# EFFICIENCY OF TRIPLE LEFT-TURN LANES AT SIGNALIZED INTERSECTIONS

**Khaled Shaaban, Ph.D., P.E., PTOE[a]**

[a]Assistant Professor, Department of Civil Engineering, Qatar University

[a]kshaaban@qu.edu.qa

**ABSTRACT**

Left-turn maneuvers can cause major delays to other traffic, and require specific analysis, design consideration, and traffic control to avoid operational and safety problems. As traffic congestion and travel demands continue to grow, alternatives such as triple left-turn lanes need to be considered. When installing a triple left-turn lane at an intersection, vehicles make their left turn movement from three separate left turn lanes. The purpose of this paper was to estimate any improvement in the efficiency of signalized intersections due to the addition of the triple left-turn lane compared to a dual left-turn lane under different scenarios using micro-simulation. A linear regression model was created to help practitioners to estimate the percentage of delay reduction expected when adding a triple left-turn. This information will be useful to improve the decision-making process of using triple left-turn lanes as an alternative solution to the traffic congestion problem.

Keywords: traffic simulation, left turn lanes, signalized intersections

## 1. INTRODUCTION

Signalized intersections represent the most critical elements of an arterial street. When traffic volumes increase on major intersecting arterials, left turning vehicles increase. The left-turn maneuver is a very complex driving challenge at high volume intersections and can have a major impact on the intersection traffic operations. Drivers turning left must find a gap in opposing traffic and check for pedestrians, bicycles, and other traffic in the intersection under a dynamic of changing traffic patterns.

Dual left-turn lanes are considered an alternative where land-use constraints and construction costs prevent a grade-separated interchange, especially where severe left-turn operational problems exist. As a general rule, dual left-turn lanes are considered in locations with left-turn demands of 300 vehicles per hour (vph) or more (Ackeret, 1994).

## 2. PREVIOUS WORK

### 2.1. Dual Left-Turn Lanes and Triple Left-Turn Lanes

Operational studies related to double left-turn lanes have focused on their efficiency in terms of saturation flow rate. Capelle and Pinnell (1961) found that the capacity of the inside and outside lane of the double left-turn movement are only 88% and 95% respectively of the capacity of the through lane.

Nicholas (1989) compared the dual and single left-turn lanes at signalized intersections as far as overall operating efficiency using the Highway Capacity software (HCS). It was found that the using the dual left-turn lane, the overall vehicular throughput was raised by 17.5%. Nicholas recommended using dual left-turn lanes at intersections with high left turning volumes and opposing traffic.

As traffic congestion and travel demands continue to grow on the street systems, the triple left-turn lane alternative was introduced. The main advantage of triple left-turns is their ability to handle large volumes. Also, they can reduce the left-turn queue length. It also helps where intersections are closely spaced. Shorter queue lengths will lower the probability for left-turn traffic to spill back onto the upstream intersection. Properly applied, triple left-turn lane can decrease total intersection delay by providing more green time for other movements through the intersection and increasing overall capacity.

There is a limited number of studies with regard to both operational characteristics and geometric design of triple left-turn lanes. However, the triple left-turn lane concept has been receiving design acceptance in the United States. In 1994, Ackeret proposed criteria for the geometric design of triple left-turn lanes at signalized intersections based on design experience gained in Las Vegas, Nevada. Ackeret has suggested that there are three general types of triple left-turn lane configurations: exclusive all lanes shadowed, exclusive outside trap lane, and permissive outside lane optional. Ackeret found that triple left-turn lanes have the ability to increase an intersection capacity to handle a large left-turn volume of left turn maneuvers (600 vph or more) and reduce delays and intersection queues. Reduction in upstream driveway conflicts by reducing queue lengths and resulting on vehicle storage lane lengths for left-turn lane. He also found that triple left-turn lanes have the ability to reduce the green time given to the left-turn movement so that it may be assigned to other intersection movements thus reducing overall intersection delay and improves the intersection level of service. Ackeret concluded that additional research is necessary and further studies are strongly required to address safety concerns by comparing crashes between double and triple left-turn lane installations.

