intersecting movements (east-west and north-south). Figure 3-3 illustrates Ring 1 of the diagram and provides a graphical example of the phase indications for left-turn phasing. In this example, phase 2 is the coordinated movement, which means that phases 3, 4, and 1 all have an opportunity to use portions of their allotted time before phase 2 begins. If any time allotted for phases 3, 4, or 1 is unused, phase 2 will start before the normal start time (commonly referred to as *early return to green*) and then remains green until its end point. The following sections of this chapter explain in more detail the nuances between different settings that affect the coordination relationship. Essentially, this is an additional layer of constraint (coordination logic) that can be applied to signalized intersections to improve the operation of a system of traffic signals.

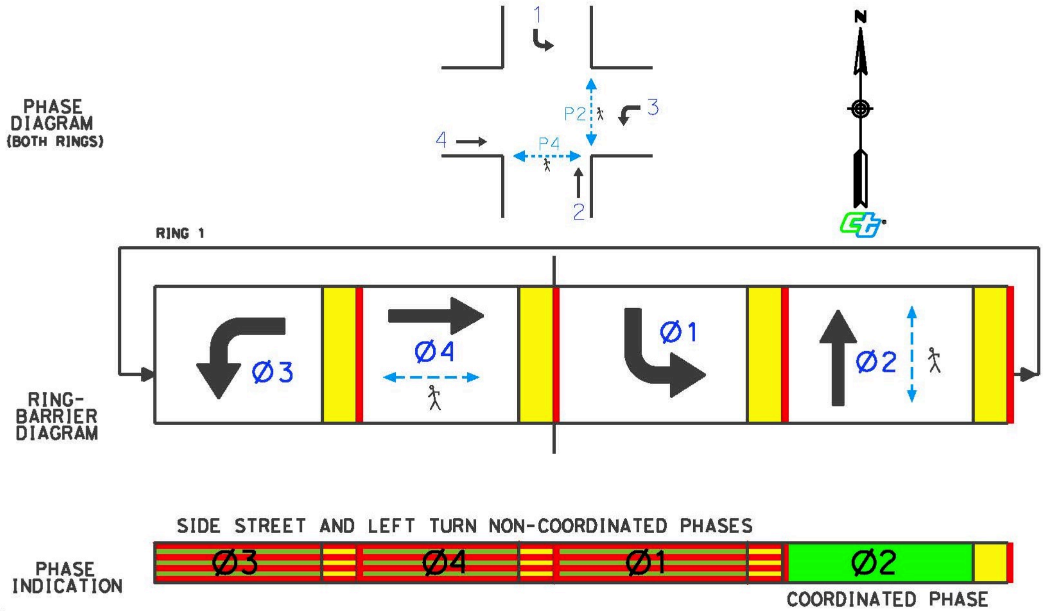

Figure 3-3 – Example of Coordination Logic within One Ring

Figure 3-4 shows an example of the relationship between two rings (rings 1 and 2) at a typical 8-phase intersection. As seen in the figure, phase 5 uses less time than phase 1. As a result, phases 1 and 6 will time concurrently before phase 1 ends and phase 2 begins. In the time-space diagram labeled "Coordinated Phase Indication," this concurrent operation of phases 1 and 6 is indicated by downward sloping left-to-right red bars, which indicate that the southbound movement is able to move through the intersection, but not the northbound movement. Additional examples of this are shown in section 3.2.4.

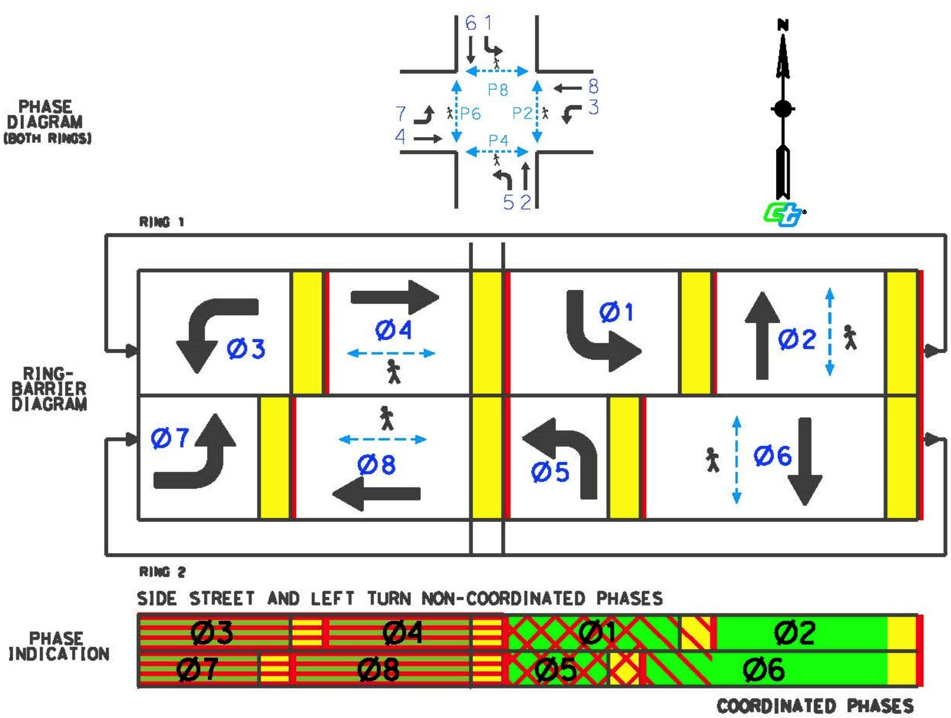

Figure 3-4 – Example Coordination using Two Rings

The effects of coordination at an individual intersection depend on the timing plan and the operations of adjacent intersections. The coordination may be beneficial to a vehicle traveling between the two intersections; however it may negatively impact a pedestrian or vehicles crossing the main street, waiting for the signal to provide the right of way. Many of the complaints from citizens related to the use of coordination address the restrictions placed that inhibits responsiveness to demand. The last section of this chapter describes the complexity of coordination in greater detail. The restriction placed on responsiveness will be further exacerbated if the cycle length selected is unnecessarily long or the coordination plan is operating when traffic volumes are lower than typical (such as holidays that fall on a weekday).

3.2.4 Summary

Coordination applications can range from two signals controlling a diamond interchange, to dozens of signals controlling a combination of actuated and fixed time controllers controlling an arterial system that bisects a grid network. Coordination strategists should refer to the Highway Capacity Manual (HCM), the recommended maximum half mile spacing between traffic signals, operational needs and engineering judgment. Performance measures should be used to document improvements, results from re-timing and to optimize operations. Intersection performance measures include delay, queue length, split failures, etc. Evaluation methods include the number of stops reduced for the main street through movements or queue management. The objectives are described in the Traffic Signal Operations Business Plan (http://traffic.onramp.dot.ca.gov/traffic-signals).

Designating the traffic movement with the greatest peak hour demand as the coordinated phase is the most common practice. The coordination logic provides unused green time for the coordinated phase especially when demand for the other movements is low, which can result in fewer stops for the traffic movements with greatest demand. This is most typically the major street through movement.

Performance measures include increased through movement, reduced delay, reduced travel times, lower greenhouse gas emissions, lower fuel consumption, and maximized bandwidth, travel speed, number of stops, pedestrian delay, transit efficiency, and overall intersection delay. The HCM quantifies some of these performance measures. This chapter presents the concepts needed to operate a signal system. The effectiveness of the signal system performance includes how well a traffic signal is timed and coordinated (where appropriate), frequency of pedestrian and bicycle traffic, and detector health. In cases of public approval, the number of complaints or phone calls is also used as a performance measure.

3.3 COORDINATION MECHANICS

Three fundamental parameters distinguish a coordinated signal system: cycle length, offset and split. These settings are necessary inputs for coordination. Figure 3-6 shows the cycle length and set of splits for an intersection, along with the offset and the relationship to the master clock. There are several ways these inputs can be interpreted by the controller and thus a description of how the inputs are used to develop the relationship between the various intersections is provided here.

3.3.1 Cycle Length

Cycle length defines the time required for a complete sequence of indications. Cycle lengths must be the same for all intersections in the coordination plan to maintain a consistent time based relationship. Exceptions would be an intersection that “half cycles,” serving the phases twice as often as the other intersections in the system or “double cycles” serving the phases once for two cycles of the master clock. The cycle length is measured from the beginning of yellow, of the first coordinated phase. Coordination occurs most commonly along an arterial at an interchange or between at least two signals. Professionals have determined cycle length through a variety of ways.

The guidelines section of this chapter further discusses how to establish the cycle length for a coordinated timing plan.

3.3.2 Splits

Within a cycle, splits are the portion of time allocated to each phase at an intersection. These are calculated based on the intersection phasing and expected demand. Splits can be expressed either in percentages of the cycle or in seconds. Split percentages typically include the yellow and all-red associated with the phase; as a result, the green percentage is less than total split for a phase. For implementation in a signal controller, the sum of the phase splits must be equal to (or less than) the cycle length, if measured in seconds (or 100 percent, if measured as a percent). In traditional coordination logic, the splits for the non-coordinated phases define the minimum amount of green for the coordinated phases.

The measured split for a phase consists of its green time, yellow change, and red clearance times. The cycle length is the sum of time for the complete sequence of indications. The observed split may be longer than the calculated split because of an abbreviated or skipped split for late vehicle arrival or for early release to green. The observed split may also be shorter than the calculated split due to low vehicle demand. In an actuated-coordinated system, the cycle length must be measured from a defined observable point, such as the beginning of the coordinated phase yellow (same point as the end of the coordinated phase green). Measuring the cycle length from the observed start of green at an actuated coordinated intersection will result in erroneous results because of the early release to green that can occur.

3.3.3 Green Factor

The green factor is the maximum amount of time allocated to non-coordinated phases. Splits are calculated based on the green factor and the yellow and red timing. Note that if the sum of minimum and maximum green is not sufficiently long, it will result in the phase not reaching the calculated split value for the phase in the absence of a pedestrian call.

Typically, the green factor provides enough time to satisfy the pedestrian requirements. However, there may be an operational need to have green factors shorter than the pedestrian timing would require. The “WALK 2” feature in TSCP (for the Model 2070 controller) provides an option to exclude pedestrian timing from the split calculations. However, this flexibility comes at the price of potentially losing coordination if the controller does not return to the coordinated phase at its assigned time. Losing coordination under light traffic or only very occasionally due to pedestrian calls may be an acceptable option.

3.3.4 Force-Offs

Force-offs provide an alternate way to control the phase splits. The force-offs are points where non-coordinated phases must end even if there is continued demand. The use of force-offs overlays a constraint on all non-coordinated phases to ensure that the coordinated phase will receive a minimum amount of time for each cycle. Note that if the sum of minimum and maximum green is not sufficiently long, it will result in the phase not reaching the force off point for the phase in the absence of a pedestrian call.

Typically, the force-offs provide enough time to satisfy the pedestrian requirements. However, if the engineer wants some flexibility, the force-off may be shorter than the pedestrian timing requirements.

The fixed force-off maintains the phase's force-off point within the cycle. If a previous non-coordinated phase ends its split early, any following phase may use the extra time up to its force-off point. This is beneficial if there are fluctuations in traffic demand and a phase needs more green time. It should be noted that the phase directly after the coordinated phase will never have an opportunity to receive more than its split time because the preceding coordinated phase has a fixed Force-off point. See section 3.3.5 regarding Yield Point.

Floating force-offs are limited to the duration of the splits that were programmed into the controller. The force-off maintains the non-coordinated maximum times for each non-coordinated phase in isolation of one another. Floating force-offs are more restrictive for the non-coordinated phases. If a phase does not use all of the allocated time, then all extra time is always given to the coordinated phase. This is illustrated in Figure 3-5. Caltrans' TSCP does not currently provide floating force-offs.

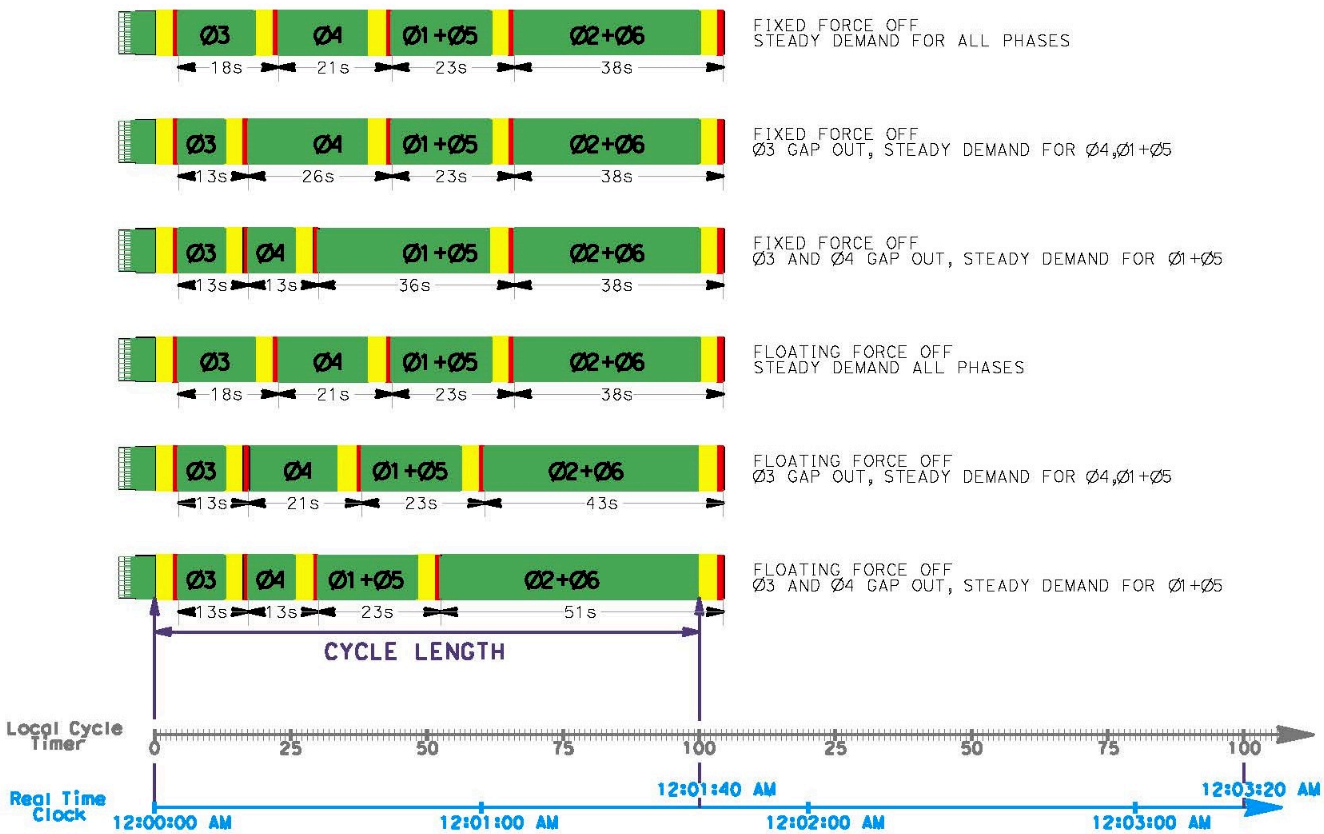

Figure 3-5 – Fixed and Floating Force-offs

3.3.5 Yield Point

The yield point is the time in the coordinated cycle where the controller makes the decision to terminate the coordinated phase. The first, or fixed, yield point is at the beginning of a new cycle (in Caltrans programs, this is at the beginning of yellow for the first coordinated phase). If there are calls to serve non-coordinated phases prior to the fixed yield point, the controller will terminate the coordinated phase at the yield point by starting its yellow clearance interval. If there are no calls to serve a non-coordinated phase, the controller will continue serving green to the coordinated phase. See Figure 3-6.

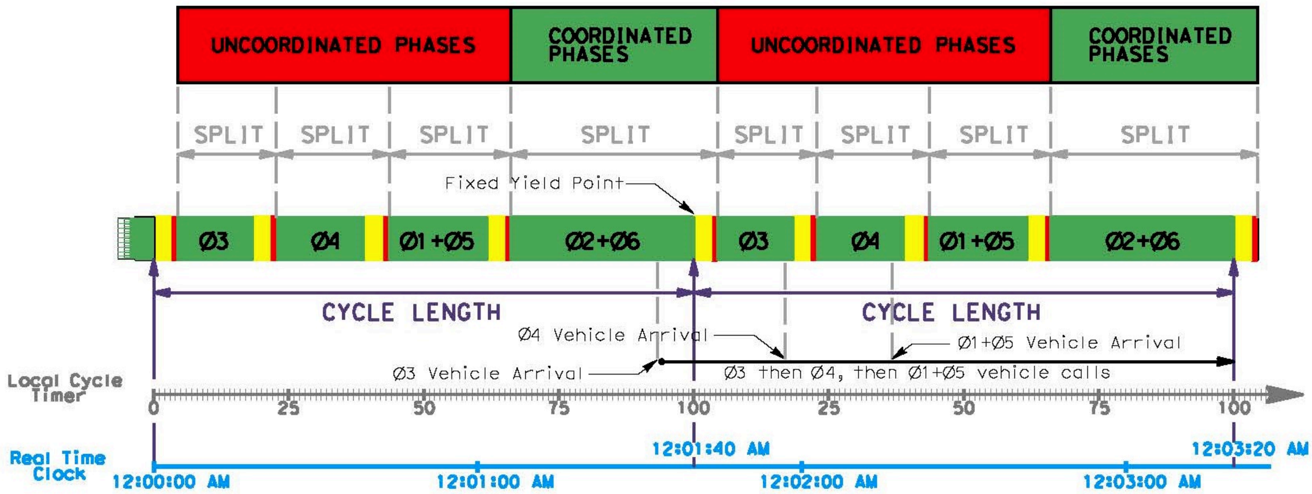

Figure 3-6 – Cycle Length and Split

If a call to serve a non-coordinated phase is placed after the fixed yield point, the controller program calculates and determines if it has enough time left in the cycle to serve that phase before its force-off point. If so, it will terminate the coordinated phase by starting its yellow clearance interval; this is called a *floating yield point*. If the controller program determines there is inadequate time to serve the calling phase, then it will again remain serving the coordinated phase until the next serviceable non-coordinated phase places a call or until the next fixed yield point is reached. See Figure 3-6A.

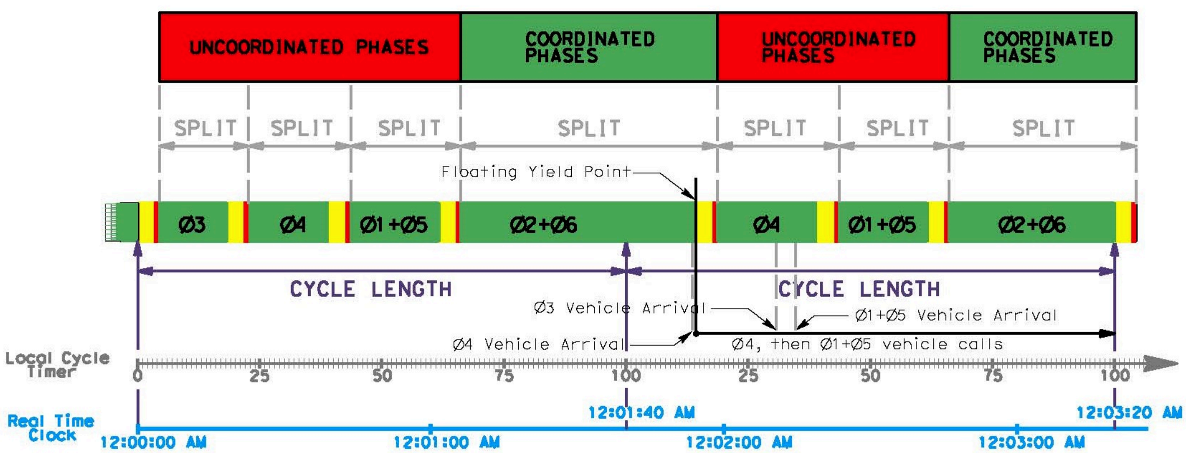

Figure 3-6A – Cycle Length and Split (Ø3 Vehicles Arrive Late)

If a call to serve a non-coordinated phase is granted, and a call to serve for a phase earlier in the sequence is received, the controller will not go back to serve it, regardless of time remaining in the cycle. Additionally, once the controller has returned to the coordinated phase green indication, it will not serve any other calls until the next fixed yield point is reached. This is called *Early Release* for the coordinated phases. See Figure 3-6B.

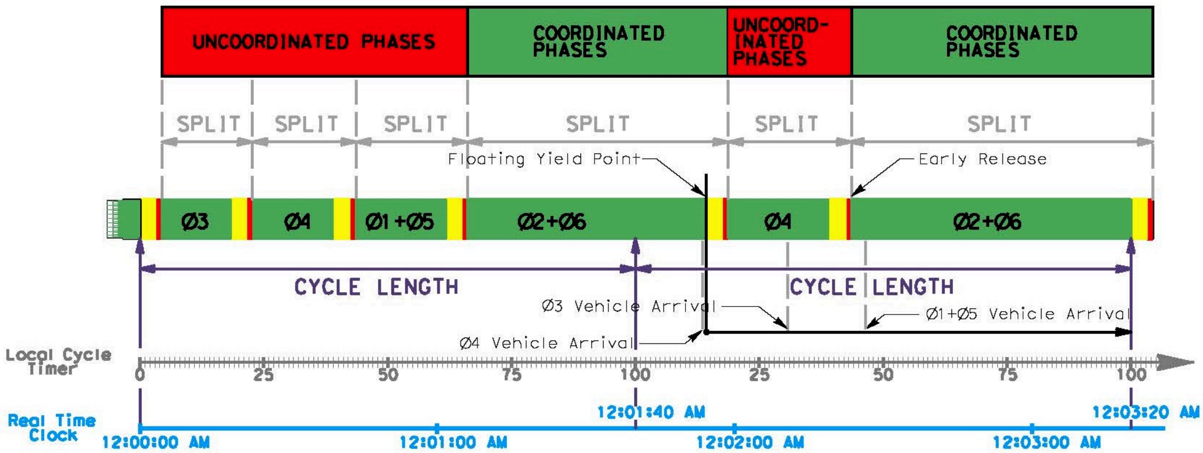

Figure 3-6B – Cycle Length and Split (Ø1, Ø3, and Ø5 Vehicles Arrive Late)

The Model 170 and 2070 controllers reference the offset point from the start of the coordinated phase yellow. Figure 3-6C illustrates the yield point.

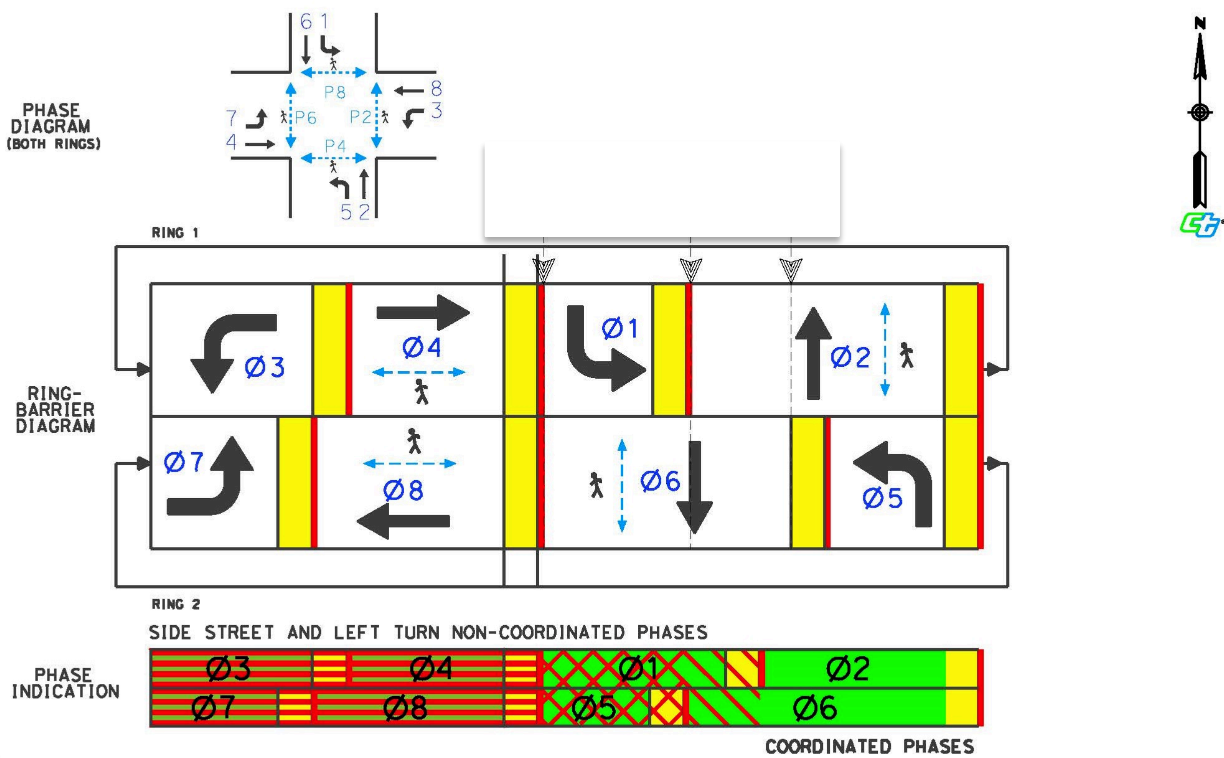

Figure 3-6C – Differences of each Reference Point on a 2-Ring Diagram

3.3.6 Offsets

Figure 3-8 illustrates offsets. For example, if Intersection B has an offset of 20 seconds after Intersection A, one should see Intersection B's yellow twenty seconds after Intersection A's yellow. The figures in this manual use the beginning of the coordinated phase yellow as the offset reference point.

Once the reference point is identified, the offset is defined as the time that elapses between when this reference point occurs at the master cycle timer and when it occurs at the subject intersection. Figure 3-7 illustrates this concept. In this example, the offset reference point is at the start of coordinated phase yellow, and a cycle length of 100 seconds is used for both intersections. The offset of the intersection on the bottom of the figure is zero and thus the local cycle timer matches the master cycle timer. The top intersection is set to an offset of 30 seconds. The coordinated phase begins its yellow at 30 seconds and 130 seconds (12:00:30 AM and 12:02:10 AM), always 30 seconds after the bottom intersection.

When the master cycle timer is referencing midnight, it means the master cycle timer is ZERO at midnight.

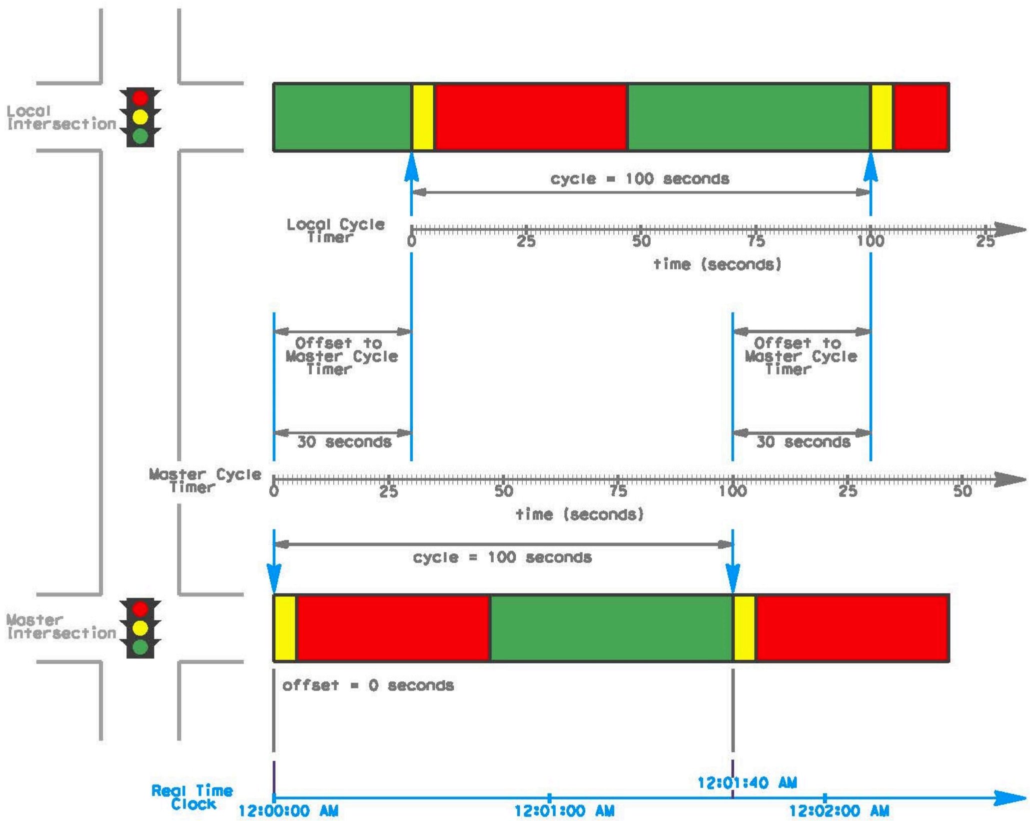

Figure 3-7 – Relationship between the Real Time Clock, the Master Cycle Timer, Local Timer and Offset

It is important that each intersection in a coordinated system have consistent master cycle timers to enable time-of-day plans to have a single reference point. It is also important to understand that when the cycle length is changed, the controller will calculate a new "sync" point based on the cycle length with reference to midnight.

3.3.7 Yellow Yield Coordination

Yellow yield coordination (also known as Y-Coord) is a type of coordination, which has a basic "master-slave" strategy. The master signal runs free and sends a green status to the slave (local controller). When the synchronized phase of the master yields (is not green), the slave uses this input to let traffic go through, that the master is sending. When the **set offset** has timed out, the hold is released on the slave's coordinated phase so it may serve the opposing calls. For more information, see Appendix L.

3.3.8 Other Coordination Settings

There are a number of controller settings that may also be known as coordination modes, which give flexibility to the user. Such coordination modes include "Rest in Walk," "Lag-Phase gap-out," "Omit-phases," "Minimum Recall," and "Maximum Recall." These modes operate in different manners, but each is designed to provide flexibility towards serving the users' needs. Applications of these modes may vary with respect to high pedestrian volumes, transit priority, or leading and lagging left turns.

3.3.9 Pre-timed and Actuated Comparison

In pre-timed systems, typical of downtown closely spaced intersections, the time relationships are "fixed." Today, most pre-timed systems use actuated controllers with phases recalled to their maximum time. In these types of systems, care should be given to the selection of walk times in order to provide a pedestrian friendly environment.

In systems with actuated phases, these relationships are less rigid and more complex. The "coordinator" uses many parameters to define where those time relationships vary and by how much. While the basic timing parameters of coordination are cycle length, splits (force-offs), and offsets; it is very important to understand the complexities of these settings and their effect on coordinated actuated operation. The following section presents the theoretical construct of coordination in an attempt to break down the complexities into the basic fundamentals, which are necessary to implement coordination consistent with the signal timing design undertaken.

3.4 TIME-SPACE DIAGRAM

The time-space diagram is a visual tool for engineers to analyze a coordination strategy and modify timing plans. The main components in a time-space diagram that are inputs include individual intersection locations, cycle length, splits, offset, left turn phasing (on the arterial in the direction of the diagram), and speed limit. The phase lengths may be approximations of their duration; in an actuated system, this changes on a cycle-by-cycle basis. The outputs of a time-space diagram include bandwidth (or vehicle progression opportunities), estimates of vehicle delay, stops, queuing and queue spillback. The following sections describe the components of a time-space diagram and how the diagram can be used to evaluate signal coordination.

3.4.1 Basic Concepts

Time, Distance, Speed, and Delay

A time-space diagram is drawn with time on the horizontal axis and distance (from a reference point) on the vertical axis. The time is relative from the master cycle timer described earlier. Vehicle trajectories are plotted on the time-space diagram and the difference in distance over time (distance divided by time, or change in y divided by x) represents the speed or a sloped line on the diagram. The trajectories always move left to right along with time, and as shown the distance traversed can be either northbound (bottom to top of the diagram) or southbound (top to bottom). Vehicles can have a positive or negative slope that indicates the movements on a street network. Stopped vehicles (no change in distance) are shown as horizontal lines. The assumed speed for coordination on the corridor may be the speed limit, the 85th-percentile speed, or a desired speed. The resulting speeds on the corridor are affected by the presence of other traffic, the signal timing settings, the acceleration and deceleration rates of the vehicles, and other elements within the streetscape. The acceleration rates are especially important considering the departures of standing queues at intersections.

Figure 3-8 shows the one-way street described in Figure 3-2, adjacent to another signalized intersection. In this diagram, the motorist experiences four different conditions in moving from a stop to the progression speed, these are:

1. Vehicles delayed (no change in distance as time moves forward);
2. Driver perception – reaction time at the onset of green;
3. Vehicle acceleration; and
4. Speed of the vehicle (often assumed to be the speed limit or an estimated progression speed)

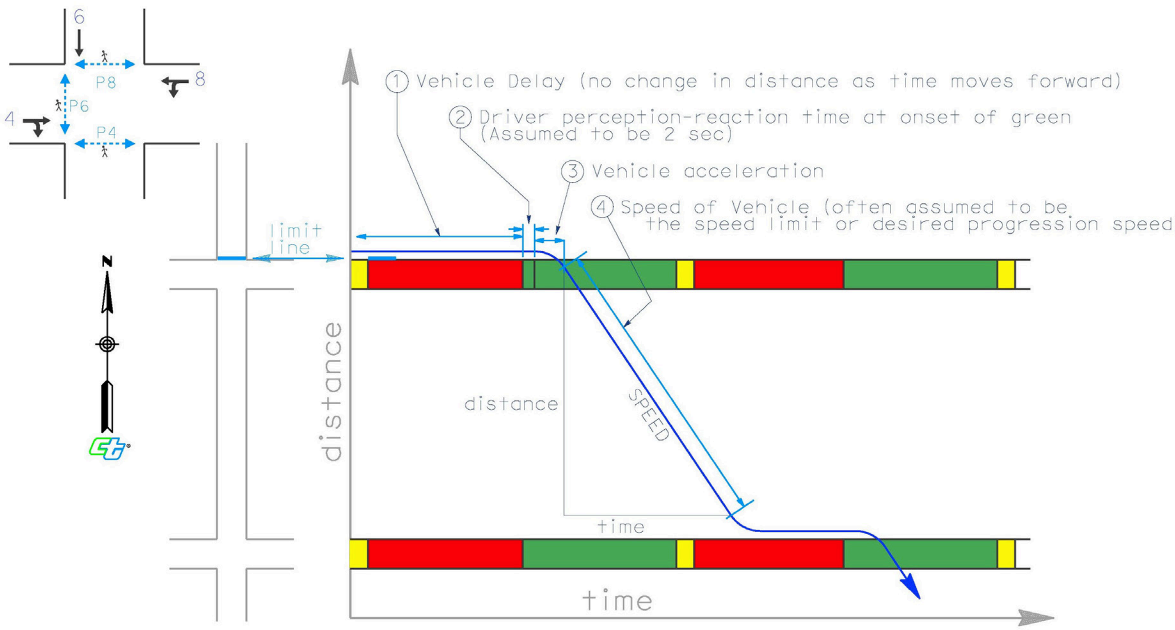

Figure 3-8 – Time-Space Diagram – Basic Concepts

Vehicles on the time-space diagram are shown as trajectories between intersections. Vehicles that turn off of the arterial are considered separately from the through vehicles, depending on the analysis. The vertical distance between two trajectories is the headway between vehicles.

Figure 3-9 shows more detail related to the range of possible trajectories for vehicles at the two-intersection network described. The representation of the one-way street is continued for simplicity. The vehicle trajectories in this figure labeled 1 through 5 are described below:

1. Vehicle delay (as in Figure 3-9);
2. Vehicle from mid-block traveling through the downstream intersection;
3. Vehicle traveling at the progression speed through the intersections; and
4. Vehicle from side street traveling to the downstream intersection; note the vehicle enters the arterial link during the red of the upstream intersection because it is on the side street turning left.

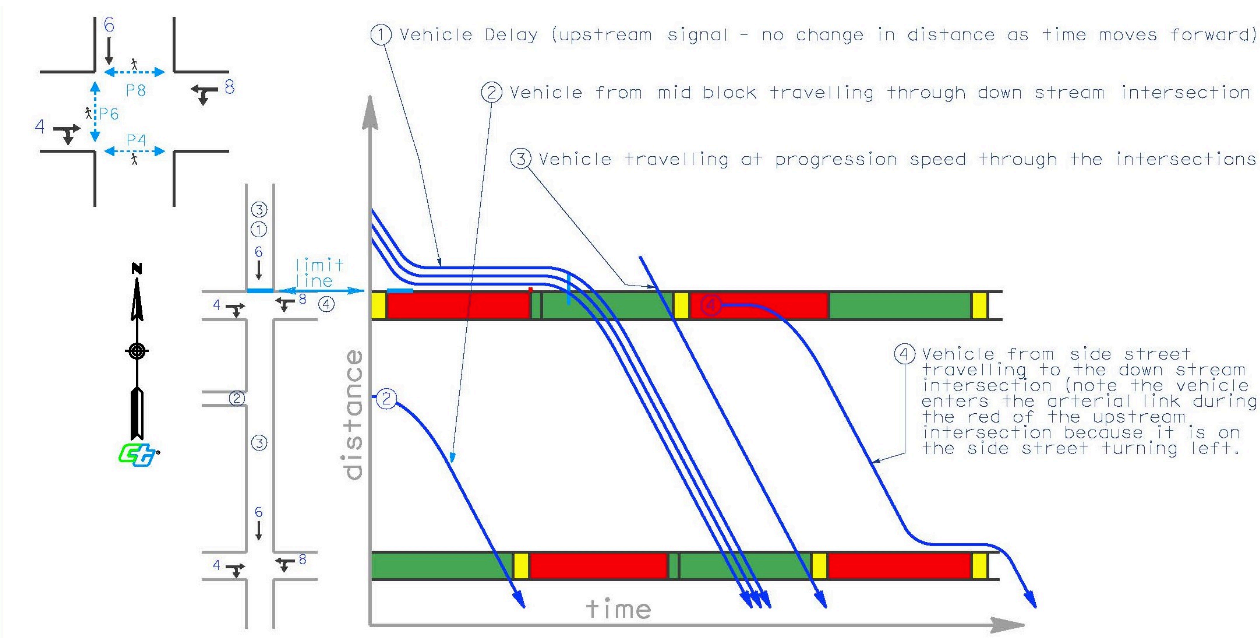

Figure 3-9 – Time-Space Diagram – One-Way Street Operation

The time-space diagram illustrates the signal phasing for the coordinated phases for each of the signalized intersections. Each signal operates with two phases, with phase 2 as the coordinated phase.

Protected left-turn phases and two-way operation on the arterial street complicates the time-space diagram slightly. Figure 3-10 shows the additional phases and two-way operation on the arterial. A 100-second cycle length is assumed. Bandwidth is shown as the shaded area between the intersections.

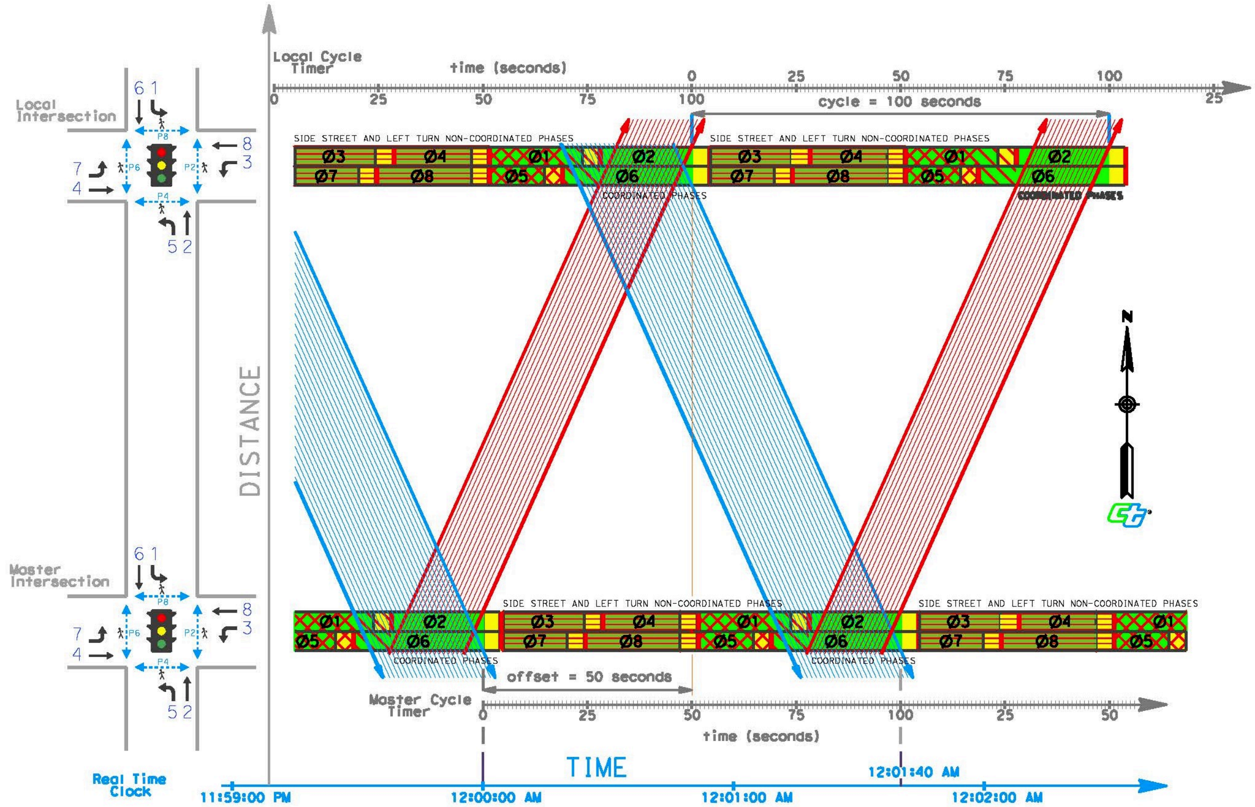

Figure 3-10 – Time-Space Diagram – Two-Way Street Operation

As illustrated in Figure 3-10, the left-turn phases result in less time for the arterial phase. Different types of phasing impact the arterial street in various ways. Accommodating left-turning vehicles at signalized intersections is a balance between intersection capacity and signal delay.

Several traffic flow assumptions are used with time-space diagrams. Time-space diagrams typically consider the through movements on the street in deference to the turning traffic and other modes on the roadway. The time-space diagram does not illustrate traffic flow consequences of the interactions between pedestrians and turning traffic, vehicular interactions at midblock driveways, impedance from shared traffic lanes, and other users of the facility. Careful consideration of these conditions must be taken into account when using the time space diagram.

3.4.2 Left-Turn Phasing

As a phase times, the utilization of that green depends on the demand in close proximity or approaching the limit line. In cases where traffic demand has not arrived, delaying the through movement may be beneficial. A corollary to this is that the traffic platoon from the upstream intersection may reach the downstream intersection too early. In either case, lagging the left turn may be beneficial to improve progression or make more efficient use of the green time.

The time-space diagram focuses on the arterial through movements (typically the coordinated phases). There are times when there are other concurrent movements occurring with the coordinated phase, such as the left turn movements. Within a time-space diagram, the left-turn movements are represented by "hatching" that is in the same direction as the coordinated phase. Note: In previous figures, phase 2 is a northbound movement and phase 6 is a southbound movement.

There are situations when other movements are assigned to the coordinated phase, such as the left turn movements. This may be done within an interchange when a left-turn movement is particularly heavy or needs additional time.

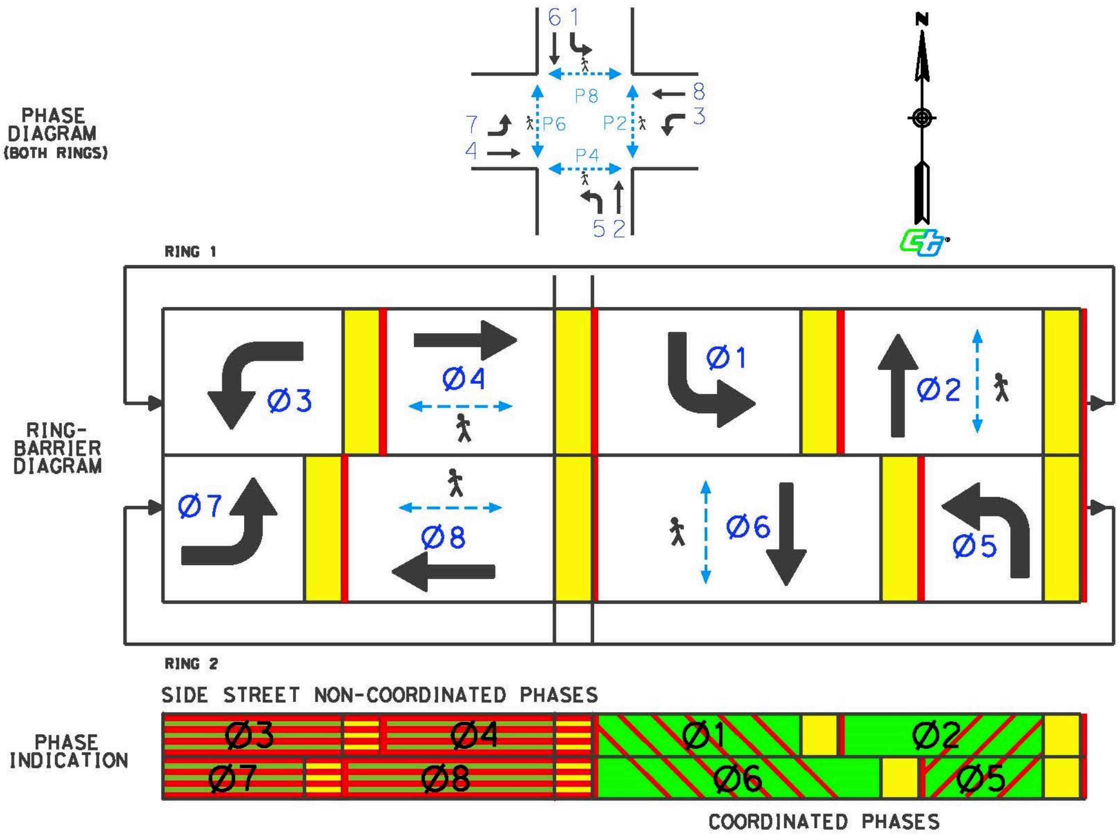

Figure 3-11 – Sequence of Left Turn Phasing as Shown in a Time-Space Diagram

As shown in Figure 3-11, the hatching for phase 5 is in the direction of phase 2 vehicle trajectories and the hatching for phase 1 is in the direction of phase 6 vehicle trajectories. When the left-turn movements occur at the same time (leading or lagging left turns), the hatching crisscrosses to show a period of time where through movements are not possible in either direction.

Lagging one or both of the left turns along an arterial to promote progression is common. Altering the order of the phases in the sequence may improve the use of the green provided, i.e. vehicles may arrive on green for their phase at the right time.

Lagging one of the left turns separates the start of the through phase from the start of the left-turn phase, which is particularly useful when upstream intersections from either direction are not equally spaced or have different offsets. This is demonstrated in Figure 3-12. Further discussion and examples are provided in Section 3.5 (Transition Logic).

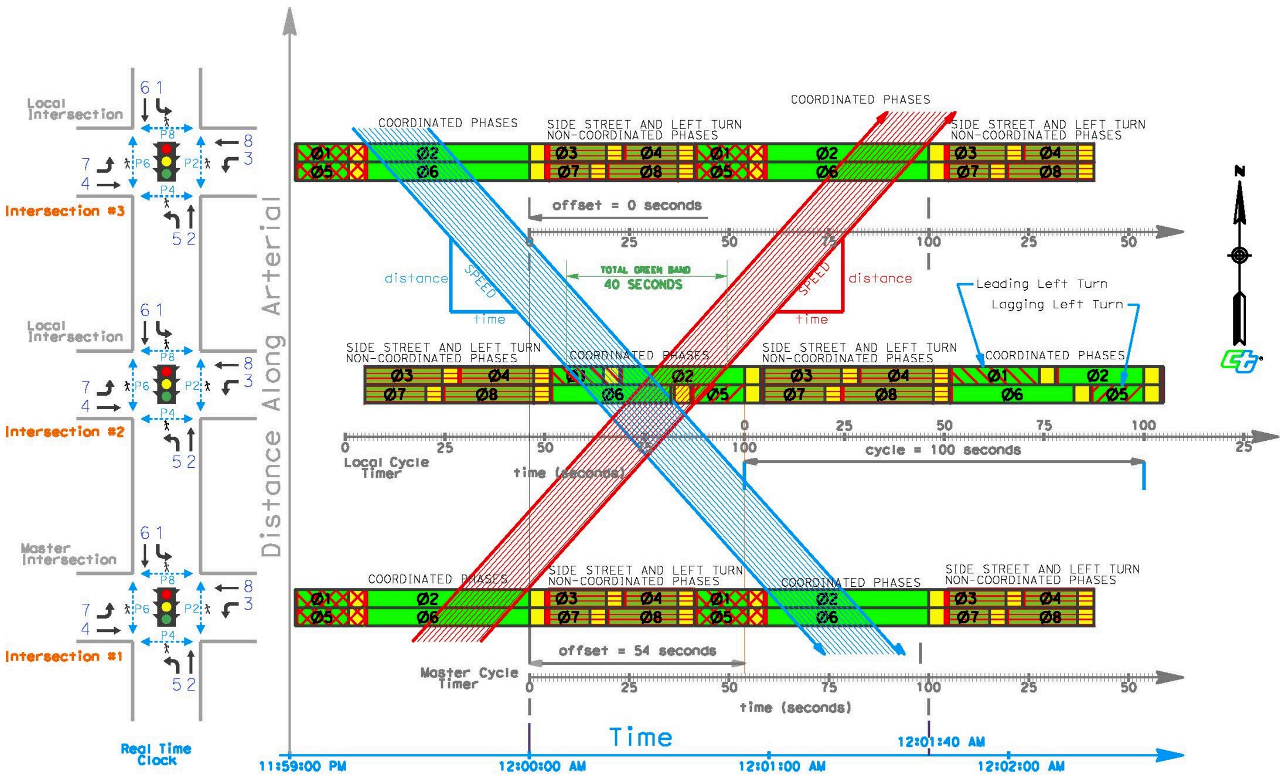

Figure 3-12 – Time-Space Diagram Example of Benefits of Lagging Left Turns

As shown in Figure 3-12, the bandwidth is increased by lagging the left turns for subsequent intersections. The benefits of the lead-lag left-turn phasing are further enhanced with protected/permissive lead-lag phasing. By allowing vehicles to turn left during the permissive interval, required left-turn green phase time is reduced, which allows more green time for the coordinated movements. This technique is especially effective for coordinated arterial signals where the progressed platoons in each direction do not pass through the signal at exactly the same time.

According to the U.S Department of Transportation, FHWA, Office of Operations' Traffic Signal Timing Manual, a 30 to 50 percent reduction in vehicle delay was documented, when comparing protected-only to protected/permissive left-turn phasing. A particular benefit of lagging the left turn is with protected/permissive left turn control; the drivers have an opportunity to find a gap, and are provided an opportunity to clear the lane at the conclusion of the permitted phase (3).

Understanding of yellow-trap issues is necessary before implementing lead-lag phasing for protected-permissive left-turn operation. The "Yellow Trap" is a condition that leads the left-turning driver into the intersection when it is possibly unsafe to do so even though the signal displays are correct. For more information, see Appendix E.

3.4.3 Bandwidth

Bandwidth is described as the amount of time available for vehicles to travel through a system at a determined progression speed. This is an outcome of the signal timing that is determined by the offsets between intersections and the allotted green time for the coordinated phase at each intersection. The bandwidth is calculated by the difference between the first and last vehicle trajectory that can travel at the progression speed without impedance. Bandwidth is a parameter that is commonly used to describe capacity or maximized vehicle throughput, but in reality it is only a measure of progression opportunities. Bandwidth is independent of traffic flows and travel paths and for that reason it may not necessarily be used by travelers. In other words, on an arterial with 10 signalized intersections, a bandwidth solution would be established to allow vehicles to travel through the entire system. In reality, one must consider how many vehicles desire to travel through all intersections without stopping.

