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16. Abstract

The objective of this project is to evaluate the operations at signalized intersections with wide medians in order to improve safety and efficiency. Intersections with wide medians are characterized by two intersections and operate differently compared to a typical intersection. Space in the wide median between the two intersections can be used to store vehicles. However management of the storage space is critical to avoid queue backing up into the upstream intersection. There are no guidelines specific to operate such intersections. This results in agencies using their discretion to develop strategies to operate such intersections, resulting in inconsistent operations. Texas Transportation Institute researchers used VISSIM simulation model to evaluate numerous strategies that were either in use by TxDOT districts or were developed by the research team. These strategies were evaluated for various widths of medians, the number of lanes for the minor street in the median, and the presence of left-turn bays on the major street. The strategies were also evaluated for low, medium, and high volumes on the major street and on the minor street as well as different percentages of turning traffic. The research project produced recommended strategies for various volume and geometric conditions.

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GUIDELINES FOR SIGNAL OPERATIONS AT INTERSECTIONS WITH WIDE MEDIANS

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Srinivasa Sunkari, P.E. (Texas) #87591. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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INTRODUCTION

BACKGROUND

Many high-speed traffic signals in rural areas have wide medians. These wide medians, coupled with low intersection volumes, require unique signal operation strategies. A median is stated to be wide if it is wider than 60 ft (*1*). Some of the medians in Texas are as wide as 300 ft and in the case of intersecting freeways, can be as wide as 1000 ft. The design and operation of traffic signals depend on numerous factors including traffic volume patterns, median widths, approach speeds, and sight distances. Frequently, Texas Department of Transportation (TxDOT) engineers may treat such an intersection almost like a diamond interchange as these widely spaced intersections have many characteristics of a diamond interchange (Figure 1) (*2*).

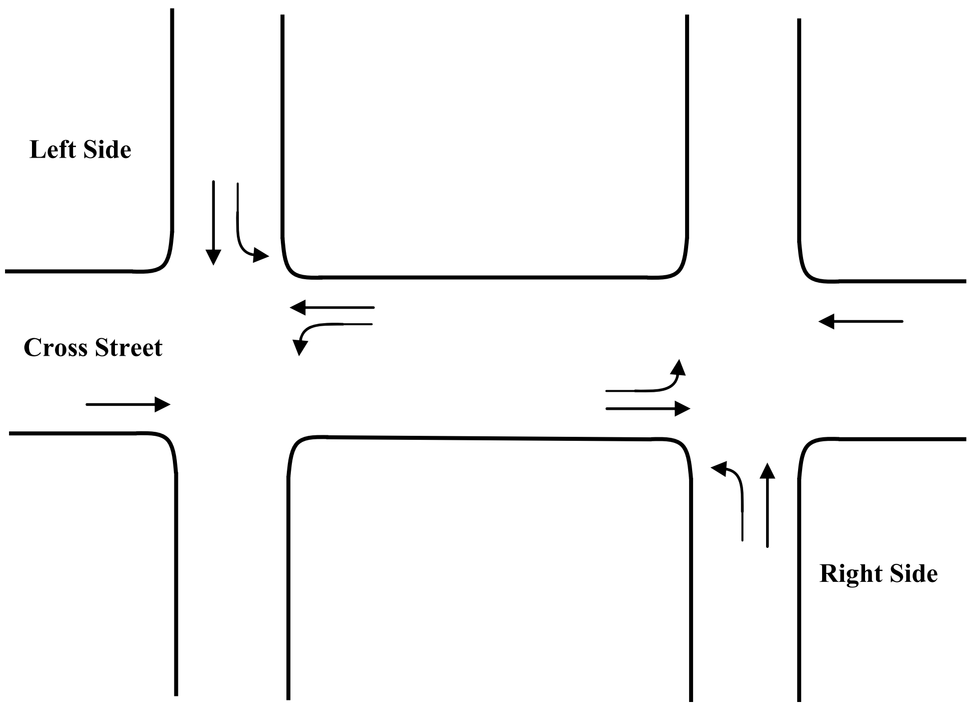


Figure 1. A Typical Wide Median Interchange.

Intersections with wide medians have some unique challenges. While the lead-lead left-turn phasing sequence is typically used at conventional intersections, such a phasing sequence is not possible with wide medians. Some districts use a left-turn phase on the major street while others do not. Some districts use trailing overlaps and some do not. TxDOT engineers currently do not have explicit guidelines to design and operate such intersections resulting in inconsistent operations. This project also will capture the operational strategies being used by some districts in TxDOT so that other districts can take advantage of such operations.

STATE OF THE PRACTICE

This section provides applicable strategies for operating wide median intersections. Wide median intersections are characterized by two intersections where the major highway intersects with the minor street with the following characteristics:

- spacing between two intersections that are greater than 60 ft and
- isolated intersections in a rural area with high-speed approaches.

Due to close signal spacing at intersections with a wide median, operational strategies selected should consider the available storage space with an objective to minimize storage in the median. Due to its similarity, diamond interchange operation can be considered as one viable option for operating wide-median intersections. Figure 2 shows typical phase numbering for diamond interchanges (*3*). Another feature in the controllers that TxDOT typically uses is the trailing overlap. Each of these options has some advantages and disadvantages and will be presented in this section.

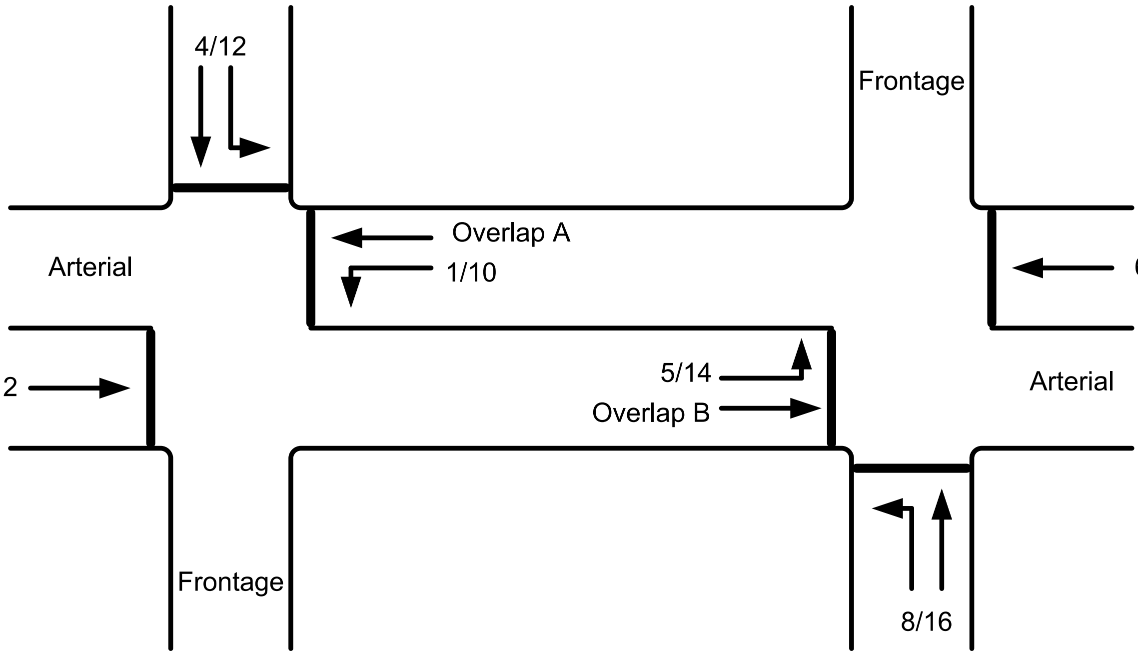


Figure 2. Diamond Interchange Numbering Scheme.

Four-Phase Sequence Operation

The four-phase sequence operation is most effective at narrow interchanges particularly those with high internal left-turn volumes. This strategy treats the interchange as a single intersection with four external approaches, with each served by a separate phase. Figure 3 and Figure 4 illustrate the four-phase sequence and the corresponding controller ring structure, respectively.

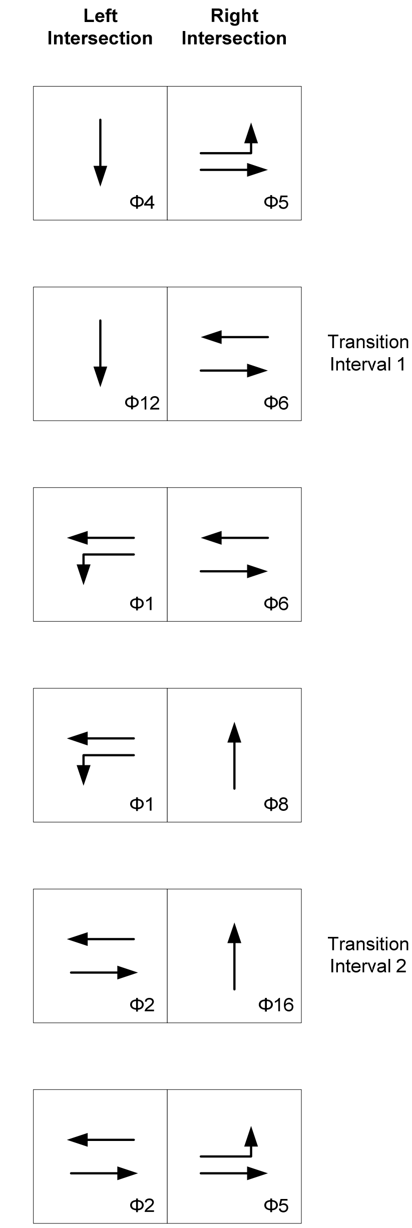


Figure 3. Four-Phase Sequence.

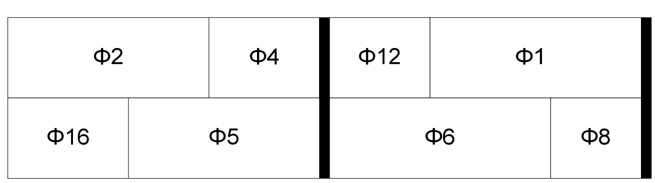


Figure 4. Four-Phase Controller Ring Structure.

The four-phase sequence possesses the following characteristics:

- Arterial (here minor-street) traffic movements have progressions through the interchange but limited ability to coordinate with adjacent intersections along the arterial street (here minor-street).
- The external approaches are fully actuated.
- Phases serving the interior of the interchange are always clear of the traffic, thus eliminating the issue of interior storage.

Transition intervals improve throughput during high-volume conditions but can become inefficient under low-volume conditions.

Three-Phase Sequence Operation

The three-phase sequence treats the interchange as two separate intersections, with each having three phases—an external arterial (here minor-street) phase, an internal phase, and a frontage road phase. The sequence starts with two external arterial (minor-street) phases, followed by the two internal left-turn phases. The two frontage road (here major-street) phases typically start and end simultaneously. However, in the case where there is no demand on one of the frontage roads, this phase will operate with a compatible internal left-turn phase. Figure 5 and Figure 6 illustrate the three-phase sequence and the corresponding controller ring structure, respectively.

The three-phase sequence is typically used when:

- There is adequate storage space between intersections when serving frontage road phases.
- The frontage road volumes are approximately balanced.

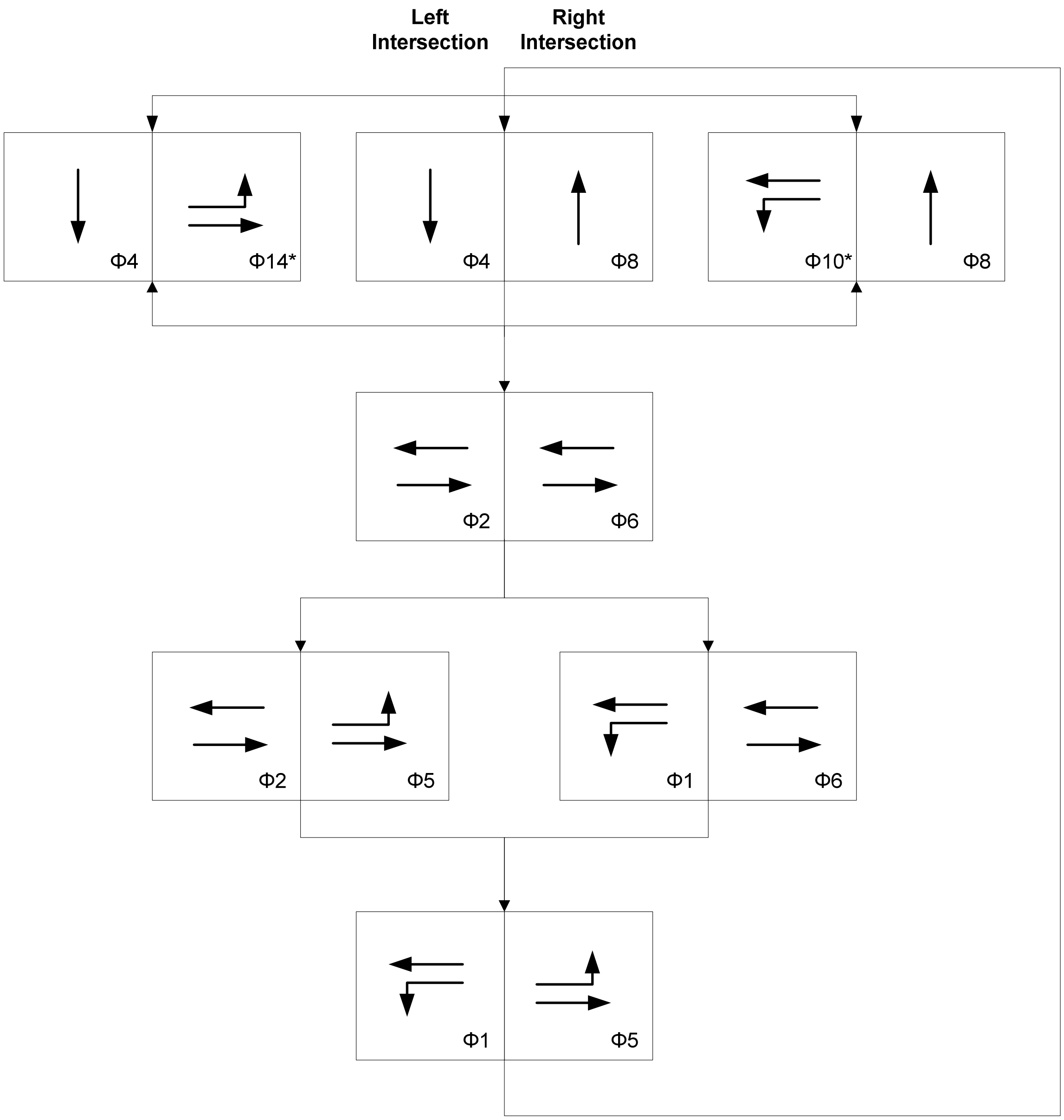


Figure 5. Three-Phase Sequence.

*Phases 10 and 14 are used in the absence of calls on Phase 4 or Phase 8 or when an internal left-turn movement is conditionally served.

Φ10*	Φ4	Φ2	Φ1
Φ14*	Φ8	Φ6	Φ5

Figure 6. Three-Phase Controller Ring Structure.

Separate Intersection Operation

The separate intersection phasing sequence assigns one ring to control each intersection of the diamond interchange. Coordination between the two intersections is maintained by specifying a common cycle length and a fixed offset between the coordinated phases at each intersection. This offset is usually referred to as "ring lag." This separate-intersection sequence is most effective at wide interchanges with unbalanced traffic movements. This sequence typically provides a good progression for only one of the two arterial (here minor-street) through movements. Figure 7 shows the separate-intersection phase sequence, and Figure 8 displays the corresponding controller ring structure.

