Operational, Environmental, and Safety Comparisons between Left-turn Bypass, Diverging Flow and Displacement Left Turn Intersections

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ABSTRACT

The intense exponential growth of the population in the United States and added vehicles to the roads has transportation planners working on solving the congestion issue. People have to travel longer distances and spend more time on the roads causing congestion of the current networks. Thus, the demand for new roadway and intersection design is a high priority, as wasted fuel and travel time increases each year. Conventional intersection design has been in use for many years and transportation engineers know that in order to improve the current design of the intersections there are limited options. There has been a new method to solve the traffic congestion issue which is the creation of unconventional arterial intersection designs (UAID). The objective of this study is to compare the operational, safety, and environmental performance of three UAID such as the Left-turn Bypass, the Diverging Flow intersection, and the Displaced Left-turn intersection.

This study will first evaluate the isolated unconventional intersection designs and then compare the intersections in a network using an existing corridor in the state of Florida. The operational performance will be evaluated based on the different results for average delay time, total number of stops, and queue time while the environmental analysis will include results for pollution levels. While conducting this study the microscopic simulation platform VISSIM v. 5.10 will be used to test different scenarios.

Keywords: Unconventional Intersection Designs, Displaced Left-turn, Diverging Flow, Upstream Signalized Crossover, Left-turn Bypass, Microsimulation.

INTRODUCTION

Traffic congestion is an ongoing issue among the transportation industry. The intense exponential growth of the population in the United States has caused expansion of the urban regions to accommodate more residential facilities. Consequently people have to travel longer distances and spend more time on the roads. All these factors cause congestion of the current networks and the improvement of roads and intersections is vital for mobility in the country. This demand for new roadway and intersection design is a high priority, as wasted fuel and travel time increases each year. Conventional intersection design has been in use for many years in the United States but with the added congestion on the roadways there is a need to alleviate traffic jams. Transportation engineers know that in order to improve the conventional design of the intersections there are limited options.

An alternative to building more lanes and make geometric changes is to optimize signal plans. This alternative is favored here since it does not bring the extra costs of redeveloping the surrounding area. In addition to the before mentioned solution, engineers have proposed new innovative designs to decrease congestion. These new alternatives tend to modify only the geometry of the intersections while still using approximately same number of lanes and left turn bay lengths similar to a conventional intersection. Moreover, safety is one of the most important goals of transportation. Over the past decades, transportation engineers have been working to improve the design of the conventional intersections to reduce accidents and increase safety, yet statistics show that the rates of accidents at intersections continue to increase.

A new method to solve the traffic congestion issue at intersections is the creation of unconventional arterial intersection designs (UAID). Many researchers have studied unconventional intersection designs performance and they have suggested that safety and operational efficiency are the major benefits of UAIDs over conventional designs (*1*). Examples of UAID's include: Median U-turn, Superstreet intersection, Continuous flow intersections, and Parallel flow intersections.

The objective of this study is to compare the operational, safety, and environmental performance of three unconventional arterial intersection designs such as the Left-turn Bypass, the Diverging Flow intersection, and the Displacement left-turn intersection. Moreover, this study introduces a novel design that is similar to the Displaced Left-turn and that is the Left-turn Bypass. Their operational performance will be evaluated based on the different results for total travel time, queue time, and delay time. The safety performance will be evaluated based on the model analysis performed by surrogate software and the environmental analysis will be developed through the software to measure the level of pollution. While conducting this study the microscopic simulation platform VISSIM v. 5.10 will be used to simulate the different designs, since this software is commonly used to evaluate operational performance of unconventional designs.

LITERATURE REVIEW

The following section describes previous work by other authors related to their research and findings in similar studies about these intersections. Please note that the Left-turn Bypass intersection has not been previously studied by other authors; therefore, there is no literature about this particular design.

Displaced Left-turn Intersection Design

Mier et al. (1994) studied the traffic performance of the Continuous Flow intersection (CFI) in comparison with a conventional intersection design. The authors found that the CFI had a capacity of nearly 50 percent higher than a conventional intersection. In addition, CFI delay at 1/5 of the conventional nearly doubled mean speed, an 80 percent increase in signal efficiency, and reduced vehicle fuel consumption and emissions of more than 1/3 (*2*).

Jagannathan and Bared (2004) studied the operational performance of the Displaced Left turn intersection (DLT) relative to a conventional intersection. The authors used three different cases for the design of the DLT. The simulation results showed that by applying the specifically selected geometric dimensions and traffic characteristics to each of the cases A, B, and C, the DLT intersection design consistently outperforms a conventional intersection design. Thus, the average intersection delay was reduced by 48 percent, 48 to 85 percent, 58 to 71 percent, and 19 to 90 percent for the first, second, and third configuration respectively (*3*).

