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16. Abstract

This report describes the research conducted to have a better understanding of the coordination features in the Eagle and Naztec traffic signal controllers. The features evaluated included force-off modes, transition modes, and coordination modes. The project illustrated many similarities in the functionality of these features in both the Eagle and Naztec controllers. The project found that using fixed force-off has the potential to significantly reduce delay to the cross street phase which is the last phase in the phasing sequence. The project evaluated the correction modes and recommended the Shortway mode of correction. Other modes can be used based on local preferences. The investigation of coordination modes revealed that no single coordination mode can be stated as the recommended mode. The research team found that it is better to determine the desired mode of operation and select the appropriate coordination mode. This approach can then be consistent methodology to select the coordination mode in both the Eagle and Naztec controllers.

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# EVALUATION OF ADVANCE COORDINATION FEATURES IN TRAFFIC SIGNAL CONTROLLERS

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# ACKNOWLEDGMENTS

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# INTRODUCTION

Most of the delay experienced by motorists in Texas cities is at traffic signals. Improving signal timing is a cost-effective way to improve traffic operations and reduce motorist delay. Traffic engineers are constantly striving to improve traffic operations along arterials by providing signal coordination. Traffic signal controllers today are very sophisticated and contain many advance coordination features that have the potential to improve traffic operations; however, traffic engineers seldom have the time and the resources to fully investigate these advance coordination features and usually use only the basic features to operate signals.

To address this issue, the Texas Department of Transportation sponsored a project to investigate the advance controller features in controllers that meet TxDOT specifications. Currently, Eagle and Naztec traffic signal controllers meet TxDOT specifications. The project identified coordination features in these controllers, investigated their functionality, and developed some methodologies to use and program features that would benefit signal operations.

## Background

Optimum traffic signal timing is one of the most cost-effective tools of alleviating congestion, improving safety, and reducing vehicular emissions available to a traffic engineer. Improving signal timings include a complete retiming of intersection timings and improving the flow of traffic along streets having several intersections. The Texas Transportation Institute has been conducting research for over 30 years to improve coordinated operations along arterials having signalized intersections. TxDOT funded TTI in the development of the PASSER family of programs to improve signal operations. Specifically PASSER II was developed in 1973 to improve signal operations by providing coordinated operations along an arterial and is being used not only by TxDOT but other agencies all over the country (*1*).

### *What is Coordination?*

As traffic volumes and the number of signalized intersections on an arterial increase, traffic engineers often face the need to improve the operation of the traffic signals so as to allow a platoon of vehicles to move through several signals without stopping. The movement of a platoon of vehicles through several signalized intersections is referred to as progression. To achieve progression, a timing relationship must be developed between successive intersections such that vehicles, traveling at a predetermined speed, can pass through the green indications at successive signals. The establishment of this timing relationship is referred to as coordinated operation or coordination (*2, 3*).

### *Means of Proving Coordination*

Coordination between intersections can be achieved by two means (*3*). The first is time-based control. Under time-based control, the signal timing relationship is maintained by very accurate time clocks internal to each controller. The clocks in each controller are set to the same time of day. In theory, with all the controllers set to the same time of day, the offset relationship

between the green indications at each successive intersection can be maintained.  However, in the past, the clocks in the controller had a tendency to drift thereby causing the intersections to operate with less-than-optimal offsets.

The other means of achieving coordination between intersections is through the use of an interconnection.  With an interconnect system, the controllers at each individual intersection (commonly referred to as the local controller) are interconnected to a master controller or a central computer either by a physical wire (a twisted-pair wire, a coaxial cable, or a fiber-optic cable) or by the use of a radio or other air-path communication media.  A primary function of the master controller is to ensure that each individual intersection control remains in step with one another (usually by sending a synchronization pulse through the interconnection).   The pulse provides a common reference point from which all the intersections can time their offsets.

## *Establishing Signal Timing Plans for Coordinated Operations*

Regardless of the type of mechanism used by the controller to achieve coordination, every coordinated system has the set of requirements for establishing the timing plans inside the controller *(4, 5)*.  The first requirement is that all the traffic signals have to operate with the same cycle length.  In establishing the coordination scheme, the engineer must find the one intersection in the system that requires the greatest cycle length to accommodate the traffic and then design the rest of the progression scheme around that intersection.  Once the system cycle length has been determined, the phase sequences and lengths (or split times) can then be determined for each intersection in the system.  The final signal parameter that must be determined is the offset.  The offset is usually defined as the time differential between the initiation of green indications of the coordinated movements relative to the master intersection (i.e., the intersection dictates the signal timing requirements of the other intersections).  The offset value is derived based upon the distance between the master intersection and the desired travel speed of traffic on the arterial.  Figure 1 shows a time-space diagram illustrating the important elements of coordination of a traffic signal system.

## *Benefits of Coordination*

The primary benefit to coordination is the reduction in delays and stops that come from allowing vehicles to move continuously through the intersections.  Figure 2 shows the effects of different offsets on stops and delays for a platoon of vehicles leaving one intersection and passing through another.  This figure shows how a good offset relationship between two intersections can reduce the number of stops and delays, while a poor offset relationship can actually cause stops and delays to increase *(4)*.

Other benefits that can occur as a result of good coordinated operations include the following:
- reduction in fuel consumption and vehicle emissions,
- maintenance of preferred travel speeds, and
- movement of platoons of vehicles through successive intersections.
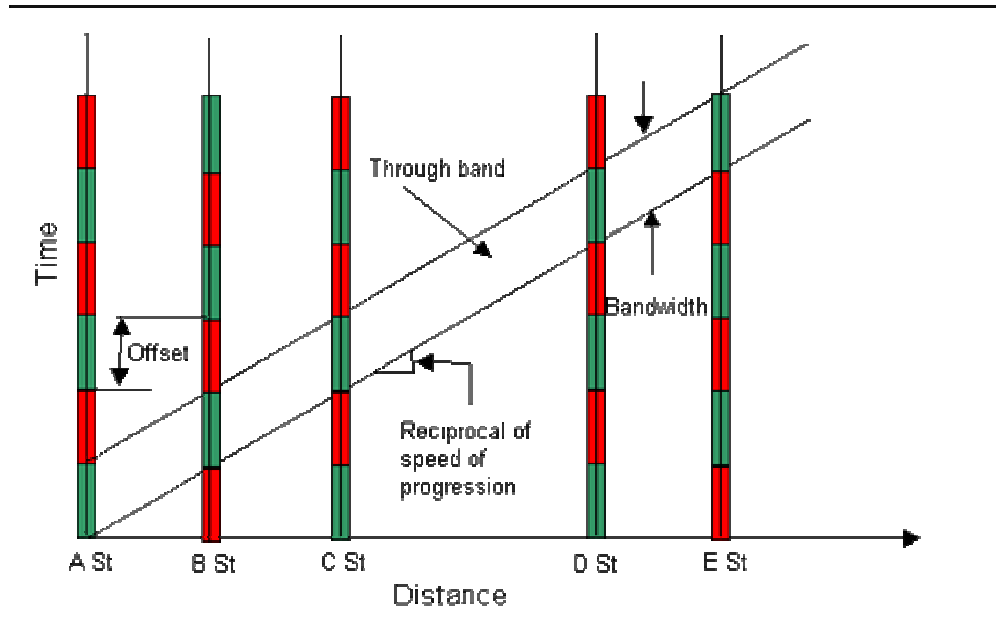
**Figure 1. Time-Space Diagram Showing Important Elements of Coordination Scheme (5).**

Factors that limit the benefits of signal coordination are as follows:
- inadequate roadway capacity;
- existence of substantial side frictions, including parking, loading, double parking, and multiple driveways;
- complicated intersections, involving multiphase control;
- wide variability in traffic speeds;
- very short signal spacing; and
- heavy turn volumes, either into or out of the street.

Pedestrian traffic can also have a significant impact on the ability to provide progression. Because of their difference in operating speed, pedestrians generally require more time to cross and clear an intersection than vehicles. This time differential has a significant impact on the amount of green time that a phase must provide. In some cases, such as at wide intersections or where there is significant pedestrian traffic, the time required by a phase to cross and clear pedestrian traffic can be longer than the time required for the traffic. As a result, it is the duration of the pedestrian walk and clearance times that dictates how long a phase must be active and not vehicular traffic, thereby reducing the effectiveness of coordination on vehicular traffic.
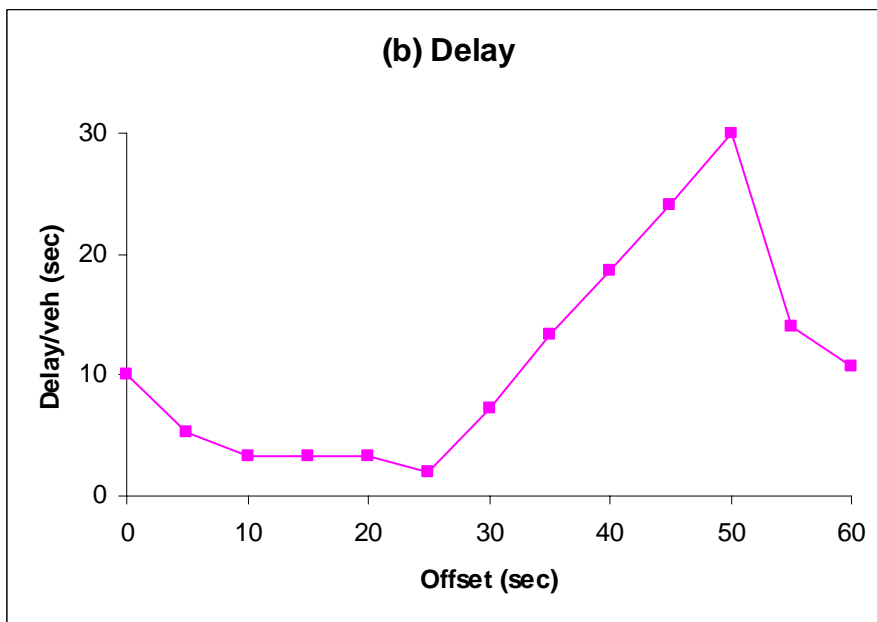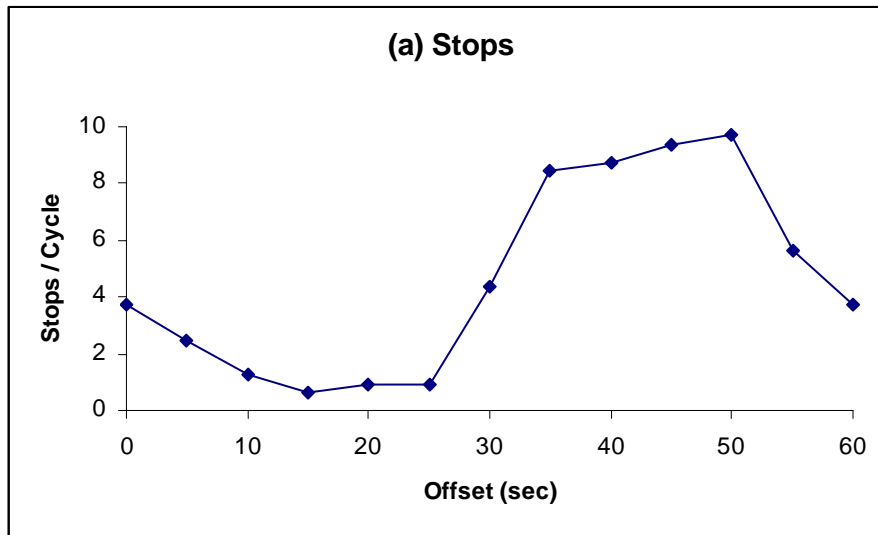
**Figure 2. Illustration of the Effect of Offset on Stops and Delay _(4)_.**

### Computer Tools for Generating Coordinated Timing Plans

Generally, there are two philosophies that are employed to compute timing plans for an arterial street *(4)*:

- maximization of the bandwidth of the progression, or
- minimization of the overall delay and stops.

Bandwidth optimization techniques, such as MAXBAND, PASSER II, and PASSER IV, use traffic volumes, signal spacing, and desired travel speed to determine the optimum width of progression band that can be accommodated on an arterial.  Because bandwidth optimization techniques are attempting to provide as wide of a progression band as possible, they generally result in longer cycle lengths so as to permit larger amounts of traffic to pass through an intersection during the green interval.  The second approach uses models that seek to minimize delay, stops, or other measures of disutility.  Examples of these types of techniques include TRANSYT-7F and SYNCHRO. These models generally attempt to find a common cycle length that minimizes the amount of overall delay in the system and then compute the offset required for progression.  As a result, these optimization techniques generally produce cycle lengths that are shorter than those produced by bandwidth optimization techniques.  Because these two approaches are attempting to develop signal timing plans to achieve different design objectives (maximize bandwidth versus minimize delay), they can result in significantly different signal timing plans for similar traffic conditions.  The selection of which philosophy to use in an area is one of local policy and personal preference.

There have been significant advances in signal controller hardware with the advent of solid-state microprocessor traffic signal controllers.  There are numerous vendors marketing their products with several features.  Many of these features have the potential to significantly improve traffic operations.  To ensure a basic level of interoperability, the National Electrical Manufacturers Association (NEMA) published a number of standards for traffic signal controller systems defining a common minimum level of functionality for traffic signal controllers *(2, 5, 6)*.  However, vendors while adhering to the common minimum functionality have added additional features that differ from vendor to vendor in implementation.  Specifically, vendors have provided numerous means of providing coordination.  There are numerous options to be chosen from various menus to provide coordination between several intersections.  Not only do the features differ from vendor to vendor, they also differ between the numerous coordination modes offered by each vendor.  Each of these options or features provided by a vendor implements the coordination plan in a significantly different manner.  While these vendors have explained how to program these features in a traffic signal controller, no information is available as to how these features differ from each other and when to use them.

Currently only Eagle Traffic Control Systems with their EPAC399 controller *(7)* and Naztec Incorporated with their Model 980 controller with Version 50 software *(8)* meet the TxDOT traffic signal controller specifications completely *(9)*.  The Eagle controller provides six operational modes, four correction modes, three maximum modes, two force modes, and two offset position modes.  Similarly, the Naztec controller provides two National Transportation Communications for ITS Protocol (NTCIP) coordination modes, seven other coordination

modes, and three correction/transition modes. Some of these features may benefit the pedestrian operations more than the traffic operations. These features can be used at locations as high pedestrian operations. Some of these modes may benefit traffic operations in a very subtle manner. And some of these features may not be appropriate for TxDOT applications. This project studied and evaluated the impact of these advanced features on traffic and pedestrian operations. TTI recently completed and presented a study on improving diamond interchange operations using advance controller features in existing controllers (*10*). This research project relied upon the methodology used in Project 0-4158 to gain a better understanding of the advance coordination featured in existing controllers.

# ADVANCE COORDINATION FEATURES

Some of the coordination features existing in Eagle and Naztec have been available for many years. While some of the features meet the TxDOT TS-2 specifications, some features are provided in addition to the specifications (*9*). There are no guidelines about the capabilities of these coordination features and how and when to use them. Typically, engineers use the basic coordination features to operate signals. With an increase in traffic volumes and congestion, it is imperative that every available feature to improve traffic operations be used. This project studied and evaluated these features in Eagle and Naztec controllers. This chapter describes the TxDOT specifications related to coordination and then briefly describes the functionality and operation of advance coordination features that can influence and improve coordination.

## TxDOT Specifications

This section describes the requirements of TxDOT specifications for coordination. Only sections that are relevant to the features tested will be addressed. These features include offset references, force-off modes, and correction modes.

Section 2.7.4.2 in the TS-2 specifications deals with the coordinator reference point (*9*). TS-2 specifications state that:

- The coordinator shall refer to a system-wide reference cycle timer (system cycle timer).

- The term $T_0$ (local zero) shall refer to the point in the local cycle timer when the first coordinated phase (or leading coordinated phase if a pair of coordinated phases was selected by the user) is scheduled on for the first time.

- The offset shall be the amount the local cycle timer is behind the system cycle timer. Example: if the offset is +10 seconds, $T_0$ (the point at which the local cycle timer is at 0) will occur when the system cycle timer is at 10 seconds.

- The offset may refer to either the beginning of green or end of green (Figure 3).

Section 2.7.4.3 states that there shall be two modes of automatic coordination programming, fixed and floating force-off modes. The specifications also state that the information required from the user to establish a pattern of force-off modes shall include the basic controller information, cycle length, phasing sequence, designation of coordinated phase(s), and offset. Using this information, the controller shall guarantee providing the programmed split times for each phase in a coordinated operation. The controller shall also calculate each phase's force-off point, beginning and ending of the permissive periods, and the ending of the pedestrian permissive periods. This is a very crucial requirement; some controllers do not calculate for some of the coordination modes. Finally, specifications state that in the floating force-off mode, each non-coordinated phase will only operate for the duration of the programmed split, even if the phase comes on early because a previous non-coordinated phase gapped out.
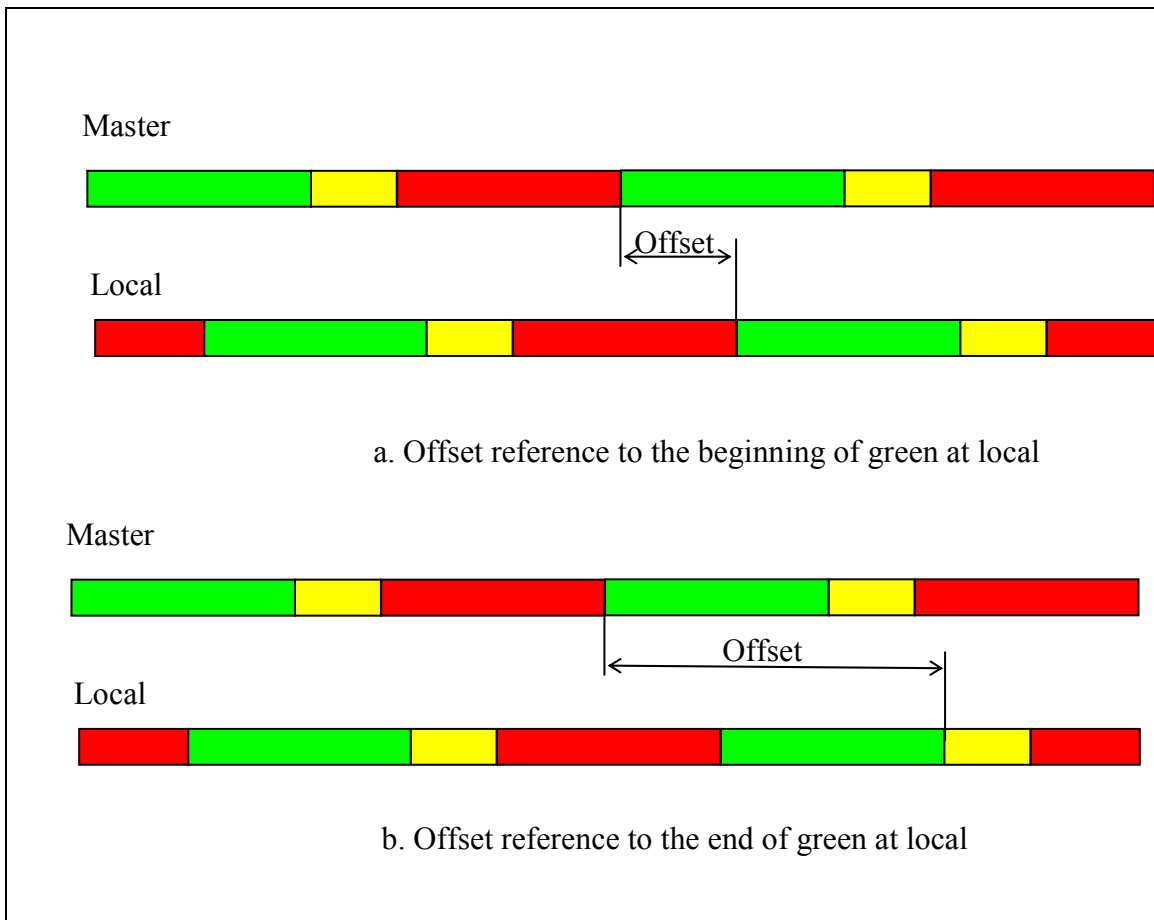
**Figure 3.  Offset Reference  Procedures.**

The specifications (Section 2.7.4.7) state that when the controller is switching from one plan to another, the coordinator shall be programmable to seek offsets by short-way (lengthening or shortening the cycle length up to 20 percent) and by dwell in the coordination phase awaiting the proper offset.  The user shall determine which method to use and may program the longest permissible dwell times.

Controller vendors frequently provide more features than specifications state.  These features include numerous coordination modes, among others and have an impact on the termination of coordination phases and service to pedestrians.  Since these features are beyond the specification requirements, there is no uniformity among the vendors about the operations of the advanced features.  However, many of these features have the potential to improve operations, as they are applicable for specific conditions or address a unique situation.  Understanding of the functioning of these features can significantly improve traffic operations at such locations.