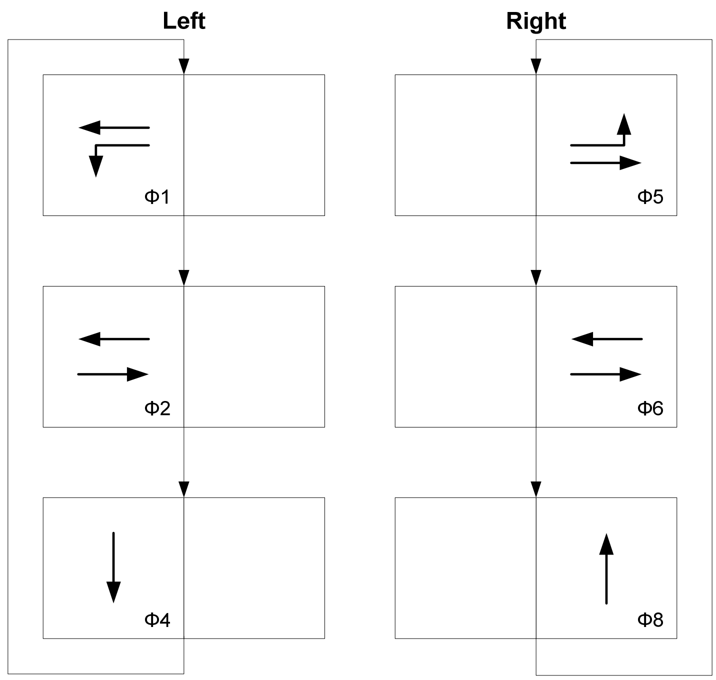


Figure 7. Separate-Intersection Phase Sequence.

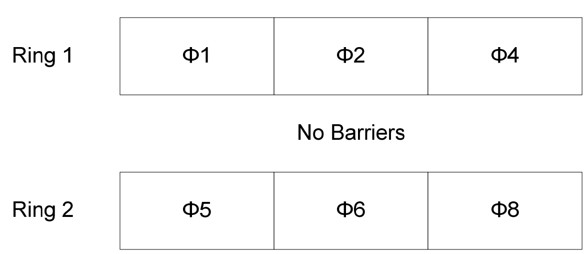


Figure 8. Separate-Intersection Controller Ring Structure.

Trailing Overlap Operation

Trailing overlap green is a controller feature that can be used to delay the green termination of the overlap phase. Overlap phases are typically used to control the internal movements at the wide-median intersections. An overlap trailing green can provide the additional green time needed for the traffic from the external approaches to proceed through the intersections without being stopped between the two intersections. Figure 9 describes how the overlap trailing green feature works. When the overlap trailing green is used, the overlap phase will continue to display green for a pre-specified interval once the parent phase of the overlap has ended. Since the overlap trailing green is no longer locked to phase timing, it must be provided a separate yellow change and red clearance.

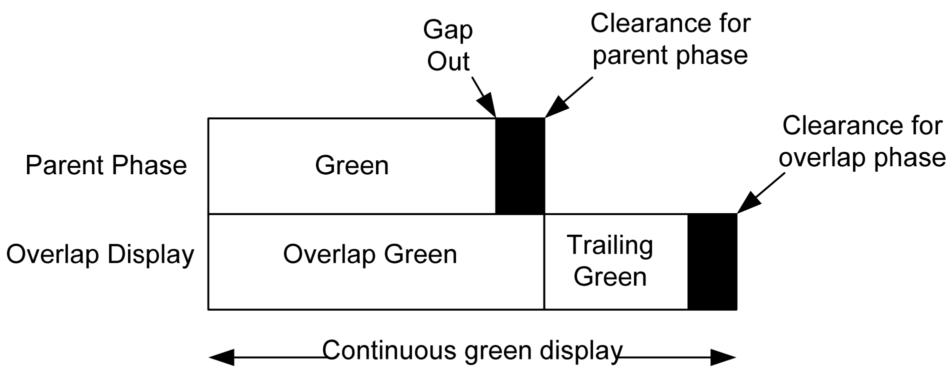


Figure 9. Overlap Trailing Green Feature.

Figure 10 shows one numbering scheme of phases used at wide-median intersections when protected left-turn phases are used on the major-street. This strategy uses an overlap on each side to clear the vehicles in the interior. Some districts have used two overlaps on each side to operate the interior as illustrated in Figure 11. Figure 12 shows the phase sequence with overlap trailing green, and Figure 13 shows the corresponding controller ring structure.

From Figure 10, Overlap A runs concurrently with the left-turn traffic from the major street (Phase 3). When the left-turn phase is terminated, the termination of the overlap green is delayed by specified amount to allow the left-turn traffic to proceed through the intersections. The trailing portion of Overlap A can run concurrently with non-conflicting phases such as Phase 8 provided that the demand for that phase exists. Similarly, the green termination of Overlap B is delayed by specified amount when Phase 2 is terminated to allow the through traffic from a minor street to proceed through the intersections without being stopped.

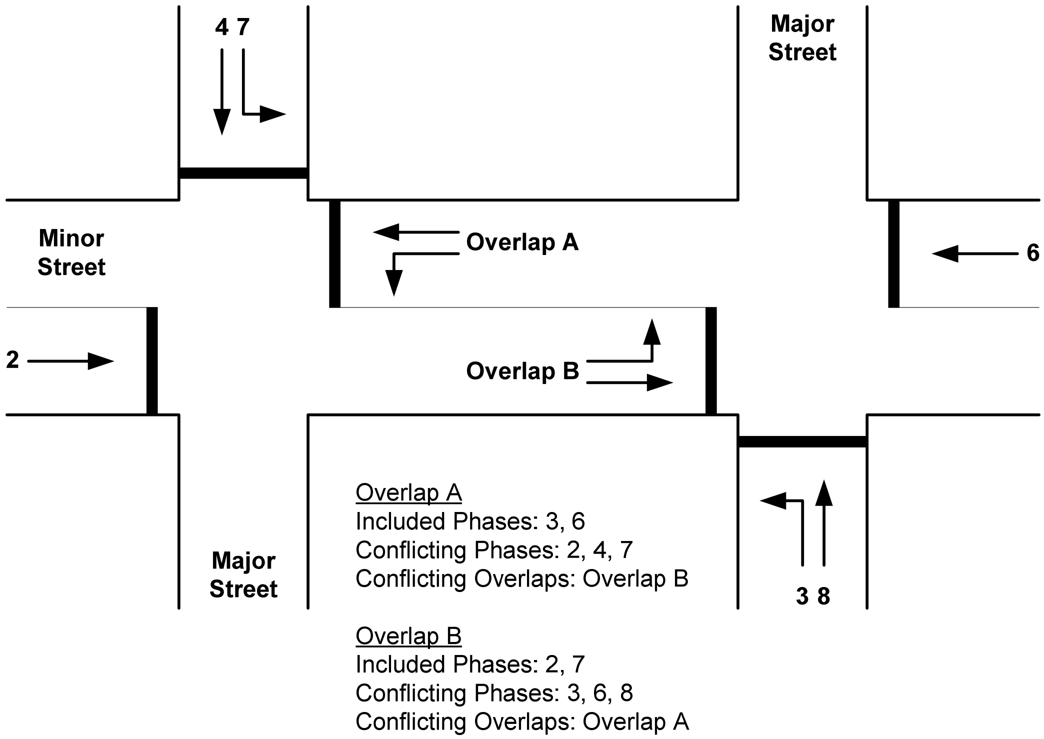


Figure 10. Numbering Scheme with Two Overlaps at Wide-Median Intersections.

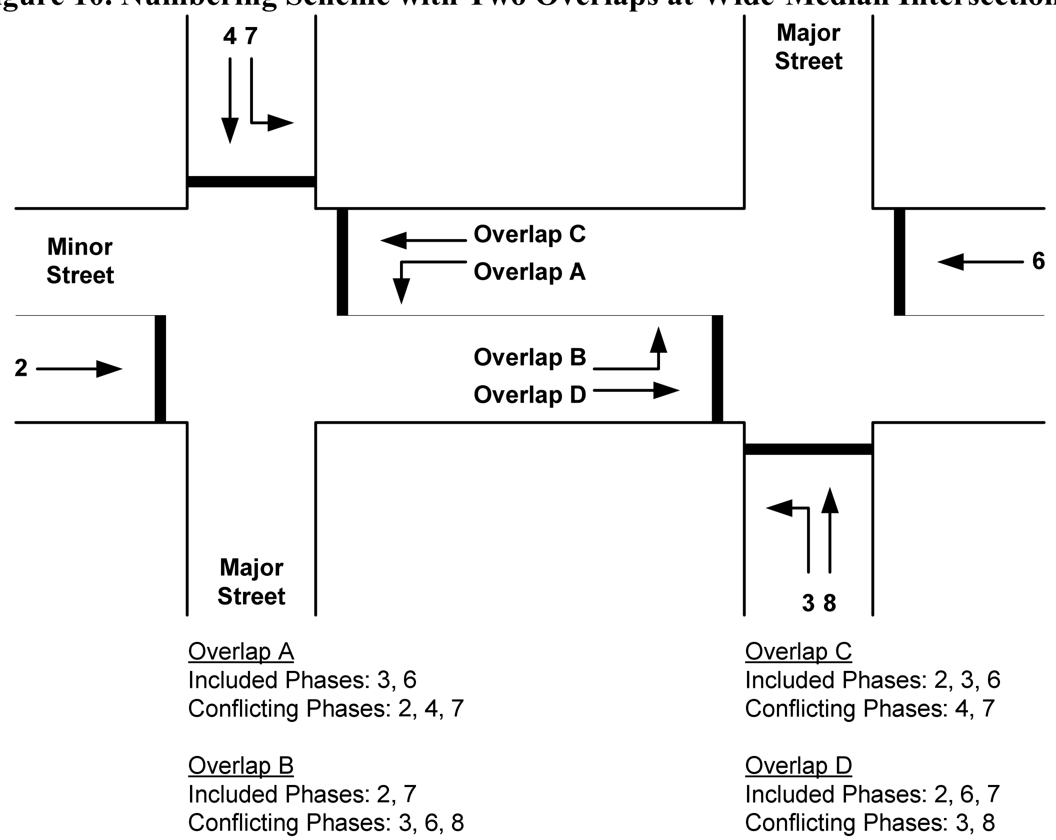
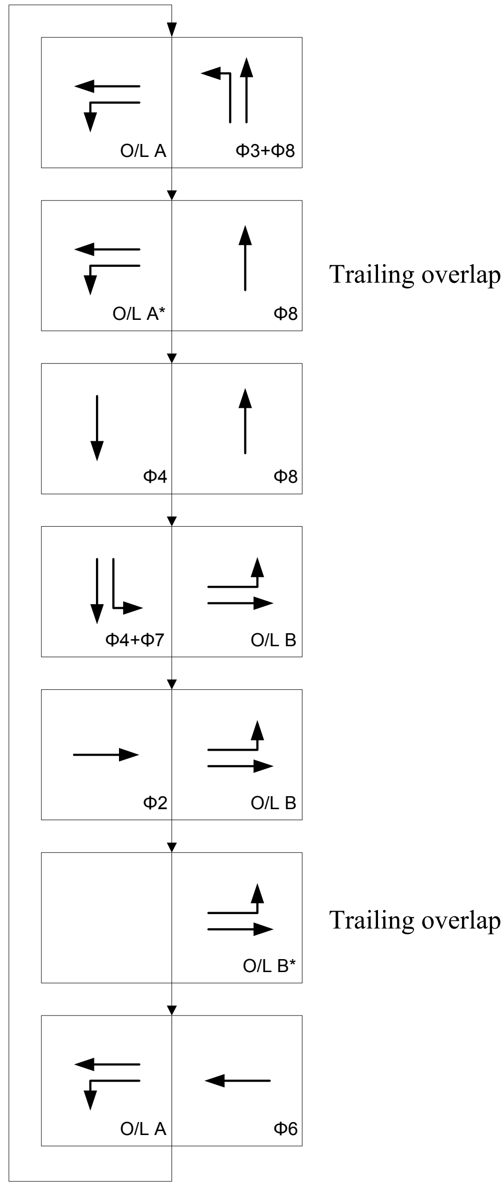


Figure 11. Numbering Scheme with Four Overlaps at Wide-Median Intersections.



* Trailing Portion of the Overlaps

Figure 12. Trailing Overlap Phase Sequence.

Φ3	Φ4	Φ2	Φ6
Φ8	Φ7		

Figure 13. Trailing Overlap Controller Ring Structure.

LIMITATIONS

Typically strategies are selected to serve the peak traffic conditions. However these strategies may not be very efficient during the off-peak conditions. The selection of the strategy depends on the intersection geometry, which includes the median width, the presence of left-turn bays on the major-street, the number of lanes in the interior, and the patterns of traffic volumes. Currently there are no specific guidelines to select the appropriate strategy. Hence, strategies are not selected and implemented in a consistent manner.

REVIEW OF CURRENT TXDOT PRACTICES

SUMMARY OF SURVEY RESULTS

To have a better understanding of TxDOT's practices, most of the districts were contacted and district traffic engineers were interviewed to document the operating practices at intersections with wide spacing. This section summarizes the findings of these interviews.

Out of the 24 districts contacted, 18 responded to the survey (a 75 percent success rate). Eleven out of the 18 districts that responded to the survey (about 60 percent) identified locations that were considered as "wide" intersections. The following gives a brief summary of the survey responses.

Definition of Wide Medians

Researchers initially classified wide medians as intersections with main street median width of 60 ft or greater to as much as 200 ft. After discussions with the districts, several other interpretations of "wide" were realized. These included the following:

- median width greater than 30 ft (in accordance with the *Manual of Uniform Traffic Control Devices* [MUTCD]),
- any intersection where a second mast arm is needed in the center of the intersection to meet distance requirements for head placement, and
- any intersection where a pedestrian refuge is needed in the middle of the intersection.

Timing Strategy

Three main timing strategies were identified from the survey results. These are:

- Typical four-phase diamond signal operation (with overlaps),
- NEMA four-phase/eight-phase operations with trailing overlap, and
- NEMA four-phase/eight-phase operations (without trailing overlap).

Trailing overlaps were used to ensure vehicles are not stuck in medians. Table 1 gives a summary of timing plans that were being used by the districts for various wide medians. Researchers made an attempt to check locations for median width and investigated to see if they fit the criteria for the project goals before being included in the list.

The eight-phase with overlap option differs from the diamond with overlap mainly because the main street operation has an exclusive phase for the left turning movement. The eight-phase with overlap typically featured a split phasing for the cross street traffic. The signal timing strategy reported by the responding agencies did suggest some consistency in timing plans currently being deployed for the wide median intersections.

Use of Section Heads

Generally, three- and five-section heads were used for interior left-turn movements. This was dependent on whether the left turns were protected only or protected and permissive, the latter operation requiring a five-section head configuration. However many intersections also used five-section heads for protected only operation. Of the 22 intersections listed in Table 1, only one of them had a three-section head for interior left turning movements. Hence from the survey results, most of the districts currently operate with five-section heads for interior left turning movements. One district did use three-section heads for all interior left turning movements. In addition, under the new revisions of MUTCD 2009, the option to use a separate signal head over the left-turn lane for protected/permissive or permissive only mode is no longer recommended.

Problems with Storage in Median

One of the responders mentioned having storage problems in the median. The majority of states that had wide medians did not have any such problems with storage in the medians. This was likely due to overlap phases and long clearance intervals employed to completely eliminate or reduce the number of vehicles being stored in the median between cycles.

Other Issues and Problems Identified at Such Wide Median Locations

There were a few other problems cited by survey responders as problematic at wide-median intersections. These included:

- some complaints about conflicting signal heads (drivers seeing a green indication at one intersection and a red indication at another). This complaint generally dissipates after the signal has been in operation for a while; and
- the location of these signals on high speed roadways and the inherent dangers associated with them.

Table 2 illustrates a sample of the questions that was used in the survey and details of the survey responses from the districts.

Table 1. Summary of Intersection Examples and Timing Strategy from Survey.