El Esaway and Sayed (2007) evaluated and compared the performance of the crossover displaced left turn (XDL), the upstream-signalized crossover intersection (USC) to a conventional design. The results of this study indicated that the XDL and USC were consistent and that by increasing the secondary intersection to primary intersection distance will increase the capacity but delays will be a little higher at low volume conditions. Furthermore, the continuous flow intersection had approximately 90 percent higher capacity than the conventional intersection while the USC intersection is about 50 percent higher than the capacity of the conventional intersection (*4*).

Edara et al (2010) analyzed the performance of the parallel flow intersection (PFI) and the displaced left turn intersection (DLT). The results indicated that on average the vehicles turning left experienced greater number of stops in a PFI than they would in the DLT design (*5*).

Diverging Flow Intersection Design

The Diverging Flow intersection is also known as the Upstream Signalized Crossover (USC) or it can be also described as a Double Crossover Intersection (DXI. One of the first attempts to describe similar type of intersection design such as the synchronized-split phasing intersection (SSI) which is also kwon as the Double Crossover Intersection (DXI) was made by Chelewicki in 2003 (*6*). In his study the author explained that there are some benefits with the Synchronized-Split Phasing intersection regarding the phase combinations that somehow are not possible in conventional intersections. The results indicated that the total delay for the network was about twice as much for the four-phase design and over five times as much for the split-phasing design as it was for the synchronized split-phasing design.

Edara, Bared, and Jagannathan (2005) studied the vehicle and pedestrian performance of the Diverging Diamond Interchange (DDI) and the Double Crossover Intersection (DXI). The results indicated that the Double Crossover intersection performs almost identical to a conventional intersection under traffic conditions for lower and medium volumes. However, for higher volumes the performance of the DXI is noticeably better than the conventional design. For the average delay results at peak volumes, the conventional design yield 220 seconds per vehicle while the DXI was only 86 seconds per vehicle (*7*).

Tabernero et al. (2005) analyzed and compared the upstream signalized crossover intersection (USC) to a conventional intersection. The study evaluated parameters such as left turn delay and through movement delay. The results indicated that for volumes less than capacity, the conventional intersection can yield lower left turn delays. However, the USC can handle more left turn volumes and still maintain acceptable level of delay of at least 60 seconds at higher left turn volumes (*8*).

Esawey and Sayed (2010) evaluated the potential implementation of an Upstream Signalized Crossover (USC) intersection in Doha, Qatar. The objective was to investigate if there will be any improvements associated with the implementation of this unconventional intersection. The results indicated that corridor travel times of the USC configuration were less than those of the conventional configuration by 14.7 and 12.2% for the AM peak period, 13.5 and 10.6% for the PM peak period for the westbound and the eastbound directions, respectively. While for the Midday peak period, the corridor travel time of the westbound direction experienced a delay reduction of 6.2% and the eastbound direction experienced a slight delay increase of 0.4% higher delay in the USC configuration (*9*).

METHODOLOGY

The following section describes the information required to evaluate the intersection designs. Thus, a brief introduction to the designs and the data input for the software is presented here. The methodology chart on figure 1 show the steps followed within this research.