A few important points to understand related to bandwidth:

- Bandwidth is different for each direction of travel on the arterial and dependent on the assumed speed on the time-space diagram.
- As additional intersections are added to the system, it is increasingly difficult to achieve and measure the impact of an additional signal.
- During periods of oversaturated conditions, bandwidth solutions may result in poor performance, often simultaneous offsets are more effective.
- Timing plans that seek the greatest bandwidth increase network delay and fuel consumption.

3.5 TRANSITION LOGIC

Transition is the process of either entering into a coordinated timing plan or changing between two plans. Transition may also be necessary after an event such as preemption or loss of coordination due to a pedestrian crossing. In general, traffic signals do not operate within the same pattern parameters and cycle lengths at all times. The pattern may change during the day due to a number of reasons:

- Time-of-day scheduled changes
- Manual operator selection
- Traffic-responsive pattern selection
- Emergency vehicle, rail-road, or other preemption
- Adaptive control system pattern selection
- Corrections to controller clock
- Pedestrian demand
- Power loss and restoration

The time-of-day schedule determines what time a plan will be active. The simplest schedules typically define an a.m., off-peak, and p.m. peak for weekdays and a different set of plans for weekends. However, all controllers have extensive scheduling options that allow users to define several dozen plans that can be activated by individual day of week, month, pre-defined holidays, or major events.

When the controller clock reaches a point where it is necessary to change the coordination plan, the cycle, split, and offset are changed. If just the splits are changed, the controller simply starts using the new splits. However, if either the offset or cycle change, the controller must shift the local offset reference point. This requires the use of an algorithm that may either shorten or lengthen the cycle to make that shift. That transition algorithm typically operates for one to five cycles, depending upon the transition mode selected and how much the cycle needs to be shifted. Consequently, the split durations during the period of transition may be different from either the previously defined splits or the new ones.

For example in the cycle length plot shown in Figure 3-13, one can see the system runs with a fixed background cycle from 6:00 AM to 10:00 PM, with cycle changes at 9:00 AM, 11:00 AM, 1:00 PM, 3:00 PM, and 7:00 PM. During each of these plan changes, the controller goes into transition, resulting in variable cycle lengths for a couple of cycles to adjust to the new plan.

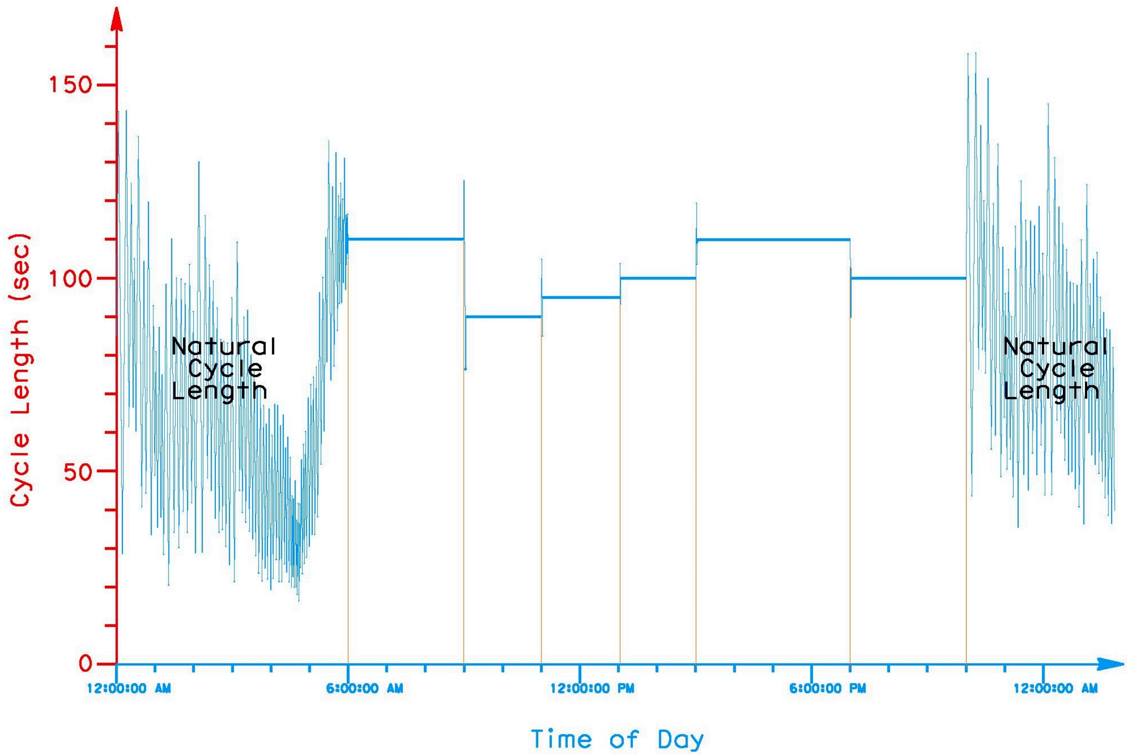

Figure 3-13 – Daily Cycle Length Fluctuations

3.5.1 Example Application of Time Based Coordination Transition

Traffic signal coordination requires adjacent signals to operate at the same cycle length or at a multiple of the cycle length with pre-determined offset and coordination points. The most common method for achieving that specified offset is called time-base coordination, where coordinated signals are configured to use the same sync reference time, such as midnight (or other time specified by a central application). When the signal is operating in a coordinated mode, it can calculate when the current cycle should begin by effectively counting forward from that sync reference time. The definition of the "start of cycle" depends on the offset reference point used by that signal, such as the start of yellow, for a coordinated phase. The transition is initiated to re-align the local zero point (when the cycle begins) with the system sync reference time (when a timing plan is initiated).

As an example of time based coordination, consider a signal that is operating a coordination pattern that calls for a 90-second cycle and a 20-second offset, with 12:00 a.m. as the sync reference time. From this information, we know that this signal should begin a 90-second cycle at **20** seconds after 12:00 AM (12:00:20 AM) and every 90 seconds thereafter. An adjacent signal operating a pattern with the same cycle length but an offset of **45** seconds should begin a 90 second cycle at 45 seconds after 12:00 AM (12:00:45 AM) and every 90 seconds thereafter. Hence these two signals will always have the same relative offset of **25** seconds (the difference between the two absolute offsets of 20 and 45 seconds).

When a signal controller begins to operate a new coordination pattern, it must establish the cycle length and offset of that pattern. The same applies when re-establishing an offset after a cycle is disrupted by preemption or a pedestrian time that exceeds the split time. By calculating back to the sync reference time (12:00 AM in the above example), the controller can determine when the offset reference point is scheduled to occur within the current cycle. In general, the next start-of-cycle time will be several seconds earlier or a few seconds later than the current cycle start time. The larger the difference between the two cycles and/or the offset values of the two patterns, the longer the transition will take. While central or master-based systems typically communicate the selection of a new timing plan to all signals in a group at the same time, the actual transition logic is executed independently at each signal, without explicit regard for the state of adjacent signals.

The Model 2070 and Model 170 controller programs allow one transition mode, which govern the precise details of how the signal resynchronizes to the new cycle and offset. The "*offset seeking*" mode is preferred. Older TSCP versions used a "dwell" method, which was not ideal for longer cycle lengths. The next section gives a brief overview of signal timing during transition for the most commonly available transition modes. However, no matter which mode is selected, traffic control can be significantly less efficient during the transition between timing plans than it was during coordination.

3.5.2 Offset Seeking Mode

The offset seeking mode of synchronization speeds up or slows down the local cycle timer, until the desired offset from the master cycle timer is achieved. Offset seeking attempts to minimize phase skipping while in transition. While Offset Seeking, the cycle length remains fixed but the splits can vary during transition; note that in offset seeking, only the duration of the green interval of the splits is modified, the yellow and red timing remains fixed. During the transition period, offset seeking will either "forward" or "backward" seek. Forward seeking speeds up the local cycle timer, while backward seeking slows down the local cycle timer. There are trade-offs with offset seeking. For example, when the local cycle timer speeds up (forward seeking), splits can lose green time; but when the local cycle timer slows down (backward seeking), splits can get additional green time. In the worst case, a split may be skipped altogether.

Forward Seeking

One second is added for every five seconds of "local cycle time" until synchronization is achieved. This will speed up the "local cycle timer" by approximately 20%.

Backward Seeking

One second is removed for every three seconds of "local cycle time" until synchronization is achieved. This will slow down the "local cycle timer" by approximately 30%.

Figure 3-14 portrays both offset seeking methods. Plan 1 has a zero offset while Plan 2 has a 30 second offset. The "Forward Seek" to attain the correct offset, shows the green times of the splits as a smaller area, denoting the speeded up cycle timer, which effectively shortens the green time. The "Backward Seek" to attain the correct offset, shows the green times of the splits as larger areas, denoting the slowed down cycle timer. This effectively lengthens the green time of each split.

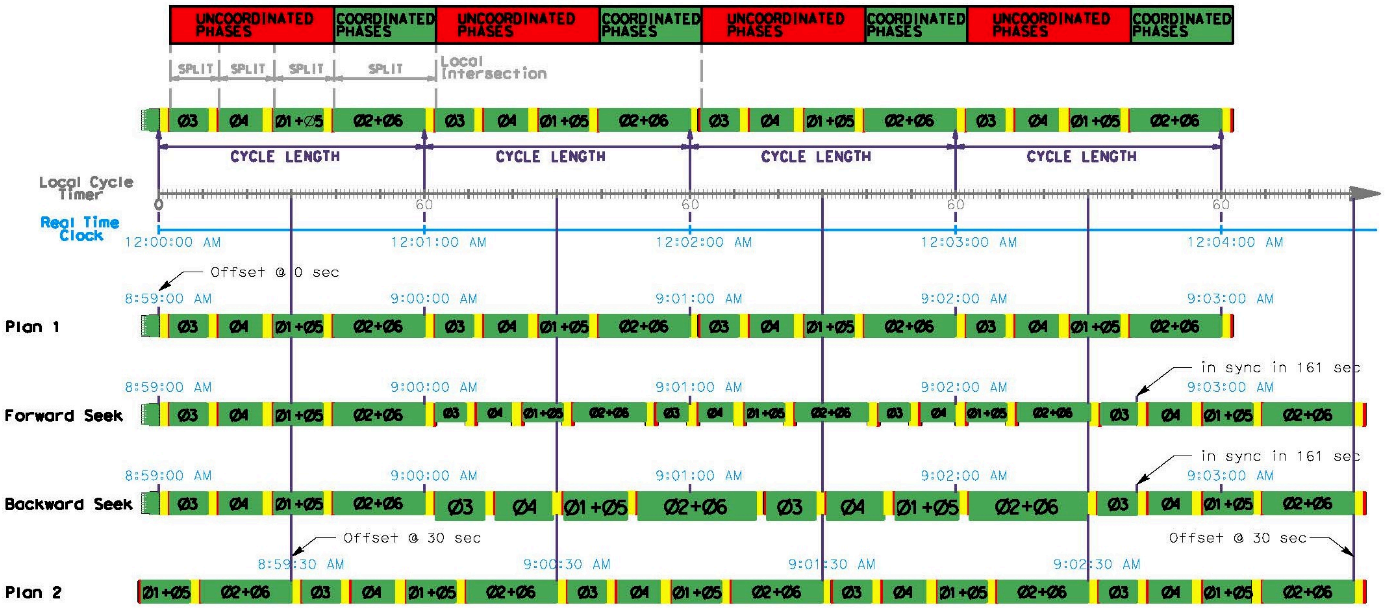

Figure 3-14 – Examples of Offset Seeking Mode

3.5.3 Operational Guidelines

Adjacent signals that change patterns simultaneously may take different amounts of time to complete their offset transitions, depending on which method is used and the size of the change required. In addition to disrupting the progression of vehicles between signals, offset transitioning artificially lengthens or shortens phases, leading to inefficient use of green time or unusual queuing. Therefore, it is best to avoid changing patterns during congested conditions when the signals need to operate at maximum efficiency. A peak-period pattern is best implemented early to ensure all offset transitioning is completed before the onset of peak traffic flows. Similarly, it is desirable to avoid frequent pattern changes.

In locations with low pedestrian demand, it may be acceptable to choose a shorter cycle length which better serves the vehicular traffic and allow coordination to be lost when a pedestrian requests service. Care should be taken in using this mode of operation if vehicle progression performance is valued; a few pedestrians may cause one or more signals in a coordinated system to be in transition almost all of the time.

3.6 COORDINATION TIMING PLAN GUIDELINES

This section provides guidelines for selecting coordination settings. The information provided is based on established practices and techniques and some acknowledgement that additional research is necessary on this subject. The guidelines address the following topics:

- Coordinated Phase Assignment
- Cycle Length Selection
- Split Distribution
- Offset Optimization

Each of these topics is addressed separately in the remainder of this section.

3.6.1 Coordinated Phase Assignment

At each intersection, a coordinated phase is designated to maintain the relationship between intersections. Common practice is to designate the main street through phase(s) as the coordinated phase(s) because the coordination places any unused split time in the coordinated phase and additional time provided to what is normally the busiest movement results in better performance. In many cases this is phases 2 and 6 for the main street through phases.

With some applications, assigning a phase other than the major street through movement has proven effective. A diamond interchange where queue management strategies are desirable is one example where a traffic signal may operate more effectively with such a designation. For more information regarding diamond interchanges, see Appendix K.

3.6.2 Cycle Length Selection

Cycle length selection should reflect local objectives and users of the system. Theoretically, shorter cycle lengths result in lower delays to potential users. As we consider more users, the cycle length may increase and tradeoffs are made between competing objectives. In most cases, the first step in determining cycle length selection is to assess each intersection for its minimum cycle length. Often, pedestrian clearance timing dictates the cycle length.

The result is typically different "optimal" cycle lengths at the intersections. As these intersections are aggregated into systems, decisions have to be made regarding whether to include the intersection in a system and in which system to include the intersection. There are cases where intersections are included in a coordination strategy that results in longer cycle lengths for the other intersections in the system. One should always consider whether intersections with long cycle length requirements would better operate independently of the system.

Cycle length selection is typically based on traffic data that is collected during representative periods. In reality, there are a wide variety of volumes that occur throughout the operation of the timing strategy. Additional information will help staff optimize the operations of a traffic signal.

Similarly, because pedestrian timing may influence cycle length, various timing strategies are used to ensure effective coordination. The traffic signal timing for pedestrians is further discussed in Appendix C. A key decision is whether pedestrians will be accommodated within the coordinated cycle length. In cases where pedestrian volumes (and the resulting actuations) are low, a choice may be made to not accommodate the pedestrian timing within the cycle length; this will result in temporary disruption to the coordination timing, as the signal either "forward" or "backward" seeks to get back *in synch* after serving the pedestrian call.

The selection of a cycle length affects intersection capacity and delays. Longer cycle lengths can increase capacity, but only marginally. Shorter cycle lengths usually result in reduced delays. Thus, the objective of choosing a cycle length is to determine the smallest value of cycle length that provides the desired level of vehicular capacity at the intersection while being appropriate for the needs of other users such as pedestrians and bicyclists.

Cycle lengths that are too long may increase congestion rather than reducing it, due to the impacts of long waiting queues on side streets and the arterial alike. Cycle lengths also result in establishing relationships between the intersections and in some cases some values work better than others, due to the time space relationship between the intersections.

In general, it is preferred that the cycle lengths for conventional, four-legged intersections not exceed 120 seconds, although larger intersections may require longer cycle lengths. Theoretically, intersection capacity increases as the cycle length becomes longer because a smaller portion of the time is associated with lost time. However, it is important to recognize that the improvements are modest and this assumes that all lanes are operating with saturated flows. This requires that turn lanes are long enough to provide sufficient storage to a particular movement; entrance to turn lanes are more likely to be blocked by through traffic queues with longer cycle lengths. As shown in Figure 3-15, the change of cycle length from two minutes (120 sec.) to three minutes (180 sec.) results in a modest 2 percent increase in potential capacity. This calculation was made by estimating the start-up delay resulting from the signal changes, as it relates to the number of times that the signal intervals change during the course of an hour. The message conveyed by the information presented in Figure 3-15 is that one should avoid placing too much emphasis on longer cycle lengths as a panacea for congested conditions.

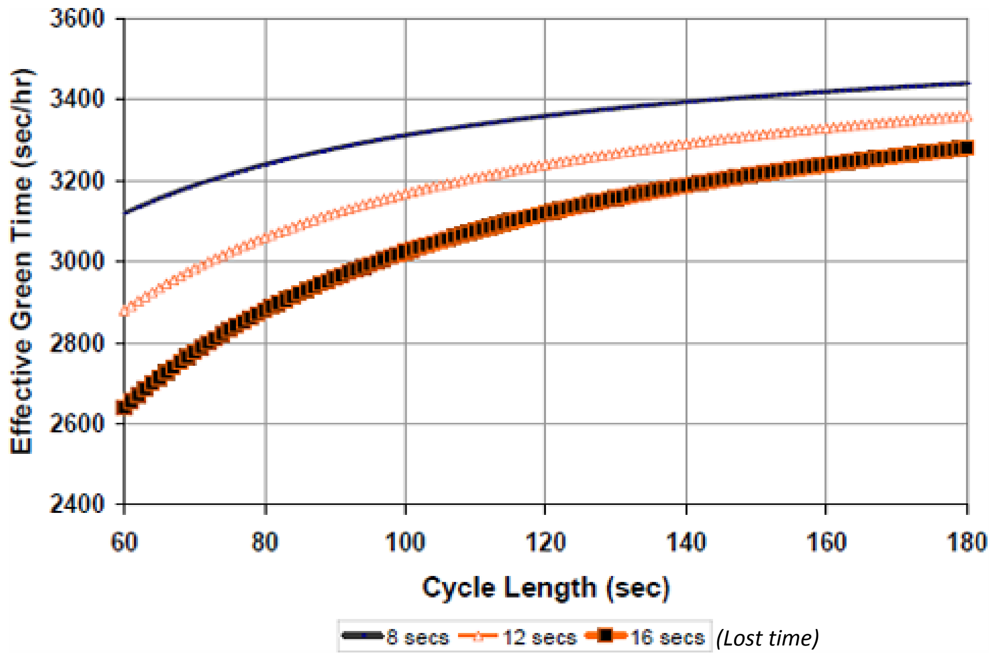

Figure 3-15 – Cycle Length & Theoretical Capacity

3.6.3 Split Distribution

The splits operate as a part of the coordinated timing plan. Once a cycle length is determined, split distribution is the process of determining how much of the cycle should be provided to each of the phases. These are maximum durations a phase may be served before it must terminate and yield to the next phase. Splits are typically allocated to provide a design level of capacity to all of the vehicle movements. Non-coordinated phases may not use the entire split allocated within the cycle, however, the coordinated phases are slightly different in this regard, in that it will always get its split time plus any unused time from the other phases. Splits are calculated values, which consist of the sum of green, yellow and red timing.

Green Factors & Force-Offs

Green factors and force-offs are used to determine the splits. When using green factors, the green factor is entered and the program (TSCP) calculates the splits. Phases with pedestrians, must consider the pedestrian timing when determining the green factor for that phase. The green factor must be long enough to accommodate both the pedestrian WALK and DON'T WALK timing, except when using "WALK 2" in which the pedestrian timing can be excluded from the green factor because the TSCP program ignores the WALK 2 pedestrian timing when calculating the phase splits. See Section 3.3.3

Three timing parameters determine the minimum green factor for a phase if the signal is to remain in coordination (not step out). These parameters are as follows:

- Pedestrian timing (Walk and Flashing Don't Walk values)
- Max Initial
- Minimum Green

The minimum green factor is usually determined by the highest of the three parameters listed above. However, when WALK2 is used, the pedestrian timing will not be a determination factor.

When using force-offs, the splits are manually calculated by the engineer. Care must be taken when calculating force-offs to avoid over-running the cycle and skipping phases. An example of calculating the force-off for a non-coordinated phase is to use the Free Operation Minimum Green for that phase added to the previous phase yellow and red time. Typically, force-offs are set to zero for the coordinated phases.

Whether determining splits by using Green Factors or Force-Offs, pedestrian, max initial, minimum green, yellow and red time need to be considered to allow enough time to serve all phases in a given cycle.

The maximum possible green for any non-coordinated phase without pedestrian timing will be the Free operation Max Green for that phase. The split green time cannot exceed that maximum green for that phase.

The intent with split times is to provide sufficient time to avoid oversaturated conditions for consecutive cycles, but over the course of an analysis period (15 minutes or one hour) split distributions seek to provide an opportunity for fluctuations in traffic volumes to be met with the slack time or variable green time, and the actuated operation will reduce phases as necessary to maintain efficient operations. Slack time is defined as the additional time in a cycle that is more than the minimum split times for the phases at the intersection. If a split time is too long, other approaches may experience increased delays, while if a split time is too short, the demand may not be served. There are often opportunities to vary controller parameters to allow for the fluctuations in daily traffic flow.

A common practice is to allocate a minimum amount of time to the minor streets and the remainder to the major or coordinated phases to enhance progression opportunities and maximize bandwidth. This methodology is used in traditional coordination, assuming the non-coordinated phases gap out. With many controller parameters and features, this allocation of green time can depend on pedestrians, transit phases, and gap settings.

Coordinated Phase

The length of the coordinated phase split is defined by the demand on the other movements. The coordinated phase receives the time within the cycle that is unused by the other phases of each ring.

There is a close relationship between the rings with the barrier on the intersecting street and therefore the various movements must be considered carefully. In periods of low demand on the non-coordinated phases, the coordinated phase may receive the entire cycle in the absence of an opposing call. The opposing call must be received before the permissive window expires.

Non-Coordinated Phase(s)

For a non-coordinated phase to time during a cycle, a call must be active, or the phase could be activated if a corresponding phase in the other ring is active and dual entry is enabled. For instance, if phase 4 and phase 8 have dual entry and phase 4 has an active call, phase 8 will be green as long as phase 4 is active. Once the phase is active the basic signal timing settings (described in Chapter 5) and the split defined in the coordination plan determine the length of the phase.

3.6.4 Offset Optimization

Offsets should consider the actual or desired travel speed between intersections, distance between signalized intersections, and traffic volumes. In an ideal coordinated system, platoons leaving an upstream intersection at the start of green should arrive at the downstream intersection near the start of the green indication or as the tail end of any standing queue is moving. For the users, this is a relative offset, where the time-distance relationship is observable and promotes progression. The actual offset is not always observable because of the actuated logic within the controller that can provide an early return to green.

The HCM suggests that an analyst should review the time-space diagrams to analyze arterial progression and the effectiveness of offsets for a set of signal timing plans. The actuated coordination logic of each signal controller causes the green time allocated to the side street to vary on a cycle by cycle basis. Thus, the time-space diagram is dynamic because of the potential of "early return to green" that results from variable demand on the non-coordinated phases. The HCM translates this assessment of offsets into an arrival type that is used to modify the second delay term of the delay equation. Determining the quality of progression factor (PF) term of the HCM average intersection delay equation is a difficult task, even if observed in the field. In fact, a study where traffic engineers were asked to observe several identical video clips of vehicles arriving at a traffic signal indicating those subjective assessments had wide ranges in estimated arrival types.

Traditional methods for field optimization have included an engineer or technician observing in the field to determine whether the timing plan is operating and whether the offsets are effectively progressing traffic between intersections. These observation periods should be sufficiently long enough to provide the engineer or technician opportunities to observe the system with normal cycle duration for non-coordinated phases and "early return to green" when non-coordinated traffic is light.

3.7 COORDINATION COMPLEXITIES

This section discusses the various complexities of signal coordination. There are many variables that that must be considered to achieve an acceptable coordination plan. The guidelines address the following topics:

- Hardware limitations
- Pedestrians
- Phase sequence
- Early return to green
- Heavy side street volumes
- Turn lane interactions
- Oversaturated conditions

Each of these topics is addressed separately in the remainder of this section.

3.7.1 Phase Sequence

The sequence of phases, particularly those of left turns, can provide measurable benefit to arterial operation. The most common phase sequencing decision, whether to lead or lag left turns, can have a particularly strong impact on the ability to provide bandwidth in both directions of an arterial.

Other phase sequence decisions, such as the sequence of left turns on the minor street or the sequence of split phasing on the minor street, do not directly impact arterial bandwidth but can affect arterial delay. These two concepts are discussed in the following sections.

Major street left-turn phase sequence

Modern controllers allow left turn phase sequences to be varied by time of day. This has traditionally been done only for protected left-turn operations, but the new controllers allow this to be extended to protected-permissive operations.

The basic concept of lagging a major street left turn is to time the left turn after the opposing through movement (assumed to be one of the coordinated phases) terminates. Figure 3-16a illustrates a typical time-space diagram showing an arterial with only leading lefts and the same arterial with both leading and lagging lefts is shown in Figure 3-16b. The arterial demonstrated in the figure has a major intersection on each end and a minor intersection in the middle. As can be seen in the figure, a lagging left turn at the middle intersection facilitates better progression in both directions because it allows the two platoons to arrive at different times in the cycle. In addition, the two major intersections benefit to some degree from selective lagging left turns.

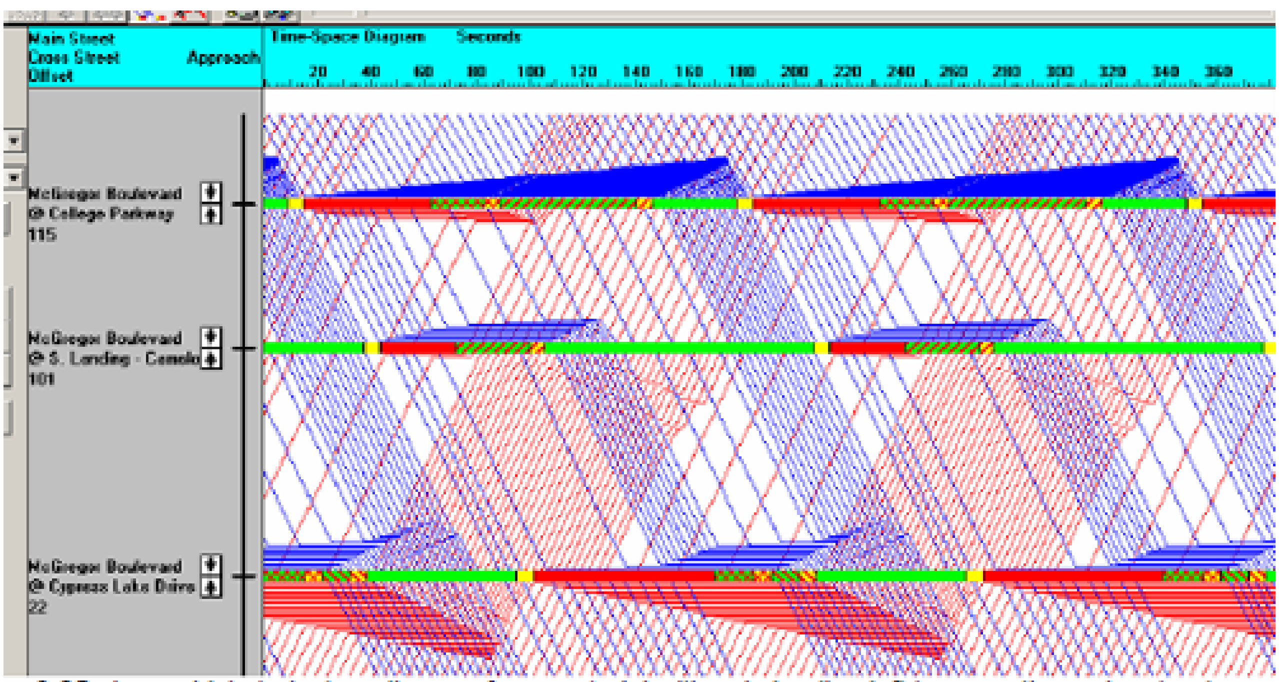

Figure 3-16a – Vehicle Trajectory Diagram for an Arterial with Only Leading Left Turns on the Major Street

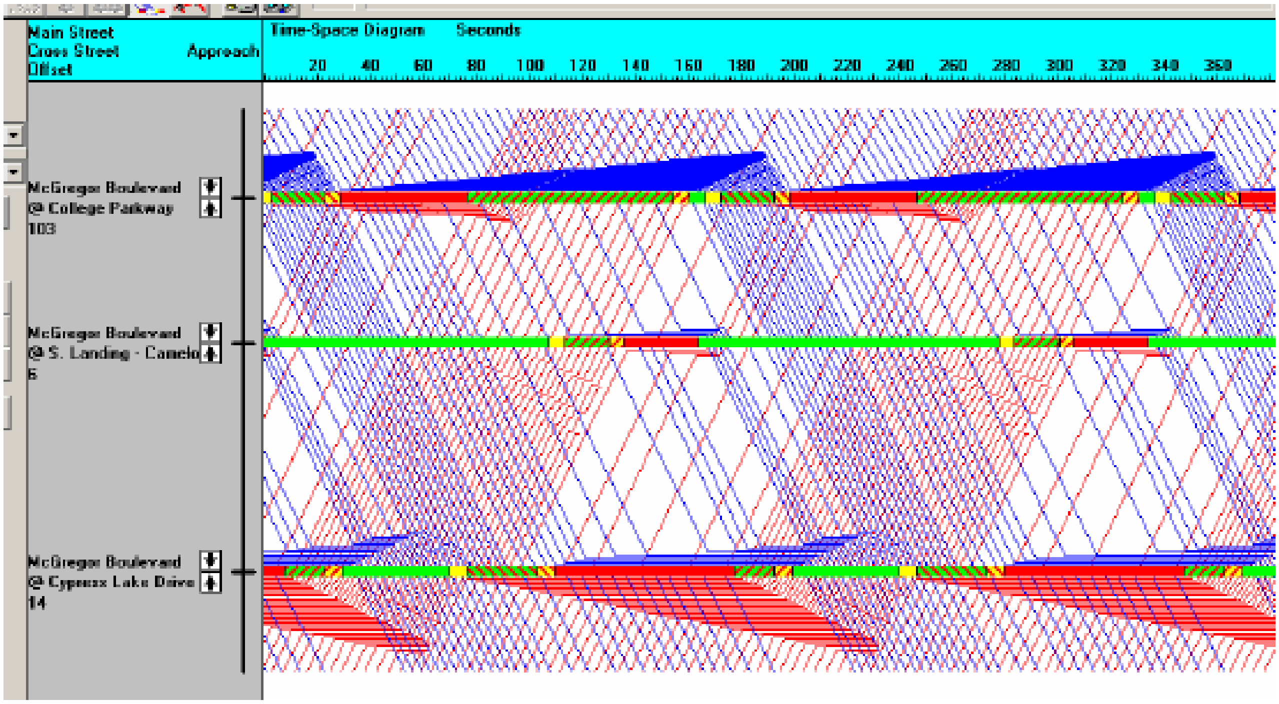

Figure 3-16b – Vehicle Trajectory Diagram for the Same Arterial but Using Selective Lagging Left Turns on the Major Street

One of the potential consequences of lagging left turns that are actuated is that the end of the adjacent coordinated phase becomes less predictable. In terms of dual-ring operation, the lagging left turn is typically served after the deterministic (yield) point is reached. The lagging left turn extends the concurrent (adjacent) through movement time indirectly, not as a result of any particular timing within the coordinated phase itself. As a result, only the detection for the lagging left turn is used to determine when to gap out the lagging left turn phase and the adjacent coordinated phase. Therefore, it is possible that the adjacent coordinated phase may gap out earlier than expected from cycle to cycle.

One technique that has been used to eliminate this variability is to use a maximum recall on the lagging left-turn phase. This can be set by time of day and can often be paired with the specific timing plan containing the lagging left turn. The use of a maximum recall on the lagging left turn makes the end of the adjacent coordinated phase more predictable. On the other hand, if the demand for the lagging left turn is highly variable or is less than the split coded, the use of the recall on the lagging left turn may give the appearance of sluggish operation or defective detection.

An additional method of dealing with the lagging left turn variability is to use Lag/Gap Out feature of the TSCP. Lag/Gap Out looks to the lagging left turn first and if there is adequate volume to keep the left turn active, the turn phase is extended, however, if the left turn gaps out, the volume on the adjacent mainline is observed and if it is sufficiently high so as to meet the gap requirements for mainline, BOTH the left turn and mainline are extended to the yield point. If both the left turn and adjacent mainline volumes gap out, then both phases are terminated and the controller proceeds to the next phase in the cycle.

Minor-street phase sequence

It may be advantageous in some circumstances to adjust the left-turn phase sequence for the minor street. In doing this, it may be possible to reduce the delay and queuing for minor-street left turns as they enter the major street and arrive at downstream intersections. Although such adjustments may affect system-wide delays and stops, they will have minimal effect on the theoretical bandwidth for the coordinated phases.

3.7.2 Early Return to Green

One of the consequences of coordinated, actuated control is the potential for the coordinated phase to begin earlier than expected. This “early return to green” occurs when the sum total of the time required by the non-coordinated phases is less than the sum total of the vehicle splits coded for the phases. While this may reduce delay at the first intersection, it may increase system delay because of inefficient flow at downstream intersections or, most important, the critical intersection of the network. Figure 3-17 illustrates this within a time-space diagram.

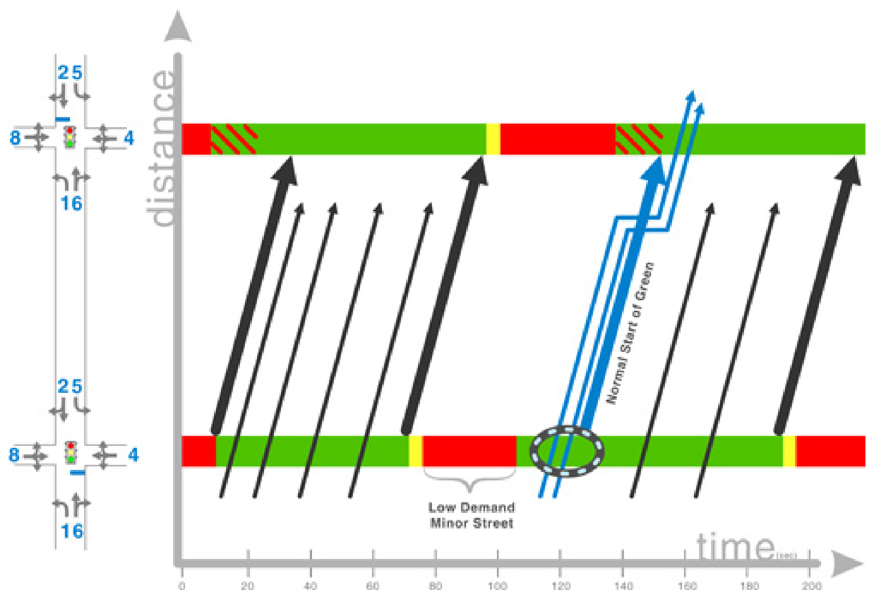

Figure 3-17 – Time-Space Diagram Example of Early Return to Green

Figure 3-17 shows that vehicles in coordinated phases that begin early may be forced to stop at one or more downstream intersections until they fall within the “band” for that direction of travel. This can result in multiple stops for vehicles and a perception of poor signal timing.

Early return to green can have a substantial negative effect on the performance of the coordinated phases. Research for offset transitioning has been completed to “smooth progression of a platoon through an intersection using the volume and occupancy profile of advance detectors” (8). Early return to green can be difficult to manage along a corridor, and it can rarely be completely prevented without eliminating most of the benefits of actuation. One technique that is sometimes used is to delay the start (offset shifted to the right) of the coordinated phase at a critical upstream intersection with sufficient non-coordinated demand (thus making its operation more predictable). Similarly, minor intersections downstream of this critical offset can be started earlier (offset is shifted left in a time-space diagram) to minimize the likelihood of a stop due to an early return to green. In either case, the engineer should use caution when shifting offsets to address early return to green in one direction may adversely affect operation in the opposite direction.

3.7.3 Heavy Side Street Volumes

Heavy side street volumes can affect the ability to progress through movements along an arterial. These volumes can come from either signalized intersections within the coordinated signal system or from unsignalized intersections, or from driveways between coordinated signals. Interchanges are a common source of heavy side street volumes.

In many cases, this additional demand proceeds along the remainder of the arterial and becomes part of the major street through demand at downstream intersections. However, this demand often enters the system outside the band established for through movements traveling end-to-end along the arterial. It is usually desirable to adjust downstream intersection timing to allow these heavy side street movements to proceed with a minimum of stops. In these cases, solutions that seek to optimize arterial bandwidth may be counterproductive to effective signal timing.

3.7.4 Turn Lane Interactions

Turn lane (or turn pocket) interactions can significantly reduce the effective capacity of an intersection. This is experienced when either demand for the turning movement exceeds the available storage space or when vehicle queues block the entrance of a turn lane. If left-turn demand cannot enter the left-turn lane due to impeding through vehicles, the left-turn phase will gap out early due to a lack of detected demand. This results in some left turning traffic requiring more than one cycle to be served.

Turn lane overflows also adversely impact progression. The impedance created by left-turn vehicles stored in the through lane prevents through traffic from proceeding to downstream intersections. As a result, any platoon of through vehicles passing through the affected intersection tends to be dispersed. This reduces the ability for downstream intersections to efficiently provide green time for the platoon.

Turn lane overflows can occur during both under-saturated and oversaturated conditions. Even if enough green time is provided to serve a given turning movement, turn lane overflow can occur if the available storage is insufficient to store the queue for a given cycle. For cases where the turn lane is fed from a two-way left-turn lane, turn lane overflow rarely has significant adverse consequences for the adjacent through movements. For locations with raised medians, on the other hand, turn lane overflow can result in left-turning vehicles extending into the adjacent through lane.

Turn lane overflow can be managed in a number of ways:

- Turn lanes can be extended to accommodate the necessary storage. This is typically the best solution, but it may be infeasible due to physical constraints, access needs, turn lane requirements for adjacent intersections, or other factors.
- Shorter cycle lengths can be used to keep overall queue lengths shorter, thus reducing the likelihood of overflow or turn lane blocking. This option is often not possible due to the constraints of cycle length to serve pedestrians.
- If the left turn is protected, protected-permissive left-turn phasing may be considered to allow some of the left turn demand to be processed during the permissive portion of the phase. This reduces the overall queue length.
- If the left turn is permissive, protected-permissive left turn phasing may be considered to provide a period of higher saturation flow rates (the protected portion of the phase). This technique, however, may result in longer cycle lengths that partially offset the gain in capacity.

- Conditional service for the phase may be invoked, bringing up the movement twice during the cycle.
- If two receiving lanes are available, the adjacent through lane can be designated as a shared left-through lane and the phasing changed to split phasing. While this is rarely desirable for major street movements, it may be an appropriate solution for minor street movements.
- At an intersection with one heavy left-turn movement on the major street, it may be preferable to designate the left-turn phase as one of the coordinated movements paired with the adjacent through movement (e.g., phases 1 and 6 or phases 2 and 5). This allows any unused time to roll over to the left-turn phase of interest, thus reducing its effective red time and associated queue formation.

3.7.5 Critical Intersection Cycle

A challenging aspect of timing an arterial street or a network of streets is the need to provide enough capacity for major intersections without creating excessive delay for minor intersections. Ideally, all of the intersections to be coordinated operate optimally with similar cycle lengths. However, most arterial streets do not have this optimal arrangement due to a mixture of simple signals (e.g., two phases) with more complex signals (e.g., eight phases), wide ranges in cross street volume (e.g., major arterials versus collectors), and variations in left-turning volumes.

The techniques to determine the ideal cycle length for each intersection in isolation were covered in section 3.6.2. The critical system cycle length is the longest optimal cycle length of any individual intersection in the system.

Several techniques can be used where there is a significant disparity in the ideal cycle length for each intersection:

- Each intersection is timed using the critical system cycle length. This ensures the ability to coordinate all of the intersections in the system. However, it may result in excessive delay at minor intersections.
- Each intersection is timed to either the critical system cycle length or to half that value. This technique is commonly referred to as "half cycling" (a minor intersection cycles twice as frequently as major intersection). This method can often produce substantially lower delays at the minor intersections where half cycling is employed. However, it may become more difficult to achieve progression in both directions along the major arterial, which may result in more arterial stops than desired.
- Each intersection is timed to either the critical system cycle length or to twice that value. This technique is commonly referred to as "double cycling" (a minor intersection cycles once for every two cycles of the major intersection). This method can often produce substantially higher delays at the minor intersections where double cycling is employed. However, it makes it easier to maintain progression in both directions along the major arterial, which should result in fewer arterial stops.
- Each intersection is timed to either the critical system cycle length or to double or half that value.

  Double Cycle and Half Cycle in TSCP

  Double Cycle: When the cycle length is 100 seconds, setting the multiplier to 2.0 will double the cycle length to 200 seconds. The non-coordinated and coordinated phases will be served during the first 100 seconds, but the coordinated (sync) phases will hold until the local cycle timer reaches 0.

Half Cycle: When the cycle length is 100 seconds, setting the multiplier to 0.5 will divide the cycle length in half to 50 seconds. The non-coordinated and coordinated (sync) phases will be severed twice in the 100-second cycle or once every 50 seconds.

- The major intersections are operated free, and the minor intersections are coordinated using a shorter cycle length. Because the major intersections are operating free, it is impossible to provide coordination through the major intersections. Therefore, major street vehicles are likely to stop at both the major intersection and at a downstream intersection due to randomness in arrival at and departure from the major intersection. This technique can often result in lower overall system delay at the expense of additional stops along the major street.

3.7.6 Oversaturated Conditions

Timing for oversaturated conditions requires different strategies than those used for under-saturated conditions. An intersection that is operating at or over capacity requires all movements to operate at a saturation flow rate to serve demand. Beyond this, the timing plan may favor the movements with the most lanes to maximize the throughput of the intersection. Obviously, the timing plan must consider whether undesirable effects such as turn lane overflow or other conditions exacerbate the problem.

Under these conditions, arriving vehicles must join the back of a queue to ensure that they enter the intersection with a minimum amount of headway (maximum saturation flow rate); however, it is impossible for vehicles on the arterial to maintain a travel speed traditionally desired for coordination.

In addition, an oversaturated approach cannot serve all arriving demand, thus creating a residual queue at the end of a cycle that carries over to subsequent cycles. This residual queue depends on demand conditions and can grow from cycle to cycle. Even when demand drops, the residual queues create saturated conditions beyond the time period when the arriving demand would create saturated conditions by itself. These residual queues can extend to adjacent intersections and prevent traffic from exiting upstream intersections if the intersections are closely spaced.

The general technique for accommodating oversaturated conditions involves managing queues. The following sections present options available for accommodating oversaturated conditions, including benefits and trade-offs.

Queue Storage on Minor Movements to Favor Major Movements

It is sometimes possible to accommodate oversaturated conditions by favoring the coordinated movements at the expense of minor street movements. Under this strategy, the coordinated phases are timed for a volume-to-capacity ratio typically no higher than 0.95 to 0.98. The minor movements receive less green time, which results in demand-to-capacity ratios exceeding 1.0. This method has a few advantages. The major street receives priority, which helps maintain traffic flow along the major street. This typically benefits the heaviest movements through the intersection, as well as the transit and emergency vehicles who frequently use the major street. In addition, demand held on side streets cannot enter downstream intersections, thus improving the actual downstream flow rate (9).

However, this type of timing strategy can have significant disadvantages. While this method can theoretically keep the major street moving, it creates extensive delay and queuing on side streets. This can result in highly negative public feedback. More importantly, it may be impossible to reduce splits for side-street through movements due to pedestrian timing requirements. If pedestrian calls are frequent enough to cause the side street through movement to time to its full split, the only movements with time available for use are the major street left turns and the minor street left turns (if present). Queue spillback for the major street left turns can exceed available storage and spill into the adjacent through movement, which may create operational and safety issues. As a result of these disadvantages, this technique is often not desirable (9).

Use of short cycle lengths

One of the most effective techniques in managing oversaturated conditions is the use of shorter cycle lengths. Shorter cycle lengths allow more frequent servicing of all movements at only a minor expense of additional loss time during the peak time period. This frequent cycling provides more equitable servicing of all movements and allows drivers to visibly experience progress, even if it takes multiple cycles to be served at a given intersection.

The disadvantage of shorter cycles is if there is insufficient time to service the pedestrians, the signal will step out of coordination whenever there is a pedestrian call. The signal will then off-seek to get back into coordination after the pedestrian service, which can cause an even more disruptive delay to all movements of the intersection.

Queue management on major street movements

An alternative technique is to selectively store queues on major street movements. Candidates for this treatment frequently include major intersections that are spaced far enough from other signalized intersections to allow the queues to grow without creating upstream intersection impacts. In addition, drivers may be more accepting of congestion at major intersections than at minor intersections.

For network applications (e.g., downtown grids), it is often best to store queues outside the network using key signals to meter traffic into the grid network. While this creates congestion at some intersections, it allows a network of intersections to operate under-saturated, thus enabling traffic to progress through the network.

Use of actuated uncoordinated operation

Removing the cycle length constraint during the oversaturated period can result in efficient allocation of green time, provided gap timers are set appropriately. There are emerging strategies such as lane-by-lane detection and measurement of flow used as opposed to presence for control logic decision-making and operation.

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APPENDIX

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F. Yellow Interval Timing

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APPENDIX A

CONTROLLER ASSEMBLY

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Controller Assembly

A.1 Type 332 Signal Controller Cabinet

This appendix will familiarize you with the Type 332 Signal Controller Cabinet, including the internal layout of the cabinet and components used in the various sections of the cabinet. Views of both the front and back of the cabinet sections will be shown with discussions of the individual component layout, designation, and proper installation of wiring.

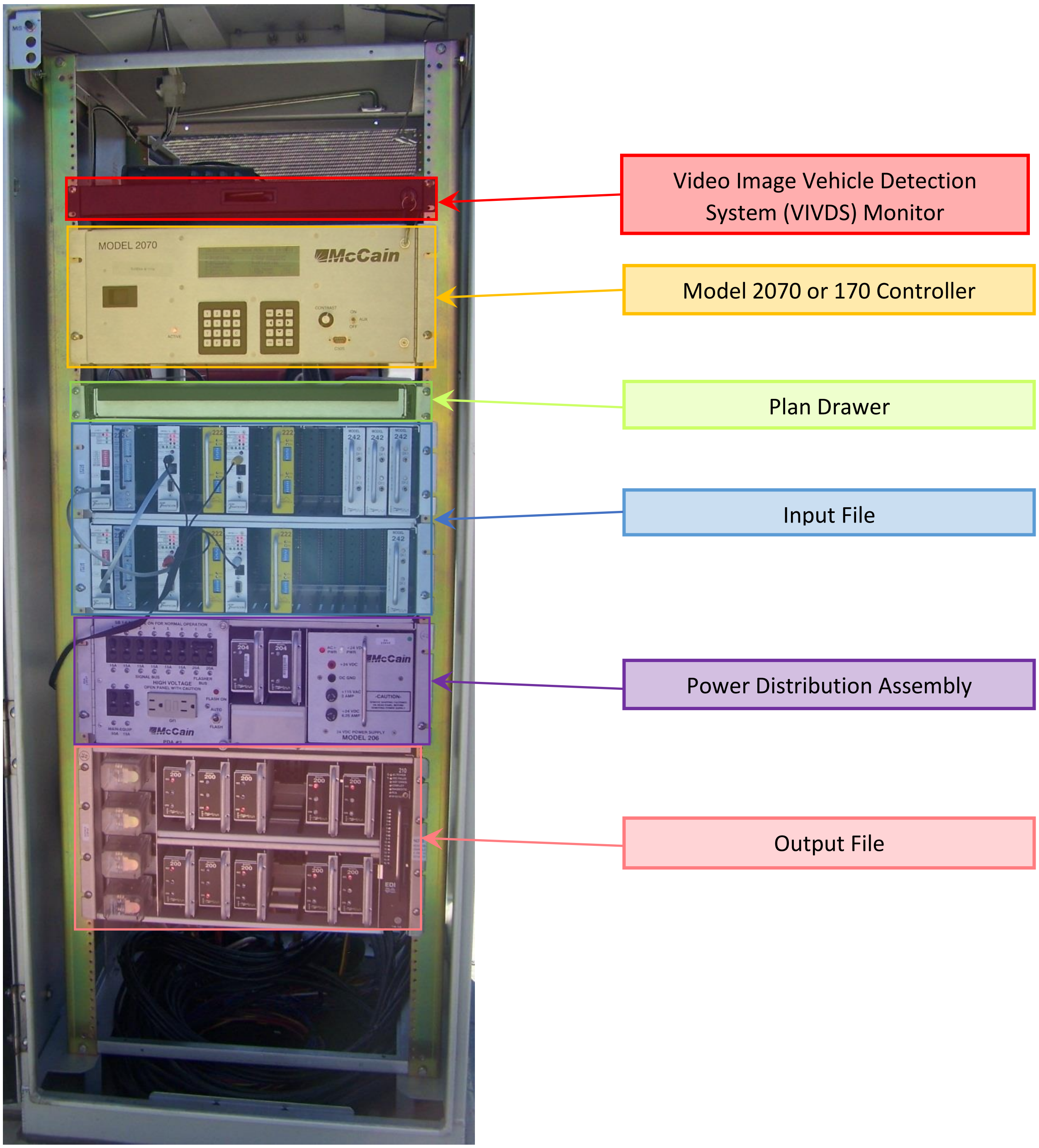


Figure A1 – Example of Type 332 Signal Controller Cabinet (front view)

A.1.1 Controller

The traffic Signal Controller is a piece of equipment much like a standard computer. It has a processor that takes information from the input file (analogous to a keyboard), runs it through a controller program to assign right of way and then sends the results through the output file to display traffic signal indications to the public (analogous to a monitor). The traffic Signal Controller is connected to the Type 332 Signal Cabinet through the 104 pin C-1 Connector, which connects the controller to the input and output files.

There are two main controller types used in Caltrans signals, the Model 170 controller which is the first generation of computer controller for signals in California, and the Model 2070 ATC controller which is first generation of the Advanced Transportation Controller (ATC), the replacement for the Model 170 controller. Both controller types are available with third party software or Caltrans-developed software to process the input and outputs for the signals.

The Caltrans signal software (C-8 and Q-7 for the Model 170 and TSCP for the Model 2070) allow many parameters of the signal to be set, including minimum and maximum green, yellow clearance intervals, all red clearance intervals, detector parameters and many others. It also has settings for signal pre-emption by rail or emergency vehicles that can modify the signal operation to allow clearance for those special vehicles.

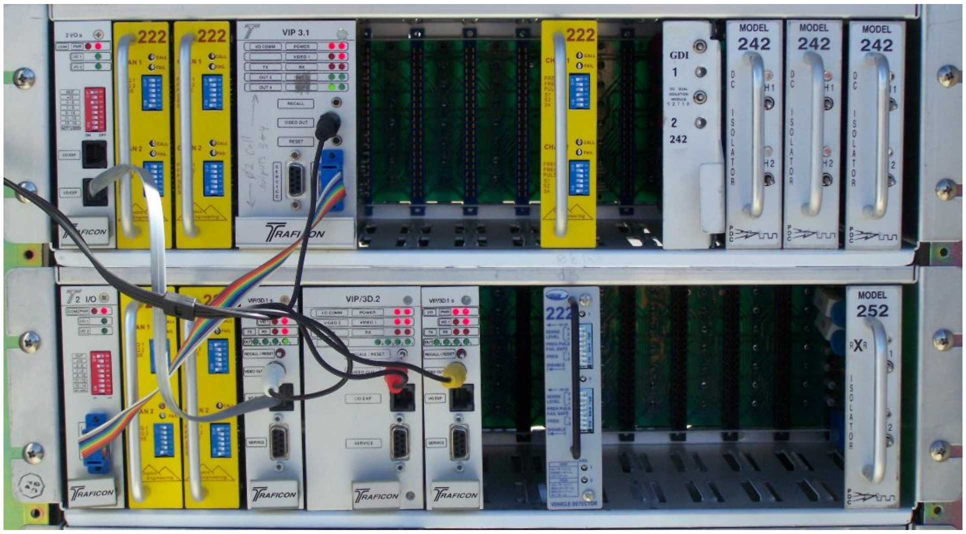
For a more detailed discussion of the controller types and software, you may refer to the C-8 Operations Manual, the TSCP Operations Manual, the Model 170 Controller Operations Manual and the 2070 Controller Operations Manual.

A.1.2 Input File

The Input File is the section of the Type 332 cabinet that interfaces the Signal Controller with the field elements that detect vehicle and pedestrian calls for right of way to be assigned. The input file is a card rack section of the cabinet that consists of two racks, the upper rack is the “I” File and the lower rack is the “J” File (see Figure A2). These racks accept 22 contact edge connect PC type cards as input devices.