**Force-off Modes**

TxDOT's TS-2 specifications require two types of force-off modes; floating and fixed force-offs. The primary difference in these modes is in the manner the excess time from one non-coordinated phase is used by another non-coordinated phase. Figure 4 illustrates an example of signal timing for an intersection. The figure illustrates that 20 seconds is allocated to all non-coordinated phases, which includes the vehicle clearance time of 5 seconds for each phase. Typically, coordinated phases will not gap out. The non-coordinated phases can gap out if they have detectors and are operated in an actuated manner.
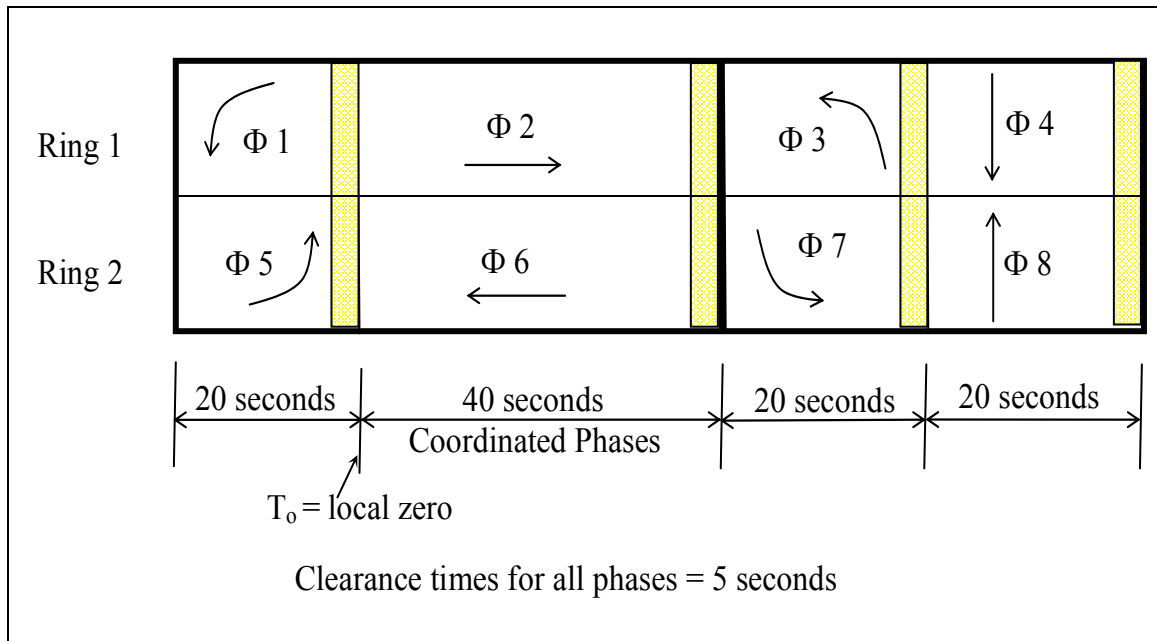


**Figure 4. Example Signal Timing.**

Typical signal timings can also be represented as shown in Figure 5. This figure illustrates the splits and the force-off points. A force-off point for each non-coordinated phase is the point in the background cycle where the respective phase must terminate to ensure that the controller returns to the coordinated phase at the proper time in the cycle (*11*). If the offset is referenced to the beginning of green (coordinated phase - local zero), force-off points for each of the phases for the example are calculated below and illustrated in Figure 5.

Force-off point for:

Phase 3 & 7:  Phase 2 & 6 split + Phase 3 & 7 split – Phase 3 and 7 clearance

$$40 + 20 - 5 = 55 \text{ seconds}$$

Phase 4 & 8:  Phase 2 & 6 split + Phase 3 & 7 split + Phase 4 & 8 split – Phase 4 and 8 clearance

$$40 + 20 + 20 - 5 = 75 \text{ seconds}$$

Phase 1 & 5:  Phase 2 & 6 split + Phase 3 & 7 split + Phase 4 & 8 split + Phase 1 & 5 split – Phase 1 and 5 clearance

$$40 + 20 + 20 + 20 - 5 = 95 \text{ seconds}$$
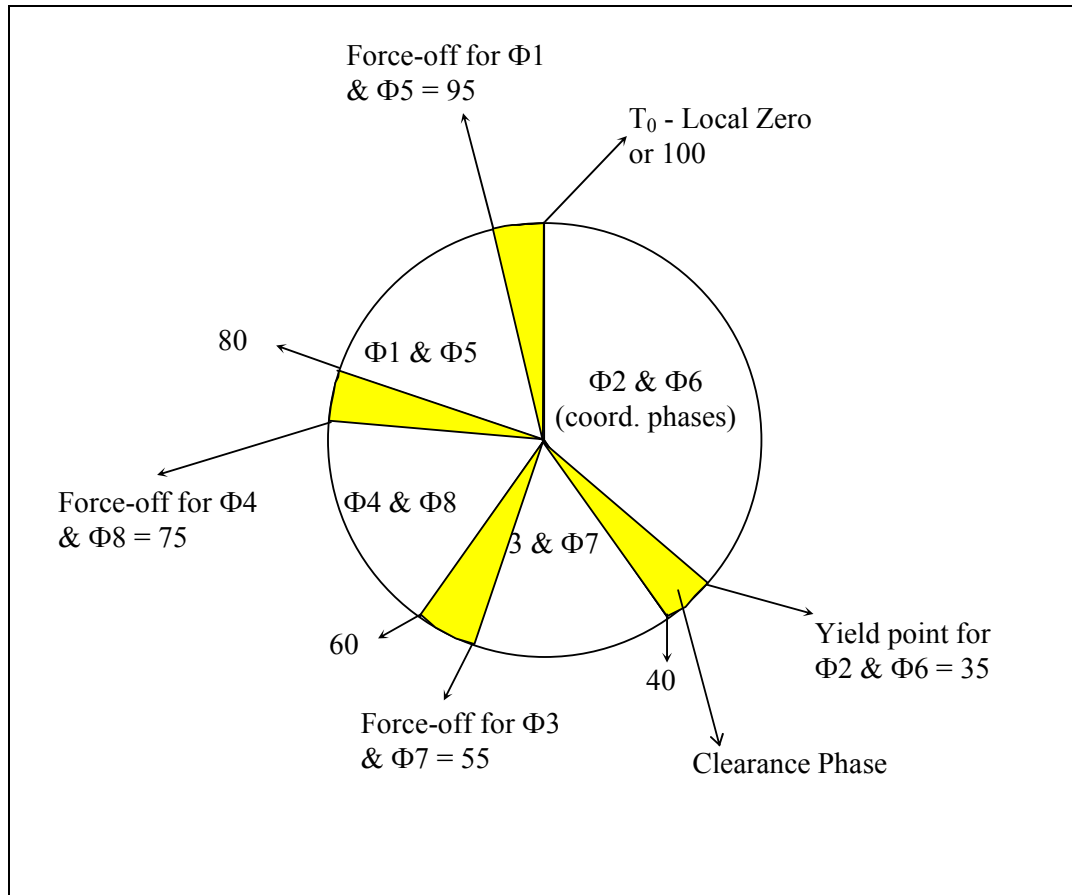


**Figure 5.  Illustration of Force-off Points.**

*Floating Force-off*

In floating force-off mode, the non-coordinated phases are limited to the duration of the splits that were programmed in the controller. In the example shown in Figure 4, phases 3 and 7 and phases 4 and 8 are programmed to operate for 20 seconds. If the demand on phases 3 and 7 is such that phases 3 and 7 only require 10 seconds, they will gap out and phases 4 and 8 will come on 10 seconds earlier. However phases 4 and 8 can only operate for a maximum of 20 seconds. After phases 4 and 8 terminate either due to a gap out or due to a max out, phases 1 and 5 will come on and they will be followed by phases 2 and 6 (coordinated phases). Since phases 3 and 7 gapped out 10 seconds early, phases 2 and 6 will have an early return of at least 10 seconds. This duration of early return will be higher if phases 4 and 8 and/or phases 1 and 5 also gap out and do not use all of their programmed time.

Figure 6 illustrates the functionality of floating force-off for the example in Figure 4 for one cycle. As seen in the figure, phases 3 and 7 for this cycle have excess capacity. At the same time, phases 4 and 8 have excess demand. However, using floating force-off does not allow for any time from phases with excess capacity to be used by a phase with excess demand. This means that phases 4 and 8 will terminate before their force-off point in the cycle. This results in an early return to the coordinated phases.
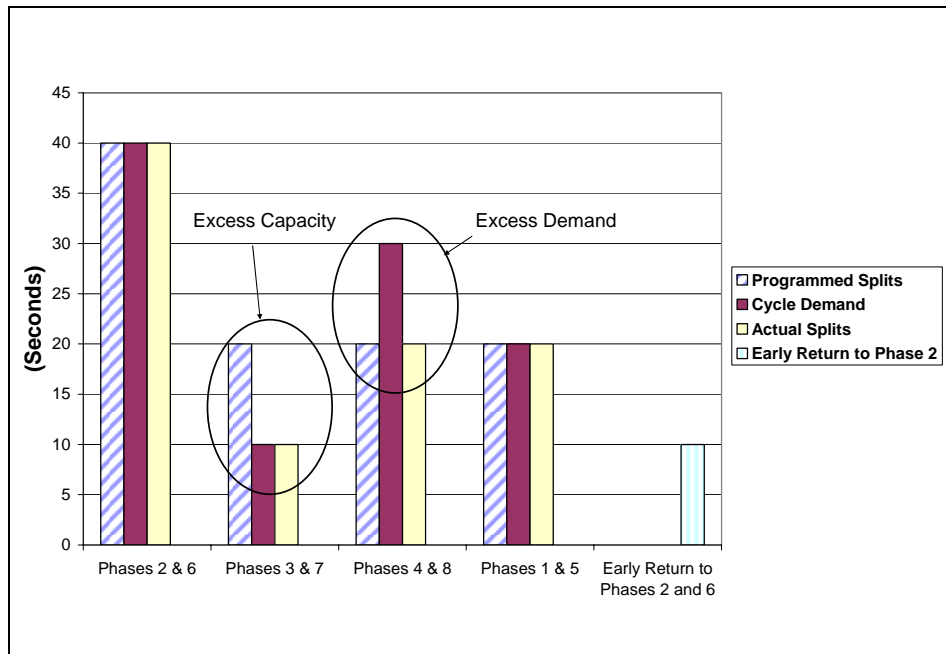


**Figure 6. Floating Force-off Example for One Cycle.**

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*Fixed Force-off*

Fixed force-off, on the other hand, allows the use of excess capacity from some phases to a subsequent phase with excess demand. The controller only allows the use of excess unused capacity and ensures that coordinated operations are not disrupted. Figure 7 illustrates an example of fixed force-off operations for the example intersection.
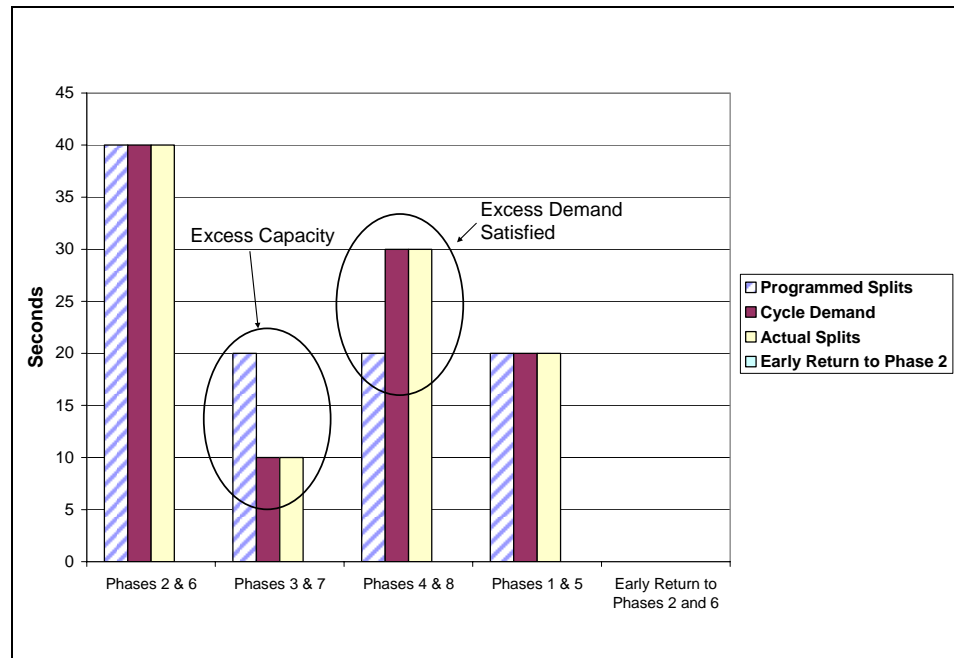


**Figure 7.  Fixed Force-off Example for One Cycle.**

As can be seen from Figure 7, the excess capacity from phases 3 and 7 is used by phases 4 and 8 where there is an excess demand. This means that phases with excess demand will terminate at the force-off point irrespective of when the phase starts. This operation also eliminates an early return to the coordinated phases, in this case, and ensures that phases can operate for a duration that is longer than the programmed split without any disruption in coordination.

Floating and fixed force-off modes are specified in TxDOT's TS-2 specifications and operate in a consistent manner in both Eagle and Naztec controllers. The example illustrated indicates that fixed force-off has significant benefits. Some of the advantages and disadvantages include:

- Fixed force-off is useful to allow better utilization of the time available from phases operating under capacity by phases having excess demand, which varies in a cyclic manner. This is the case when the phase(s) earlier in the phasing sequence is under capacity more often than the other phases.

- Fixed force-off minimizes the early return to coordinated phases, which can be helpful in a network having closely spaced intersections. An early return to the coordinated phase at a signal can cause the platoon to start early and reach the downsteam signal before the onset of the coordinated phase, resulting in poor progression.

- Fixed force-off, minimizes the early return to the coordinated phase which can be a disadvantage. Under congested conditions on the arterial, an early return can result in the queue clearance for coordinated phases. Minimizing early return to coordinated phases can cause significant disruption to coordinated operations. This disadvantage can be overcome by adjusting the splits and/or offsets at the intersection to minimize disruption.

Overall, fixed force-off has the potential to improve signal operations by better utilization of any excess capacity. However, fixed force-off will only benefit if the phases that are more likely to be under capacity are earlier in the phasing sequence. Hence, this excess time can be available to be used by a subsequent phase with a higher demand. In the Eagle controller, floating force-off and fixed force are known as Plan and Cycle, respectively. Finally, an option selected in this feature is applicable for all patterns.

**Coordination Modes**

There are numerous modes of operation that have an impact on coordination. These modes operate differently in different controllers. The following sections discuss the modes in Eagle and Naztec controllers.

*EPAC 300 Eagle Controller*

Eagle has six different coordination modes (7). Selection of a coordination mode implies that the mode is applicable for all the patterns programmed in the controller. The six coordination modes are detailed below.

*Yield Mode*

Figure 8 illustrates the Yield mode in Eagle controller for the example intersection (12).
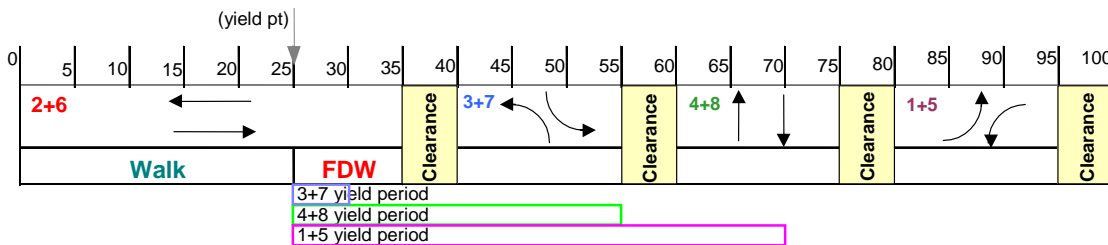


**Figure 8. Yield Mode in Eagle Controller.**

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Yield mode is characterized by:

- The pedestrian phase <u>dwells</u> in the "Walk" display. This application is useful at high pedestrian demand locations.

- The <u>end of walk is actuated,</u> i.e., "Walk" terminates after the yield point only due to the presence of a conflicting call. This can cause higher delay to the non-coordinated phases during off-peak as they will have to wait for the pedestrian clearance to complete to be served.

- At the end of the coordinated phase split, the controller can <u>yield to any of the non-coordinated phases</u>. This can result in lower delay to the non-coordinated phases during moderate traffic conditions since the controller can yield to any of the non-coordinated phases.

- Since the non-coordinated phases can start early, the coordinated phases can have <u>very early return</u>. Early return to the coordinated phases can cause inefficient operations for closely spaced intersections. However, early return can also clear queues on coordinated phases if there are consistent queues at the beginning of green.

*Permissive Mode*

Figure 9 illustrates the Permissive mode in the Eagle controller for our example intersection.
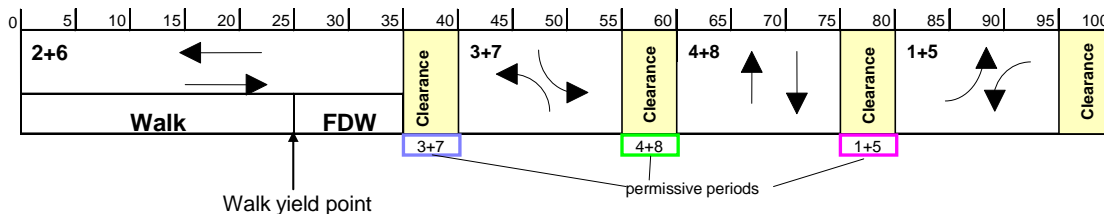


**Figure 9.  Permissive Mode in Eagle Controller.**

Permissive mode is characterized by:

- The pedestrian phase for the coordinated phase <u>dwells</u> in the "Walk" display. Hence, this mode will be beneficial at high pedestrian demand locations.

- Unlike in the Yield mode, the Walk display will <u>terminate at a fixed point</u> in the cycle to ensure that the next non-coordinated phase can be serviced without any delay.

- At the end of the coordinated phase split, the <u>controller will yield ONLY to the next phase</u> in the sequence (phases 3 and 7). If there is no demand on the next phase (phases 3 and 7), their time will be added to the end of the coordinated phase. If there is a demand on a subsequent phase afterwards (phases 4 and 8), the coordinated

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phases will yield to those phases only after the completion of the split time of a previous phase (phases 3 and 7). However, if the coordinated phase does yield to phases 3 and 7 due to a demand and they gap out, phases 4 and 8 and the subsequent phases can be activated immediately. This can result in higher delays for the non-coordinated phases that are later in the sequence under very light conditions. Under moderate conditions, there is no difference in this aspect between the Yield mode and the Permissive mode.

- If the non-coordinated phases gap out, the controller will <u>return early</u> to the coordinated phase, which can either impede progression under closely spaced intersections or can improve operation by clearing queues at the onset of the green. This will depend on local conditions.

- This mode works very well for a majority of coordinated intersections.

*Permissive Yield*

Permissive yield mode is very similar to Permissive mode with two significant differences, and is illustrated in Figure 10.
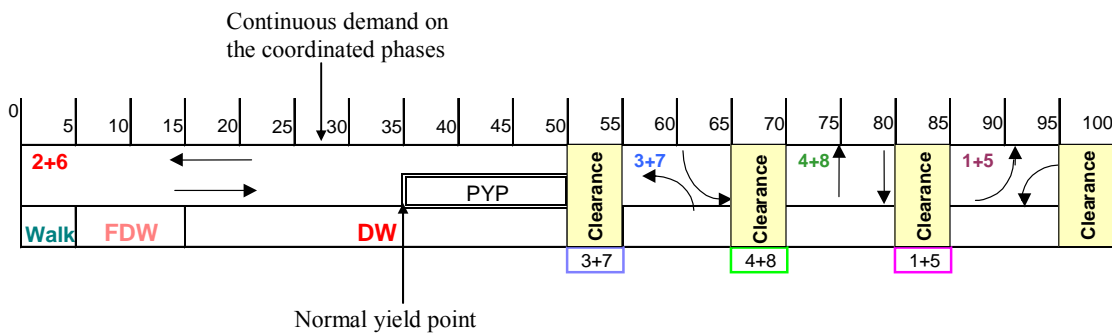


**Figure 10. Permissive Yield Mode in Eagle Controller.**

Permissive yield mode is characterized by:

- The <u>Walk indication is actuated</u> and is equal to the time programmed in the controller for Walk. This can result in delaying pedestrians at high pedestrian volume locations.

- The <u>coordinated phase can extend</u> beyond the normal yield point and is actuated in the time period called Permissive Yield Period (PYP). This excess time is taken in proportion from the remaining non-coordinated phases while ensuring they serve at least their minimum times.

- As in the Permissive mode, the controller has a <u>controlled yield</u> from the coordinated phase to the non-coordinated phases.

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- Also as in Permissive mode, if the non-coordinated phase gaps out early, there is an <u>early return</u> to the coordinated phases.

- This mode <u>will not operate when using the Shortway</u> offset correction.

- This mode is applicable for very light traffic conditions (small cycle length) that still require coordination. Under such conditions, the coordinated phase can take advantage of the early return, extending the coordinated phase, as well as utilizing the time of the subsequent phase if there is no demand. Similarly, very light traffic conditions will have less traffic on the non-coordinated phases, and hence, they will not be adversely affected by any phase truncation.

*Permissive Omit*

Permissive Omit is very similar to Permissive Yield with the following exception:

- Permissive Omit <u>prevents an early return</u> to the coordinated phase.