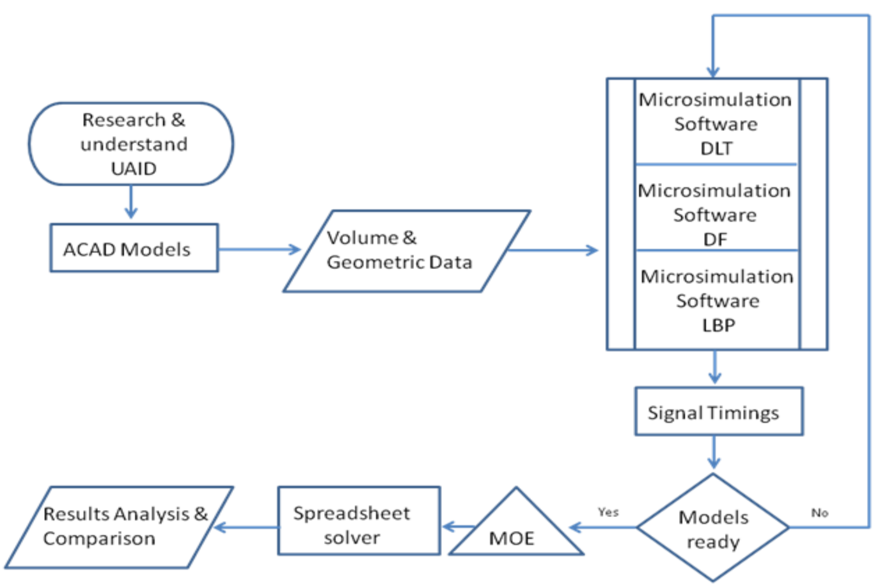


Figure 1- Methodology Chart

The analysis and understanding of the three unconventional intersections was completed first in order to identify the geometric characteristics and optimal signal plans for the study. First a throughout description of the three intersections is provided before analyzing their performance. The Displaced Left-turn (DLT) intersection design is the most common among the unconventional designs, it has been implemented in the field and there are some of them already built as partial and full intersections within the United States. The main goal of the Displaced Left-turn (DLT) intersection design is to minimize congestion at the main intersection by removing the conflict of left turning vehicles and by moving the left turn movement to an upstream signalized location. Traffic that would turn left at the main intersection in a conventional design now has to cross opposing through lanes at a signal-controlled intersection several hundred feet upstream and then travel on a new roadway parallel to the opposing lanes.

Moreover the Diverging Flow intersection (DF) is similar to the DLT in the way that it reduces congestion by removing the left turning movement away from the main intersection by displacing the left turn lanes upstream of the primary intersection. Next, the Left-turn Bypass intersection (LBP) will be introduced. This intersection in particular has not been studied in the past which gives the opportunity to work with it in several aspects. This intersection also removes the conflicts at the main intersection at the left turn lanes by sending the traffic through a bypass that goes parallel to the each approach of the intersection. The main goal of this new design is very similar to the other two intersections; it will minimize congestion at the main intersection by removing the conflict of left turning vehicles. Figure 2 below depicts the design of the three unconventional designs.