The “I” and “J” files have 14 card slots, numbered from left to right. Slots 1-9 are standard vehicle detection slots and can use vehicle detector cards such as the Model 222 Detector Card, a Video Image Vehicle Detection System (VIVDS) Detector Card or a Microwave Detector Card. Slots 11-14 are typically used for DC or AC isolator cards for pedestrian detection, Emergency Vehicle Preemption (EVP) and Railroad Preemption (see Figure A3). Each detector slot of each file is broken into an upper and lower input, this allows for 36 vehicle detector inputs, 4 pedestrian inputs, 4 EVP inputs, 2 Railroad inputs and 8 spare input locations. With the addition of an auxiliary input file harness, the vehicle detection inputs can be increased to 40 by utilizing slot 10 as vehicle detector slots.

Input File



“I” File

“J” File

Figure A2 – View of Card Rack with Input Files (I and J)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
"I"	U	1 Ø1 E,CT	3 Ø2 E,CT #1 ADV	5 Ø2 E,CT #1 MID	7 Ø2 CALL	9 Ø2 E,CT	11 Ø4 E,CT	13 Ø4 E,CT	15 Ø4 CALL	17 Ø1 E,CT	19 Ø2 E,CT	ADV	PED Ø2	PED Ø6	FLH
	L	Ø1 E,CT 2	#2 ADV Ø2 E,CT 4	#2 MID Ø2 E 6	Ø2 E,CT 8	Ø2 E,CT 10	Ø4 E,CT 12	Ø4 E 14	Ø4 CALL 16	#1 Ø8 E,CT 18	Ø4 E,CT 20	BBS	PED Ø4	PED Ø8	STOP TIME
"J"	U	21 Ø5 E,CT	23 Ø6 E,CT #1 ADV	25 Ø6 E,CT #1 MID	27 Ø6 CALL	29 Ø7 E,CT #1 RR	31 Ø7 E,CT #1 LL	33 Ø8 E,CT	35 Ø8 CALL	37 Ø5 E,CT	39 Ø6 E,CT	SP2	EVA	EVB	RR1
	L	Ø5 E,CT 22	#2 ADV Ø6 E,CT 24	#1 MID Ø6 E 26	Ø6 E,CT 28	#2 RR Ø7 E,CT 30	#2 LL Ø7 E,CT 32	Ø8 E 34	Ø8 E,CT 36	#1 Ø7 E,CT 38	Ø8 E,CT 40	SP3	EVC	EVD	RR2

LEGEND	
(hatched yellow)	= VIVDS
(yellow)	= LOOP DETECTOR
(orange)	= LOAD SWITCHES
(hatched white)	= VIVDS NOT ASSIGNED

Figure A3 – Typical Detector Wiring (reflecting upper and lower for both I and J files)

The input files are affixed to an internal cabinet wiring harness that has a 104 pin C-1 plug which connects to the Model 170/2070 controller. The internal wiring harness also connects the input file to terminal blocks on the side dead panels of the Type 332 controller cabinet where field wiring terminations are made (see Figure A4 and Figure A5).

Both Figure A3 and Figure A5 are part of an excel spread sheet called the “Field Wiring Diagram” that is produced for each signalized intersection. The full spread sheet is attached at the end of Appendix A.

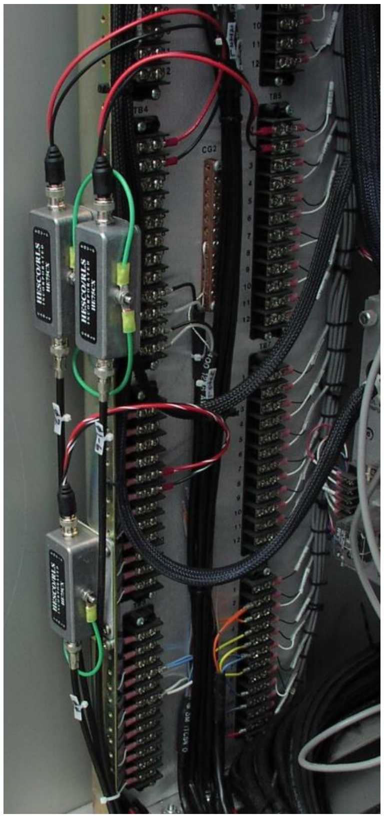


Figure A4 – Example of Terminal Block Wiring

POS	A	B	
TB2-1	DET 1	I-1D	Ø1
2		I-1E	Ø1
3	DET 2	I-1J	Ø1
4		I-1K	Ø1
5	DET 3	I-2D	Ø2
6		I-2E	Ø2
7	DET 4	I-2J	Ø2
8		I-2K	Ø2
9	DET 5	I-3D	Ø2
10		I-3E	Ø2
11	DET 6	I-3J	Ø2
12		I-3K	Ø2

POS	A	B	
TB3-1	DET 19	J-1D	Ø5
2		J-1E	Ø5
3	DET 20	J-1J	Ø5
4		J-1K	Ø5
5	DET 21	J-2D	Ø6
6		J-2E	Ø6
7	DET 22	J-2J	Ø6
8		J-2K	Ø6
9	DET 23	J-3D	Ø6
10		J-3E	Ø6
11	DET 24	J-3J	Ø6
12		J-3K	Ø6

POS	A	B	
TB8-1	MANUAL	I-11D	ADE
2	SPARE	I-11J	SP1
3	11 COM	I-11K	SP1
4	PED 02	I-12D	02 PED
5	PED 04	I-12J	04 PED
6	12 COM	I-12K	04 PED
7	PED 06	I-13D	06 PED
8	PED 08	I-13J	08 PED
9	13 COM	I-13K	08 PED
10	FLH SENSE	I-14D	FLH
11	STOP TIME	I-14J	STOP TIME
12	14 COM	I-14K	STOP TIME

POS	A	B	
TB4-1	DET 7	I-4D	Ø2
2		I-4E	Ø2
3	DET 8	I-4J	Ø2
4		I-4K	Ø2
5	DET 9	I-5D	Ø3
6		I-5E	Ø3
7	DET 10	I-5J	Ø3
8		I-5K	Ø3
9	DET 11	I-6D	Ø4
10		I-6E	Ø4
11	DET 12	I-6J	Ø4
12		I-6K	Ø4

POS	A	B	
TB5-1	DET 25	J-4D	Ø6
2		J-4E	Ø6
3	DET 26	J-4J	Ø6
4		J-4K	Ø6
5	DET 27	J-5D	Ø7
6		J-5E	Ø7
7	DET 28	J-5J	Ø7
8		J-5K	Ø7
9	DET 29	J-6D	Ø8
10		J-6E	Ø8
11	DET 30	J-6J	Ø8
12		J-6K	Ø8

POS	A	B	
TB9-1	SPARE 2	J-11D	SP2
2	SPARE 2	J-11J	SP3
3	11 COM	J-11K	SP3
4	EM 25	J-12D	EVA
5	EM 61	J-12J	EVC
6	12 COM	J-12K	EVA/EVC COM
7	EM 47	J-13D	EVB
8	EM 81	J-13J	EVD
9	13 COM	J-13K	EVB/EVD COM
10	RR 25	J-14D	RR1
11	RR47	J-14J	RR2
12	14 COM	J-14K	RR1/RR2 COM

POS	A	B	
TB6-1	DET 13	I-7D	Ø4
2		I-7E	Ø4
3	DET 14	I-7J	Ø4
4		I-7K	Ø4
5	DET 15	I-8D	Ø4
6		I-8E	Ø4
7	DET 16	I-8J	Ø4
8		I-8K	Ø4
9	DET 17	I-9D	Ø1
10		I-9E	Ø1
11	DET 18	I-9J	Ø3
12		I-9K	Ø3

POS	A	B	
TB7-1	DET 31	J-7D	Ø8
2		J-7E	Ø8
3	DET 32	J-7J	Ø8
4		J-7K	Ø8
5	DET 33	J-8D	Ø8
6		J-8E	Ø8
7	DET 34	J-8J	Ø8
8		J-8K	Ø8
9	DET 35	J-9D	Ø5
10		J-9E	Ø5
11	DET 36	J-9J	Ø7
12		J-9K	Ø7

LEGEND

NA - Not Assigned
OF - Output File
IFI - Input File #I
IFJ - Input File #J
M - Monitor Module
I-ID - IFI Slot I Connector, Pin D
RR25 - Railroad Preempt, 02 and 05
EM25 - Emergency Vehicle, 02 and 05
OII - Output File Terminal Block Position II

Figure A5 – Panel Terminal Block Assignment Detail

A.1.2.1 Model 222 Detector Card

The 222 Detector Card is a device that detects the change in inductance caused by a vehicle moving over a loop of wire in the pavement. When the cards detects a change in the inductance, it places a “call” to the controller. The 222 card has several settings that allow you to “tune” the card to the particular site (see Figure A6). You can change the frequency of the RLC circuit made by the detector, the Detector Lead-in Cable (DLC) and the in-pavement loop. You can change the sensitivity of the RLC circuit made by the detector card to accommodate various loop configurations and the need to pick up various vehicles. One must be careful when setting the frequency and sensitivity because if done improperly, the loop can miss calls for certain vehicles, or can “lock up” whereby it places a constant call even when no vehicles are present or can pick up vehicles from adjacent lanes. However, when installed and set properly, the loops in the right configuration with the correct detector settings can detect vehicles ranging from a bicycle to a semi-tractor trailer combination.

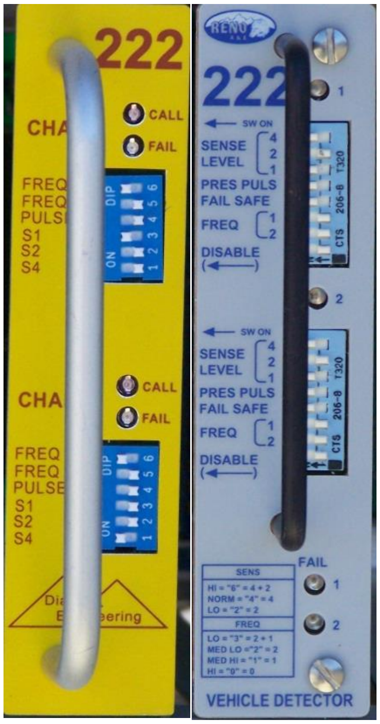


Figure A6 – Front view of Type 222 Detector Card

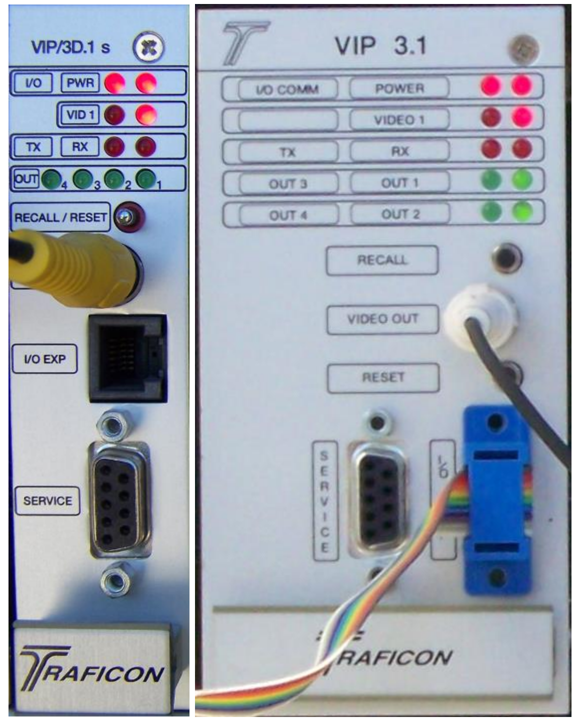


Figure A7 – Front view of Video Image Vehicle Detector System

Figure A7 shows two form factors for VIVDS detection cards, they are both 4 channel cards. However, one card takes up two slots while the other only takes up one slot. The two-slot-wide card provides outputs for the all the slots it covers, while the single wide card provides outputs for the slot it occupies and optionally the slot to the left (of the one it occupies). The advantage of the single slot card is it allows the placement of another card in the slot to the left of the VIVDS card for another type of detection. For instance, a loop detector card could be placed in the slot immediately to the left of the single slot card and each card would then provide 2 outputs. This is advantageous in the Model 332 Cabinet with the limited number of input detector slots available.

A.1.2.2 Model 242 DC Isolator Card

The 242 DC Isolator Card (see Figure A8) is a single slot card that interfaces between the controller and a contact switch that allows for a “call” for service from a device. For instance, if a pedestrian activates (pushes) a push button, a contact closure is made and the DC isolator card detects that and passes that information on to the controller which then provides a pedestrian phase to allow the pedestrian to cross the street. The DC isolator card can also be used for some preemption circuits and to place the controller into a frozen “STOP TIME” state whereby whatever indications are displayed stay in that condition until the “STOP TIME” switch is turned off. They are also used to pass on a call for the signal cabinet to go into “flashing all red.” The DC Isolator card has a switch for each upper and lower input (Channel 1 and Channel 2, respectively) that is a three position toggle switch with “on”(up), “off”(center) and “momentary on”(down) positions.

Figure A8 – Front view of 242 DC Isolator Card

Figure A9 – Front view of 252 Railroad Isolator Card

The field terminations for the DC isolator inputs are on the terminal blocks located on the side dead panel on terminal blocks, TB-8 and TB-9 (see Figure A4 and Figure A5).

A.1.2.3 Model 252 Railroad Preemption Card

The 252 Railroad Isolator Card is an AC isolator Card that provides the interface between the controller and the Railroad Crossing Gates (see Figure 9) and is located in the "J" File in slot 14 (see Figure A2 and Figure A3). The field terminations for the AC isolator inputs are on the terminal blocks located on the side dead panel on terminal block TB-9 (see Figure A4 and Figure A5). The AC Isolator card has a switch for each upper and lower input (Channel 1 and Channel 2, respectively) that is a three-position toggle switch with "on"(up), "off"(center) and "momentary on"(down) positions.

A.1.2.4 Emergency Vehicle Preemption Card

The Emergency Vehicle Preemption (EVP) cards are positioned in the "J" file in slots 12 and 13 (see Figure A3). These cards are called Discriminator cards in the industry and are used to preempt the signal for emergency vehicles such as Fire Engines but can also be used to provide a "soft" preemption for mass transit vehicles (See Figure A10). These are optical or GPS cards that detect either a strobe of infrared light or position of a vehicle by a GPS location. The discriminator card can be configured to determine which type of vehicle is making a call (class of vehicle, either emergency or mass transit) and can be configured to screen those calls by comparing the vehicle identification number which is encoded into the Infrared strobe. When the discriminator card detects an emergency vehicle call for service that meets the vehicle class and authorized ID, it passes on that call to the controller which terminates the conflicting phases of the signal and provides a green indication for traffic travelling the same direction as the emergency vehicle, to allow them to clear out of the way.

In Mass Transit mode, the EVP provides a "soft" preemption which means that it will not terminate a conflicting phase to provide a green phase for the mass transit vehicle. However, it will extend a green indication for traffic travelling the same direction as the mass transit vehicle to allow the mass transit vehicle to pass through the intersection, minimizing stops and delays.

A.1.3 Output File

The Output File is the section of the Type 332 cabinet that interfaces the Signal Controller with the field display elements which indicate to vehicles and pedestrians what moves are allowed or disallowed. The output file consists of three sections, a load switch section, a flasher relay section and the Conflict Monitor (see Figure A11).

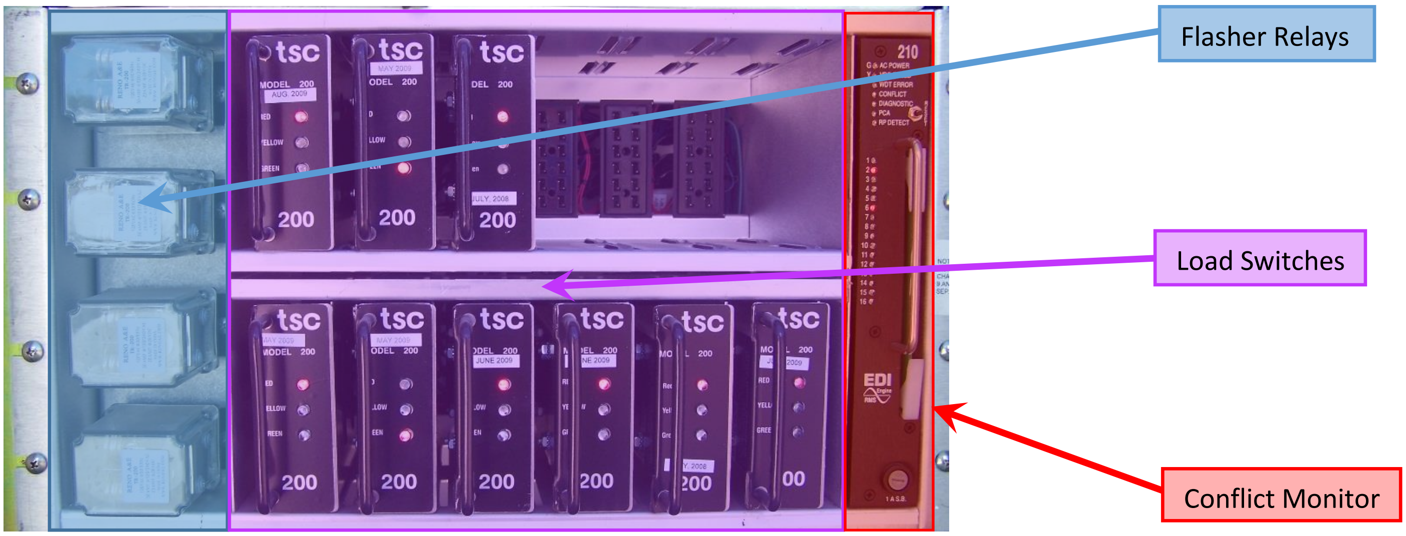


Figure A11 – Front view of the Output File in a Traffic Signal Controller Cabinet

A.1.3.1 Output File Load Switches

The Load Switch section of the output file directs power to the various signal displays to provide the green, yellow and red indications with power. Load switches are solid state switches or electrical relays that allow the controller, which operates in a 12/24-volt DC environment, to direct a 120-volt AC current to various signal displays. Each load switch plugs into a load switch bay in the back panel of the cabinet. The number of load switch bays will dictate the number of output channels that the signal has to work with at the intersection. A load switch is typically required for each vehicle signal phase, each pedestrian phase and if needed, each overlap phase.

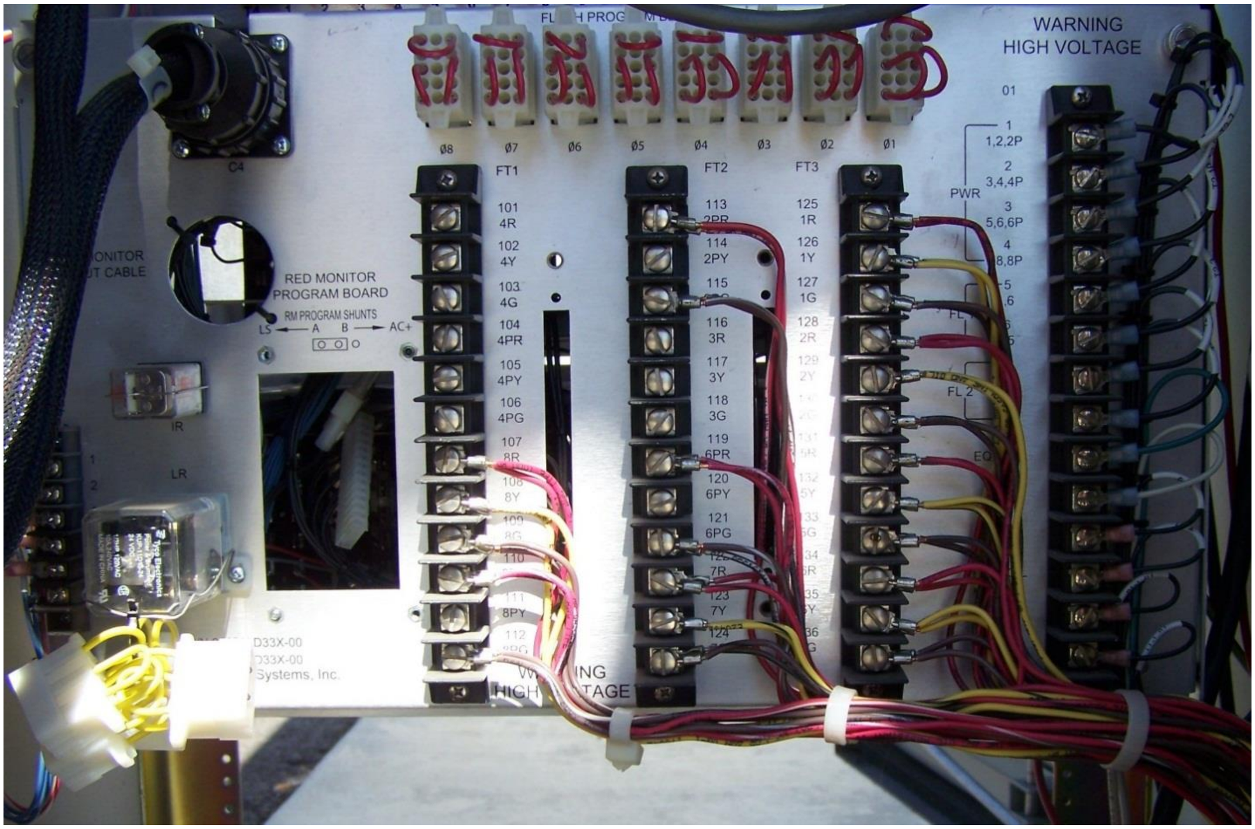
Figure A12 shows the standard layout of the output file for a Model 332 Signal Cabinet from the front of the cabinet. The Model 2070 Controller allows all of the outputs to be re-designated as needed for the intersection geometry and movements allowed and if needed, an auxiliary output file can be included to get additional outputs.

Figure A12 - Standard layout of the output file for a Model 332 Traffic Signal Cabinet

Figure A13 shows the output file from the field-wiring side of the Type 332 controller cabinet (view from the back door), which is where the conductors for the field elements are connected to the load switches. Figure A14 is a part of an excel spreadsheet called the "Field Wiring Diagram" that is produced for each signalized intersection. The full spread sheet is attached at the end of Appendix F. The table shown in Figure A14 corresponds to the output file section of the "Field Wiring Diagram" for the particular cabinet shown in Figure A13.

It is important for verification of correct field wiring termination and future maintenance activities that the Cabinet Field Wiring be installed in a clean workman-like manner. Poorly installed Cabinet Field Wiring can make troubleshooting much more difficult and complicates the addition of new equipment in the cabinet, as well as making cabinet replacement much more difficult in the event of a cabinet knock down. The conformance to clean workmanlike installation requires open communication between Traffic Operations Staff, Construction Personnel, Maintenance personnel and the Contractor. It is important that the Contractor and Construction staff understand the reasoning behind the need for a clean wiring installation to ensure compliance with the request.

An example of desired cabinet field wiring and poor cabinet field wiring can be found in Figure A21 and Figure A22, respectively.



TYPICAL FIELD TERMINALS

Field Terminal	Function		Field Terminal	Function		Field Terminal	Function	
101	SWPK 4 - RED		113	SWPK 2P - RED	Ø2 DONT WALK	125	SWPK 1 - RED	
102	SWPK 4 - YEL	Ø4	114	SWPK 2P - YEL		126	SWPK 1 - YEL	Ø1
103	SWPK 4 - GRN		115	SWPK 2P - GRN	Ø2 WALK	127	SWPK 1 - GRN	
104	SWPK 4P - RED	Ø4 DONT WALK	116	SWPK 3 - RED		128	SWPK 2 - RED	
105	SWPK 4P - YEL		117	SWPK 3 - YEL	Ø3	129	SWPK 2 - YEL	Ø2
106	SWPK 4P - GRN	Ø4 WALK	118	SWPK 3 - GRN		130	SWPK 2 - GRN	
107	SWPK 8 - RED		119	SWPK 6P - RED	Ø6 DONT WALK	131	SWPK 5 - RED	
108	SWPK 8 - YEL	Ø8	120	SWPK 6P - YEL		132	SWPK 5 - YEL	Ø5
109	SWPK 8 - GRN		121	SWPK 6P - GRN	Ø6 WALK	133	SWPK 5 - GRN	
110	SWPK 8P - RED	Ø8 DONT WALK	122	SWPK 7 - RED		134	SWPK 6 - RED	
111	SWPK 8P - YEL		123	SWPK 7 - YEL	Ø7	135	SWPK 6 - YEL	Ø6
112	SWPK 8P - GRN	Ø8 WALK	124	SWPK 7 - GRN		136	SWPK 6 - GRN	

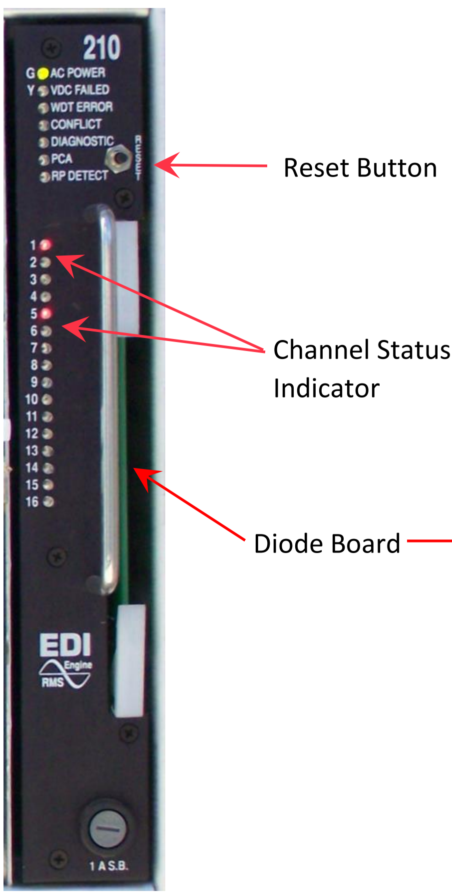
Figure A14 – Example of table for the "Field Wiring Diagram" that is produced for each traffic signal

A.1.3.2 Output File Flasher Relays

The Flasher Relay section of the output file is responsible for directing power from either the output file load switches to the traffic signal indications or connecting the flasher units to the traffic signal indications which happens when the signal is placed on “all red flash” for all approaches.

A.1.3.3 Output File Conflict Monitor

The Model 210 Conflict Monitor is a device that checks the voltages for the controller and the outputs of the load switches (voltages on all of the green and yellow indications) to verify that there are no indications showing that would allow conflicting vehicle or pedestrian movements to enter the intersection at the same time, due to malfunction of the controller unit, load switches, field wiring and loads or mis-wiring of the cabinet (see Figure A15). The Diode Program Card provides the means to assign non-conflicting channels (see Figure A16). The card is initially supplied with 120 diodes mounted on it; this permits all channels to conflict with all other channels. To program a *NON-CONFLICTING* (permissive) channel pair, the appropriate diode must be removed from the program card. For example, if channel 2 Green or Yellow is permissive with channel 6 Green or Yellow, the diode labeled "2-6" is removed. See Figure A17 and Figure A18 for samples of the “Diode Board” spreadsheet attached at the end of this appendix.



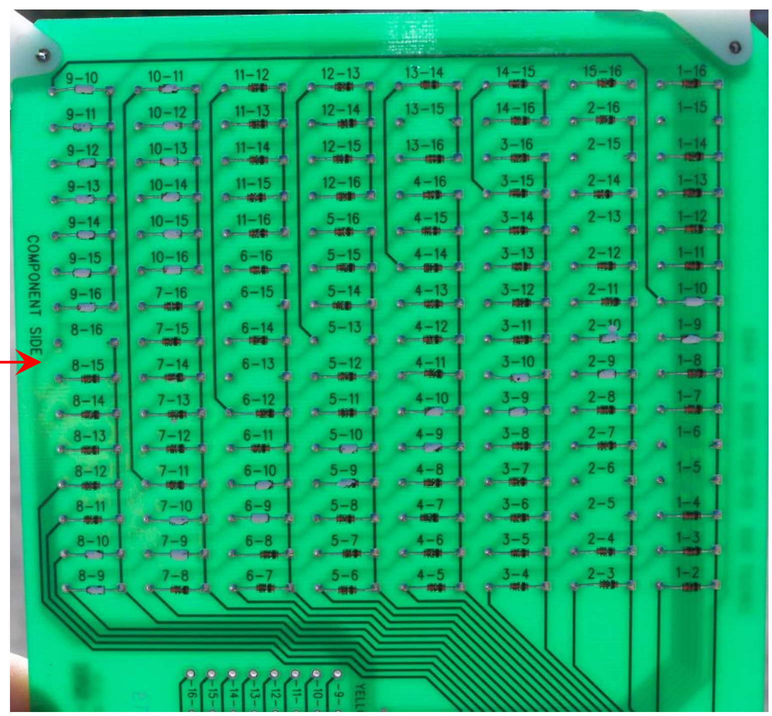


Figure A15 – Model 210 Conflict Monitor

Figure A16 – Diode Program Card used to assign non-conflicting channels

INTERSECTION:	**Alexander & Xavier**	CO-RTE-PM:	**CAL-XX-00.00**
CITY:	**Celebrity City**	DATE:	**9/3/2015**
		BY:	**Someone**

CALTRANS District 2
Traffic Operations
Diode Board

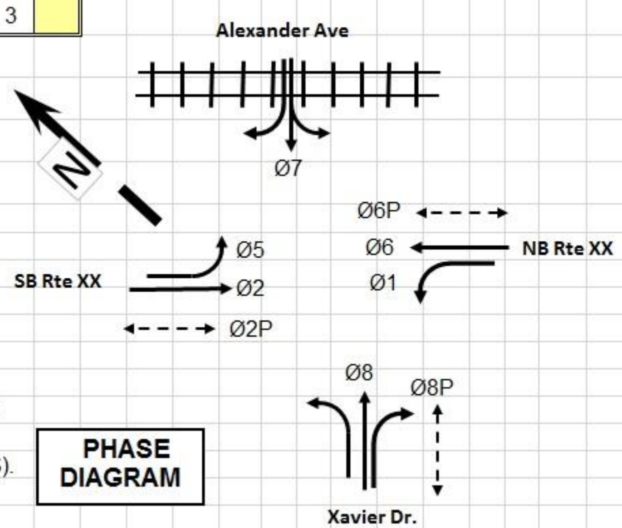
TYPE 170 CONTROLLER
MODEL 210 CONFLICT MONITOR PROGRAMMING INSTRUCTIONS

CHANNELS AND PHASES

	CHANNEL 16 = Ø8 PED.	CHANNEL 15 = Ø6 PED.	CHANNEL 14 = Ø4 PED.	CHANNEL 13 = Ø2 PED.	CHANNEL 12 = SPECIAL	CHANNEL 11 = SPECIAL	CH. 10 = OVERLAP "B" Ø6PED YELLOW (GRN. ARROW) + Ø8PED YELLOW (YEL. ARROW)	CH. 9 = OVERLAP "A" Ø2PED YELLOW (GRN. ARROW) + Ø4PED YELLOW (YEL. ARROW)
1		X						
2		X		X				
3								
4								
5				X				
6		X		X				
7								
8	X							
9								
10								
11								
12								
13		X						
14								
15								

CHANNELS AND PHASES

	CHANNEL 8 = Ø8	CHANNEL 7 = Ø7	CHAN. 6 = Ø6	CHAN. 5 = Ø5	CH.4 = Ø4	CH.3 = Ø3	CH.2 =Ø2
1			X	X			
2			X	X			
3							
4							
5							
6							
7							



PHASE DIAGRAM

NOTES:
1. CONFLICT MONITOR PROGRAM CARD IS SUPPLIED WITH ALL 120 DIODES MOUNTED, WHICH CAUSES ALL CHANNELS (PHASES) TO BE IN CONFLICT WITH EACH OTHER.
2. MARK CHANNELS (PHASES) WHICH ARE NOT CONFLICTING FOR THIS INTERSECTION (INCLUDE PEDS AND OVERLAPS).
3. REMOVE DIODES FOR THESE CHANNELS (PHASES).
4. MARK CARD WITH INTERSECTION NAME.

Figure A17 – Example of Diode Board spreadsheet for Model 2010 Conflict Monitor

INTERSECTION:	Alexander & Xavier	CO-RTE-PM:	CAL-XX-00.00
CITY:	Celebrity City	DATE:	9/3/2015
		BY:	Someone

CALTRANS District X
Traffic Operations
Diode Board

CONFLICT MONITOR DIODE BOARD

9-10	10-11	11-12	12-13	13-14	14-15	15-16	1-16
9-11	10-12	11-13	12-14	13-15 X	14-16	2-16	1-15 X
9-12	10-13	11-14	12-15	13-16	3-16	2-15 X	1-14
9-13	10-14	11-15	12-16	4-16	3-15	2-14	1-13
9-14	10-15	11-16	5-16	4-15	3-14	2-13 X	1-12
9-15	10-16	6-16	5-15	4-14	3-13	2-12	1-11
9-16	7-16	6-15 X	5-14	4-13	3-12	2-11	1-10
8-16 X	7-15	6-14	5-13 X	4-12	3-11	2-10	1-9
8-15	7-14	6-13 X	5-12	4-11	3-10	2-9	1-8
8-14	7-13	6-12	5-11	4-10	3-9	2-8	1-7
8-13	7-12	6-11	5-10	4-9	3-8	2-7	1-6 X
8-12	7-11	6-10	5-9	4-8	3-7	2-6 X	1-5 X
8-11	7-10	6-9	5-8	4-7	3-6	2-5 X	1-4
8-10	7-9	6-8	5-7	4-6	3-5	2-4	1-3
8-9	7-8	6-7	5-6	4-5	3-4	2-3	1-2

Figure A18 – Example of Worksheet for Conflict Monitor Diode Board

The Model 210 also monitors and provides error sensing of the cabinet 24VDC supply and the controller unit Watchdog signal. If a fault condition is determined to have occurred, a relay output places the cabinet and intersection into Flash operation. It does this by energizing the cabinet Power Relay Coils that transfer field outputs from the Output File Switch Pack outputs to the Flasher Unit outputs. At the same time, the unit places the controller in a Stop Time state and the front panel indications of the Model 210 describe the applicable fault condition. The Model 210, once entering into a Failed State, will remain in the Failed State until a Reset command is issued. Reset can be issued only by the front panel Reset button.

A.1.4 Power Distribution Assembly

The Power Distribution Assembly is the section of the Type 332 cabinet that provides AC and DC power to the controller, cabinet input file, cabinet output file, flashers and equipment outlets for power tools or additional devices such as VIVDS monitors.

The Power Distribution Assembly consists of three front sections and the Outlet Panel on the back (see Figure A19 and Figure A20). The front sections are:

1. Model 206 Power Supply
2. Model 204 Flasher Units
3. Power Distribution Panel

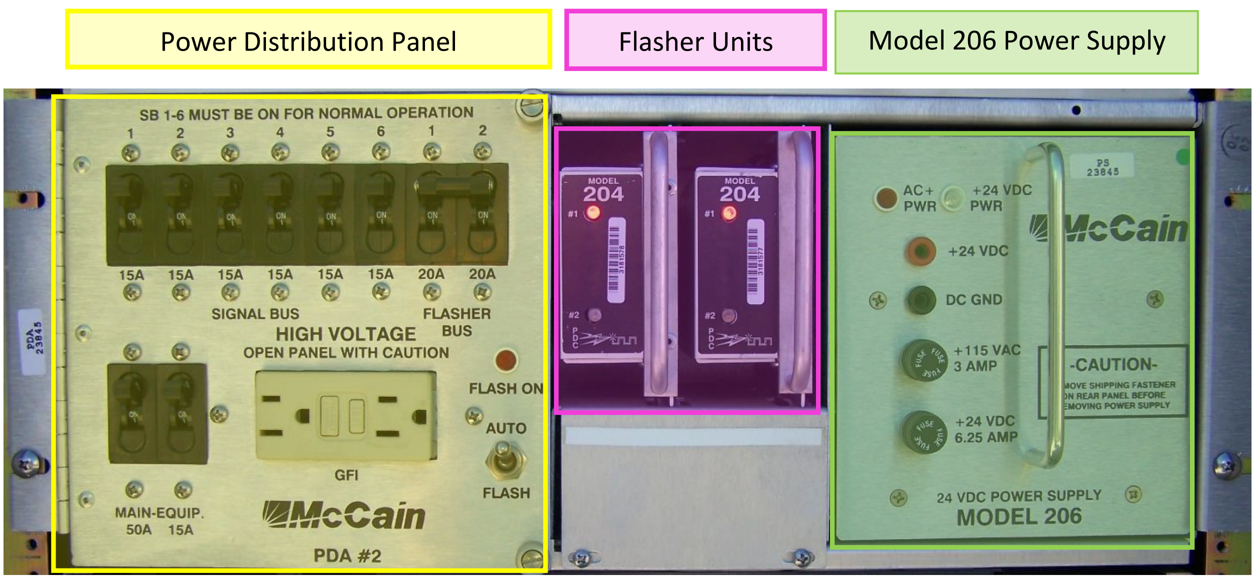


Figure A19 – Example of Power Distribution Assembly

A.1.4.1 Model 206 Power Supply

The Model 206 Power Supply provides 24 VDC to the Input and Output Files for use by their associated devices. The front of the unit includes input and output indicator lights, input and output fuse protection and banana jack style test points for testing the output voltage.

A.1.4.2 Model 204 Flasher Unit

The Model 204 Flasher Units are modular plug-in devices containing one flasher control circuit and two solid state switches. The function of the Flasher Unit is to alternately open and close connections between the AC power and external traffic signal load. The two alternating flash circuits are synchronized so as to never be on or off at the same time and to provide 50 to 60 flashes per minute.

A.1.4.3 Power Distribution Panel

The Power Distribution Panel includes the Main Equipment breaker, the Signal Bus breakers the Flasher Bus breakers, the 120VAC equipment receptacle and the “AUTO/FLASH” switch. The “AUTO/FLASH” switch is a double pole single throw switch that when in the “AUTO” (up) position, de-energizes a Power Relay Coil which allows the Load Switches to control the signal indications. When the switch is in the “FLASH” position, the power relay coil is energized and the “STOP TIME” is applied to the controller; this allows the Model 204 Flasher Units to control the signal indications.

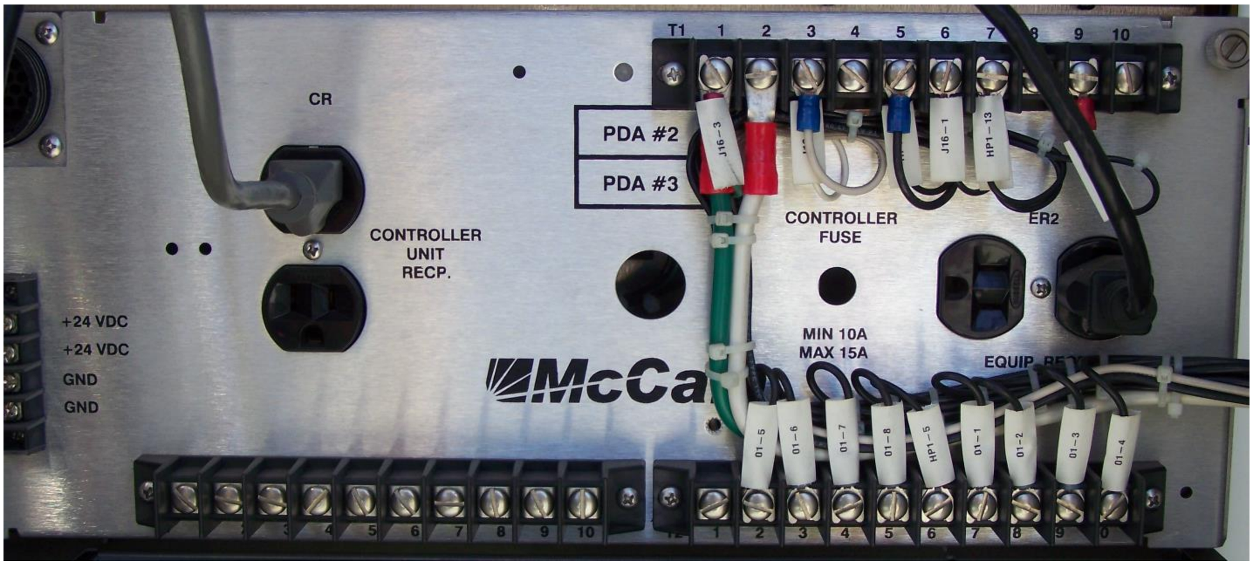


Figure A20 – Backside of Power Distribution Assembly

The backside of the Power Distribution Assembly has two 120V duplex receptacles, one for the Controller and one for other equipment (see Figure A20). There are also 4 terminal blocks for wire connections. The T1 terminal block has the input power terminals and supplies 120V power to the Equipment Receptacles, the PDA Circuit Breakers (Main and CB-5/6) and the Model 206 Power Supply. The T2 terminal block provides 120V power to the PDA Circuit Breakers (CB-1/2/3/4) and the Flasher Units. The T3 terminal block supplies 24V DC to the Input Files. The T4 terminal block is an unused terminal block (see the TEES for more detail, http://www.dot.ca.gov/hq/traffops/tech/tees.html).

A.1.5 Controller Cabinet Field Wiring

A.1.5.1 Desirable Field Wiring

Figure A21 is an example of a clean desirable Cabinet Field Wiring installation. As can be seen, using a few clipped wire ties results in conductors that are easily traceable to the cables and then to the conduit. If it was needed for a conductor to be changed or added, it could be laced in with the existing conductors and the cables tied into the clean bundles again. With this Cabinet Field Wiring installation, the back panel of the output file could be opened without disturbing the field wiring connections.

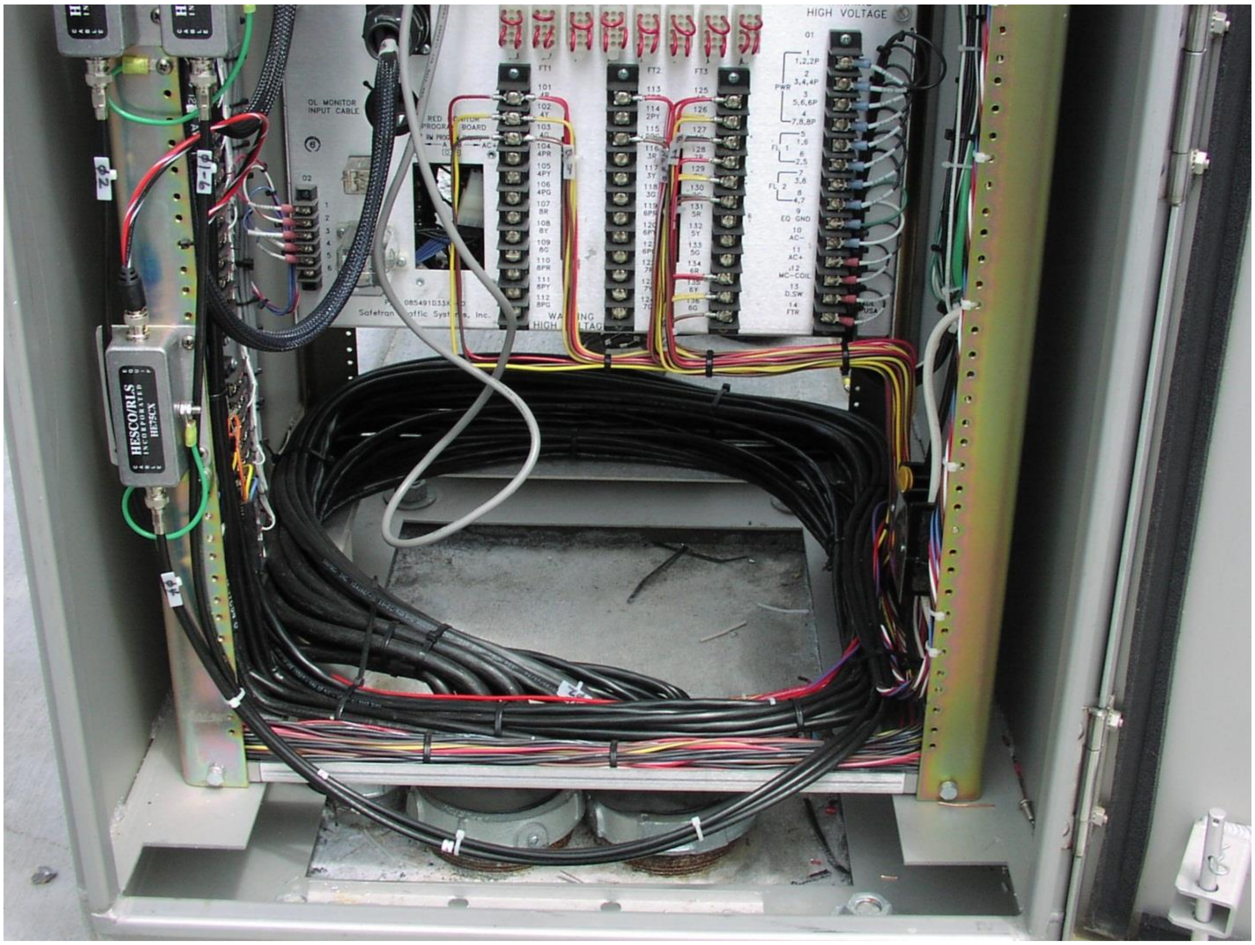


Figure A21 – Example of desirable field wiring in the Type 332 Controller Cabinet

A.1.5.2 Undesirable Field Wiring

Figure A22 is an example of a poor Cabinet Field Wiring installation. It can be seen that tracing conductors out and identifying which cable the conductors were from would be very difficult and modifying the installation would be a very tedious and slow process. With this Cabinet Field Wiring installation, the back panel of the output file could not be opened without likely disturbing the field wiring connections.