- If the coordinated phase yields to a non-coordinated phase, the <u>controller dwells in the non-coordinated phase</u> until the controller reaches an appropriate point in the cycle where it has to service the coordinated phase (local zero in Figure 5).

- Like the Permissive Yield mode, Walk indication is actuated and is on only for its programmed duration; the coordinated phase can extend and is actuated in the extended portion; and the controller has a controlled yield from the coordinated phase to the non-coordinated phases.

- This mode is useful where an early return to the coordinated phase will seriously impede efficient progression at the downstream intersection. It is useful in arterials with closely spaced intersections.

*Sequential Omit*

Sequential Omit mode is very similar to Permissive Omit with two major differences. Figure 11 illustrates the Sequential Omit mode.

Sequential Omit mode is characterized by:

- The permissive period for each non-coordinated phase starts with the end of the permissive period of the previous phase. Hence, unlike in the Permissive modes, phases later in the sequence (phases 4 and 8 and phases 1 and 5) can start much earlier if there is no demand on the first non-coordinated phase (phases 3 and 7).

- Omit on the coordinated phase is lifted at the end of the last permissive period (in this case, at 80 in the cycle). This means that the early return on the coordinated phase is allowed in a marginal manner.
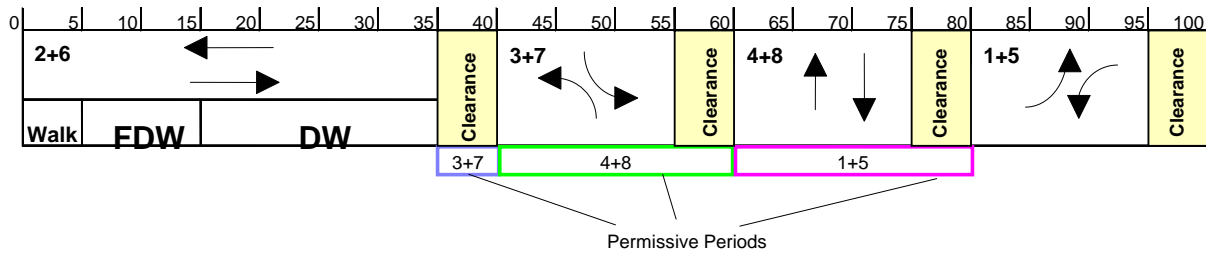
**Figure 11. Sequential Omit Mode in Eagle Controller.**

*Actuated Coordinated*

Actuated coordinated mode is a combination of all the previous coordination modes and is illustrated in Figure 12.
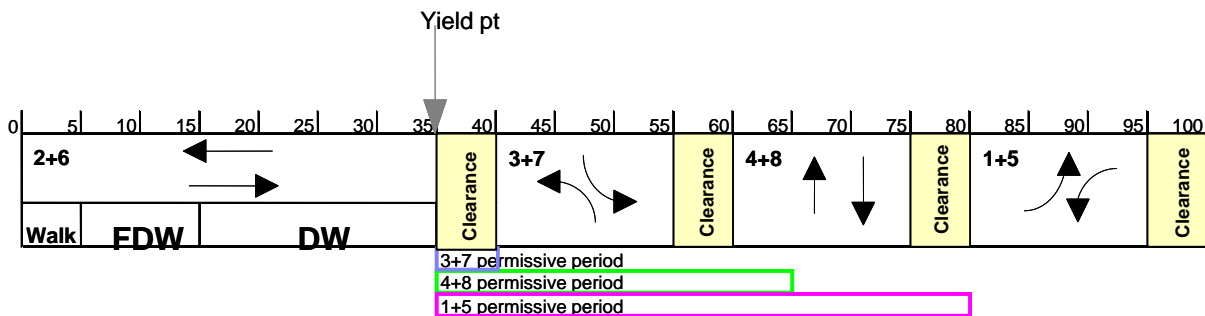


**Figure 12. Actuated Coordinated Mode in Eagle Controller.**

Actuated coordinated mode is characterized by:

- Actuated Walk is equal to the duration of Walk timing programmed.

- The coordinated phase yields to all the non-coordinated phases at the yield point.

- The <u>end of coordinated phase is actuated</u> and has a PYP after the Yield point. This means that the coordinated phase can be extended beyond its yield point.

- The <u>coordinated phase is fully actuated after the PYP</u> and prior to the end of permissive period of the phase before the coordinated phase (80 seconds). This means that phases 2 and 6 can yield to phases 3 and 7 at 35 seconds, phases 3 and 7 can gap out after 10 seconds at 50 seconds, phases 2 and 6 can come on at 55 seconds due to absence of calls on phases 4 and 8 and on phases 1 and 5. Phases 2 and 6 under such conditions will be fully actuated and can even gap out to phases 1 and 5 if there is a demand on them before 80 seconds in the cycle. Figure 13 illustrates the scenario described.

17
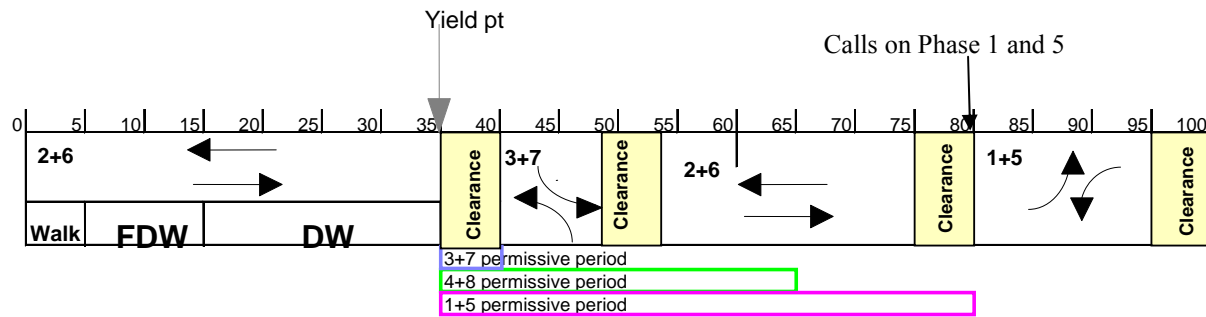
**Figure 13. Example of Actuated Coordinated Mode Operation.**

## Naztec Controller

Naztec controller (8) features nine coordination features. These nine modes are categorized into two groups: NTCIP Modes and Other Modes. Listed next are the nine coordination modes:

- NTCIP Modes

  - Floating force-off and

  - Fixed force-off.

- Other Modes

  - Easy,

  - Permissive-Single,

  - Permissive force-off,

  - Permissive force-off percent,

  - Permissive-float,

  - Permissive float percent, and

  - Force/yield.

There is a primary difference between the NTCIP modes and the other modes. In NTCIP modes, the controller automatically calculates the force-off points, yield points, and apply points necessary to run coordinated operations. In the other modes, apart from Easy mode, force-off times and permissive periods will have to be calculated and programmed (Section 13.2) (8). However, TxDOT's TS-2 specification (Section 2.7.4.4) states that the traffic signal controller

should calculate the force-off points, vehicle permissive windows, and pedestrian permissive windows (9).  Moreover, a study of these other modes revealed that these modes were individually designed for specific customers for a customized mode of operation and were not being used anywhere else.  Hence, these coordination modes will not be evaluated.  However, the Naztec controller has numerous other coordination features that can be used in conjunction with the NTCIP modes to program the controller to obtain desirable coordinated operations.  This section will discuss the coordination features that will be useful.

*Early Yield*

Early Yield mode is used to change the yield point of the coordinated phase.  Using Early Yield, it is possible to terminate the coordinate phase earlier by up to 25 seconds.  This can happen if there are no actuations on the coordinated phases and there are calls on the non-coordinated phases.  Typically, time is not taken away from coordinated phases; however, some unique applications may warrant such an operation.  Figure 14 illustrates the operation of Early Yield.  Early Yield when selected is applicable for individual patterns.
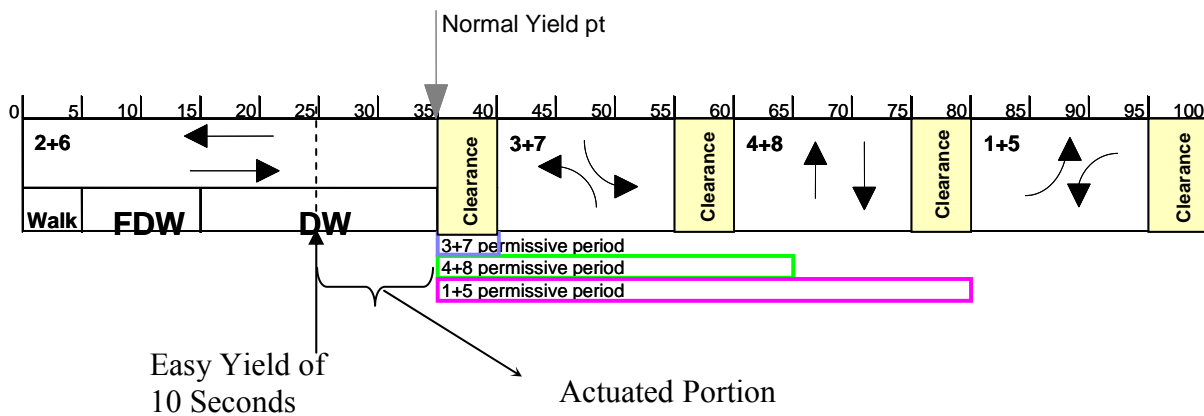


**Figure 14.  Early Yield in Naztec Controller.**

*Stop in Walk*

Frequently, traffic engineers are faced with a conflict between pedestrian requirements and traffic requirements.  For wide streets (especially when crossing the main street), the pedestrian clearance times can be very high.  Many times, the traffic demand on the cross-street associated with the pedestrian movement is lower than the pedestrian requirement.  Providing for pedestrian requirement in the green splits may not provide good progression along the arterial.  If the frequency of pedestrian actuations is low, the traffic engineer has the option of providing for the vehicular demand in the split.  However, the Naztec controller diagnostics will detect a split that is smaller than the pedestrian requirements and not allow for coordination to set in.  The parameter Stop in Walk will assist in overcoming this problem.

By allowing Stop in Walk, the controller timer will stop when ever a pedestrian is serviced.  This allows the pedestrian to be serviced while providing only the optimal requirements to vehicular demands.  However, this means that the controller goes out of coordination whenever a pedestrian is serviced.  Stop in Walk, when programmed, is applicable for all patterns.

Figure 15 illustrates such an example.  The example has the following timing requirements:

Vehicle Demand for Phase 4 and 8:          20 seconds (including clearance)

Pedestrian requirements for Phase 4 and 8:  Pedestrian Walk:              5 seconds

Pedestrian Clearance:        20 seconds
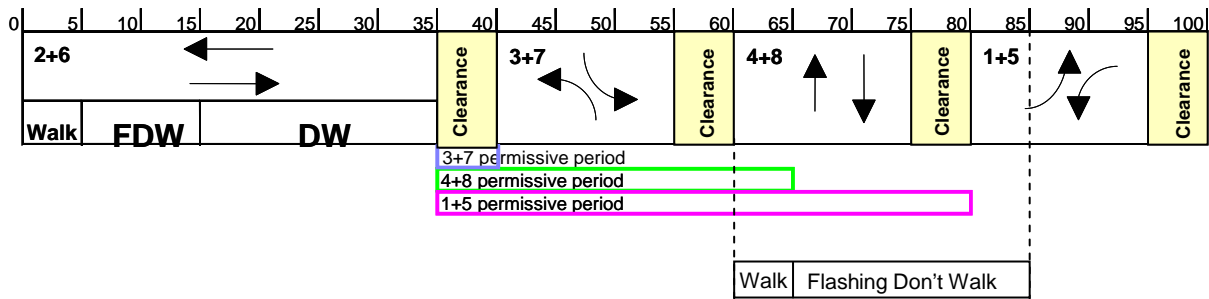


a.  Controller timed for optimum traffic demand even though pedestrian requirement is higher than traffic demand.
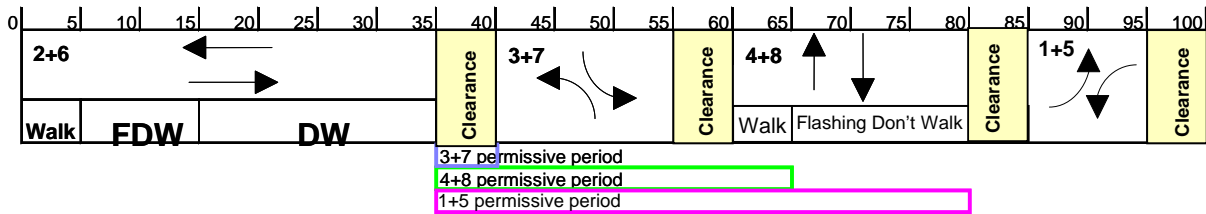


b.  Controller accommodating the higher pedestrian requirement.

**Figure 15.  Accommodating High Pedestrian Requirements Using STOP IN WALK.**

As can be seen from Figure 15a, the controller can operate with optimum vehicular timing (for phases 4 and 8) even though pedestrian requirement is higher than the vehicular demand.  This can happen only if Stop in Walk is selected.  When there is a pedestrian call, the controller services the pedestrian timing by extending phases 4 and 8.  The controller goes out of coordination.  However, the controller services the motorists in an optimum manner for a

majority of the time.  Stop in Walk feature is useful for such conditions and should only be used when the pedestrian demand is low.  This prevents the controller from losing coordination frequently.  Using Shortway Transition (discussed in a later section) with Stop in Walk ensures that the controller loses coordination for a minimum duration.

*Walk Recycle*

Walk Recycle determines the pedestrian indications after the termination of pedestrian clearance for the coordinated phase.  There are six options for Walk Recycle.  Each of the option benefits pedestrians and non-coordinated phases to varying degree.  Walk Recycle options, when selected, are applicable for all patterns.  The six options for Walk Recycle are:

- No_Recycle: Walk will not be recycled until the controller reaches local zero.  This feature assists non-coordinated phases moderately, and its use depends on local policy.

- Immediate:  Walk will be immediately recycled after the pedestrian clearance.  This feature tends to assist pedestrians but in an undesirable manner.  This feature can cause confusion for pedestrians and can take the controller out of coordination; hence it is not desirable.

- $\Phi1256$_Inhibit:  This feature is applicable when $\Phi4$ & 8 are the main street.  Walk is inhibited during $\Phi1$, 2, 5, and 6 permissive periods.  This feature assists pedestrians and non-coordinated phases moderately.

- $\Phi3478$_Inhibit: This feature is applicable when $\Phi2$ & 6 are the main street.  Walk is inhibited during $\Phi3$, 4, 7, and 8 permissive periods.  This feature assists pedestrians and non-coordinated phases moderately.

- No_PED_Inhibit: This feature will allow Walk to come on when Pedestrian Omits are lifted on the coordinated phase.  This feature tends to help pedestrians more than other features without the undesirable characteristics of Immediate Walk Recycle.

- Never: This feature prevents Walk to come on until a cross street has been serviced.  Its use depends on local policy.  This feature tends to help cross-street traffic more than pedestrians during off-peak conditions.

Figure 16 illustrates the Walk recycle operation when there is no traffic on any conflicting phase, i.e., the controller is dwelling in the coordinated phases continuously. Typically, the Walk indication will recycle during light traffic conditions with the exception of Immediate Recycle.  As can be seen from Figure 16, Immediate Recycle alternates between Walk, Flashing Don't Walk, and Walk continuously, which is neither efficient nor elegant for pedestrians and motorists; hence, it is not recommended for use.  Use of other options is guided by local policy.

**Figure 16. Arterial Walk Recycle Operations When No Traffic Exists on Conflicting Phases.**

*Leave Walk Before*

The Leave Walk entry determines the termination of "Walk" when Walk has not been recycled yet. This option, when selected, is applicable for all patterns. There are two options for Leave Walk Before:

- Timed: In this case, Walk is terminated at the last possible time that it can be terminated so as to ensure that the cross-street traffic is serviced without any delay.

- On Demand: In this case, Walk is terminated as soon as a call is placed on a conflicting phase. Hence, it can terminate earlier than necessary, as well as terminate late into the signal phase, resulting in a delay to service the cross-street phase.

Figure 17 illustrates the functionality of Leave Walk. It is clearly seen that when Timed is selected, the Walk indication always terminates at a predetermined time even if there is no demand on a conflicting phase. This is consistent and services the cross-street traffic without unnecessary delay. On Demand option, on the other hand, terminates the Walk indication immediately after a call is received on a conflicting phase. This can result in inconsistent Walk

durations and, if the call from the conflicting phase comes late in the arterial phase, will delay servicing the conflicting phases. Leave Walk After is similar to Leave Walk Before except that it deals with leaving Walk after a Walk indication recycles.
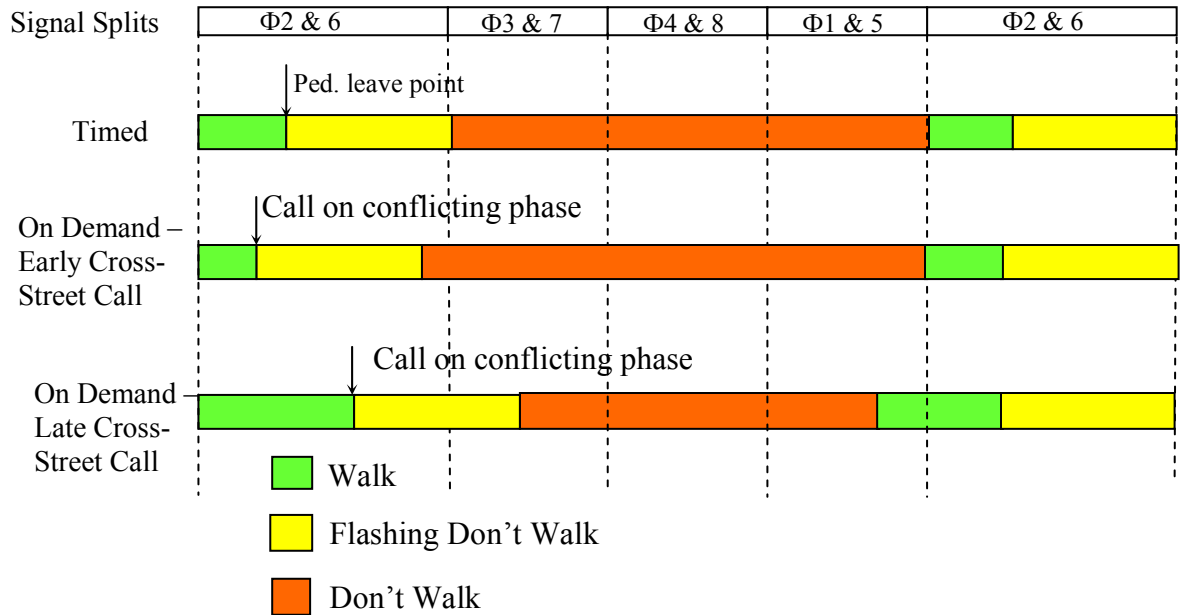


**Figure 17. Walk Termination during Leave Walk Before**

*Rest in Walk*

Rest in Walk allows the controller to rest in the Walk indication during the coordinated phase. This mode provides maximum opportunity for pedestrians to begin crossing the street. The walk and pedestrian clearance is timed such that the end of pedestrian clearance is at the phase force-off point to ensure that the conflicting phases are serviced without delay. Rest in Walk will not work if Walk Recycle is set to No_Recycle or Never. This is a very useful feature, which will improve operations at the intersections. It should be used in conjunction with the appropriate settings in Walk Recycle and Leave Walk. This feature, when selected, will be applicable for all patterns and all phases.

*Return Hold (Ret Hld)*

Return Hold places a hold on the coordinated phases so that they can only leave at the force-off point. It applies to only the fixed and floating force-off modes. Not using Return Hold allows the coordinated phase to gap out. This feature, when selected is applicable for the pattern selected. A typical example is the behavior of the coordinated phase during light traffic conditions which is described as follows:

- A single vehicle call is received on phases 3 and 7 while the controller is in the coordinated phases.

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- No calls are received on phases 4 and 8 and on phases 1 and 5.

- Phases 2 and 6 terminate at the force-off point and service phases 3 and 7.

- Since there are no calls on phases 4 and 8 and on phases 1 and 5, controller reverts back to phases 2 and 6 after servicing the minimum for phases 3 and 7 even if there is no demand on phases 2 and 6.

- Then a vehicle places a call on phases 1 and 5 while the controller is dwelling in phases 2 and 6.

- Ret Hld has an impact on what the controller does at this point of time.

- If Ret Hld is not selected, phases 2 and 6 gap out and the controller services phases 1 and 5 as long as the controller can get back to the beginning of phases 2 and 6 on time. Thus phases 1 and 5 are not delayed excessively during an off-peak time.

- On the other hand if Ret Hld is activated, phases 2 and 6 will not gap out until their force-off point resulting in phases 1 and 5 not being serviced for another cycle.

- The choice to use this feature is a policy decision. However, not selecting Ret Hld does present some unusual phasing sequences.