District	Intersection		Approach Speed (mph)	Section Head[1]	Median Width (feet)	Signal Timing Strategy
	Main Street	Cross Street				
Abilene	SH70	SH 92	< 45	5	150	NEMA 8-phase*
Bryan	US 290	Loop 577	> 45	5	120	NEMA 8-phase with trailing overlap
	SH 21	CR 300	> 45	NA		NEMA 8-phase
	SH 36/ US190	US 77	> 45	NA	60	NEMA 8-phase
	FM 2818	Beck Street Extension	> 45	5	110	NEMA 8-phase with trailing overlap
Dallas	US 287	SH 360	> 45	5	190	Diamond
	SH 114 at	Litsey	> 45	5	300	Diamond
Laredo	Loop 20	McPherson	60	5	220	Diamond
	Loop 20	International	60	5	220	NEMA 8-phase*
	FM 1472	Pan America	65	5	105	NEMA 8-phase
	FM 1472	Trade Center	60	5	95	NEMA 8-phase
	FM 1472	Muller	55	5	100	NEMA 8-phase*
San Antonio	US 90	FM 471	45	3	65	NEMA 8-phase
	Loop 1604	Potranco	55	5	135	NEMA 8-phase with trailing overlap
	Loop 1604	Marbach Rd	55	5	70	NEMA 8-phase with trailing overlap*
	Loop 1604	W Military	55	5	100	NEMA 8-phase with trailing overlap
	Loop 1604	Wiseman Blvd	55	5	100	NEMA 8-phase with trailing overlap
Yoakum	SH 35	SH 238	> 45		105	Diamond*
	SH 35	US 87	> 45	5	140	Diamond*
	SH 35	Travis St	< 45	5	105	Diamond*
	SH 35	FM 3084	< 45	5	120	Diamond*
	SH 35	FM 1090	< 45	5	120	Diamond*

* signal timing provided; [1] traffic signal section head for interior left turning movement
NA- information not applicable to intersection or not provided

Table 2. Questions Used for Discussion with the Districts.

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Questions for Discussion with Districts

1. Do you have any wide median intersections at signalized intersections in your district? ("wide" medians defined as any medians greater than 60 feet)

2. How many of such wide median intersections are located on:
   - High speed roads/rural – greater than 45 mph
   - Low speed roads/urban – less than 45 mph

3. How are these signals generally timed? (Is there a reason for the timing strategy deployed (volumes, approach speeds, median width, etc.?)
   - separate intersections with offset (similar to diamond interchange operations)/single intersections (potential for trapping vehicles in median)
   - presence or absence of left-turn phase
   - trailing overlap feature

4. What kind of section heads are used in the district for interior movements? (Is there a reason for the choice made?)
   - Three, four, or five section heads

5. Is it possible to obtain timing plans currently deployed at various wide median locations in your district?

6. Do you have any problems with storage within the median? (Do you utilize the storage within the median as part of whatever timing strategy you have running?)

7. Have you encountered any issues/problems with operating the current timing strategy at these intersections?
   - driver confusion with regards to operation
   - driver violations
   - safety/crash potential problems
   - timing difficulties

STUDY DESIGN

FACTORS AFFECTING CONTROL STRATEGIES

The objective of this task is to identify factors that would affect signal timing strategies at wide median intersections. Wide median intersections alternatively can be viewed as two closely spaced intersections. Under certain circumstances the signals can be operated in a manner similar to diamond interchanges. However, unlike diamond interchanges, these wide-median intersections generally have low- to moderate-volume traffic from minor streets instead of heavy-volume major-streets. Design and operation of traffic signals depend on numerous factors like traffic volumes and patterns, approach speeds, and sight distances, among others. These factors influence the type of left-turn treatment (protected, protected-permissive, or permissive) and left-turn phasing (lead-lead or lead-lag or lag-lag). At widely spaced intersections additional factors such as the median width, traffic volumes, and distribution of traffic movements at the intersections will influence the performance of signal operations.

Three main factors were identified based on the results of surveys sent out to several TxDOT districts and researcher experience. These factors and their potential impacts on signalization options for wide-median intersections are discussed in more details in the following sections. The following control strategies are discussed with the definition of median spacing widths ranging from a narrow that can be defined as 100 ft or lesser to wide (300 ft or lesser). The median width of 400 ft or greater is unusual for the types of intersections. Such median widths are more common for the diamond interchanges. Guidelines for operating diamond intersections are available from previous Texas Transportation Institute (TTI) research studies.

Median Width Spacing

Median width and traffic volumes influence the selection of the phasing strategy to operate the intersection. Median width has a direct impact on storage of vehicles in the median. Intersections with narrower medians can store fewer vehicles. It is critical that vehicles stored in the median do not back up into the upstream intersection.

There are numerous ways to operate a signal with wide medians. While some intersections have an exclusive phase for the left-turn movement from the major-street, some do not. Typically intersections with narrower medians tend to have a phase for the left-turn movement from the major-street (Figure 14). This is essential to meter the entry of vehicles into the median. Most intersections with wider medians do not have an exclusive phase for the left-turn movement from the major-street (Figure 15). Thus left-turn vehicles from the major-street turn into the median during the major-street phase and get stored.

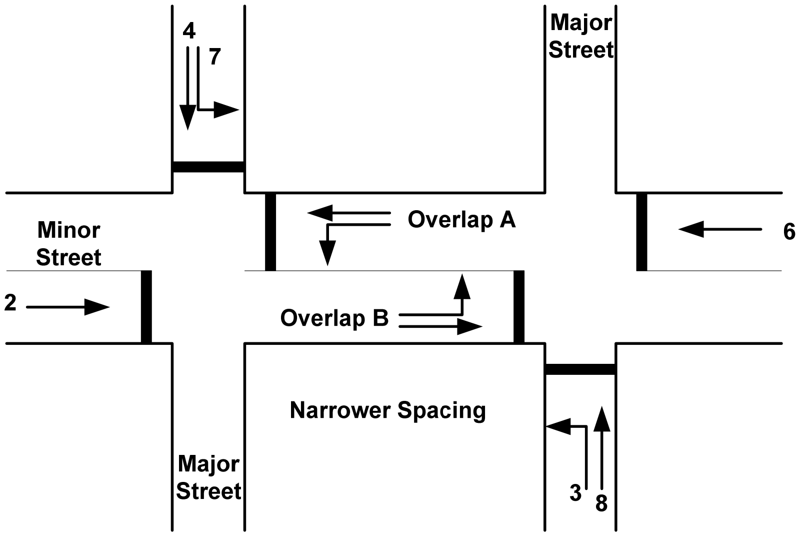

Figure 14. Intersection with an Exclusive Phase for Major-Street Left-Turn Movements.

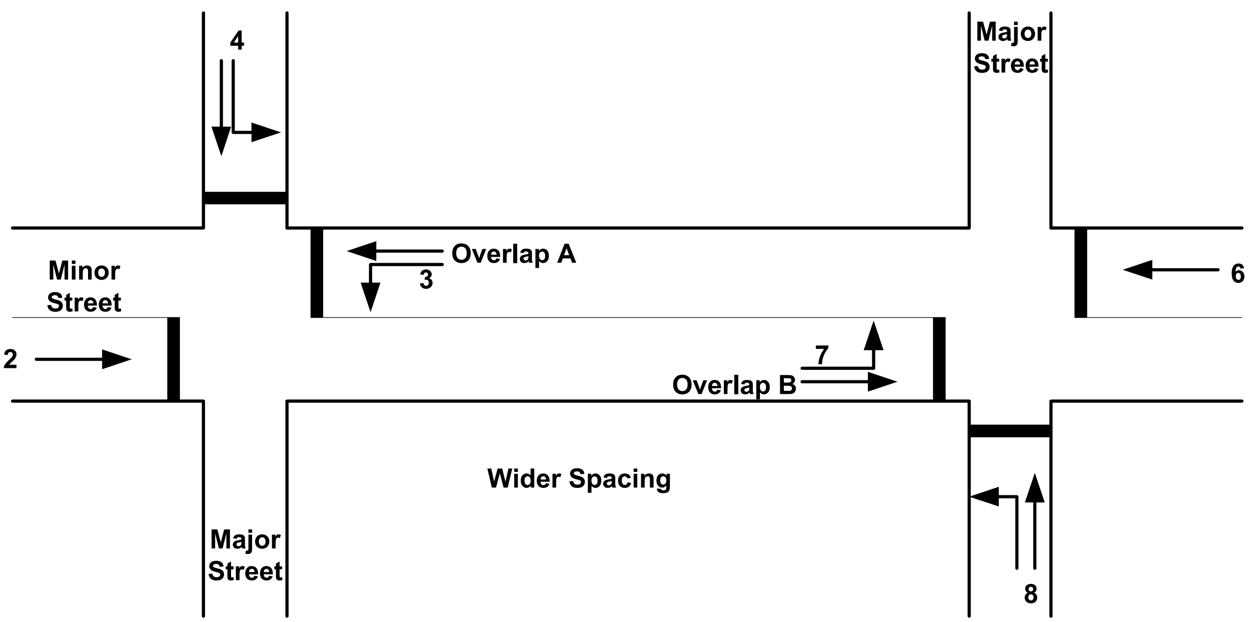

Figure 15. Intersection without an Exclusive Phase for Major-Street Left-Turn Movements.

Median width also impacts the time required to service each vehicle on the minor street. For example, as illustrated in Figure 15, a westbound left turning vehicle (Phase 6) at an intersection with a wider median requires a significantly longer time to clear the intersection when compared to a westbound left turning vehicle at an intersection with a narrower median. Hence, a single vehicle on the minor street can delay vehicles on the major street for a significant period. Among other techniques used when the major street have an exclusive phase for left turning traffic is lead-lag left-turn phasing and trailing overlaps.

Some districts have also experimented with the use of diamond phasing for operating such intersections. Based on the spacing and traffic characteristics, both four-phase and three-phase operations have been used. While in the diamond mode, it would also be possible to use the separate intersection mode and under certain circumstances, even two-phase operations may be applicable.

Traffic Volume

Traffic volumes and patterns influence the selection of the phasing strategy to operate the intersection. High left turning traffic volumes at wider medians will demand that interior left turning traffic be cleared during a cycle. Thus, a four-phase operation with overlaps or a trailing overlap phasing configuration will be needed to clear the interior movements during the cycle. However, if through movement volumes are also heavy, this may limit the amount of green available to the interior phases. Thus the traffic volumes for each movement at the intersection dictates to a large extent how much green time and hence phasing strategies will best suit that particular location. Similarly the type of vehicle arrival patterns on the minor street does have an impact on the strategy to be selected. Light but steady volumes on the minor street can cause frequent disruptions to the major street movements. Under such circumstances strategies that will minimize the onset of yellow for the high speed approaches should be identified.

Interior Lanes Geometry

The presence of an exclusive left-turn lane in the interior of a wide median intersection (illustrated in Figure 16) will determine to a large extent the kind of phasing for the interior movements. For example, a single lane for interior movements prohibits the operation of protected permissive phasing for interior left turns. Similarly, without the presence of an exclusive left-turn lane, some phasing strategies cannot be implemented.

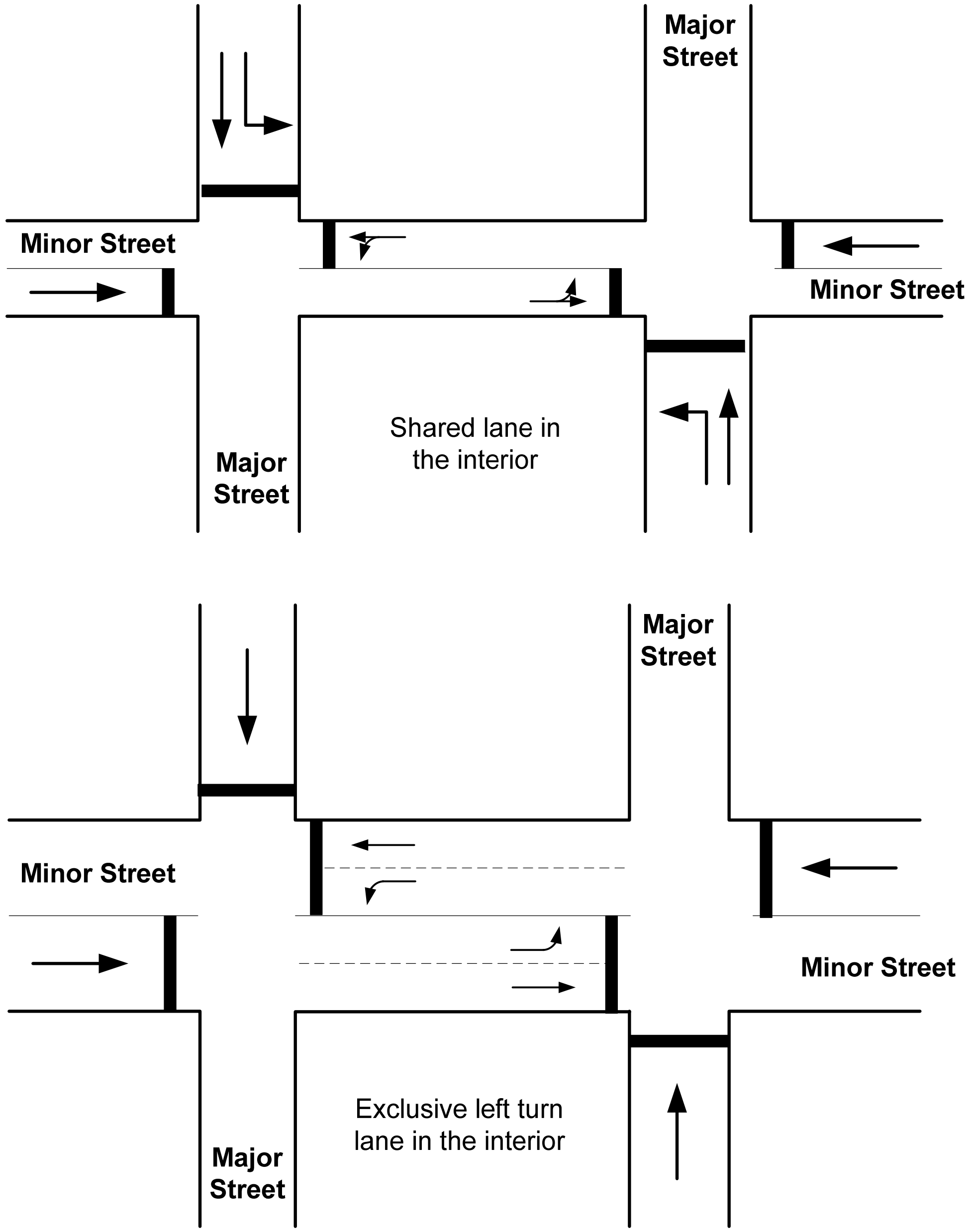

Figure 16. Impact of Interior Lane Geometry on Signal Phasing.

Detector Configuration

The nature of the main roadway approach detection has an impact on what timing strategies can be employed at a wide-median intersection. High-speed roadways (greater than 45 mph) tend to require some form of dilemma zone protection deployment on the approaches. This is usually in the form of multiple loops on the approach. However sometimes video detection is used that provides only stop bar detection. At intersections having a detector configuration for dilemma zone protection (as illustrated in Figure 17), strategies such as standard four-phase operation can be inefficient to operate without modifications.

