Evaluating the Operational Impact of Left-Turn Exclusive Number of Lanes: A Case Study from Qatar

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ABSTRACT

Left-turning movements can significantly reduce the overall capacity of signalized intersections due to the queueing built up. Intersections with heavy left-turning volumes tend to use multiple lanes to accommodate left-turn movements, such as double and triple left-turn lanes. This study compares the potential impact of different left-turn configurations for saturated/near saturated levels. A signalized intersection located in the city of Doha, Qatar, is selected to be examined and evaluated. A microscopic simulation approach is used to replicate the existing conditions before implementing different traffic demands, left-turn bay configurations, and traffic control parameters. The results suggest that signalized intersections, in general, and left-turn movements, in particular, benefit from multiple left-turn lanes. However, the anticipated operational benefits vary depending on several factors, such as the demand for left-turn movements and the length of the left-turn bay. The findings obtained from this study could be helpful for planners and decision-makers to decide the type of left-turn lane treatment needed to increase the capacity for different conditions. This work can be extended to mathematically quantify the expected operational improvements at signalized intersections

Keywords: Micro-simulation; Traffic signal; Intersection; Left turn; Traffic operations

1 INTRODUCTION

Major intersections with high left-turning volumes are often seen along urban corridors, which cause major congestion and lower capacity problems along these corridors (Saha et al., 2017; Ghanim & Shaaban 2019; Ghanim & Abu-Lebdeh 2016). One of the solutions to improve these conditions and avoid increasing the green time for the left turning movement is increasing the number of left-turn lanes per approach at the intersection to two or three left-turn lanes (Spring & Thomas, 1999; Sando & Mussa, 2003; Yang & Zhou, 2011; Qi et al. 2016).

Adding these lanes has many advantages, including a reduction in the queues and delay for the left turning movements and a reduction in the length of the left-turn lanes since vehicles will be stored in multiple lanes instead of a single lane. However, a proper decision is needed when deciding between dual and triple left-turn lanes because of the major difference in land-use needs and construction costs. Few studies investigated and compared the effects of the geometry of the turn lane and traffic signal characteristics on the operations of dual and triple left-turn lanes, especially in the case of near-saturation conditions. In general, most of the studies focused on investigating the saturation flow rate when studying double and triple left-turn lanes.

In regard to dual left-turn lanes, Capelle and Pinnell (1961) reported that the capacity of the inside and outside lanes are 12% and 5% below the through lane capacity. Nicholas (1989) investigated the efficiency of dual left-turn lanes and reported that the overall capacity increased by 17.5% in the case dual left-turn lane. In regard to triple left-turn lanes, Leonard (1994) found that the saturation flow for the inside, middle, and outside lanes is 1,946, 1,950, and 1,891 vehicles per hour green per lane (vphgpl), respectively. The results indicated a significant difference for the outside lane compared to the other two lanes. Stokes (1995) reported no significant difference between the saturation flow rate of the inside, middle, and outside left-turn lanes. Moreover, the same study reported no difference between the left-turn and through lane saturation flow rates. Ackeret (1996) reported that the saturation flow is 1,825, 1,809, and 1,773 vphgpl for the outside, middle, and inside left-turn lanes, respectively. This research uses different geometric design and traffic volume scenarios in order to identify the best cases to use dual or triple left-turn lanes in near-saturated conditions at signalized intersections.

2 RESEARCH OBJECTIVES

The objective of this research is to evaluate the potential benefits of converting an exclusive single left-turn lane into double or triple lanes configurations at signalized intersections and to identify the level at which it would be beneficial to increase the number of exclusive left-turn lanes. Ultimately, the outcomes of this study can be further employed to quantify the expected level of improvements that the number of exclusive left-turn lanes has on the operational performance of signalized intersections.

3 METHODOLOGY

In order to meet the previously mentioned research objectives, an intersection in the city of Doha, Qatar, is selected. The intersection is a four-leg intersection that is currently operational and signalized. The aerial image of the intersection can be seen in Figure 1. Turning movement counts were collected at different peak periods and have been used later for the calibration process. A microscopic environment is used to calibrate the intersection before different scenarios are tested and examined. Traffic simulation modeling is a well-known tool that enables the simulation and analysis of various traffic conditions in a safe and cost-effective way. To accomplish the objectives of the study, traffic simulation models are used to model and analyze the different left-turn treatments for various traffic and geometric conditions.