*Minimum Permissive (Vehicle/Pedestrian)*

This parameter can be selected for each pattern. Enabling this feature prevents a late call on a phase (very close to the force-off point), by either a vehicle or a pedestrian, to be serviced immediately causing the controller to temporarily lose coordination and delaying service to the non-coordinated phases (Figure 18). These late calls will be serviced whenever the coordinated phases come back on. Minimum Permissive (v/p), when selected, is applicable on a pattern basis.

*Coord Yield*

Coord Yield is applicable under very unique conditions. It is applicable when operating lead-lag phasing for the coordinated phases under very light traffic conditions. It minimizes the delay of the controller to return to the coordinated phase. Figure 19 illustrates the methodology of Coord Yield. The phasing sequence starts with phases 1 and 6 followed by phases 2 and 6 and phases 2 and 5. If after servicing phases 2 and 5, there are no calls on the cross-street, the controller can revert back to phases 2 and 6.

As can be seen from Figure 19, the permissive period of phase 6 does not start until the initiation of phases 3 and 7. However, if phase 5 gaps out after servicing only the minimum time phase 6 cannot come on until the beginning of the phase 6 permissive period. Programming a negative value of Coord Yield allows phase 6 to come on earlier than its normal permissive period. As mentioned earlier, of Coord Yield can only be used is in very unique situations and hence should be used judiciously. This feature is applicable for all patterns.
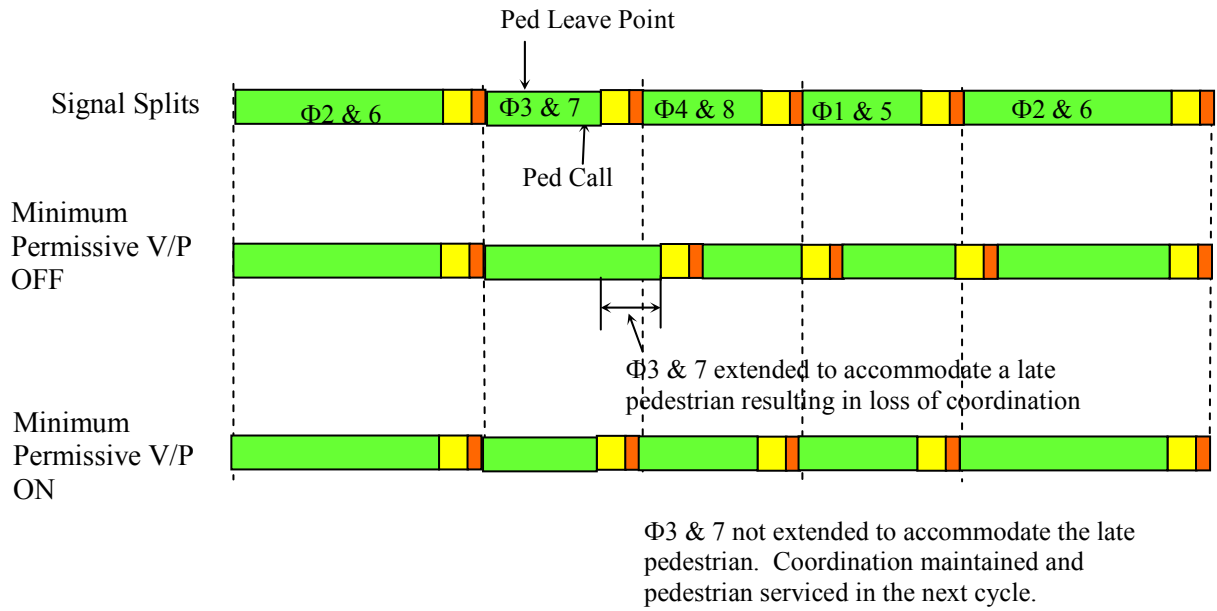
Figure 18.  Functionality of Minimum Permissive V/P.
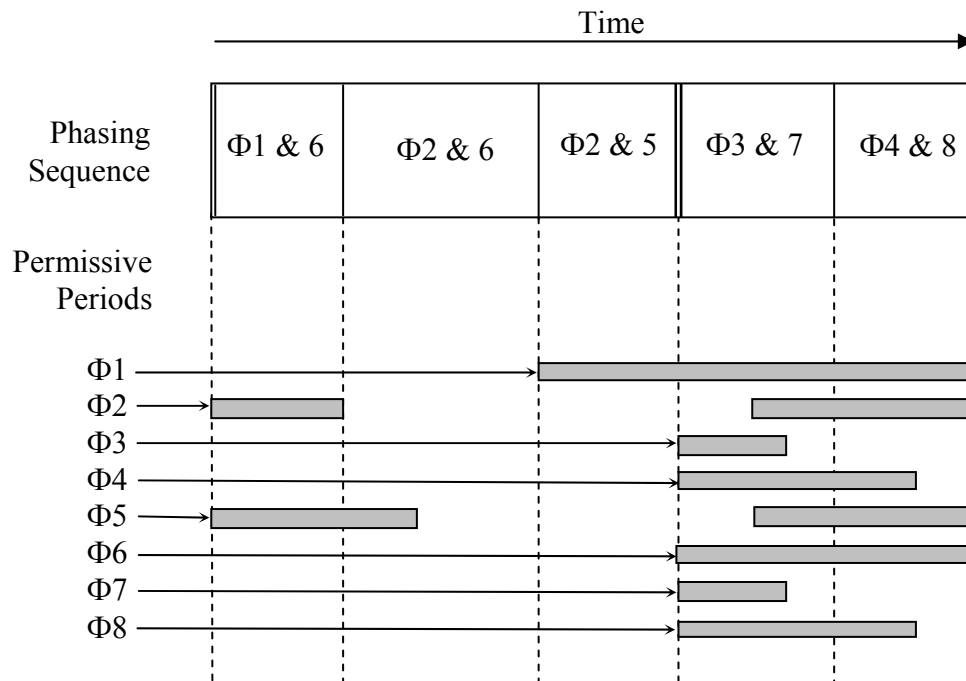


Figure 19.  Illustration of Coord Yield.

**Correction Modes**

Correction modes are used to move the controller from one pattern to another or from free mode of operations to a coordinated pattern. The controller is not in coordination for the duration of the correction. Hence the objective of selecting the appropriate correction mode is to minimize the duration of correction and to minimize disruption to all motorists. These two objectives may counteract each other; hence, it is essential to select the mode that is least disruptive to the intersection as well as arterial operations. While Eagle and Naztec controllers have some similarities in their modes, there are also some differences. This section describes these coordination modes.

*EPAC 300 Eagle Controller*

The Eagle controller has five different modes of correction. The correction mode selected will apply for all patterns and not for individual patterns. The five modes of correction in Eagle are described below.

*Dwell*

During the Dwell mode, the controller rests in the coordinated phase until the correction is made. This however causes excessive delays to the non-coordinated phases and is undesirable.

*Max Dwell*

Max Dwell functions similarly to the Dwell correction mode. The controller rests in the coordinated phase to achieve coordination; however, the controller can rest only for the time specified as the Dwell time. This mode causes less disruption to the non-coordinated phases than the Dwell mode.

*Shortway*

The Shortway correction mode's objective is to achieve coordination in the quickest fashion. The mode either shortens the split times for all phases or lengthens the coordination phase to correct the offset. The mode chooses a path to ensure that the correction is never over 50 percent and the cycle length never changes over 18.75 percent. The controller, when shortening the split times, also estimates the number of cycles required to achieve coordination. If the number of cycles required is five or greater, the mode lengthens the coordinate phases instead of shortening all the phases. This mode is the most widely used correction mode.

*Shortway+*

The Shortway+ mode achieves correction by adding time to the coordinated phase such that the cycle length doesn't change by over 18.75 percent. After the dwell period, the remaining phases are timed, and the process is repeated until correction is complete.

*Shortway-2*

The Shortway-2 mode achieves correction similar to Shortway except that when going long (adding time), the time is added to all phases in proportion of their split instead of adding time only to the coordinated phase.

**Naztec Controller**

The Naztec controller features three correction modes and allows the user to specify the percentage of time by which the correction takes place. The controller also has a feature to exempt some phases from the correction process. In the Naztec controller, the choice of correction mode can be made for each coordination pattern. The correction modes available on the Naztec controller are described below.

*Short (Shortway)*

The Short field sets the percentage reduction in the split time for all phases during transition. This value ranges from 0 to 24 percent. Programming a value of 0 percent disables the Shortway transition. The controller diagnostics however use the percentage entered to ensure that the minimum phase times are guaranteed when the Shortway transition is applied. Shortway transition is an excellent tool to use in conjunction with the Stop-In Walk feature discussed earlier.

*Long (Long way)*

The Long field sets the percentage increase or extension in the split time for each phase during transition. Its value ranges from 0 to 99 percent. Long way is disabled when a value of 0 percent is programmed. It is possible to use only Shortway by programming a 0 percent value for Long way. It is, however, advisable to program both Shortway and Long way to enable the controller to select the quickest path to reach coordination. TxDOT's TS-2 specifications suggest lengthening or shortening the cycle length by up to 20 percent (9).

*Dwell*

The Dwell correction mode is activated when a value of 0 percent is entered for Shortway and Long way and a value for Dwell is programmed. The Dwell method corrects the offset by resting in the coordinated phase until the desired offset is reached or the Dwell time has expired. Increasing the Dwell value reduces the number of cycles required to correct, but it also causes excessive delays to the motorists on the non-coordinated phases.

Naztec also uses a parameter called No Short Φs. This feature permits the user to identify up to four phases, which will not be shortened when the Short-Way correction mode is being used. This ensures that a pattern with small split times for some phases can still use the Short-Way correction without modifying the splits with small times.

**Offset Reference**

Both Eagle and Naztec controllers allow the offset to reference either the beginning of arterial green or the end of arterial green. The selection is based on local policy and has no direct impact on operations.

**Maximum Mode**

Both Eagle and Naztec offer a Maximum Mode feature. Those using the Maximum Mode feature can select from Max 1, Max 2, and Max Inhibit. Selecting Max 1 or Max 2 places an upper limit on the duration of the phase or split in the pattern equal to Max 1 or Max 2, respectively. On the other hand, selecting the Max Inhibit feature does not place any constraints on the duration of the phases.

There are no compelling reasons to use a particular choice of Maximum Mode when using the Eagle Controller. Local policy can be a guide. However, the choice of Maximum Mode has an impact on operations when using Naztec controllers. Selecting the Max Inhibit mode prevents the use of floating force-off mode in Naztec controllers. Hence, the user should select either Max 1 or Max 2 as the Maximum Mode. The user will also have to make sure that the maximum values are larger than the phase timings for all the patterns being used. Attention will also have to be given to the value placed on the Long way correction mode. The values in Max 1 or Max 2 should be large enough to accommodate the increase in the size of the splits during correction.

**Dynamic Split**

Dynamic Split, also called Coordinated Adaptive Split (CAS) in the Eagle controller (7) and Critical Intersection Control (CIC) in the Naztec controller (8), can modify the actual splits for the non-coordinated phases while maintaining coordination. Dynamic Split works by taking some time (a very small interval) from a non-coordinated phase that is gapping out and adding a non-coordinated phase that is being forced off consecutively. This feature changes the splits gradually and reverts back gradually to the original splits if the traffic patterns change. This feature is discussed and evaluated in more detail in an earlier report for TxDOT and will not be discussed here (10).

# EVALUATION AND IMPLEMENTATION

The advance features discussed earlier were tested and evaluated in the TransLink® laboratory at the Texas Transportation Institute. The TransLink® laboratory is a state-of-the-art facility at TTI that is equipped for conducting advanced research in traffic signal control equipment. The TransLink® laboratory has equipment from multiple vendors, including the Eagle and Naztec signal controller units. The laboratory also has numerous signal controller cabinets and testing equipment like the Hardware-in-the-Loop Traffic Simulation System (*13*).

## Development of Hardware-in-the-Loop Testing

Hardware-in-the-loop (HITL) traffic simulation is a technology where a microscopic traffic simulation model is connected to one or more real traffic signal controllers that interact with the simulation model. The connection is established through a controller interface device (CID). The simulation model operates in real time and simulates the movement of vehicles over detectors. The resulting detector actuations are then sent to the signal controller(s) through the CID. The controller reacts to the detector inputs in the same way as if controlling a real interchange, by changing signal phases as needed. The phase status is then returned from the controller to the simulation model, where the simulated vehicles react to the phase indications by stopping or going as appropriate. Figure 20 shows the flow of data between the simulation model and the traffic signal controller, while Figure 21 shows a typical hardware-in-the-loop simulation setup used for evaluating controller features (*10*).

This research project used CORSIM simulation model (*11*). Using the TransLink's Hardware-in-the-Loop Traffic Simulation System allowed the internal CORSIM signal control logic to be replaced with the actual controller hardware on which the features to be tested were implemented.

### *Off-peak and Peak*

HITL testing was developed for evaluating the coordination features during off-peak and peak conditions. While some features will only be tested during off-peak (transition modes), some will be tested only during peak conditions (force-off conditions); some will be tested in both off-peak and peak conditions (coordination modes). Volumes available for a five-intersection network were obtained from the City of College Station, Texas. This network exhibited a variety of geometric features and researchers estimated it to be representative of the arterials in the state. Figure 22 illustrates the network layout, and Table 1 and Table 2 illustrate the volumes used in the network.
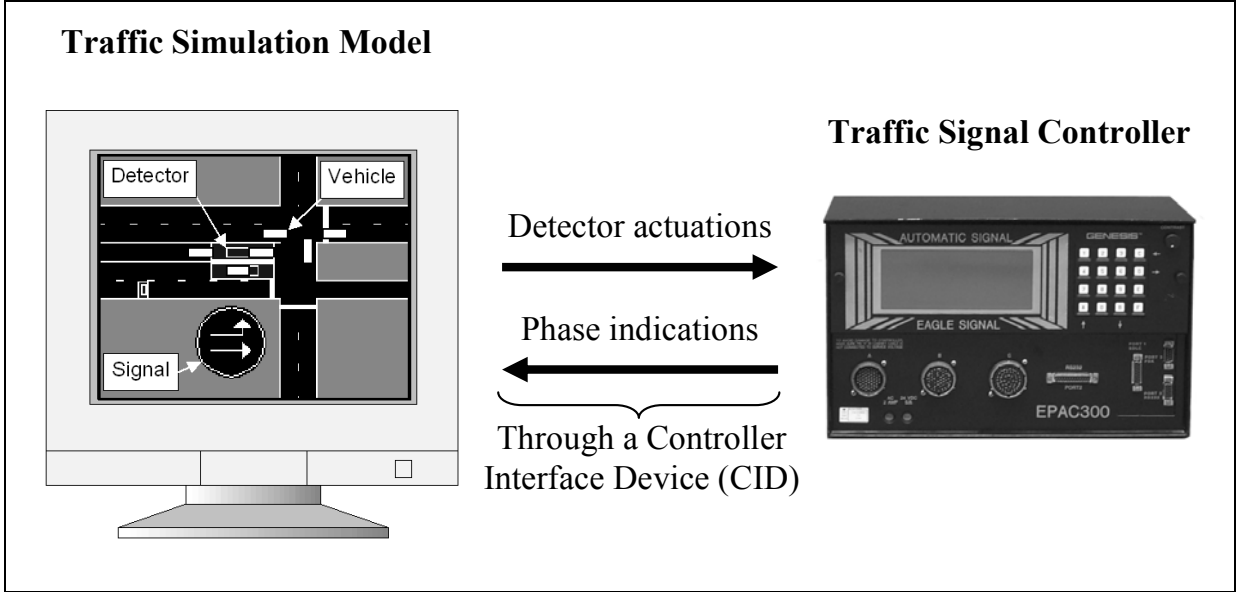
**Figure 20. Flow of Data during a Hardware-in-the-Loop Simulation.**
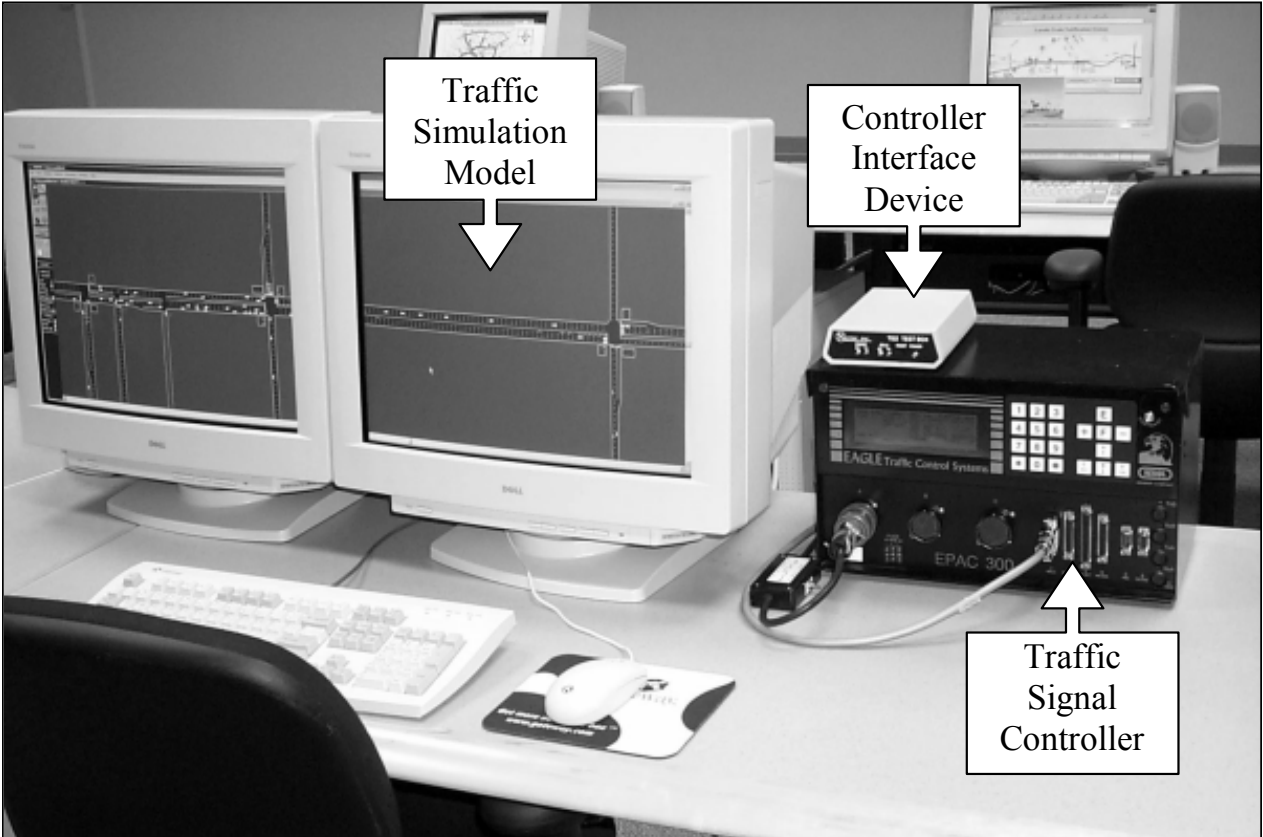


**Figure 21. Typical Hardware-in-the-Loop Simulation Setup.**
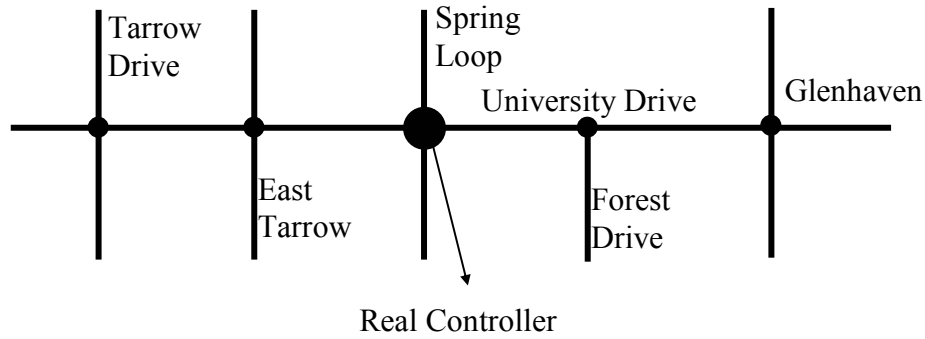
**Figure 22. Network Layout for HITL.**

**Table 1. Peak Volumes for the Network.**

| Intersection | Eastbound | | | Westbound | | | Northbound | | | Southbound | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Left | Through | Right | Left | Through | Right | Left | Through | Right | Left | Through | Right |
| | | | | | | | | | | | | |
| Tarrow | 78 | 379 | 36 | 33 | 1496 | 61 | 72 | 196 | 24 | 56 | 121 | 102 |
| E Tarrow | 64 | 378 | 17 | 62 | 1419 | 128 | 72 | 147 | 64 | 62 | 78 | 99 |
| Spring Loop | 22 | 473 | 9 | 168 | 1324 | 231 | 238 | 128 | 78 | 280 | 260 | 47 |
| Forest Drive | | 766 | 65 | 30 | 1698 | | 25 | | 30 | | | |
| Glenhaven | 29 | 682 | 85 | 157 | 1641 | 6 | 80 | 1 | 45 | 1 | 1 | 7 |

**Table 2. Off-Peak Volumes for the Network.**

| Intersection | Eastbound | | | Westbound | | | Northbound | | | Southbound | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Left | Through | Right | Left | Through | Right | Left | Through | Right | Left | Through | Right |
| | | | | | | | | | | | | |
| Tarrow | 280 | 1209 | 77 | 66 | 995 | 45 | 75 | 50 | 96 | 133 | 129 | 371 |
| E Tarrow | 280 | 1083 | 75 | 25 | 821 | 95 | 100 | 75 | 75 | 125 | 120 | 185 |
| Spring Loop | 50 | 1216 | 17 | 74 | 866 | 184 | 27 | 91 | 67 | 145 | 41 | 48 |
| Forest Drive | | 1388 | 40 | 20 | 1084 | | 40 | | 20 | | | |
| Glenhaven | 115 | 1228 | 65 | 86 | 968 | 35 | 91 | 19 | 45 | 43 | 15 | 45 |

Based on the traffic volumes, researchers developed optimum signal timings for the peak volumes and off-peak volumes. It was essential to use optimum signal timings to evaluate the coordination features. This ensured a fair evaluation of the impact of the coordination features being tested. The optimization process yielded cycle lengths of 110 seconds and 100 seconds, respectively, for the peak and off-peak periods. These optimum timings were coded in CORSIM for all intersections except for Spring Loop. The signal timings for the Spring Loop intersection were coded into a traffic signal controller. Table 3 and Figure 23 illustrate the signal timings and phasing sequence used at Spring Loop.