Shen (2001) presented a study that aims to determine the minimum merging section lengths for triple left-turn lanes with downstream lane reductions. Simulation models were successfully developed to estimate the effects of different merging section lengths on average vehicle delay under various traffic and control scenarios. The average delay experienced by vehicles, traveling on the downstream roadway, were modeled through curve fitting as a function of merging section length, left-turn green time, left-turn heavy vehicle percentage and downstream free-flow speed. A look-up table for determining the minimum merging section lengths was developed based on a set of linear relationships that showed the minimum merging section length to:

- increase linearly with the left-turn green phase length
- increase at a decreasing rate with percentage of heavy vehicles
- increase at a decreasing rate with downstream free-flow speed

Although the simulation models produced results that gave very logical relationships among all of the variables considered, further studies were recommended to attempt to validate the simulated results with field data when they can be collected.

There is a limited literature discussing triple left-turn lanes. A better understanding of the efficiency and capacity of triple left-turn lanes at signalized intersections is needed to improve the decision-making process of using triple left-turn lanes as an alternative solution to the traffic congestion problem.

### 2.2. Simulation

Traffic simulation is a great tool to assess traffic operations along intersections and roadway segments. There are several microscopic models commercially available including CORSIM, AIMSIM, Paramics, SimTraffic, and VISSIM. Microscopic simulation of traffic has become a valuable aid in assessing the system performance of traffic flows and networks. Microscopic simulation tools allow for detailed analysis of traffic systems and have great potential for analyzing alternative strategies. They implicitly account for the stochastic nature of the transportation system and can provide both temporal and spatial information down to the individual vehicle level.

Modeling and simulation of this research was carried unsing PTV's VISSIM, a behavior based micro-simulation software. VISSIM (2011) is a stochastic microscopic, time step and behavior based simulation model developed to analyze the full range of functionally classified roadways and public transportation operations. VISSIM can model integrated roadway networks found in a typical corridor as well as various modes consisting of general purpose traffic, buses, light rail, heavy rail, trucks, pedestrians, and bicyclists. The model contains a psycho-physical car following model for longitudinal vehicle movement and a rule-based algorithm for lateral movements (lane changing). The model was developed at the University of Karlsruhe, Germany during the early 1970s. Commercial distribution of VISSIM began in 1993 by PTV Transworld AG, who continues to distribute and maintain VISSIM until today. VISSIM can be applied as a useful tool in a variety of transportation problem settings. Modeling of intersections in VISSIM requires the detailed coding of links, connectors, priority rules, speed zones and gap acceptance (VISSIM 2011).

## 3. METHODOLOGY

### 3.1. Geometric Design of the Analyzed Intersection

The analyzed intersection was a four-leg intersection. Each of the four approaches had the same number of lanes: two through lanes, dual left-turn lanes, and one right turn lane. The methodology of the analysis was to add an imaginary third left turn lane to one of the approaches and study the delay for different scenarios using the micro-simulation software VISSIM. The eastbound approach for the studied intersection was used for the analysis. The approach was selected since it has the highest left-turn volume , the highest delay for the existing condition (dual left-turn), and the receiving section for the left turn movement is a three-lane section. This last reason was important because in this case there was no need to design a merging lane with downstream lane reduction in order to have three receiving lanes for the three left turn lanes. All left turn movements at the intersection are protected-only.

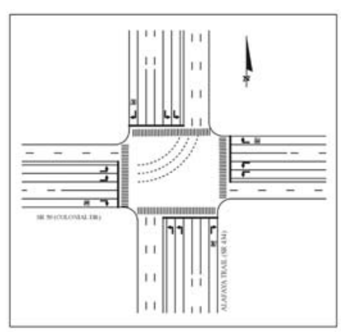

Figure 1: Geometric Configuration of the Studied Intersection

### 3.2. Calibration Process

The VISSIM model was calibrated using real data obtained for the studied intersection from the maintaining agency and using the HCS software. HCS is well-known software in the field of analysis of signalized intersections. HCS calculates the delays for signalized intersections using the methodology described in the Highway Capacity Manual. An assumption was made that the delay computed using the HCS software is the true value of delay.

Traffic volumes on each link, turning movement counts on each approach, geometric features, and signal timing were used to create the model. The first step in the calibration process was to use the peak hour volume data to create the model in the VISSIM software. These turning movement volumes in addition to geometric configuration and signal timing information, were entered into the VISSIM software. Delay was then computed for each approach. The same data was entered in the HCS software and delay was calculated for each approach. A comparison was done between the two outputs from HCS and VISSIM for all approaches. The absolute percentage error was calculated for each approach. The absolute percentage error for an approach is defined as the difference between the delay from HCS and the simulated delay divided by the delay from HCS multiplying by 100%.