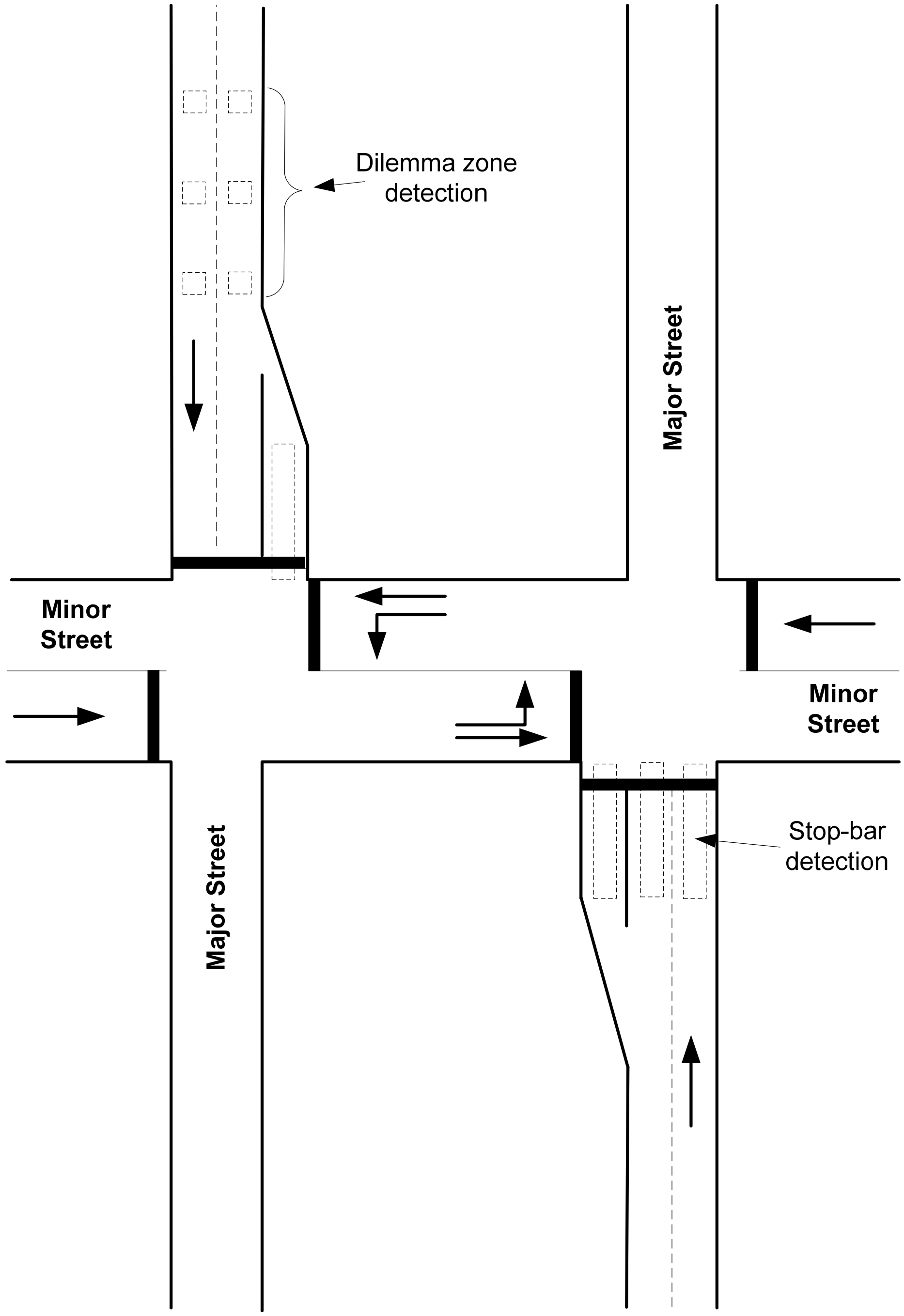

Figure 17. Types of Detector Configuration for Major Street Movement.

Additional Factors

Other factors like approach grade as well as percentage of trucks using the intersection will have an impact on strategies to be selected. From the system-wide perspective the need to maintain driver expectancy should be considered. From a corridor-wide perspective, the need to ensure design consistency may govern the choice of the timing strategies. For instance, in corridors that typically are operating four-phase (similar to diamond) operation along an entire corridor, the change to a three-phase might cause significant driver expectancy issues that needs to be addressed for example through prior education to the public.

DEVELOP CONTROL STRATEGIES

Previous chapters have documented the literature review for operating intersections with wide medians, TxDOT practices to operate such intersections, and factors affecting the operations of such intersections. This chapter examines the candidate control strategies for operating intersections with wide medians. Literature review as well as a review of TxDOT practices indicated some inconsistency in the use of exclusive left-turn phases on the major street. The literature also illustrated that strategies were categorized into either using the diamond mode or the non-diamond mode. Intersections using diamond interchange type of strategy will not have an exclusive phase for the left-turn movements. This section describes the strategies evaluated in this research, which include those in both diamond and non-diamond modes.

Diamond Interchange Mode

Diamond mode is considered as a strategy because it shares a lot of similarities with an intersection with wide medians. As illustrated in the literature review, an intersection can be operated either in the three-phase, four-phase, or separate intersection mode. Due to the strong likelihood of low volume conditions, researchers also evaluated a two-phase operation to operate these signals. Figure 18 illustrates the diamond interchange type phasing applied at an intersection with a wide median.

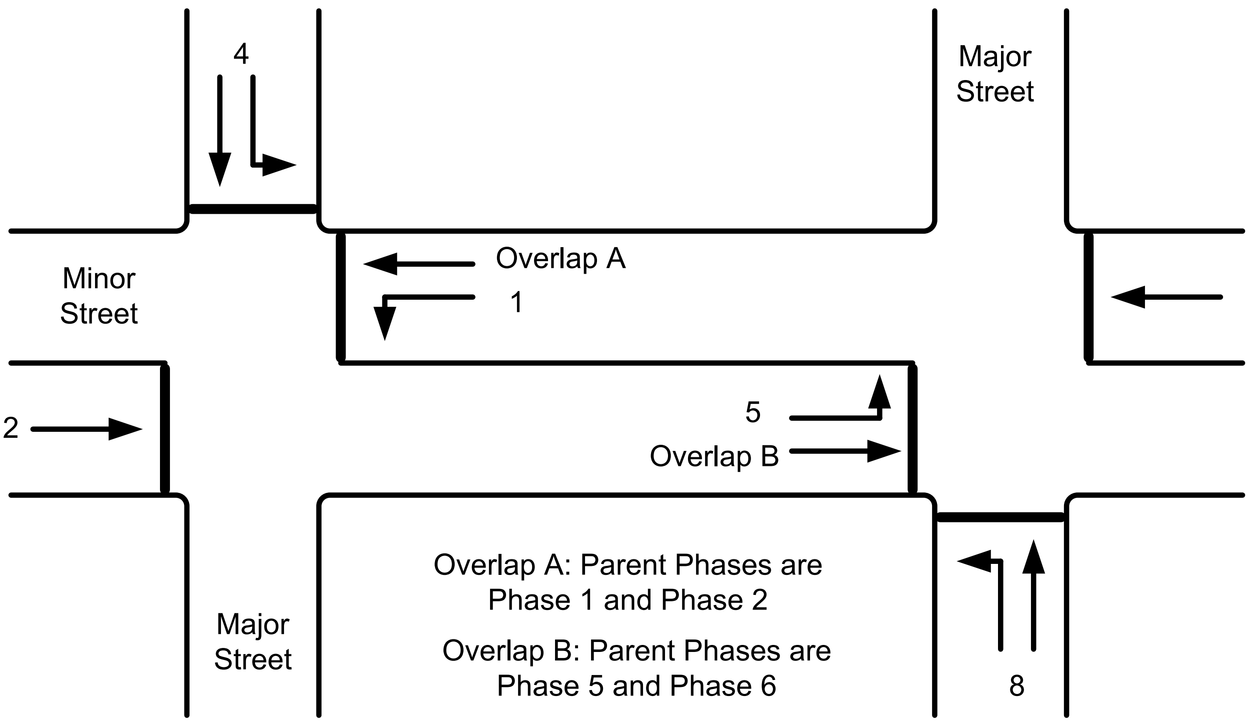

Figure 18. Diamond Interchange Type Phasing at a Wide Median Intersection.

Three-Phase Strategy

Three-phase strategy is typically used at diamond interchanges when the spacing between the freeway ramps is large. This facilitates storage of vehicles between the frontage roads. Three-phase strategy is also applicable at a diamond interchange when the demands on the frontage roads are approximately equal. These two characteristics of three-phase operation make this strategy potentially applicable for intersections with wide medians. Specifically, wide medians can allow for storage of vehicles. Secondly the major street approaches typically have equal demands, which again would suit a three-phase type operation.

However a three-phase type of operation can stack up vehicles in the interior. With limited storage, the interior queue can spill back into the upstream intersection. Secondly, a three-phase strategy tends to provide progression to the minor street by lagging the left-turn movements. Under low volume conditions, such a strategy can be inefficient. Researchers evaluated the three-phase strategy as illustrated in Figure 5 and Figure 19.

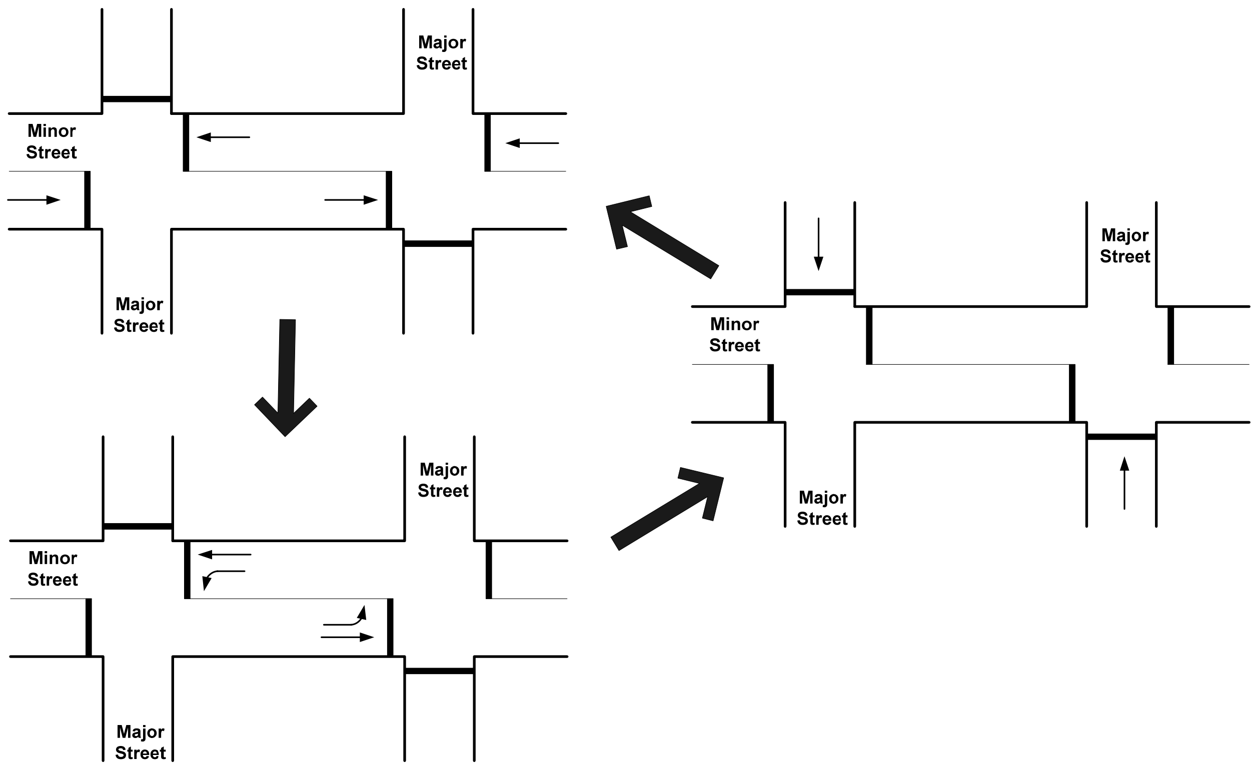

Figure 19. Three-Phase Strategy.

Four-Phase Strategy

A four-phase strategy is typically used at diamond interchanges in urban areas where the spacing between the ramps is limited. Thus it is imperative that the strategy does not store vehicles in the interior. A four-phase strategy treats the major street and minor-street approaches with equal importance and serves one movement at a time. This aspect of four-phase is efficient during a high percentage of turning traffic from the minor street. Four-phase also uses a fixed overlap interval. This fixed overlap is employed to improve efficiency during high-volume conditions by providing additional green time to the frontage traffic while the minor-street traffic is still traveling through the interior. This portion of overlap is roughly timed according the time it takes to travel through the spacing between the two intersections. Thus the four-phase strategy is very efficient during high volume conditions, with high turning percentages and narrow spacing between the intersections.

However, the main limitation of this strategy for operating wide-median intersections is similar to the limitation of three-phase strategy. Rural intersections are characterized by low volume conditions, and thus make the use of four-phase strategy very inefficient. However, in practice, it was discovered that some TxDOT districts do use four-phase operations to operate wide-median intersections. Thus TTI researchers evaluated the four-phase strategy as illustrated in Figure 20.

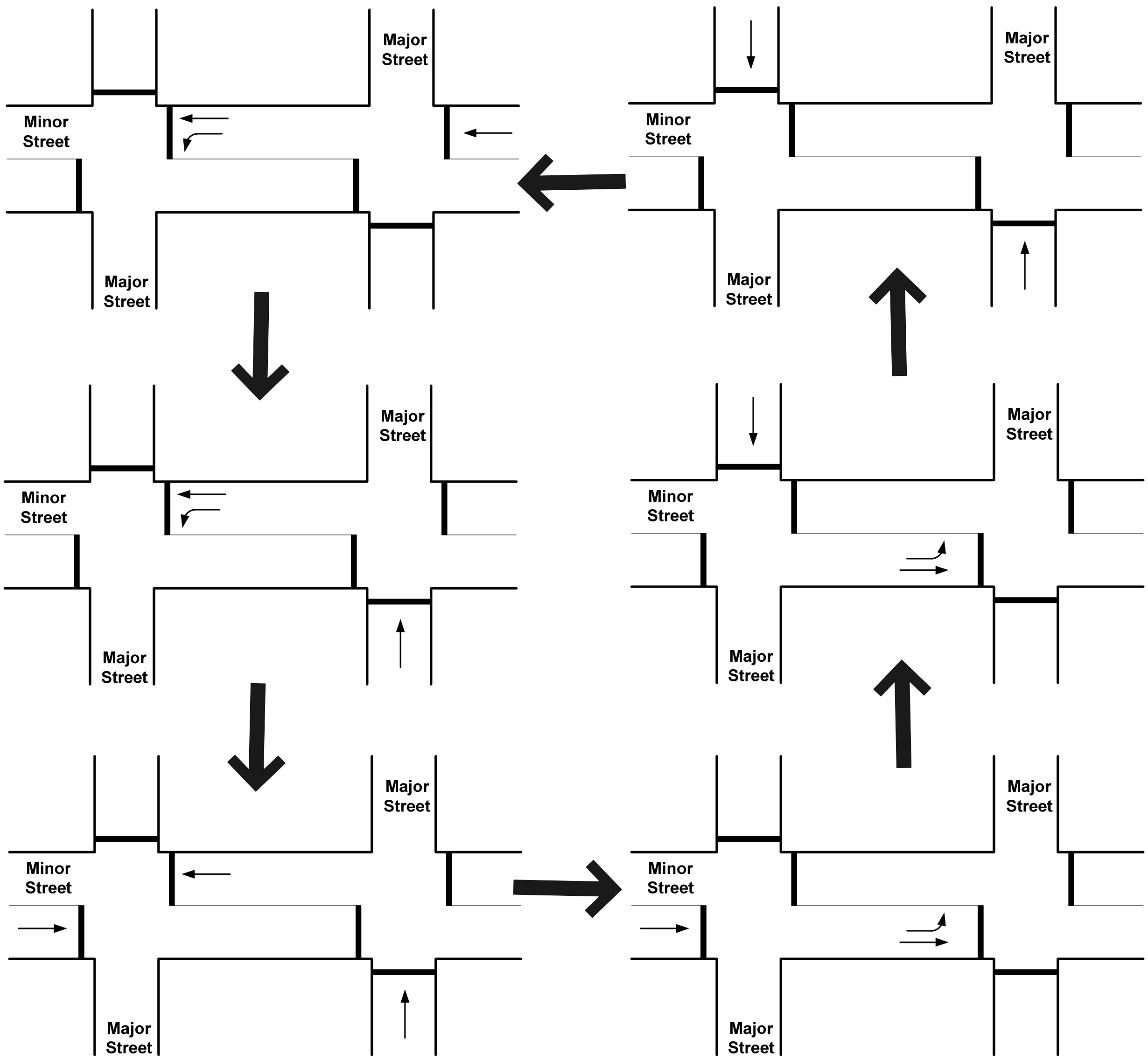

Figure 20. Four-Phase Strategy.