**Table 3.  Signal Timings at Spring Loop Intersection.**

|  | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 | Phase 6 | Phase 7 | Phase 8 | Offset | Alternate Sequence |
|---|---|---|---|---|---|---|---|---|---|---|
|  | **EB Left** | **WB Thru** | **NB** | **SB** | **WB Left** | **EB Thru** | **Omit** | **Omit** |  |  |
| Min Grn | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |  |  |
| Passage | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |  |  |
| Max 1 | 25 | 35 | 25 | 35 | 25 | 35 | 25 | 35 |  |  |
| Yellow | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |  |  |
| All-Red | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |  |  |
| Walk |  | 7 | 3 | 3 |  | 7 |  |  |  |  |
| FDW |  | 12 | 21 | 21 |  | 13 |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
| 2/1/1 | 15 | 45 | 26 | 24 | 15 | 45 | Omit | Omit | 0 | 1 |
| 4/2/1 | 15 | 46 | 15 | 24 | 15 | 46 | Omit | Omit | 0 | 1 |
|  |  |  |  |  |  |  |  |  |  |  |
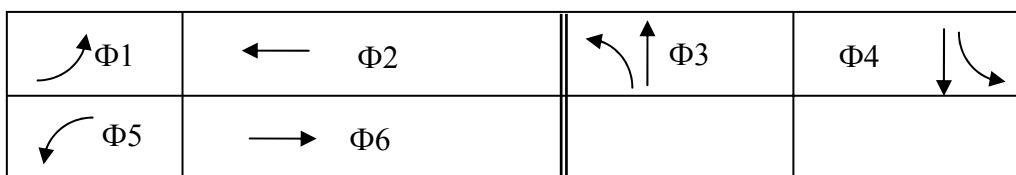


**Figure 23.  Phasing Sequence at Spring Loop Intersection.**

As mentioned earlier, researchers decided to make five simulation runs to test each coordination feature.  Random seed numbers in Card Type 2 in the CORSIM input files were changed for these five runs to generate the following randomness:

- Entry 5 – variation for entry headway,

- Entry 18 – variation in the routing pattern of each vehicle and characteristics of driver/vehicle combination, and

- Entry 19 – variation in responses to traffic choices (accepting gaps in traffic and lane blockages).

Introducing this randomness provided a means to evaluate a feature under typical conditions with adequate randomness to capture the normal variation in traffic conditions.

***Travel Time Measurements Using Buses***

It was necessary to evaluate the impact of various coordination features on travel time along the arterial.  Since HITL was being used to evaluate the various features, travel time was evaluated by using a bus route along the entire length of the arterial.  Using buses along a bus

route on the arterial gives the opportunity to obtain the travel time and the stop time in each of the individual links of the arterial. This level of discrepancy facilitates an understanding of the travel time profile in each individual link.

In a one hour simulation, 40 buses were coded to travel along the arterial to give an adequate sample size to evaluate the impact on travel time. Bus frequency was also calculated to devise bus arrival patterns that ensured that the buses would arrive at different points in the cycle. This enabled a thorough evaluation of the travel time, assuming random arrivals of buses. For the purpose of these simulation runs, a headway of 87 seconds was used to mimic the random arrivals of buses.

*Pedestrian Delay Estimation*

Many of the coordination modes have an impact on pedestrian service. While some of the modes dwell in Walk, others just provide the programmed duration of Walk. To quantify the delay experienced by pedestrians, a utility called PedSim was used. PedSim, when used in conjunction with HITL, places pedestrian calls on the traffic signal controller. PedSim can be configured to place pedestrian calls on specific phases and pedestrian volumes. During HITL evaluation of the coordination modes, PedSim was configured to place 100 pedestrian calls on phases 2 and 6.

**Hardware-in-the-Loop Testing**

Researchers performed HITL testing to evaluate the coordination features. EPAC 300 Eagle and Naztec 980 series controllers were evaluated. The firmware version tested in Eagle controller and Naztec controllers was 3.32k and 980 v50.34F. Each simulation was run for 60 minutes. However, the total simulation was much longer and illustrated in Table 4.

**Table 4.  Components of a Simulation Run.**

| Interval | Duration | Function | Comment |
|---|---|---|---|
| 1 | 3 minutes | Initialization | Initialize the simulation model |
| 2 | 3 minutes | Reset queues with no input volumes | Reset queues formed during initialization so that when simulation starts, there are no queues. |
| 3 | 60 minutes | Simulation | Perform simulation |
| 4 | 15 minutes | Queue dissipation with no input volumes | Capture the delay experienced by vehicles and queues generated during simulation |

Table 4 illustrates that each simulation run takes over 81 minutes to run.  A similar process was used to create the simulation input file for testing all coordination features.  The next section describes the methodology used to make HITL simulation runs.

*Synchronize Real Controller with CORSIM Controllers*

One of the challenges of using a real controller along with a CORSIM controller in the HITL simulation is to ensure that the real controller and the CORSIM controllers are coordinated with each other.  To do that requires a thorough understanding of the functionality of coordinators in the real controllers and in CORSIM.  This section describes the procedure used to synchronize the real controller with the controllers in CORSIM.

In CORSIM, the yield point (offset) of a traffic signal is referenced to the start of simulation time (including the initialization period).  This means that the onset of local zero, which is the coordinator reference point, depends on when the simulation starts.  Let us take the case of our CORSIM file:

Initialization time     =     3 minutes

                        =     180 seconds

Cycle length            =     100 seconds

Simulation start time   =     8:00:00AM

Hence, at the start of the simulation time at 8:00:00 AM, the coordinator of CORSIM controller is at 80 seconds (180 – 100).

Hence, after the start of simulation, the local coordinator is at local zero for the first time at 8:00:20, i.e., 8:00:00 + (100 – 80) seconds.

Next, an examination of the coordinator of the real controller revealed that the coordinator in the real controller resets at midnight.  The behavior of the coordinator throughout the day is such that the local zero is always at a multiple of the cycle length in progress.  Hence, this means that in a real controller, the cycle length guides the onset of the local zero with respect to the actual clock time.  Table 5 illustrates the onset of the local zero at the real clock time for two cycle lengths of 100 seconds and 110 seconds.

The discussion so far illustrates the differences between the CORSIM controller and the real controller in the manner of the onset of the local zero.  To summarize:

- The onset of the local zero in the CORSIM controller depends on when the simulation starts and is a multiple of the cycle length from the start of simulation.

- The onset of the local controller in the real controller depends on the cycle length in use and is a multiple of the cycle length from midnight irrespective of the cycle lengths used until then.

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- To synchronize the real controller with the CORSIM controller, the local zero of the real controller and the CORSIM controller for the intersection in question (Spring Loop, in our case) need to coincide.

**Table 5.  Local Zero Times for a Real Controller.**

| Cycle Length Cycle # | 100 Secs Local Zero | Time | 110 Secs Local Zero | Time |
|---|---|---|---|---|
| 1 | 100 | 0:01:40 | 110 | 0:01:50 |
| 2 | 200 | 0:03:20 | 220 | 0:03:40 |
| 3 | 300 | 0:05:00 | 330 | 0:05:30 |
| 4 | 400 | 0:06:40 | 440 | 0:07:20 |
| 5 | 500 | 0:08:20 | 550 | 0:09:10 |
| 6 | 600 | 0:10:00 | 660 | 0:11:00 |
| 7 | 700 | 0:11:40 | 770 | 0:12:50 |
| 8 | 800 | 0:13:20 | 880 | 0:14:40 |
| 9 | 900 | 0:15:00 | 990 | 0:16:30 |
| 10 | 1000 | 0:16:40 | 1100 | 0:18:20 |
| 11 | 1100 | 0:18:20 | 1210 | 0:20:10 |
| 12 | 1200 | 0:20:00 | 1320 | 0:22:00 |
| 13 | 1300 | 0:21:40 | 1430 | 0:23:50 |
| 14 | 1400 | 0:23:20 | 1540 | 0:25:40 |
| 15 | 1500 | 0:25:00 | 1650 | 0:27:30 |
| 16 | 1600 | 0:26:40 | 1760 | 0:29:20 |
| 17 | 1700 | 0:28:20 | 1870 | 0:31:10 |
| 18 | 1800 | 0:30:00 | 1980 | 0:33:00 |
| 19 | 1900 | 0:31:40 | 2090 | 0:34:50 |
| 20 | 2000 | 0:33:20 | 2200 | 0:36:40 |
| 269 | 26900 | 7:28:20 | 29590 | 8:13:10 |
| 270 | 27000 | 7:30:00 | 29700 | 8:15:00 |
| 271 | 27100 | 7:31:40 | 29810 | 8:16:50 |
| 272 | 27200 | 7:33:20 | 29920 | 8:18:40 |
| 273 | 27300 | 7:35:00 | 30030 | 8:20:30 |
| 274 | 27400 | 7:36:40 | 30140 | 8:22:20 |
| 275 | 27500 | 7:38:20 | 30250 | 8:24:10 |
| 276 | 27600 | 7:40:00 | 30360 | 8:26:00 |
| 277 | 27700 | 7:41:40 | 30470 | 8:27:50 |
| 278 | 27800 | 7:43:20 | 30580 | 8:29:40 |
| 279 | 27900 | 7:45:00 | 30690 | 8:31:30 |
| 280 | 28000 | 7:46:40 | 30800 | 8:33:20 |
| 281 | 28100 | 7:48:20 | 30910 | 8:35:10 |
| 282 | 28200 | 7:50:00 | 31020 | 8:37:00 |
| 283 | 28300 | 7:51:40 | 31130 | 8:38:50 |
| 284 | 28400 | 7:53:20 | 31240 | 8:40:40 |
| 285 | 28500 | 7:55:00 | 31350 | 8:42:30 |
| 286 | 28600 | 7:56:40 | 31460 | 8:44:20 |
| 287 | 28700 | 7:58:20 | 31570 | 8:46:10 |
| 288 | 28800 | 8:00:00 | 31680 | 8:48:00 |
| 289 | 28900 | 8:01:40 | 31790 | 8:49:50 |
| 290 | 29000 | 8:03:20 | 31900 | 8:51:40 |
| 291 | 29100 | 8:05:00 | 32010 | 8:53:30 |
| 292 | 29200 | 8:06:40 | 32120 | 8:55:20 |
| 293 | 29300 | 8:08:20 | 32230 | 8:57:10 |
| 294 | 29400 | 8:10:00 | 32340 | 8:59:00 |
| 295 | 29500 | 8:11:40 | 32450 | 9:00:50 |
| 296 | 29600 | 8:13:20 | 32560 | 9:02:40 |
| 297 | 29700 | 8:15:00 | 32670 | 9:04:30 |
| 298 | 29800 | 8:16:40 | 32780 | 9:06:20 |

Synchronization of the real controller with the CORSIM controller for a simulation run using a single cycle length like during the force-off testing and Coordination modes testing is very simple.  The analyst needs to start the simulation at a local zero in the real controller.  This results in the coordinators for the real controller and the CORSIM controller moving in a synchronized manner.  This is done by observing the local clock and starting the simulation when the controller reaches local zero.

Testing of Transition modes is more complicated since it involves a change in cycle length during the simulation.  Local zero for the real controller and CORSIM has to coincide before and after the transition for the controllers to be in sync.  CORSIM has a different methodology to transition from one pattern (Pattern A) to the other (Pattern B).  The CORSIM coordinator uses the last local zero for Pattern A as the reference point, and the local zero in Pattern B is calculated as a multiple of the cycle length in Pattern B with reference to the last local zero for Pattern A.  The controller basically dwells in the coordinated phase until it reaches a local zero for Pattern B.

The research team made a decision to change from Pattern A with a cycle length of 100 seconds to Pattern B with a cycle length of 110 seconds about 15 minutes into the simulation.  That would be close to 8:18 AM in the simulation clock as there is a three minute window of no traffic demand as illustrated in.  Since the simulation process also includes a three minute initialization window, at least a total window of 21 minutes is required to operate the signal controller in Pattern A with a cycle length of 100 seconds.

21 minutes = 1260 seconds

To be in sync with a cycle length of 100 seconds, the CORSIM simulation model will have to start 1300 seconds (nearest multiple of 100 seconds greater than 1260) before a change in pattern is made in the real controller.

1300 seconds = 21 minutes and 40 seconds

The next parameter to be considered is the time at which Pattern A should change to Pattern B in the real controller.  The time at which it should happen should be a local zero for both Pattern A and Pattern B.  Reviewing Table 5, it is seen that 8:15:00 is a common local zero for both patterns.  Hence, the real controller was programmed to change from Pattern A to Pattern B at 8:15 AM.

Using the calculation made earlier, it was determined that the CORSIM simulation should start 21 minutes 40 seconds before 8:15 AM, which translates to starting the CORSIM simulation at 7:53:20 AM.  Table 6 illustrates the process of synchronizing the CORSIM controller with a real controller during a transition with a change in cycle length.  A similar procedure can be followed to calculate a transition between other cycle lengths.  To summarize:

- Program the real controller to change from a 100 second cycle length to a 110 second cycle length at 8:15 AM.

- Set the clock in the real controller to 7:30 AM.

- Verify that the real controller is in Pattern A and has finished correcting.

- Start the simulation at 7:53:20 AM, which happens to be a local zero for a 100 second cycle length.

- The real controller and the CORSIM controller should be in sync in Pattern A.

- The real controller will change to Pattern B at 8:15 AM.

- After a few cycles of correction, it will be seen that the real controller is in sync again with the CORSIM controller.

**Table 6.  Illustration of Synchronizing Controllers during Transition.**

| Cycle Length | Local Zero Times | | |
|---|---|---|---|
| | Real Controller | CORSIM | |
| | 7:53:20 | 7:57:00 | ← Start of simulation |
| | 7:55:00 | 7:58:40 | (7:57:00 = 8:00 – 3 minutes |
| | 7:56:40 | 8:00:20 | for initialization) |
| | 7:58:20 | 8:02:00 | |
| | 8:00:00 | 8:03:40 | |
| | 8:01:40 | 8:05:20 | |
| 100 Seconds | 8:03:20 | 8:07:00 | |
| | 8:05:00 | 8:08:40 | |
| | 8:06:40 | 8:10:20 | |
| | 8:08:20 | 8:12:00 | |
| | 8:10:00 | 8:13:40 | |
| | 8:11:40 | 8:15:20 | |
| | 8:13:20 | 8:17:00 | |
| | 8:15:00 | 8:18:40 | |
| Correction | 8:16:50 | 8:20:30 | |
| | 8:18:40 | 8:22:20 | |
| | 8:20:30 | 8:24:10 | Change in pattern |
| | 8:22:20 | 8:26:00 | |
| 110 Seconds | 8:24:10 | 8:27:50 | |
| | 8:26:00 | 8:29:40 | |
| | 8:27:50 | 8:31:30 | |
| | 8:29:40 | 8:33:20 | |
| | 8:31:30 | 8:35:10 | |

*Statistical Analyses*

Researchers compared results from the HITL simulation runs to identify the features that would be different from the others.  For some features, a statistical analysis was warranted.  The purpose of a statistical analysis is to find out whether the controller operational features to be studied will produce significantly different results in system performance measures.

Two types of statistical analysis involved in this study include the student *t-statistical test* (t-Test) and the *analysis of variance* (ANOVA) *(14)*. The t-Test is used when comparison is made with two operational features, while ANOVA is used when comparisons are made across multiple features. Generally, multiple simulation runs with different random seeds are conducted for each operational feature, and the mean and standard deviation of a performance measure (e.g., delay, travel time) are calculated for each feature. The mean and standard deviation are the required input parameters for conducting both t-Test and ANOVA.

The basic information for conducting the t-Test includes the means and standard deviations from the two scenarios to be compared. Several computer software packages are available to conduct the t-Test analysis. In this study, the researchers used the statistical analysis tool embedded in Excel to perform the t-Test. The analysis tool in Excel requires the results from each individual runs and the software itself calculates the mean, standard deviation, and other statistical parameters. The software provides the results, as shown in Table 7.

**Table 7. An Example of Two-Sample t-Test.**

t-Test: Two-Samples Assuming Unequal Variances

|                              | Case 1   | Case 2 |
|------------------------------|----------|--------|
| Mean                         | 23.92    | 24.22  |
| Variance                     | 23.092   | 18.832 |
| Observations                 | 5        | 5      |
| Hypothesized Mean Difference | 0        |        |
|                              |          |        |
| Df                           | 8        |        |
| t Stat                       | -0.1036  |        |
| P(T<=t) one-tail             | 0.460017 |        |
| t Critical one-tail          | 1.859548 |        |
| P(T<=t) two-tail             | 0.920034 |        |
| t Critical two-tail          | 2.306006 |        |

For example, for the two cases compared, Case 1 has a mean value of 23.92, and Case 2 has a mean value of 24.22. The P-value (two-tail) is used to judge whether to reject the null hypothesis; i.e., the two cases have equal means. In this example, the P-value is 0.92, which is significantly greater than 0.05, the generally accepted criteria. Therefore, it can be concluded that the two cases compared have the same mean values.

For comparing multiple cases, researchers used the ANOVA analysis process. The method we selected for the ANOVA is called the Tukey's test. Similarly, ANOVA analysis requires the mean and standard deviation from each scenario to be compared. The P-values are calculated and tabulated with a matrix for all the scenarios to make conclusions on the difference in means following the same principle of the T-Test. ANOVA also calculates the P-value based on the multiple scenario comparison results to indicate whether any one pair of the scenarios has significantly different mean values.

*Force-offs*

Force-off mode was the first coordination feature to be tested. Force-off modes were tested and evaluated in an Eagle controller. The default mode in both Eagle and Naztec controllers was the floating force-off (Plan in Eagle). Five one-hour runs were made for the floating force-off mode and the fixed force-off mode. Some tools were developed to reduce the output file created by CORSIM. One of these tools facilitated extraction of delay experienced by the motorists at the intersection of Spring Loop (which is using the real controller). This delay was obtained for both the overall intersection as well as for each approach at the intersection.

Figure 24 illustrates the reduction in delay experienced by the intersection due to the use of fixed force-off. We can see that overall intersection delay decreased by about 50 percent from 68 seconds per vehicle to 32 seconds per vehicle with a standard deviation of about 4 seconds (illustrated by the vertical line in the bars). This reduction was obtained by just changing the force-off parameter from Floating to Fixed and without any change in the signal timing for the same traffic conditions.
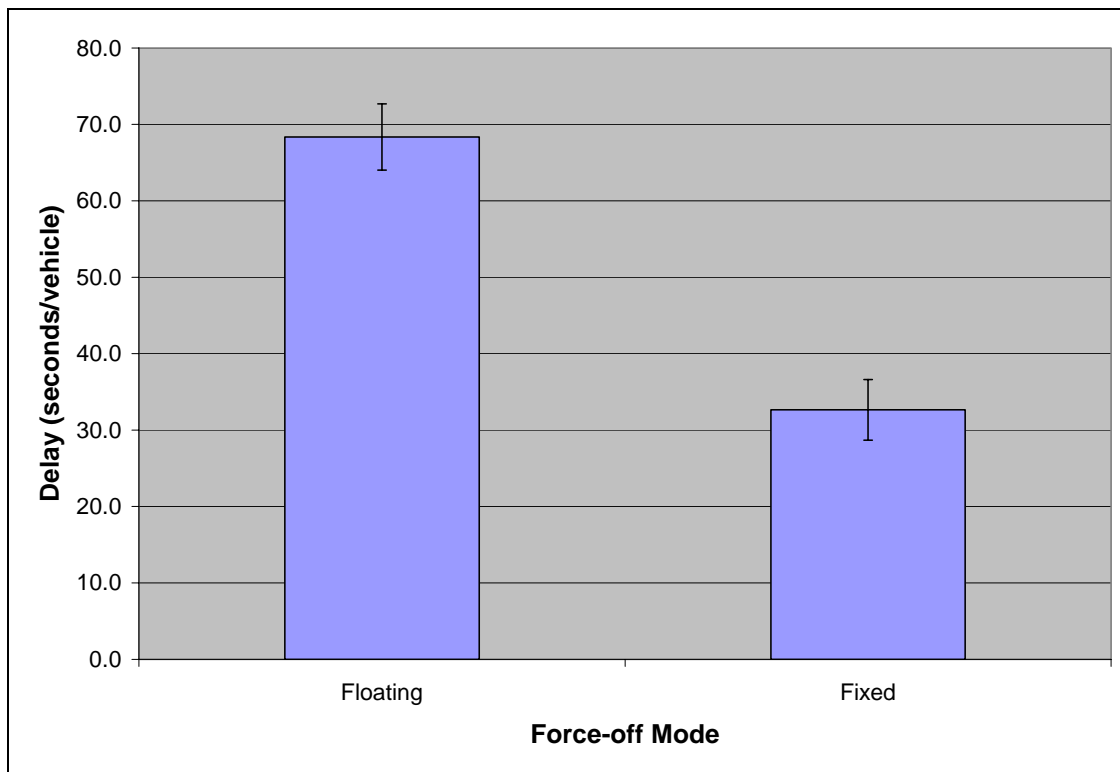


**Figure 24. Reduction in Overall Intersection Delay Due to Fixed Force-off.**

Figure 25 illustrates the change in delay experienced on an approach-by-approach basis. It is clearly seen that the southbound approach benefited significantly due to fixed force-off. The approach delay decreased from 290 seconds per vehicle to 79 seconds per vehicle, with only a marginal increase in the delays for the arterial approaches (eastbound and westbound). This is happening because the excess time available from the northbound approach is being utilized by the southbound approach instead of transferring to the arterial approaches.