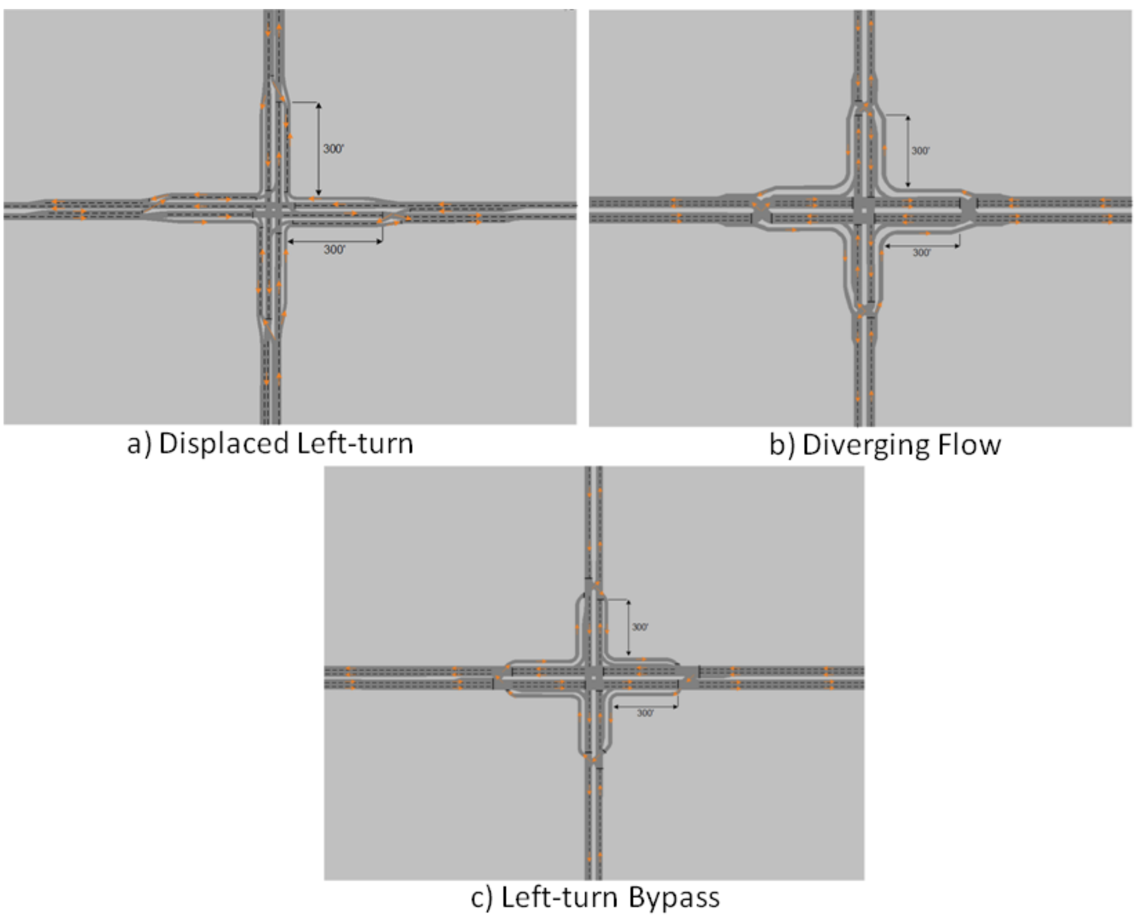


Figure 2- Unconventional Intersection Designs Description

This study was developed in two phases; the first phase of this study will evaluate and compare the performance of the isolated unconventional intersection designs to their conventional counterpart. The evaluation will contain different scenarios using random generator and the volumes will be based on theoretical data that will vary from low, medium, and high traffic input. The second phase of the study will compare these intersections in the network using an existing corridor that interacts with a major highway in the state of Florida. This model will be calibrated and evaluated using existing data for this corridor.

The geometric characteristics of the unconventional designs will be consistent in order to have a reasonable analysis and comparison. Each intersection will have 3 trough lanes, 1 right turning lane pocket of 300 feet and 1 left turning lane pocket of 300 feet. The traffic demand data for this study was generated hypothetically with values ranging from low to high to simulate peak and off-peak traffic. Thus, the volumes were also designed under balanced and unbalanced conditions to allocate any traffic fluctuations that might affect the study. In addition to this, the volumes for the left-turn movements were also altered to quantify for the effect of this parameters.

Three different scenarios were tested in this study, balanced conditions, unbalanced conditions, and an existing corridor as a case study. The balanced flow conditions means that the volumes will be equivalent at all approaches including the Eastbound, Westbound, Northbound and Southbound. For this study, three scenarios will be considered. First of all a 50-50 split will be used which means that traffic will be distributed equally at the four approaches. Then, the left-turn movement will be changed to 10%, 15% and 30%.

For the unbalanced flow conditions six scenarios will be considered. First of all, a 60-40 split will be used, which is to allocate 60 percent of the flow on the east bound of the major road and 40 percent on west bound of the major road, and the minor road will be kept constant at 50 percent each bound. The other two scenarios are a 70-30 and a 80-20 splits respectively with the same description as the 60-40 scenario. The left-turn percentage is also altered for this scenario from 10%, 15% and 30% as in the balanced condition. Table 1 shows the proposed scenarios for the overall study.

Table 1 - Proposed Scenarios

Balanced condition			
Approach volume (vph)		Intersections	Turning Fraction
Major road	Minor road		
50%	50%	DLT, DF and LBP	85 / 10 / 5
60%	40%		80 / 15 / 5
70%	30%		75 / 20 / 5
80%	20%		65 / 30 / 5

Unbalanced condition				
Approach volume (vph)			Intersections	Turning Fraction
Major road		Minor road		
East	West	North/South		
60%	40%	50%	DLT, DF and LBP	85 / 10 / 5 80 / 15 / 5 75 / 20 / 5 65 / 30 / 5
70%	30%	50%		
80%	20%	50%		