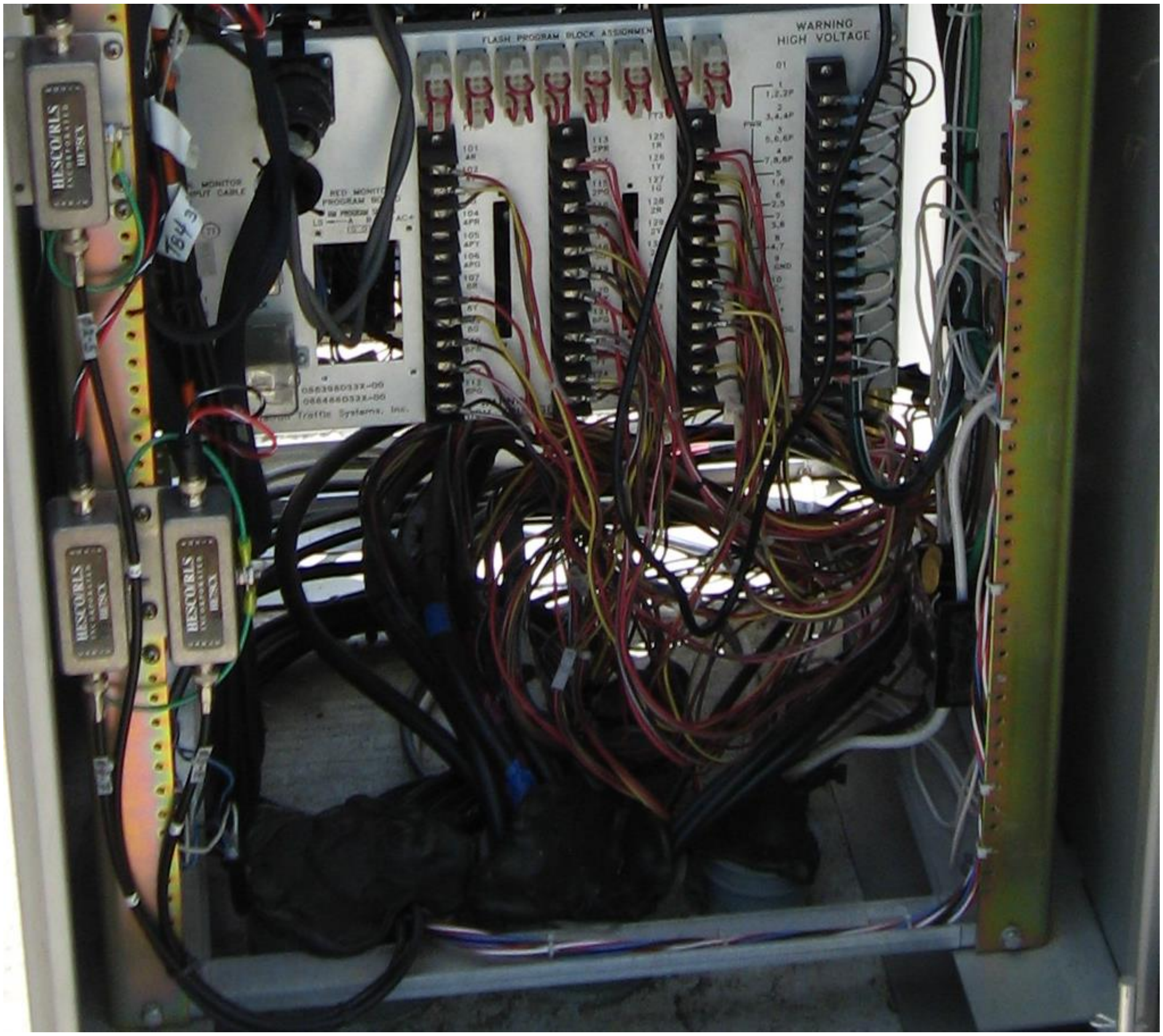


Figure A22 - Example of undesirable field wiring in the Type 332 Controller Cabinet

LOCATION ____________ CO ______ RTE ______ PM ______

LEGEND	
(olive)	= VVDS
(yellow)	= LOOP DETECTOR
(orange)	= LOAD SWITCHES
(grey)	= VVDS NOT ASSIGNED
(red)	= DAMAGED

TYPICAL DETECTOR FIELD WIRING

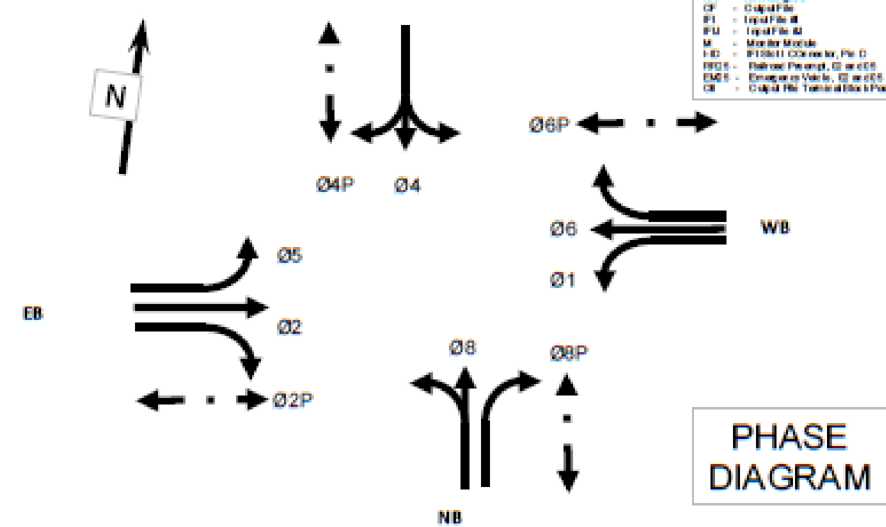
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
"I"	U	1 Ø1 E,CT	3 Ø2 E,CT	5 Ø2 E,CT	7 Ø2 CALL	9 Ø3 E,CT	11 Ø4 E,CT	13 Ø4 E,CT	15 Ø4 CALL	17 Ø1 E,CT	19 Ø2 E,CT	ADV	PED Ø2	PED Ø6	FLH
	L	Ø1 E,CT 2	Ø2 E,CT 4	Ø2 E 6	Ø2 E,CT 8	Ø3 E,CT 10	Ø4 E,CT 12	Ø4 E 14	Ø4 CALL 16	Ø3 E,CT 18	Ø4 E,CT 20	SP1	PED Ø4	PED Ø8	STOP TIME
"J"	U	21 Ø5 E,CT	23 Ø6 E,CT	25 Ø6 E,CT	27 Ø6 CALL	29 Ø7 E,CT	31 Ø8 E,CT	33 Ø8 E,CT	35 Ø8 CALL	37 Ø5 E,CT	39 Ø6 E,CT	SP2	EVA	EVB	RR1
	L	Ø5 E,CT 22	Ø6 E,CT 24	Ø6 E 26	Ø6 E,CT 28	Ø7 E,CT 30	Ø8 E,CT 32	Ø8 E 34	Ø8 E,CT 36	Ø7 E,CT 38	Ø8 E,CT 40	SP3	EVC	EVD	RR2

TYPICAL FIELD TERMINALS

Field Terminal	Function		Field Terminal	Function		Field Terminal	Function	
101	SWPK 4 - RED		113	SWPK 2P - RED	Ø2 DON'T WALK	125	SWPK 1 - RED	
102	SWPK 4 - YEL	Ø4	114	SWPK 2P - YEL		126	SWPK 1 - YEL	Ø1
103	SWPK 4 - GRN		115	SWPK 2P - GRN	Ø2 WALK	127	SWPK 1 - GRN	
104	SWPK 4P - RED	Ø4 DON'T WALK	116	SWPK 3 - RED		128	SWPK 2 - RED	
105	SWPK 4P - YEL		117	SWPK 3 - YEL	Ø3	129	SWPK 2 - YEL	Ø2
106	SWPK 4P - GRN	Ø4 WALK	118	SWPK 3 - GRN		130	SWPK 2 - GRN	
107	SWPK 8 - RED		119	SWPK 6P - RED	Ø6 DON'T WALK	131	SWPK 5 - RED	
108	SWPK 8 - YEL	Ø8	120	SWPK 6P - YEL		132	SWPK 5 - YEL	Ø5
109	SWPK 8 - GRN		121	SWPK 6P - GRN	Ø6 WALK	133	SWPK 5 - GRN	
110	SWPK 8P - RED	Ø8 DON'T WALK	122	SWPK 7 - RED		134	SWPK 6 - RED	
111	SWPK 8P - YEL		123	SWPK 7 - YEL	Ø7	135	SWPK 6 - YEL	Ø6
112	SWPK 8P - GRN	Ø8 WALK	124	SWPK 7 - GRN		136	SWPK 6 - GRN	

LEGEND

NA - Not Assigned
OF - Output File
IFI - Input File I
IFJ - Input File J
M - Monitor Module
I-HD - [illegible] Connector, Pin D
RRDS - Railroad Preempt, [illegible]
EMDS - Emergency Vehicle, [illegible]
OF - Output File Terminal Block Position 8



PANEL TERMINAL BLOCK ASSIGNMENT DETAIL

POS	A	B	
TB2-1	DET 1	I-1D	Ø1
2		I-1E	Ø1
3	DET 2	I-1J	Ø1
4		I-1K	Ø1
5	DET 3	I-2D	Ø2
6		I-2E	Ø2
7	DET 4	I-2J	Ø2
8		I-2K	Ø2
9	DET 5	I-3D	Ø2
10		I-3E	Ø2
11	DET 6	I-3J	Ø2
12		I-3K	Ø2

POS	A	B	
TB3-1	DET 21	J-1D	Ø5
2		J-1E	Ø5
3	DET 22	J-1J	Ø5
4		J-1K	Ø5
5	DET 23	J-2D	Ø6
6		J-2E	Ø6
7	DET 24	J-2J	Ø6
8		J-2K	Ø6
9	DET 25	J-3D	Ø6
10		J-3E	Ø6
11	DET 26	J-3J	Ø6
12		J-3K	Ø6

POS	A	B	
TB8-1	MANUAL	I-11D	ADV
2	SPARE	I-11J	SP1
3	11 COM	I-11K	SP1
4	PED Ø2	I-12D	Ø2 PED
5	PED Ø4	I-12J	Ø4 PED
6	12 COM	I-12K	Ø4 PED
7	PED Ø6	I-13D	Ø6 PED
8	PED Ø8	I-13J	Ø8 PED
9	13 COM	I-13K	Ø8 PED
10	FLH SENSE	I-14D	FLH
11	STOP TIME	I-14J	STOP TIME
12	14 COM	I-14K	STOP TIME

POS	A	B	
TB4-1	DET 7	I-4D	Ø2
2		I-4E	Ø2
3	DET 8	I-4J	Ø2
4		I-4K	Ø2
5	DET 9	I-5D	Ø3
6		I-5E	Ø3
7	DET 10	I-5J	Ø3
8		I-5K	Ø3
9	DET 11	I-6D	Ø4
10		I-6E	Ø4
11	DET 12	I-6J	Ø4
12		I-6K	Ø4

POS	A	B	
TB5-1	DET 27	J-4D	Ø6
2		J-4E	Ø6
3	DET 28	J-4J	Ø6
4		J-4K	Ø6
5	DET 29	J-5D	Ø7
6		J-5E	Ø7
7	DET 30	J-5J	Ø7
8		J-5K	Ø7
9	DET 31	J-6D	Ø8
10		J-6E	Ø8
11	DET 32	J-6J	Ø8
12		J-6K	Ø8

POS	A	B	
TB9-1	SPARE 2	J-11D	SP2
2	SPARE 3	J-11J	SP3
3	11 COM	J-11K	SP3
4	EM 25	J-12D	EVA
5	EM 61	J-12J	EVC
6	12 COM	J-12K	EVA/EVC COM
7	EM 47	J-13D	EVB
8	EM 81	J-13J	EVD
9	13 COM	J-13K	EVB/EVD COM
10	RR 25	J-14D	RR1
11	RR 47	J-14J	RR2
12	14 COM	J-14K	RR1/RR2 COM

POS	A	B	
TB6-1	DET 13	I-7D	Ø4
2		I-7E	Ø4
3	DET 14	I-7J	Ø4
4		I-7K	Ø4
5	DET 15	I-8D	Ø4
6		I-8E	Ø4
7	DET 16	I-8J	Ø4
8		I-8K	Ø4
9	DET 17	I-9D	Ø1
10		I-9E	Ø1
11	DET 18	I-9J	Ø3
12		I-9K	Ø3

POS	A	B	
TB7-1	DET 33	J-7D	Ø8
2		J-7E	Ø8
3	DET 34	J-7J	Ø8
4		J-7K	Ø8
5	DET 35	J-8D	Ø8
6		J-8E	Ø8
7	DET 36	J-8J	Ø8
8		J-8K	Ø8
9	DET 37	J-9D	Ø5
10		J-9E	Ø5
11	DET 38	J-9J	Ø7
12		J-9K	Ø7

POS	A	B	
TB10-1	DET 19	I-10D	Ø2
2		I-10E	Ø2
3	DET 20	I-10J	Ø4
4		I-10K	Ø4
5	DET 39	J-10D	Ø6
6		J-10E	Ø6
7	DET 40	J-10J	Ø8
8		J-10K	Ø8
9			
10			
11			
12			

1 of 1

INTERSECTION: ______________________ CO-RTE-PM: ______________

CITY: ______________________ DATE: ______________

BY: ______________

CALTRANS District 2
Traffic Operations
Diode Board

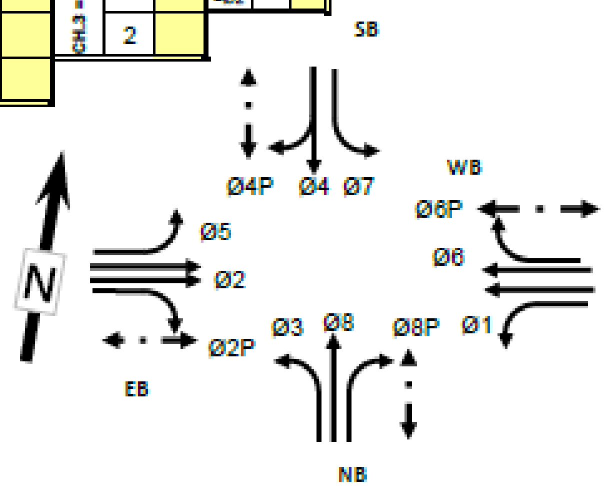
TYPE 170 CONTROLLER
MODEL 210 CONFLICT MONITOR PROGRAMMING INSTRUCTIONS

CHANNELS AND PHASES

CHANNEL 16 = Ø8 PED.	CHANNEL 15 = Ø6 PED.	CHANNEL 14 = Ø4 PED.	CHANNEL 13 = Ø2 PED.	CHANNEL 12 = SPECIAL	CHANNEL 11 = SPECIAL	CH. 10 = OVERLAP "B" Ø6PED YELLOW + Ø8PED YELLOW (GRN. ARROW) (YEL. ARROW)	CH. 9 = OVERLAP "A" Ø2PED YELLOW + Ø4PED YELLOW (GRN. ARROW) (YEL. ARROW)
1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	
10	10	10	10	10	10		
11	11	11	11	11			
12	12	12	12				
13	13	13					
14	14						
15							

CHANNELS AND PHASES

CHANNEL 8 = Ø8	CHANNEL 7 = Ø7	CHAN. 6 = Ø6	CHAN. 5 = Ø5	CH.4 = Ø4	CH.3 = Ø3	CH.2 =Ø2
1	1	1	1	1	1	1
2	2	2	2	2	2	
3	3	3	3	3		
4	4	4	4			
5	5	5				
6	6					
7						



PHASE DIAGRAM

NOTES:

1. CONFLICT MONITOR PROGRAM CARD IS SUPPLIED WITH ALL 120 DIODES MOUNTED, WHICH CAUSES ALL CHANNELS (PHASES) TO BE IN CONFLICT WITH EACH OTHER.
2. MARK CHANNELS (PHASES) WHICH ARE NOT CONFLICTING FOR THIS INTERSECTION (INCLUDE PEDS AND OVERLAPS).
3. REMOVE DIODES FOR THESE CHANNELS (PHASES).
4. MARK CARD WITH INTERSECTION NAME.

APPENDIX B

SIGNAL CONTROLLER ASSEMBLY RECORD (SCAR)

Each controller cabinet should have a Signal Controller Assembly Record (SCAR) which documents the specific configuration of that unique signalized intersection. The SCAR will include:

1. Conflict Monitor Board Worksheet for Configuration Set-up (See example in Figure B2).
2. Schematic of Cabinet Rear View, Input/Output Files, Auxiliary Output File details with Overlaps shown (See example in Figure B3).
3. Schematic with Typical Interconnect Connections (if Model 170 controller at this location); see example in Figure B5.
4. Terminal Board Configuration (see example in Figure B6).
5. Detector Attributes and Access codes documentation (if Model 170 controller at this location); see example in Figure B7b.
6. Table displaying Model 2070 Detector and Port Assignment (see example in Figure B8).
7. Signal Timing Chart
8. Signalized Intersection Reference Drawing

The following pages (8) are the minimum documents that should be included for each controller cabinet for traffic signals. These are listed as SCAR Page1, SCAR Page 2, SCAR Page 3, SCAR Page 4, SCAR Page 5, SCAR Page 6, SCAR Page 7 and SCAR Page 8. Details of each of the portions described in the SCAR follow the example pages.

LOCATION PCH CO. LA RTE. 1 P.M.

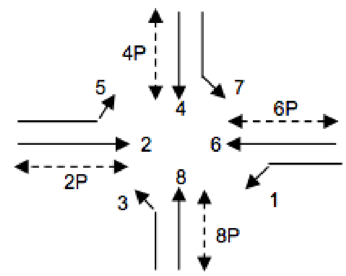
Cherry Ave DATE BY

CONFLICT MONITOR - DIODE BOARD for MODEL 210

CONFLICT MONITOR PROGRAMMING INSTRUCTIONS

CHANNELS AND PHASES

CHANNEL 16 - 08 PED	CHANNEL 15 - 06 PED	CHANNEL 14 - 04 PED	CHANNEL 13 - 02 PED	CHANNEL 12 - SPECIAL (OLD)	CHANNEL 11 - SPECIAL (OLC)	Channel 10- Overlap "F" for 3 colors overlap. CHANNEL 10 - OVERLAP "B" for 2 colors overlap. 06 PED, YELLOW + 08 PED, YELLOW (GREEN ARROW) (YELLOW ARROW) (OLF / OLB)	Channel 9- Overlap "E" for 3 colors overlap. CHANNEL 9 - OVERLAP "A" for 2 colors overlap. 02 PED, YELLOW + 04 PED, YELLOW (GREEN ARROW) (YELLOW ARROW) (OVE / OLA)
1	1	1	1	1	1	1	1
2	> 2	2	> 2	2	2	2	2
3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5
6	> 6	6	> 6	6	6	6	6
7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	
10	10	10	10	10	10		
11	11	11	11	11			
12	12	12	12				
13	> 13	13					
14	14						
15							



CHANNELS AND PHASES

CHANNEL 8 - 08	CHANNEL 7 - 07	CHANNEL 6 - 06	CHANNEL 5 - 05	CHANNEL 4 - 04	CH 3 - 03	CH 2 02
1	1	1	1	1	1	1
2	2	> 2	2	2	2	
3	3	3	3	3		
4	4	4	4			
5	5	5				
6	6					
7						

NOTES:

1. CONFLICT MONITOR PROGRAM CARD IS SUPPLIED WITH ALL 120 DIODES MOUNTED WHICH CAUSES ALL CHANNELS (PHASES) TO BE IN THE CONFLICT WITH EACH OTHER.
2. MARK CHANNELS (PHASES) WHICH ARE NOT CONFLICTING THIS INTERSECTION. (INCLUDING PEDS AND OVERLAPS)
3. REMOVE DIODES FOR THESE CHANNELS (PHASES).
4. MARK CARD WITH INTERSECTION NAME.

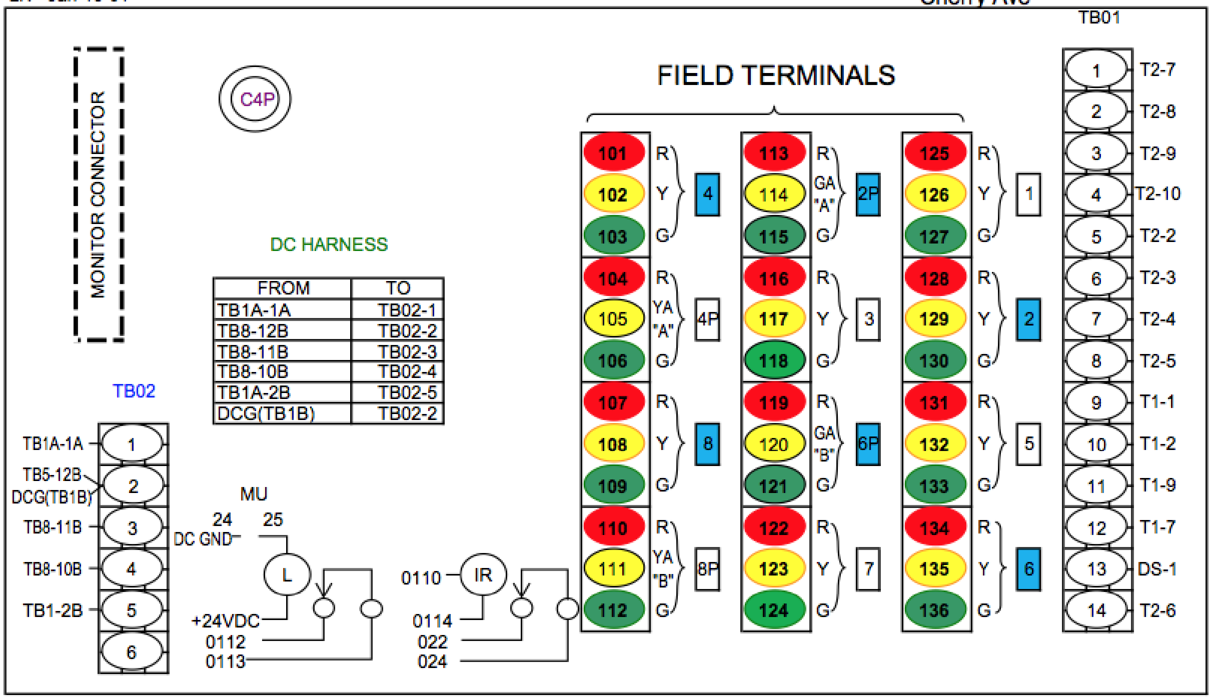
Form TS - 3
LN - Jan 10 - 01
Updated Oct 28-15

SCAR Page 1: Conflict Monitor Board Worksheet

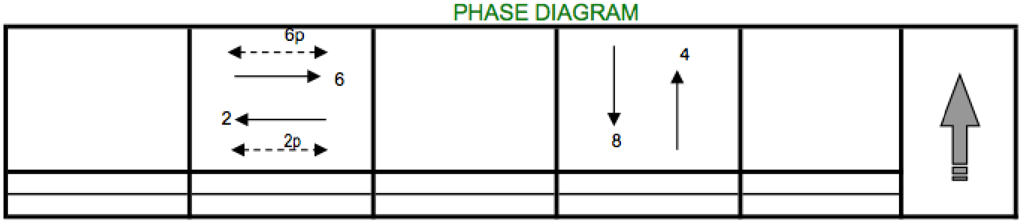
Form TS-2
LN - Jan-10-01

Location: PCH
Cherry Ave

REAR VIEW



PHASE DIAGRAM



INPUT FILE "I" (1)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
U	1CT & EXT	~~2 CT & EXT~~	2 CT & EXT	2 CALL	3 CT &EXT	4 CT & EXT	~~4 CT & EXT~~	4 CALL	1 CT & EXT	2 CT & EXT	Manual Advance	~~2PPB~~	~~6PPB~~	~~Flash Advance~~	U
L	1 CT & EXT	~~2 CT & EXT~~	2 CT & EXT	2 CALL	3 CT &EXT	4 CT & EXT	~~7 EXT & CT~~	4 CALL	3 CT & EXT	4 CT & EXT	Spare 1	4PPB	8PPB	~~Stop Time~~	L

INPUT FILE "J" (2)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
U	5CT & EXT	~~6 CT & EXT~~	6 CT & EXT	6 CALL	7 CT &EXT	8 CT & EXT	~~8 CT & EXT~~	8 CALL	5 CT & EXT	6 CT & EXT	Spare 2	2 & 5 EVA	4 & 7 EVB	~~2 & 6 R/R~~	U
L	5 CT & EXT	~~6 CT & EXT~~	6 CT & EXT	6 CALL	7 CT &EXT	8 CT & EXT	~~8 EXT & CT~~	8 CALL	7 CT & EXT	8 EXT & CT	Spare 3	6 & 1 EVC	8 & 3 EVD	~~4 & 7 R/R~~	L

OUTPUT FILE

		1	~~2~~	~~2P~~	3	~~4~~	4P
		5	~~6~~	~~6P~~	7	~~8~~	8P
Old	FTR FTR	OLC	OLD		OLA	OLB	
		LS1	LS2		LS4	LS5	
New	OLA (E)	FTR	OLB (F)		OLC	FTR	OLD
	SP9		SP10		SP12		SP13

SWITCH PACK FIELD TERMINALS

SP=SWPK= switch pack or LS=load switch

Field Term.		Function	Field Term.		Function	Field Term.		Function
A101	OVB	SWPK 13-RED (5)	A111-01		SWPK3-RED	A121	OVC	SWPK 9-RED (1)
A102	OLD	SWPK 13-YEL (5)	A112-02		SWPK3-YEL	A122	OLA	SWPK 9-YEL (1)
A103		SWPK 13-GRN (5)	A113-03		SWPK3-GRN	A133		SWPK 9-GRN (1)
TSW1-A104-02		SWPK6-RED	A114	OVA	SWPK 12-RED (4)	A124	OVD	SWPK 10-RED (2)
TSW3-A105		SWPK6-YEL	A115	OLC	SWPK 12-YEL (4)	A125	OLB	SWPK 10-YEL (2)
TSW2-A106-03		SWPK6-GRN	A116	"A"	SWPK 12-GRN (4)	A126		SWPK 10-GRN (2)

AUXILIARY OUTPUT FILE DETAIL

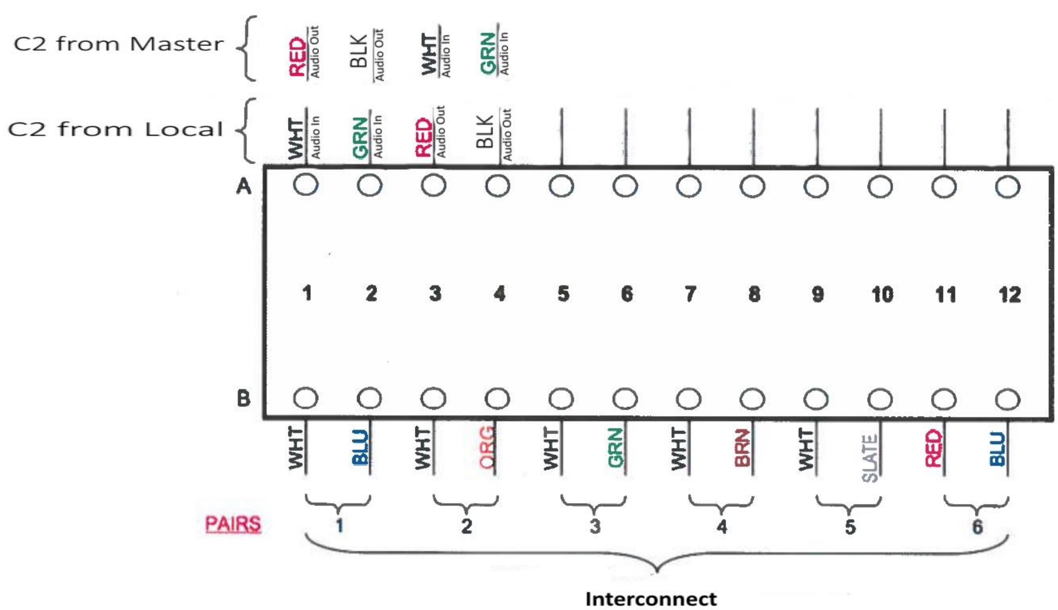
SCAR Page 2: Conflict Monitor Board Worksheet

TYPICAL INTERCONNECT CONNECTIONS

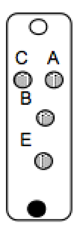
TYPE 170 CONTROLLER SYSTEMS

TB - 0 (SPARE TERMINAL BLOCK)

Location:

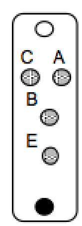


OLD TYPE



	C2			
OLD TYPE	INTERCONNECT HARNESS			NEW TYPE
A	(White)	AUDIO IN	(White)	A
B	(Black)	AUDIO IN	(Green)	B
C	(Red)	AUDIO OUT	(Red)	C
E	(Green)	AUDIO OUT	(Black)	E

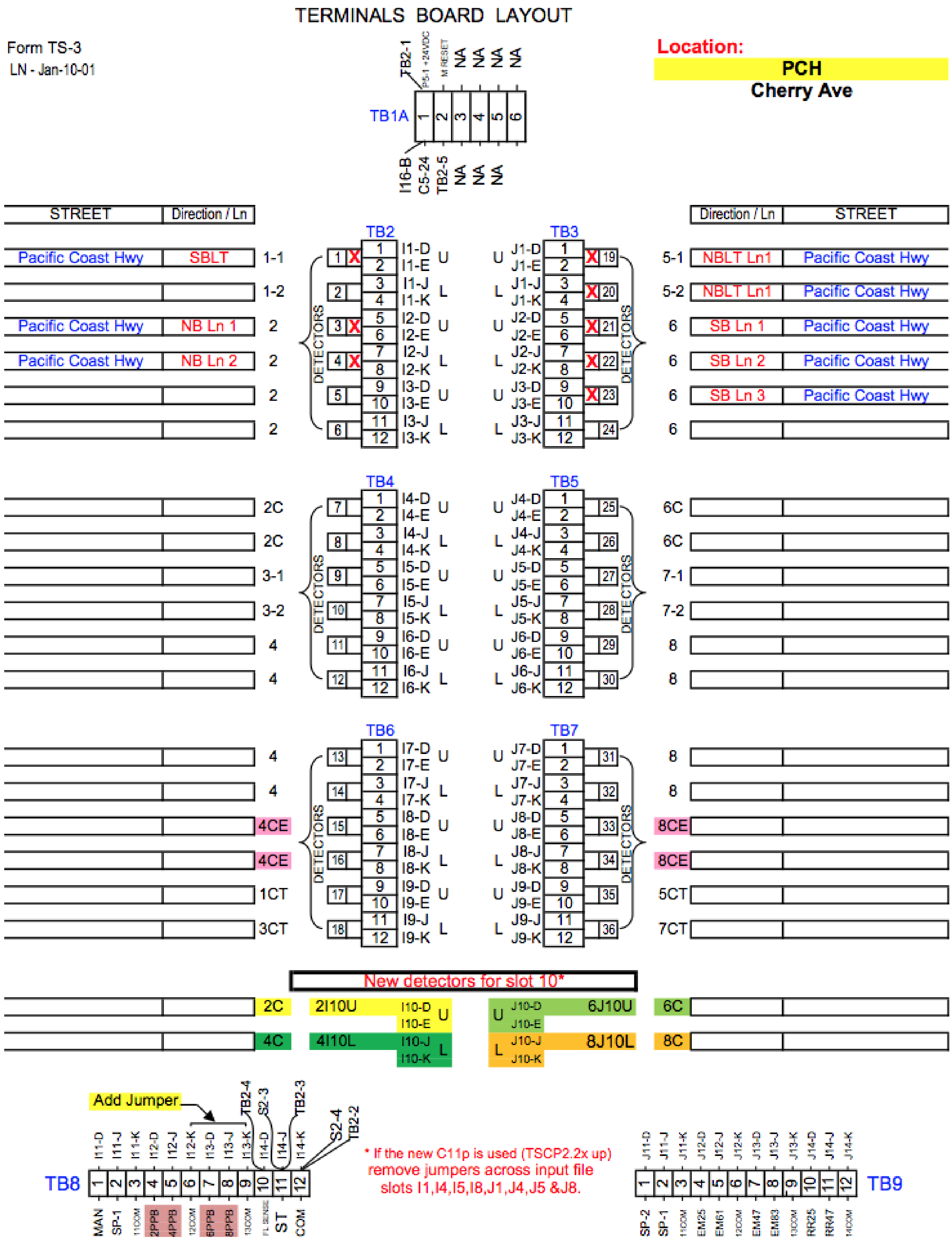
NEW TYPE



NOTES:

1. ALL SPARE INTERCONNECT CONDUCTORS SHALL BE TERMINATED IN A GROUND LUG AND ATTACHED TO CABINET GROUND.
2. SHIELD SHALL BE GROUNDED TO CABINET WITH COPPER GROUNDING STRAP.

SCAR Page 3: Interconnect Connections



SCAR Page 4: Terminal Board Configuration

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
"I"	U	FZ1 E, CT	FZ2 E, CT	FZ2 E, CT	FZ2 C, CT	FZ3 E, CT	FZ4 E, CT	FZ4 E, CT	FZ4 C,CT	FZ1 E, CT	FZ2 E, CT	Man Adv	PED FZ 2	PED FZ 6	Flash Adv
	L	FZ1 E, CT	FZ2 E, CT	FZ2 E	FZ4 C, CT	FZ3 E, CT	FZ4 E, CT	FZ4 E,CT	FZ4 C, CT	FZ3 E, CT	FZ4 E,CT	SP1	PED FZ 4	PED FZ 8	STOP TIME
"J"	U	FZ5 E, CT	FZ6 E, CT	FZ6 E, CT	FZ6 C, CT	FZ7 E, CT	FZ8 E, CT	FZ8 E, CT	FZ8 C, CT	FZ5 E, CT	FZ6 E, CT	SP2	EVA	EVB	RR1
	L	FZ5 E, CT	FZ6 E, CT	FZ6 E,CT	FZ6 C, CT	FZ7 E, CT	FZ8 E, CT	FZ8 E	FZ8 C, CT	FZ7 E, CT	FZ8 E, CT	SP3	EVC	EVD	RR2

INPUT FILE LAYOUT

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
"I"	U	D10 D30 D50	D11 D31 D51	D13 D33 D53	D15 D35 ---	D16 D36 D56	D17 D37 D57	D19 D39 D59	D1B D3B --- D7B	D1C D3C D5C					
	L		D12 D32 D52	D14 D34 ---			D18 D38 D58	D1A D3A ---		D1D D3D D5D					
"J"	U	D20 D40 D60	D21 D41 D61	D23 D43 D63	D25 D45 ---	D26 D46 D66	D27 D47 D67	D29 D49 D69	D2B D4B --- D8B	D2C D4C D6C					
	L		D22 D42 D62	D24 D44 ---			D28 D48 D68	D2A D4A ---		D2D D4D D6D					

VEHICLE DETECTOR ACCESS CODES for 170 Controller

1) TOPCODE - TO ACCESS OR CHANGE "DELAY" TIME

2) MIDDLE CODE - TO ACCESS OR CHANGE "CARRY OVER" TIME.

3) BOTTOM CODE - TO OBSERVE COUNT ON THAT DETETECTOR.

LEGEND:

ADV - ADVANCE (FUTURE)
CALL - CALL
CT - COUNT
E - EXTENSION
EV - EMRGENCY VEHICLE

FLH - FLASH SENSE (FUTURE)
PED - PEDESTRIAN PUSH BUTTON
RR - RAILROAD PRE-EMPT
SP - SPARE
NA - ASSIGNED

NEW DETECTORS

SCAR Page 5: Detector Attributes and Access Codes

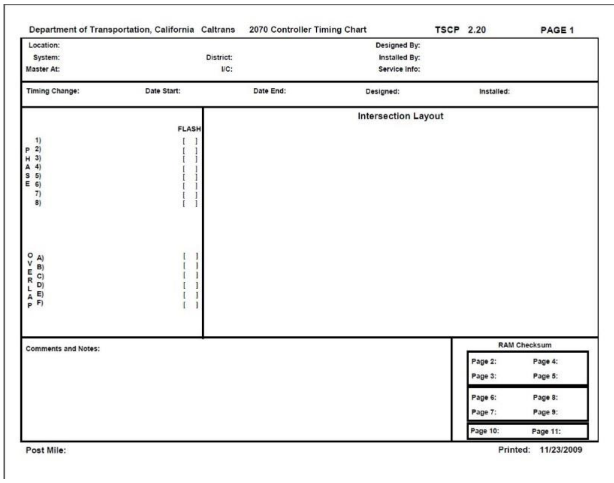
Caltrans Default Detector Assignment

DETECTOR NUMBER	INPUT SLOT	PORT	DETECTOR NUMBER	INPUT SLOT	PORT
1	1I1U	3.2	21	5J1U	3.1
2	1I1L	7.2	22	5J1L	7.1
3	2I2U	1.1	23	6J2U	1.2
4	2I2L	1.5	24	6J2L	1.6
5	2I3U	4.5	25	6J3U	4.6
6	2I3L	6.2	26	6J3L	6.3
7	2I4U	2.1	27	6J4U	2.2
8	2I4L	7.4	28	6J4L	7.3
9	3I5U	3.4	29	7J5U	3.3
10	3I5L	7.6	30	7J5L	7.5
11	4I6U	1.3	31	8J6U	1.4
12	4I6L	1.7	32	8J6L	1.8
13	4I7U	4.7	33	8J7U	4.8
14	4I7L	6.4	34	8J7L	6.5
15	4I8U	2.3	35	8J8U	2.4
16	4I8L	7.8	36	8J8L	7.7
17	1I9U	3.6	37	5J9U	3.5
18	3I9L	3.8	38	7J9L	3.7
19	2I10U	4.1	39	6J10U	4.3
20	4I10L	4.2	40	8J10L	4.4
			41	PED2	5.1
			42	PED4	5.3
			43	PED6	5.2
			44	PED8	5.4

Caltrans Type 332 Cabinet Input File Layout / Port Assignments

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Input File I	U	Ø1 3.2 C1-56 TB2 1,2	Ø2 1.1 C1-39 TB2 5,6	Ø2 4.5 C1-63 TB2 9,10	Ø2 2.1 C1-47 TB4 1,2	Ø3 3.4 C1-58 TB4 5,6	Ø4 1.3 C1-41 TB4 9,10	Ø4 4.7 C1-165 TB6 1,2	Ø4 2.3 C1-149 TB6 5,6	Ø1 3.6 C1-60 TB6 9,10	Ø2 4.1 C11-10	Manual 6.6 C1-80 TB8 1,3	2-PPB 5.1 C1-67 TB8 4,6	6-PPB 5.2 C1-68 TB8 7,9	FLASH SENSE 6.7 C1-81 TB8 10,12
	L	Ø1 7.2 C11-16 TB2 3,4	Ø2 1.5 C1-43 TB2 7,8	Ø2 6.2 C1-76 TB2 11,12	Ø2 7.4 C11-18 TB4 3,4	Ø3 7.6 C11-20 TB4 7,8	Ø4 1.7 C1-45 TB4 11,12	Ø4 6.4 C1-78 TB6 3,4	Ø4 7.8 C11-22 TB6 7,8	Ø3 3.8 C1-62 TB6 11,12	Ø4 4.2 C11-11	BBS 2.7 C1-53 TB8 2,3	4-PPB 5.3 C1-69 TB8 5,6	8-PPB 5.4 C1-70 TB8 8,9	STOP TIME 6.8 C1-82 TB8 11,12
Input File J	U	Ø5 3.1 C1-55 TB3 1,2	Ø6 1.2 C1-40 TB3 5,6	Ø6 4.6 C1-64 TB3 9,10	Ø6 2.2 C1-48 TB5 1,2	Ø7 3.3 C1-57 TB5 5,6	Ø8 1.4 C1-42 TB5 9,10	Ø8 4.8 C1-66 TB7 1,2	Ø8 2.4 C1-50 TB7 5,6	Ø5 3.5 C1-59 TB7 9,10	Ø6 4.3 C11-12	Spare 2 2.8 C1-54 TB9 1,3	EVA 5.5 C1-71 TB9 4,2,6	EVB 5.6 C1-72 TB9 7,3,9	RR1 2.5 C1-51 TB9 10,12
	L	Ø5 7.1 C11-15 TB3 3,4	Ø6 1.6 C1-44 TB3 7,8	Ø6 6.3 C1-77 TB3 11,12	Ø6 7.3 C11-17 TB5 3,4	Ø7 7.5 C11-19 TB5 7,8	Ø8 1.8 C1-46 TB5 11,12	Ø8 6.5 C1-79 TB7 3,4	Ø8 7.7 C11-21 TB7 7,8	Ø7 3.7 C1-61 TB7 11,12	Ø8 4.4 C11-13	Spare 3 6.1 C1-75 TB9 2,3	EVC 5.7 C1-73 TB9 5,2,6	EVD 5.8 C1-74 TB9 8,3,9	RR2 2.6 C1-52 TB9 11,12

SCAR Page 6: Model 2070 Detector and Port Assignments



Department of Transportation, California Caltrans 2070 Controller Timing Chart TSCP 2.20 PAGE 1

Location: Designed By:
System: District: Installed By:
Master At: I/C: Service Info:

Timing Change: Date Start: Date End: Designed: Installed:

Intersection Layout

FLASH

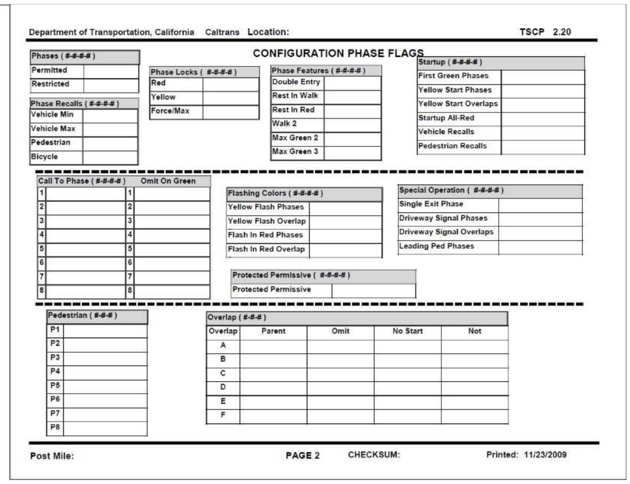
PHASE 1) 2) 3) 4) 5) 6) 7) 8)

OVERLAP A) B) C) D) E) F)

Comments and Notes:

RAM Checksum
Page 2: Page 4:
Page 3: Page 5:
Page 6: Page 8:
Page 7: Page 9:
Page 10: Page 11:

Post Mile: Printed: 11/23/2009



Department of Transportation, California Caltrans Location: TSCP 2.20

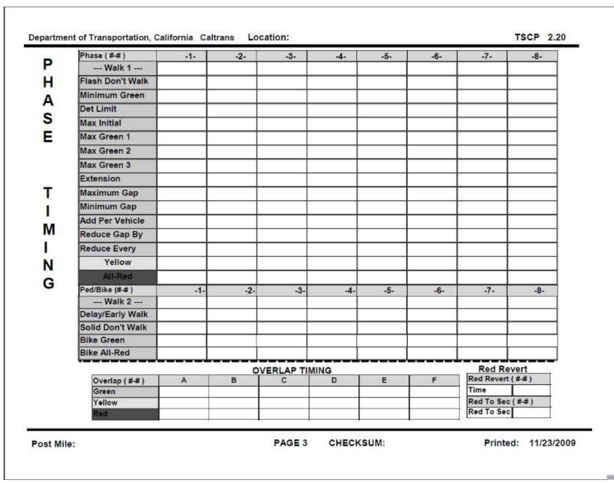
CONFIGURATION PHASE FLAGS

Phases (#-#-#-#): Permitted, Restricted
Phase Recalls (#-#-#-#): Vehicle Min, Vehicle Max, Pedestrian, Bicycle
Phase Locks (#-#-#-#): Red, Yellow, Force/Max
Phase Features (#-#-#-#): Double Entry, Rest In Walk, Rest In Red, Walk 2, Max Green 2, Max Green 3
Startup (#-#-#-#): First Green Phases, Yellow Start Phases, Yellow Start Overlaps, Startup All-Red, Vehicle Recalls, Pedestrian Recalls

Call To Phase (#-#-#-#) 1–8; Omit On Green 1–8
Flashing Colors (#-#-#-#): Yellow Flash Phases, Yellow Flash Overlap, Flash In Red Phases, Flash In Red Overlap
Special Operation (#-#-#-#): Single Exit Phase, Driveway Signal Phases, Driveway Signal Overlaps, Leading Ped Phases
Protected Permissive (#-#-#-#): Protected Permissive

Pedestrian (#-#-#): P1–P8
Overlap (#-#-#): Overlap, Parent, Omit, No Start, Not; A–F

Post Mile: PAGE 2 CHECKSUM: Printed: 11/23/2009



Department of Transportation, California Caltrans Location: TSCP 2.20

PHASE TIMING

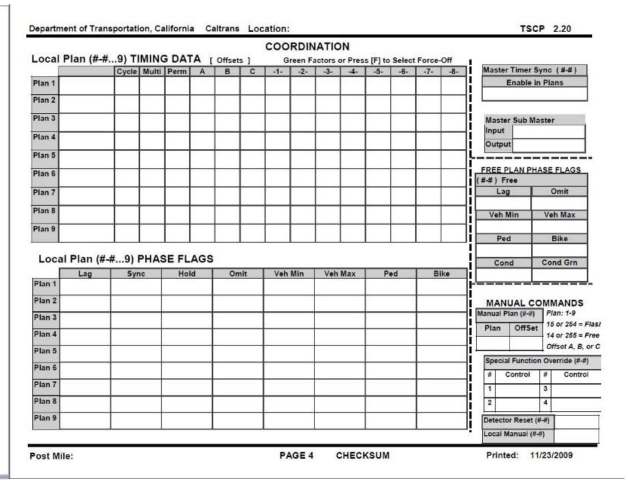
Phase (#-#): -1- -2- -3- -4- -5- -6- -7- -8-
--- Walk 1 ---, Flash Don't Walk, Minimum Green, Det Limit, Max Initial, Max Green 1, Max Green 2, Max Green 3, Extension, Maximum Gap, Minimum Gap, Add Per Vehicle, Reduce Gap By, Reduce Every, Yellow, All-Red

Ped/Bike (#-#): -1- -2- -3- -4- -5- -6- -7- -8-
--- Walk 2 ---, Delay/Early Walk, Solid Don't Walk, Bike Green, Bike All-Red

OVERLAP TIMING
Overlap (#-#): A B C D E F; Green, Yellow, Red

Red Revert
Red Revert (#-#): Time
Red To Sec (#-#)
Red To Sec

Post Mile: PAGE 3 CHECKSUM: Printed: 11/23/2009



Department of Transportation, California Caltrans Location: TSCP 2.20

COORDINATION

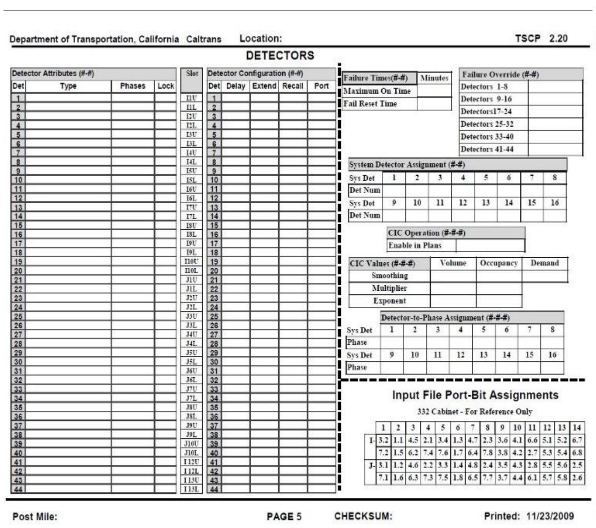
Local Plan (#-#...9) TIMING DATA [Offsets] Green Factors or Press [F] to Select Force-Off
Cycle, Multi, Perm, A, B, C, -1- -2- -3- -4- -5- -6- -7- -8-; Plan 1 – Plan 9

Master Timer Sync (#-#): Enable in Plans
Master Sub Master: Input, Output
FREE PLAN PHASE FLAGS (#-#) Free: Lag, Omit, Veh Min, Veh Max, Ped, Bike, Cond, Cond Grn

Local Plan (#-#...9) PHASE FLAGS
Lag, Sync, Hold, Omit, Veh Min, Veh Max, Ped, Bike; Plan 1 – Plan 9

MANUAL COMMANDS
Manual Plan (#-#): Plan, OffSet — Plan: 1-9; 15 or 254 = Flash; 14 or 255 = Free; Offset A, B, or C
Special Function Override (#-#): #, Control, #, Control; 1, 3; 2, 4
Detector Reset (#-#)
Local Manual (#-#)

Post Mile: PAGE 4 CHECKSUM Printed: 11/23/2009



Department of Transportation, California Caltrans Location: TSCP 2.20

DETECTORS

Detector Attributes (#-#): Det, Type, Phases, Lock; 1–44
Slot: I1U, I1L, I2U, I2L, … I13U, I13L
Detector Configuration (#-#): Det, Delay, Extend, Recall, Port; 1–44

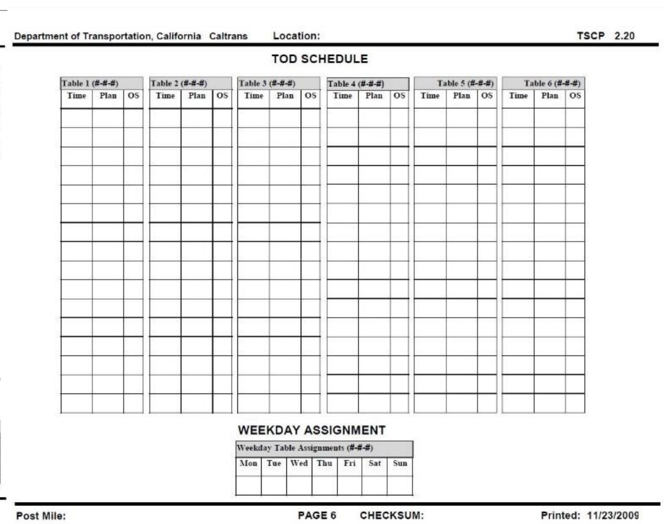
Failure Times (#-#): Minutes; Maximum On Time, Fail Reset Time
Failure Override (#-#): Detectors 1-8, Detectors 9-16, Detectors 17-24, Detectors 25-32, Detectors 33-40, Detectors 41-44

System Detector Assignment (#-#): Sys Det 1–8, Det Num; Sys Det 9–16, Det Num
CIC Operation (#-#): Enable in Plans
CIC Values (#-#): Volume, Occupancy, Demand; Smoothing, Multiplier, Exponent
Detector-to-Phase Assignment (#-#): Sys Det 1–8, Phase; Sys Det 9–16, Phase

Input File Port-Bit Assignments
332 Cabinet - For Reference Only

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
I-	3.2	1.1	4.5	2.1	3.4	1.3	4.7	2.3	3.6	4.1	6.6	5.1	5.2	6.7
	7.2	1.5	6.2	7.4	7.6	1.7	6.4	7.8	3.8	4.2	2.7	5.3	5.4	6.8
J-	3.1	1.2	4.6	2.2	3.3	1.4	4.8	2.4	3.5	4.3	2.8	5.5	5.6	2.5
	7.1	1.6	6.3	7.3	7.5	1.8	6.5	7.7	3.7	4.4	6.1	5.7	5.8	2.6

Post Mile: PAGE 5 CHECKSUM: Printed: 11/23/2009



Department of Transportation, California Caltrans Location: TSCP 2.20

TOD SCHEDULE

Table 1 (#-#-#) … Table 6 (#-#-#): Time, Plan, OS

WEEKDAY ASSIGNMENT
Weekday Table Assignments (#-#-#): Mon, Tue, Wed, Thu, Fri, Sat, Sun

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Department of Transportation, California Caltrans Location: TSCP 2.20

HOLIDAY TABLES

Floating Holiday Table (#-#-#)				
#	Mnth	Week	DOW	Table
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				

Fixed Holiday Table (#-#-#)				
#	Mnth	Day	DOW	Table
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				

Solar Clock Data (#-#)	
North Latitude	
West Longitude	
Local Time Zone	

Sabbatical Clock (#-#)	
Hebrew	
Sabbath	
Holiday	

Daylight Saving (#-#)	
Enabled	

TOD FUNCTIONS

TOD Functions (#-#)					
#	Start	End	DOW	Action	Phases
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					

Action Codes:
0. None
1. Permitted
2. Restricted
4. Veh Min Recall
5. Veh Max Recall
6. Ped Recall
7. Bike Recall
8. Red Lock
9. Yellow Lock
10. Force/Max Lock
11.Double Entry
12. Y-Coord C
13. Y-Coord D
14. Free
15. Flashing
16. Walk 2
17. Max Green 2
18. Max Green 3
19. Rest in Walk
20. Rest in Red
21. Free Lag Phases
22. Special Functions
23. Truck Preempt
24. Conditional Service
25. Conditional Service
26. Leading Ped
41. Protected Permissive
42. Protected Permissive

Action Code = Phases added to normal setting
100+Action Code = Phases removed
200+Action Code = Phases replaced

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Department of Transportation, California Caltrans Location: TSCP 2.20

COMMUNICATIONS

C2 (#-#-#)	
Address	
Protocol	
Limit Access	
Baud	
Parity	
Data Bits	
Stop Bits	
RTS On Time	
RTS Off Time	
Handshaking	

C20 (#-#-#)	
Address	
Protocol	
Limit Access	
Baud	
Parity	
Data Bits	
Stop Bits	
RTS On Time	
RTS Off Time	
Handshaking	

C21 (#-#-#)	
Address	
Protocol	
Limit Access	
Baud	
Parity	
Data Bits	
Stop Bits	
RTS On Time	
RTS Off Time	
Handshaking	

Limit Access:
0-None
1-Status Only
2-Status, Set Pattern, Time
3-Status, Set Pattern, Time, Manual Plan

SOFT LOGIC

Soft Logic (#-#)							
#	Data	OP	Data	OP	Data	OP	Data
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							

*Refer to User's Manual for Data and OP Codes

CALLBACK NUMBERS

Callback Numbers (#-#...#)	
Line Out	
Local Toll	
Long Distance	
Delay	
Area Code	
Phone Number	
Line Out	
Local Toll	
Long Distance	
Delay	
Area Code	
Phone Number	
Line Out	
Local Toll	
Long Distance	
Delay	
Area Code	
Phone Number	

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Department of Transportation, California Caltrans Location: TSCP 2.20

RAILROAD PREEMPTION

RR 1 (#-#-#)	Timing	Phase Flags (#-#-#)			Pedestrian Flags (#-#-#)			Overlap Flags (#-#-#)		
		Grn Hold	Yel Flash	Red Flash	Walk	Flash DW	Solid DW	Grn Hold	Yel Flash	Red Flash
Delay										
Clear1										
Clear 2										
Clear 3										
Hold										
Exit										
Min Grn										
Ped Clr										

Exit Parameters (#-#-#)			
Phase Green	Overlap Green	Vehicle Recall	Ped Call

Configuration (#-#-#)		
Port	Latching	Power-Up

RR 2 (#-#-#)	Timing	Phase Flags (#-#-#)			Pedestrian Flags (#-#-#)			Overlap Flags (#-#-#)		
		Grn Hold	Yel Flash	Red Flash	Walk	Flash DW	Solid DW	Grn Hold	Yel Flash	Red Flash
Delay										
Clear1										
Clear 2										
Clear 3										
Hold										
Exit										
Min Grn										
Ped Clr										

Exit Parameters (#-#-#)			
Phase Green	Overlap Green	Vehicle Recall	Ped Recall

Configuration (#-#-#)		
Port	Latching	Power-up

EMERGENCY VEHICLE PREEMPTION

EVA (#-A)	Preempt Timers			Phase Green	Overlap Green
	Delay	Clear	Max		

Port	Latching	Phase Termination

EVB (#-B)	Preempt Timers			Phase Green	Overlap Green
	Delay	Clear	Max		

Port	Latching	Phase Termination

EVC (#-C)	Preempt Timers			Phase Green	Overlap Green
	Delay	Clear	Max		

Port	Latching	Phase Termination

EVD (#-D)	Preempt Timers			Phase Green	Overlap Green
	Delay	Clear	Max		

Port	Latching	Phase Termination

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Department of Transportation, California Caltrans Location: TSCP 2.20

INPUTS

	7 Wire I/C (#-#-#-#)				
		Input	Port	Input	Port
Enable					
Max ON					
Max OFF					

Manual Control (#-#-#-#)	
Input	Port
Manual Advance	
Advance Enable	

Battery Backup (#-#-#-#)	
Port	Operation

Cabinet Status (#-#-#-#)	
Input	Port
Flash Bus	
Door Ajar	
Flash Sense	
Stop Time	

Special Function (#-#-#-#)	
Input	Port
1	
2	
3	
4	

Y-Coordination (#-#-#-#)	
Port C	Port D

OUTPUTS

Loadswitch Assignments (#-#-#)							+
A							
B							
X							

Loadswitch Codes:
0 Unused (no output)
1-8 Vehicle 1-8
9-14 Overlap A-F
21-28 Ped 1-8
41-47 Special Functions
41 Protected Permissive Flashing Phase 1
43 Protected Permissive Flashing Phase 3
45 Protected Permissive Flashing Phase 5
47 Protected Permissive Flashing Phase 7
51-57 Special Functions
71-72 Seven Wire I/C

+ middle output of loadswitches 3 and 6 Channel 9 and 10

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Department of Transportation, California Caltrans Location: TSCP 2.20

YELLOW YIELD COOORDINATION

Y-Coord Plans (#-C,D)	Long Grn	No Grn	Offset	Perm	Force-Offs -1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	Coord	Lag	Min Recall	Restricted
Plan C																
Plan D																

TRANSIT PRIORITY

Local Plans (#-E1...9)		Early Green	Green Extend	Inhibit Cycles	Phase 1 Minimum	Phase 2 Minimum	Phase 3 Minimum	Phase 4 Minimum	Phase 5 Minimum	Phase 6 Minimum	Phase 7 Minimum	Phase 8 Minimum
Plan												
Plan												
Plan												
Plan												
Plan												
Plan												
Plan												
Plan												
Plan												

Enable Priority (#-#-#)	
Enable in Plan	

Free Plans (#-#-#)	
Max Green Hold	Hold Phase

Access Utilities (#-#)	
Password	***
Timeout	

TRUCK PREEMPTION

Truck Preemption (#-#)	Passage	CarryOver	Clearance	Next Preempt	Phase Green	Det 2 Port	Det 3 Port	Det 4 Port	Sign Outpu	Slave Input	Slave Outpu

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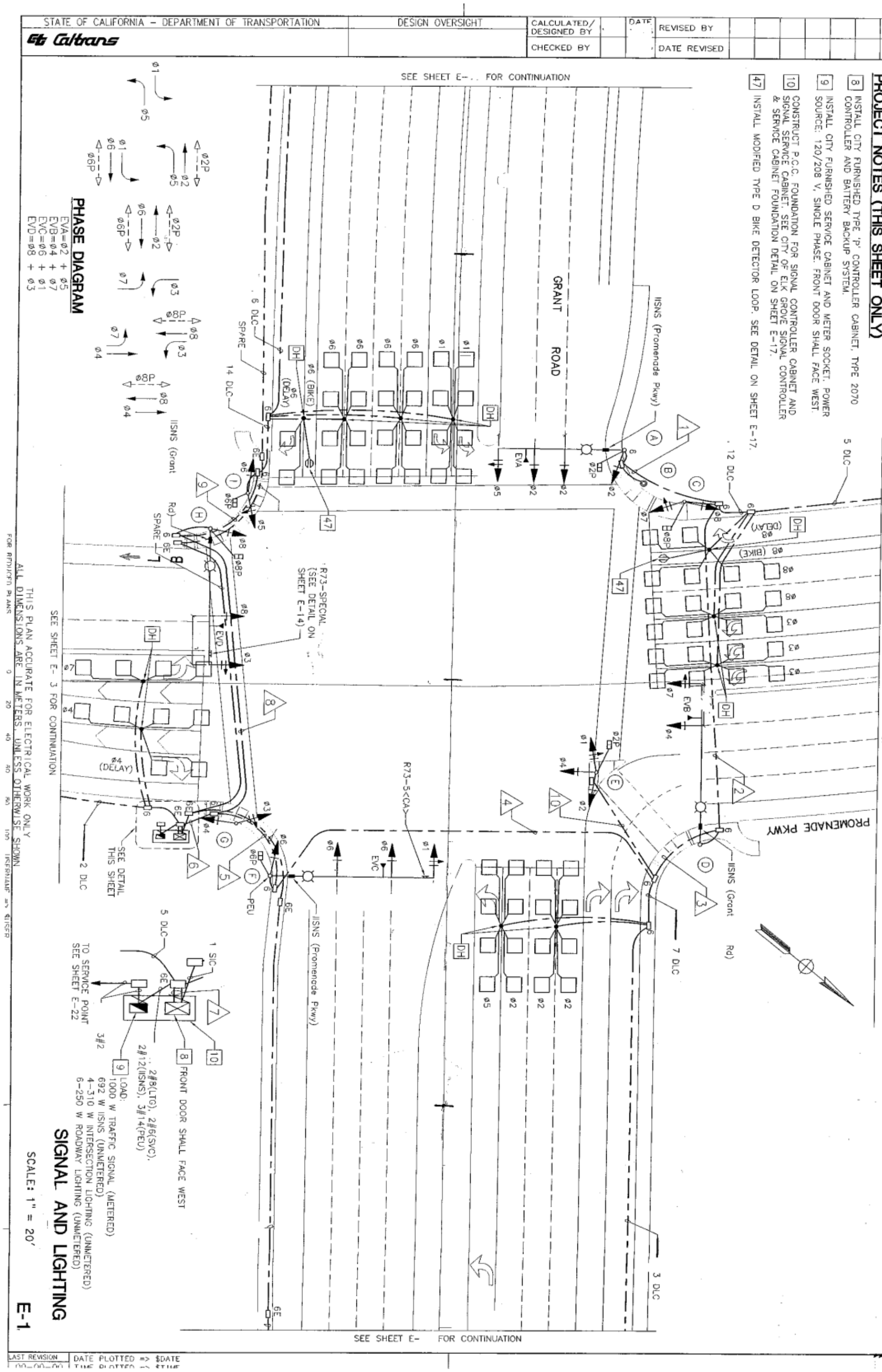
SCAR Page 7: Signal Timing Chart



SCAR Page 8: Signalized Intersection Reference Drawing

Conflict Monitor – Diode board for Model 210

The conflict monitor (Model 210) is critical to prevent conflicting phases from being simultaneously illuminated. The conflict monitor is a diode board, which provides the means to assign non-conflicting phases (or channels) to pass through, without putting the intersection into RED flashing mode. The signal operations engineer should remove the conflicting diodes for the allowed phases, and that will disable sensing of the Green and/or Yellow input signals for those selected phases.