The goal was to achieve an of error of five percent or less. To achieve this goal, VISSIM variables needed to be adjusted. The main VISSIM variables are divided into three main categories. The first category is related to the vehicle types and classes. This category includes the desired speed distribution, and vehicle types. These variables affect the roadway capacity and achievable travel speeds. The desired speed will be achieved by the driver if not hindered by other vehicles. Higher speed vehicles will check for a possibility of passing. The speed distribution used was in the range of 40 MPH to 60 MPH based on a spot speed study conducted at the intersection. According to the turning movement counts at the intersection, percentage of trucks in the traffic stream was negligible. Based on this information, the vehicle-type variable in the VISSIM software was set to. Mileage distribution for all cars was set to the range of zero miles to 200,000 miles.

The second category is the driving behavior. Driving behavior is composed of two main factors. The first factor is the general driver factor. This factor includes the average standstill distance, which defines the average desired distance between stopped cars and also between cars and stop lines (signal heads, priority rules, etc.). It also includes the maximum deceleration, which is the fastest any vehicle can slow down. The second factor is the lane change behavior. This includes the waiting time before diffusion which is the maximum amount of time a vehicle can wait at the emergency stop position waiting for a gap to change lanes in order to stay on its route (VISSIM 2001). An emergency stop is when a car cannot change lanes while moving, so, it has to stop to find a gap to change lanes. Vehicles will be deleted from the network one reaching this time. Default values for VISSIM software were used for these variables during the calibration process.

The third category is related to the simulation parameter, which is mainly the random seed parameter. The random seed parameter is generated using this parameter. The simulation runs will result identical results if they have the same input files and same random seeds numbers. By using a different random seed number, a stochastic variation of input flows occurs and therefore the results of the simulation runs will also change. Eighteen iterations were completed with eighteen different random seed numbers until an error percentage of less than five percent or less was achieved for all approaches. The other sets of data were then entered into the model and the delay was calculated from the VISSIM model and from the HCS software.

The second step was to compare the data obtained from the model against the data from the HCS software. According to Kelton (2000), there are two approaches to statistically compare the outputs from the real-world system with the simulation outputs. These two approaches are the visual inspection approach, and the statistical approach. The visual inspection approach was conducted by comparing the outputs from the HCS and simulation output data. Assuming that $X_i$ is the delay obtained from the HCS software and $Y_i$ is the corresponding delay obtained from the simulation model, a plot of $X_i$ and $Y_i$ is created such that the horizontal axis denotes each data set and the vertical axis denotes the delay obtained from HCS and simulated model. The user can then eyeball the difference to see if there is a major difference between the different values of $X_i$ and $Y_i$. The visual inspection of the data showed that there were no major differences between the simulated delay and the HCS delay. A sample data set comparison is shown in Figure 2.

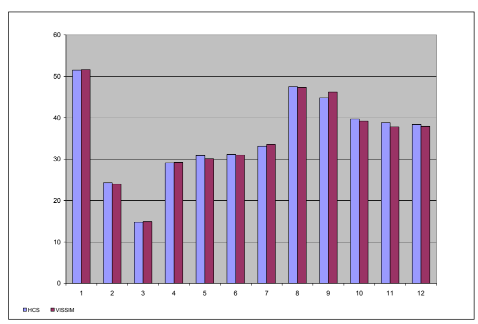


Figure 2: HCS Delay vs. VISSIM

A paired t-test was performed to determine if there is a difference between the means of the simulation results and the HCS results. The statistical analysis of the errors was performed using SPSS software (Version 19). The results of the test indicated, that at the 95% confidence level, the mean difference between the simulated results and the HCS results included zero, which indicated that the difference between the two values is statistically insignificant.

### 3.3. Analysis

The methodology of the analysis was to use the calibrated model to add an imaginary third left turn lane to one of the approaches and study the delay for different scenarios using the simulation software (VISSIM). The eastbound approach was used for the analysis. This approach had the highest left-turn volume, the highest delay for the existing condition (dual left-turn), and the receiving section for the left turn movement is a three-lane section. This last reason was important due to the need for a third receiving lane for the three left turn lanes.