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The southbound approach is also benefiting from the fixed force-off mode because it is the last phase in the phasing sequence, as illustrated in Figure 23. This reinforces the explanation described in the earlier section and as illustrated in Figure 6 and Figure 7.

Researchers conducted a study of the force-off modes in the Naztec controller. Some HITL simulation runs were made and compared with the HITL simulation runs made with the Eagle controller. It was observed that the functionality of force-off modes in Naztec was similar to Eagle, and hence, more simulation runs were not made. The findings of the force-off modes in the Eagle controller also apply to the Naztec controller.
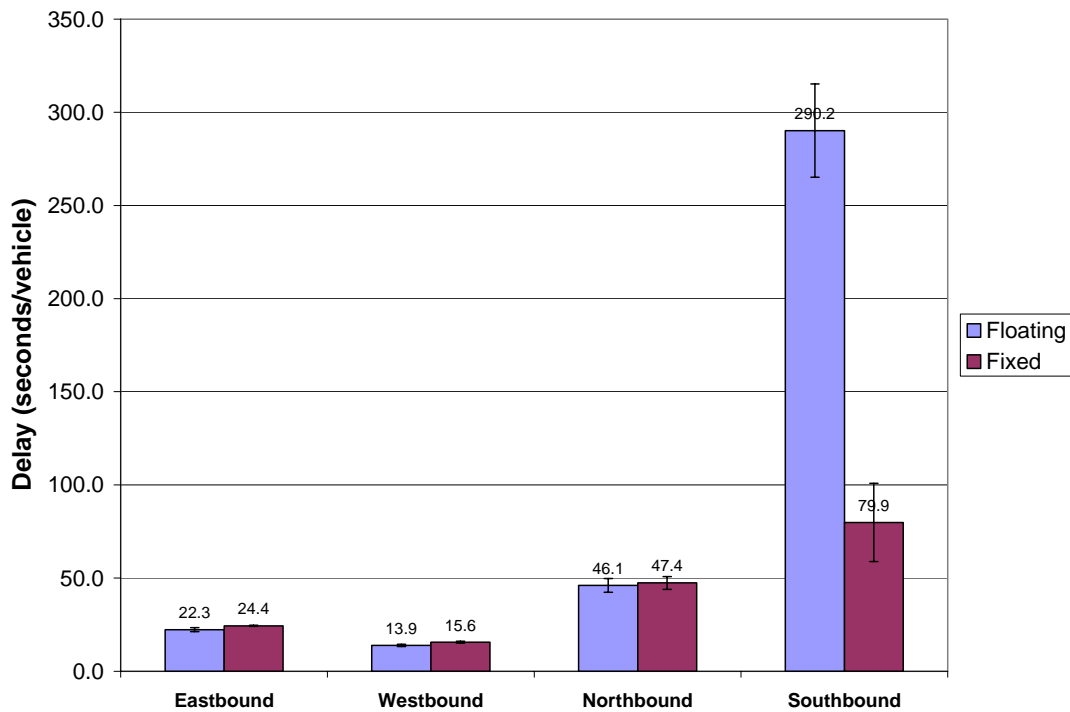


**Figure 25. Reduction in Approach Delay Due to Fixed Force-off.**

*Transition*

The next coordination feature to be tested was the transition mode. Once again, the modes in the Eagle controller were tested. HITL simulation was used to evaluate the various options in transition modes. These HITL simulation runs were made using off-peak volume conditions since transition between patterns is usually made during the off-peak conditions. Options tested in the Eagle controller were:

- Shortway,

- Shortway+,

- Shortway-2,

- Dwell, and

- Dwell with Int.

A maximum dwell of 60 seconds was used in the Dwell Int. Table 8 illustrates a comparison of the delays experienced by the motorists when testing the transition modes.

**Table 8. Comparison of Delay Experienced in Transition Modes in Eagle Controller.**

| | | East Bound | West Bound | North Bound | South Bound | Average Intersection Delay |
|---|---|---|---|---|---|---|
| **Dwell** | *Average* | 14.4 | 12.0 | 63.8 | 57.4 | 24.0 |
| | *StDEV* | 0.3 | 0.4 | 35.4 | 26.5 | 6.7 |
| **Dwell-Int** | *Average* | 14.2 | 12.3 | 48.8 | 45.0 | 21.1 |
| | *StDEV* | 0.3 | 0.6 | 1.9 | 1.9 | 0.4 |
| **Shortway** | *Average* | 14.8 | 12.5 | 47.8 | 45.1 | 21.2 |
| | *StDEV* | 0.5 | 0.5 | 2.9 | 1.5 | 0.4 |
| **Shortway-2** | *Average* | 14.9 | 12.3 | 48.9 | 45.4 | 21.3 |
| | *StDEV* | 0.5 | 0.2 | 1.8 | 1.5 | 0.3 |
| **Shortway+** | *Average* | 14.6 | 12.0 | 48.2 | 45.3 | 21.0 |
| | *StDEV* | 0.5 | 0.4 | 1.6 | 1.7 | 0.3 |

As can be seen, motorists on the northbound and southbound approaches experienced the most delay during the Dwell mode. The same delays also experienced a high level of standard deviation. The delays experienced in other modes were relatively uniform for all modes. Similarly travel time experienced by the motorists was also measured and is illustrated in Table 9. As can be seen in the table, there does not appear to be any noticeable difference in the travel time experienced between any of the transition modes for either the eastbound or the westbound traffic. The travel time is lower for westbound traffic because it is the direction of the peak traffic in the AM peak.

**Table 9. Comparison of Travel Time Experienced in Transition Modes in Eagle Controller.**

| **Direction** | | Travel Time | | | | |
|---|---|---|---|---|---|---|
| | | Dwell | Dwell-Int | Shortway | Shortway-2 | Shortway+ |
| EB | Average | 81.0 | 80.5 | 83.1 | 81.9 | 82.1 |
| | StDev | 1.1 | 1.6 | 1.3 | 1.5 | 1.7 |
| WB | Average | 72.1 | 73.0 | 72.2 | 71.6 | 72.3 |
| | StDev | 1.7 | 1.8 | 1.9 | 1.7 | 1.0 |

As described earlier, t-Test with the Tukey's test were conducted to analyze the delays experienced by motorists for the individual approaches as well as the overall intersection delay.

Similar tests were also made to evaluate the travel time along the arterial. The statistical analysis can be summarized as follows:

- There is no statistically significant difference between the various modes for the overall intersection delay. However, Dwell mode tends to increase the average delay for the intersection.

- There is no statistically significant difference in the delay experienced by various approaches. However, Dwell mode tends to increase the delay for the cross-street approaches.

- Dwell mode tends to favor the arterial approaches. However, there is no statistically significant difference in the travel time experienced between any of the transition modes.

- By concept, Shortway in the Eagle controller is designed to complete the transition process the quickest.

- The equivalent of Shortway in the Naztec controller is to program Short and Long with a percentage change not to exceed 17 percent. Up to four phases can be identified that are too small to be shortened so that they are not shortened further.

- Dwell causes the most disruption to the cross-street without any noticeable benefits to either the arterial approaches or the overall intersection.

- Use of other modes is based on local policies and priorities.

*Coordination Modes Features*

Coordination modes described in the earlier section vary from Eagle to Naztec controller. The coordination modes for the Eagle controller are very easy to select and operate. Each coordination mode has specific features and operates in a well-defined manner. The operation of these coordination modes cannot be changed. The only way they can be influenced is by changing the force-off modes or transition modes. The coordination modes in an Eagle controller are:

- Yield,

- Permissive,

- Permissive Yield,

- Permissive Omit,

- Sequential Omit, and

- Actuated Coordinated.

As mentioned in the earlier section, coordination modes in the Naztec controller do not meet the specified practice.  The user needs to calculate the force-off points and permissive periods.  Hence, they were not evaluated.  However, Naztec has numerous other coordination features that can be used to operate the signal controller in a manner similar to the coordination modes in the Eagle controller.  These features have a user-defined value and are not just features that are either turned off or on.  They can be turned on and then a value is specified for their manner of operation.  They are:

- Early Yield,

- Stop in Walk,

- Rest in Walk,

- Leave Walk Before,

- Return Hold,

- Minimum Permissive, and

- Coord Yield.

All the coordination modes were tested by using the HITL simulations.  They were tested in both the peak period and the off-peak period.  Similar to the HITL simulation runs of the other modes, five runs were made for each mode for each period.  Table 10 summarizes the operational characteristics of coordination modes in the Eagle controller.

**Table 10. Characteristics of Coordination Modes in Eagle Controller.**

| Mode | Dwell in Walk | Extend Coordinated Phase | Coordinated Phase Yields | Omit Early Return | Coordinated Phase Actuated |
|---|---|---|---|---|---|
| **Yield** | Yes (End Actuated) | No | To any phase | No | No |
| **Permissive** | Yes (End Fixed) | No | Only to next phase | No | No |
| **Permissive Yield** | No | Yes | Only to next phase | No | No |
| **Permissive Omit** | No | Yes | Only to next phase | Yes | No |
| **Sequential Omit** | No | Yes | To next phase but earlier | Somewhat | No |
| **Actuated Coordinated** | No | Yes | To any phase | No | Yes |

The HITL simulation runs made were reduced to estimate the average intersection delay, average approach delay, and arterial travel time. Table 11 illustrates the average intersection delay during off-peak conditions.

**Table 11. Average Intersection Delay Using Eagle Coordination Modes (Off-Peak).**

| Mode | Yield (Seconds) | Perm (Seconds) | Perm-Yield (Seconds) | Perm-Omt (Seconds) | Seq-Omt (Seconds) | Act-Coord (Seconds) |
|---|---|---|---|---|---|---|
| Average | 12.2 | 12.1 | 12.1 | 18.2 | 14.5 | 12.3 |
| StDev | 0.4 | 0.4 | 0.4 | 0.5 | 0.5 | 0.4 |

Table 11 illustrates that the average intersection delay is about 12 seconds, except for permissive omit and sequential omit. A statistical analysis was performed to see if the difference is significant. Table 12 illustrates the results of the analysis.

**Table 12.  ANOVA Results for Average Intersection Delay (Off-Peak).**

|  | Yield | Permissive Mode | Permissive Yield | Permissive Omit | Sequential Omit |
|---|---|---|---|---|---|
| **Permissive Mode** | No |  |  |  |  |
| **Permissive Yield** | No | No |  |  |  |
| **Permissive Omit** | Yes | Yes | Yes |  |  |
| **Sequential Omit** | Yes | Yes | Yes | Yes |  |
| **Actuated Coordinated** | No | No | No | Yes | Yes |

Table 12 illustrates that the average intersection delay experienced during Permissive Omit and Sequential Omit modes are significantly different from the other modes.  An analysis of the impact on individual approaches indicated the following:

- There was no statistically significant difference in the delay experienced by the cross-street approaches.

- There was a statistically significant difference in the delay experienced by the arterial approaches.

A significant characteristic of the Permissive Omit and Sequential Omit modes is that they omit the early return to the coordinated phase.  This factor appears to have a significant negative impact on the intersection delay.  To further estimate the impact of the coordination modes on arterial operations, arterial travel times were calculated and illustrated in Table 13. This table illustrates that the travel time experienced in the eastbound direction under Permissive Omit mode is much higher than the other modes.  This finding again lends to the premise that omitting the early return to the arterial phases is having a negative impact on the intersection as well as arterial operations.  Results of an ANOVA test however, indicated that the differences in travel time were not significantly different statistically.

**Table 13. Arterial Travel Time Using Eagle Coordination Modes (Off-Peak).**

| Direction | | Travel Time (Seconds) | | | | | |
|-----------|---------|-------|------|---------|---------|---------|-----------|
| | | Yield | Perm | Perm-Yld | Perm-Omt | Seq-Omt | Act Coord |
| EB | Average | 72.8 | 73.4 | 73.9 | 88.4 | 78.4 | 74.8 |
| | StDev | 0.7 | 1.8 | 2.1 | 2.0 | 1.6 | 1.1 |
| WB | Average | 75.1 | 74.7 | 73.4 | 74.4 | 74.4 | 73.7 |
| | StDev | 2.2 | 1.8 | 2.1 | 2.4 | 2.4 | 1.1 |

Hence the impact of the Eagle coordination modes on off-peak conditions can be summarized as follows:

- The delay experienced by the intersection and the arterial approaches during Permissive Omit and Sequential Omit is statistically significantly higher than other coordination modes.

- The travel time experienced by the arterial during Permissive Omit and Sequential Omit is higher than the other modes. However, the difference is not statistically significantly different from the other modes.

- Permissive Omit and Sequential Omit tend to increase the intersection delay, arterial approach delay, and arterial travel time.

HITL runs for the peak conditions were then analyzed. Table 14 illustrates the average intersection delay experienced during peak conditions.

**Table 14. Average Intersection Delay Using Eagle Coordination Modes (Peak).**

| Mode | Yield (Seconds) | Perm (Seconds) | Perm-Yield (Seconds) | Perm-Omt (Seconds) | Seq-Omt (Seconds) | Act-Coord (Seconds) |
|------|------|------|------|------|------|------|
| Average | 32.9 | 32.9 | 31.9 | 37.0 | 34.7 | 33.0 |
| StDev | 4.1 | 3.9 | 4.2 | 1.4 | 4.2 | 3.9 |

The table indicates that the delay experienced during Permissive Omit mode is higher than other modes. However, the ANOVA analysis indicated the differences in intersection delay between the various modes is not statistically significant. Upon comparing the delays experienced by each approach, researchers found that the arterial approaches experienced higher delays during the Permissive Omit and Sequential Omit modes and that these delays were statistically significantly different from the others.

An analysis of the arterial travel times indicated results that were similar to the off-peak conditions. Table 15 illustrates the arterial travel times experienced during the peak periods. It is clearly seen from the table that the travel time in the eastbound direction during the Permissive Mode is much higher than the other modes. This difference was also found to be statistically significant.

**Table 15. Arterial Travel Times Using Eagle Coordination Modes (Peak).**

| Direction | | Travel Time (Seconds) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Yield | Perm | Perm-Yld | Perm-Omt | Seq-Omt | Act Coord |
| EB | Average | 86.7 | 86.8 | 89.5 | 102.4 | 92.9 | 90.0 |
| | StDev | 2.2 | 2.2 | 3.2 | 2.1 | 2.6 | 3.2 |
| WB | Average | 74.3 | 74.6 | 75.0 | 83.0 | 77.9 | 75.1 |
| | StDev | 1.0 | 1.0 | 1.4 | 1.7 | 1.7 | 0.8 |

Hence, the use of Eagle coordination modes during the peak periods can be summarized as follows:

- Permissive Omit and Sequential Omit modes tend to increase the average intersection delay and the arterial approach delays.

- The arterial approach delays for the Permissive Omit and Sequential Omit modes are statistically significant from the other modes.

- The travel in the east-bound (off-peak direction) is significantly higher than the other modes.

- Permissive Omit and Sequential Omit tend to increase the intersection delay, arterial approach delay, and arterial travel time.

Finally, an evaluation of the impact of the coordination modes was done. The PedSim tool was used to place 100 pedestrian calls during the simulation periods. A logger application was utilized to detect and time stamp the pedestrian calls, the onset of Walk, the onset of Pedestrian Clearance, and the onset of Don't Walk. This process was repeated for all coordination modes. The logger files were analyzed with a tool to estimate the delay experienced by the pedestrians. Delay experienced by a pedestrian is defined as the time between the onset of a pedestrian call and the onset of the Walk duration. Pedestrian calls received during the Walk were ignored.

Figure 26 illustrates the impact of the various Eagle coordination modes on pedestrian service. The primary Y-axis illustrates the total delay experienced by the pedestrians during the simulation period. As can be seen from the figure, pedestrian delay is significantly lower during Yield and Permissive modes. The secondary Y-axis illustrates the number of pedestrian calls to be serviced. As can be seen, the number of pedestrian calls is also significantly lower during Yield and Permissive modes. This is because the pedestrian phase dwells in the Walk indication in the Yield and Permissive modes. This results in fewer pedestrian calls to be serviced and less pedestrian delay experienced.
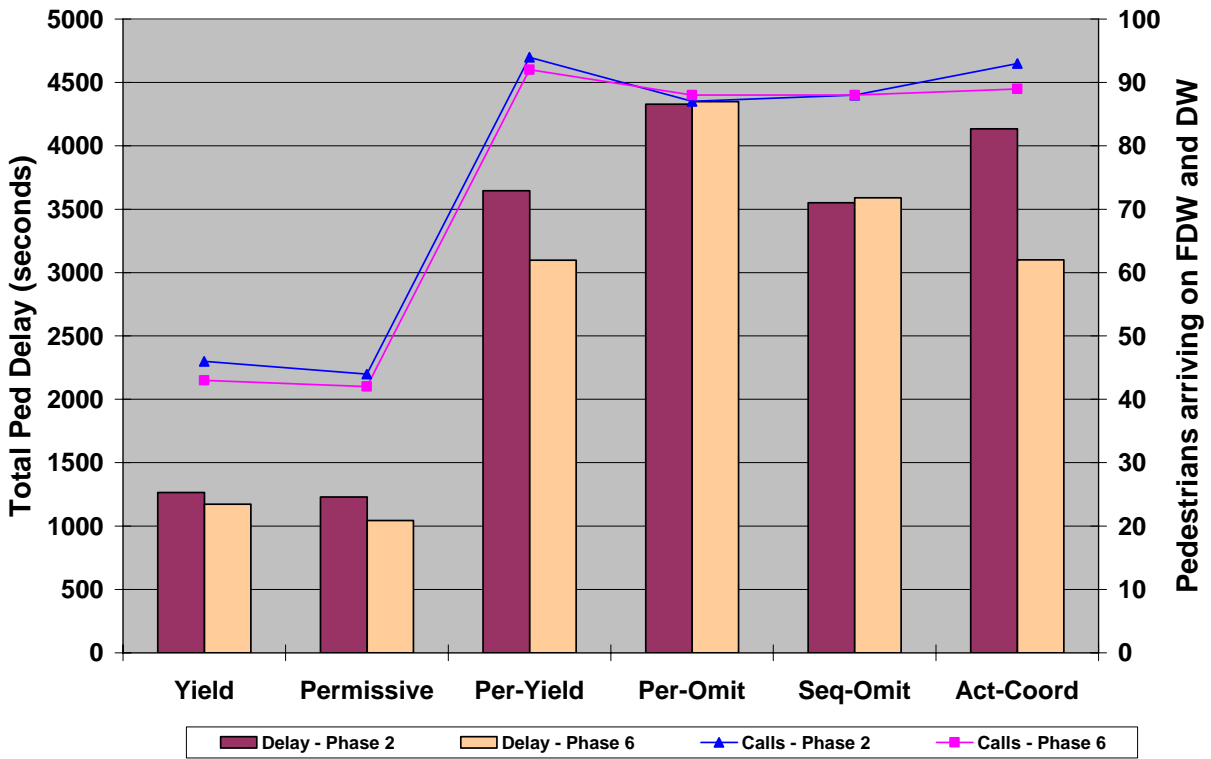
**Figure 26. Comparison of the Pedestrian Service Under Various Eagle Coordination Modes.**

# CONCLUSIONS AND RECOMMENDATIONS

The previous section described the implementation procedure followed to evaluate the coordination features in Eagle and Naztec controllers. This chapter provides some recommendations about the use of these features.

## Force-off Modes

There are two modes of force-off evaluated in this project - floating force-off and fixed force-off. In the Eagle controller, floating force-off is known as Plan, and fixed force-off is known as Cycle. The functionality of the force-off modes is identical in both controllers.