The card (pc board) is initially supplied with 120 diodes. This allows all the channels to conflict with all other channels. To program a non-conflicting channel pair (permissive phases), the appropriate diode(s) must be removed from the Model 210 card. Figure B1 below shows a Model 210 diode board.

Programming instructions:
If channel 2 GREEN or YELLOW (same as phase 2) is permissive with channel 6 GREEN or YELLOW, remove the diode labeled “2-6.”
If Ped 2 (pedestrian phase) is allowed, remove the diode labeled “13-2.”
If Ped 6 is allowed, remove the diode labeled “15-13.”
If phases 2 and 6, as well as Ped 2 and Ped 6 are allowed, remove the diodes labeled “13-6,” “15-2” and “15-13.”
On the conflict monitor board the diodes labeled “2-6” or “6-2” are both identical. Channel and phase can be used interchangeably; channel 2 is phase 2 and channel 3 is phase 3, etc.

Channels 9 through 12 are overlap phases A, B, C, D, E and F, respectively (see Appendix E regarding overlap phases).
Channels 9 and 10 can be used for 2-color overlaps or 3-color overlaps with an AUX (auxiliary) output file.

Channels 13 through 16 are pedestrian phases. Specifically, channel 13 is for Ped 2, channel 14 is for Ped 4, and channel 15 is for Ped 6, and channel 16 is for Ped 8. Figure B2 below shows an example of the documentation to aid in the conflict monitor board configuration.

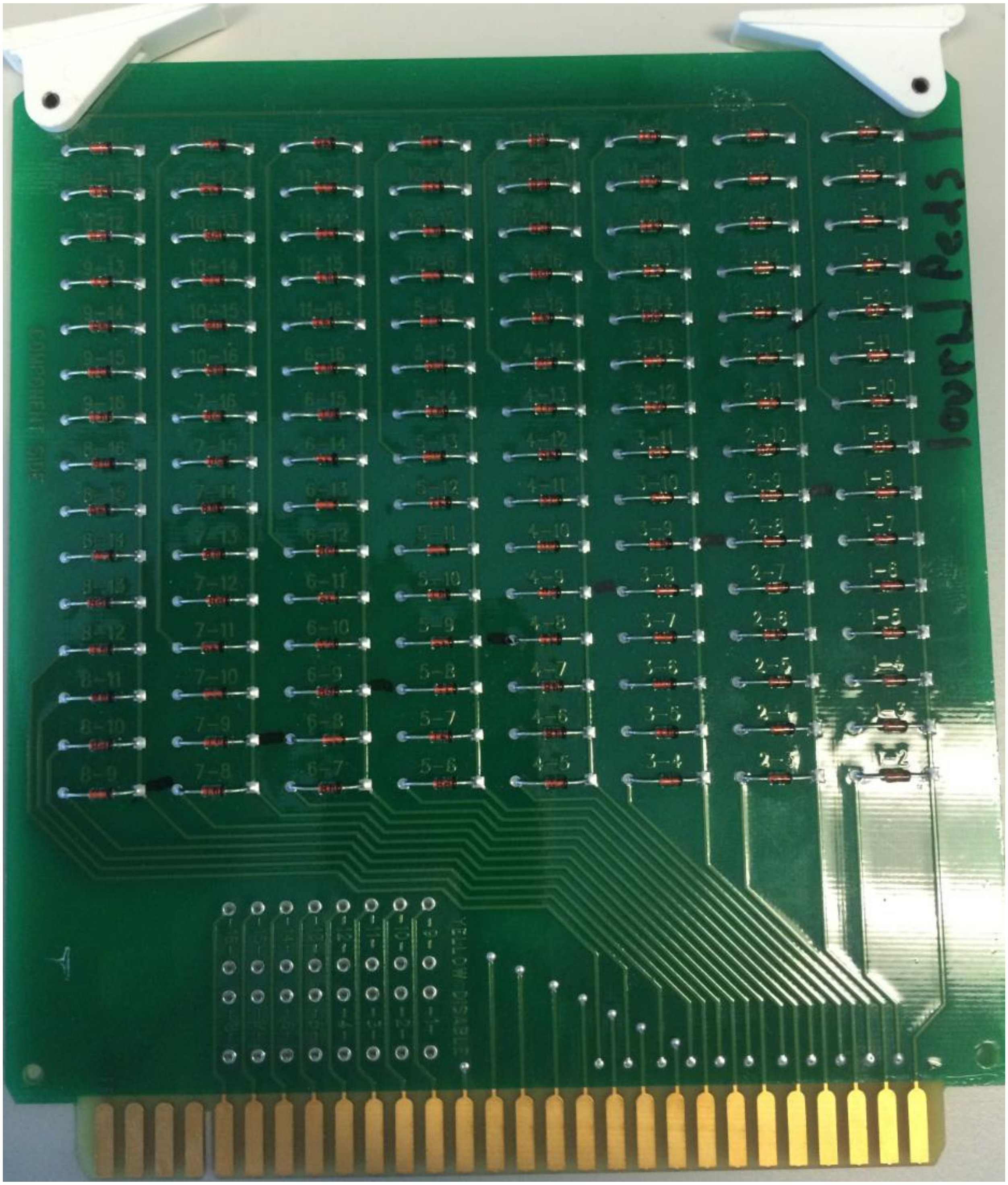


Figure B1 – Example of Conflict Monitor Board

LOCATION PCH CO. LA RTE. 1 P.M.

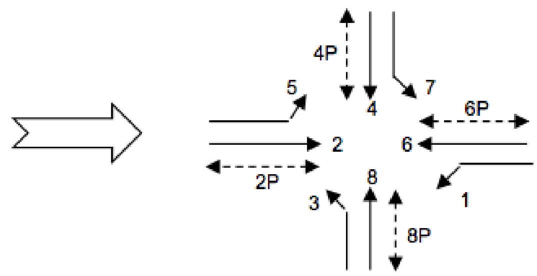
Cherry Ave DATE BY

CONFLICT MONITOR - DIODE BOARD for MODEL 210

CONFLICT MONITOR PROGRAMMING INSTRUCTIONS

CHANNELS AND PHASES

Channel	Phases
CHANNEL 16 - 08 PED	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15
CHANNEL 15 - 06 PED	1, > 2, 3, 4, 5, > 6, 7, 8, 9, 10, 11, 12, > 13, 14
CHANNEL 14 - 04 PED	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
CHANNEL 13 - 02 PED	1, > 2, 3, 4, 5, > 6, 7, 8, 9, 10, 11, 12
CHANNEL 12 - SPECIAL (OLD)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
CHANNEL 11 - SPECIAL (OLC)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
OLF / OLB — Channel 10- Overlap "F" for 3 colors overlap. CHANNEL 10 - OVERLAP "B" for 2 colors overlap. 06 PED, YELLOW + 08 PED, YELLOW (GREEN ARROW) (YELLOW ARROW)	1, 2, 3, 4, 5, 6, 7, 8, 9
OVE / OLA — Channel 9- Overlap "E" for 3 colors overlap. CHANNEL 9 - OVERLAP "A" for 2 colors overlap. 02 PED, YELLOW + 04 PED, YELLOW (GREEN ARROW) (YELLOW ARROW)	1, 2, 3, 4, 5, 6, 7, 8



CHANNELS AND PHASES

Channel	Phases
CHANNEL 8 - 08	1, 2, 3, 4, 5, 6, 7
CHANNEL 7 - 07	1, 2, 3, 4, 5, 6
CHANNEL 6 - 06	1, > 2, 3, 4, 5
CHANNEL 5 - 05	1, 2, 3, 4
CHANNEL 4 - 04	1, 2, 3
CH 3 - 03	1, 2
CH 2 02	1

NOTES:

1. CONFLICT MONITOR PROGRAM CARD IS SUPPLIED WITH ALL 120 DIODES MOUNTED WHICH CAUSES ALL CHANNELS (PHASES) TO BE IN THE CONFLICT WITH EACH OTHER.
2. MARK CHANNELS (PHASES) WHICH ARE NOT CONFLICTING THIS INTERSECTION. (INCLUDING PEDS AND OVERLAPS)
3. REMOVE DIODES FOR THESE CHANNELS (PHASES).
4. MARK CARD WITH INTERSECTION NAME.

Form TS - 3
LN - Jan 10 - 01
Updated Oct 28-15

Figure B2 – Example of Conflict Monitor Board Worksheet for Configuration Set-up.

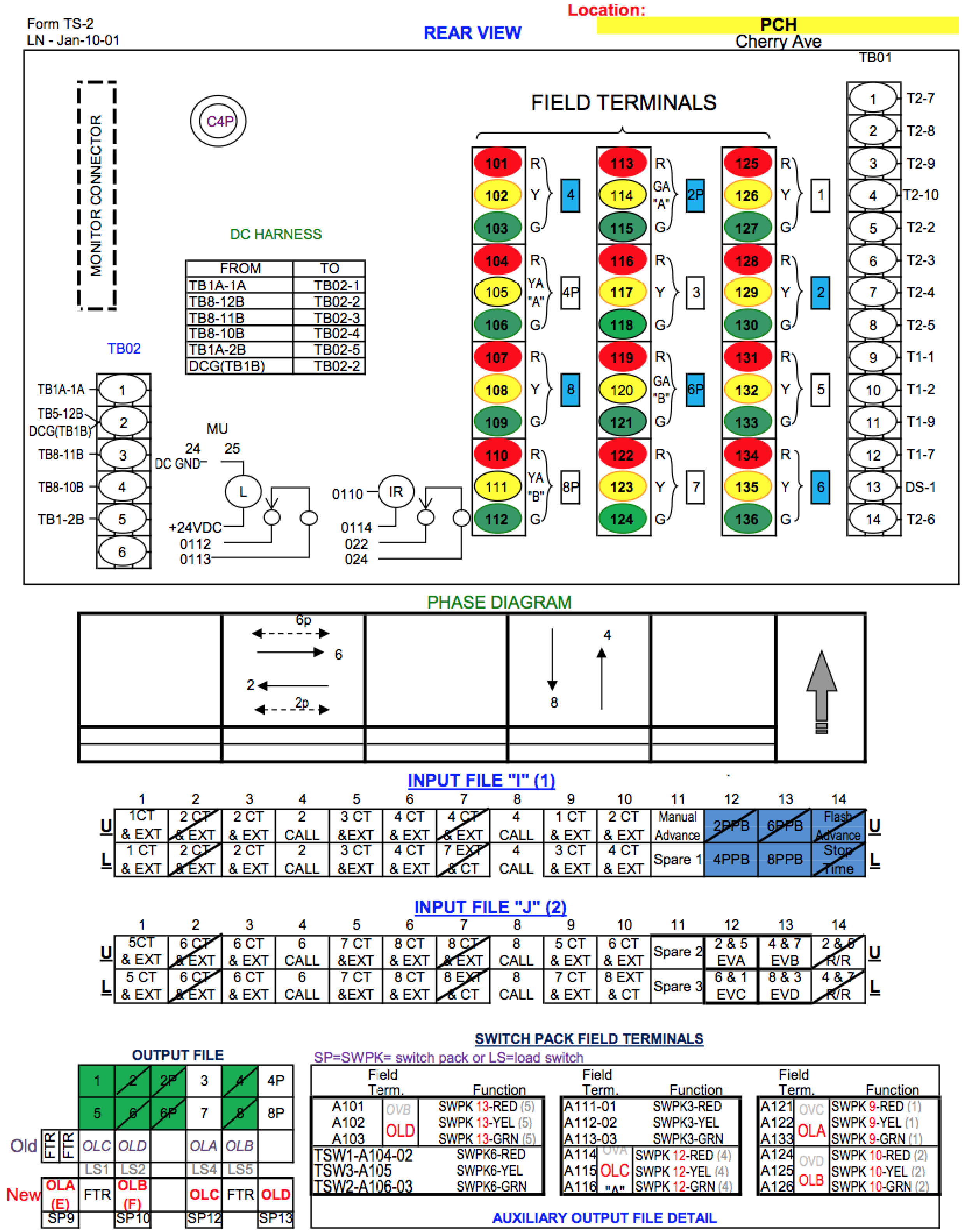


Figure B3 – Schematic of Cabinet Rear View, Input/Output Files, Auxiliary Output File details with Overlaps shown (lower left-hand corner shown in red)

Overlaps Phases
There are four (4), three-color PROGRAMMABLE OVERLAPS and two (2), two-color overlaps available for each location with either TSCP (Traffic Signal Controller Program) in the Model 2070 controller or C8 in the Model 170 controller.

The overlap phases differ at each location. Care must be taken when the overlap phase(s) is (are) used, and when cutting the conflicted monitor diode board (removing diodes).

The overlap forms a separate movement that derives its operation from its assigned phases (also called parent phases). A simultaneous PARENT PHASE(S) is (are) required to be ON when an overlap phase(s) is (are) used. For example, Overlap A or phases 8 and 1, [symbolized by OLA (8+1)], is ON with phase 1. Therefore, phase 1 is the PARENT PHASE for OLA. Also, phases 1 through 8 are potential PARENT PHASES.

TWO-COLOR OVERLAPS

Method 1:
The two-color overlap can be connected directly with the left turn phase, if appropriate for the field conditions. For example: Phase 1 left turn and phase 8 right turn, will form the 8+1 overlap. This means when phase 1 is Green, phase 8 right turn arrow is Green as well. However, the right turn lane must be exclusive and NO U-TURN is allowed on phase 1. With this method, NO additional diodes need to be removed.

Advantage: This method results in less time to set up and is easy to implement. The Right-turn arrow will always be ON with the left turn phase.
Disadvantage: This may result in a conflict when an Emergency Vehicle Preemption is called, since the Right-turn arrow can be controlled.

Method 2:
However, to get a "true" two-color overlap; the following steps are required.

For OLA:
The Yellow Arrow must be connected to terminal 105 (Ped 4).
Note: It is important to remember that the Ped phase is only used with the Red (Hand) and Green (Walk)].
The Green Arrow must be connected to terminal 114 (Ped 2).
Depending on which of the combinations is used below, the suggested diodes must be removed.

2-colors Overlap - Suggested diodes to be removed:

OLA		
	8+1	
	4+5	
	2+3	
	6+7	9-3, 9-4, 9-7, 9-14

For OLB:

The Yellow Arrow must be connected to terminal 111 (Ped 8).
Note: It is important to remember that the Ped phase is only used with the Red (Hand) and Green (Walk)].
The Green Arrow must be connected to terminal 120 (Ped 6).
Depending on which of the combination is used below, the suggested diodes must be removed.

OLB

☐	**8+1**	10-1, 10-5, 10-6, 10-15
☐	**4+5**	10-1, 10-2, 10-5, 10-13
☐	**2+3**	10-3, 10-7, 10-8, 10-16
☐	**6+7**	10-3, 10-4, 10-7, 10-14

When choosing either method, care must be taken in regard to the emergency vehicle preemption (EV) use, considering whether there may be any pedestrian conflict.

If method 2 is chosen, the PARENT PHASE(S) must be determined.

For all 3-color overlap phases, refer to the C8 or TSCP manual for more detail information. It is important to consult and/or review with other traffic signal engineers.

Input – Output Files

Documentation of the input and output files are intended for use during construction or in case damage has been done by an external force (i.e. cabinet knockdown), so that maintenance may restore the signal to the original condition. This also helps keep track of the inventory of the number of detector cards and load switch at each location.

On the documentation, it is important to highlight and/or cross out the phases that are allowed. See Figures B6 and B7b.

Example: If phases 2, 4, 6, 8, Ped 2 and Ped 8 are allowed, we either highlight or place an X marked over the phase being used on the document shown in Figures B6 and B7b.

Since phase 4 is highlighted, the contractor or maintenance will know this phase is being used and the three wires for phase 4 must be "landed" (connected) at terminal 101 for Red, 102 for Yellow and 103 for the Green indication.
The Phase Diagram drawing assists the technician with understanding what phases are being used. Both the Input Files I (upper) and J (lower) indicate which detector slots will be occupied and its function.

The detectors can either set for Call, Count and Extent or both.
The switch pack field terminals and output file indicate where the load switch should be for phases 1 through 8 and for the 3-color overlaps (OLA, OLB, OLC and/or OLD).

Terminals Board Layout

As part of record keeping and to understand where everything must go, the terminal board layout will help keep everything in proper perspective. See Figure B4 below for a photo of the Terminal Block 0.
The documentation for Terminal Block 0 is shown in Figure B5. These documents (Figures B6 and B7) will be prepared by the Signal Timing Engineer before the signal turn-on and sent to construction for implementation. This will result in time savings and prevent confusion in the field.

Example:
Slot 1I1U, TB2 terminal 1 and 2 (or D and E) is assigned to Pacific Coast Hwy and that is SBLT (Southbound Left-Turn).
The Terminal Board Layout, if implemented correctly, will assist the engineer with determining the correct and actual volume – occupancy per lane(s). The information is then loaded into the computer to calculate the split and offset suggested for each location.

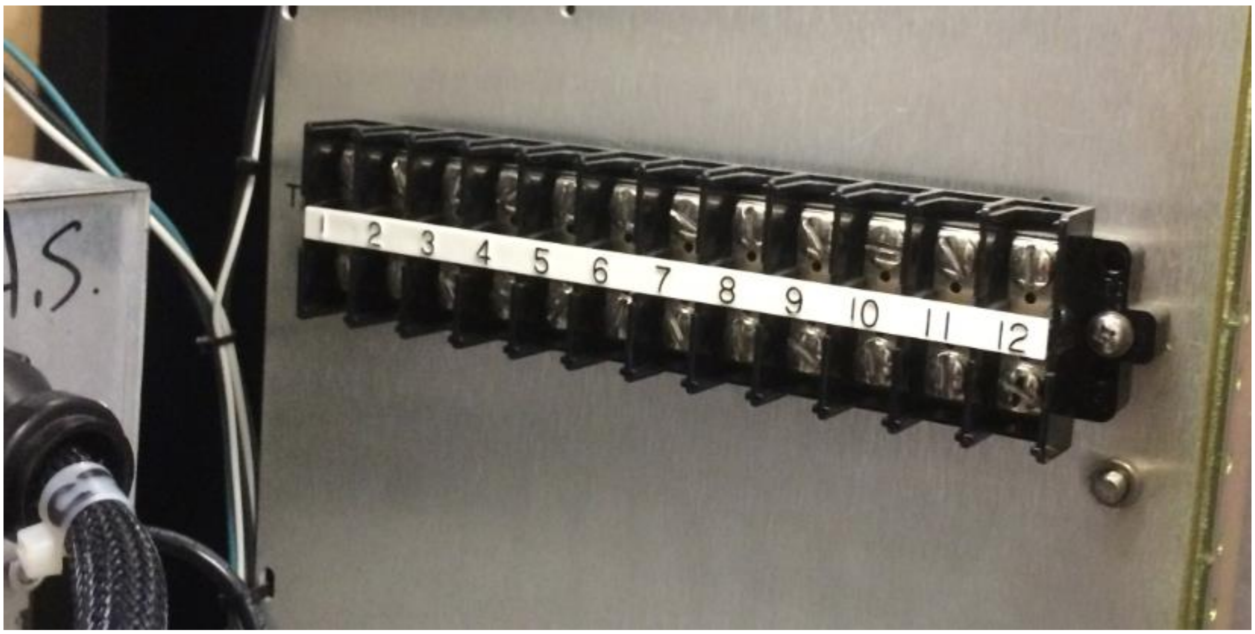


Figure B4 – Example of Terminal Block 0 in Type 332 traffic signal cabinet for typical interconnect (connections)

Typical Signal Interconnect Connections

Figure B5 shows typical interconnect connections for the Model 170 Controller, which is seen on the back side of the cabinet. Figure B6 shows the documentation used for the terminal board configuration.

Figure B7a shows an example of Type 222 detector cards in the controller cabinet. Figure B7b shows the detector attributes and access codes for the Model 170 controller.

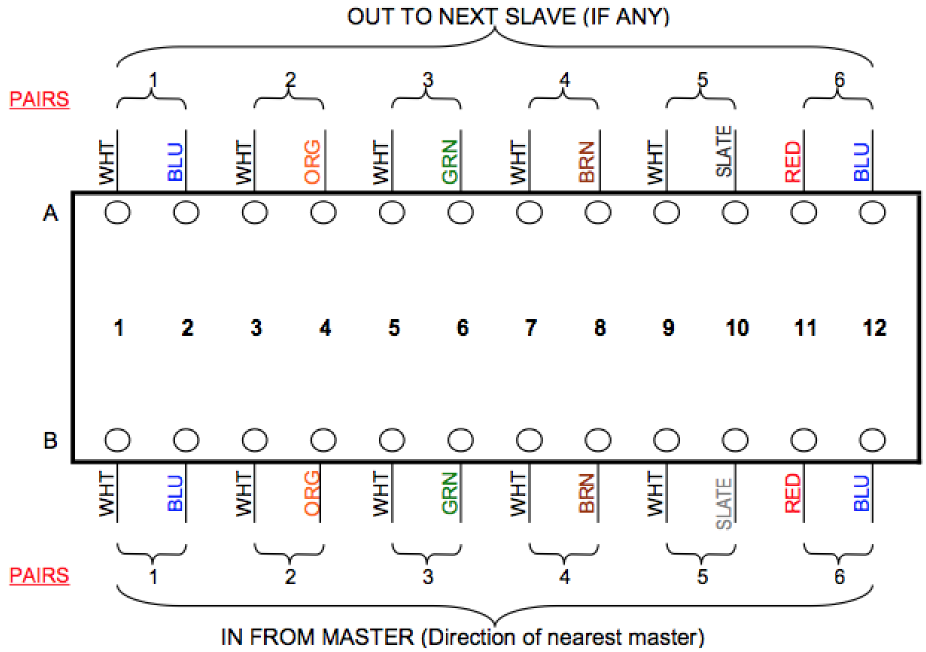
Figure B8 shows the Caltrans Type 332 cabinet input file layout and port assignments for the Model 2070 controller.

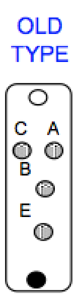
TYPICAL INTERCONNECT CONNECTIONS

TYPE 170 CONTROLLER SYSTEMS

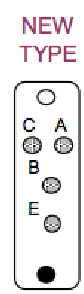
TB - 0 (SPARE TERMINAL BLOCK)

Location:





	C2			
OLD TYPE		INTERCONNECT HARNESS		NEW TYPE
A	(White)	AUDIO IN	(White)	A
B	(Black)	AUDIO IN	(Green)	B
C	(Red)	AUDIO OUT	(Red)	C
E	(Green)	AUDIO OUT	(Black)	E



NOTES:

1. ALL SPARE INTERCONNECT CONDUCTORS SHALL BE TERMINATED IN A GROUND LUG AND ATTACHED TO CABINET GROUND.
2. SHIELD SHALL BE GROUNDED TO CABINET WITH COPPER GROUNDING STRAP.

Figure B5 – Typical Interconnect Connections for the Model 170 Controller

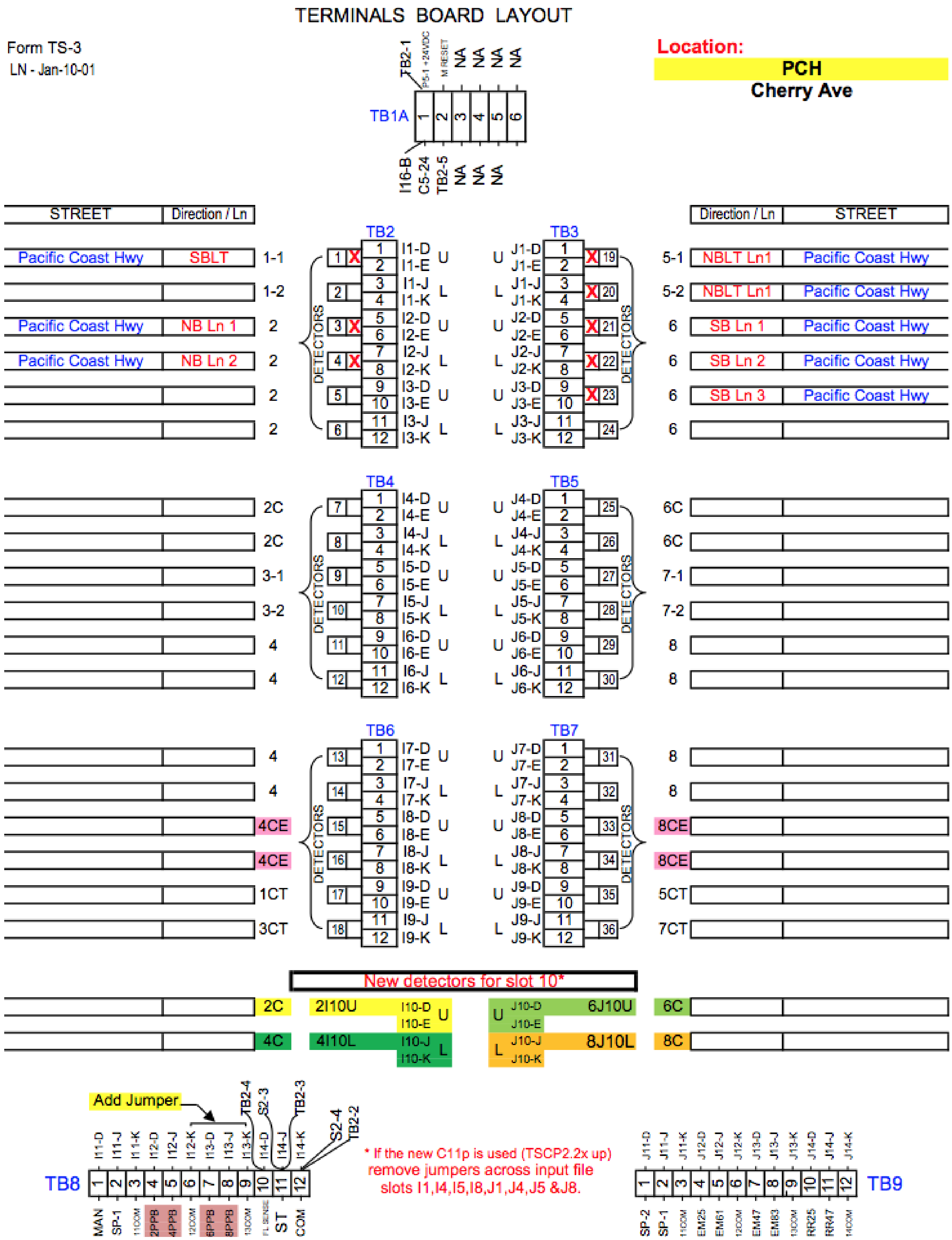


Figure B6 – Documentation for Terminal Board Configuration

Figure B7a – Example of Type 222 Detector Cards in the Controller Cabinet

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
"I"	U	FZ1 E, CT	FZ2 E, CT	FZ2 E, CT	FZ2 C, CT	FZ3 E, CT	FZ4 E, CT	FZ4 E, CT	FZ4 C,CT	FZ1 E, CT	FZ2 E, CT	Man Adv	PED FZ 2	PED FZ 6	Flash Adv
	L	FZ1 E, CT	FZ2 E, CT	FZ2 E	FZ4 C, CT	FZ3 E, CT	FZ4 E, CT	FZ4 E,CT	FZ4 C, CT	FZ3 E, CT	FZ4 E,CT	SP1	PED FZ 4	PED FZ 8	STOP TIME
"J"	U	FZ5 E, CT	FZ6 E, CT	FZ6 E, CT	FZ6 C, CT	FZ7 E, CT	FZ8 E, CT	FZ8 E, CT	FZ8 C, CT	FZ5 E, CT	FZ6 E, CT	SP2	EVA	EVB	RR1
	L	FZ5 E, CT	FZ6 E, CT	FZ6 E,CT	FZ6 C, CT	FZ7 E, CT	FZ8 E, CT	FZ8 E	FZ8 C, CT	FZ7 E, CT	FZ8 E, CT	SP3	EVC	EVD	RR2

INPUT FILE LAYOUT

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
"I"	U	D10 D30 D50	D11 D31 D51	D13 D33 D53	D15 D35 ---	D16 D36 D56	D17 D37 D57	D19 D39 D59	D1B D3B --- D7B	D1C D3C D5C					
	L		D12 D32 D52	D14 D34 ---			D18 D38 D58	D1A D3A ---		D1D D3D D5D					
"J"	U	D20 D40 D60	D21 D41 D61	D23 D43 D63	D25 D45 ---	D26 D46 D66	D27 D47 D67	D29 D49 D69	D2B D4B --- D8B	D2C D4C D6C					
	L		D22 D42 D62	D24 D44 ---			D28 D48 D68	D2A D4A ---		D2D D4D D6D					

VEHICLE DETECTOR ACCESS CODES for 170 Controller

1) TOPCODE - TO ACCESS OR CHANGE "DELAY" TIME

2) MIDDLE CODE - TO ACCESS OR CHANGE "CARRY OVER" TIME.

3) BOTTOM CODE - TO OBSERVE COUNT ON THAT DETETECTOR.

LEGEND:

ADV - ADVANCE (FUTURE)
CALL - CALL
CT - COUNT
E - EXTENSION
EV - EMRGENCY VEHICLE
NEW DETECTORS

FLH - FLASH SENSE (FUTURE)
PED - PEDESTRIAN PUSH BUTTON
RR - RAILROAD PRE-EMPT
SP - SPARE
NA - ASSIGNED

Figure B7b - Detector Attributes and Access Codes for the Model 170 Controllers

Model 2070 Detector and PORT assignments

Figure B8a below displays the "typical" Model 2070 controller detector and port assignment for the back of the controller. The numbers shown in red correspond to a pin number in the C1 connector (to the C1 cable, which connects the detector cards to the signal controller). Figure B8b displays the Caltrans Type 332 cabinet input file layout (port assignments).

Caltrans Default Detector Assignment

DETECTOR NUMBER	INPUT SLOT	PORT	DETECTOR NUMBER	INPUT SLOT	PORT
1	1I1U	3.2	21	5J1U	3.1
2	1I1L	7.2	22	5J1L	7.1
3	2I2U	1.1	23	6J2U	1.2
4	2I2L	1.5	24	6J2L	1.6
5	2I3U	4.5	25	6J3U	4.6
6	2I3L	6.2	26	6J3L	6.3
7	2I4U	2.1	27	6J4U	2.2
8	2I4L	7.4	28	6J4L	7.3
9	3I5U	3.4	29	7J5U	3.3
10	3I5L	7.6	30	7J5L	7.5
11	4I6U	1.3	31	8J6U	1.4
12	4I6L	1.7	32	8J6L	1.8
13	4I7U	4.7	33	8J7U	4.8
14	4I7L	6.4	34	8J7L	6.5
15	4I8U	2.3	35	8J8U	2.4
16	4I8L	7.8	36	8J8L	7.7
17	1I9U	3.6	37	5J9U	3.5
18	3I9L	3.8	38	7J9L	3.7
19	2I10U	4.1	39	6J10U	4.3
20	4I10L	4.2	40	8J10L	4.4
			41	PED2	5.1
			42	PED4	5.3
			43	PED6	5.2
			44	PED8	5.4

Figure B8a – Model 2070 Detector and Port Assignments

Caltrans Type 332 Cabinet Input File Layout / Port Assignments

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Input File I	U	Ø1 3.2 C1-56 TB2 1,2	Ø2 1.1 C1-39 TB2 5,6	Ø2 4.5 C1-63 TB2 9,10	Ø2 2.1 C1-47 TB4 1,2	Ø3 3.4 C1-58 TB4 5,6	Ø4 1.3 C1-41 TB4 9,10	Ø4 4.7 C1-165 TB6 1,2	Ø4 2.3 C1-149 TB6 5,6	Ø1 3.6 C1-60 TB6 9,10	Ø2 4.1 C11-10	Manual 6.6 C1-80 TB8 1,3	2-PPB 5.1 C1-67 TB8 4,6	6-PPB 5.2 C1-68 TB8 7,9	FLASH SENSE 6.7 C1-81 TB8 10,12
	L	Ø1 7.2 C11-16 TB2 3,4	Ø2 1.5 C1-43 TB2 7,8	Ø2 6.2 C1-76 TB2 11,12	Ø2 7.4 C11-18 TB4 3,4	Ø3 7.6 C11-20 TB4 7,8	Ø4 1.7 C1-45 TB4 11,12	Ø4 6.4 C1-78 TB6 3,4	Ø4 7.8 C11-22 TB6 7,8	Ø3 3.8 C1-62 TB6 11,12	Ø4 4.2 C11-11	BBS 2.7 C1-53 TB8 2,3	4-PPB 5.3 C1-69 TB8 5,6	8-PPB 5.4 C1-70 TB8 8,9	STOP TIME 6.8 C1-82 TB8 11,12
Input File J	U	Ø5 3.1 C1-55 TB3 1,2	Ø6 1.2 C1-40 TB3 5,6	Ø6 4.6 C1-64 TB3 9,10	Ø6 2.2 C1-48 TB5 1,2	Ø7 3.3 C1-57 TB5 5,6	Ø8 1.4 C1-42 TB5 9,10	Ø8 4.8 C1-66 TB7 1,2	Ø8 2.4 C1-50 TB7 5,6	Ø5 3.5 C1-59 TB7 9,10	Ø6 4.3 C11-12	Spare 2 2.8 C1-54 TB9 1,3	EVA 5.5 C1-71 TB9 4,2,6	EVB 5.6 C1-72 TB9 7,3,9	RR1 2.5 C1-51 TB9 10,12
	L	Ø5 7.1 C11-15 TB3 3,4	Ø6 1.6 C1-44 TB3 7,8	Ø6 6.3 C1-77 TB3 11,12	Ø6 7.3 C11-17 TB5 3,4	Ø7 7.5 C11-19 TB5 7,8	Ø8 1.8 C1-46 TB5 11,12	Ø8 6.5 C1-79 TB7 3,4	Ø8 7.7 C11-21 TB7 7,8	Ø7 3.7 C1-61 TB7 11,12	Ø8 4.4 C11-13	Spare 3 6.1 C1-75 TB9 2,3	EVC 5.7 C1-73 TB9 5,2,6	EVD 5.8 C1-74 TB9 8,3,9	RR2 2.6 C1-52 TB9 11,12

Figure B8b – Caltrans Type 332 Cabinet Input File Layout Port Assignments

APPENDIX C

PEDESTRIAN SIGNAL TIMING

Specific terms related to pedestrian signal timing are as follows:
Pedestrian Recall – A recall mode where there is a continuous call for pedestrian service resulting in the pedestrian walk and clearance phases to occur each time the phase times.

Pedestrian Change Interval – Also known as the "Flash Don't Walk." (FDW) The time provided for a pedestrian to cross the entire width of the intersection.

Pedestrian Phase – Time allocated to pedestrian traffic that may be concurrent with vehicular phases.

Pedestrian Walk Interval – An indication to the pedestrian that it allows pedestrians to begin crossing the intersection.

Each of the concepts is explained in further detail below.

Walk Interval

The walk interval should be long enough to allow a pedestrian that has pushed the pedestrian push button (and at intersections with Pedestrian Recall) adequate time to perceive the WALK indication and enter the crosswalk before the pedestrian clearance interval begins. In many cases, the pedestrian phase will be set to rest in the walk interval to maximize the walk display during a vehicle green. The walk interval may be extended in some controllers during coordination. A pedestrian recall mode, as discussed in a later section, can be used to eliminate the need for a pedestrian to push buttons and ensures that the pedestrian phase is presented each cycle.

The length of the walk interval is established by policy. The CA MUTCD indicates that the walk duration should be at least 7 seconds, but indicates that a duration as low as 4 seconds may be used if pedestrian volumes are low or pedestrian behavior does not justify the need for 7 seconds. Consideration should be given to walk durations longer than 7 seconds at locations where large groups of pedestrians cross. Table 2-5 summarizes the recommended walk interval durations based on the guidance provided in the CA MUTCD.

Conditions	**Walk Interval Duration (PW), seconds**
High pedestrian volume areas *(e.g., school, central business district, sports venues, etc.)*	10 to 15
Typical pedestrian volume and longer cycle length	7 to 10
Typical pedestrian volume and shorter cycle length	7
Low pedestrian volume	4
Where older or disabled pedestrians are present	Distance to center of road divided by 2.8 feet per second

Table C1 - Pedestrian walk interval duration

Pedestrian Change Interval

The pedestrian change interval follows the walk interval. When the pedestrian change interval begins, pedestrians should either complete their crossing, if already in the intersection, or refrain from entering the intersection until the next pedestrian walk interval is displayed. The CA MUTCD states that 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 Walk Interval 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 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 at the beginning of the Walk indication to travel at a walking speed of 3.0 feet per second to the far side of the traveled way being crossed or to a median of sufficient width for pedestrians to wait. Where older or disabled pedestrians routinely use the crosswalk, a walking speed of 2.8 feet per second should be considered to determine the pedestrian clearance time.

The overall pedestrian clearance time is equal to the pedestrian change interval plus a buffer interval (consisting of a steady up raised hand of at least 3 seconds). The buffer allows for a 3 second period prior to the release of any conflicting vehicular movement. The relationship between pedestrian change interval, pedestrian clearance interval and the buffer interval is demonstrated in Figure 2-3. Pedestrian clearance time for typical pedestrian crossing distances can be obtained from Table 2-6. See Figure 2-4 for a graphical representation of the pedestrian crossing distance.

Pedestrian Crossing Distance, ft.		Walking Speed, ft/s	
	2.8	3.5	4.0
		Pedestrian Clearance Time (PCT), *seconds*	
40	13	11	10
60	21	17	15
80	28	23	20
100	35	29	25

Table C2 - Pedestrian clearance time

CA MUTCD Section 4E.06 Pedestrian Intervals and Signal Phases

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.*

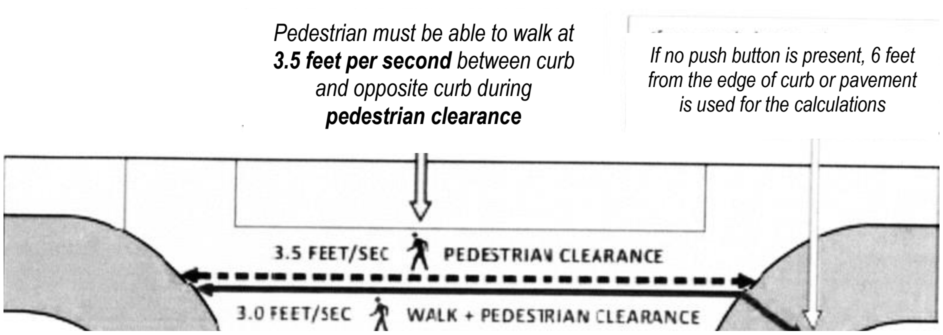


Figure C1- Example of Pedestrian Crossing Distance

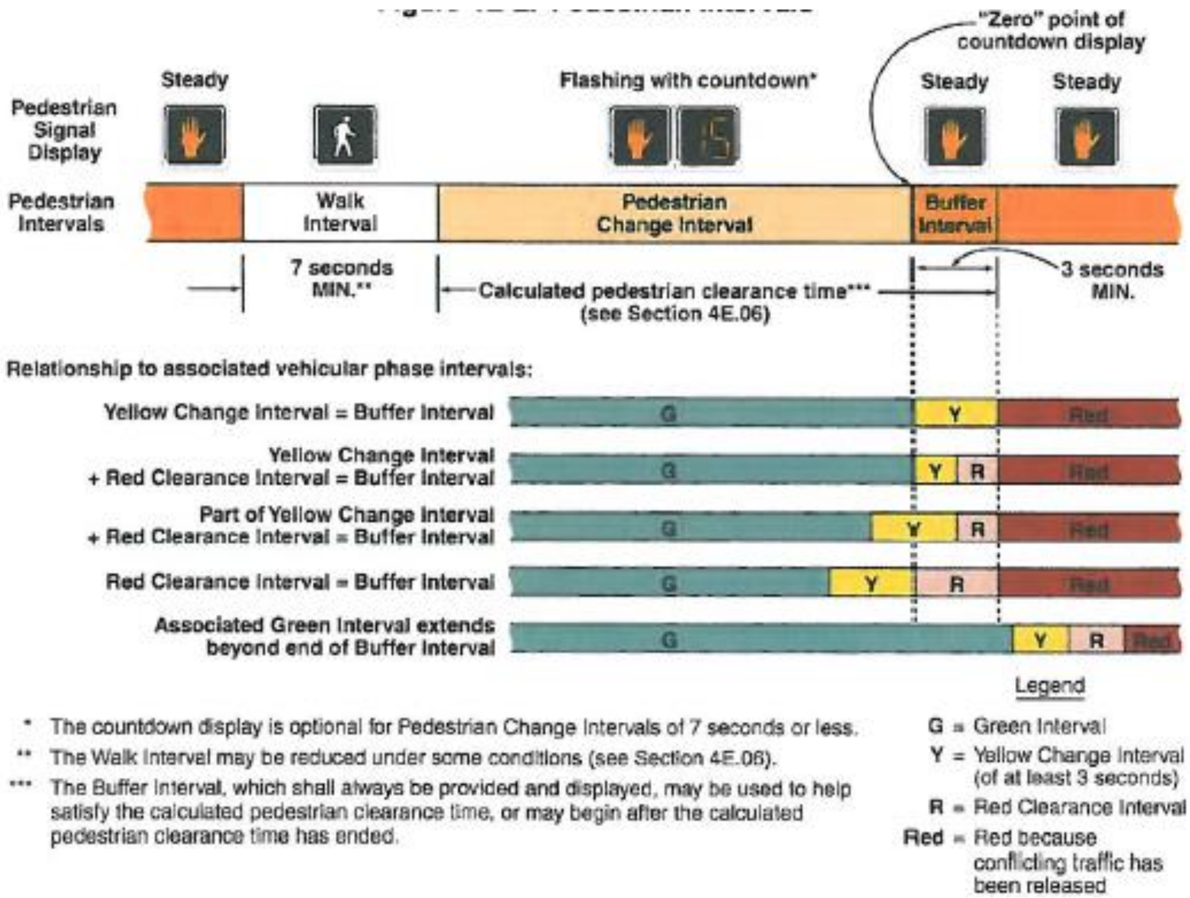


Figure C2 - California MUTCD 2014: Pedestrian Intervals (Walk and Pedestrian Change)

A leading pedestrian interval may be used to start pedestrians before the parallel concurrent vehicular movement. 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.

APPENDIX D

ONE-WAY TRAFFIC SIGNAL TIMING

One-way traffic signals are used to alternate traffic, where construction or an emergency has limited the roadway to one lane. It is best to keep the limit lines as close together as possible. This takes effort on the signal operations side to give input during the design phase of the project. Designers tend to expand the length of the operation to give the contractor room to stage and store equipment. It's best to stage and store equipment outside of the signal system so traffic delay and the tendency for motorists to ignore the traffic signal are reduced.

When the distance from a loop detector to the controller cabinet is greater than 1,000 feet, the vehicle detection becomes unreliable. An additional cabinet may be used closer to the inductive loop detector and the electrical signal may be brought back from the digital output of the I-file to the input of the I-file to the main controller. There are other options for vehicle detection.

Streets and driveways intersecting within the one-way system should be provided their own phase. Sometimes it may be beneficial to limit the access from the streets and driveways to only right turns.

There are several points to consider for proper signal timing in a one-way traffic signal:

1. When there is not a clear line-of-sight from limit line to limit line, it is critical that a temporary one-way traffic signal be used with a state-approved **conflict monitor.**
2. Use **yellow timing** appropriate for the approach speed.
3. Base all red clearance timing on actual field measurements of traffic travelling through the signal system.
4. A separate **all-red clearance time may be used for bicycles**, when they activate a push button.
5. A **bicycle push button** is recommended for uphill direction.
6. It is important **not to gap-out too quickly** since there is a lot of lost time during the clearance phases.
7. When there is not a clear line-of-sight from limit line to limit line, it is recommended to **modify the flash load switches** so during conflict they will output a **solid red indication**.

Figure D1 below shows an example of one-way traffic signal where there is no clear view of both limit lines.

Figure D1 – Example of One-way Traffic Signal Where There is No Clear View of Both Limit Lines

APPENDIX E

YELLOW TRAP

E.1 Left Turn Phasing

There are five options for the left-turn phasing at an intersection: permissive only, protected only, protected-permissive, split phasing, and prohibited. Phasing can have a significant impact on signal system effectiveness for a number of reasons, including:

- Permissive only left turn operation may reduce delay for the intersection, but may adversely affect intersection safety, because it requires motorists to choose acceptable gaps.
- Protected only left-turn phases may reduce delay for turning vehicles but are likely to increase overall intersection delay.
- Protected-permissive left turn phases can offer a good compromise between safety and efficiency but could limit available options to maximize signal progression during coordination unless innovative displays are used.
- Split phasing may be applicable with shared lanes, but could increase coordinated cycle length if both split phases are provided a concurrent pedestrian phase.
- Prohibited left turns may be used selectively to reduce conflicts at the intersection.

Protected and Permissive Left Turn Phasing

If a protected left turn phase is to be used (left turn made without conflicts with opposing traffic) left turns may or may not also be permitted on a circular green or Flashing Yellow Arrow (FYA, see Figure E2) indication with opposing traffic. In general, it is desirable to allow this permissive left turn movement unless there are overriding safety concerns which make such phasing particularly hazardous.

- Use of a permissive left turn can significantly reduce overall intersection delay as well as delay to left turners.
- Use of permissive left turn phasing may reduce the required length of left turn storage on the approach and allow an approach with substandard left turn storage to operate more efficiently.

Certain situations exist where safety considerations generally precluded the use of permissive left turns. In these cases, left turns should be restricted to the exclusive left turn phases. Such situations include:

- Intersection approaches where crash experience or traffic conflicts criteria are used as the basis for installing separate left turn phasing.
- Blind intersections where the horizontal or vertical alignment of the road does not allow the left turning driver adequate sight distance to judge whether or not a gap in on-coming traffic is long enough to more safely complete his turn.
- High-speed and/or multilane approaches may make it difficult for left turning drivers to judge gaps in oncoming traffic. Such locations should be evaluated on an individual basis.
- Unusual geometric or traffic conditions may complicate the driver’s task and necessitate the prohibition of permissive left turns. An example of such conditions is an approach where dual left turns are provided.
- When normal lead-lag phasing is used (due to left turn trapping).

Some of the issues noted above that preclude the use of permissive left turns may only be applicable during certain times of the day. Traditionally, this would require protected only operation for the entire day. The use of the FYA display (see section G-3) would allow the indication to operate as protected only during some times of the day and permissive or protected/permissive during others. The use of the FYA display can also eliminate the left turn trapping problem that is discussed in the next section.

A critical element to the operation of a traffic signal is the determination of the appropriate phasing sequence. At signalized intersections where traffic volumes are heavy or speeds are high, vehicles attempting to turn left across opposing traffic may constitute significant operational and capacity problems. Based on this, there are additional considerations for determining the left turn phasing alternative. These include:

- *Heaviest Left Turn Protected* - This is a leading left phase scheme in which the left-turning vehicles from only one approach are protected and move on an arrow indication proceeding the opposing through movement; or a lagging left when the protected left turn follows the through movement phase.
- *Both Left Turns Protected (Without Overlap)* - When the opposing left turns move simultaneously followed by the through movements, it is called a "lead dual left." If the left turns follow the through movement, it is called a "lag dual left."
- *Both Left Turns Protected (With Overlap)* - In this operation, opposing left turns start simultaneously. When one terminates, the through movement in the same direction as the extending left movement is started. When the extended left is terminated, the remaining through movement is started. When this type of phasing is used on both streets, it is termed "quad left phasing".
- *Lead Lag* - This phasing is combined with a leading protected left in one direction, followed by the through movements, followed by a lag left in the opposing direction. It is sometimes used in systems to provide a wider two-way through band.
- *Directional Separation (Split)* - First, one approach moves with all opposing traffic stopped, then the other approach moves with the first approach stopped.

Figure E1 shows the above basic left turn phasing schemes. Whether or not separate left turn phasing should be provided is a decision that must be based on engineering analysis. This analysis may involve serious trade-offs between safety, capacity, and delay considerations.

- Separation of left turns and opposing traffic may reduce crashes that result from conflicts between these movements, and may increase left turn capacity. However, through traffic capacity may be reduced.
- Left turn phasing may reduce peak period delay for left turners, but may increase overall intersection delay. Off-peak left turn delay may also increase.