The first part of the analysis was to estimate any improvement in the efficiency of intersection due to the addition of triple left-turn lane under different scenarios. The analysis was conducted by comparing two models; one for the existing conditions (Case 1 – Dual Left-Turn Lanes) and one by adding a third left turn lane to one of the eastbound approach (Case 2 – Triple Left-Turn Lanes). Hypothetical values were used in the study to create different scenarios. There were three parameters identified for this research: the approach left turn volume (increasing the existing left turn volume by 1% at a time until reaching a 20% increase), the left turn green time (decreasing and increasing the left turn green time by one second at a time until reaching a range of -40% to +40% ), and the length of the left turn lane (decreasing and increasing the length of the left turn lane by one car at a time until reaching a range of -55% to +55%). The total number of scenarios developed was one hundred twenty two (122) scenarios.

Based on the micro-simulation results, it was concluded that the decrease in delay ranged from 13 percent to 84 percent by using the triple left-turn lanes in place of dual left-turn lanes for the study case. The results of the analysis indicated that the installation of triple left-turn lanes is favorable in intersections containing high volumes of left-turning traffic, limited pocket length and/or constraints on increasing the green time. Figure 3 shows the percentage of delay reduced by adding a triple left-turn lane for the studied scenarios.

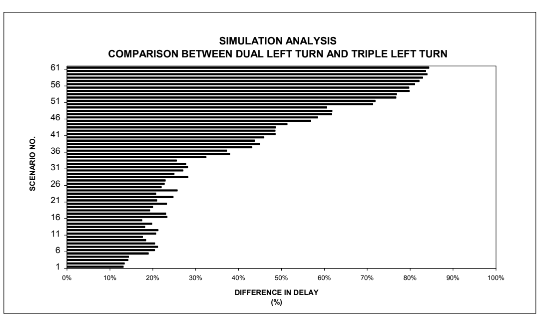


Figure 3: Percentage of Delay Reduced by Adding a Triple Left-Turn Lane

Based on the analysis, adding a triple left-turn lane will reduce the delay at the intersection but considering the high cost of right of way acquisition and construction, a benefit cost analysis should be conducted for each case to determine if adding a triple left-turn lane is the best alternative to consider. A linear regression model was created to estimate the percentage of delay reduction expected when adding a triple left-turn lane for their particular case. This percentage will be useful to improve the decision-making process of using triple left-turn lanes as an alternative solution to the traffic congestion problem.

The independent variables selected for including in the model were the left turn volume, the left turn green time, and the length of the left turn lane. The delay reduction forecasting model was therefore developed using the following convention:

- The response variable is:
    1. Delay Reduction Percentage; DRP
- The independent variable are:
    1. Left turn volume; LTV
    2. Left turn green time; LTGT
    3. Length of left turn lane; LLTL

The multiple linear regression model developed was checked for multicolinearity. All the statistical analyses were conducted using the SPSS software (Version 19) and according to standard Statistical Textbooks. The delay reduction forecasting model had the following form:

DRP= 1.544 + 0.001 LTV – 0.038 LLGT – 0.002 LLTL

Output from the SPSS software used to develop the model reported an $R^2$ of 0.729 and an $R^2$ (adj) of 0.715. An analysis of variance for the model indicated that the model estimated by the regression procedure is significant at an $\alpha$ - Level of 0.05, indicating that at least one coefficient is different from zero. Each variable in the model was tested for significance. Analyzing the residuals plots generated by the statistical software, a histogram of residuals shows a pattern consistent with a normal distribution. Based on the results obtained from the statistical analysis, the model should have good predictive ability to estimate the of delay reduction expected. To further test the forecasting model, a validation study must be conducted using another set of data.

## 4. CONCLUSIONS AND RECOMMENDATIONS

This paper developed a delay reduction percentage model to calculate the reduction in delay expected when adding a triple left turn lane at an intersection using three variables. The predictors used in the model included:

- Left turn volume
- Left turn green time
- Length of left turn lane

A statistical examination concluded that the model was capable of explaining 73% of the variability in the delay reduction percentage. The model developed in this research can be used to help practitioners to estimate the percentage of reduction in delay when adding a triple left turn lane to an approach. Further research is needed to incorporate additional variables and to validate the model using other sets of data.

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## AUTHORS BIOGRAPHY

**Dr. Khaled Shaaban** holds a Ph.D. degree in Transportation Engineering and is an assistant professor in the Department of Civil Engineering at Qatar University. Before joining Qatar University, Dr. Shaaban served as an adjunct professor in the Civil and Environmental Engineering Department at the University of Central Florida for five years where he taught graduate and undergraduate courses in transportation planning and traffic engineering. Dr. Shaaban’s interest in research has recently focused on the use of simulation to conduct traffic engineering studies to enhance the operation and safety of highways and streets.