

# Left-turn Treatment Guidelines for Signalized Intersections



## Note

This document provides guidance for the treatment of left-turn movements at existing and proposed traffic signal installations. This is based on a combination of guidance from NCHRP Report 457, the ITE Traffic Engineering Handbook, and our own experience and practices. As the document stresses, the guidance is not intended to be used in a "cookie cutter" fashion and engineering judgment should be used in all cases.

July 2023

CDOT HQ Traffic Safety & Engineering Branch

## INTRODUCTION

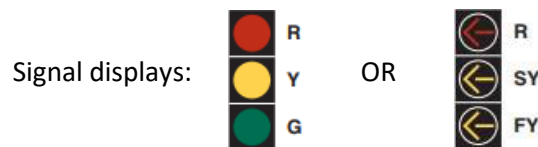
A lack of statewide left-turn phasing guidance may lead to inconsistencies and variations in left-turn phasing mode decisions across each Region and the state. Generally, left-turn phasing mode selection should not be solely based on a quantitative evaluation; engineering judgment plays a significant role in all left-turn phasing mode selection decisions.

This document is intended to serve as guidance on left-turn phasing mode selection. This guidance is not meant to establish a prescriptive methodology for determination of left-turn phasing mode selection. Rather, it is meant to provide a framework for consideration by the engineer when evaluating the factors that influence left-turn mode selection.

The Manual on Uniform Traffic Control Devices (MUTCD) defines four left-turn phasing modes:

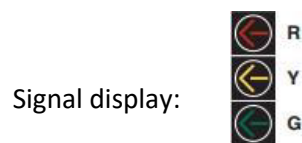
### PERMISSIVE MODE

Turns are made only on a CIRCULAR GREEN signal indication, a flashing left-turn YELLOW ARROW signal indication, or a flashing left-turn RED ARROW signal indication after yielding to pedestrians, if any, and/or opposing traffic, if any. Turning vehicles may enter and occupy the intersection in a space not conflicting with opposing traffic during a CIRCULAR GREEN or FLASHING YELLOW signal indication while yielding to opposing traffic or pedestrians and depart the intersection under any signal indication if no conflicts exist.



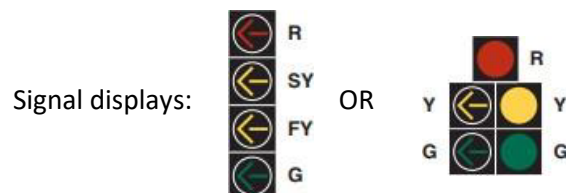
### PROTECTED-ONLY MODE

Turns are made only when a left-turn GREEN ARROW signal indication is displayed. Turning vehicles may not enter the intersection at any other time.




### PROTECTED-PERMITTED MODE

Both PROTECTED and PERMISSIVE modes occur on an approach during the same cycle. Turns are made either when a left-turn GREEN ARROW signal is displayed or on a CIRCULAR GREEN signal indication, a flashing left-turn YELLOW ARROW signal indication, or a flashing left-turn RED ARROW signal indication after yielding to pedestrians, if any, and/or opposing traffic, if any.



## VARIABLE LEFT-TURN MODE

The operating mode changes among the PROTECTED ONLY mode and/or the PROTECTED-PERMITTED mode and/or the PERMISSIVE mode during different periods of the day or as traffic conditions change. This configuration is typically used to address crash patterns that have a time of day pattern or provide a protected pedestrian interval.

Signal display:  (Flashing yellow indication is omitted during protected-only operation; solid green indication is omitted during permissive-only operation)

It is not necessary that the same mode of left-turn operation or same type of left-turn signal face be used on every approach to a signalized location. Selecting different modes and types of left-turn signal faces for various approaches to the same signalized location is acceptable. However, it is recommended that signal faces with left-turn phasing on opposing approaches follow the same layout to avoid confusion for drivers. In any case, the MUTCD should be followed when determining left-turn signal faces for specific situations.

### ADVANTAGES / DISADVANTAGES OF LEFT-TURN PHASING

Proper selection of left-turn phasing mode is important for a number of reasons, including:

- **Permissive-Only** left-turn operation may reduce delay for the intersection, but may adversely affect intersection safety, because it relies on motorists' ability to choose acceptable gaps.
- **Protected-Only** left-turn phases are likely to increase overall intersection delay but improve safety for left-turning vehicles by eliminating the need to find gaps in opposing traffic.
- **Protected-Permissive** left-turn phases can offer a good compromise between safety and efficiency but could limit available options to maximize signal progression during coordination unless flashing yellow arrow left-turn displays are used.