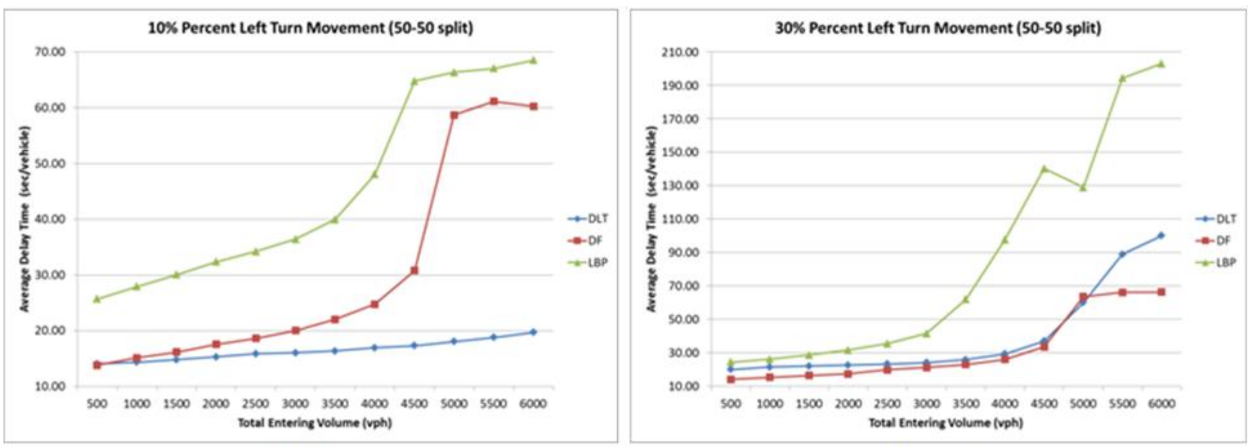
For the corridor case study, an existing network in the city of Boca Raton Florida was utilized. The study area of this project revolves around one of the major arterial roads found in Boca Raton Florida. It covers just over 3.5 miles, and runs from East to West. There are three lanes per direction, and the prove vehicle run along the middle lane at an average speed of 45 mph. The section of the arterial in our study consists of 11 signalized intersections, including on and off-ramps that give access to the I-95 interstate that runs North-South. This corridor was used due to its interaction and proximity to a major Florida state highway and the congestion seen nonstop at several of its intersections.

This study also includes optimization of the signal timing plans and cycle length for each of the designs. For the Displaced Left-turn design a cycle length of 60 seconds was found to be optimal according to literature provided by previous authors (3). For the Diverging Flow intersection there is also literature that suggests an optimal cycle length of 40 seconds. Thus, this cycle was proven to be the optimal by this study also. The procedure to find this cycle was as follows: the cycle was changed from 40 second to 60 seconds in increments of 5 seconds and running simulation to obtain different parameters to see which cycle length yielded the best results. After this, the 40 seconds cycle length was implemented to both the Diverging Flow and Left-turn Bypass model since they have similar geometries. However, the signal phases were different from one design to another and this signal plans are only optimal for this particular study.

RESULTS

Using the micro simulation software VISSIM v. 5.10, three scenarios were tested for each of the intersections during phase one of this study. Thus, during these simulation runs 10 different replications were used as well as different random seeds. The software yielded results for several different measures of effectiveness; however, for the purpose of this study only average delay will be used in this section. The results were averaged using Microsoft excel and then compared for each intersection design.

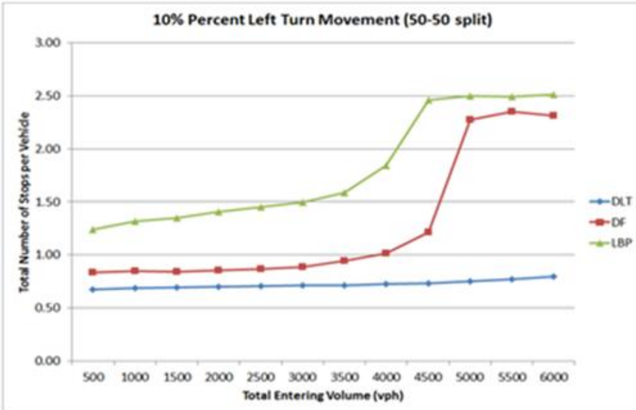
First, the results for average delay for balanced conditions indicated that the Displaced Left turn intersection consistently has better performance over the other two unconventional designs. Three different left turn percentages were used to account for left turn movements' variance. The results for average delay of the balanced condition with 10% and 30% are shown in figure x below.



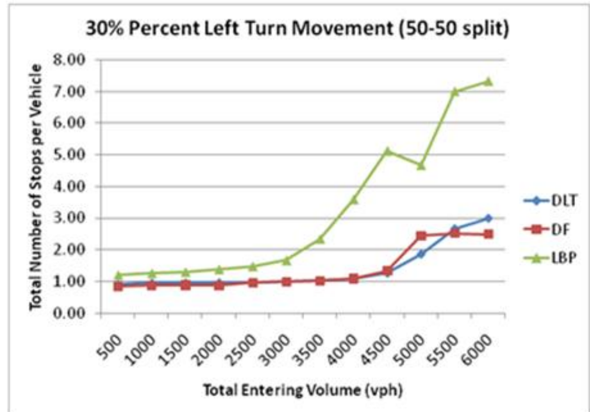
a) 10 Percent b) 30 Percent

Figure 3 - Average Delay Results for all three unconventional Intersection Designs - Balanced Condition

Then, the results for total number of stops for balanced conditions indicated that the DLT performs better for a 10% left turn movement; however, for higher left-turn percentages such as 30%, the results vary for volumes up to 4,500 vehicles per hou (medium). Thus, the DF and DLT intersections show similar results for low to medium volumes until they reach a point at which the DLT increases the number of stops consistently but the DF stays with constant values. The results for total number of stops for the balanced condition with 10% and 30% are shown in figure x below.