Separate Intersection Strategy

The separate intersection phasing strategy assigns one ring to control each intersection of the diamond interchange. Coordination between the two intersections is maintained by specifying a common cycle length and a fixed offset between the coordinated phases at each intersection. This offset is usually referred to as “ring lag.” This separate-intersection sequence is most effective at wide interchange with unbalanced traffic movements. This sequence typically provides a good progression for only one of the two minor-street through movements.

Two-Phase Strategy

Increasingly two-phase strategy is being investigated as an option at diamond interchanges during extremely low volume conditions like at night time. The strategy basically functions at locations where protected-permitted operation is implemented by omitting the left-turn phase by time of day. This strategy is particularly applicable where a separate intersection strategy is used. Other factors that influence the selection of two-phase strategy are the availability of good sight distance and adequate lighting at the intersection.

Non-Diamond Mode

At locations where the diamond mode is not used, the minor-street approaches have typically been operated in a split phase mode. This primarily has been done to account for the low volume nature of these intersections. In majority of such intersections a trailing overlap is used to keep the median clear of vehicles. Trailing overlap is a controller feature that is used to delay the green termination of the overlap. Overlaps are typically used to control the internal movements at the wide-median intersections. Trailing overlaps can provide the additional green time needed for the traffic from the external approaches to proceed through the intersections without being stopped between the two intersections. In the non-diamond mode, we will evaluate strategies utilizing split phasing with and without trailing overlaps.

We will also investigate multiple types of overlaps. Most of the TxDOT districts surveyed use a single overlap for both the left turn and through movements in the interior as illustrated in Figure 10. However some districts also use two overlaps as illustrated in Figure 11. Both these types of overlap configurations will be evaluated.

As stated earlier, most of the wide median intersections use split phasing with trailing overlaps. The phasing sequence used in this strategy can have an impact on the efficiency of signal operations. Figure 12 and Figure 13 illustrate an example of timing plans with split phasing using trailing overlaps. Split phasing strategy without trailing overlaps is very similar to separate intersection operations strategy and will not be further discussed here. However the strategy will be evaluated for intersections with wide medians to assess its effectiveness.

STRATEGIES EVALUATED

Previous sections have documented the literature review for operating intersections with wide medians, TxDOT practices to operate such intersections, factors affecting the operations of such intersections, and identified the control strategies that will be investigated to operate intersections with wide medians. Literature review as well as a review of TxDOT practices indicated some intersections use an exclusive phase for the left-turn movements from the major street while some intersections do not. The literature also illustrated that strategies were categorized into either using the diamond mode or the non-diamond mode. Diamond phasing was not used for cases with only a single lane in the interior as diamond operations require an exclusive left-turn phase for the interior and the lack of a turn bay precludes such a phasing. However when only a single lane is present in the interior, a four-phase type operation was simulated. This operation was simulated without the fixed intervals.

Preliminary evaluation of the strategies traditionally being used also indicated that the trailing overlap feature tends to be inefficient in many cases. These factors resulted in the selection of the control strategies illustrated in Table 3 for evaluation. Six strategies were evaluated for intersections with a single lane in the interior, and seven strategies were evaluated for intersections with more than two lanes in the interior of the intersection.

Table 3. Control Strategies Selected for Evaluation.

Single Lane in the Interior	Two Lanes in the Interior
Split phase	Split phase
Split phase with trailing overlap	Split phase with trailing overlap
Two-phase operation	Two-phase operation
Four-phase type operation without fixed intervals	Three-phase diamond operation
Split phase with separate major-street left-turn phase	Four-phase diamond operation
Split phase with separate major-street left-turn phase and a trailing overlap	Split phase with separate major-street left-turn phase
	Split phase with separate major-street left-turn phase and a trailing overlap

The signal operations were set up in VISSIM simulation software using Ring Barrier Controller (RBC) module. Figure 21 through Figure 29 summarize the phase assignment, detector mapping, and ring structure used to simulate different strategies evaluated in this study.

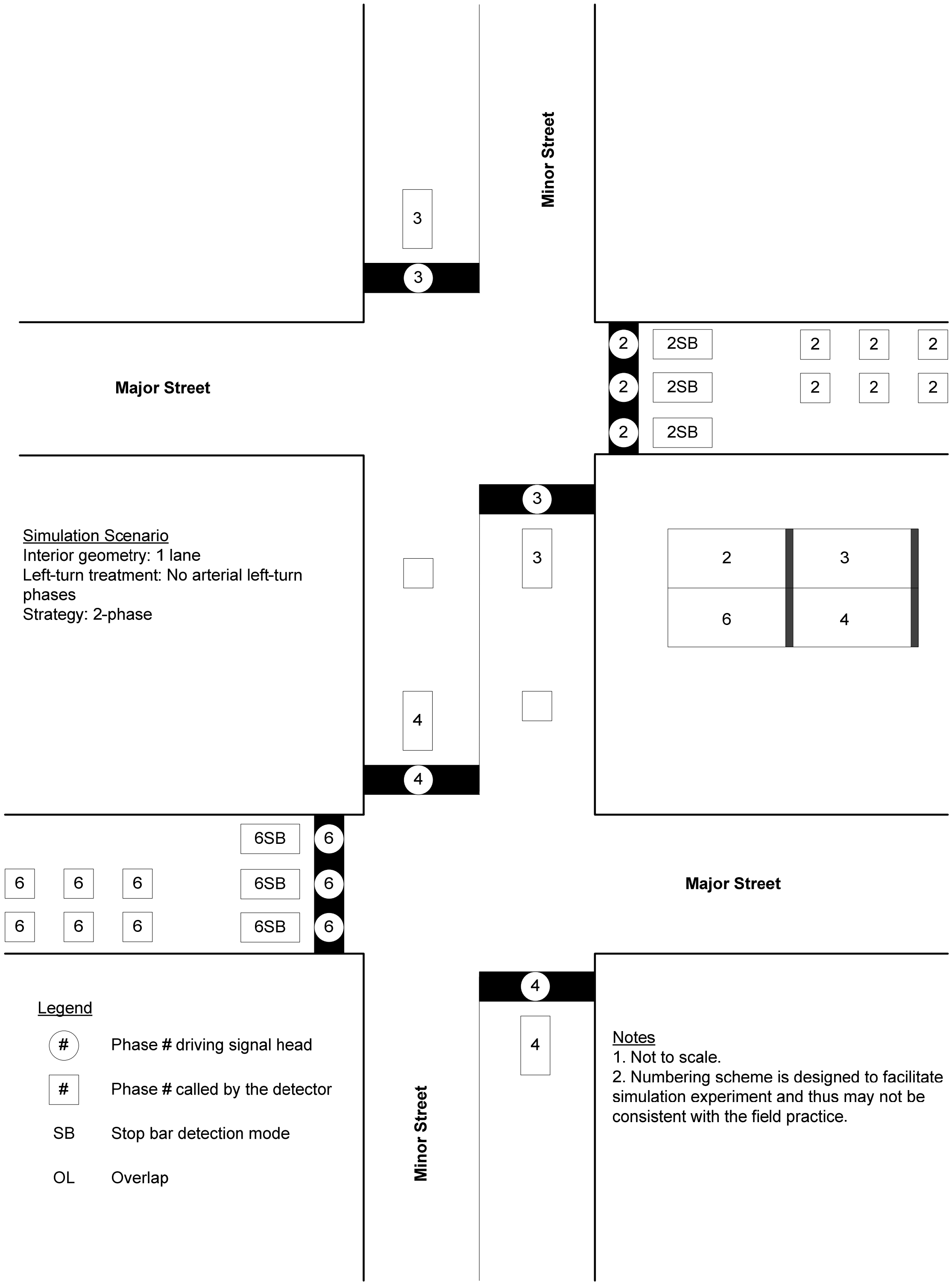

Figure 21. Two-Phase Strategy for 1-Lane Interior.

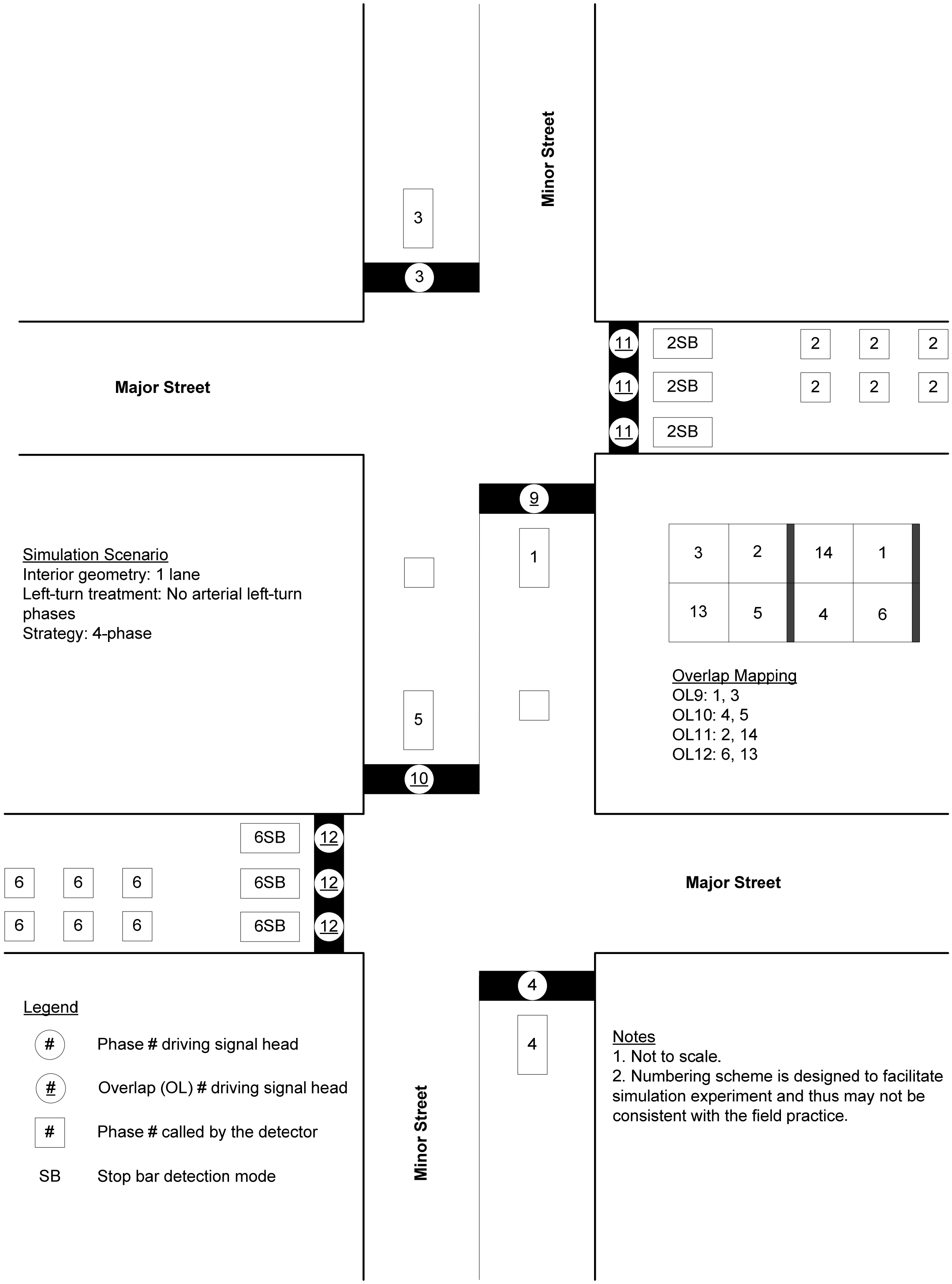

Figure 22. Four-Phase Strategy for 1-Lane Interior.

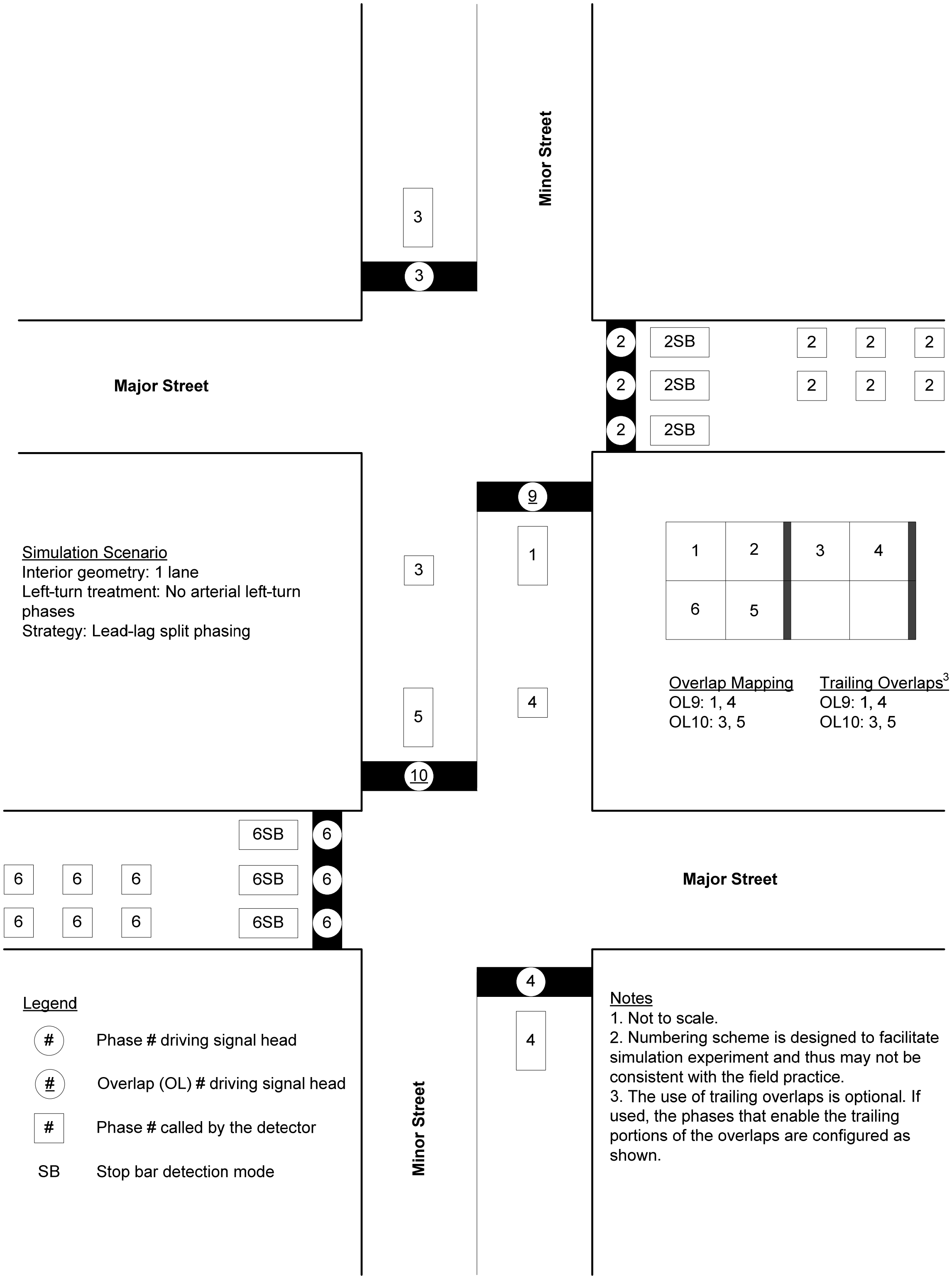

Figure 23. Lead-Lag Split Phasing for 1-Lane Interior without Major-Street Left-Turn Phase.