### WHEN SHOULD A SIGNAL EVALUATION OCCUR?

Determining the appropriate time to evaluate a traffic signal using the criteria laid out in this document will typically fall under several categories. The following are recommendations to promote a guided approach to choosing the correct time to evaluate an intersection:

- Crash rates at an intersection are known to be high.
- A new signal is being installed at an intersection.
- Intersection geometry has been updated.
- Surrounding land use or population has dramatically changed.
- Public complaints for a particular intersection are numerous.

It should be noted that evaluation of an intersection based on the above recommendations could potentially occur in quick succession if strictly adhered to. It is therefore recommended that intersections not be evaluated more than once every three years. This will also provide opportunity for evaluating other intersections that meet these criteria without spending a disproportionate amount of time on any individual intersection.

## **SELECTION OF LEFT-TURN PHASING MODE**

Left-turn phasing mode selection should not be a solely threshold-based quantitative evaluation of measurable inputs. Although in some cases this guidance refers to discrete values and specific thresholds, engineering judgment plays a role in all left-turn phasing mode selection decisions. The main goals of providing safety and efficiency should provide direction for the personnel responsible for selecting left-turn phasing. The satisfaction of a particular value or threshold shall not in itself require the installation of a particular left-turn phasing mode. However, by following the guidance in this document, engineers will be working within a common framework when making left-turn phasing mode decisions.

This document lays out overall general guidance and two distinct use cases under which left-turn phasing would likely be evaluated. The general guidance includes safety criteria to be applied to any signal being evaluated. Many of the safety criteria are implemented as proactive measures to prevent accidents from occurring. The first use case is used to evaluate an intersection with an existing signal but no left-turn phases. These criteria are volume and delay driven. The second use case is used to evaluate an intersection with protected-permitted phasing for the purposes of applying protected-only phasing. The criteria for this case are driven by crash data based on Level of Service of Safety (LOSS). This criteria is useful for all types of intersections and applies data calibrated for Colorado crash history. This ensures dangerous intersections that may not experience high crash rates (rural intersections for example) are still considered for protected-only left-turn phasing.

Summaries of each case are provided below:

### **SAFETY CRITERIA: EVALUATION FOR ALL SIGNALS**

Any existing or planned traffic signal being evaluated for left-turn phasing should go through the safety evaluation. This includes criteria such as intersection geometry, existing or planned pedestrian/bicycle facilities, and accident threshold criteria.

### **CASE 1: EXISTING SIGNAL WITHOUT LEFT-TURN PHASING**

Use the criteria for this case to guide the decision of whether or not to provide protected-permitted phasing at an intersection that does not currently have left-turn phasing for an existing signal. This case will most likely cover intersections in areas that have seen increased congestion issues due to increased demand.

### **CASE 2: EXISTING SIGNAL WITH PROTECTED-PERMITTED LEFT-TURN PHASING**

Use the criteria for this case to guide decisions of whether or not to provide protected-only left-turn phasing at an intersection that has protected-permitted left-turn phasing. This case will most likely cover intersections that see repeated complaints to improve safety that may not be addressed in the Safety Criteria or Case 1. Examples include intersections where accidents might occur at rates that do not meet the typical crash criteria, but are higher than expected when compared to similar facilities.

## **SAFETY EVALUATION FOR ALL SIGNALS**

Safety criteria should be evaluated at new, planned, or existing intersections. The flow chart at the end of this document includes criteria that act as a means to provide both proactive and reactive measures in improving safety of vehicular, pedestrian, and bicycle traffic. If a criteria results in a left-turn phasing recommendation, then the analysis does not have to continue to subsequent criteria. Below is a description of each criteria.

1. **Pedestrian Criteria** - The first criteria is included to address intersections with high pedestrian crossing volumes conflicting with left-turning vehicles. Severe injury and fatality are common outcomes for pedestrian related crashes. In cases with high pedestrian traffic, protected-only left-turn phasing is preferred to remove the conflict between vehicular and pedestrian traffic.

- If a study finds that the cross product of conflicting pedestrians and left-turning vehicles is greater than 10,000 veh\*ped, then protected only phasing should be considered.

**Source:** [pbot-ssl-left-turn-guide-form-version-2021-05-14.pdf \(portland.gov\)](#)

2. **Bicycle Criteria**- This criteria is included to address high bicycle volumes crossing intersections on separated bike lanes. Severe injury and fatality are common outcomes for bicycle related crashes. In cases with high bicycle traffic, protected-only left-turn phasing is preferred to remove the conflict between vehicular and bicycle traffic.

- Approaches where peak hour volumes crossing separated bike lanes exceed the values in the table below should be considered for protected-only phasing.