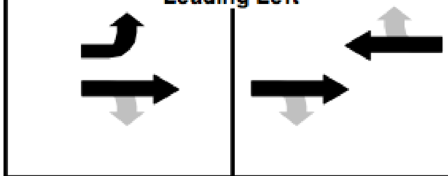
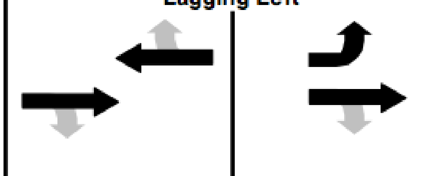
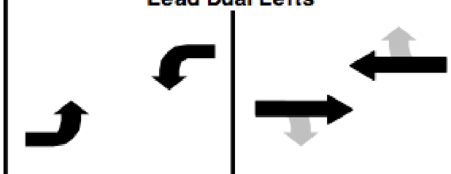
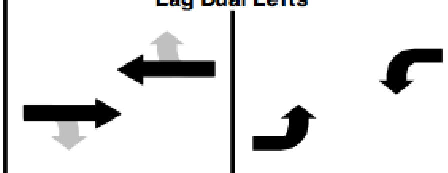
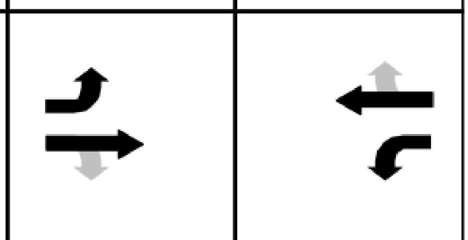
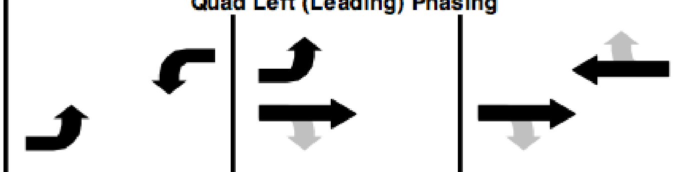
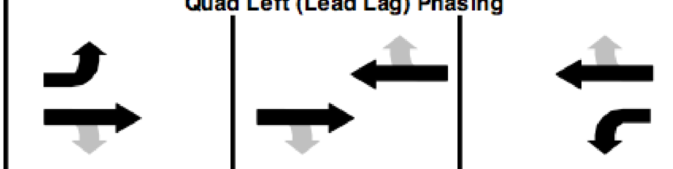
Heaviest Left Turn Protected This is a leading left phase scheme in which the left-turning vehicles from only one approach are protected and move on an arrow indication proceeding the opposing through movement; or a lagging left when the protected left turn follows the through movement phase.	**Leading Left**  **- OR -** **Lagging Left** 
Both Left Turns Protected (Without Overlap) When the opposing left turns move simultaneously followed by the through movements, it is called a "lead dual left". If the left turns follow the through movement, it is called a "lag dual left".	**Lead Dual Lefts**  **- OR -** **Lag Dual Lefts** 
Directional Seperation (Split) First, one approach moves with all opposing traffic stopped, then the other approach moves with the first approach stopped.	
Both Turns Protected (with Overlap) In this operation, opposing left turns start simultaneously. When one terminates, the through movement in the same direction as the extending left movement is started. When the extended left is terminated, the remaining through movement is started. When this type of phasing is used on both streets, it is termed "quad left phasing". ***Lead Lag*** phasing is combined with a leading protected left in one direction, followed by the through movements, followed by a lag left in the opposing direction. It is sometimes used in systems to provide a wider two-way through band. .	**Quad Left (Leading) Phasing**  **- OR -** **Quad Left (Lead Lag) Phasing** 

Figure E1 – Left Turn Phasing

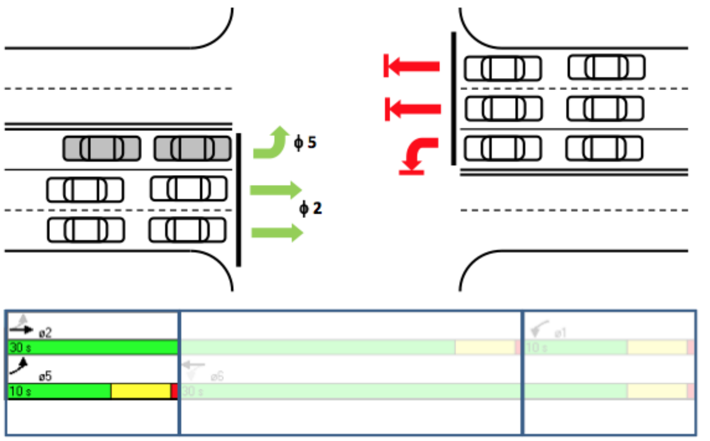
E.2 Left Turn Trapping

As noted earlier, the combination of a permitted left turns with lead-lag creates a situation commonly called the "left-turn trap" (when no FYA is used).

Consider Figure E2 for an eastbound leading left scenario. There is no real problem with the westbound situation here; these left turners are presented in stage 2 with a green ball after a period of obvious opposing flow. It is clear they must yield to the eastbound through traffic. In stage 3 this movement is protected and, again three is no problem. The transition is given by green ball direct to green arrow, but even if a yellow ball was displayed at the end of stage 2, there is no problem.

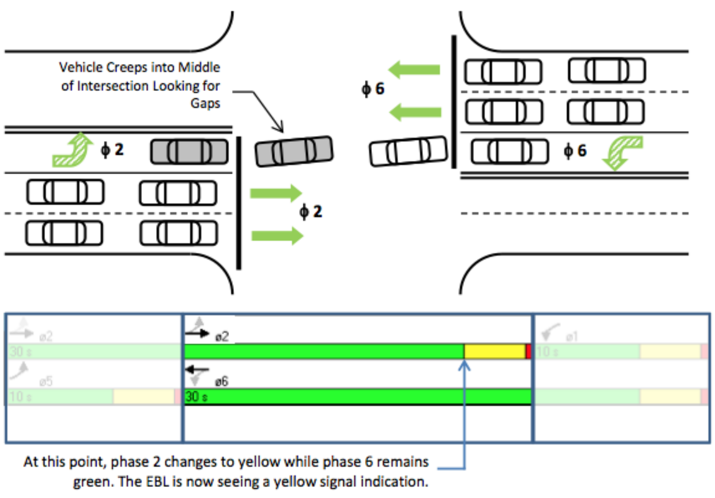
The problem is with the eastbound left turns. If this scenario is allowed, any left turner who had not been able to find a gap during the stage 2 green would be presented with a yellow indication at its end. Since these drivers see a yellow indication on all facing displays (through and left), they may incorrectly presume that the westbound through is likewise receiving a yellow indication and is about to stop. When the signal turns red (eastbound) the turner will: 1) at best be stuck (now illegally), in the middle of the intersection with nowhere to go, or 2) at worst, commit the left turn thinking the opposition is stopping, creating a potential conflict.

Refer to Figure E3 for information on how the flashing yellow arrow can eliminate the left turn trap condition.



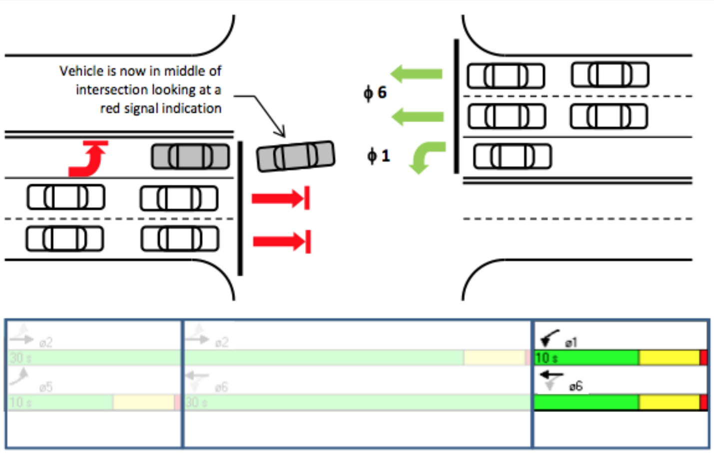
Stage 1: Phase 5 eastbound (EBL) shows a protected left turn arrow while phase 2 eastbound shows a green ball. The opposing WB movements are stopped.

No issues during this stage; the left turn vehicles have a protected movement.



Stage 2: The EBL and WBL now operate as permitted lefts (sees a green ball indication). During this stage, the EBL may creep into the middle of the intersection looking for gaps in the opposing traffic. Note that the EBL is actually operating as Phase 2 permitted.

At the end of this stage is when the problem occurs. Phase 2 indications will change to yellow. The EBL vehicle now has to consider how to clear the intersection and may falsely assume the opposing through is seeing a yellow indication and is about to stop. In fact, the WBT remains green since phase 1 WBL is up next.



Stage 3: Now, phase 1 WBL shows a green arrow (protected) operation while phase 6 WBT remains green. The EBL may have assumed the WBT was stopping and attempts to sneak through the intersections creating a crash situation.

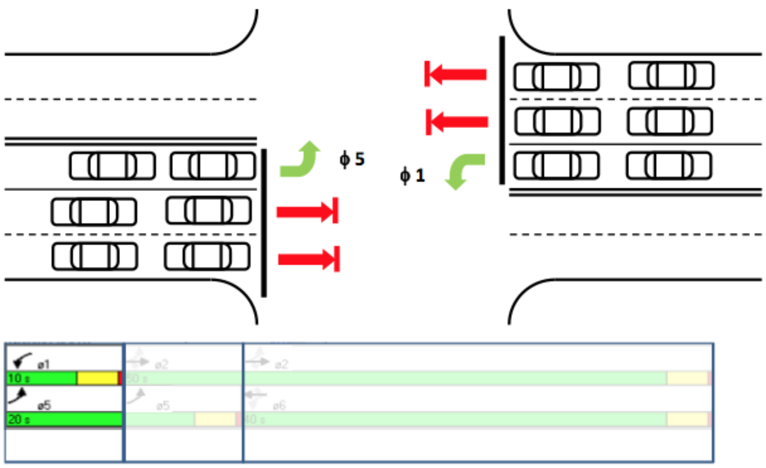
Figure E2 – Lead/Lad Left Turn Trap

Flashing Yellow Arrow and the Left Turn Trap

Figure E3 illustrates a left turn trap with traditional lead/lag phasing (i.e., a green ball indication is used for the permitted left turns). Using a FYA indication can eliminate the trap condition illustrated in this exhibit.

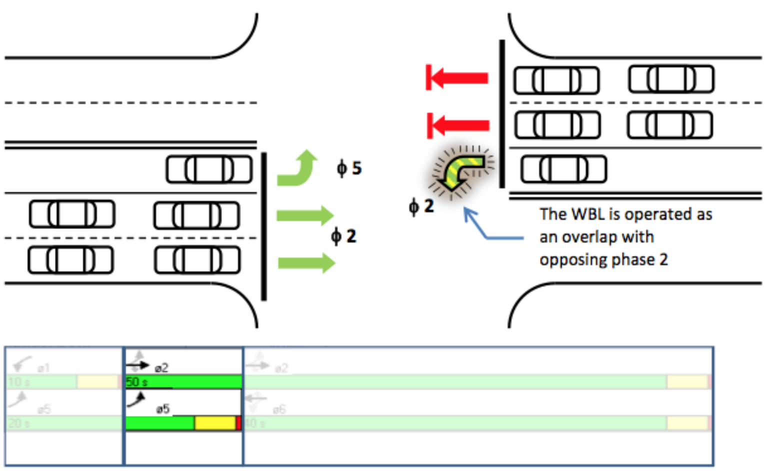
Once again, consider the EBL vehicle. During stage 1, the EBL receives a green arrow and proceeds under the protected movement. During stage 2, the EBL shows the flashing yellow arrow indication and the movement operates as a permissive movement. In stage 3, the EBL remains a flashing yellow arrow indication instead of turning red. The EBL FYA actually operates as an overlap to phase 6. Therefore, the EBL and opposing WBT terminate at the same time as expected by the driver.

Figure E3 illustrates the signal operation of the FYA even under the "soft-trap" condition and how this can be eliminated.

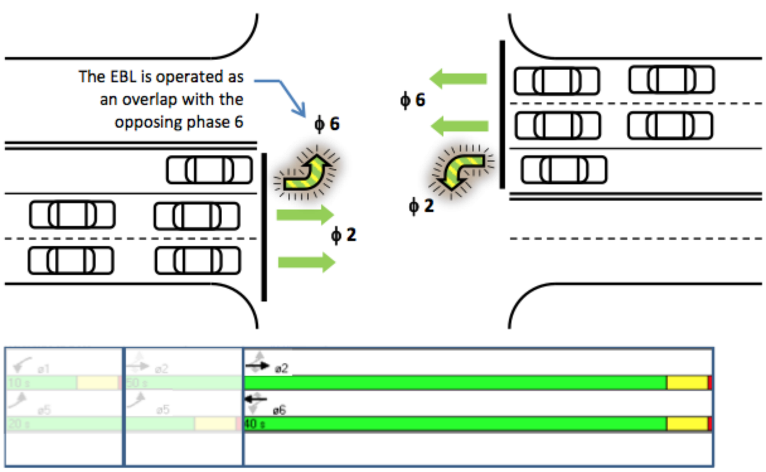


Stage 1: During this stage, normal leading protected and opposing left turn phases operate. This is the typical operation even with a traditional 5-section signal indication.

At the end of this stage, phase 1 clears the intersection with a solid yellow arrow.



Stage 2: During this stage phase 2 begins green as phase 5 continues green in normal operation. The opposing left turn is operated as a FYA. In a traditional 5-section operation, the opposing left turn would be red.



Stage 3: In this stage, phase 2 and 6 throughs receive a green ball indication. The opposing lefts are operated as an FYA overlap with the opposing through. This will ensure that the left turn clears (turns yellow) and then red with the opposing through, thus eliminating the left turn trap.

Figure E3 – Flashing Yellow Arrow (FYA) to Eliminate Left Turn Trap

E.3 Flashing Yellow Arrow Display

The Flashing Yellow Arrow (FYA) head is a signal that uses a flashing yellow arrow indication for permissive left turns instead of using a green ball. A 7-year national study determined that the 4-section FYA signal head with a red arrow on top, followed by a steady yellow arrow, a flashing yellow arrow, and then a green arrow on the bottom has the best driver recognition, based on driver confirmation and field implementation studies.

The FYA head is now the recommended left turn head in the 2014 CA MUTCD (4D.04.E.2). This version of the MUTCD includes language on the use of the flashing yellow arrow for permitted left turns that states:

> "Vehicular traffic, on an approach to an intersection, facing a flashing YELLOW ARROW signal indication, displayed alone or in combination with another signal indication, is permitted to cautiously enter the intersection only to make the movement indicated by such arrow, or other such movement as is permitted by other signal indications displayed at the same time.
> Such vehicular traffic, including vehicles turning right or left or making a U-turn, shall yield the right- of-way to:
> - a) Pedestrians lawfully within an associated crosswalk, and
> - b) Other vehicles lawfully within the intersection.
>
> In addition, vehicular traffic turning left or making a U-turn to the left shall yield the right-of-way to other vehicles approaching from the opposite direction so closely as to constitute an immediate hazard during the time when such turning vehicle is moving across or within the intersection."

The associated figure from the 2014 CA MUTCD is shown below (Figure E4):

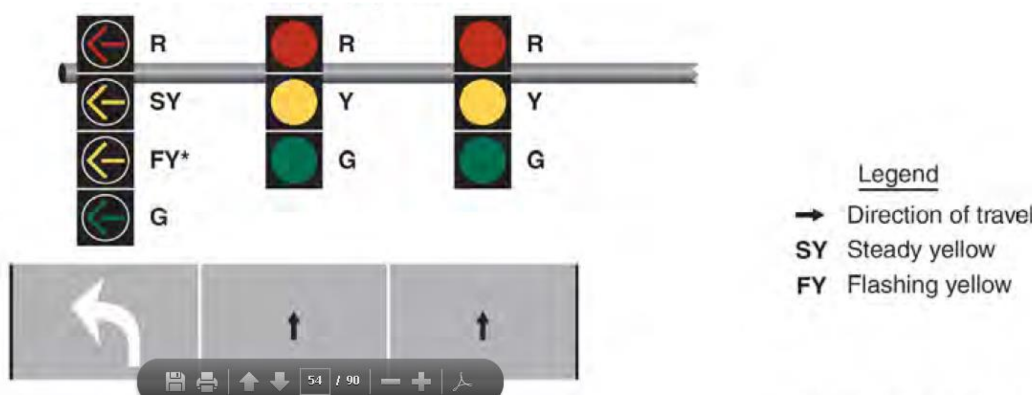


Figure E4 – Typical Position and Arrangements of Separate Signal Faces with Flashing Yellow Arrow for Protected/Permissive Mode and Protected Only Left Turns

APPENDIX F

YELLOW INTERVAL TIMING

F.1 Yellow Signal Phase Change Interval For Through Movements

This section applies to calculations of yellow timing for through movements. For calculation of yellow timing for protected-only left-turn and right-turn movements, see section F.2.

Vehicle phase change and clearance intervals are intended to provide a uniform and orderly transition between two conflicting phases. It consists of a yellow change interval and a red clearance interval. The yellow vehicle change interval should be followed by an all-red clearance interval of sufficient duration to permit the intersection to clear before cross traffic is released. The length of the yellow vehicle change interval and the all-red clearance interval shall be established on the basis of these guidelines and engineering judgment.

The CA MUTCD Section 4D.26 (Yellow Change and Red Clearance Intervals) and the associated Table 4D-102 (CA) (Minimum Yellow Change Interval Timing) is based on the Institute of Transportation Engineers (ITE) formulas for phase change intervals; these formulas shown below are general and should only be used as a guide. Other factors at an intersection (such as approach grades, visibility, truck traffic and local traffic characteristics) should be considered. It is important that approach grades and truck traffic are considered in determining the yellow and red intervals. The yellow change interval must not be too short (causing quick stops and/or red violations) nor too long (encouraging vehicles to enter late in the yellow interval).

An engineering study may be used to determine the approach speed. The posted speed limit may be assumed to be the approach speed when an engineering study is not available.

Yellow Change Interval

The intent of the steady yellow interval is to warn traffic of an impending change in the right-of-way assignment. Yellow vehicle change intervals should have a range of 3 to 6 seconds.

The following formulas may be used to determine the yellow time. This is based on the Institute of Transportation Engineers equation for yellow change interval.

(1) Minimum yellow vehicle change interval = $t_1 + t_2$

Reaction time $t_1 = 1$ sec

$t_2 = 1.4v / (2a + 64.4g)$

Where:

g = % grade divided by 100 (downhill is negative grade)

a = deceleration rate of 10 feet per second per second

v = design speed

Experience has shown that a perception-reaction time t_1 of one second (1 sec.) is realistic. Also, deceleration rates of 8 and 12 feet per second per second are the lower and upper limits for establishing vehicle change intervals. Typically, drivers in large urban cities will exhibit higher rates of deceleration than drivers in smaller towns or on rural highways. For typical applications, a deceleration rate (a) of 10 feet per second per second will be used in calculating the yellow vehicle change interval.

If the 85th percentile of the approach speed of the through movement has been determined, table (a) of Table 4D-102 (CA) of the CA MUTCD should be used for determining the yellow change interval (seen in Table F1).

a - For Speed determined by 85th Percentile

SPEED (Determined by 85th Percentile Speed)*	MINIMUM YELLOW INTERVAL
mph	Seconds
25 or less	3.0
30	3.2
35	3.6
40	3.9
45	4.3
50	4.7
55	5.0
60	5.4
65	5.8

*See Section 4D.26 Standard under paragraph 14b

Table F1: Table for determining the minimum yellow interval for through movements if the 85 percentile of the approach speed has been determined.

If the 85th percentile of the approach speed of through movement has not been determined, table (b) of Table 4D-102 (CA) of the CA MUTCD should be used for determining the yellow change interval (seen in Table F2), based on the posted speed limit.

b - For Posted or Prima Facie Speed

POSTED SPEED or UNPOSTED PRIMA FACIE SPEED	MINIMUM YELLOW INTERVAL*	MINIMUM YELLOW INTERVAL*
mph	Seconds	Seconds
15	N/A	3.0
20	N/A	3.2
25	N/A	3.6
30	3.7	N/A
35	4.1	N/A
40	4.4	N/A
45	4.8	N/A
50	5.2	N/A
55	5.5	N/A
60 or higher	5.9	N/A

Table F2: Table for determining the minimum yellow interval for through movements if the 85 percentile of the approach speed has not been determined.

Red Clearance Interval
The red clearance interval is an interval at the end of yellow change interval during which the phase has a red-signal display before the display of green for the next phase. The intent of this interval is to allow time for vehicles that entered the intersection during the yellow change interval to clear the intersection prior to the next phase. The following formulas may be used to determine the red time. This is based on the Institute of Transportation Engineers (ITE) equation for red clearance interval.

(2) All Red Clearance Interval =

$$t_3 = (W + L) / (1.47V)$$

Where:
V = Posted Speed in miles per hour
W = Intersection Width (ft), stop bar to the farthest conflicting lane
L = Length of Vehicle (ft), assumed to be 20 feet

Phase Change Interval
Total Phase Change Interval = $t_1 + t_2 + t_3$

F.2 Left-Turn Signal Timing

This section applies to calculations of yellow timing for left-turn movements. For calculation of yellow timing for through movements, see section D.1. **A yellow change interval should have a minimum duration of 3 seconds and a maximum duration of 6 seconds.**
In the case of a left-turning vehicle, the distance through the intersection is measured from the near-side stop line to the far edge of the last conflicting traffic lane along the left-turning vehicle path. **The typical approach speed for left turning vehicles is assumed to be 25 mph.** A different speed may be used at very large intersections, complex intersections, single-point diamond interchanges and at multi-legged intersections. If the approach speed through the left turn for vehicles is determined to be greater than 25 mph, table F3 may be used.

Approach Speed through Left-Turn	Minimum Yellow Interval
mph	**seconds**
25 or less	3.0
30	3.2
35	3.6
40	3.9

Table F3: Table for determining the minimum yellow interval for Left-Turn movements. If not measured, assume 25 mph.

Red Clearance Interval

The following formula may be used to determine the red clearance interval, based on the Institute of Transportation Engineers (ITE) equation:

$$t_3 = (W + L) / 1.47V$$

Where:

t_3 = maximum length of red clearance interval, to the nearest 0.1 second

W = Travel distance of left turning vehicle, in feet, measured in a straight line chord from the point where the near-side stop line intersects the outermost left turn lane line, directly to the point where the extension of the outside edge of the receiving lane for the outermost turning movement intersects the extension of the outside edge of the outermost conflicting traffic lane.

L = length of vehicle, assumed to be 20 feet

V = speed of left turning vehicle through the intersection, assumed to be 25 mph

The minimum value for red clearance intervals shall be 1.0 second, but should not exceed 6.0 seconds.

APPENDIX G

OVERLAPS

Overlap Phasing
An overlap is a right-of-way indication that allows traffic movement when the right-of-way is assigned to two or more traffic phases. An overlap occurs when one green signal indication is illuminated by more than one phase output from a controller.

Right Turn Overlap (Controller Programmed)
Refer to the Figure G1 below. In this case, the NBR (northbound right turn movement) is assigned as overlap A in the controller. The parent phases for OL A are 1 and 8.

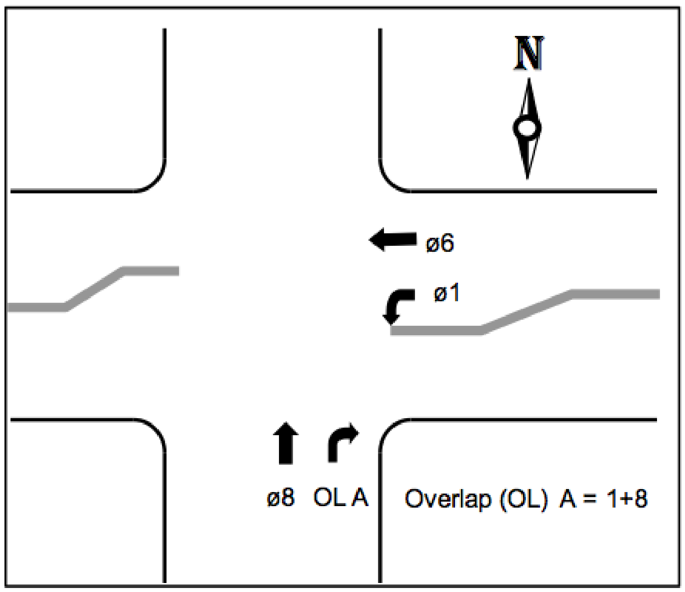


Figure G1 – Right Turn Overlap Phasing

For this case, the yellow ball and red clearance is NOT displayed and green arrow will continue to be displayed during change from phase 1 to 8.

Controller programming can omit the right turn arrow if there is a conflicting pedestrian call.

Note: Programming the controller for the Overlap is preferred over a “Hardwired Overlap”.

Right Turn Overlap (Hardwired)
Refer to Figure G1. For the hardwired overlap, the NBR (northbound right turn movement) is wired directly with the WBL (westbound left turn movement). For this case, the yellow ball and red clearance is displayed during change from phase 1 to 8. This operation cannot be used if there is a conflicting pedestrian crossing.

Overlaps with U-Turns
When a right turn overlap is used, consideration should be given to the conflicting U-turn (westbound U-turn in the image above). In some instances, it might be necessary to prohibit U-turns. Another option is to use a "U-Turn Yield to Right Turn" sign.

Close Ramp Intersections Using Signal Controller with Overlaps
Refer to Figure G2. In this case, the WBT (westbound through movement) at the west ramp is assigned as overlap A in the controller. The parent phases for OL A are 1 and 2.

The EBT (eastbound through movement) at the east ramp is assigned overlap B in the controller. The parent phases for OL B are 5 and 6.

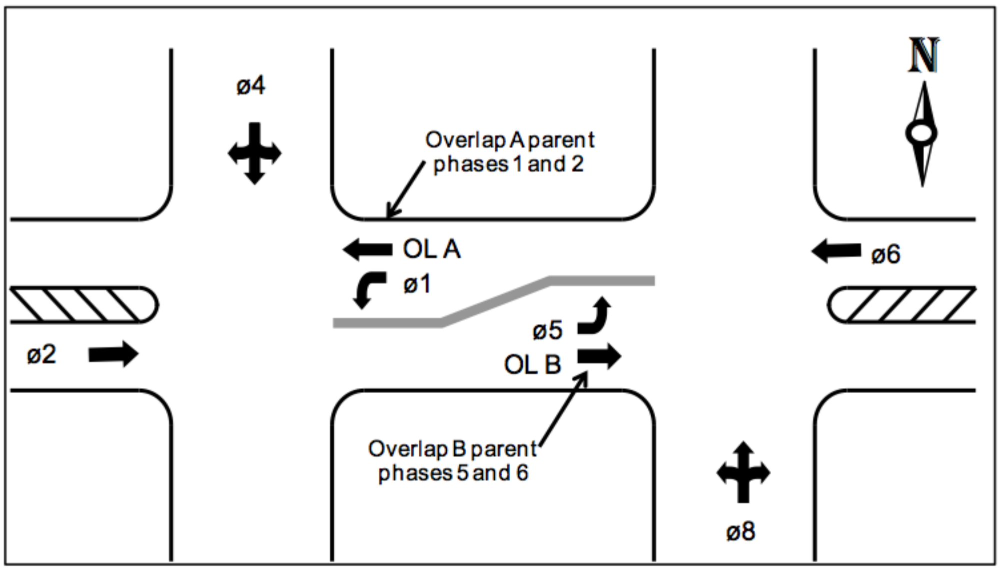


Figure G2 – Overlap Phasing

Another example may be seen in Figure K3.

APPENDIX H

PROCEDURE FOR OFF-PEAK FIELD REVIEW AND AM & PM PEAK FIELD REVIEW

Core working hours: start hours typically begin work day as between 6am and 9am, and end the work day between 3:00pm and 5pm.
It is acceptable that the AM peak field review be completed on a different day than when the PM peak field review is completed.

Pre-Field Review Work
The field review work requires prior preparation in the office, to prepare documents such as the specific documents needed in the field, reference drawings (or as-built plans), copy of the existing timing chart/sheet, copy of the "binder (such as the "Signal Controller Assembly Book (SCAR)" which is described in Appendix A), which includes excel spreadsheets with signalized intersection details), other related documents and the date of previous field review. Documents may include details such as the 210 conflict monitor board (removal of appropriate diodes).

Work should be documented by completing the appropriate attached worksheets titled "FIELD REVIEW: Surveillance and Off-Peak" or "FIELD REVIEW: AM (or PM) PEAK." For a more detailed list, the attached checklist may be used. The following steps describe the procedure for off-peak field reviews and the AM and PM peak field reviews:

OFF-PEAK Field Review
1. Note date and time of field review on document.
2. Compare reference drawing with field conditions (signal modifications, such as number of left-turn and through lanes, overlap phases, signs and striping, configuration of inductive loop detectors), etc.
3. Check posted speed limit signs for all approaches and record.
4. Evaluate and record if advance flashing beacon associated with this signalized intersection is functioning properly and whether it is still needed. Make recommendations if needed.
5. Check all timing parameters with timing chart and in controller (RAM locations in controller).
6. Check detection system (detector cards in the cabinet and visual review of loop detector sealants, or other detection technology). *Record observations.*
7. Review signal timing for all movements. Observations should include: gap-out timing, extended timing, max and min green timing, yellow and all-red timing, etc., to determine whether timing has been set appropriately. *Record observations.*
8. Review Emergency Vehicle pre-emption detectors with log records and/or field-test unit (if available). *Record results.*
9. Review Railroad preemption detectors (Model 252 AC isolator card). May coordinate with the railroad company.
10. Check the signal coordination with the other signals, if location is coordinated. Check whether traffic signal timing (green factors, time allocated for phases, splits, etc.) is appropriate for traffic flow pattern(s). Check communications between master and local

controller. *Record observations.* If possible, use tool such as TranSync to document time-space diagram for further study/refinement (compare with previous time-space diagram, etc.)

11. Check by driving through corridor, using stop watch to compare offset timing with intended offset (use mobile tool such as TranSync, if available).
12. Review Maintenance log (work done by maintenance).
13. Review event recorder of Model 2070 controller (conflict, short-power failure, long-power failure (indicates power issues), Emergency Vehicle pre-emptions, etc.).
14. Document any additional work, changes, modifications performed. Notify appropriate unit regarding issues that need to be addressed.
15. Update field register log (such as Activity Log Card kept in controller cabinet).
16. Make adjustment(s) to signal timing as necessary.

Procedure for AM/PM Peak Reviews

The core hours for staff to properly perform AM and PM peak field reviews are as follows. The AM peak field reviews timeframe typically begin between 6am and 9am, and PM peak field review typically represents the end the work day, between 3:00pm and 5pm. The steps to perform the peak field review include the steps described above (steps 1 through 16) as well as the additional steps described below:

AM & PM PEAK Field Review

17. When cabinet has a Model 170 or 2070 controller, complete the provided draft AM & PM Field Review form for reviewing signal timing for each of the phases and cycle length.
18. Observe progression of traffic: Do vehicles cross the intersection within one cycle? Two cycles? More than two cycles? *Document observations.*
19. For coordinated intersections, observe progression of traffic: Does mainline traffic progress through the system without stopping? How much delay is induced to the side street and left-turn traffic? Is traffic backing up onto the freeway? Do vehicles cross the intersection within one cycle? Two cycles? More than two cycles?
20. Make adjustments to coordination offsets, as necessary (based on recommended timing on Field Review form).
21. For un-coordinated intersections, verify that the maximum green times are appropriate for the traffic volumes. This includes considerations for preventing traffic from backing onto the freeway, or into the through lanes.

Post-Field Review Work

1. Complete field review report. Include record in data files per specific location for 5 years.
2. Notify appropriate unit(s) regarding issue(s) that need to be addressed (such as Maintenance, Traffic Engineering/Safety, etc.).
3. Report via TRAC ticket(s).

Annual Traffic Signal Operations Review Checklist

	Pre-Field Review (Office Work)	Yes	No
	Location name:		
1	Review date and peak period (AM or PM):		
2	Previous review date for same peak period:		
3	Did you gather a copy of the current timing sheets (including detector sheet, conflict monitor sheet, etc.)?		
4	Did you gather a copy of the current plan sheets?		
5	Did you gather a copy of any pending permit or construction projects at this location?		
6	Did you gather a copy of the current calculation sheet for clearance intervals?		
7	Do the clearance intervals (yellow, red, bike min green, FDW) match the calculation sheet?		
8	Is the conflict monitor page correct?		
9	Central System Checks		
10	Is the signal communicating properly with the central system?		
11	Is the detection showing properly in the central system?		
12	Does the central system database match the timing records and controller timing?		
13	Does the controller's clock have the correct date and time?		
14	Are the intersection diagram and arterial display correct?		
15	If the signal is coordinated, do the cycle timers count correctly?		
16	*Any pre-field review work that cannot be completed in the office, should be completed in the field.		
	Field Review (Field Work)	Yes	No
17	Does the cabinet have the proper paperwork (timing and intersection diagrams)?		
18	Do the timing sheets in the cabinet match the office records?		
19	Is the signal communicating properly with the Field Master?		
20	Is the detection working properly? (Check each individually)		
21	Do the emergency vehicle and railroad preemption detectors work?		
22	Do the posted speed limits match the calculation sheet?		
23	If there are flashing beacons, are they still needed and functioning properly?		
24	Is this signal coordinated with any other traffic signal? Is it working as intended?		
25	If not, does this signal need to be coordinated with another signal?		
26	Can the signal operations be improved?		
27	Did anything get added to or removed from the intersection since the previous field review?		
28	Do the field conditions match the plans (restriping, lane combines, bike lanes)?		
29	Have any new signs been installed (NTOR or No U-turn) that require a timing modification?		
30	Are all of the signal indications correct (arrow vs circular) and functioning?		
31	Do the pedestrian crossing lengths match the calculation sheet?		
32	Do all pedestrian indications and push buttons function correctly?		
33	Does the FDW countdown time display correctly?		
34	Are the APS messages correct?		
35	Does the APS station (button) light up when pressed to show an active call?		
36	Does the push button vibrate during WALK?		
37	Enter any physical cabinet changes made into the cabinet log.		
	Post-Field Tasks (Office Work)		*Completed*
38	Create TRAC ticket.		
39	Update office and maintenance records if necessary.		
40	Inform maintenance of any malfunctions or deficiencies.		
41	If it is noticed that any design or operational change can improve the efficiency of the traffic signal, send your findings to traffic engineering or appropriate unit for further study.		
42	If necessary, update cabinet and maintenance office records.		

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FIELD REVIEW

SURVEILLANCE AND OFF PEAK

LOCATION: ______________________________ DATE / TIME: ______________
P.M. ____________________________________
TRAC Ticket No. __________________________ T.E. _______________________

	Description	Y	N	Comments
1	Compare reference drawing with field conditions (signal modifications, such as number of left-turn and through lanes, signs and striping, etc).			
2	Check posted speed limit for all approaches and record			
3	Evaluate advance flashing beacon associated with signal.			
4	Check all timing parameters with timing chart and in controller.			
5	Check detection system (Detector card and visual review of loop detector, sealants, or other detection technology). Record observation.			
6	Review signal timing for all movements (gap-out timing, max and min green timing, yellow and all-red timing, etc. Record observation.			
7	Review Emergency Vehicle preemption detectors with event log records. Field test unit if available. Record observation.			
8	Review Railroad preemption detector and operation. May coordinate with Railroad company.			
9	Check signal coordination with other signals. Check timing such as green factors, cycle length, offsets etc. Check communication between master and local controller.			
10	Check by driving through corridor, using stop watch to compare offset timing with intended offset.			
11	Make adjustment(s) to signal timing as necessary.			
12	Review event recorder pf Model 2070 controller (conflict, short power failure, long power failure, emergency vehicle preemption, etc.)			
13	Document any additional work, changes, modification performed. Notify appropriate unit regarding issues that need to be addressed.			
14	Update field register log.			
15	Any additional remark/comments			

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FIELD REVIEW

☐ AM PEAK ☐ PM PEAK

LOCATION: ______________________________ DATE / TIME: ______________

P.M. ____________________________________

TRAC Ticket No. __________________________ T.E. _______________________

	Description	Y	N	Comments
1	Check timing parameters with timing chart and in controller.			
2	Check loop detection system			
3	Review signal timing for all movements (gap-out timing, max and min green timing, yellow and all-red timing, etc. Record observation.			
4	Check signal coordination with other signals. Check timing such as green factor, cycle length, offset, etc. Check communication between master and local controller.			
5	Check by driving through corridor, using stop watch to compare offset timing with intended offset.			
6	Observe through and turning movement pattern.			
7	Observe progression of traffic noting possible delays based on number of cycles a vehicle can pass through the intersection.			
8	Observe any incident that may affect traffic progression.			
9	Check if signals from other local agencies are in coordination with CT.			
10	Make adjustment(s) to signal timing as necessary, such as splits and offsets.			
11	Document any additional work, changes, modifications performed. Notify appropriate unit regarding issues that need to be addressed.			
12	Update field register log			
13	Any additional remark/comments			

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APPENDIX I

TRAFFIC SIGNAL MANAGEMENT AND SURVEILLANCE SYSTEM (TSMSS)

CTNET was developed in-house and designed to work with the Model 170e traffic signal controller. Most traffic signals are still coordinated with a field master controller that only reports signal status back to CTNET. CTNET does not have the capability of managing or synchronizing traffic signals, resulting in limited signal coordination and control. Additionally, the Model 170e controller is obsolete and being replaced with the Model 2070 controller. Consequently, CTNET has become outdated and needed to be replaced with a modern Traffic Management and Surveillance System (TSMSS) to work with the Model 2070 controllers and meet the Department goals of better managing, controlling, and operating Caltrans' traffic signal systems. The various benefits are listed below.

BENEFITS

- Remote Monitoring
- Reduces vehicle accidents
- Improve signal coordination/synchronization with Local Agencies
- Reduces number of stops
- Improves mobility
- Reduces energy and fuel consumption
- Provides environmental benefits from reduced vehicle emissions

SAFETY

- Remote monitoring of traffic signals enables signal Operations Staff to work from a safer environment

COLLABORATION

- TSMSS Working Group with members from Districts and HQ was established to design the functional requirements

PARTNERSHIP/STEWARDSHIP

- Improve signal coordination/synchronization with Local Agencies that share arterials with Caltrans

COST SAVINGS

Remote monitoring will reduce traffic signal maintenance:

- Overtime Charges
- Travel Charges (Mileage, Fuel)
- Scheduling

TransSuite® Traffic Control System (TCS)

TransSuite® TCS is a hybrid traffic control system. Although, it communicates with all traffic signal devices once-per-second (a configurable parameter), it does not directly control signal movements. The system commands each intersection controller to follow a timing plan or timing pattern, that resides within their local database and then verifies that the controllers adhere to the commanded patterns. TransSuite® TCS is a highly flexible system both in terms of architecture and in the increasing number of supported traffic control devices, controller hardware/firmware platforms, and communications protocols. TransSuite® TCS consists of several system and software components, including the following user interface applications:

- TCS Management User Interface
- ATMS Navigator
- ATMS Explorer
- ATMS System Log Viewer
- Unified Controller Manager

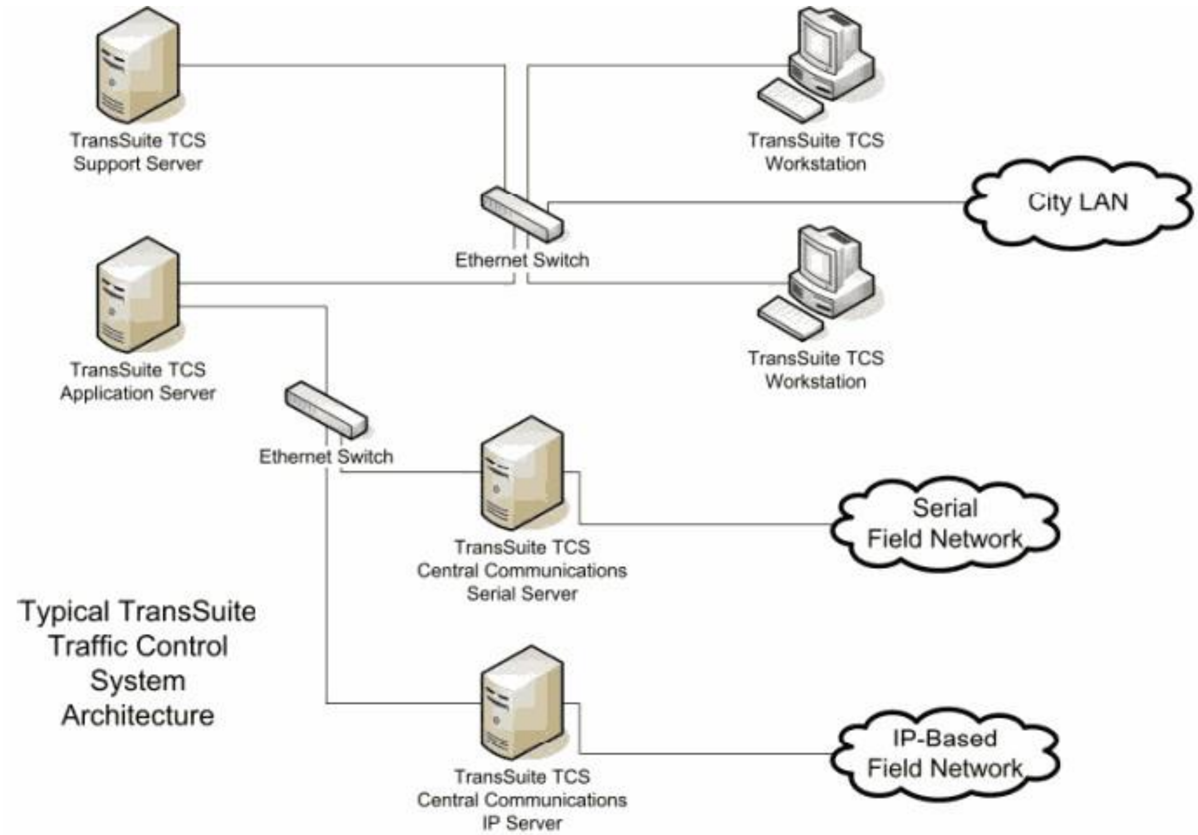


Figure I1 – TransSuite TSC User Interfaces

TCS Management User Interface
The TransSuite TCS Management User Interface (MUI) is the primary interface for configuring, monitoring, operating and controlling the TransSuite TCS system.

The key features of the Management User Interface are:

- Detailed views of real time and historical intersection controller and detector status data
- Summary views that allow users to easily compare the data of many different devices
- Extensive failure management views and configuration options, including support for paging, text, and email alerts, when certain conditions are detected
- Command and control functions that remotely affect intersection controllers in the field
- Flexible multi-level hierarchy for group-based control that helps manage systems of any size Support for advanced operations such as Critical Intersection Control, Traffic Responsive Operation, and Real-Time Split Adjustment
- Close integration with other TransSuite User Interface applications such as ATMS Ma and the Unified Controller Manager

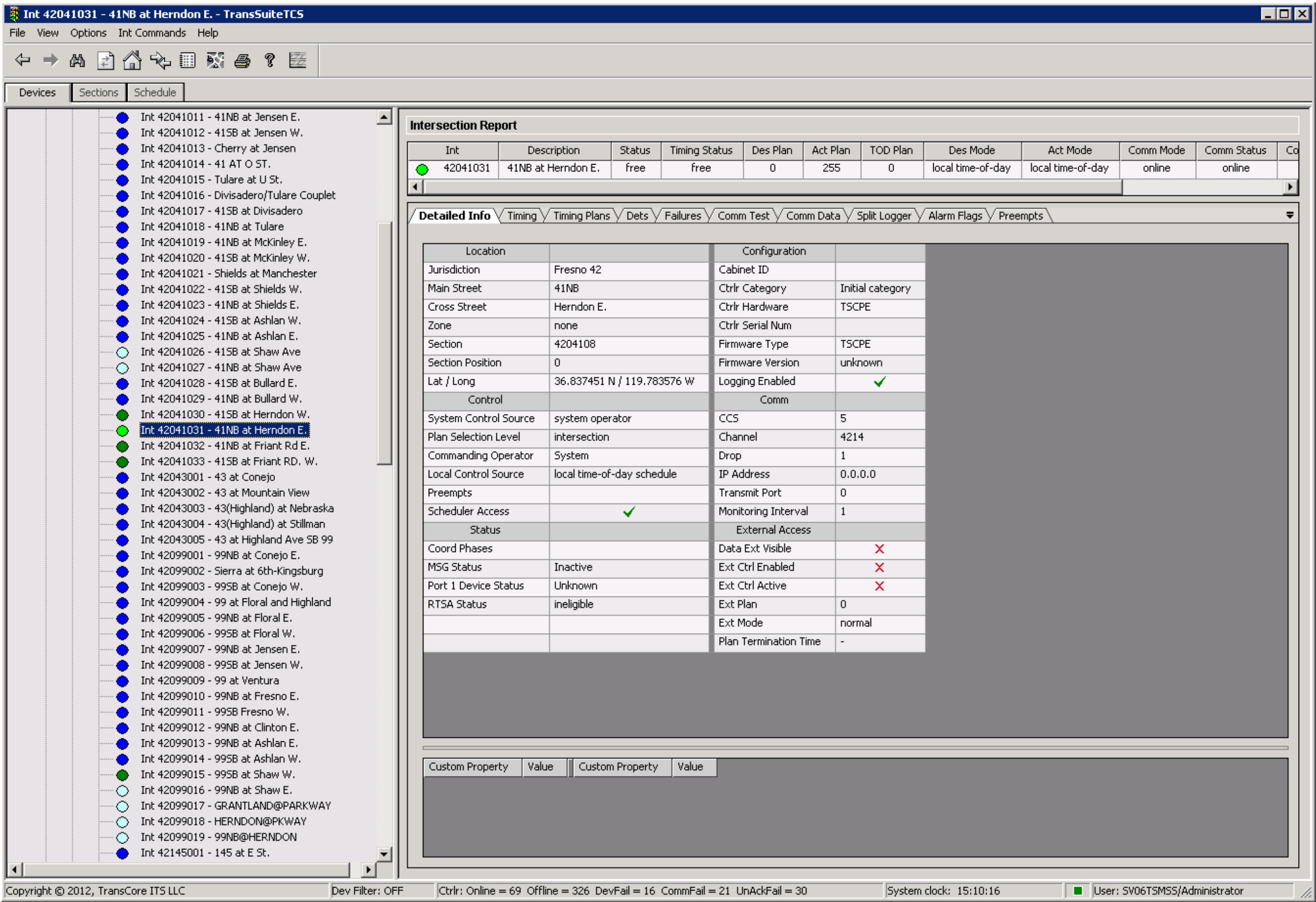


Figure I2 – Example of TSMSS User Interface for Specific Signalized Intersection

ATMS Map

The ATMS Map shows the status of system components at their locations within the roadway network. The application provides a geographically accurate map background over which various types of dynamic icons can be displayed. An example is shown below (Figure I3).

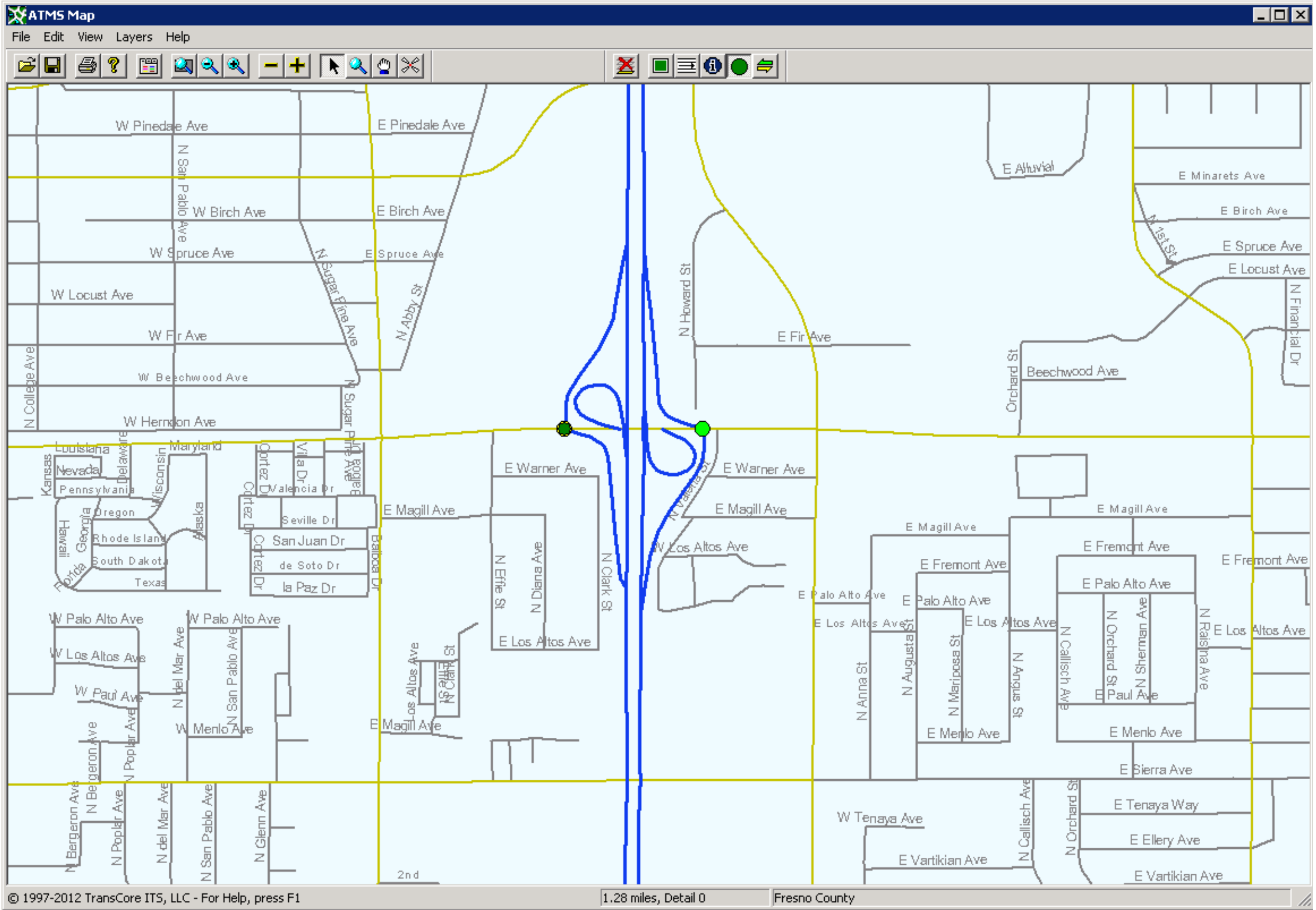


Figure I3 – Example of TSMSS ATMS Map

Operators can pan and zoom the map view to quickly navigate throughout the system and activate or deactivate the individual layers according to their needs. Operators can interact with the icons to see more detailed information and to issue commands to devices in the field.

TransSuite® TCS provides the following map layers:

- *TCS Controller Layer*: Contains icons that represent intersection controllers at their geographic positions. Intersection icons can display various types of operational and timing statuses and provide command options for authorized users.

- *TCS Arterial Link Layer*: Displays aggregate volumes, occupancy, and speed measurements from detectors along arterial segments.

Depending on the needs of the client, additional map layers may be provided. For detailed information, refer to ATMS Map documentation.

ATMS Explorer

TransSuite ATMS Explorer (XPL) is a powerful graphics platform that can be used to build and display custom diagrams that show the status and operation of components within the system.