Fixed force-off mode tends to better utilize the slack time available on a cross-street phase during cyclic variations in demand. By ordering a heavier phase later in the phasing sequence, the slack time from the earlier, lighter phase is used by the later, heavier (or more critical) phase instead of being transferred to the coordinated phase. Using fixed force-off mode at intersections having such a traffic pattern can provide a significant benefit to the cross-street phase. Hence, researchers recommend that the users use fixed force-off as a default force-off mode.

The advantages of fixed force-off include taking advantages of cyclic variations in the demand on the cross-street to reduce delay to the heavier or more critical cross-street phase. Under certain circumstances fixed force off reduces overall intersection delay. Under conditions where an early return to the coordinated phase is not very desirable, use of fixed force-off modes allows the controller an opportunity to utilize the time on the cross street instead of transferring it to the arterial. In fixed force-off, however there are fewer chances to return early to the arterial phase than in floating force-off. Under circumstances that require returning early to the arterial phases as much as possible, fixed force-off is more disadvantageous.

## Transition Modes

Eagle has five types of transition modes that cannot be modified. Naztec has three types of modes that can be modified to yield four transition modes. Evaluation of the transition modes in the Eagle controller revealed that there was no statistically significant difference between the intersection delays, approach delays, and arterial travel time experienced in any of the modes. However, Dwell modes consistently experienced higher cross-street delays. On the other hand, Shortway transition mode is technically the best mode to quickly get from one point to the other. Authors recommend that:

- When using the Eagle controller, Shortway transition mode be used.

- When using the Eagle controller, Dwell mode is not used.

- When using the Naztec controller, use Short and Long modes with 17 percent as the correction in each mode. That percentage allows the controller to get back in sync in three cycles.

**Coordination Modes or Features**

Analysis of the six coordination modes illustrated the complexity of selecting a mode in the Eagle controller. The review of the coordination modes and features in the Naztec controllers illustrated the need to approach this topic from the point of view of desirable coordination features or coordinated operations instead of coordination modes. Hence, it was decided to identify some conditions (examples) that would represent likely traffic conditions encountered. Then some recommendations can be made regarding the use of coordination modes or coordination features. Following are some examples of the scenarios and the recommended use of coordination modes in Eagle controllers or coordination features in Naztec controllers.

**Example 1**. Location having a high-pedestrian volume

        Eagle controller:      Use Yield or Permissive Modes

        Naztec controller:     Rest in Walk – On

                              Walk Recycle – $\Phi3478\_Inh$

                              Leave Walk Before – Timed

                              Leave Walk After – Timed

**Example 2**. Location having low pedestrian volume, low cross-street volume, but having a wide arterial resulting in a pedestrian requirement greater than the cross street vehicle requirement.

        Eagle controller:      Use Permissive Yield Mode

                              Use Shortway transition

        Naztec controller:     Stop in Walk – On

                              Use Shortway transition

                              Minimum Permissive – On

**Example 3**. Allow the end of the coordinated phase to be actuated. This is applicable due to the lack of a consistent platoon size on the arterial. Hence, a coordinated phase that gaps out to service the cross-street phase would reduce delay to the cross street.

        Eagle controller:      Use Permissive Yield

        Naztec controller:     Use Early Yield

**Example 4**. Omit early return to the coordinated phase. Such operations are beneficial for closely spaced intersections.

Eagle controller:      Use Permissive Omit

Fixed Force-off with max recall on the last non-coordinated phase

Max recall on all phases

Naztec controller:     No specific coordination feature

Fixed Force-off with max recall on the last non-coordinated phase

Max recall on all phases

The examples identified above give a summary of the types of coordinated operations that would benefit from specific coordination modes.  This chapter provided some recommendations about the use of various coordination features that can significantly improve coordination operations.

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# APPENDIX A  PRODUCT 2 - ENGINEER AND TECHNICIAN IMPLEMENTATION HANDBOOK

## Coordination Procedures

This section describes the coordination procedure to be followed for a signalized intersection. Figure 27 illustrates typical phase layout at an intersection.
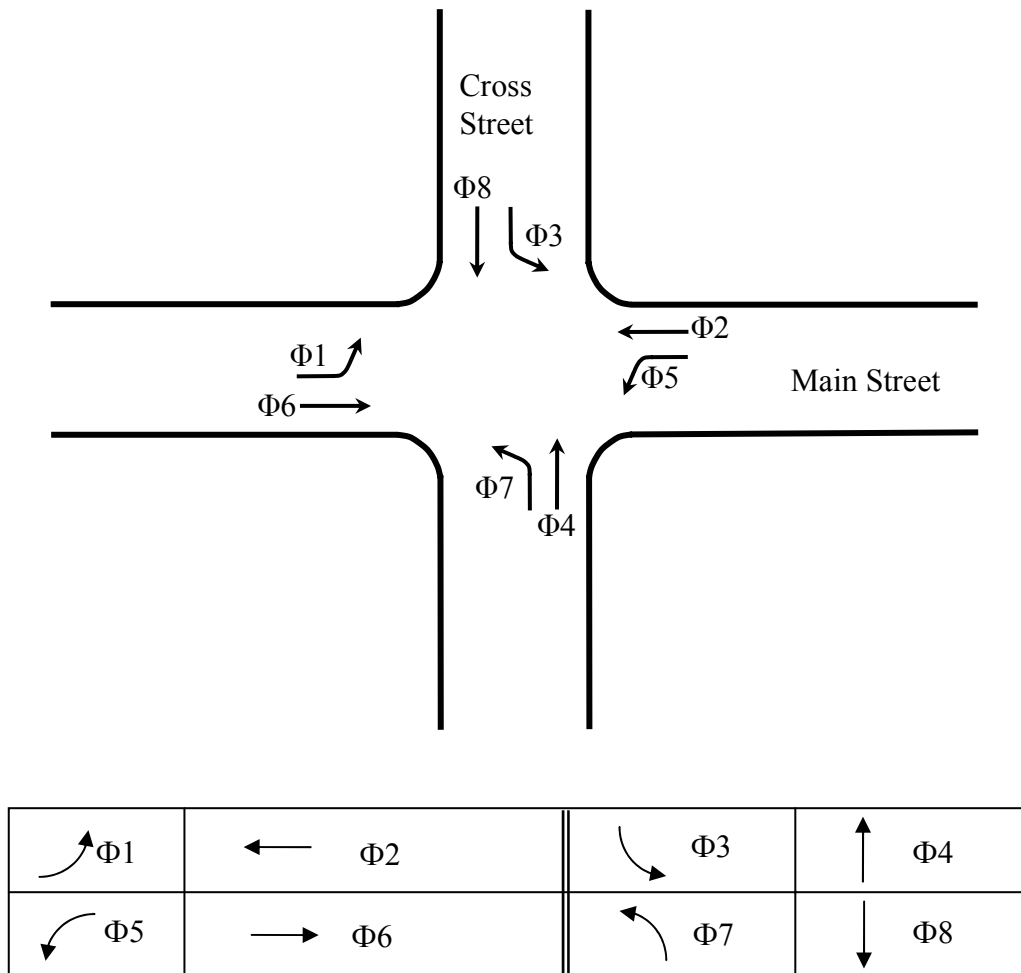


**Figure 27. Typical Phasing Layout and Sequence for an Intersection.**

## How to Program Coordination?

### *Needs*

The phasing sequence at a typical intersection is illustrated in Figure 27. Usually progression is provided along the main street. Hence, Phase 2 and Phase 6 on the main street are

typically the coordinated phases. To program coordination within a controller, the traffic engineer requires some basic timing information and coordinated signal timing plans for the intersection. This timing information includes minimum green, passage times, maximum green, yellow duration, all-red durations, coordination plans or splits, and the time period for implementing the timing plan. For the purposes of this example, we assume that these timings have been developed and are ready to be programmed in the traffic signal controller. Table 16 illustrates an example of a basic timing for an eight-phase intersection. Table 17 illustrates an example of a coordinated timings plan.

**Table 16.  Example of Basic Timing for an Intersection.**

|  | **Phase 1** ⤴ | **Phase 2** ← | **Phase 3** ⤵ | **Phase 4** ↑ | **Phase 5** ⤸ | **Phase 6** → | **Phase 7** ⤺ | **Phase 8** ↓ |
|---|---|---|---|---|---|---|---|---|
| Min. Green | 5 | 15 | 5 | 10 | 5 | 15 | 5 | 10 |
| Passage/10 | 10 | 20 | 10 | 15 | 10 | 20 | 10 | 15 |
| Max. Green | 30 | 80 | 30 | 60 | 30 | 80 | 30 | 60 |
| Yellow/10 | 40 | 45 | 40 | 40 | 40 | 45 | 40 | 40 |
| All-Red/10 | 20 | 15 | 20 | 20 | 20 | 15 | 20 | 20 |

**Table 17.  Example of Coordination Plan for an Intersection (Split Timings).**

|  | Phase 1 | Phase 2 | Phase 3 | Phase 4 | Phase 5 | Phase 6 | Phase 7 | Phase 8 | Offset | Cycle Length |
|---|---|---|---|---|---|---|---|---|---|---|
| **AM Peak** (07:00 to 10:00) | 15 | 60 | 15 | 40 | 15 | 60 | 15 | 40 | 20 | 120 |
| **Noon Peak** (10:00 to 16:00) | 15 | 45 | 15 | 25 | 15 | 45 | 15 | 25 | 25 | 100 |
| **PM Peak** (16:00 to 18:30) | 15 | 65 | 15 | 45 | 15 | 65 | 15 | 45 | 15 | 130 |

*Basic Coordination in an Eagle Controller*

Before the timings are programmed into the EPAC controller, the following checks will have to be performed to make sure that the splits are selected properly. The splits include the clearance time; i.e., the split consists of the green time, yellow time, and the all-red time.

1.  Sum of splits for Phase 1 and Phase 2 should be equal to the sum of the splits of Phase 5 and Phase 6.
    Split $\Phi1$ + Split $\Phi2$ = Split $\Phi5$ + Split $\Phi6$

2.  Sum of splits for $\Phi3$ and $\Phi4$ should be equal to the sum of the splits of $\Phi7$ and $\Phi8$.
    Split $\Phi3$ + Split $\Phi4$ = Split $\Phi7$ + Split $\Phi8$

3.  Sum of splits for Phases 1, 2, 3, and 4 should be equal to the sum of the splits for Phases 5, 6, 7, and 8, and they should be equal to the cycle length.

Split Φ1 + Split Φ2 + Split Φ3 + Split Φ4    = Split Φ5 + Split Φ6 + Split Φ7 + Split Φ8
                                             = Cycle length

4. The traffic engineer needs to ensure that the split for each phase should be greater than the sum of the minimum green, yellow, and all-red for the same phase by at least 1 second. This rule should be checked for every phase.

   For example:

   Split Φ2+ 1 second ≥ Φ2 Minimum green + Φ2 Yellow + Φ2 All-red

Once the timings in Table 16 and Table 17 are checked to comply with the rules of thumb, they can be programmed into the traffic signal controller as shown below. First the basic timings in Table 1 will be programmed.

1. Press "3" from the MAIN MENU to show PHASE MENU.
2. Press "1" from the PHASE MENU to show VEHICLE TIMES SCREEN.
3. In the appropriate column for each phase, enter the data from Table 1. You will enter the minimum green (MIN GREEN), passage time (PASS/10), maximum green (MAX # 1), yellow times (YEL/10), and all-red times (RED/10).
4. The timings for basic data have been entered into the controller.

Once the basic timings are entered, the coordination plans or the split timings can be entered as follows.

1. Press "5" from the MAIN MENU to show COORD DATA.
2. Press "1" from the COORD DATA MENU to show the COORD SETUP SCREEN.
3. Some suggested parameter settings in the COORD SETUP SCREEN are described below:
   OPER:      Set this to "Auto" so it is able to run the coordination plans.
   MODE:      Set this to "0" as a type of coordination mode. More details of these coordination modes are discussed in the advanced coordination features section.
   MAX:       Set this to 'Inhibit Max' so the Max times that you programmed in PHASE DATA don't override the split times that you set in COORD DATA.
   CORR:      Set this input to "2" to select SWY (Shortway) as a means of correction in this example. More details of these correction modes are discussed in the advanced coordination features section.
   OFST:      Set this input to "1" to time the offset from the end of coordinated phase green.
   FRCE:      Set this input to "0" (PLN) as a force-off mode. More details of the force-off modes are discussed in the advanced coordination features section.
4. COORD SETUP has been entered. Press "F" to go back to the COORD DATA MENU.
5. Next, the split data need to be entered. Enter the split data for the AM peak in Table 2. Press "3" in the COORD DATA to select DIAL/SPLIT DATA.

6.  Enter a DIAL number and a SPLIT number in the respective fields.  DIAL/SPLIT numbers range from 1 to 4.  For this example, enter "1" for DIAL and "1" for SPLIT numbers.
7.  In the next field, LEVEL, press "1" to get to DIAL 1 SPLIT 1 PARAMETERS.
8.  There are three rows of data that could be entered.  Three OFFSET values for each DIAL/SPLIT combination can be entered.  Each row also contains input for ALT SEQ (alternate sequence) and PATN MODE (pattern mode or coordination mode).  Under certain advance conditions, R2 LAG (ring 2 lag), R3 LAG (ring 3 lag), and R4 LAG (ring 4 lag) are used.  ALT SEQ is used to change the ring structure to enable phase sequence changes like lead/lag phasing or lag/lag phasing.
9.  Phasing sequence can be changed in a controller either by changing the ring structure or by using alternate sequences.  Changing phasing sequences by using alternate sequences is preferred because these phase sequences can be modified by time of day.  Programming alternate sequences is described in the next step.
10. Enter "F" three times to go back to the MAIN MENU.
11. Select "4" to get to UNIT DATA MENU.  Select "6" to open the ALT SEQUENCES SCREEN.  Up to 15 SEQ (alternate sequences) can be programmed.  Each alternate sequence can have up to eight PHASE PAIRS to REVERSE.  For simplicity sake, only one pair will be reversed for the demonstration.  In this example, PP1 in SEQ 1 is used to reverse phase pairs Phase 1 and Phase 2.  This results in a phasing sequence as seen in Figure 28.
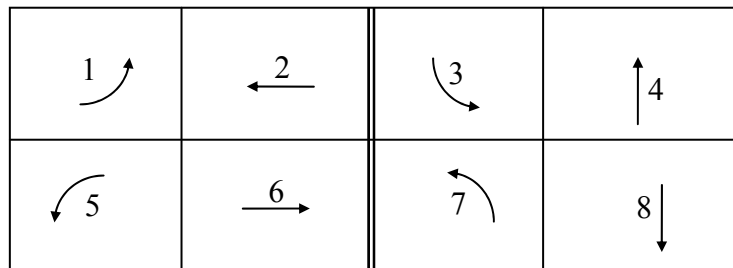


Before Phase Reversal – Lead/Lead Phasing
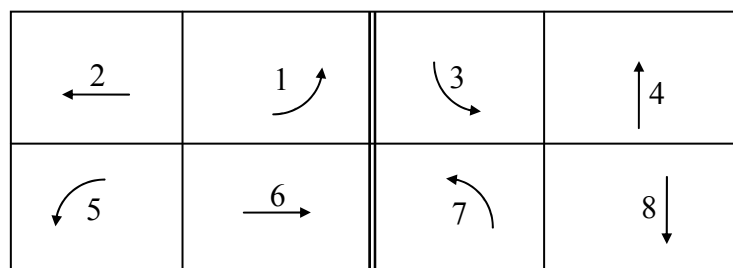


After Phase Reversal of Phase 1 and Phase 2 – Lead/Lag Phasing

**Figure 28.  Example of a Phase Reversal.**

12. Press "E" to edit the ALT SEQ screen.  In the row for SEQ 01, under PP1, type "01-02." This means that ALT SEQ 01 has the pair of Phase 1 and Phase 2 phases reversed.

Selecting ALT SEQ "01" permits lead/lag phasing along the main street, with Phase 2 and Phase 5 as the starting phases and Phase 1 and Phase 6 as the ending phases for the main street.  Press "F" twice to return to the MAIN MENU.

13. Continue the process of entering the splits, which were started in Step 8.  Press "5" for COORD DATA, and press "3" to enter the DIAL/SPLIT screen.  Enter 1 for DIAL, SPLIT, and LEVEL to enter the DIAL 1 SPLIT 1 PARAMETERS.
14. Enter 20 as the OFFSET #1 for this plan.  Enter "01" under ALT SEQ if phase reversal of Phase 1 and Phase 2 is desired.
15. Enter PATN MODE as "0."  It is possible to specify a pattern mode or coordination mode for each plan.  More details about the selection of coordination mode are discussed in the advance coordination features section.
16. Press "F" to return to the DIAL/SPLIT screen.  Move the cursor to CYCLE LENGTH, and enter the appropriate AM peak Cycle length of 120.
17. Move the cursor to LEVEL and enter "2" to enter DIAL 1 SPLIT 1 PHASE PARAMETERS.  The split data and the phase mode data will be entered in this screen.
18. Enter the timings for the split data for the AM peak, specified in Table 17, into the controller under each phase from Phase 1 to Phase 8.
19. Next, enter the mode for each phase under each phase number.  Typically, Phase 2 and Phase 6 are the coordinated phases.  Enter "1" for the mode for Phase 2 and Phase 6 to designate them as coordinated phases.  Typically, other phases are fully actuated and can be designated by entering "0" for the mode.  They can also be designated to function with a minimum recall (use "2" for mode) or maximum recall (use "3" for mode) or other modes.  For this example, consider the non-coordinated phases to be fully actuated.
20. Now that the split data have been entered, the controller needs to be programmed to bring up the specified plan with a "DIAL/SPLIT/OFFSET" of "1/1/1."  This is done by specifying this plan as a traffic event.
21. Press the "F" key three times to reach the MAIN MENU.  Then press "6" to the TIME BASE DATA MENU.
22. Press "2" and ensure that the time and date are correct.
23. From the TIME BASE DATA MENU, press "3" to enter the TRAFFIC EVENTS MENU.  Press "E" to program a schedule to call the plan 1/1/1.  Press "1" to add a plan.  Under the DD (day), enter "2" for Monday.  Move the cursor and under HH and MM enter "07" and "00," respectively, for 7 AM.  Under DL, SP, and OF enter 1, 1, and 1, respectively.  You have now programmed to call the 1/1/1 plan at 7:00 on a Monday.  Typically, the controller is programmed to call this plan for all week days, and hence, this plan will be seen as a traffic event for all the weekdays (DD 2 to DD 6).
24. If the plan is not equated, the user needs to use the EQUATE/TRANSFER function.  From the TIME BASE DATA MENU, press "6" to go to EQUATE/TRANSFER.  Move the cursor to the FROM field.  Enter "2" for the DD value you have programmed in for 1/1/1 in the FROM field.  Move the cursor to the TO field.  Type "3" and then "E" to equate it to Tuesday.  Continue equating the plan for the rest of the weekdays.
25. This procedure describes programming an EPAC Eagle controller to perform coordination.  Similarly, other plans can be programmed to provide coordination at other times of the day.

*Force-offs*

The various force-offs can be selected from the coordination data menu.

1. Press "5" from the MAIN MENU to show COORD DATA.
2. Press "1" from the COORD DATA MENU to show the COORD SETUP SCREEN.
3. Move the cursor to FRCE.

FRCE: Set this input to "0" (PLN) if a floating force-off mode is desired. Set this input to "1" (CYC) if a fixed force-off mode is desired.

*Transitions*

The various force-offs can be selected from the coordination data menu.

1. Press "5" from the MAIN MENU to show COORD DATA.
2. Press "1" from the COORD DATA MENU to show the COORD SETUP SCREEN.
3. Move the cursor to CORR.

CORR:   Set this input to select the desired means of correction. Select the input correction modes as illustrated below.
0 - Dwell
1 - Dwell with Int.
2 - Shortway
3 - Shortway+
4 - Shortway-2

*Coordination Features (Coordination Modes)*

The various force-offs can be selected from the coordination data menu.

1. Press "5" from the MAIN MENU to show COORD DATA.
2. Press "1" from the COORD DATA MENU to show COORD SETUP SCREEN.
3. Move the cursor to MODE.

MODE:   Set this input to select the desired coordination mode. Select the input coordination modes as illustrated below.

0 - Permissive
1 - Yield
2 - Permissive Yield
3 - Permissive Omit
4 - Sequential Omit
5 - Fully Actuated

### Basic Coordination in a Naztec Controller

This section demonstrates the process of programming basic coordination in a Naztec controller. The phasing sequence illustrated in Figure 27 and signal timings illustrated in Table 16 and Table 17 will be used. Similar to the EPAC 300 Eagle controller, the following checks will have to be performed to ensure that the splits are selected properly before the timings are programmed into the Naztec controller. The splits include the clearance time; i.e., the split consists of the green time, yellow time, and the all-red time.

1. Sum of splits for Φ1 and Φ2 should be equal to the sum of the splits of Φ5 and Φ6.
   Split Φ1 + Split Φ2 = Split Φ5 + Split Φ6

2. Sum of splits for Φ3 and Φ4 should be equal to the sum of the splits of Φ7 and Φ8.
   Split Φ3 + Split Φ4 = Split Φ7 + Split Φ8

3. Sum of splits for Phases 1, 2, 3, and 4 should be equal to the sum of the splits for Phases 5, 6, 7, and 8, and they should be equal to the cycle length
   Split Φ1 + Split Φ2 + Split Φ3 + Split Φ4    = Split Φ5 + Split Φ6 + Split Φ7 + Split Φ8
                                             = Cycle length

Once the timings in Table 16 and Table 17 are checked to comply with the rules of thumb, they can be programmed into the traffic signal controller as shown below. First the basic timings in Table 1 will be programmed.