**Source:** [MassDOT Separated Bike Lane Planning & Design Guide: Chapter 6, Signals](#)

| Separated Bike Lane Operation | Motor Vehicles Per Hour Turning Across Separated Bike Lane |                                   |                                    |                    |
|-------------------------------|--|-----------------------------------|------------------------------------|--------------------|
|                               | Two-Way Street   |                                   |                                    | One-Way Street     |
|                               | Right Turn   | Left-turn Across One Vehicle Lane | Left-turn Across Two Vehicle Lanes | Right or Left-turn |
| One-Way                       | 150  | 100                               | 50                                 | 150                |
| Two-Way                       | 100  | 50                                | 0                                  | 100                |

3. **Crash History**– This criteria is included to address instances of high approach turn crash history. When evaluating this criteria, data available for the most recent 36 months (3 years) should be obtained. If approach turn crashes meet or exceed the values below for the specific time period, then protected only left-turn phasing should be considered.

- **4 OR MORE** IN THE MOST RECENT **12 MONTHS**
- **6 OR MORE** IN THE MOST RECENT **24 MONTHS**
- **8 OR MORE** IN THE MOST RECENT **36 MONTHS**

4. **Sight Distance** – This criteria is included to address left-turning vehicles that may have obscured sight distance. Sight distance is included as part of intersection design. However, if minimum sight distance cannot be provided or if new obstacles are presented at an intersection after design (examples might include foliage or high heavy traffic volume in opposing lanes), then left-turn phasing should be considered to provide left-turning vehicles a safe time to maneuver.

- If minimum sight distance is not provided based on the table below, then proceed to criteria #5.

Source: [Traffic Signal Timing Manual: Chapter 4 – Office of Operations \(dot.gov\)](#)

| <u>Oncoming Traffic Speed Limit (mph)</u> | <u>Minimum Sight Distance to Oncoming Vehicles, SD<sub>c</sub> (ft)</u> |
|---|---|
| 25  | 200   |
| 30  | 240   |
| 35  | 280   |
| 40  | 320   |
| 45  | 360   |
| 50  | 400   |
| 55  | 440   |
| 60  | 480   |

5. **Sight Distance (continued)** – This criteria is included to provide the option of meeting sight distance requirements where possible.

- If obstructions can be removed (for example foliage, trees, or shrubbery, or correcting negative offset), then criteria #6 should be evaluated next. If obstructions can not be removed, then protected-only left-turn phasing should be considered.

Source: [Traffic Signal Timing Manual: Chapter 4 - Office of Operations \(dot.gov\)](#)

6. **Opposing Traffic Speed Limit** - This criteria is included to address approaches where left-turning vehicles cross opposing through lanes with high speed limits. High opposing speeds present left-turning vehicles with less time to make turning maneuvers, make it more difficult to judge gaps, and present increased safety risks when crashes occur.

- If speeds on approaches opposing a subject left-turn exceed 45 mph in urban areas or 55 mph in rural areas, then protected-only phasing should be considered.

7. **Number of Left-turn Lanes** - This criteria is included to address approaches where there are multiple left-turn lanes on an approach. Turning from lanes further from the center line or median may present drivers with difficult gap acceptance choices in addition to longer crossing distances. Additionally, when multiple left-turn lanes are present, lanes furthest from the centerline or median may be negatively offset which will negatively impact sight distance.

- If there are three or more left-turn lanes on an approach, then protected-only phasing is required.

Source: [Traffic Signal Timing Manual: Chapter 4 - Office of Operations \(dot.gov\)](#)

**8. Number of Left-turn Lanes (continued)** - This criteria is included to further address instances where multiple left-turn lanes exist on an approach. Under specific circumstances (see criteria #9 and #10), it may be acceptable to provide left-turn phasing other than protected-only.

- If there are two left-turn lanes on the subject approach, proceed to criteria #9. Otherwise, proceed to criteria #11.

**Source:** [Traffic Signal Timing Manual: Chapter 4 - Office of Operations \(dot.gov\)](#)

**9. Number of Left-turn Lanes (continued)** - This criteria addresses instances where approaches with dual left-turn lanes must cross over a main street with a coordinated or rest-on green phase.

- If an approach with two left-turn lanes crosses opposing through lanes with phases that are coordinated or rest-on green, and the opposing through movement has a speed limit that is greater than 35 mph, then protected-only phasing should be considered. Otherwise, proceed to criteria #10.

**10. Number of Left-turn Lanes (continued)** - If a dual-left-turn approach does not cross over an opposing main street through, then the number of opposing through lanes is considered.

