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A simulation-based approach in determining permitted left-turn capacities

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ABSTRACT

A fundamental objective of traffic signal operations is the development of phasing plans that reduce delays while maintaining a high level of safety. One issue of concern is the treatment of left-turn phasing, which can operate as a protected movement, a permitted movement yielding to conflicting traffic, a combination protected–permitted movement or as a split-phase intersection. While protected-only movements can improve safety for the turning movement, they can also increase delays and congestion at the intersection. Most states maintain independent guidance for determining left-turn phasing; however, the most common identified guidance for protected left-turn phases is using a threshold based on the cross product of the left-turn volume and opposing through movements. The use of the cross product has been questioned recently as an indicator for determining phase selection. Based on simulation analysis within this research, the cross product is shown to be a poor indicator of left-turn capacity and congestion at the intersection.

This research proposes a simplified single variable exponential model to determine left-turn capacity based on opposing volume and percent green time to determine left-turn capacity thresholds for protected left-turn phasing. The model is developed based on observed capacity from 450 VISSIM microsimulation scenarios which evaluated varying opposing volume, opposing number of lanes, cycle lengths and green time splits. Validation of the model based on complex Highway Capacity Manual procedures, indicates that the proposed model provides similar correlation to observed capacities. Finally, a nomograph is developed which presents the model in a simple form for interpretation and application by practicing traffic engineers, when required to determine left-turn phasing options. This procedure allows simple determination based on minimum input data needs similar to the cross product determination, without the need for complex hand calculations or computing requirements of the Highway Capacity Manual.

1. Introduction

A fundamental objective of traffic signals is the development of signal plans that improve efficiency of operations and reduce delays while maintaining a high level of safety. One issue of concern is the treatment of left-turn phasing, which can operate as a protected movement, a permitted movement yielding to conflicting traffic, a combination

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protected–permitted movement or as a split-phase intersection. While protected-only movements and split phasing can improve safety for the turning movement, they can also increase delays and congestion at the intersection. Permitted movements can safely serve traffic when volumes are lower, such as during off-peak periods, but may experience safety or capacity problems with high volumes, such as during the AM and PM peak periods.

Left-turning maneuvers are considered as one of the most hazardous traffic movements, since turning vehicles have to cross in front of the oncoming through traffic. The difficulty of completing this movement is evident in crash statistics indicating that 45 percent of all crashes that occur at intersections throughout the United States involve left-turning vehicles even though left-turning movements represent a disproportionate small percentage (10–15 percent) of all the approach traffic (Maze et al., 1994). To alleviate this problem and improve safety, exclusive left-turn phasing is frequently installed at traffic signals. A constant tradeoff between the goals of efficiency and safety is present and must be considered when determining the final phasing plan.

The issue of left-turn phasing is a two-step process. The first question is whether a separate left-turn phase is warranted. Major factors affecting this decision are left-turn volumes, opposing volumes, left-turn delays, and left-turn accidents. After a decision has been made to add a left-turn phase, one of two basic phasing methods is commonly used: (1) a combination of protected and permitted left-turn movements, where during a portion of the left-turn phase the left-turning movement is protected from opposing traffic but drivers can continue to turn left during the remaining green through phase when there are available gaps in the opposing traffic or (2) protected-only, where the driver is allowed to turn left only during the green arrow portion of the cycle while the opposing traffic is stopped. Most current state policies prescribe the use of protected-only phasing for perceived hazardous geometric configurations, such as when three or more opposing through lanes are present, when dual left-turn lanes exist, or if there is insufficient sight distance for the turning vehicle and opposing traffic.

There is no nation-wide accepted criterion for the installation and usage of left-turn phasing despite the fact that studies exist that have developed guidelines for the use of left-turn phasing. The common ground of the existing guidelines is the use of simplified cross products of left turn and opposing volumes, the use of threshold values for crashes and acceptable delays as means to make a decision. Moreover, each state has its own criteria in determining when a severe crash problem occurs and when a left-turn treatment is needed or warranted.

The potential for improving existing guidance aiming to enhance vehicular efficiency and intersection safety led to this study with a primary objective to determine any potential changes to existing practices and policies with regards to permitted left-turn phasing. This paper presents the findings of simulation-based analysis to determine factors affecting left-turn capacity and how they may be used to develop new guidance for left-turn phase selection. This research establishes operational thresholds for left-turn phases and provides validation of the simulation models. These models will then be used in subsequent phases of the research to further develop safety based guidance for left-turn phasing.

2. Literature review

This literature review primarily focuses on evaluating current research findings and reviewing policies of other state agencies relative to permitted left-turn guidelines. As noted above, there are four basic approaches in treating left turns at a signalized intersection: protected, permitted, protected/permitted, and split phasing. Under protected-only phasing, left-turning vehicles have the right-of-way. Under permitted-only phasing, all left-turning vehicles must yield to oncoming traffic before turning. The protected/permitted phasing has both a protected and a permitted movement. Finally, in the split phasing, traffic from two opposing intersection approaches moves during separate phases.

For most state practices, guidelines, are used when determining a certain phasing plan. Pline in the NCHRP Synthesis 225 (1996) has identified that the general national practices utilize traffic volume, delay, crash history, and visibility as factors when considering the selection of the appropriate left-turn phase. However, the study does not provide any general guidance on the values to be used but rather identifies the need for local guidance.

In 1979, Agent developed one of the first efforts for addressing left-turn phasing. He proposed a set of warrants for intersections with a left-turn lane that were based on crash experience, delays, volumes, and traffic conflicts (Agent, 1979). The warrants were based on a set of Kentucky intersections and state practices at the time of the research. These warrants were evaluated and augmented with guidelines for protected/permitted in 1985 (Agent, 1985). The updated guidelines were based on a study of 58 intersections in Kentucky where protected/permitted phasing was in place. Agent found that a considerable increase in left-turn crashes occurred when protected/permitted phasing replaced protected phasing and where protected/permitted phasing was in place at approaches with a speed limit greater than 45 mph. After further analysis, the study concluded that protected/permitted phasing can be used to decrease delay at an intersection, unless certain conditions exist that could produce an increase in crashes, including the following:

- Speed limit is greater than 45 mph.
- Protected phasing is currently in place and the speed limit is greater than 35 mph.
- There are three or more opposing through lanes.
- Left-turn lane has a separate signal head due to intersection geometrics. 10
- Dual left-turn lanes are present.
- Left-turn crash problem is present at the intersection.