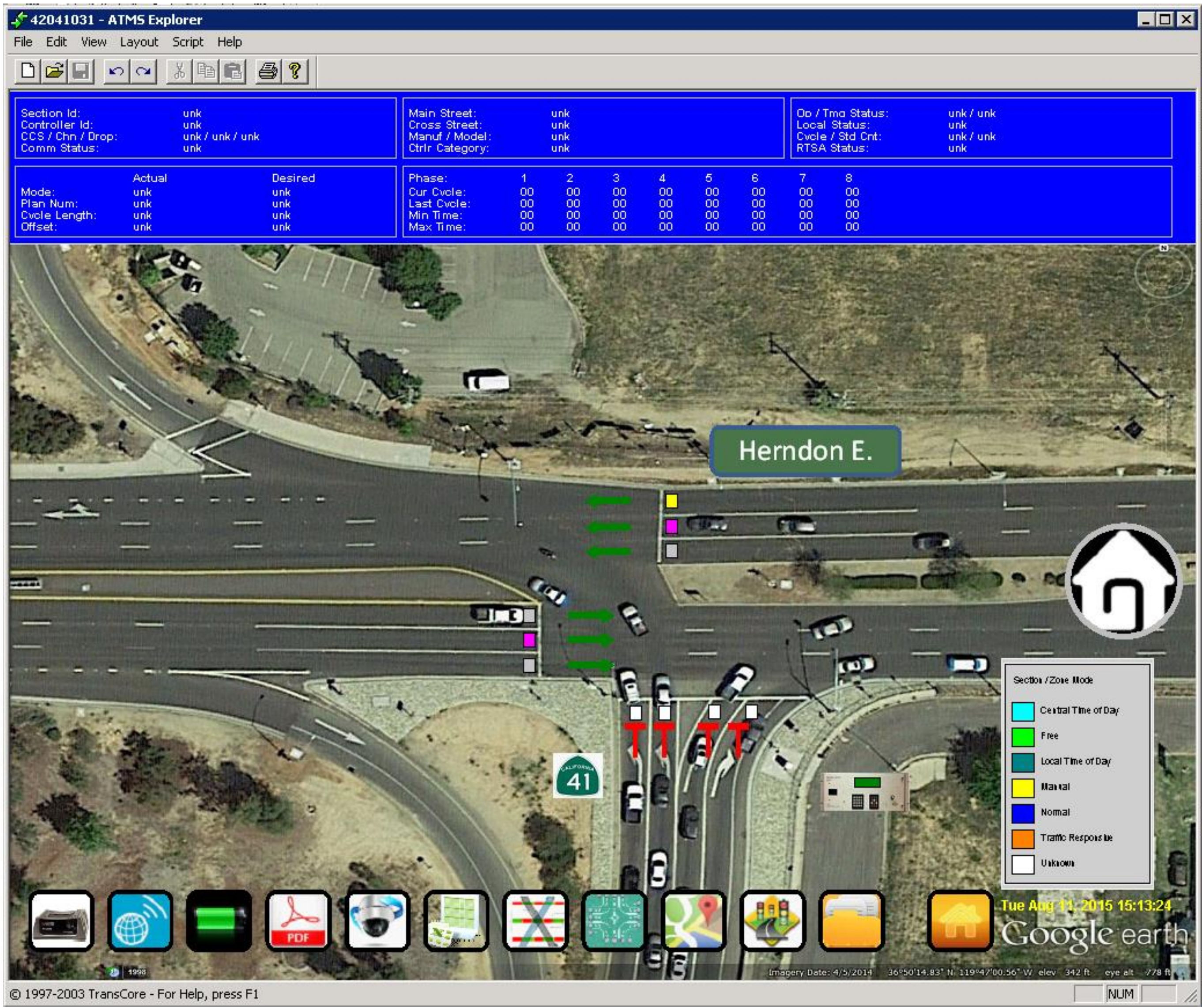


Figure I4 – Example of TSMSS "ATMS Explorer" with ActiveX Control Icons

Each ATMS Explorer diagram consists of a set of icons that are drawn on top of a static background image. These "icons" can be ActiveX controls or other types of embeddable objects, such as CorelDraw drawings or Microsoft Excel spreadsheets. ATMS Explorer includes special support for the following:

- ATMS controls (such as intersection controller icons, green arrow icons, pedestrian icons, and many more)
- Linking diagrams together to allow for easy navigation from one intersection to another
- Integration with other TransSuite® applications

For detailed information, refer to the ATMS Explorer documentation.

ATMS System Log Viewer
ATMS System Log Viewer displays event messages that have been generated by the other TransSuite applications.

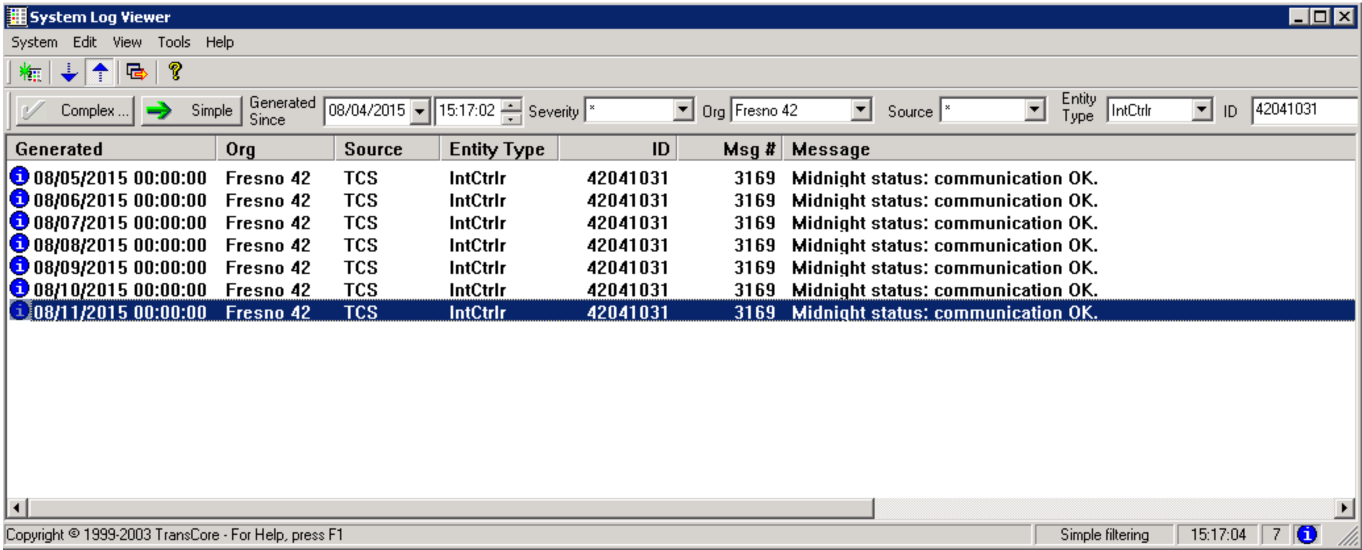


Figure I5 – Example of TSMSS System Log Viewer

Log entries are created for all activities that change the operation of the TCS or that affect the operation of connected systems. These include operator login, starting and stopping of services and applications, and sending commands to devices. The ATMS System Log also contains error messages and other information useful for diagnosing problems. For more detailed information, refer to the ATMS System Log Viewer documentation.

Unified Controller Manager
The TransCore TransSuite® Unified Controller Manager (UCM) is a tool for managing multiple versions of an intersection controller's database. Beside the controller resident database, the UCM provides access to other copies of the controller's database. It also provides a mechanism to provide the controller's database to TransSuite® TCS for use in monitoring the intersection's operation.

Having database versions serves several purposes. It primarily creates a temporal record of the changes to an intersection's database and provides a mechanism to develop new versions in anticipation of future events such as new phasing configurations or timing changes for multiple intersections that must be installed simultaneously. " Versioning" also allows for storing special timing versions to meet seasonal, recurring special event, or emergency response needs. These versions can be downloaded to the intersection controller when circumstances call for their use.

With the intersection controller databases stored in a central repository, disaster recovery provisions are more readily implemented and managed. Backup copies of the central repository can be created and stored in other remote facilities to reduce the system's susceptibility to catastrophic events and reduce the time to resume normal operations. For more detailed information, refer to the Unified Controller Manager user's manual for more information.

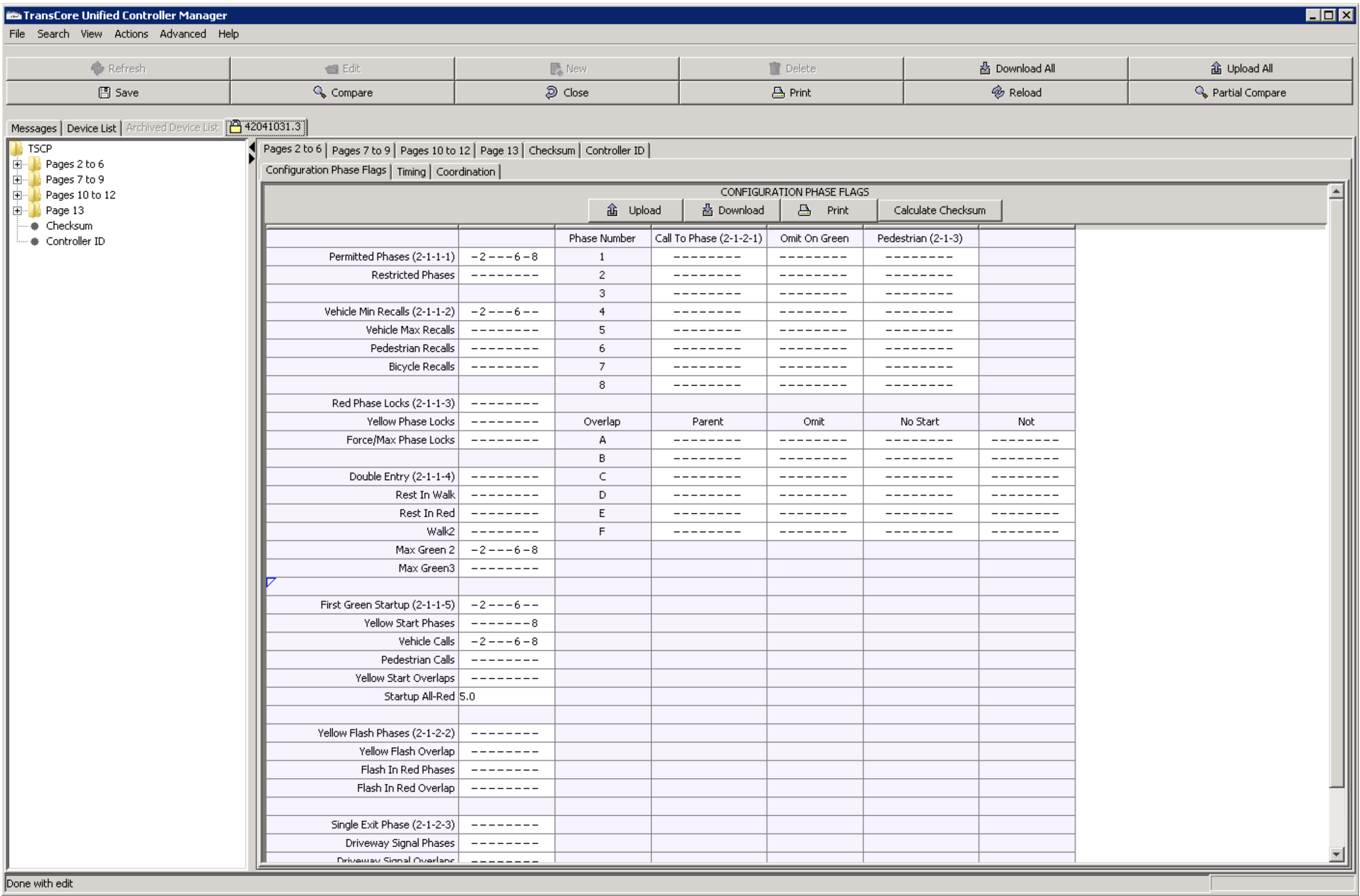


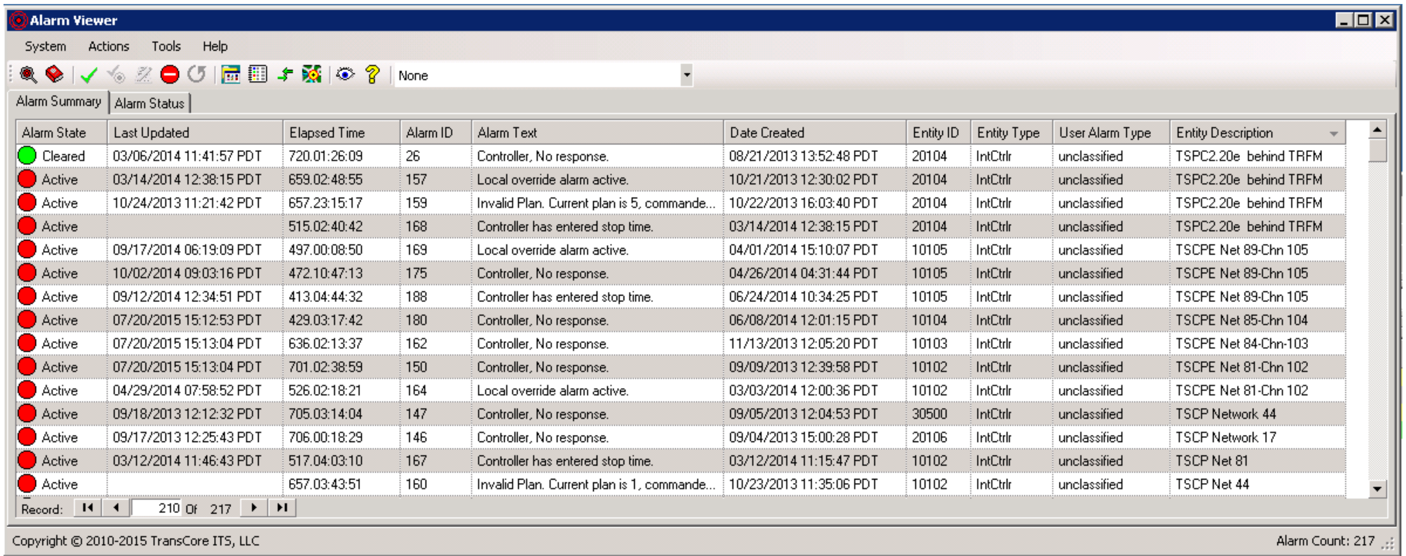
Figure I6 – Example of TransCore Unified Controller Manager

Alarm Viewer

The Alarm Viewer is a tool that provides customizable notifications in response to system events. These notifications inform appropriate staff of a range of events from individual intersection failures at critical locations to key equipment failures that involve many intersections. The Alarm Viewer user interface is shown below in Figure I7.

The Alarm Viewer starts automatically at logon and is accessible through the system tray. It contains its own Help information regarding the configuration of notifications.

Note that the TransSuite® TCS System Commands Configure Alarms dialog is used to enable event messages to generate alarms. This customization should be performed prior to entering notification data in the Alarm Viewer.



Alarm State	Last Updated	Elapsed Time	Alarm ID	Alarm Text	Date Created	Entity ID	Entity Type	User Alarm Type	Entity Description
Cleared	03/06/2014 11:41:57 PDT	720.01:26:09	26	Controller, No response.	08/21/2013 13:52:48 PDT	20104	IntCtrlr	unclassified	TSPC2.20e behind TRFM
Active	03/14/2014 12:38:15 PDT	659.02:48:55	157	Local override alarm active.	10/21/2013 12:30:02 PDT	20104	IntCtrlr	unclassified	TSPC2.20e behind TRFM
Active	10/24/2013 11:21:42 PDT	657.23:15:17	159	Invalid Plan. Current plan is 5, commande...	10/22/2013 16:03:40 PDT	20104	IntCtrlr	unclassified	TSPC2.20e behind TRFM
Active		515.02:40:42	168	Controller has entered stop time.	03/14/2014 12:38:15 PDT	20104	IntCtrlr	unclassified	TSPC2.20e behind TRFM
Active	09/17/2014 06:19:09 PDT	497.00:08:50	169	Local override alarm active.	04/01/2014 15:10:07 PDT	10105	IntCtrlr	unclassified	TSCPE Net 89-Chn 105
Active	10/02/2014 09:03:16 PDT	472.10:47:13	175	Controller, No response.	04/26/2014 04:31:44 PDT	10105	IntCtrlr	unclassified	TSCPE Net 89-Chn 105
Active	09/12/2014 12:34:51 PDT	413.04:44:32	188	Controller has entered stop time.	06/24/2014 10:34:25 PDT	10105	IntCtrlr	unclassified	TSCPE Net 89-Chn 105
Active	07/20/2015 15:12:53 PDT	429.03:17:42	180	Controller, No response.	06/08/2014 12:01:15 PDT	10104	IntCtrlr	unclassified	TSCPE Net 85-Chn 104
Active	07/20/2015 15:13:04 PDT	636.02:13:37	162	Controller, No response.	11/13/2013 12:05:20 PDT	10103	IntCtrlr	unclassified	TSCPE Net 84-Chn-103
Active	07/20/2015 15:13:04 PDT	701.02:38:59	150	Controller, No response.	09/09/2013 12:39:58 PDT	10102	IntCtrlr	unclassified	TSCPE Net 81-Chn 102
Active	04/29/2014 07:58:52 PDT	526.02:18:21	164	Local override alarm active.	03/03/2014 12:00:36 PDT	10102	IntCtrlr	unclassified	TSCPE Net 81-Chn 102
Active	09/18/2013 12:12:32 PDT	705.03:14:04	147	Controller, No response.	09/05/2013 12:04:53 PDT	30500	IntCtrlr	unclassified	TSCP Network 44
Active	09/17/2013 12:25:43 PDT	706.00:18:29	146	Controller, No response.	09/04/2013 15:00:28 PDT	20106	IntCtrlr	unclassified	TSCP Network 17
Active	03/12/2014 11:46:43 PDT	517.04:03:10	167	Controller has entered stop time.	03/12/2014 11:15:47 PDT	10102	IntCtrlr	unclassified	TSCP Net 81
Active		657.03:43:51	160	Invalid Plan. Current plan is 1, commande...	10/23/2013 11:35:06 PDT	10102	IntCtrlr	unclassified	TSCP Net 44

Figure I3 – Example of Alarm Viewer

APPENDIX J

RECORD RETENTION

Documents for traffic signal operations (signal timing plans, etc.) shall be five years plus the current year.

As per the Traffic Operations Policy Directive (TOPD) 11-03-R1, “Record Retention Policy for Traffic Safety and Traffic Accident Surveillance and Analysis Systems (TASAS)” (http://www.dot.ca.gov/trafficops/policy/11-03-R1.pdf):

“The purpose of this record retention policy is to provide consistency in the destruction of electronic collision data, reports generated from TSN, and documents related to traffic safety investigations and monitoring reports…”

“Destruction of the traffic safety investigation records, traffic collision reports, HSIP monitoring reports and supporting documentation, should be completed by the end of the first quarter.”

Likewise, the traffic signal timing plans should be destroyed after the 5-year plus current year timeframe.

APPENDIX K

DIAMOND INTERCHANGES

The Model 2070 controller can be used to operate an interchange in a diamond operation similar to when using the Model 170 controller diamond program. The photo below is of the interchange of Highway 20 and Highway 49 in District 3. It has a diamond configuration with two intersections and can be operated using one Model 2070 controller running TSCP (Traffic Signal Controller Program).

Although not a specific feature of TSCP, there is not one configuration that fits all diamond interchanges. Each diamond interchange is unique and requires programming combinations of overlaps and phases in coordination. Most diamond interchanges run very short cycle lengths because there is not much storage capacity between the intersections and longer cycle lengths will result in major backups on the surface streets and ramps. Each diamond interchange has to be thought out carefully, configured, then fined-tuned. Below is an example of a diamond interchange in District 3. The timing and coordination parameters may be seen in the attached configuration table.

Figure K1 – Aerial View of Diamond Interchange in District 3 (Highway 20 and Highway 49)

The specific changes/differences from a "typical" traffic signal for configuring phases for traffic signal operations for a diamond interchange are as follows:

- Page 2: Restrict phases 4 and 8. Set PED phases P2 to phases 3 and 6. Use overlaps A-F as shown below.
- Page 4: Set lag phases as shown in 7E.
- Page 7: Detector 41 set to phase 3.
- Page 12: Assign load switches as shown below.

Shown below is an example of the configurations for the diamond interchange at Empire Street in District 3.

California Department of Transportation, Caltrans — Location: Nevada County 49 and Empire St — TSCP 2.20

CONFIGURATION PHASE FLAGS

Phases (2-1-1-1)	
Permitted	1 2 3 4 5 6 7 8
Restricted	. . . 4 . . . 8

Phase Recalls (2-1-1-2)	
Vehicle Min	. . . .
Vehicle Max	. . . .
Pedestrian	. . . .
Bicycle	. . . .

Phase Locks (2-1-1-3)	
Red	. . . .
Yellow	. . . .
Force/Max	. . . .

Phase Features (2-1-1-4)	
Double Entry	. . . .
Rest In Walk	. . . .
Rest In Red	. . . .
Walk 2	. . . .
Max Green 2	. . . .
Max Green 3	. . . .

Startup (2-1-1-5)	
First Green Phases	. 2 . . 5 . . .
Yellow Start Phases	. . . .
Vehicle Calls	1 2 3 4 5 6 7 8
Pedestrian Calls	. . 3 . . 6 . .
Yellow Start Overlaps	. . . . . .
Startup All-Red	6.0

Call To Phase (2-1-2-1)		Omit On Green	
1	. . . .	1	. . . .
2	. . . .	2	. . . .
3	. . . .	3	. . . .
4	. . . .	4	. . . .
5	. . . .	5	. . . .
6	. . . .	6	. . . .
7	. . . .	7	. . . .
8	. . . .	8	. . . .

Flashing Colors (2-1-2-2)	
Yellow Flash Phases	. . . .
Yellow Flash Overlap	. . . . . .
Flash In Red Phases	. . . .
Flash In Red Overlap	. . . . . .

Special Operation (2-1-2-3)	
Single Exit Phase	. . . .
Driveway Signal Phases	. . . .
Driveway Signal Overlaps	. . . . . .
Leading Ped Phases	. . . .

Protected Permissive (2-1-2-4)	
Protected Permissive	. . . .

Pedestrian (2-1-3)	
P1	. . . .
P2	. . 3 . . 6 . .
P3	. . . .
P4	. . . .
P5	. . . .
P6	. . . . . 6 . .
P7	. . . .
P8	. . . .

Overlap (2-1-4)				
Overlap	Parent	Omit	No Start	Not
A	. . . 4 5 . 7 .	. . . .	. . . .	. . . .
B	1 . 3 8	. . . .	. . . .	. . . .
C	1 2 3 . 5 6 . 8	. . . .	. . . .	. . . .
D	1 2 . 4 5 6 7 .	. . . .	. . . .	. . . .
E	. 2	. . . .	. . . .	. . . .
F	. . . . . 6 . .	. . . .	. . . .	. . . .

Post Mile: Empire Diamond — PAGE 2 — CHECKSUM: 34A7 — Printed: 10/15/2015

Figure K2 – Example of Configuration Page for the Empire Street Diamond Interchange in District 3

Figure K3 below shows a sketched example of a diamond interchange and planned phasing.

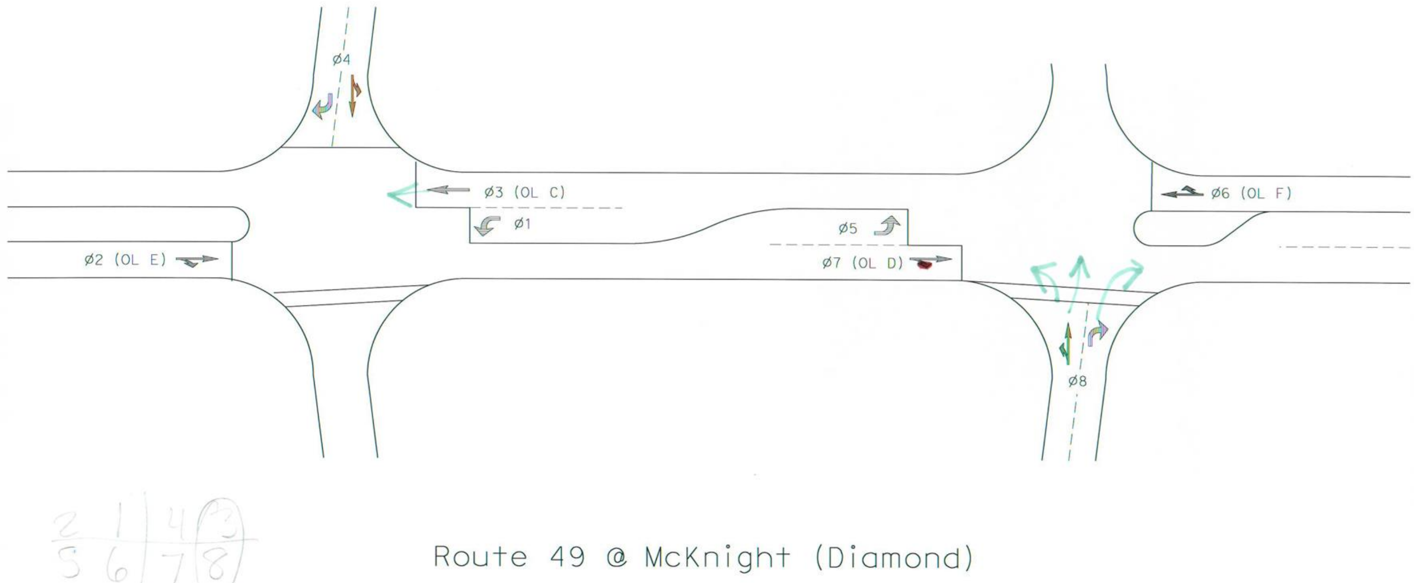


Figure K3 – Example of Diamond Interchange in District 3

APPENDIX L

YELLOW YIELD COORDINATION (Y-COORD)

Yellow yield coordination (also known as Y-Coord) is a type of coordination, which has a basic "master-slave" strategy. The master signal sends a green status to the local controller (slave). When the synchronized phase of the master yields (is not green), the local uses this input to let traffic go through that the master is sending. When the **set offset** has timed out, the hold is released on the local's coordinated phase so it may serve the opposing calls.
"No green" and "long green" are timers used to limit the local's cycle length, often in cases where the master is dwelling on green or in red flash. The "force-off" timer keeps the local's cycle time from exceeding that of the master.

Yellow yield coordination (also known as Y-Coord) is a type of coordination, which has a basic "master-slave" strategy. The master signal sends a green status to the local through a relay. The secondary contacts of the relays are tied to Spare 2 or 3 inputs. The input to the local controller is low when the master is green, and it goes high when the monitored master controller is not green. The program provides yield control plans; each plan has individual settings for offsets and associated timers. The plans are set by Time-of-Day. When the Time-of-Day routine is set for yield control, a hold is placed on the designated coordinated phases of the local controller. When the synchronized phase of the master yields (not green), the offset timer of the local controller is started. When the set offset has timed out, the hold is released on the locals' coordinated phases so it can accept opposing calls. For lead-lag phase operation, an additional timing function is available. After the offset timer has timed out, the lag-offset timer starts and the local yields to the lag left turn, if there is a call. Once the lag left turn is accepted, the following two conditions must be met before it yields to the side street.

1) The lag-offset timer has timed-out.
2) The lag left-turn phase is either gapped-out or maxed-out.

When there is no lag call, the local holds in the coordinated phases until the lag-offset timer is timed out, then it yields to the side street. Any late lag calls will not be accepted until the next cycle.

The interconnect signal from the master intersection comes in through input file designation J11. When the sync phase of the master intersection turns green, the No-Green timer is reset and the Long-Green timer is started. When the Master Controller yields to an opposing call, the input resets the Long-Green timer and starts the No-Green timer. If either the Long-Green timer or the No-Green timer is timed out, the program sets the local intersection free. The operator must set the following parameters:

- Y-COORDINATION RECALL PHASES – Flags for the phases to be recalled only during Y-coordination. However, these phases will not be recalled if the system goes free.

- PERM. TIME – This timer starts timing after the offset timer has timed out to allow the local to answer any opposing calls.

- OFFSET – Each yield from the Master Controller starts the offset timer at the local to provide an offset before the local intersection yields.

- FORCEOFF TIMER – This timer starts timing after the offset timer has timed out. It is the one and only force-off for the non-coordination phases. This timer should not be set too low, as the program automatically recalls phases that have been forced off. Within TSCP, the force-off timer may be set for each phase. However, C8 has only one (1) force-off timer for all phases.

- LONG-GREEN TIMER – A green input from the Master Controller that exceeds the set table Long-Green time causes the local intersection to go free.

- NO-GREEN TIMER – A No-Green input from the Master Controller that exceeds the set table No-Green time causes the local intersection to go free.

- COORDINATED PHASES – Flags for coordinated phases must be entered

- LAG – Phases to be lagging.

  Additional control parameters are available in TSCP:
- OMIT – The omit entry is used to select the phases that are to be omitted during Free Operation. Omitted phases will not be served whenever the Free Plan is in effect. Any number of phases may be selected.

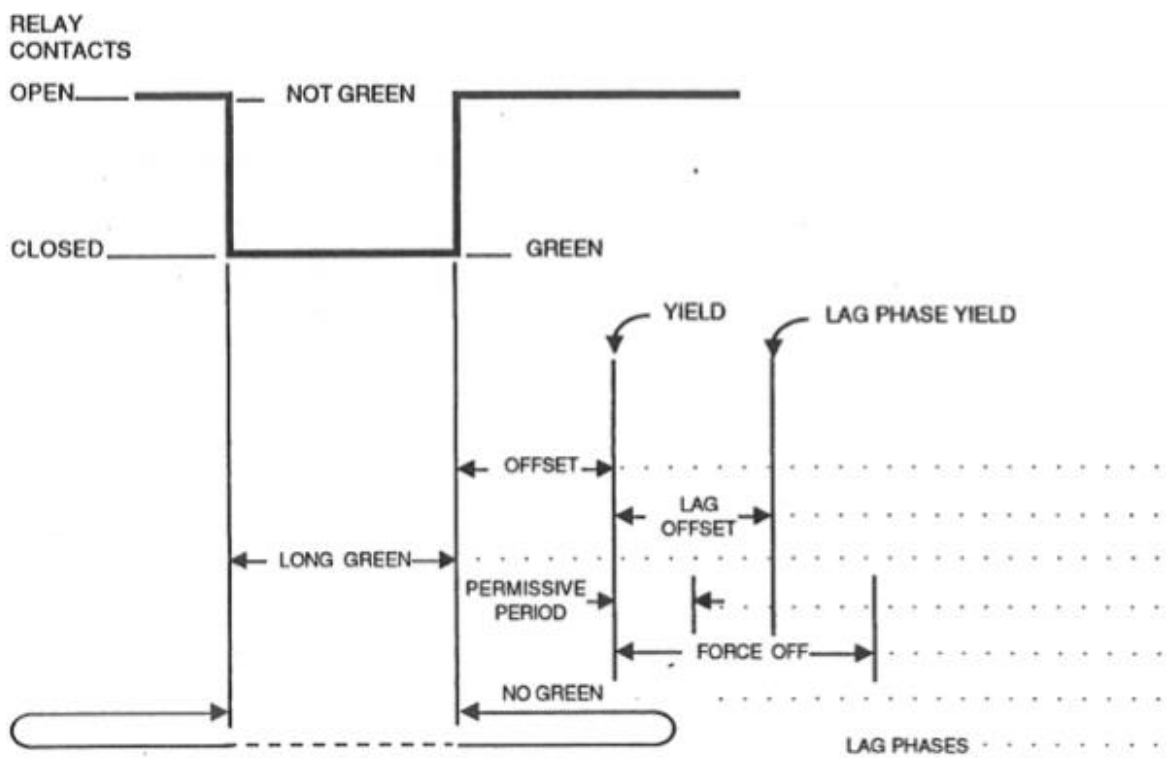
- PED ENTRY – The Ped entry is used to select the phases that are to have a Pedestrian Recall placed during Free Operation. Max Recall phases will be serviced every cycle. Any number of phases may be selected, but only permitted pedestrian phases will have a call placed.

- BIKE – The Bike entry is used to select the phases that are to have a Bicycle Recall placed during Free Operation. Bike Recall phases will be serviced every cycle. Any number of phases may be selected, but only permitted phases will have a call placed.

- RESTRICTED – The restricted entry is used to select the phases that are to be Restricted during Y-Coord operation. Both sync phase cannot be restricted at the same time. Restricted phases for all operations should be set at (2-1-2).

Figure L1 below shows the detail of the Yellow Yield Coordination signal.

YELLOW YIELD COORDINATION



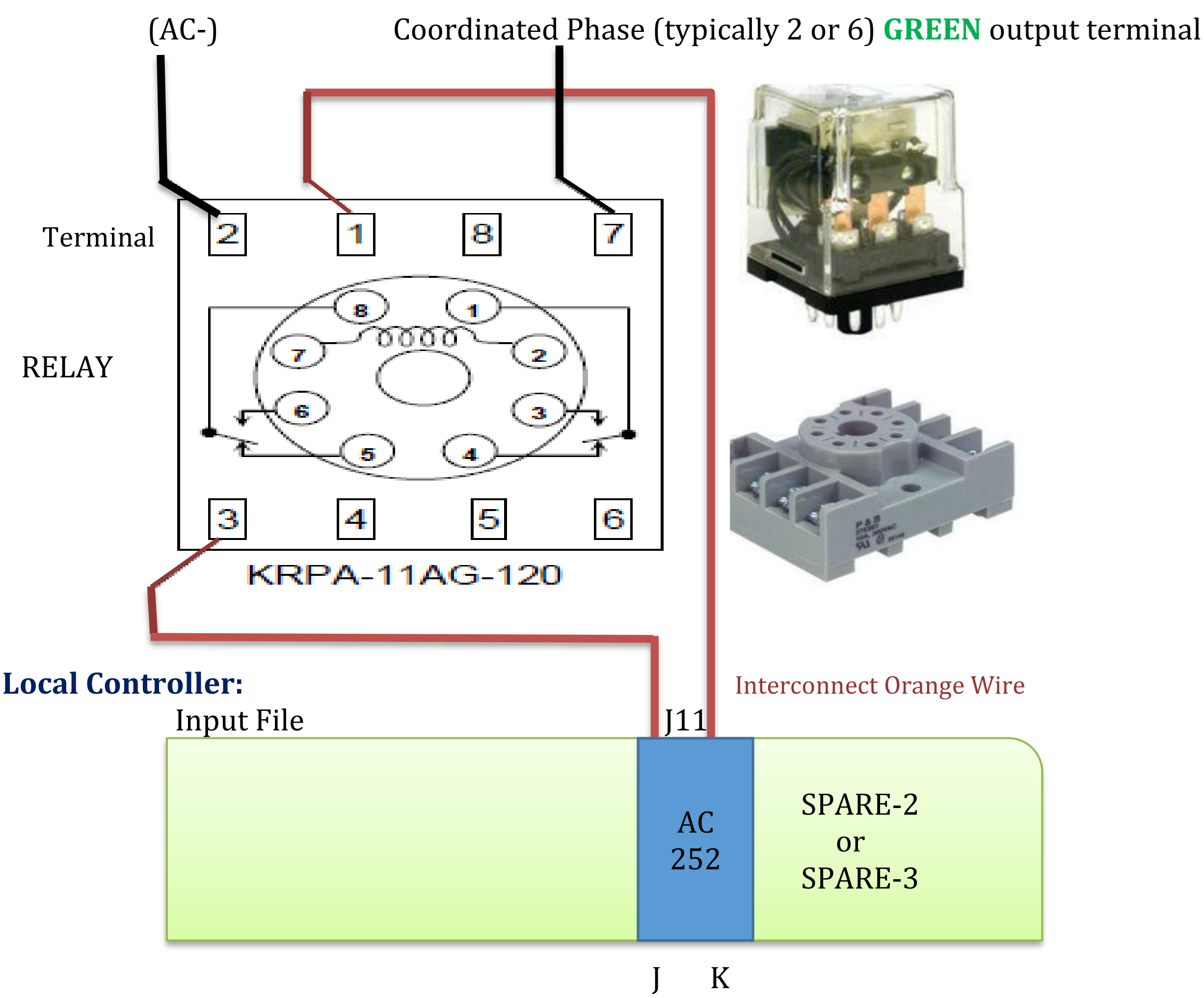
	'7'-KEY ACTIVITY CODE 'C'		'7'-KEY ACTIVITY CODE 'D'	
	SPARE - 3 INPUT		SPARE - 2 INPUT	
	LOCATION OF		LOCATION OF	
	TIME	TIMER*	TIME	TIMER*
OFFSET	C-C-A	C-C-B	C-D-A	C-D-B
LAG OFFSET	C-C-5	C-C-C	C-D-5	C-D-C
LONG GREEN	C-C-7	C-C-E	C-D-7	C-D-E
PERMISSIVE PERIOD	C-C-4	C-C-9	C-D-4	C-D-9
FORCE OFF	C-C-6	C-C-D	C-D-6	C-D-D
NO GREEN	C-C-8	C-C-F	C-D-8	C-D-F
LAG PHASES	C - F - A		C - F - B	
Y-COORD MIN RECALL*	E - F - 2		E - F - 3	
COORD PHASES	C - F - C			

* Observation Only

Note: The controller will go free if either of the 'LONG GREEN' or 'NO GREEN' timers time out

Figure L1 – Schematic of Yellow Yield Coordination Signal

Coordination Master Controller:
During Time Base Coordination, the input to the local controller unit is high when the SYNC phase of the master is **GREEN**, and goes low at the end of the GREEN.



The interconnect wires (shown in orange above) from the master intersection comes in through the SPARE-3 Input File designation J11L, terminal J and K (or TB9 pin 2, 3). When the SYNC phase of the **master intersection turns GREEN**, the input at the local controller will **reset** the NO-GREEN timer and **start the LONG-GREEN** timer in the program (reference to the offset).

When the SYNC phase of the master intersection yields or has ended, the input at the local controller resets the LONG GREEN timer and starts the NO-GREEN timer in the program. If either the LONG-GREEN or NO-GREEN timer has timed out, the program releases the hold on the local intersection (out of synchronization).

APPENDIX M

SIGNALIZED INTERSECTIONS AT OR NEAR RAILROAD CROSSINGS

In order to determine the traffic signal timing for traffic signal preemption at or near railroad crossings, the worksheet shown below must be used. The main purpose of the worksheet is to determine if additional time (advance preemption) is required for the traffic signal to move stationary vehicles out of the crossing before the arrival of the train. The worksheet is actually an Excel spreadsheet; the user enters the required data into the appropriate cells, and the timing is automatically calculated. The worksheet may be found in Figure M1 and on the Traffic Signal Operations intranet webpage, under the heading "**Signalized Intersections Near At-Grade Railroad Crossings**:"
http://traffic.onramp.dot.ca.gov/traffic-signals

The following terms are defined for use of the worksheet:

Buffer Time (BT)** Buffer time is discretionary and may be provided in addition to minimum time (MT) and clearance time (CT) to accommodate minor variations in train handling. Buffer time is a railroad design element and should *NOT* be considered in the traffic signal design process.

Clear Storage Distance (**CSD**)** The distance available for vehicle storage measured between 6 feet from the rail nearest the intersection to the intersection stop bar or the normal stopping point on the highway.

Clearance Time (**CT**)** For two-quadrant warning devices, the minimum track clearance distance is the length along the highway at one or more railroad tracks, measured from the railroad warning device to 6 feet beyond the track(s) measured perpendicular to the far highway, as appropriate, to obtain the longer distance. If the minimum track clearance distance exceeds 35 feet, clearance time is one second for each additional 10 feet, or portion thereof, over 35 feet. CT may also be added to account for the site-specific needs. Examples of CT include additional time for simultaneous preemption and/or additional gate delay time.

Equipment Response Time (**ERT**)** is the amount of time the railroad train detection equipment needs once a train has entered the track circuit before it can be acted upon. This can be set to zero or more seconds, and is typically between 2 and 5 seconds, depending on the type of train detection equipment.

Maximum Preemption Time (**MPT**)** is the maximum amount of time needed, following initiation of the preemption sequence for the highway traffic signals to complete the timing of the right-of-way transfer time, queue clearance time, and separation time:

MPT = RWTT + QCT + ST without vehicle-gate interaction
MPT = MWT + APT with vehicle-gate interaction

Minimum Time (**MT**)** is one of the two components of the minimum warning time (MWT) and is usually equal to 20 seconds.

Minimum Track Clearance Distance (**MTCD**)** is the length along a highway at one or more railroad tracks, measured either from the railroad stop line, warning device, or 12 feet perpendicular to the track centerline, to 6 feet beyond the track(s), measured perpendicular to the far rail, along the centerline or right edge line of the highway, as appropriate, to obtain the longest distance.

Minimum Warning Time (**MWT**) (Through Train Movement)** is the least amount of time active warning devices shall operate prior to the arrival of the train at a railroad-highway crossing. It can be defined as the sum of MT (usually 20 seconds) and CT (clearance time).

Queue Clearance Time** is the time required for the design vehicle stopped within the minimum track clearance distance to start up and move through the minimum track clearance distance.

Minimum Walk Time is the minimum amount of walk time that must be completed prior to entry into preemption. This may be set to zero or more seconds, based on the desired operation of the traffic signal during entry into preemption.

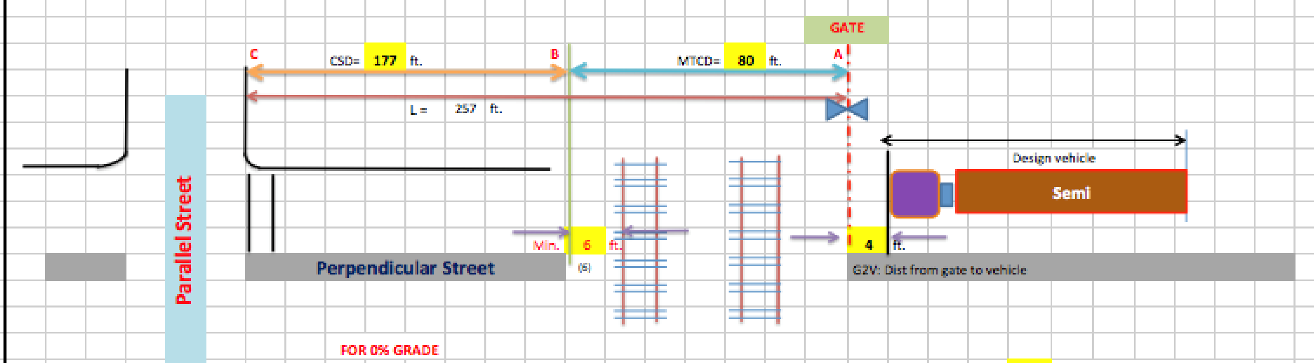
Non-Interaction Gate Descent Time is the time (seconds) during gate descent that the gate will not interact with (i.e. not hit) the design vehicle if it is located under the gate. In other words, it is the time that expires after the gate starts to descend until it hits the design vehicle located under the gate.

Track Clearance Green** interval if the time required, for the track clearance green interval to avoid the occurrence of the preemption trap and to provide enough time for the design vehicle to clear the portion of the CSD. Track clearance green interval time is the maximum of the Minimum Green time (15 seconds) and the time required to clear the portion of the CSD.

Guide for determining the time requirements for Traffic Signal Preemption
At Highway -Rail grade Crossing (No Grade)

Figure M1 – Example of Worksheet

Parallel Street Name:			
Cross Street Name:		Date:	
City:		Timing Engineer :	
County:		District:	
Railroad Company:		Railroad Contact:	
Crossing DOT # :		Phone # :	LN: May 5-2015 Rev K1



Enter values in the Yellow boxes.

Definitions

L = Queue start-up distance, also stop line distance

CSD= Clear Storage Distance

MTCD= Minimum Track Clearance Distance

Point A: RR Limit Line or Gate

Point B: 6 ft. from Far Rail of Last Track (measured along road CL or edge as appropriate)

Point C: Edge of parallel road or shoulder.

Min Track Clearance Dist., MTCD	80	ft.
Clear Storage Dist., CSD	177	ft.
Length, L	257	ft.
G2V: Dist. from gate to vehicle	4	ft.

	Car	Truck	Bus	Semi 75 ft.	
Vehicle Length (ft.)	15	30	40	75	
Vehicle Height (ft.)	5	14	11	14	
Queue Space (ft./veh)	21	36	46	81	
# Vehicles entirely within L (veh)	12	7	5	3	Use
Start moving last vehicle in L (sec)	20.0	12.7	11.5	13.0	Max 1= 20.0
Move entire vehicle thru MTCD (sec)	6.6	7.9	6.9	17.2	Max 2= 17.0
Move front of vehicle thru L (sec)	11.4	12.6	10.4	22.3	Max 3= 22.0
Move entire vehicle past gate (sec)	2.4	3.9	3.8	11.8	Max 4= 12.0
					0
					0
Non-interaction gate descent time (sec)	10.1	2.9	4.0	2.9	Min= 3
Include as Design Vehicle? Yes "x"	x	x	x	x	Yes if marked

These formulas are based on the LADOT R x R calculation worksheets.

Vehicle-gate interaction check.

(x) [ ] YES if marked

Traffic Signal System

Track Clearance Green (TCG)	42	sec.	
Queue Clearance Time (QCT)	37	sec.	(Max 1 + Max 2)
Min Walk	0	sec.	Min GRN 0
Max Ped Clearance	0	sec.	Default = (0)
Controller response time to preempt	0	sec.	(0) or Program preempt delay or additional RWTT due to overlap.
Max. right of way transfer time, RWTT	6.0	sec.	(YEL: 5 + RED: 1
Separation Time (4 to 8 sec.),ST	4	sec.	
Maximum Preemption Time (MPT)	47	sec.	(MWT+APT or QCT+RWTT+ST)

(Worst case scenario, if more than one Design Vehicles and/or Vehicle-gate interaction are marked.)

Train Signal System

Light Flash(3-9s)	3	sec.	(3)
Gate descent(8-20s)	12	sec.	(12)
Gate down	5	sec.	(5)
*MT =	20	sec.	

Minimum Time, MT	20	sec.	
Clearance Time, CT	5	sec.	CT= 0 sec., if MTCD < 35 ft. Additional CT* = 0 (0)
Minimum Warning Time, MWT	25	sec.	(MT+CT)
*Buffer Time, BT	0	sec.	(5 sec.) New & recommended value. [|]
Total Warning Time, TWT	25	sec.	(MT+CT+BT)
*Equipment Response Time, ERT	0	sec.	(5 sec.) New & recommended value. [|]
**Advance Preemption Time, APT	22	sec.	Additional or existing adv. preemption time required * 0 (0) Calculated 22
Total Approach Time, TAT	47	sec.	(TWT+ERT+APT)
Maximum Authorized Speed, MAS	79	mph	
Total Approach Distance, TAD	5446	ft.	

Instructions:

To complete form, enter values:

[yellow] Enter values in the Yellow boxes.

(0) [orange] Default values or TBD by the Engineer.

* To be provided by railroad company or set at default value.

** For maximum APT, marked "X" on all Design Vehicle and Vehicle-gate interaction.

Note(s):

An overview of the implementation of the railroad preemption design requirements mandated by the California Public Utilities Commission (CPUC), Safety Enforcement Division, Rail Crossings and Engineering Branch, in their letter "Railroad Preemption of Traffic Signals" to Caltrans dated July 28, 2016. The design requirements specify providing supervised circuits, advanced pedestrian circuit, gate down/island crossing and health check circuits, and maximum preemption timer for activating, monitoring, and operating the traffic signal during railroad preemption.

Legacy Many traffic signals on the State Highway System (SHS) respond to a railroad preemption using a single or double break 120VAC circuit. The circuit is normally closed (no preemption) and opened (active preemption) when a train is approaching. When a preemption is activated, the traffic signal immediately transitions to the track clearance green phases, then holds in limited service or flashing all-red, and exits the preemption operation when the preemption is no longer active. There is no maximum preemption timeout capability, so the traffic signal will remain in preemption as long as the preemption is active.

The legacy circuit design and the railroad preemption operation in Caltrans traffic signal program were redesigned in order to satisfy the CPUC design requirements.

Design and Operational Requirements CTSCP was redesigned to accept 2 supervised circuits, a gate down/ island circuit, and advanced pedestrian preemption circuit. Additionally, right-of-way transfer and maximum preemption timers were implemented, and 2 sign outputs were added to enable turning on blank out signs during preemption. Refer to the "Traffic Signal Preemption at Rail Road Crossings" design guide for circuit details, number of conductors, and connecting the circuits. Table 1 below describes the functionality of the rail preemption configuration in CTSCP and the corresponding enumerated design requirements from the CPUC letter that were satisfied. Table 2 describes operational requirements and the corresponding CPUC requirements satisfied. Inputs that are ON (high) display an "*" and inputs that are OFF (low) display a "." on the front panel assembly of the model 2070 controller.

Function	Description	CPUC Design Requirement
Advanced Pedestrian Preemption (APP)	Used to temporarily control phase, overlap, and pedestrian movements with interval control prior to an active RR preemption. This is not a supervised circuit.	1,4,14
Preemption Relay (PR)	Activates the railroad preemption. Used to activate advanced preemption or to immediately transition to the track clearance step interval. Supervised circuits require 2 inputs. Unsupervised require 1 input (legacy system). This is a supervised circuit.	1,2,4,14

Crossing Relay (XR)	Simultaneous preemption clears all advanced preemption when active and will immediately transition to track clearance green. If XR has been activated without or before PR, the preempt will immediately start and transition to the first track clearance step interval. This is a supervised that requires 2 inputs.	1,4,14
Gate Down	Monitors gate down during preemption. The traffic signal will remain in track clearance green until the gate down confirmation is received before transitioning to limited service. When active, the traffic signal will transition to limited service after completing the track clearance green interval/s. The gate circuit is not supervised and requires 1 input.	5,6
Island Occupied	Monitors the island crossing during preemption. The traffic signal will remain in track clearance green until the gate down or island occupied confirmation is received before transitioning to limited service. When active, the traffic signal will transition to limited service after completing the track clearance green interval/s. The island circuit is not supervised and requires 1 input.	5,6
Health Check	Outputs the real-time status of the traffic intersection. Output will remain low if the intersection is in good health. Output will go high if the traffic signal has faulted and all-red flash. Will not go high during railroad preemption all-red flash operation. Circuit is fused but not supervised.	16
Sign 1	Used to turn on a blank out sign during preemption. Requires 1 output.	9,10
Sign 2	Used to turn on a blank out sign during preemption. Requires 1 output.	9,10
Right-of-Way Transfer Timer (RWTT)	The maximum all-red or combined yellow change and red clearance time (Y+R) it takes the traffic signal to transition to the track clearance phases. Observes startup all-red, red-revert, phase red, phase yellow, overlap red, and overlap yellow.	4,

Maximum Preemption Timer	Maximum time the preemption can be active. This is a count-up timer and will go to fault all-red flash when the Maximum-On time is exceeded. The timer will reset automatically when the preemption becomes inactive.	12

Table 1: Design Requirements

Description	CPUC Design Requirement
Do NOT use all-red-flash operation for traffic signal indications during a railroad preemption hold interval unless a diagnostic team identifies the need for such.	8
Provide a maximum preemption timer when using limited service operation during the railroad preemption-hold phase.	12
Provide pedestrian clearance time during railroad preemption, prior to the track clearance green phase, for the crosswalks that are between the intersection and the grade crossing. Provide advanced preemption and interval control.	4,14
Do not install pedestrian signal heads with countdown timers at intersections interconnected with grade crossings unless there is sufficient preemption time to provide and accurate countdown.	15
Provide a right-of-way transfer timer as part of the timing for advance preemption.	4
Display the track clearance phases as green until or past the time that the grade crossing approach gate reaches the horizontal position and traffic clears the minimum track clearance distance.	5
Use limited service operation at a signalized intersection and/or blank-out turn-prohibition signs during the railroad preemption hold phase to restrict movements from the intersection towards the tracks.	10
If railroad preemption is active during startup of the traffic signal, or a supervised circuit faults, or the maximum time is exceeded, the signal will transition to all-red flash.	Startup or Fault Condition or Maximum Preemption

Table 2: Operational Requirements

Use of HRI IEEE 1570 (currently not available in CTSCP) HRI may provide the functionality of the hard-wire circuits. HRI uses EIA-485 communication between the traffic signal and railroad bungalow to activate preemption, monitors APP, gate, and island, and provides health status of the traffic signal (operating normally or flashing). HRI can be used with the hard wire circuitry for redundancy or standalone (Design requirement 2). HRI is not commercially available and CTSCP does not support HRI.

Detailed Descriptions

Advanced Pedestrian Preemption (APP) Inputs There is one APP input defined per railroad preemption. When active, APP inputs can start Interval Control in CTSCP if one or more Interval Control steps have been defined.

The APP inputs will be ignored by CTSCP if the Primary Relay (PR) or the Crossing Relay (XR) inputs are active commanding track clearance. When PR or XR are active, any remaining Interval Control timing will be aborted immediately, and the railroad preemption will transition to the first clearance step interval (CLEAR 1). If either of the APP inputs are still active after the end of a railroad preemption, the APP inputs will be ignored until the input(s) have toggled at least momentarily to the inactive state.