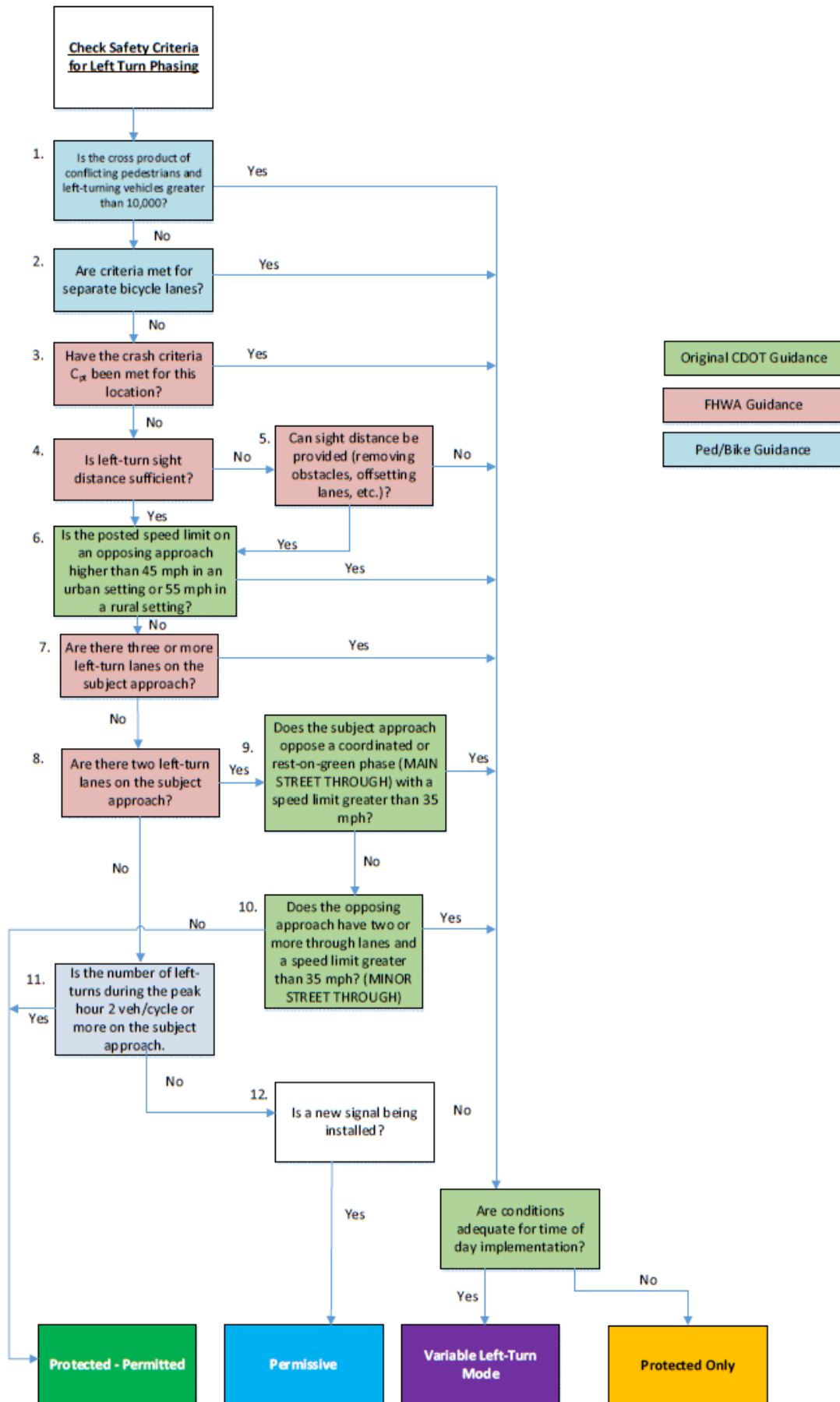
- If a dual left-turn approach crosses over an opposing through movement with two or more lanes and the opposing through movement has a speed limit that is greater than 35 mph, then protected-only phasing should be considered. Otherwise, protected-permitted phasing should be considered.

**11. Peak Hour Left-turn Volume** – This criteria addresses approaches with left-turn volumes that exceed the expected number of vehicles that can typically perform a turn maneuver during the yellow and all-red phases. When left-turn vehicle volumes become excessive, it can become difficult for drivers to clear a queue within one cycle. Left-turn phasing provides drivers with designated time to make their maneuver and prevent cycle failure.

- If left-turn volume on the subject approach is greater than 2 veh/cycle, then protected-permitted phasing should be considered.