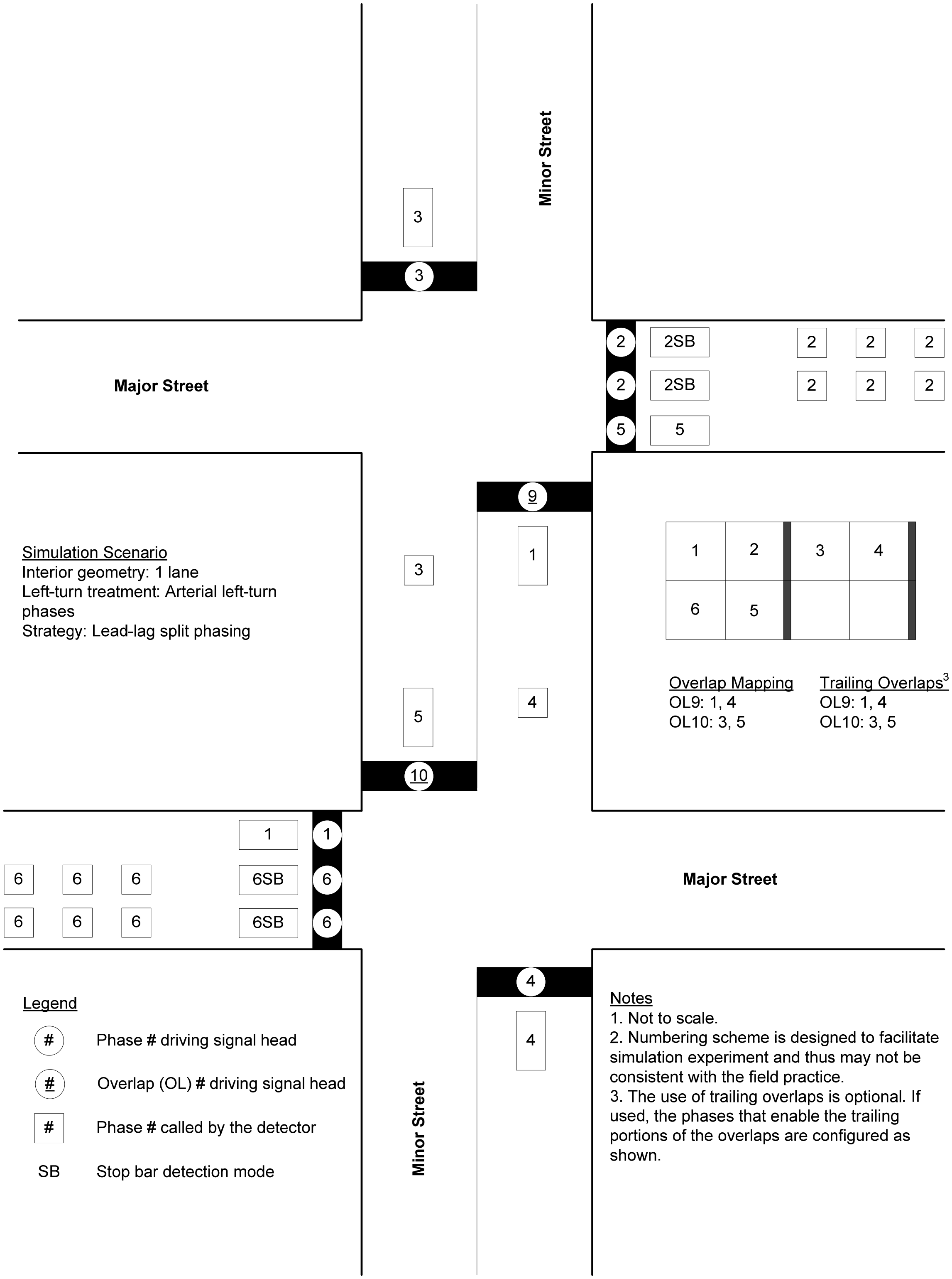

Figure 24. Lead-Lag Split Phasing for 1-Lane Interior with Major-Street Left-Turn Phase.

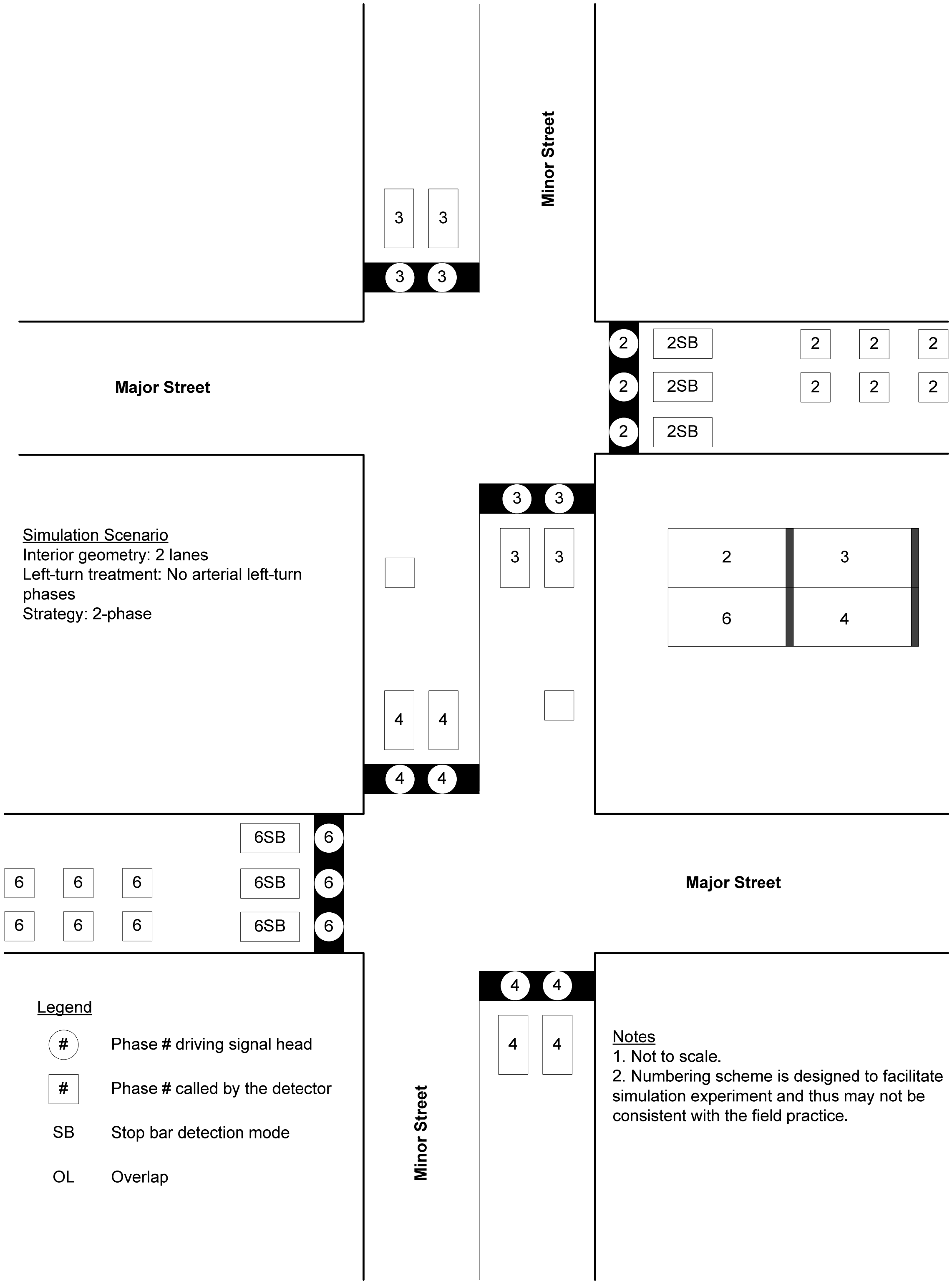

Figure 25. Two-Phase Strategy for 2-Lane Interior.

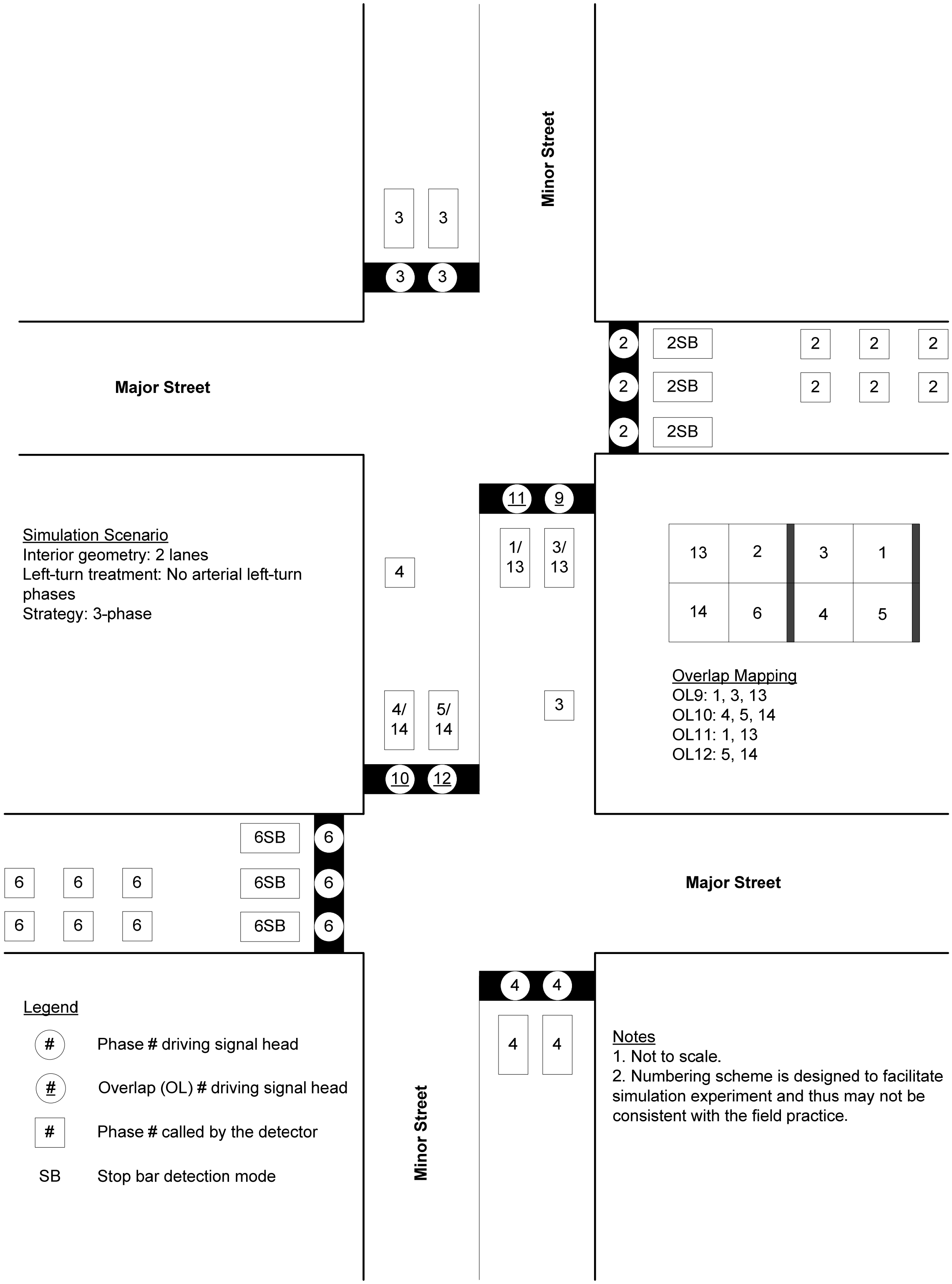

Figure 26. Three-Phase Strategy for 2-Lane Interior.

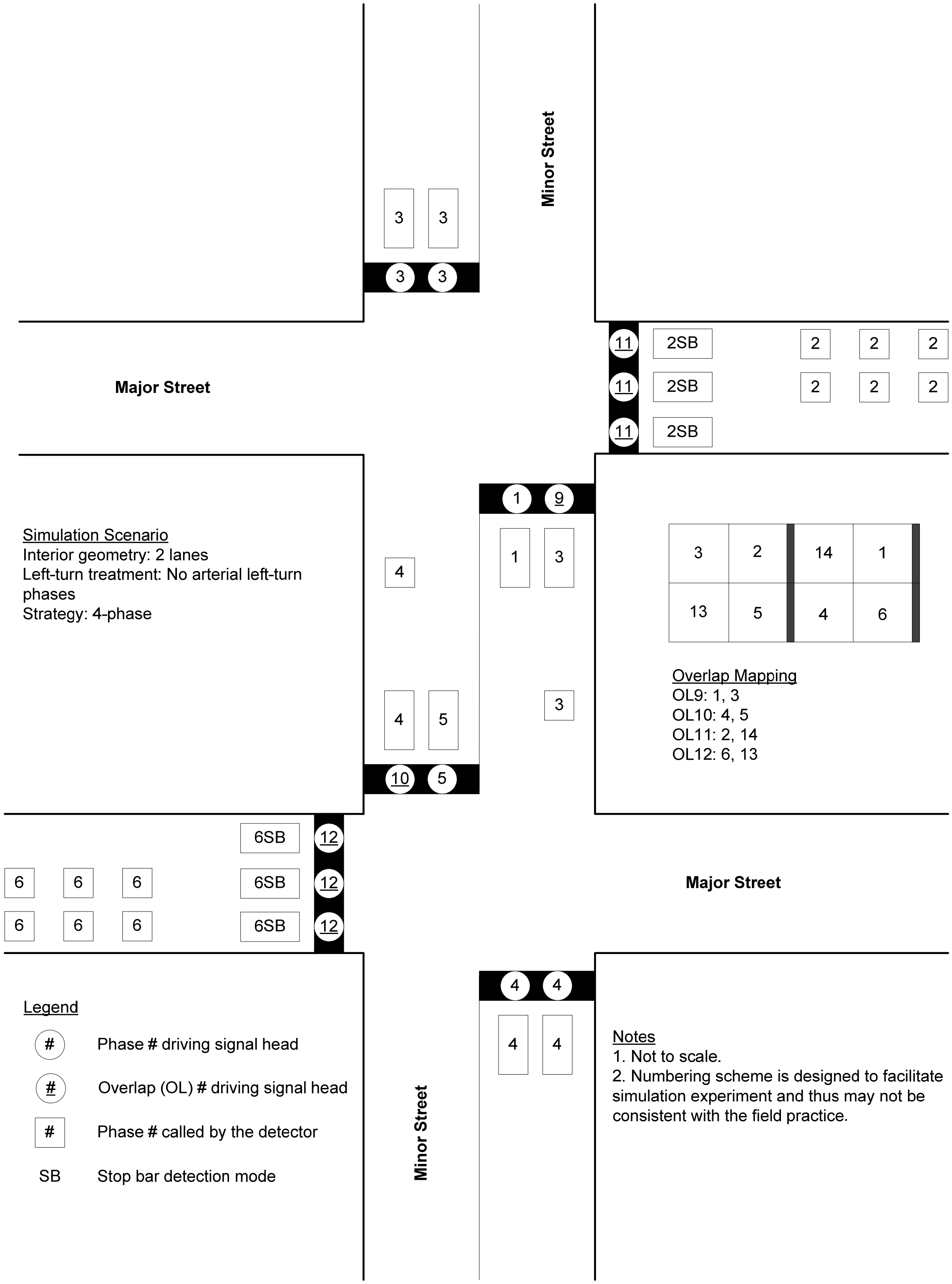

Figure 27. Four-Phase Strategy for 2-Lane Interior.