Preemption Relay (PR) Inputs (Advanced Preemption AP) When defined, these inputs, called “PR1” and “PR2”, are intended to be in opposite logical states which are used to determine whether the railroad preemption is active or inactive. Normal operation PR1 is on and PR2 is off. In preemption, PR1 is off and PR2 is on. Because the inputs are supervised, a fault will occur if both inputs are in the same logical state (either both “high” (on) or both “low” (off)), and the traffic signal will go to all-red flash. Table 3 below summarizes the possible states of the PR1 and PR2 inputs and their corresponding preemption state.

PR1	PR2	STATE	SIGNAL OPERATION
ON	OFF	INACTIVE	NORMAL
OFF	ON	ACTIVE	PREEMPTION
OFF	OFF	FAULT	ALL-RED FLASH
ON	ON	FAULT	ALL-RED FLASH

Table 3: PR 1/PR 2 States

As with the Crossing Relay Inputs (table 4 below), CTSCP will put the intersection in to an all-red flashing state if the controller is started with railroad preemption active. Both “PR1” and “PR2” require dedicated logical ports to be assigned within CTSCP.

Railroad preemption is still available for legacy crossings assigning only PR1 and leaving PR2 unassigned.

Crossing Relay (XR) Inputs (Simultaneous Preemption) The XR inputs supervise advanced and advanced pedestrian preemption. Train speed can vary during advanced preemption. As illustrated in Figure 1 below, if a train activates the railroad preemption relay PR and reaches the crossing relay XR sooner than expected, all advanced preemption timing will be truncated and the traffic signal will transition to track clearance. Additionally, the crossing relay can be switched to active at any time by the rail company to bypass advanced preemption. The preemption relays (PR) are placed at a prescribed distance from the railroad crossing. The crossing relays (XR) are placed closer to the railroad crossing than the preemption relays (PR). When PR or XR are active, the traffic signal will transition to track clearance.

Same as the PR inputs, normal operation XR1 is on and XR2 is off (inactive). When XR1 is off and XR2 is on (active), the timing of any advanced preemption or interval control steps (see interval control below) is interrupted and the preemption is immediately transitioned into timing the right-of-way transfer timer before starting track clearance. XR1 and XR2 are supervised inputs and will fault if both inputs are in the same state (see Table 4 below).

XR1 Input	XR2 Input	STATE	SIGNAL OPERATION
ON	OFF	INACTIVE	NORMAL
OFF	ON	ACTIVE	PREEMPTION
OFF	OFF	FAULT	ALL-RED FLASH
ON	ON	FAULT	ALL-RED FLASH

Table 4: XR 1/XR2 States

If XR1 is off and XR2 is on (active) when the railroad preemption relays PR are active, CTSCP will not time advanced preemption and will immediately transition to track clearance. If the railroad preemption relay inputs PR are in a normal state (inactive) and XR inputs are active, CTSCP will immediately transition to track clearance.

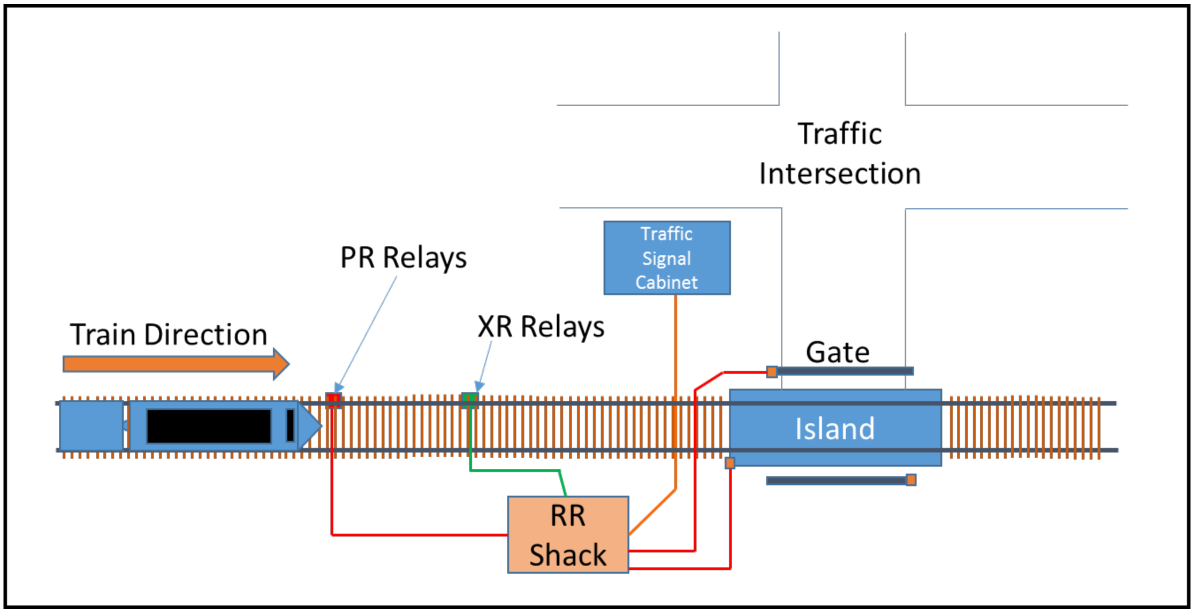


Figure 1: PR and XR Relay Track Placements

Interval Control Interval Control provides up to 8 intervals, or "steps" in which CTSCP can be used to serve active phases during the timing of a railroad preemption delay interval (timed in parallel). Each step can be configured to:

- Run up to 255 seconds.
- Permit or deny the timing of available phases, overlaps, and pedestrian crossings.
- Hold, force-off, or advance phases.
- Place calls on other phases.

The total amount of time for all the configured Interval Control steps should be greater than the amount of time specified for the railroad preemption "DELAY" interval by a sufficient margin so as to prevent the service of pedestrian phases prior to the start of the Right-of-way Transfer Timer. If an arriving train activates the crossing relays (XR) before either the preemption "DELAY" interval or Interval Control has finished timing, CTSCP will interrupt any remaining timing and proceed to the timing of the Right-of-Way Transfer Timer (see below). Figure 2 illustrates an example of the timing relationship between Interval Control and railroad preemption.

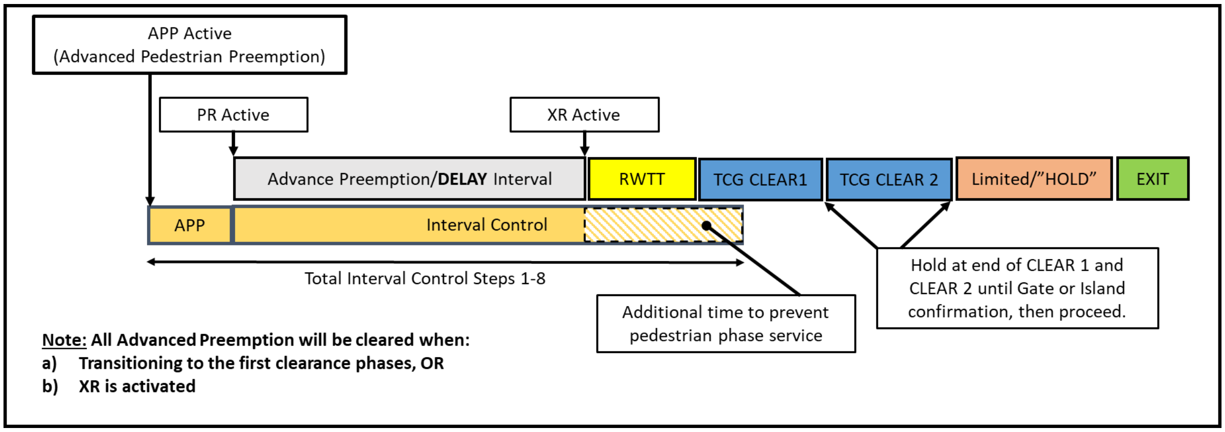


Figure 2: Interval Control and Railroad Preemption Timing Relationship

Gate-Down and Island-Occupied Inputs Gate-Down (G) and Island-Occupied (I) inputs monitor the railroad crossing gates and the island crossing respectively. If the gate fails to come down during preemption, the traffic signal will display track clearance green until either the crossing gates are in the horizontal down position or a train is detected on the island. The Gate-Down and Island-Occupied inputs require a dedicated logical input port as shown in table 5. The inputs are ignored when the railroad preemption is inactive. Additionally, the island-occupied can be used to determine whether to execute the railroad exit routine if defined. Once the railroad preemption is no longer active and the train has crossed the island, the traffic signal can resume operation without timing the Exit routine. If the island-occupied was never detected during the rail preemption, the Exit routine will be executed after the railroad preemption becomes inactive.

GATE/ISLAND INPUT	GATE DOWN	ISLAND-OCCUPIED	STATE
OFF	VERTICAL	UNOCCUPIED	INACTIVE
ON	HORIZONTAL	OCCUPIED	ACTIVE

Table 5: Gate and Island Monitoring

Right-of-Way Transfer Timer The Right-of-Way Transfer Timer (RWTT) allows for the consistent timing of railroad preemptions by representing the maximum all-red or combined yellow change and red clearance time (Y+R) it takes the traffic signal to transition to the track clearance phases. This timer is not user-configurable within CTSCP because it is calculated on a per-cycle basis by determining the maximum of the sum of the phase yellow and red timing for each active phase. Regardless of the state of the intersection, the RWTT will always time for this maximum value.

Latching A railroad preemption can be configured to "latch" once an the railroad preemption is activated. The Latch setting allows the user to "lock-in" the railroad preemption. If latched, then all configured railroad step intervals will be executed even if the railroad preemption is deactivated. If not latched, then the railroad preemption can exit any time the input is deactivated. This is true for both PR and XR inputs on a per-railroad basis.

Health Check The Health Check output continuously indicates the real-time health status of the traffic intersection. If defined, the output will be remain deactivated (low) when the controller is NOT in flash state. When the controller enters flashing state, the output will be activated (high).

Maximum-On Timer The Maximum-On Timer is configured for each preemption and is timed in minutes with 255 minutes (4 hours, 15 minutes) being its maximum value. The maximum timer starts timing at the beginning or as soon as a preemption is active and is reset when the preemption exits and becomes inactive. If the Maximum-On timer for a railroad preemption is exceeded during an active preemption, CTSCP will put the intersection into an all-red flashing state until the preemption becomes inactive then the maximum timer will be reset for the next preemption and the signal will resume operation.

C8 Railroad Operation The model 170 controller program C8 does not support the railroad design requirements CPUC mandated due to the physical limitations of the controller. C8 does not support the multi-inputs needed for supervised preemption, advanced pedestrian preemption, gate/island monitoring, or battery backup. All model 170 controllers at traffic signals shall be replaced with the model 2070 controller by June 2020, outlined in the *Model 170 C8 Railroad 1 Operational Policy* dated October 22, 2019 in Appendix P.

Additional Resources

For more information, please consult:

- IEEE 1570 *Standard for the Interface between the Rail Subsystem and the Highway Subsystem at the Highway Rail Intersection*, October, 2002.
- 24769-NCHRP *Traffic Signal Preemption at Intersections Near Highway-Rail Grade Crossings*, 2017
- The California Manual on Uniform Traffic Control Devices (CAMUTCD).
- CPUC letter *Railroad Preemption of Traffic Signals* to Caltrans, July 28, 2016

List of Acronyms

APP – Advanced Pedestrian Preemption
AP – advanced Preemption
RWTT/RTT – Right-of-Way Transfer Timer
MWT—Minimum Warning Time
TCG – Track Clearance Green
CPUC – California Public Utilities Commission
CTSCP – Caltrans Traffic Signal Control Program
FIFO – First In – First Out
HRI – Highway Rail Intersection (IEEE 1570)
PR – Primary Relays (Advanced Preemption)
XR – Crossing Relays (Simultaneous Preemption)

APPENDIX N

CRITICAL INTERSECTION METHODS (10)

Much of early research regarding cycle length selection recommended evaluating the intersections and identifying the critical intersection, which was typically the intersection with the highest demand. A cycle length is established for this location and is selected so that it will be sufficient to maintain under-saturated conditions. This fundamental assumption is currently being investigated to determine if there are further strategies for dealing with oversaturated conditions.

The critical intersection approach considers a signalized intersection in isolation to other intersections and for this reason may not always yield the optimum cycle length. Most of the analytical tools developed for cycle length selection focus on under-saturated flow. The tools also do not consider the constraints of the intersections beyond the lost time and saturation flow rate. These critical intersection approaches to cycle length selection are primarily for isolated intersections and are all based on the assumption that vehicular delay is most important. This approach analyzes the intersection with the heaviest traffic to determine a minimum cycle length and used that to set the remaining intersections. The first step is to consider each intersection as though it is isolated to determine the minimum (optimum) cycle length needed at each intersection, as though it were isolated. The traditional models use Webster's model to determine optimal cycle length. Webster used computer simulation and field observation to develop a cycle-optimization equation intended to minimize delays when arrivals are random. The formula is as follows:

$C = (1.5L + 5) / (1.0 - Y)$ **Equation (N1)**

Where:

C = optimum cycle length (sec)
Y = critical lane volume divided by the saturation flow, summed over the phases
L = lost time per cycle (sec)

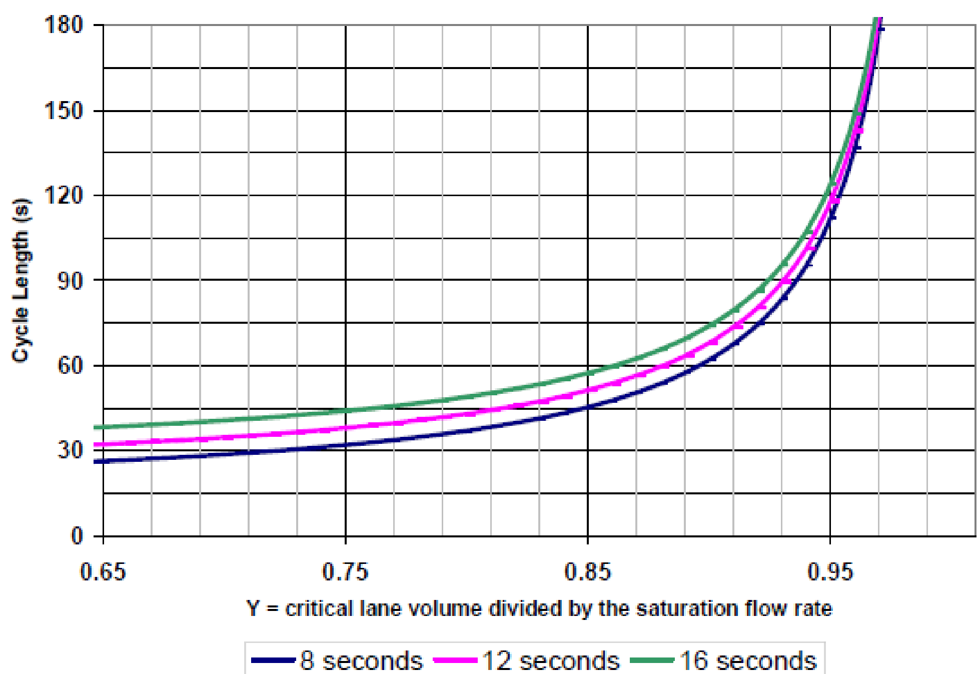


Figure N1 – Webster's Optimum Cycle Length

In practice, much of the assessment of signalized intersections is completed using the Highway Capacity Manual (HCM) procedure on "Signalized Intersections." The HCM provides a few pieces of guidance on cycle lengths, but also notes limitations to the methodology. The current methodology does not take into account the potential impact that downstream congestion can have on intersection operation. Nor does the methodology detect or adjust for turn-pocket overflows and the impacts they have on through traffic and intersection operation.

The HCM offers a quick estimation method for the selection of a cycle length. The formula for cycle length estimation is as follows:

$$C = \frac{L}{1 - \frac{\min(CS, RS)}{RS}}$$ **Equation (N2)**

where:

C = cycle length (s),

L = total lost time (s),

CS = critical sum of traffic volumes from the critical movement analysis (veh/h),

RS = reference sum flow rate = 1,710 · $PHF \cdot f_a$ (veh/h),

f_a = area type adjustment factor (0.90 if CBD, 1.00 otherwise).

Primarily, this calculation is intended for planning-level analyses. This equation suggests that as the intersection approaches capacity, the cycle length should increase up to a maximum value, which the HCM suggests is set by the local jurisdiction (such as 150 seconds). The minimum cycle length suggested for use is 60 seconds. The equation does not explicitly address the pedestrian crossing requirements, left turn type and minimum green times necessary to meet driver expectancies.

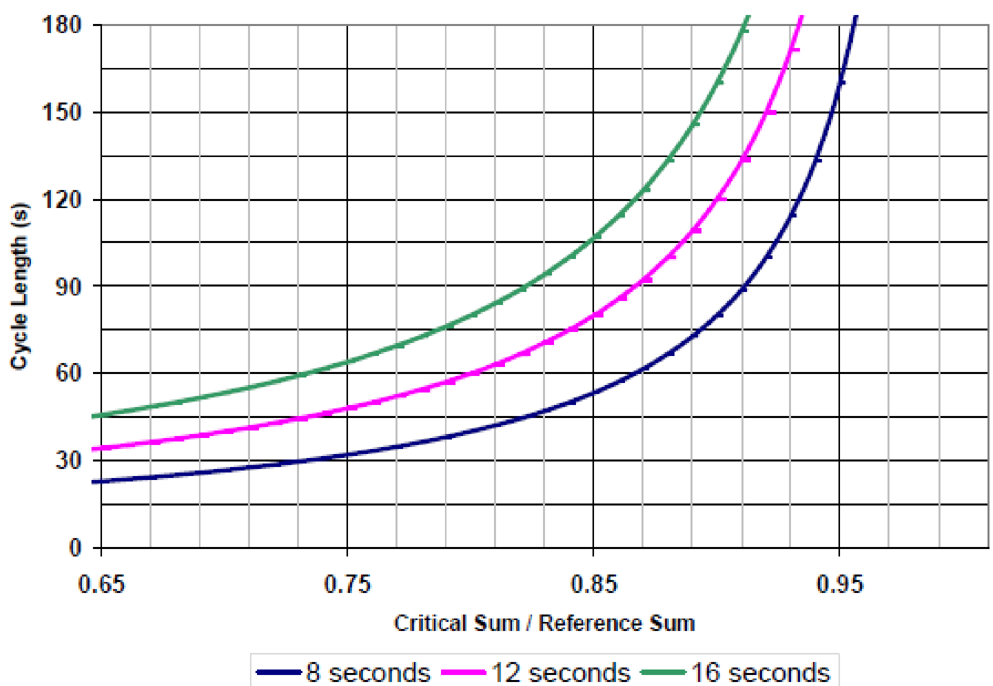


Figure N2 – HCM Cycle Length Estimation

In both Webster's and the HCM's estimation, the sum of the critical lane flows is a representation of the demand at the intersection. The *critical lane* is defined as the intersection approach with the greatest demand of all the approaches that are serviced during a given signal phase. For example, during the main street phase, on a street with two-way traffic, the critical lane would be the one lane in either direction that has the greatest demand. Y is the sum of the critical lane flows divided by 900, which is the percent of available intersection capacity that is in demand. If Y = 1, the intersection is saturated and the equation is no longer applicable. The situations where longer cycle lengths degrade intersection performance are a result of specific elements that lead to poor performance.

Longer cycle lengths will increase congestion in cases such as when:

- Upstream throughput exceeds downstream link capacity. Long cycles may move more vehicles through an intersection than can be handled downstream
- Turning bay storage is exceeded. Long cycle lengths may cause vehicles in left-turn bays to back up into through lanes. In a similar manner, long cycles may cause through traffic to back up beyond turn bays, restricting their access
- Increased variability in actuated green times. Long cycles result in high variability in the side street green time used, which may result in poor arrival types at the downstream intersection. This is particularly noteworthy when split times exceed 50 seconds.

The delay experienced by a motorist depends on cycle length and volume. Higher volumes always lead to longer delays. Shorter cycle lengths reduce delay, provided they do not result in inadequate intersection capacity. Oversaturated conditions require special considerations, and these models are not valid during that range of conditions.

Network Approaches

The network approach to cycle length selection considers multiple intersections to determine an optimal cycle length. Most applications of network approaches use signal timing optimization models.

There are a number of computer programs that can be used to assist in selection of a cycle length. The Federal Highway Administration's (FHWA's) Traffic Analysis Toolbox describes additional resources (https://ops.fhwa.dot.gov/trafficanalysistools/index.htm). Three of the more popular programs of this type are Synchro, PASSER™ II, and TRANSYT-7F. Synchro is commonly used in Caltrans; licenses are available to all the districts. Caltrans recently began the procurement process for both the TranSync-D and TranSync-M software. This tool not only assists in evaluating and optimizing signal timing, it also provides a powerful tool for traffic signal timing of synchronized signals (http://trans-intelligence.com/files/TranSync-D%20Pamphlet.pdf) and (http://trans-intelligence.com).

These signal timing optimization models consider the network being analyzed and determine an optimal solution based on a given set of inputs. The range of cycle lengths is based on the users input. The optimization models use the individual intersection characteristics, the volume to capacity ratios of each intersection, the link speed, and the distance between the intersections to estimate the performance for each individual cycle length and resulting plan. The models make assumptions based on the inputs related to the splits and offsets to determine performance measures that can be compared to timing policies. Because the models are imperfect a significant amount of effort is necessary to take an initially screened plan to a point that can be field implemented. The timing policies described previously, the optimization policies, and the criteria for determining which criteria to use to select a signal timing plan must be considered prior to and as a part of the optimization process.

A recent FHWA publication devotes a significant number of pages describing various optimization software packages available, so only the pertinent elements will be described here. The optimization models change with new versions of the software and for that reason, the documentation is best handled by the individual software producer. Their guidance related to the development of timing plans is most important.

The PASSER program uses the concepts described in Webster's equation to determine the appropriate cycle length. The program uses a hill climbing algorithm to estimate delay at each intersection with the cycle length input to further quantify the performance of the system and maximize bandwidth using the pre-calculated splits as input to that model. At the optimization stage, it can find the cycle length, offsets, and phase sequences that produce maximum two-way progression. Essentially, PASSER uses the concepts described in Webster's equation for selection of cycle length and, "after calculating the minimum delay cycle length for all intersections in the arterial street, the largest minimum delay cycle length is selected as the shortest cycle length for the system and that the longest allowable cycle length should be no more than 10 to 15 seconds longer than the shortest allowable cycle length to minimize the excess delay at the non-critical intersections."

TRANSYT-7F allows the user to define the performance function used for optimization. TRANSYT-7F was initially designed to select signal timings that produce minimum network delay and stops. Subsequent modifications added the capability to select several other objectives, including minimization of fuel consumption and maximization of progression opportunities. During its optimization process, TRANSYT-7F generates second-by-second flow profiles of vehicles on all links in the network and analyzes these profiles to determine performance measures. This model considers the formation and dissipation of queues in space. In addition, it accounts for flow interactions on adjacent links through a step-by-step analysis of all links in the system. TRANSYT-7F assesses cycle length by calculating equal saturation splits and applies a hill-climbing method to optimize signal offsets and splits.

In similar fashion, Synchro uses its algorithm to estimate arrivals at each intersection in the network and to calculate percentile signal delay, stops, and a queue penalty, which addresses the impact of queuing on arterial performance. The performance index is calculated for each cycle length based on the splits and offsets assumed within the model as constrained by the user. There are various steps to developing an "optimal" timing plan, but one of the limitations of this model is the inability to define the parameters within the Performance Index calculation.

$$PI = \frac{D \cdot 1 + St \cdot 10 + QP \cdot 100}{3600}$$ **Equation (N3)**

where

PI = Performance Index

D = Percentile Signal Delay (s)

St = Vehicle Stops (vph)

QP = Queue Penalty (vehicles affected)

APPENDIX O
GLOSSARY

Accident Modification Factors - A means of quantifying crash reductions associated with safety improvements.

Actuated Signal Control - Phase time based on detection data.

Adaptive Signal Control - A signal control concept where vehicular traffic in a network is detected at a point upstream and/or downstream and an algorithm is used to predict when and where traffic will be and to make signal adjustments at downstream intersections based on those predictions.

Added Initial - An interval that times concurrently with the minimum green interval and increases by each vehicle actuation received during the initial period. This time cannot exceed the maximum initial.

Analysis Period - A single time period during which capacity analysis is performed on a transportation facility. If the demand exceeds capacity during an analysis period, consecutive analysis periods can be selected to account for initial queue from the previous analysis period. Also referred to as time interval.

Analytical Model - A model that relates system components using theoretical considerations tempered, validated, and calibrated by field data.

Annual Average Daily Traffic - The total volume of traffic passing a point or segment of a highway facility in both directions for one year divided by the number of days in the year.

Approach - A set of lanes at an intersection that accommodates all left-turn, through, and right-turn movements from a given direction.

Approach Grade - The grade of an intersection approach, expressed as a percentage, with positive values for upgrade and negative for downgrade.

Area Type - A geographic parameter reflecting the variation of saturation flows in different areas.

Arrival Rate - The mean of a statistical distribution of vehicles arriving at a point or uniform segment of a lane or roadway.

Arrival Type - Six assigned categories for determining the quality of progression at a signalized intersection.

Arterial - A signalized street that primarily serves through traffic and that secondarily provides access to abutting properties, with signal spacings of 2.0 miles or less.

Arterial LOS - An arterial and network-level performance measure associated with the class of arterial and the travel speed of arterial under study.

Automatic Vehicle Location (AVL) System - An intelligent transportation system (ITS) technology to track vehicle location, speed and other measures within a system. Most applications are found on transit vehicles and systems.

Average Speed - The average distance a vehicle travels within a measured amount of time.

Average Travel Speed - The length of the highway segment divided by the average travel time of all vehicles traversing the segment, including all stopped delay times.

Back of Queue - The distance between the stop line of a signalized intersection and the farthest reach of an upstream queue, expressed as a number of vehicles. The vehicles previously stopped at the front of the queue are counted even if they begin moving.

Bandwidth - The maximum amount of green time for a designated direction as it passes through a corridor at an assumed constant speed, typically measured in seconds.

Bandwidth Attainability - A measure of how well the bandwidth makes use of the available green time for the coordinated movements at the most critical intersection in the corridor.

Bandwidth Efficiency - A measure that normalizes bandwidth against the cycle length for the arterial under study.

Barnes' Dance - A common term for an exclusive pedestrian phase where pedestrians may cross all intersections legs and sometimes diagonally.

Barrier - A separation of intersecting movements in separate rings to prevent operating conflicting phases at the same time.

Base Condition - The best possible characteristic in terms of capacity for a given type of transportation facility; that is, further improvements would not increase capacity; a condition without hindrances or delays.

Base Saturation Flow Rate - The maximum steady flow rate—expressed in passenger cars per hour per lane—at which previously stopped passenger cars can cross the stop line of a signalized intersection under base conditions, assuming that the green signal is available and no lost times are experienced.

Call - A term used to describe the presence of vehicle, bicycle, or pedestrian demand in an actuated detection controller system.

Capacity - The maximum rate at which vehicles can pass through the intersection under prevailing conditions. It is also the ratio of time during which vehicles may enter the intersection.

Carryover - A term commonly used for the "extend" setting in controller manuals. It is another way to describe the time provided for a vehicle to traverse from one detector to the next.

Change Interval - The yellow plus red clearance interval that occurs between phases of a traffic signal to provide for clearance of the intersection before conflicting movements are released. Also known as the clearance interval.

Clearance Lost Time - The time, in seconds, between signal phases during which an intersection is not used by any traffic.

Clearance Time - The time loss at a transit stop, not including passenger dwell times. This parameter can be the minimum time between one transit vehicle leaving a stop and the following vehicle entering and can include any delay waiting for a sufficient gap in traffic to allow the transit vehicle to reenter the travel lane.

Condition Diagram - An illustration used to highlight the existing characteristics (i.e., number of lanes, signs, adjacent driveways, turn-bay lengths, traffic control, and land uses) of an intersection.

Concurrent Phases - Two or more phases in separate rings that are able to operate together without conflicting movements.

Congested Flow - A traffic flow condition caused by a downstream bottleneck.

Control Delay - The amount of additional travel time experienced by a user attributable to a control device.

Controller Memory - A term that refers to the controller's ability to "remember" (i.e., retain) a detector actuation and includes one of two modes (non-locking or locking).

Coordinated-Actuated - Signal operations in coordination with other intersections, and using vehicle, bicycle, and/or pedestrian detection to define signal timing.

Coordinated Phase(s) - The phase (or phases) that is provided a fixed minimum amount of time each cycle under a coordinated timing plan. This phase is typically the major through phase on an arterial.

Coordination - The ability to synchronize multiple intersections to enhance the operation of one or more directional movements in a system.

Corridor - A set of essentially parallel transportation facilities designed for travel between two points. A corridor contains several subsystems, such as freeways, rural (or two-lane) highways, arterials, transit, and pedestrian and bicycle facilities.

Critical Lane Group - The lane groups that have the highest flow ratio for a given signal phase.

Critical Movement Analysis - A simplified technique for estimating phasing needs and signal timing parameters.

Critical Speed - The speed at which capacity occurs for a facility, usually expressed as miles per hour.

Critical Volume-to-Capacity Ratio - The proportion of available intersection capacity used by vehicles in critical lane groups.

Crosswalk - A marked area for pedestrians crossing the street at an intersection or designated midblock location.

Cycle - A complete sequence of signal indications.

Cycle Length - The time required for a complete sequence of signal indications.

Cycle Failure - Occasion where all queued vehicular demand cannot be served by a single green indication or signal phase.

Dallas Display - A type of signal display that attempts to avoid "yellow trap" problem by using louvers on the yellow and green ball indications to restrict visibility of the left-turn display to adjacent lanes, while displaying indications based on the opposing through movement.

Delay
1. The additional travel time experienced by a driver, passenger, or pedestrian.
2. A detector parameter typically used with stop-line, presence mode detection for turn movements from exclusive lanes.

Density - The number of vehicles on a roadway segment averaged over space, usually expressed as vehicles per mile or vehicles per mile per lane. (See also: volume-density, sometimes referred to as density timing)

Demand - The volume of traffic at an intersection, approach, or movement.

Detector - A device used to count and/or determine the presence of a vehicle, bicycle, or pedestrian.

Dilemma Zone - There are two types of dilemma zones.
Type I: occurs when yellow and red clearance times are too short for a driver to either stop or clear the intersection before the beginning of a conflicting phase.
Type II: also known as an "Option Zone", or "Indecision Zone". This occurs as the result of different drivers making different decisions on whether to go or stop, upon the change from a green to yellow indication.

Double Cycle - A cycle length that allows phases to be serviced twice as often as the other intersections in the coordinated system.

Downstream - The direction of traffic flow.

Early Return to Green - A term used to describe the servicing of a coordinated phase in advance of its programmed begin time as a result of unused time from non-coordinated phases.

Effective Green Time - The time during which a given traffic movement or set of movements may proceed; it is equal to the cycle length minus the effective red time.

Effective Red Time - The time during which a given traffic movement or set of movements is directed to stop; it is equal to the cycle length minus the effective green time.

Effective Walkway Width - The width, in feet, of a walkway usable by pedestrians, or the total walkway width minus the width of unusable buffer zones along the curb and building line.

Exclusive Pedestrian Phase - An additional phase that is configured such that no vehicular movements are served concurrently with pedestrian traffic. (See also: Barnes' Dance).

Exclusive Turn Lane - A designated left or right-turn lane or lanes used only by vehicles making those turns.

Extend - A detector parameter that extends a detector actuation by a user-settable fixed amount. It is typically used with detection designs that combine multiple advance detectors and stop-line detection for safe phase termination of high-speed intersection approaches.

Field Implementation - A term used to describe the installation of new signal timings in the controller and the review of traffic operations at the intersection.

Fixed Force Off - A force off mode where force off points cannot move. Under this mode, non-coordinated phases can utilize unused time of previous phases.

Fixed Time Signal Control - A preset time is given to each movement every cycle regardless of changes in traffic conditions.

Flashing Don't Walk - An indication warning pedestrians that the walk indication has ended and the don't walk indication will begin at the end of the pedestrian clearance interval.

Flashing Yellow Arrow - A type of signal head display that attempts to avoid the “yellow trap” problem by providing a permissive indication to the driver that operates concurrent with the opposing through movement rather than the adjacent through movement.

Floating Force Off - A force off mode where force off points can move depending on the demand of previous phases. Under this mode, non-coordinated phase times are limited to their defined split amount of time and all unused time is dedicated to the coordinated phase. Essentially, the split time is treated as a maximum amount for the non-coordinated phases.

Floating Car method - A commonly employed technique for travel time runs which requires the vehicle driver to “float” with the traffic stream while traveling at a speed that is representative of the other vehicles on the roadway and to pass as many vehicles as pass the floating car.

Flow Rate - The equivalent hourly rate at which vehicles, bicycles, or persons pass a point on a lane, roadway, or other traffic way; computed as the number of vehicles, bicycles, or persons passing the point, divided by the time interval (usually less than 1 h) in which they pass; expressed as vehicles, bicycles, or persons per hour.

Flow Ratio - The ratio of the actual flow rate to the saturation flow rate for a lane group at an intersection.

Force Off - A point within a cycle where a phase must end regardless of continued demand. These points in a coordinated cycle ensure that the coordinated phase returns in time to maintain its designated offset.

Free Flow - A flow of traffic unaffected by upstream or downstream conditions.

Fully Actuated Control - A signal operation in which vehicle detectors at each approach to the intersection control the occurrence and length of every phase.

Gap - The time, in seconds, for the front bumper of the second of two successive vehicles to reach the starting point of the front bumper of the first.

Gap Reduction - This is a feature that reduces the passage time to a smaller value while the phase is active.

Green Time - The duration, in seconds, of the green indication for a given movement at a signalized intersection.

Green Time Ratio - The ratio of the effective green time of a phase to the cycle length.

Green Extension - A signal priority treatment to extend a current green phase to give priority to a specific movement or vehicle, typically transit.

Hardware - The devices that physically operate the signal timing controls, including the controller, detectors, signal heads, and conflict monitor.

Headway

- (1) The time, in seconds, between two successive vehicles as they pass a point on the roadway, measured from the same common feature of both vehicles (i.e. the front axle or the front bumper);
- (2) The time, in minutes, between the passing of the front ends of successive transit units (vehicles or trains) moving along the same lane or track (or other guideway) in the same direction.

Hardware in the Loop (HITL) - A means of providing a direct linkage between simulation models and actual signal controllers.

Highway Capacity Manual - A National Academies of Science/Transportation Research Board manual containing a collection of state-of-the-art techniques for estimating the capacity and determining the level-of-service for transportation facilities, including intersections and roadways as well as facilities for transit, bicycles, and pedestrians.

Inhibit Max - A basic timing parameter that removes the Maximum Green input as a phase parameter during coordination and allows the phase to extend beyond its normal maximum green values.

Interval - The duration of time where a traffic signal indications do not change state (red, yellow, green, flashing don't walk). A traffic signal controller also has timing intervals (min green, passage time) that determine the length of the green interval.

Intersection Delay – Average - The total additional travel time experienced by users as a result of control measures and interactions with other users divided by the volume departing from the intersection.

Intersection Level of Service - A qualitative measure describing operational conditions based on average intersection delay.

Isolated Intersection - An intersection at least one mile from the nearest upstream signalized intersection.

Lagging Pedestrian Interval - A pedestrian timing option that starts pedestrian walk interval several seconds after the adjacent through movement phase, thus allowing a waiting right-turn queue to clear before the pedestrian walk indication is presented and thereby reducing conflicts with right-turning vehicles.

Lane Group - A set of lanes established at an intersection approach for separate capacity and level-of-service analysis.

Lane Group Delay - The control delay for a given lane group.

Lane Utilization - The distribution of vehicles among lanes when two or more lanes are available for a movement; however, as demand approaches capacity, uniform lane utilization develops.

Leading Pedestrian Interval - A pedestrian interval option that starts a few seconds before the adjacent through movement phase, thus allowing pedestrians to establish a presence in the crosswalk and thereby reducing conflicts with turning vehicles.

Lead-Lag Left-Turn Phasing - A left-turn phase sequence where one left-turn movement begins with the adjacent through movement and the opposing left-turn movement begins at the end of the conflicting through movement. This option may create a "yellow trap" with some permissive signal displays.

Level of Service - A qualitative measure describing operational conditions within a traffic stream, based on service measures such as speed and travel time, freedom to maneuver, traffic interruptions, comfort, and convenience.

Local Controller - The device used to operate and control the signal displays using signal timing provided by the user, master controller, or central signal system.

Locking Mode - A controller memory mode used to trigger a call for service for the first actuation received by the controller on a specified channel during the red interval

Lost Time - The portion of time at the beginning of each green period and a portion of each yellow change plus red clearance period that is not usable by vehicles.

Master Clock - The background timing mechanism within the controller logic to which each controller is referenced during coordinated operations.

Master Controller - An optional component of a signal system that facilitates coordination of a signal system with the local controller.

California Manual on Traffic Control Devices (CA MUTCD) - Document that provides the standards and guidance for installation and maintenance for traffic control devices on roadways.

Maximum Allowable Headway (MAH) / Maximum Time Separation - The maximum time separation between vehicle calls on an approach without gapping out the phase, typically defined by passage time or gap time. Maximum allowable headway refers to spacing between common points of vehicles in a single lane, but the term is commonly used to refer to maximum time separation in single or multi-lane approaches as well.

Maximum Green - The maximum length of time that a phase can be green in the presence of a conflicting call.

Maximum Initial - The maximum period of time for which the Added Initial can extend the initial green period. This cannot be less than the Minimum Green time.

Maximum Recall - A recall mode that places a continuous call on a phase.

Measure of Effectiveness - A quantitative parameter indicating the performance of a transportation facility or service.

Minimum Gap - This volume density parameter that specifies the minimum green extension when gap reduction is used.

Minimum Green - The first timed portion of the green interval which may be set in consideration driver expectancy and the storage of vehicles between the detectors and the stop line when volume density or presence detection is not used.

Minimum Recall - A recall parameter the phase is timed for its minimum green time regardless what the demand is for the movement.

Movement - A term used to describe the user type (vehicle or pedestrian) and action (turning movement) taken at an intersection. Two different types of movements include those that have the right of way and those that must yield consistent with the rules of the road or the Uniform Vehicle Code.

Non-locking Mode - A controller memory mode that does not retain an actuation received from a detector by the controller after the actuation is dropped by the detection unit.

Occupancy - The percent of time that a detector indicates a vehicle is present over a total time period.

Offset - The time relationship between coordinated phases defined reference point and a defined master reference (master clock or sync pulse).

Offset Reference Point (Coordination Point) - The defined point that creates an association between a signalized intersection and the master clock.

Overflow Queue - Queued vehicles left over from a green phase at a signalized intersection.

Oversaturation - A traffic condition in which the arrival flow rate exceeds capacity.

Passage Time (Vehicle Interval, Gap, Passage Gap, Unit Extension) - A phase timer that ends a phase when the time from the last detector output exceeds the timer setting.

Pattern Sync Reference - The set start of the master clock.

Peak-hour Factor - The hourly volume during the maximum-volume hour of the day divided by four times the peak 15-min flow rate within the peak hour; a measure of traffic demand fluctuation within the peak hour.

Pedestrian - An individual traveling on foot.

Pedestrian Recall - A recall mode where there is a continuous call for pedestrian service resulting in the pedestrian walk and clearance phases to occur each time the phase times.

Pedestrian Clearance Interval - Also known as "Flash Don't Walk". The time provided for a pedestrian to cross the entire width of the intersection.

Pedestrian Phase - Time allocated to pedestrian traffic that may be concurrent with vehicular phases.

Pedestrian Scramble - See Exclusive Pedestrian Phase

Pedestrian Walk Interval - An indication to the pedestrian that it allows pedestrians to begin crossing the intersection.

Pedestrian Walking Speed - The average walking speed of pedestrians, in feet per second.

Percent Runs Stopped - The percentage of the total number of travel time runs conducted during which a vehicle stops.

Performance Index - An arterial and network-level performance measure that allows several measures of effectiveness to be mathematically combined.

Performance Measures - Signal system related effects on stops, vehicle delay, arterial travel time, or existence of spill back queuing between closely spaced intersections.

Permissive Movements - A movement where it is allowed to proceed if there are available gaps in the conflicting flow.

Permissive Period - A period of time during the coordinated cycle in which calls on conflicting phases will be result in the coordinated phase transitioning to non-coordinated phase(s).

Permitted Plus Protected - Compound left-turn protection that displays the permitted phase before the protected phase.

Permitted Turn - Left or right turn at a signalized intersection that is made against an opposing or conflicting vehicular or pedestrian flow.

Phase - A controller timing unit associated with the control of one or more movements. *The MUTCD defines a phase as the right-of-way, yellow change, and red clearance intervals in a cycle that are assigned to an independent traffic movement.*

Phasing Indication - The current display for a given phase (green, yellow, red, walk, flashing don't walk, or don't walk).

Phase Pair - A combination of two phases allowed within the same ring and between the same barriers such as 1+2, 5+6, 3+4, and 7+8.

Phase Recall - A call is placed for a specified phase each time the controller is servicing a conflicting phase. This will ensure that the specified phase will be serviced again. Types of recall include soft, minimum, and maximum. Soft recall only calls the phase back if there is an absence of conflicting calls.

Phase Sequence - The order of a series of phases.

Phasing Diagram - A graphical representation of a sequence of phases.

Platoon - A group of vehicles or pedestrians traveling together as a group, either voluntarily or involuntarily because of signal control, geometrics, or other factors.

Preemption - Traffic signal preemption is the transfer of normal operation of a traffic control signal to a special control mode of operation.

Preempt Trap - A condition that can occur when a preemption call is serviced at a signalized intersection near an at-grade train-roadway crossing, where not enough clearance green time is provided to clear a queue of vehicles, and a vehicle could be trapped on the tracks with the railroad crossing lights and gates come down.

Presence Mode - A detection mode where a signal is sent to the controller for the duration of time a vehicle is inside the detection zone.

Pre-timed Control - A signal control in which the cycle length, phase plan, and phase times are preset to repeat continuously.

Priority - Traffic signal priority (TSP) is an operational strategy communicated between transit vehicles and traffic signals to alter signal timing for the benefit or priority of transit vehicle. Green extension, red truncation, and phase skipping are examples of signal timing alterations under TSP.

Progression Adjustment Factor - A factor used to account for the effect of signal progression on traffic flow; applied only to uniform delay.

Protected Movements - A movement where it has the right-of-way and there are no conflicting movements occurring.

Protected Plus Permitted - Compound left-turn protection at a signalized intersection that displays the protected phase before the permitted phase.

Protected Turn - The left or right turns at a signalized intersection that are made with no opposing or conflicting vehicular or pedestrian flow allowed.

Pulse Mode - A detection mode where vehicle detection is represented by a single "on" pulse to the controller.

Queue - A line of vehicles, bicycles, or persons waiting to be served by the system in which the flow rate from the front of the queue determines the average speed within the queue. Slowly moving vehicles or people joining the rear of the queue are usually considered part of the queue. The internal queue dynamics can involve starts and stops. A faster-moving line of vehicles is often referred to as a moving queue or a platoon.

Queue Discharge - A flow with high density and low speed, in which queued vehicles start to disperse. Usually denoted as Level of Service F.

Queue Spillback - A term used to describe vehicles stopped at an intersection that exceed the available storage capacity for a particular movement.

Queue Storage Ratio - The parameter that uses three parameters (back of queue, queued vehicle spacing, and available storage space) to determine if blockage will occur.

Red Change Interval - The period of time following a yellow period indicating the end of a phase and stopping the flow of traffic.

Red Time - The period, expressed in seconds, in the signal cycle during which, for a given phase or lane group, the signal is red.

Red Truncation - A signal priority treatment to terminate non-priority approach green phasing early in order to more quickly return to green for the priority approach. This treatment is also known as early return to green.

Ring – An array of independent timing sequences. For example, with a dual-ring controller, opposing left-turn arrows may turn red independently, depending on the amount of traffic. A typical controller is an "8-phase, dual ring control."

Ring Barrier Diagram - A graphical representation of phases within a set of rings and phases within a set of barriers.

Saturation Flow Rate - The equivalent hourly rate at which vehicles can traverse an intersection approach under prevailing conditions, assuming a constant green indication at all time and no loss time, in vehicles per hour or vehicles per hour per lane.

Saturation Headway - The average headway between vehicles occurring after the fourth vehicle in the queue and continuing until the last vehicle in the initial queue clears the intersection.

Section - A group of signalized intersections used to analyze traffic operations, develop new signal timings, and operate in the same control mode—manual, time of day, or traffic responsive

Segment - A portion of a facility on which a capacity analysis is performed; it is the basic unit for the analysis, a one-directional distance. A segment is defined by two endpoints.

Semi-Actuated Control - A type of signal control where detection is provided for the minor movements only and the signal timing returns to the major movement because it has no detection and is placed in recall.

Signal Head - An assembly of one or more signal indications.

Signal Coordination - An operational mode that synchronizes a series of traffic signals to enhance the operation of one or more directional movements.

Signal Warrant - A threshold condition to determine whether a traffic signal is justified based on satisfaction of an engineering study. There are eight warrants provided in the MUTCD.

Signalization Condition - A phase diagram illustrating the phase plan, cycle length, green time, change interval, and clearance time interval of a signalized intersection.

Simple Left Turn Protection - A signal phasing scheme that provides a single protected phase in each cycle for a left turn.

Simultaneous Gap - This parameter requires all phases to concurrently "gap out" prior to crossing the barrier.

Software in the Loop (SITL) - A means of providing a direct linkage between simulation models and software emulations of controllers,

Speed - A rate of motion expressed as distance per unit of time.

Split - The time assigned to a phase (green and the greater of the yellow plus all-red or the pedestrian walk and clearance times) during coordinated operations. May be expressed in seconds or percent.

Start-up Lost Time - The additional time, in seconds, consumed by the first few vehicles in a queue at a signalized intersection above and beyond the saturation headway, because of the need to react to the initiation of the green phase and to accelerate.

Stopped Delay - A measurement of the aggregate sum of stopped vehicles for a particular time interval divided by the total entering volume for that movement.

Stop Time - A portion of control delay when vehicles are at a complete stop.

Time-Before-Reduction - This volume density timing period begins when the phase is Green and there is a serviceable call on a conflicting phase. When this period is completed, the linear reduction of the Passage Time begins.

Time of Day Plans - Signal timing plans associated to specific hours of the day associated with fluctuations in demand.

Time-Space Diagram - A chart that plots the location of signalized intersections along the vertical axis and the signal timing along the horizontal axis. This is a visual tool that illustrates coordination relationships between intersections.

Time-To-Reduce - This volume density timing period begins when the Time-Before-Reduction ends and controls the linear rate of reduction until the Minimum Gap is achieved.

Total Delay - The sum of all components of delay for any lane group, including control delay, traffic delay, geometric delay, and incident delay.

Total Lost Time - The time per signal cycle during which the intersection is effectively not used by any movement; this occurs during the change and clearance intervals and at the beginning of most phases.

Track Clearance Green Time - Associated with rail preemption at signalized intersection near rail crossings. Track clearance green time is the signal timing provided to an approach to ensure queued vehicles can be moved off the rail crossing, prior to the beginning of railroad warning lights and gate lowering.

Traffic Control Center (Traffic Management Center) - An optional physical component of a signal system which contains the operational database that stores controller data, allows monitoring of the system, and allows timing and other parameters to be modified.

Traffic Control Devices - A device used to control conflicting traffic flows, typically at an intersection. Examples include traffic signals, stop signs, yield signs, and roundabouts.

Traffic Responsive Operation - A signal operational method which uses data from traffic detectors, rather than time of day, to automatically select the timing plan best suited to current traffic conditions.

Traffic Signal - A device to warn, control, or direct at least one traffic movement at an intersection.

Traffic Signal Controller - A device controlling indication changes at a traffic signal.

Traffic Signal Inventory - A database related to the traffic signal including information such as location, signal layout, signal timing, coordinated or uncoordinated signal operation, communication, operating agency, and history of updates.

Transit Efficiency - Performance measures for transit vehicles such as percent on-time, ridership, and travel time.

Travel Time (Average) - The total elapsed time spent traversing a specified distance. The average travel time represents an average of the runs for a particular link or corridor.

Travel Time and Delay Study - This study is used to evaluate the quality of traffic movements along an arterial and determine the locations, types, and extent of traffic delays. Typical measures of effectiveness include travel time, delay, percent runs stopped, and average speed.

Two-way Left-turn Lane - A lane in the median area that extends continuously along a street or highway and is marked to provide a deceleration and storage area, out of the through-traffic stream, for vehicles traveling in either direction to use in making left turns at intersections and driveways.

Uniform Delay - The first term of the equation for lane group control delay, assuming uniform arrivals.

Uniform Vehicle Code - A set of traffic laws prepared by the National Committee on Uniform Traffic Laws and Ordinances. The specific traffic laws within the code vary from state to state and within different jurisdictions.

Unit Extension - See passage time.

Unmet Demand - The number of vehicles on a signalized lane group that have not been served at any point in time as a result of operation in which demand exceeds capacity, in either the current or previous analysis period. This does not include the normal cyclical queue formation on the red and discharge on the green phase.

Upstream - The direction from which traffic is flowing.

Variable Initial - A volume density parameter that uses detector activity to determine if the initial green interval will exceed minimum green time.

Volume - The number of persons or vehicles passing a point on a lane, roadway, or other traffic-way during some time interval, often 1 hour, expressed in vehicles, bicycles, or persons per hour.

Volume-Density - A phase timing function that uses parameters (variable initial, min gap, time before reduction, time to reduce) to provide appropriate minimum green time to clear intersection queues when stop bar detectors are not used and/or it is desired to adjust the passage time.

Volume-to-Capacity Ratio - Also known as degree of saturation is a ratio of demand volume to the capacity for a subject movement.

Walk Interval - An indication providing right-of-way to pedestrians during a phase.

Yellow Change Interval - An indication warning users that the green indication has ended and the red indication will begin.

Yellow Extension - The portion of the yellow change interval that some vehicles use to pass through the intersection during the yellow change interval.

Yellow Trap - A condition that leads the left-turning driver into the intersection when it is possibly unsafe to do so even though the signal displays are correct.

Yield Point - A point in a coordinated signal operation that defines where the controller decides to terminate the coordinated phase.

APPENDIX P

POLICIES AND MEMOS

Memorandum

Making Conservation a California Way of Life.

To: DISTRICT DIRECTORS
DEPUTY DISTRICT DIRECTORS, Traffic Operations

Date: October 22, 2019

From: JASVINDERJIT S. BHULLAR
Chief
Division of Traffic Operations

Subject: MODEL 170 C8 RAILROAD 1 OPERATIONAL POLICY

The Model 170 controller and C8 traffic signal firmware program are over 30 years old and are no longer maintained or upgraded by the Division of Traffic Operations. Since 2003, the California Department of Transportation standard is the Caltrans Traffic Signal Control Program (CTSCP) which was developed for use at signalized intersections running on the Model 2070 controller. The CTSCP is designed with a fully functioning Railroad Preemption module and a dedicated module to support the Battery Backup System (BBS) as a separate input, independent of railroad preemption.

Effective Immediately, all districts shall take the following actions:

1. Replace all Model 170 controllers with Model 2070 controllers at traffic signals by June 2020.
2. Use CTSCP for traffic signals with the Model 2070 controller.
3. Only use railroad preemption for its intended purpose and connect the BBS to the battery backup input as documented in the CTSCP User's Manual.
4. As an interim measure, until the controller and software are replaced, ensure side-street phases are permitted in the existing C8 program.

In addition, all districts shall continue the following practices of:

1. Thoroughly bench testing the operational configuration, timing and setup of the traffic signal control program and controller prior to deployment in the field and operate the traffic signals in conformance with the California Manual on Uniform Traffic Control Devices (CAMUTCD).

2. Coordinating with Maintenance to regularly check the BBS at 90-day intervals and maintain accurate timing sheets and log files of all repairs, changes and updates at all traffic signals locations in their District for a minimum of five (5) years per Appendix J of the Traffic Signal Operations Manual and section K.04.4 of the Maintenance Manual.

The actions and practices in this memo will be incorporated in the update of Traffic Signal Operations Manual scheduled to be released in January 2020.

If you have any questions, please contact Patrick Leung, Acting Chief, Office of Transportation Management Systems, Division of Traffic Operations at (916) 654-4591 or by email at <Patrick.Leung@dot.ca.gov>.

c: Steve Takigawa, Deputy Director, Maintenance and Operations
Monica Kress, Deputy Division Chief, Division of Traffic Operations
Patrick Leung, Acting Chief, Office of Transportation Management Systems, Division of Traffic Operations

APPENDIX R

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