**Source:** [Traffic Signal Timing Manual: Chapter 4 – Office of Operations \(dot.gov\)](#)

**12.** This criteria addresses instances where a subject approach is part of a new traffic signal. In such cases, permissive left-turn phasing can be considered when traffic volumes are unknown and assumed to be low.

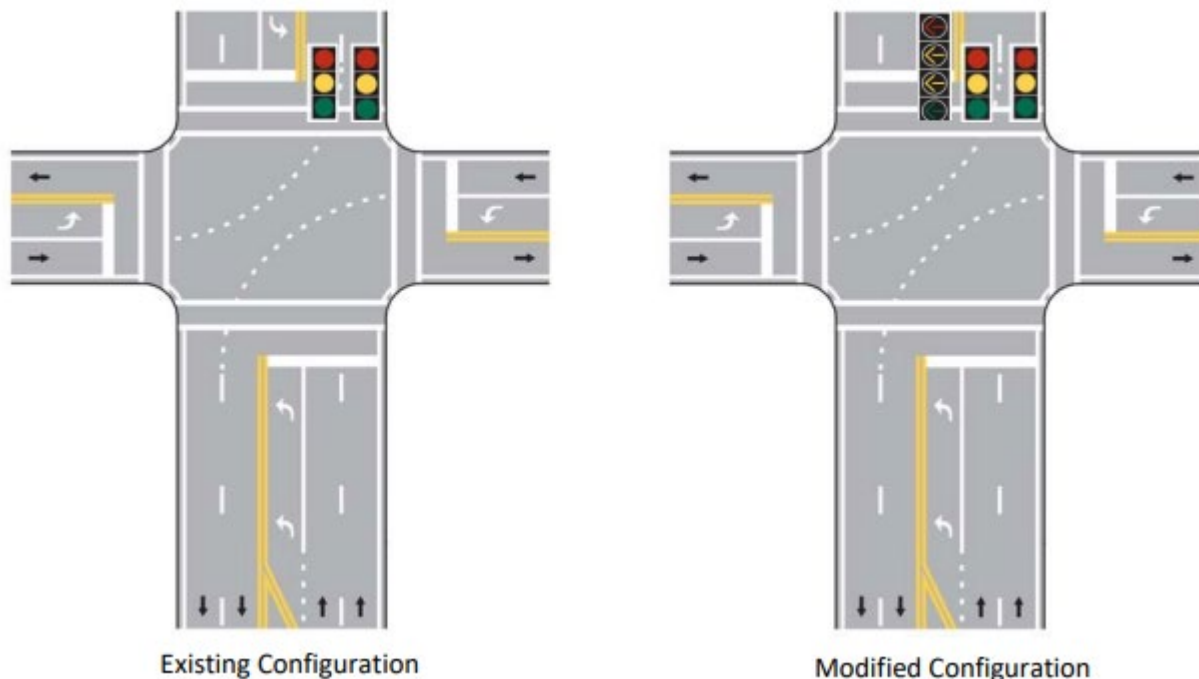


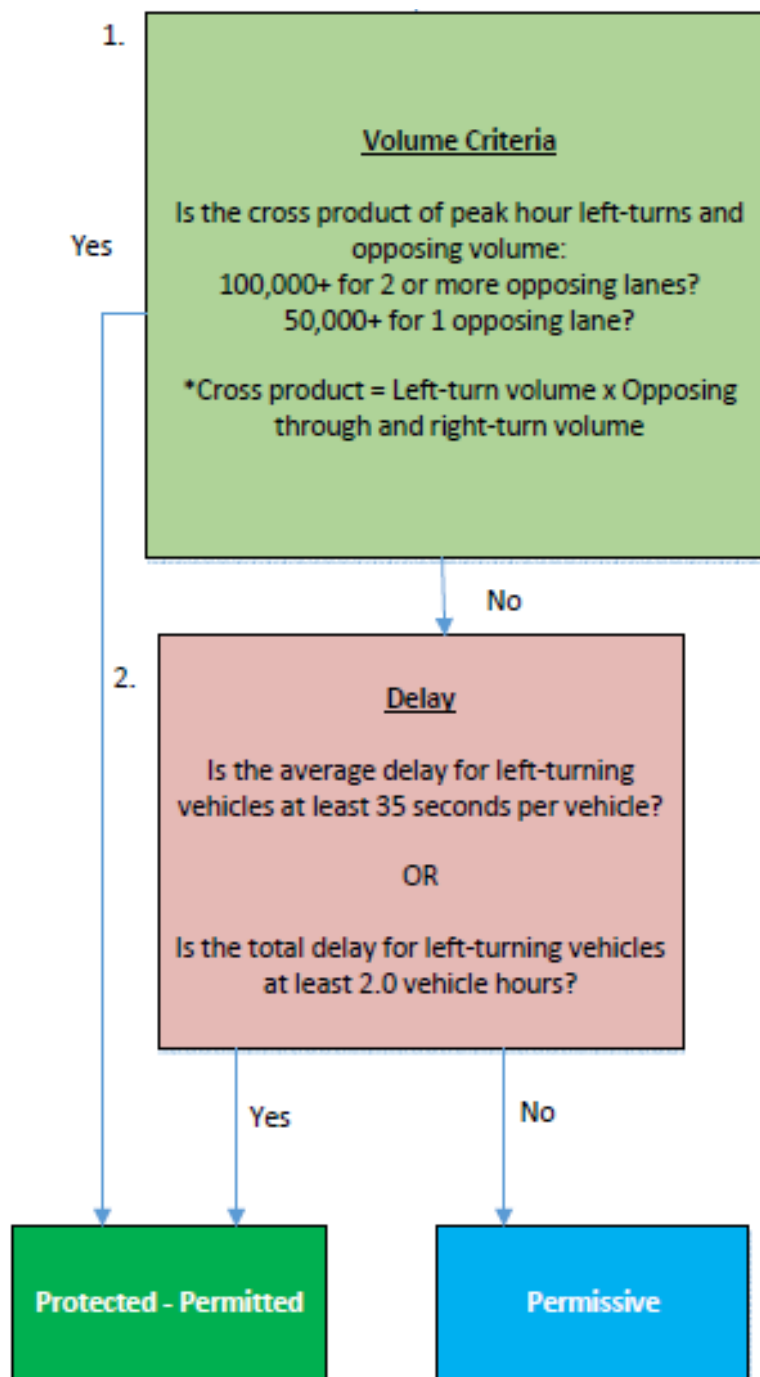


## CASE 1 –EXISTING SIGNAL WITHOUT LEFT-TURN PHASING

This case applies to situations where a separate left-turn lane(s) exists without a corresponding left-turn signal phase and hasn't met any of the safety criteria for protected-only or protected-permitted left-turn phasing. In Case 1, left-turn approaches may benefit from left-turn phasing where excessive opposing through volumes or excessive delay for left-turning vehicles exists. Satisfaction of Criteria 1 or Criteria 2 below may be used to determine whether protected-permitted left-turn phasing may be appropriate:

- 1. Peak Hour Volumes** – This criteria addresses instances where high opposing volumes may create difficult gap acceptance situations for left-turning vehicles. In this case, determine the cross product of the hourly left-turn volume on the subject approach and multiply it by the opposing hourly through volume.
  - If the cross product value exceeds 50,000 for instances with a single opposing through lane or 100,000 for instances with two opposing through lanes, then protected-permitted phasing should be considered.
- 2. Left-turn Vehicle Delay** - This criteria addresses instances where delay for left-turning vehicles is excessive and do not meet the cross product thresholds in criteria #1.
  - In cases where left-turning vehicles experience delay greater than 35 seconds per vehicle, or total delay for left-turning vehicles is greater than 2.0 vehicle hour, then protected-permitted phasing should be considered.