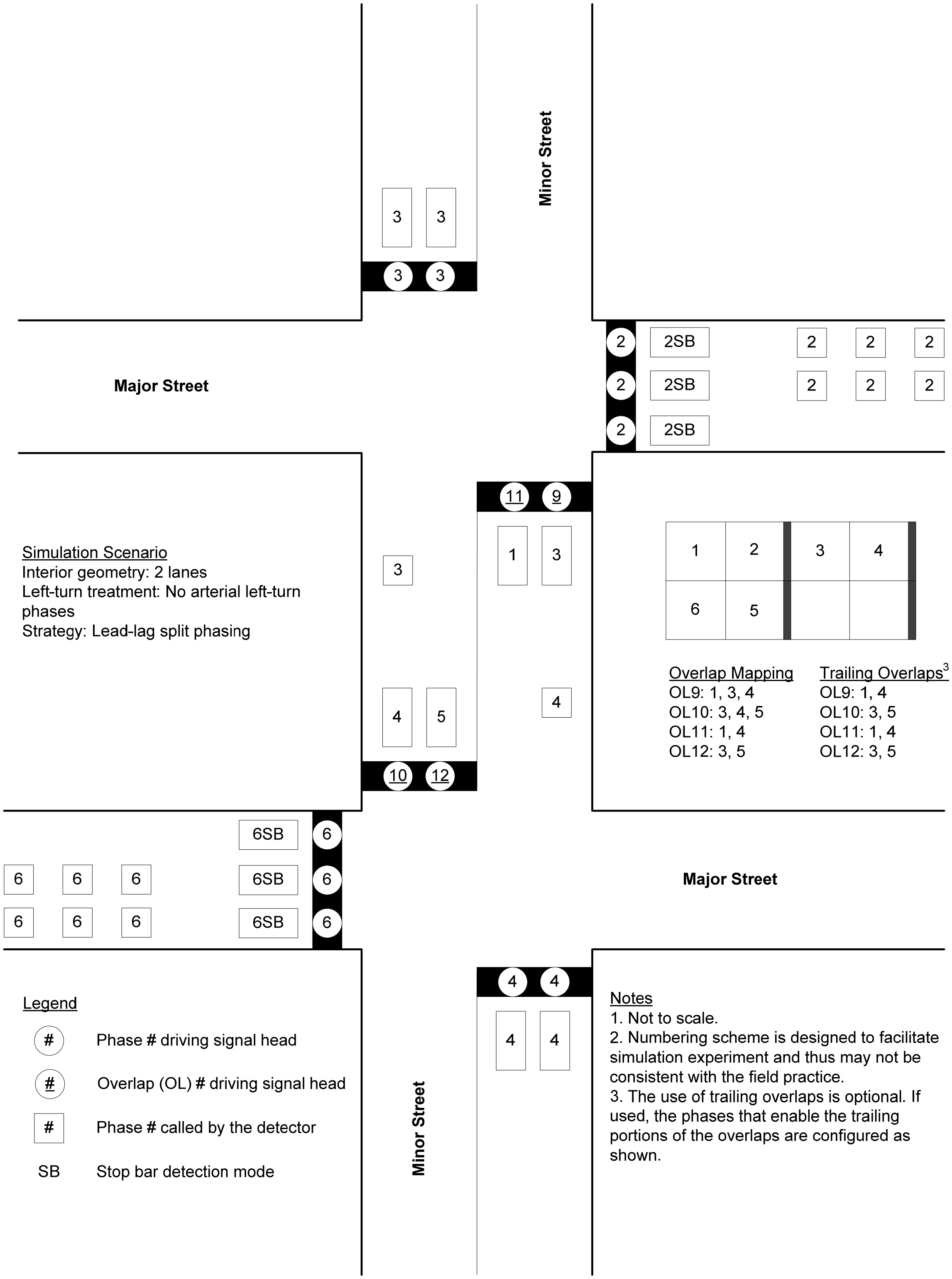

Figure 28. Lead-Lag Split Phasing for 2-Lane Interior without Major-Street Left-Turn Phase.

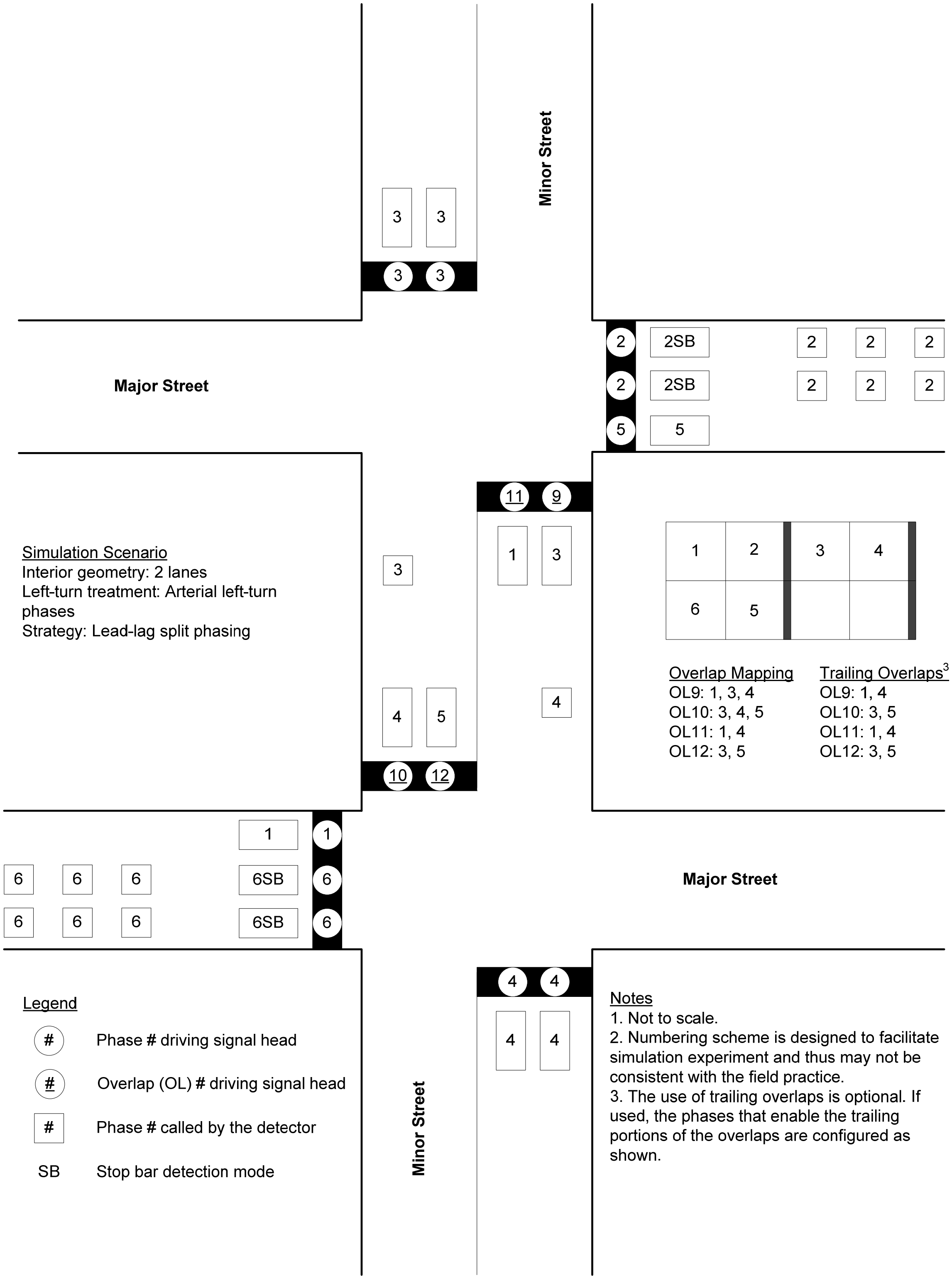

Figure 29. Lead-Lag Split Phasing for 2-Lane Interior with Major-Street Left-Turn Phase.

Figure 30 shows typical signal timing parameters that were configured similarly for all the movements in order for the observed measures of effectiveness (MOEs) to be comparable across different strategies. Special features such as trailing overlaps were configured as needed.

Basic

SG Number	1	2	3	4	5	6
SG Name						
Min Green	5	15	7	7	5	15
Veh Extension	1	2	3	3	1	2
Max 1	20	40	35	35	20	40
Yellow	3	5	3	3	3	5
Red Clear	1	3	1	1	1	3

Figure 30. Example of Typical Signal Timing Parameters Used in the Simulation.

SCENARIOS EVALUATED

The applicability of strategies is influenced by the intersection geometry as well as volumes. It is critical to select a strategy that would enable the engineer to operate the intersection during the peak as well as off-peak conditions. Ideally a strategy that would work for all operating conditions should be chosen. But it is very unlikely that one strategy would work for the entire day. Thus the operator will have to select strategies from a library of strategies that will be compatible with each other to switch back and forth based on varying volume conditions. The evaluation would thus cover a thorough range of geometric and volume scenarios for such intersections.

Volumes

The volumes along the major street ranged from 250 vehicles per hour to 1250 vehicles per hour to cover low volume as well as high volume conditions. Minor street volumes were varied as a percentage of the major street volumes from 10 percent to 30 percent. The turning percentages along the major street also varied from 5 percent to 15 percent. Turning percentages on the minor street were also varied to simulate low to high turning percentages. However, controls were established to maintain some consistency in the number of vehicles in the interior of the intersection. Table 4 illustrates the volume scenarios evaluated in the simulation model. These volumes are configured such that the traffic volumes using the interior are controlled across different scenarios. The traffic movements contributing to the interior volumes are major-street left-turn, major-street U-turn, minor-street through, and minor-street left-turn volumes. Three levels of interior volume were evaluated, which are 10 percent, 20 percent, and 30 percent.

Geometry

These intersections were evaluated using median widths of 100 ft, 200 ft, and 300 ft. Initially simulation runs were conducted with a single lane in the median in each direction for the minor street. Subsequently the simulation runs were repeated for the scenario with two lanes in the median (one lane for left-turning traffic) in each direction. Figure 31 illustrates these intersection layouts in VISSIM simulation model to simulate these scenarios. Each scenario in Table 4 was simulated with six random seed numbers. Hence over 10,000 simulation runs were made to simulate all volume, geometric, and operating strategies scenarios.

Table 4. Traffic Volume Scenarios Evaluated.

	Major	Major	Minor	Minor	Turning Movement													
Number	EB	WB	NB	SB	EBT	EBL	EBR	EBU	WBT	WBL	WBR	WBU	NBT	NBL	NBR	SBT	SBL	SBR
1	250	250	10%	10%	75%	10%	10%	5%	75%	10%	10%	5%	10%	60%	30%	10%	60%	30%
2	500	500	10%	10%	75%	10%	10%	5%	75%	10%	10%	5%	10%	60%	30%	10%	60%	30%
3	750	750	10%	10%	75%	10%	10%	5%	75%	10%	10%	5%	10%	60%	30%	10%	60%	30%
4	1000	1000	10%	10%	75%	10%	10%	5%	75%	10%	10%	5%	10%	60%	30%	10%	60%	30%
5	1250	1250	10%	10%	75%	10%	10%	5%	75%	10%	10%	5%	10%	60%	30%	10%	60%	30%
6	250	250	20%	20%	75%	10%	10%	5%	75%	10%	10%	5%	10%	35%	55%	10%	35%	55%
7	500	500	20%	20%	75%	10%	10%	5%	75%	10%	10%	5%	10%	35%	55%	10%	35%	55%
8	750	750	20%	20%	75%	10%	10%	5%	75%	10%	10%	5%	10%	35%	55%	10%	35%	55%
9	1000	1000	20%	20%	75%	10%	10%	5%	75%	10%	10%	5%	10%	35%	55%	10%	35%	55%
10	1250	1250	20%	20%	75%	10%	10%	5%	75%	10%	10%	5%	10%	35%	55%	10%	35%	55%
11	250	250	30%	30%	75%	10%	10%	5%	75%	10%	10%	5%	10%	27%	63%	10%	27%	63%
12	500	500	30%	30%	75%	10%	10%	5%	75%	10%	10%	5%	10%	27%	63%	10%	27%	63%
13	750	750	30%	30%	75%	10%	10%	5%	75%	10%	10%	5%	10%	27%	63%	10%	27%	63%
14	1000	1000	30%	30%	75%	10%	10%	5%	75%	10%	10%	5%	10%	27%	63%	10%	27%	63%
15	1250	1250	30%	30%	75%	10%	10%	5%	75%	10%	10%	5%	10%	27%	63%	10%	27%	63%
16	250	250	10%	10%	75%	5%	20%	0%	75%	5%	20%	0%	5%	55%	40%	5%	55%	40%
17	500	500	10%	10%	75%	5%	20%	0%	75%	5%	20%	0%	5%	55%	40%	5%	55%	40%
18	750	750	10%	10%	75%	5%	20%	0%	75%	5%	20%	0%	5%	55%	40%	5%	55%	40%
19	1000	1000	10%	10%	75%	5%	20%	0%	75%	5%	20%	0%	5%	55%	40%	5%	55%	40%
20	1250	1250	10%	10%	75%	5%	20%	0%	75%	5%	20%	0%	5%	55%	40%	5%	55%	40%
21	250	250	20%	20%	75%	5%	20%	0%	75%	5%	20%	0%	5%	30%	65%	5%	30%	65%
22	500	500	20%	20%	75%	5%	20%	0%	75%	5%	20%	0%	5%	30%	65%	5%	30%	65%
23	750	750	20%	20%	75%	5%	20%	0%	75%	5%	20%	0%	5%	30%	65%	5%	30%	65%
24	1000	1000	20%	20%	75%	5%	20%	0%	75%	5%	20%	0%	5%	30%	65%	5%	30%	65%
25	1250	1250	20%	20%	75%	5%	20%	0%	75%	5%	20%	0%	5%	30%	65%	5%	30%	65%
26	250	250	30%	30%	75%	5%	20%	0%	75%	5%	20%	0%	5%	22%	73%	5%	22%	73%
27	500	500	30%	30%	75%	5%	20%	0%	75%	5%	20%	0%	5%	22%	73%	5%	22%	73%
28	750	750	30%	30%	75%	5%	20%	0%	75%	5%	20%	0%	5%	22%	73%	5%	22%	73%
29	1000	1000	30%	30%	75%	5%	20%	0%	75%	5%	20%	0%	5%	22%	73%	5%	22%	73%
30	1250	1250	30%	30%	75%	5%	20%	0%	75%	5%	20%	0%	5%	22%	73%	5%	22%	73%
31	250	250	10%	10%	65%	15%	10%	10%	65%	15%	10%	10%	15%	65%	20%	15%	65%	20%
32	500	500	10%	10%	65%	15%	10%	10%	65%	15%	10%	10%	15%	65%	20%	15%	65%	20%
33	750	750	10%	10%	65%	15%	10%	10%	65%	15%	10%	10%	15%	65%	20%	15%	65%	20%
34	1000	1000	10%	10%	65%	15%	10%	10%	65%	15%	10%	10%	15%	65%	20%	15%	65%	20%
35	1250	1250	10%	10%	65%	15%	10%	10%	65%	15%	10%	10%	15%	65%	20%	15%	65%	20%
36	250	250	20%	20%	65%	15%	10%	10%	65%	15%	10%	10%	15%	40%	45%	15%	40%	45%
37	500	500	20%	20%	65%	15%	10%	10%	65%	15%	10%	10%	15%	40%	45%	15%	40%	45%
38	750	750	20%	20%	65%	15%	10%	10%	65%	15%	10%	10%	15%	40%	45%	15%	40%	45%
39	1000	1000	20%	20%	65%	15%	10%	10%	65%	15%	10%	10%	15%	40%	45%	15%	40%	45%
40	1250	1250	20%	20%	65%	15%	10%	10%	65%	15%	10%	10%	15%	40%	45%	15%	40%	45%
41	250	250	30%	30%	65%	15%	10%	10%	65%	15%	10%	10%	15%	32%	53%	15%	32%	53%
42	500	500	30%	30%	65%	15%	10%	10%	65%	15%	10%	10%	15%	32%	53%	15%	32%	53%
43	750	750	30%	30%	65%	15%	10%	10%	65%	15%	10%	10%	15%	32%	53%	15%	32%	53%
44	1000	1000	30%	30%	65%	15%	10%	10%	65%	15%	10%	10%	15%	32%	53%	15%	32%	53%
45	1250	1250	30%	30%	65%	15%	10%	10%	65%	15%	10%	10%	15%	32%	53%	15%	32%	53%

Figure 31. Simulation Run in the VISSIM Simuation Model.