1. Press "1" from the Main Menu to show Controller menu.
2. Press "1" from the Controller menu to show PHASES menu.
3. Press "1" from the PHASES menu to show Times menu.
4. In the appropriate column for each phase, enter the data from Table 1. You will enter the minimum green (Min Grn), passage time (Gap, Ext), maximum green (MAX # 1), yellow times (Yel Clr), and all-red times (Red Clr).
5. The timings for basic data have been entered into the controller. You can also enter data for the Walk duration, Pedestrian clearance (Ped Clr), Red Revert, volume density functions like Added Initial (Add Init), Maximum Initial (Max Init) and Gap Reduction data, and special feature like Dynamic Maximum. In this example, such data will not be entered.

Once the basic timings are entered, the coordination plans or the split timings can be entered as follows.

1. Press "2" from the Main Menu to show Coordinate parameters. We will be coding data in the Modes Options (Selection 1), Pattern Tables (Selection 4), Transition and Correction Modes (Selection 5), and Splits (Selection 7).
2. Press "1" to show the Coordination Modes menu. Some parameters to be programmed are described below.
   Test OpMode: This mode is used to select the manner of coordination. Setting this field to "0" will allow the controller coordinator to operate according to time of day schedule. Selecting any value from 1 to 253 overrides the automatic schedule operations and the controller will operate the pattern selected.

Selecting 254 will enable the controller to operate in a free mode and selecting 255 will place the controller in a manual flash. For this example, code "0" to enable automatic time of day operations.

Correction: This input designates the correction mode to be used when transitioning between patterns. The correction modes available to be selected are SHORT/LONG, LONG, and DWELL. A discussion about the selection of the appropriate mode to select is available in the advance coordination features section. For this example, select SHORT/LONG as the correction mode.

Maximum: This input determines an upper limit if any on maximum time to be used during coordination. The options to select are Max_1, Max_2, and Max_Inh (maximum inhibit). In Naztec controller, using Max_Inh prevents some features of force off options. Hence, for this example, select Max_1 as the option.

Force-Off: This input determines the manner in which any excess time from a non-coordinated phase is used. A detailed discussion about this option is described in the advance coordination section. For this example, select "Fixed" force-off option.

3.  Press ESC to go back to the Coordination Parameters screen. The next parameter to be programmed is the Pattern Table.

4.  Press "4" to select "Pattern Tbl." For each pattern, a cycle length, offset, split, and sequence need to be programmed. Let us designate Pattern 1 for the AM peak, Pattern 2 for the noon peak, and Pattern 3 for the PM peak. Table 17 illustrates the cycle length and the offset information for the three time periods. Let us also designate the split numbers to be designated similarly with split 1, 2, and 3 to represent the split timings for the AM peak, noon peak, and the PM peak respectively.

5.  The final column in Pattern Tbl is "Seqnc" (phasing sequence). This input determines the phasing sequence the controller uses and can be changed for each pattern. Phasing sequence can be changed in the Controller menu. Press ESC twice to get to the Main menu. Press "1" to get to Controller menu. Press "2" to select UNIT and RING menu. Press 4 to select sequence. A total of 16 sequences can be selected. A sequence can consist of a number of rings ranging from one ring to four rings. Usually a two ring operation is used. A total of 16 phases can be used for each sequence. However, eight phases are typically for a normal intersection. Typically, Sequence 1 in Naztec controller uses an eight-phase lead-lead phasing operation for the Main-street and side-street. Sequence 2 in Naztec controller uses an eight-phase lead-lag operation with phase 1 leading for the Main-street and lead-lead operation for the side-street. These two phasing sequences are illustrated in Figure 29. Naztec specified all combination of phasing sequences for a dual-ring eight-phase operation in these 16 sequences. Users can select the appropriate sequence or custom create a sequence for special phasing sequences. Then the appropriate sequence is designated in the Pattern table of the Coordination menu. In this example, Sequence 1 is the sequence to be used and is coded. Hence, the Pattern table screen will look as seen in Table 18.
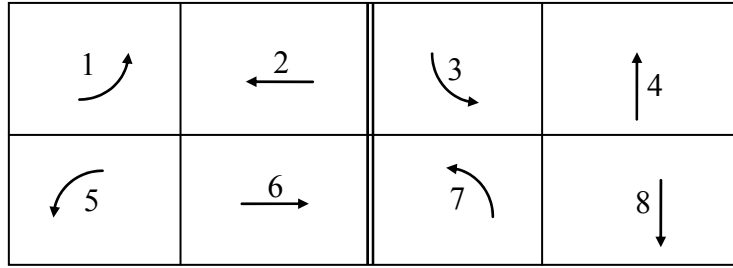
Sequence 1 – Lead/Lead Phasing (Main-Street)
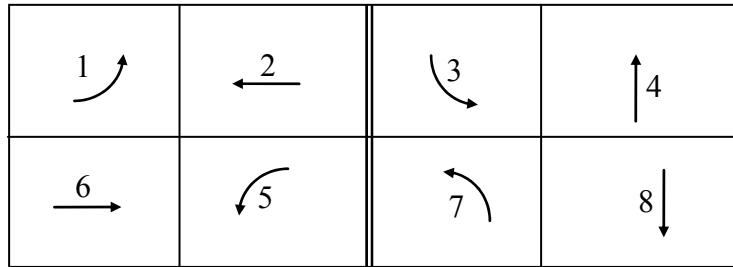


Sequence 2 – Lead/Lag Phasing (Main-Street)

**Figure 29.  Default Sequencing in Naztec Controller.**

**Table 18.  Pattern Table for the Example in Naztec Controller.**

| Pat # | Cycle | Offset | Split | Seqnc |
|-------|-------|--------|-------|-------|
| 1 | 120 | 20 | 1 | 1 |
| 2 | 100 | 25 | 2 | 1 |
| 3 | 130 | 15 | 3 | 1 |

6.  Once the Pattern table is coded, Transition and Coordination Phase menu is coded next. The user can get to the Transition and Coordination Phase menu from the Coordination Parameters menu by pressing "5." This screen has two parts. A Transition modes screen (which is the default screen that comes up first) and an Advanced Coordination input screen which can be viewed by moving the curser to the left. In the Transition modes screen, transition modes for each Pattern coded earlier can be further elaborated. In this screen, the percentages for the Short and Long modes can be stated. A non-zero value for these fields indicates the value by which the split time can change during transitioning. A "0" value for the percentage for either Short or Long means that the controller will not use that mode. The maximum value of Dwell can also be stated. If any phases are too short that they cannot be shortened further, up to four phases that cannot be shortened can

be specified in the next four columns. For this example, let us code 17 percent for both Short and Long for all three Patterns,and 0 for Dwell. And since the split time for Phase 4 and 8 during the noon peak time is very low, designate them as No Short Phases. The screen will appear as seen in Table 19.

**Table 19. Transition Details for the Example Intersection in Naztec Controller.**

| Pat# | Short | Long | Dwell | | No Short Φ⟶ | | |
|---|---|---|---|---|---|---|---|
| 1 | 17 | 17 | 0 | 0 | 0 | 0 | 0 |
| 2 | 17 | 17 | 0 | 4 | 8 | 0 | 0 |
| 3 | 17 | 17 | 0 | 0 | 0 | 0 | 0 |

7. Additional details about some advance coordination input are programmed on the next screen. Details about ErlyYld (Early Yield), Offset (offset reference point), Ret Hld, Flt (float), and MinPermV/P can be programmed on this screen. More details about these parameters are discussed in the advance coordination features section. For this example, the user is recommended to program this screen as illustrated in Table 20.

**Table 20. Coordination Inputs in Transition Table in Naztec Controller.**

| ⟵# | ErlyYld | Offset | RetHld | Flt | MinPermV/P |
|---|---|---|---|---|---|
| 1 | 0 | BegGrn | X | | |
| 2 | 0 | BegGrn | X | | |
| 3 | 0 | BegGrn | X | | |

8. Once the data is programmed in the Transition menu, the Split data is programmed next by pressing "7" from the Coordination Parameters menu. Then the Split number is entered (1 for the AM peak, 2 for the noon peak, and 3 for the PM peak) and the splits as detailed in Table 17 are programmed for each split in the respective Split Table.

9. The user is then recommended to designate only one phase as the coordinated phase. In this example, phase 2 can be the coordinated phase.

10. The user then selects the mode for each phase. The definitions of the various modes are given next. In this example, the user is recommended to select Max settings for the coordinated phases and NON for the remaining phases. This process should be repeated for three peak periods.

NON:  NONE specifies no recalls for the phase when the split table is active.

MIN:  min recall set for this phase when the split table is active (overrides all recalls programmed under Controller Menu).

MAX:  max recall set for this phase when the split table is active (overrides all recalls programmed under Controller Menu).

PED:  ped recall set for this phase when the split table is active (overrides all recalls programmed under Controller Menu).

MxP:  max + ped recall set for this phase when the split table is active (overrides all recalls programmed under Controller Menu).

OMT:  omit this phase if it is enabled when the split table is active.

Enb:  enable this phase if it is not enabled when the split table is active.

11. The user has thus completed the entire controller programming necessary to define the splits, offsets, and phasing sequences.

12. The next item is to program the schedule of these patterns. This is done in the Time Based Scheduler menu. From the Main menu, press "4" to get to Time Based Scheduler menu.

13. Press "5" to select Action Table. In the action table, each pattern defined earlier is assigned to a particular action number. In this example, assign Pattern 1, 2, and 3 to Action 1, 2, and 3 respectively. This means that Action 1 is for the AM peak, Action 2 is for the noon peak and Action 3 is for the PM peak. If the user wishes, Pattern 254 (free) and/or Pattern 255 (flashing operation) can also be programmed for a specific action item.

14. Press "ESC" to return to the Time Based Scheduler. Press "4" to select Day Plan. In this menu, the schedule of the Actions can be defined during the day. Press "1" to define/view Day Plan 1. Each change in the time of day plan can be defined as an Event in the Day Plan. For this example, program the Day Plan as illustrated in Table 21.

**Table 21. Day Plan Table for Example Intersection.**

| Plan- 1 | Evt | Time | Actn | Evt | Time | Actn |
|---------|-----|-------|------|-----|-------|------|
| Link: 0 | 1 | 07:00 | 1 | 2 | 10:00 | 2 |
|  | 3 | 16:00 | 3 | 4 | 18:30 | 2 |

15. Press "ESC" to return to the Time Based Scheduler. Press "2" for Easy Schedule. This menu allows for scheduling a particular Day Plan by the day of the week and the month of the year. Up to 95 schedules can be programmed.

16. In the Easy Schedule menu, the user needs to select the frequency of the Day Plan defined earlier. Day Plan 1 is assumed to be the plan for weekdays from Monday to Friday for all the days of the month and for all the days of the year. The user can program the Easy Schedule as seen in Table 22.

**Table 22. Easy Schedule Menu for the Example Intersection.**

| # | Day | Mo: From - Thru | Dom: From - Thru | Plan |
|---|-----|-----------------|------------------|------|
| 1 | M-F | 01 - 12 | 01 - 31 | 1 |
| 2 | OFF | 00 - 00 | 00 - 00 | 1 |
| 3 | OFF | 00 - 00 ↓ | 00 - 00 | 1 |

17. These steps illustrate the procedure to program a Naztec controller for basic coordination. This procedure can be used to program other plans for weekends or nights or special events.

***Force-offs***

The force-off modes can be selected to potentially improve the utilization of some excess time from a non-coordinated phase that comes earlier in the phasing sequence to benefit another non-coordinated phase that comes later in the phasing sequence. The two options for the force-off modes are floating force-off and fixed force-off. The user can select the force-off mode from the Main menu.

1. From the Main menu, press "2" to select Coordinate Parameters menu.

2. Press "1" to select Modes menu.

3. Move the cursor to the right to the Force-Off option. The user has three options of Force-Off: FLOAT, FIXED, and OTHERS. The recommendation is to select either FLOAT or FIXED force-off options. More details about the selection of the appropriate force-off modes are described in the advance coordination features section.

4. On the same screen, ensure that either MAX_1 or MAX_2 is selected as the Maximum mode. Do not select MAX_INH.

*Transitions*

Transition modes determine the mode of transition from one pattern to the other. Transition mode can be selected for all Patterns in the Coordination Modes menu. The following steps illustrate the programming of the transition modes.

1. From the Main menu, press "2" to select Coordinate Parameters menu.

2. Press "1" to select Coordination Modes menu.

3. Move the cursor down to the Correction option.

4. The user has the option of selecting from SHORT/LONG, LONG, and DWELL transition modes. The recommendation is to select SHORT/LONG transition mode. More details about the selection of the appropriate transition mode are described in the advance coordination features section.

5. The transition mode can also be selected for each pattern. This selection will override the selection of the transition mode described earlier.

6. From the Main menu, press "2" to select Coordinate Parameters menu. Press "5" to select Trans, CoorΦ+ menu.

7. For each pattern, theuser can define the percentage change in the cycle length during transition. The recommendation is to use 17 percent for both Short and Long. However, if zero values for Short and Long are programmed, the controller selects the Dwell mode.

8. If SHORT/LONG mode is selected, and if the phases are already very short, users can select up to four phases which cannot be shortened.

9. Move the cursor to the right and specify phases which should not be shortened.

*Coordination Features*

Naztec controllers have a number of coordination features which can be used to obtain a desirable coordinated operation. More details about the selection and use of these features are described in the advance coordination features section.

*Early Yield*

Early Yield is used to modify the yield point of a coordinated phase. This feature allows the coordinated phase to be terminated earlier. More details about the use of this feature are described in the advance coordination section. The user can program the controller as follows.

1. From the Main menu, press "2" to select Coordinate Parameters menu.

2. Press "5" to select Trans, CoorΦ+ menu.

3. Move the cursor to the left to reveal another screen illustrating the input fields for ErlyYld, Offset, Ret Hld, Flt, and MinPermV/P.

4. Move the cursor to ErlyYld field and enter a value between 0 and 25 seconds for each pattern.

*Stop in Walk*

This feature is useful at locations where the time required to service a pedestrian is more than the time available to service the associated traffic movements.

1. From the Main menu, press "2" to select Coordinate Parameters menu.

2. Press "1" to select Coordination Modes menu.

3. Move the cursor to the right to view the + features.

4. Move the cursor down until you reach the Stop in Walk field.

5. Turn the feature ON or OFF by pressing "0."

*Rest in Walk*

This feature determines if the pedestrian signal can rest in the walk indication. This feature is very useful at locations of high pedestrian traffic. The user can activate this feature as follows.

1. From the Main menu, press "1" to get to the Controller menu.

2. From the Controller menu, press "1" to get to the Phases menu.

3. From the Phases menu, press "2" to get to the Options menu.

4. In the Options menu, scroll down the cursor to the row for Rest In Walk input.

5. Select the phases for which you want the Walk indication to rest.

*Leave Walk Before*

Leave Walk Before determines when the Walk indication can terminate if the phase has not yet reached the yield point. This determines if the walk indication should terminate at a fixed point in the cycle or only due to a conflicting call. More details of the applicability of this feature is described in the advance coordination features section.

1. From the Main menu, press "2" to select Coordinate Parameters menu.

2. Press "1" to select Coordination Modes menu.

3. Move the cursor to the right to view the + features.

4. Move the cursor below until it reaches Leave Walk for the Before option.  The user can select from either TIMED or DEMAND by pressing the "0" button.

The feature works similarly for Leave Walk After.  This applies for the termination of the walk indication when the coordination phase had already gone past the yield point.

*Return Hold*

Return Hold prevents the coordinated phase from terminating in case of a very early return to the coordinated phase.  More details of the applicability of this feature is described in the advance coordination features section.

1. From the Main menu, press "2" to select Coordinate Parameters menu.

2. Press "5" to select Trans, CoorΦ+ menu.

3. Move the cursor to the left to reveal another screen illustrating the input fields for ErlyYld, Offset, Ret Hld, Flt, and MinPermV/P.

4. Move the cursor to Ret Hld field and press "0"to either activate or to not activate for each pattern.

*Minimum Permissive*

Enabling Minimum Permissive (Vehicles/Pedestrians) prevents servicing a vehicle or a pedestrian that arrive late in the cycle.  More details of the applicability of this feature are described in the advance coordination features section.

1. From the Main menu, press "2" to select Coordinate Parameters menu.

2. Press "5" to select Trans, CoorΦ+ menu.

3. Move the cursor to the left to reveal another screen illustrating the input fields for ErlyYld, Offset, Ret Hld, Flt, and MinPermV/P.

4. Move the cursor to MinPermV/P fields and press "0" to either activate or to not activate the minimum permissive for vehicles and/or pedestrians for each pattern.

*Coord Yield*

Coord Yield allows for more efficient lead-lag operations during very light conditions. More details of the applicability of this feature are described in the advance coordination features section.

1.  From the Main menu, press "2" to select Coordinate Parameters menu.

2.  Press "1" to select Coordination Modes menu.

3.  Move the cursor to the right to view the + features.

4.  Move the cursor below to the Coord Yield field.  Enter a value between -15 to + 15 seconds.

# APPENDIX B PRODUCT 3 – CATALOG OF ADVANCE COORDINATION FEATURES

**Eagle Controller**

Plan Force-off:  This feature is equivalent to the floating force-off.  It allows each non-coordinated phase to be serviced only for the duration for which it was programmed.  Any unused time from a non-coordinated phase is transferred to the coordinated phase.

Cycle Force-off:  This feature is equivalent to the fixed force-off.  It allows a non-coordinated phase to utilize any unused time from a previous non-coordinated phase.

Shortway Transition:  This is a method to transition from one pattern to the other.  This mode determines the quickest path to get from one pattern to the other, either by adding time to the coordinated phases or subtracting time from all the phases such that the cycle length does not change more than 18.75 percent.

Shortway+ Transition:  This is a method to transition from one pattern to the other.  In this mode, time is added only to the coordinated phases (not more than 18.75 percent) to transition from one pattern to the other.

Shortway-2 Transition:  This is a method to transition from one pattern to the other.  In this mode, time is added (not more than 18.75 percent) to all the phases in proportion to their programmed phase times to get from one pattern to the other.

Dwell Transition:  This is a method to transition from one pattern to the other.  In this mode, the coordinated phase dwells in green until the controller completes the transition from one pattern to the other.  This mode causes delays to the cross-street phases.

Dwell with Int Transition:  This is a method to transition from one pattern to the other.  This mode is similar to the Dwell Transition.  The coordinated phase dwells in green.  However, there is a maximum duration the coordinated phase dwells in green.  This mode reduces the delay experienced by the cross-street phases during the dwell mode.

Yield:  In this coordination mode, the pedestrian phase for the coordination phases dwells in the Walk indication.  The coordinated phase yields to any of the non-coordinated phases at the yield point.

Permissive:  In this coordination mode, the pedestrian phase for the coordination phases dwells in the Walk indication.  The coordinated phase yields only to the next non-coordinated phases at the yield point.

Permissive Yield:  In this coordination mode, the coordinated phase can be extended, and the pedestrian phase for the coordination phases dwells in the Walk indication.

Permissive Omit:  In this coordination mode, the coordinated phase can be extended; the pedestrian phase for the coordination phases dwells in the Walk indication, and early return to the coordinated phase is omitted.

Sequential Omit:  In this coordination mode, the coordinated phase can be extended; the pedestrian phase for the coordination phases dwells in the Walk indication, and early return to the coordinated phase is reduced.

Actuated Coordinated:  In this coordination mode, the coordinated phase can be extended, and it is actuated if it is on the outside of its coordinated window.

**Naztec Controller**

Floating Force-off:  This feature allows each non-coordinated phase to be serviced only for the duration for which it was programmed.  Any unused time from a non-coordinated phase is transferred to the coordinated phase.

Fixed Force-off:  This feature allows a non-coordinated phase to utilize any unused time from a previous non-coordinated phase.

Short:  This is a method to transition from one pattern to the other.  It shortens the phase times to transition from one pattern to the other.

Long:  This is a method to transition from one pattern to the other.  It lengthens the phase times to transition from one pattern to the other.

Short and Long:  This transition method is equivalent to the Shortway method of transitioning from one pattern to the other in the Eagle controller.

Dwell:  This transition method is equivalent to the Dwell method of transitioning from one pattern to the other in the Eagle controller.

Early Yield:  This is a coordination feature that can truncate the coordinated phase.

Stop in Walk:  This feature stops the clock when a Walk indication comes on.

Walk Recycle:  This feature specifies the behavior of the pedestrian phases after the termination of pedestrian clearances.

Leave Walk:  This feature determines the manner of the termination of the Walk indication.

Rest in Walk:  This feature allows for the Walk indication to dwell.

Return Hold:  This feature prevents the termination of the coordination phase if it comes on very early.

Minimum Permissive:  This feature prevents the servicing of either pedestrian or vehicular calls if they come on very late in the permissive period.

Coord. Yield:  This feature allows for an early return to the leading through phase in a lead-lag phasing operation.