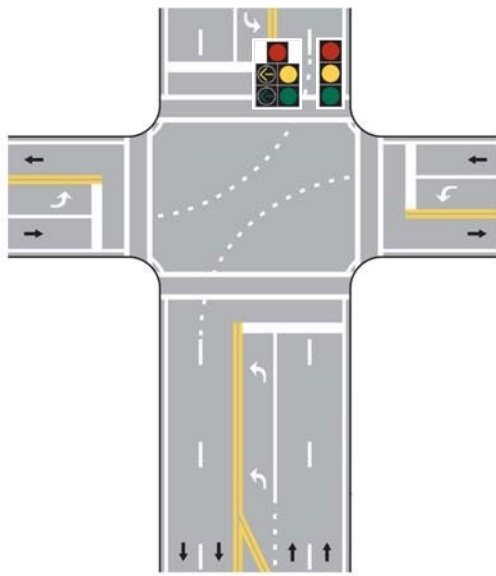


## CASE 2 – EXISTING SIGNAL WITH PROTECTED-PERMITTED LEFT-TURN PHASING

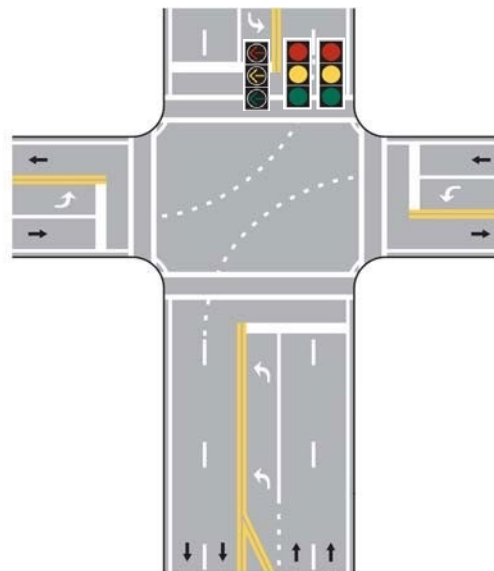
In situations where a separate left-turn lane(s) exists at a signalized intersection and left-turn phasing is currently protected-permitted, satisfaction of Criteria 1 can be used to determine whether protected-only left-turn phasing or variable left-turn phasing is appropriate.

**1. Intersection Diagnostics and Safety Performance Function** – This criteria addresses intersections where protected-permitted left-turn phasing exists but still experiences abnormal crash history. Intersection diagnostics and safety performance functions evaluate crash patterns for intersections of similar geometric layout, surrounding land uses, and volumes. This method allows for a more thorough analysis of intersections that may not experience crash rates as high as other facilities with higher volumes; thereby finding potential approach turn crash patterns that do not meet crash history criteria in the safety section. If the below criteria are met, then protected-only phasing should be considered. Time of day phasing can be considered where daily or weekly pattern in approach turn crashes emerge.

- An investigation of the most-recent 5 years of crash data for the intersection indicates a minimum of 5 left-turn opposing crashes have occurred for the subject movement(s),  
**AND**
- the proportion of approach turn crashes for the intersection overall is significantly higher than normal for the intersection type (when compared to similar intersections statewide),  
**AND**
- The intersection's overall crash frequency results in a Level of Service of Safety (LOSS) greater than 2 for either total or severe crashes (higher than average crash frequency compared to similar intersections statewide).



Existing Configuration



Modified Configuration

### Intersections Diagnostics

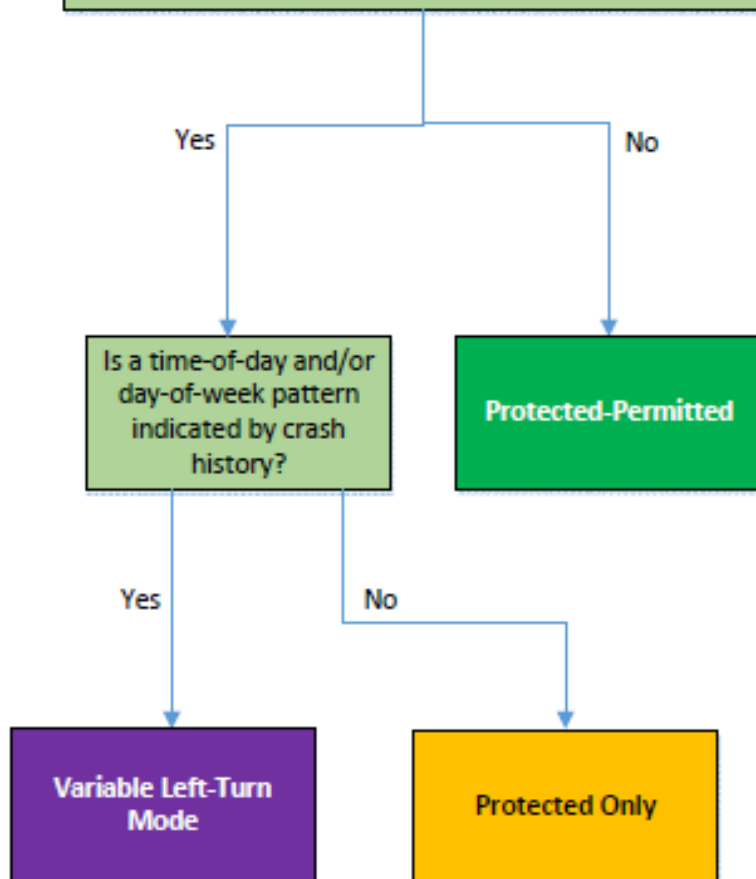
A minimum of 5 left-turn opposing crashes have occurred for the subject movement(s) over the past 5 years.

AND

The proportion of approach turn crashes for the intersection overall is significantly higher than normal for the intersection type (when compared to similar intersections statewide).