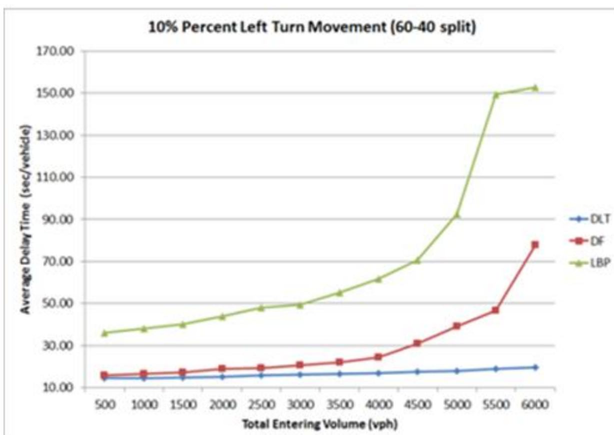
a) 10 Percent



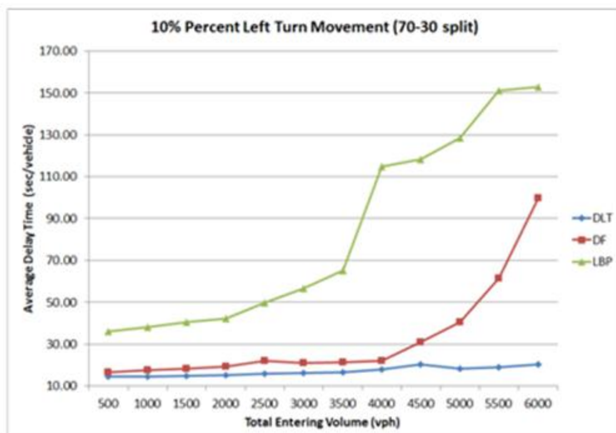
b) 30 Percent

Figure 4 - Total Number of Stops Results for all Three Unconventional Intersection Designs

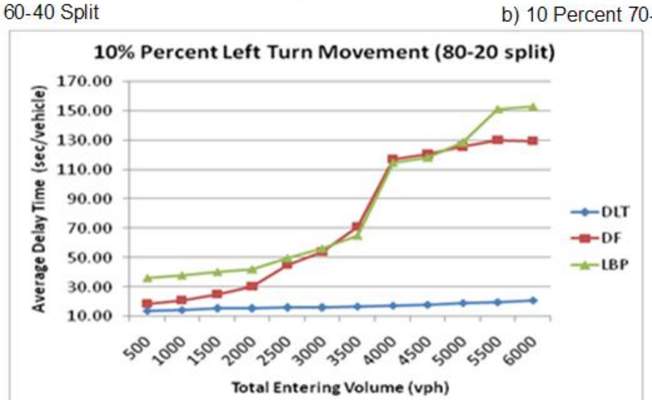
Then, the results for unbalanced conditions are presented in the figure below. These results show that for different percentage distribution on the major road, affect the results for the average delay. The most significant variation can be seen on the 80-20 split where the Displaced Left-turn maintains an average delay less than 15 seconds per vehicle. However the Diverging Flow and Left-turn Bypass show an exponential increase in delay after just low to medium volumes.



a) 10 Percent 60-40 Split



b) 10 Percent 70-30 Split



c) 10 Percent 80-20 Split

Figure 5 - Average Delay Results for all Three Unconventional Intersection Designs - Unbalanced Condition

Conclusions

This study compared the operational performance of three unconventional intersection designs, the Displaced Left-turn, Diverging Flow, and Left-turn Bypass intersection. The results indicated that the Displaced Left-turn intersection operates better for almost all the scenarios described. The DLT consistently reports better results for average delay of less than 20 seconds per vehicle while the other two designs do not operate well. However, the diverging flow intersection design shows to operate well for low to medium volumes of up to 4,000 vehicles per hour. Thus, the number of stops at the Diverging Flow intersection is significantly less than for the Left-turn bypass.

This study recommends additional work for different signal timings and optimization of these for the network and/or for the isolated cases as well.

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