EVALUATION AND CONCLUSION

The results of the simulation runs were evaluated for minimizing delays and queue lengths. Control delays experienced by vehicles for the major-streets as well as the entire intersection were recorded. Queue lengths were recorded for the interior links as well as the major-street approaches to evaluate the storage utilization factor. The storage utilization factor was calculated by dividing the 95th percentile queue length with the available storage space (i.e., the median width and the length of left-turn bay for the interior and major-street left-turn queues, respectively). The collected MOEs were intersection delay and queue length. The results from the same scenario were normalized across all the strategies evaluated. Table 5 illustrates the format of the preliminary results from the simulation study. The value of 1.00 implies the lowest value observed for the scenario; in other words, the strategy produces the lowest delay or the shortest queue length. The normalized values greater than 1.00 indicate a relative percentage to the best MOEs. For example, the delay index of 1.20 indicates that the delay for such strategy is 20 percent higher than the best case observed for the scenario.

Table 5. Format of Preliminary Results for the Simulation Study.

Network Setup (100ft, 1-lane interior)								Delay Comparison Index - Intersection					
	Arterial Tot	Minor of Arterial	Arterial Thru	Arterial Left	Arterial Right	Arterial U-Turn	Interior of Tot	Trail	Split	2 phase	3 phase	4 phase	4 phase wo FI*
Scenario 1	250	10%	75%	10%	10%	5%	20%	1.06	1.04	1.00	1.09	1.27	1.27
Scenario 2	500	10%	75%	10%	10%	5%	20%	21.20	1.00	1.03	1.35	1.34	1.34
Scenario 3	750	10%	75%	10%	10%	5%	20%	1.69	1.00	1.45	2.35	1.44	1.44
Scenario 4	1000	10%	75%	10%	10%	5%	20%	3.69	1.00	4.54	6.41	1.55	1.55
Scenario 5	1250	10%	75%	10%	10%	5%	20%	6.70	1.00	6.98	9.79	1.64	1.64
Scenario 6	250	20%	75%	10%	10%	5%	20%	1.17	1.06	1.00	1.19	1.41	1.41
Scenario 7	500	20%	75%	10%	10%	5%	20%	1.36	1.00	1.02	1.51	1.36	1.36
Scenario 8	750	20%	75%	10%	10%	5%	20%	1.82	1.00	1.40	5.23	1.45	1.45
Scenario 9	1000	20%	75%	10%	10%	5%	20%	3.94	1.00	4.30	6.80	1.54	1.54
Scenario 10	1250	20%	75%	10%	10%	5%	20%	6.29	1.00	6.13	10.35	1.78	1.78
Scenario 11	250	30%	75%	10%	10%	5%	20%	1.25	1.06	1.00	1.19	1.43	1.43
Scenario 12	500	30%	75%	10%	10%	5%	20%	1.45	1.04	1.00	1.77	1.45	1.45
Scenario 13	750	30%	75%	10%	10%	5%	20%	1.96	1.00	1.29	5.61	1.47	1.47
Scenario 14	1000	30%	75%	10%	10%	5%	20%	3.59	1.00	3.81	7.19	1.49	1.49
Scenario 15	1250	30%	75%	10%	10%	5%	20%	5.05	1.00	4.69	8.01	1.64	1.64

*- four-phase strategy without fixed overlap intervals, which is similar to split phasing on all approaches

RESULTS

Table 6 illustrates the results of evaluation of all strategies for different volume and geometric scenarios. The simulation results resulted in the following findings.

- **Trailing overlaps tend to increase overall delay**. Trailing overlap is a very common feature used at intersections with wide medians. This feature ensures that no vehicles are stored in the interior. However in lower volume conditions, this can be inefficient. Table 6 illustrates that only for intersections with small medians (100-ft wide), for extremely high volumes (1250 vph), and high turning/cross street traffic (30 percent) trailing overlap was found to be more efficient than other strategies. Thus trailing overlap should be used sparingly.
- **Two-phase operations for low volumes**. Table 6 also illustrates that a two-phase operation seems to be recommended for most of the scenarios. The recommendation for two-phase operation increases as the median width increases. While two-phase was recommended for most of the cases when the median width is 300 ft, it is recommended for about half of the cases when the median width is a 100 ft. Within a certain median width two-phase operation is not recommended for higher volumes. Thus it can be stated that under high volume and small median spacing, a two-phase operation is not recommended. For cases of narrow medians and high turning percentages, it is recommended to use either a major-street left-turn phase or use four-phase operation. In some cases right of way may not be available for have a left-turn lane. Then four-phase operation is the only strategy recommended. However when there is only a single lane in the interior, a four-phase operation is not possible. In such cases, a four-phase type operation without the fixed intervals is recommended.
- **Phasing sequence using a major-street left-turn phase.** Due to geometric limitations, lead-lag phasing is recommended for intersection with wide medians having exclusive major-street left-turn phases. This will avoid conflict between these two movements. However, simulation studies have found that the heavier left-turn movement should lag the lighter left-turn movement.

CONCLUSIONS

Table 6 serves as a guide to select the appropriate operating strategy for various geometric and traffic conditions. However, traffic conditions change throughout the day. Thus more than one strategy may have to be selected. Strategies should be selected such that engineers can switch to the other appropriate strategies for other times of the day.

This project specifically examined signal timing strategies for intersections with wide medians. The one-year time frame allowed us to focus more on signal timing issues and less on signal design issues. The scope of this project emphasized the signal operational guidance rather than the signal design guidance, which becomes complicated for intersections with medians of 30 to 100 ft. However, the operational guidance for intersections with less than 100 ft of median width would be the same as those recommended for 100 ft. The future research should focus on the design guidance for such intersections including the applicability of additional mast arms in the medians and the use of internal clearances or all-red intervals. Other issues to consider include the limitations of using four-phase operations for intersections with such medians widths (30 ft to 100 ft), confusion caused to motorists turning from the major-street when the mast arm is located in the median, and warrants for using protected or protected/permissive operations for the minor street. Given the resources available for this one-year project, researchers focused on developing the guidance on the signal timings for this type of intersections. Nevertheless, the engineers must also consider the signal design issues and exercise their engineering judgment in designing such intersections.

Table 6. Recommended Strategies.

1-Lane, 100 ft	% Interior Traffic*			1-Lane, 200 ft	% Interior Traffic*			1-Lane, 300 ft	% Interior Traffic*		
Volume	10%	20%	30%	Volume	10%	20%	30%	Volume	10%	20%	30%
250	2P, SP	2P, SP	SP, 2P	250	2P	2P	2P, SP	250	2P	2P	2P
500	2P, SP	SP, 2P	SP, 2P	500	2P	2P	2P, SP	500	2P	2P	2P
750	2P	SP, 2P	SPL, 4PO	750	2P	2P	2P, SPL	750	2P	2P	2P
1000	2P	4PO, SPL	4PO	1000	2P	2P	SPL, 4PO	1000	2P	2P	4PO
1250	2P	4PO, SPL	4PO	1250	2P	2P	4PO	1250	2P	2P	4PO

*Major LT + Minor Thru/LT (all three panels)

2-Lane, 100 ft	% Interior Traffic*			2-Lane, 200 ft	% Interior Traffic*			2-Lane, 300 ft	% Interior Traffic*		
Volume	10%	20%	30%	Volume	10%	20%	30%	Volume	10%	20%	30%
250	2P	2P	2P	250	2P, SP	2P	2P	250	SP	2P	2P
500	2P	2P	2P	500	2P	2P	2P	500	2P	2P	2P
750	2P	2P	4P	750	2P	2P	2P	750	2P	2P	2P
1000	2P	2P, 4P	4P	1000	2P	2P	4P	1000	2P	2P	2P
1250	2P	4P	TRL, 4P	1250	2P	2P	SPL, 4P	1250	2P	2P	4P

*Major LT + Minor Thru/LT (all three panels)

Strategies Legend

2P	Two Phase
3P	Three Phase
4P	Four Phase
4PO	Four Phase with Fixed Transition Intervals Omitted
SP	Split Phasing
TR	Split Phasing with Trailing Overlaps
SPL	Split Phasing with Separate Major-Street Left-Turn Phase
TRL	Split Phasing with Trailing Overlaps and Separate Major-Street Left-Turn Phase

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APPENDIX - GUIDELINES FOR OPERATING WIDELY SPACED INTERSECTIONS

STRATEGIES EVALUATED

In this study, TTI researchers documented the literature review for operating intersections with wide medians, reviewed TxDOT practices to operate such intersections, identified factors affecting the operations of such intersections, performed the evaluation and then identified the control strategies appropriate for operating intersections with wide medians under a variety of scenarios. Literature review as well as a review of TxDOT practices indicated some intersections use an exclusive phase for the left-turn movements from the major street while some intersections do not. The literature also illustrated that strategies were categorized into either using the diamond mode or the non-diamond mode. Intersections using a diamond interchange type of strategy will not have an exclusive phase for the left-turn movements. Evaluation of the strategies traditionally being used also indicated that the trailing overlap feature tends to be inefficient in many cases. These factors resulted in the selection of the following control strategies for evaluation.

Single Lane in the Interior in Each Approach

- Split phase
- Split phase with trailing overlap
- Two-phase operation
- Four-phase type operation without fixed intervals
- Split phase with separate arterial left-turn phase
- Split phase with separate arterial left-turn phase and a trailing overlap

Two Lanes in the Interior in Each Approach

- Split phase
- Split phase with trailing overlap
- Two-phase operation
- Three-phase diamond operation
- Four-phase diamond operation
- Split phase with separate arterial left-turn phase
- Split phase with separate arterial left-turn phase and a trailing overlap

RESULTS

TTI researchers used various volumes, median widths, and turning percentages for evaluating each of the strategies listed above. The volumes along the major street ranged from 250 vehicles per hour to 1250 vehicles per hour to cover low volume as well as high volume conditions. The turning percentages along with minor street volumes were varied to evaluate the impact of the volume changes along the minor movements on the major street movements and in-turn the strategies to be selected. Finally these intersections were evaluated using median widths of 100 ft, 200 ft, and 300 ft. Table A-1 illustrates the results of evaluation of all strategies for different volume and geometric scenarios.

Table A-1. Results of the Evaluation of Strategies.

1-Lane, 100 ft				1-Lane, 200 ft				1-Lane, 300 ft			
	% Interior Traffic*				% Interior Traffic*				% Interior Traffic*		
Volume	10%	20%	30%	**Volume**	10%	20%	30%	**Volume**	10%	20%	30%
250	2P, SP	2P, SP	SP, 2P	250	2P	2P	2P, SP	250	2P	2P	2P
500	2P, SP	SP, 2P	SP, 2P	500	2P	2P	2P, SP	500	2P	2P	2P
750	2P	SP, 2P	SPL, 4PO	750	2P	2P	2P, SPL	750	2P	2P	2P
1000	2P	4PO, SPL	4PO	1000	2P	2P	SPL, 4PO	1000	2P	2P	4PO
1250	2P	4PO, SPL	4PO	1250	2P	2P	4PO	1250	2P	2P	4PO
*Arterial LT + Minor Thru/LT				*Arterial LT + Minor Thru/LT				*Arterial LT + Minor Thru/LT			

2-Lane, 100 ft				2-Lane, 200 ft				2-Lane, 300 ft			
	% Interior Traffic*				% Interior Traffic*				% Interior Traffic*		
Volume	10%	20%	30%	**Volume**	10%	20%	30%	**Volume**	10%	20%	30%
250	2P	2P	2P	250	2P, SP	2P	2P	250	SP	2P	2P
500	2P	2P	2P	500	2P	2P	2P	500	2P	2P	2P
750	2P	2P	4P	750	2P	2P	2P	750	2P	2P	2P
1000	2P	2P, 4P	4P	1000	2P	2P	4P	1000	2P	2P	2P
1250	2P	4P	TRL, 4P	1250	2P	2P	SPL, 4P	1250	2P	2P	4P
*Arterial LT + Minor Thru/LT				*Arterial LT + Minor Thru/LT				*Arterial LT + Minor Thru/LT			

Strategies Legend

2P	Two Phase
3P	Three Phase
4P	Four Phase
4PO	Four Phase with Fixed Transition Intervals Omitted
SP	Split Phasing
TR	Split Phasing with Trailing Overlaps
SPL	Split Phasing with Separate Arterial Left-Turn Phase
TRL	Split Phasing with Trailing Overlaps and Separate Arterial Left-Turn Phase

VISSIM simulation model was used to simulate these scenarios. Each scenario was simulated with six random seed numbers. Hence overall almost 10,000 simulation runs were made. The simulation results resulted in the following findings.

Trailing Overlaps Tend to Increase Overall Delay

Trailing overlap is a very common feature used at intersections with wide medians. This feature ensures that no vehicles are stored in the interior. However in lower volume conditions, this can be inefficient. Table A-1 illustrates that only for intersections with small medians (100 ft wide), for extremely high volumes (1250 vph), and high turning/cross street traffic (30 percent) trailing overlap was found to be more efficient than other strategies. Thus trailing overlap should be used sparingly.

Two-Phase Operations for Low Volumes

Table A-1 also illustrates that two-phase operation seems to be recommended for most of the scenarios. The recommendation tends to favor the two-phase operation as the median width increases. While two-phase was recommended for most of the cases when the median width is 300 ft, it is recommended for about half of the cases when the median width is a 100 ft. Within a certain median width two-phase operation is more appropriate for lower volumes. Thus it can be stated that for intersections with small median spacing having high volumes, a two-phase operation is not recommended. For cases of narrow medians and high turning percentages, it is recommended to use either an arterial left-turn phase or use four-phase operation. In some cases right of way may not be available for have a left-turn lane. Then four-phase operation is the only strategy recommended. However when there is only a single lane in the interior, standard four-phase operation with fixed intervals is not possible due to the potential rear-end collisions between left turn and through traffic in the interior. In such cases, four-phase type operation without the fixed intervals is recommended. This strategy is also called split phasing on all four approaches.

Phasing Sequence Using an Arterial Left-Turn Phase

Due to geometric limitations, lead-lag phasing is recommended for intersections with a wide median having exclusive arterial left-turn phases. This will avoid conflict between these two movements. However, simulation studies have found that the heavier left-turn movement should lag the lighter left-turn movement.

CONCLUSIONS

Table A-1 serves as a guide to select the appropriate operating strategy for various geometric and traffic conditions. However, traffic conditions change throughout the day. Thus more than one strategy may have to be selected. Strategies should be selected such that it will be possible to switch to the other appropriate strategies for other times of the day. Table A-2 illustrates the suggested strategies for various median spacing, volume levels, and turning percentages. Local traffic engineers can select either from the diamond mode or the non-diamond mode (only non-diamond mode if a single lane in the interior) and if necessary select a strategy by time of day to maximize efficiency and minimize delay.

Table A-2. Suggested Strategies to be Used for Various Median Width, Volume Levels, and Turning Percentages.

Lanes in the interior	Volume	Turning Traffic	100 ft width		200 ft width		300 ft width	
			Non-diamond	Diamond	Non-diamond	Diamond	Non-diamond	Diamond
1	Low	Low	2P	None	2P	None	2P	None
		High	2P		SP		2P	
	Medium	Low	2P		2P		2P	
		High	4PO		2P		2P	
	High	Low	2P		2P		2P	
		High	4PO		4PO		4PO	
2	Low	Low	2P	2P*	2P	2P*	SP	2P*
		High	2P	2P*	2P	2P*	2P	2P*
	Medium	Low	2P	2P*	2P	2P*	2P	2P*
		High	TRL	4P	2P	2P*	2P	2P*
	High	Low	2P	4P	2P	2P*	2P	2P*
		High	TRL	4P	SPL	4P		4P

2P*- two-phase operations using separate intersection mode within the diamond mode