AND

The intersection overall crash frequency results in a level of service of safety (LOSS) greater than 2 for either total or severe crashes (higher than the average crash frequency compared to similar intersections statewide)



## OTHER CONSIDERATIONS

### *Dual Left-turn Lanes*

National traffic engineering guidance (including the Traffic Signal Timing Manual, Federal Highway Administration; and the Traffic Control Devices Handbook, Institute of Transportation Engineers) recommend Protected Only Mode for left-turn movements served by two or more lanes. **Protected Only is the default mode of left-turn phasing for dual left-turn lane installations along state highways in Colorado.** However, permissive left-turns from dual left-turn lanes is not expressly prohibited by governing standards such as the MUTCD or A Policy on Geometric Design of Highways and Streets, American Association of State Highway and Transportation Officials (AASHTO). The decision of whether to deviate from a Protected Only Mode for dual left-turn lanes should be determined on the basis of an engineering study.

Dual-left-turn lanes opposing a single through lane on the minor road approach do not normally require protected-only phasing and may operate with protected-permitted mode if sufficient sight distance is available.

In addition to the criteria described in the above cases, factors to be considered when evaluating whether permissive left-turn movements (normally implemented as Protected/Permitted Mode left-turn phasing) may be appropriate for dual left-turn lane applications include, but are not limited to:

- **Sight Distance.** Sight distance must be adequate for Protected/Permitted Mode left-turn phasing.
- **Intersection Geometry.** Protected/Permitted Mode left-turn phasing may be more suited to locations where complementary measures exist such as offset left-turn lanes and flashing yellow arrow signal heads. In cases where opposing left-turn lanes overlap, Protected/Permitted Mode left-turns may not be feasible.
- **Crossing Distance / Number of Opposing Lanes.** Protected/Permitted Mode left-turn phasing is less desirable when crossing distances are very large (for example, multilane divided highways).
- **Crash History.** Protected/Permitted Mode left-turns should not be employed where there is a pattern of left-turn crashes involving opposing traffic and/or pedestrians.
- **Pedestrian Considerations.** Where the potential exists for frequent conflicts between permissive left-turns and pedestrians exist, Protected Only Mode should be considered.
- **Speed Limit.** Protected/Permitted Mode left-turn phasing may not be compatible with high speed intersection approaches.
- **Corridor Consistency.** Along an urban arterial segment, Protected/Permitted Mode left-turn phasing should not be allowed if they would be inconsistent with the remainder of the segment.
- **Existing Left-turn Phasing.** The safety implications of converting from Protected Only to Protected/Permitted Mode left-turn phasing should be considered.

Engineering studies resulting in a recommendation of Protected/Permitted Mode left-turn phasing at state highway locations having dual left-turn lanes shall be reviewed by the Region Traffic Engineer prior to implementation.

## OTHER CONSIDERATIONS CONTINUED...

### ***Triple Left-turn Lanes***

Protected-only left-turn phasing mode is required for all triple left-turn lane installations.

### ***Advance Detection***

Advance mainline detection combined with dilemma zone preemption or other fully-actuated operation should be considered for signalized intersections that may operate without coordination during some or all times. At such intersections, left-turn phasing on approaches meeting the above criteria should be operated in protected-only mode during these times in addition to times identified as having approach turn patterns.

In some cases, based on site-specific intersection and operational characteristics, the Department reserves the right to exercise engineering judgment to preserve safety and mobility.

### ***Lagging Left-turns***

Traditionally, left-turn phases in Colorado have been applied in a “leading” configuration wherein the left-turn phase is activated prior to the opposing through movement phase. In some cases, traffic conditions may be improved by “lagging” one or more of the left-turn phases at an intersection such that they are activated following termination of the opposing through movement phase. This is most often done to improve progression in conjunction with a leading left-turn phase on the opposite approach but may also involve lagging both opposing left-turn phases. This should be determined based on site-specific traffic conditions. To prevent the occurrence of a “yellow trap”, the approach opposing an approach with a lagging left-turn phase should only be operated in protected-only mode.

## CHOOSING SIGNAL FACES

The above guidelines provide various cases and criteria for determining what type of left-turn phasing could be implemented based on a variety of existing conditions. Once it has been determined that installing left-turn phasing is appropriate for the approach being evaluated, several factors can be considered when choosing what type of signal face should be used for the left-turn phasing.

- **Considerations for intersections that have opposing or adjacent approaches with left-turn phasing signal heads already installed:** If an approach is being evaluated for left-turn phasing and the opposing approach already has a signal head for left-turn phasing, it would be recommended to use the same type of signal head on both approaches. This will help avoid any driver confusion.
- **Considerations for mast arm length and existing signal head arrangement considerations:** If an intersection is going to have new left-turn phasing installed, the mast arm may need to be lengthened to ensure the signal head is appropriately arranged over the left-turn lane.