Figure 1: Aerial Image Showing the Study Intersection

3.1 Geometric Layout

As can be seen in Figure 1, the intersection consists of four approaches. Each approach consists of the exclusive left-turn bay (with various lengths and number of lanes), three lanes for through movements, and channelized right-turn lane.

In this research, the geometric configurations of the northbound only (i.e., the south approach) have been manipulated. Currently, this approach has three lanes for left-turn movements, and the bay length is 300 meters of storage. The geometric configurations of this lane have been modified to accommodate different scenarios as follow:

- The number of lanes of the exclusive left-turn bay (single, double and triple lanes)
- The length of the exclusive left-turn bay (300, 200, and 100 meters)

3.2 Traffic Controller

Since the volume-to-capacity (g/C) ratio depends on the cycle length and effective green, three cycle lengths were examined 90, 120, and 150 seconds. Meanwhile, the effective green is kept constant at 30 seconds. This way, the effective-green-to-cycle ratio (g/C) ratio will be 0.2, 0.25, and 0.33. A yellow interval of four seconds and an all-red interval of one second are also used.

3.3 Traffic Volumes

A wide range of left-turn traffic demand has been used to cover unsaturated, near-saturated and over-saturated traffic conditions. Accordingly, the left-turn volumes are: 200, 300, 400, 500, 750, 900 and 1000. While these numbers represent the demand, depending on the congestion level, part of the demand was able to pass through the intersection, as will be illustrated later. Different turning movements can be estimated based on traffic design hour factors (Ghanim & Abu-Lebdeh, 2019; Ghanim, 2011). The following assumptions are further made to assure an experimental controlled environment. First, the right-turn movements are ignored (i.e., 0% for right-turn movements). Secondly, only passenger cars were considered to overrule the impact of heavy trucks.

3.4 Calibration of Simulation Environment

There are different microscopic traffic simulation packages available in the market, including CORSIM, Paramics, SimTraffic, and VISSIM (Holm et al., 2007; Chen et al., 2016; Nyame et al.; 2018; Shaaban & Kim, 2016; Sun, 2018). These packages are capable of modeling different types of intersections with different variety of geometry and traffic characteristics in order to conduct traffic operations studies including unsignalized intersections (Kaysi & Alam, 2000; Chowdhury et al.; 2005; Liu et al., 2012), signalized intersections (Shaaban & Ghanim, 2018, Ghanim & Shaaban, 2019, Shaaban et al., 2019a), and roundabouts (Bared & Afshar, 2009; Shaaban et al., 2019b; Elhassy et al., 2020). These packages provide a reliable technique for a detailed analysis of different scenarios and strategies. In this study, VISSIM was selected to compare and evaluate the performance of the different proposed alternatives. The intersection has been calibrated to reflect the recommendations of the Ministry of Transport and Communications in Qatar.

4 SIMULATION RESULTS

The simulation results of 540 scenarios are collected and summarized. For each scenario, a total of 10 multiple runs are averaged to represent one scenario. The results are analyzed, and the average delay (in seconds per vehicle) values are presented and discussed in this paper.

4.1 Single Lane vs. Double Lane Comparison

The first comparison in this research is a comparison between having a single left-turn lane or double left-lanes to accommodate the left-turning movements. Figure 2 summarizes the finding in terms of average delay and left-turn hourly discharge rate. The results also aggregated to show the cases associated with two g/C values, 0.2 and 0.25. Moreover, three storage lengths are considered (100, 200, and 300 meters). As for the single-lane scenarios, it can be seen that they can accommodate traffic up to a certain limit before the delay values significantly increase, indicating a grid-lock. The limits are 400 veh/hr for a g/C ratio of 0.2 and 500 veh/hr for a 0.25 ratio of g/C regardless of the left-turn storage length. It both cases, the saturation flow rate is 2,000 vehicles per hour. With respect to the discharge rates, a similar trend can be seen, where the single-lane configurations reach the capacity at earlier traffic demand. It should be noted that for the lowest traffic demand of 200 veh/hr, traffic delay is already exceeding 50 seconds.

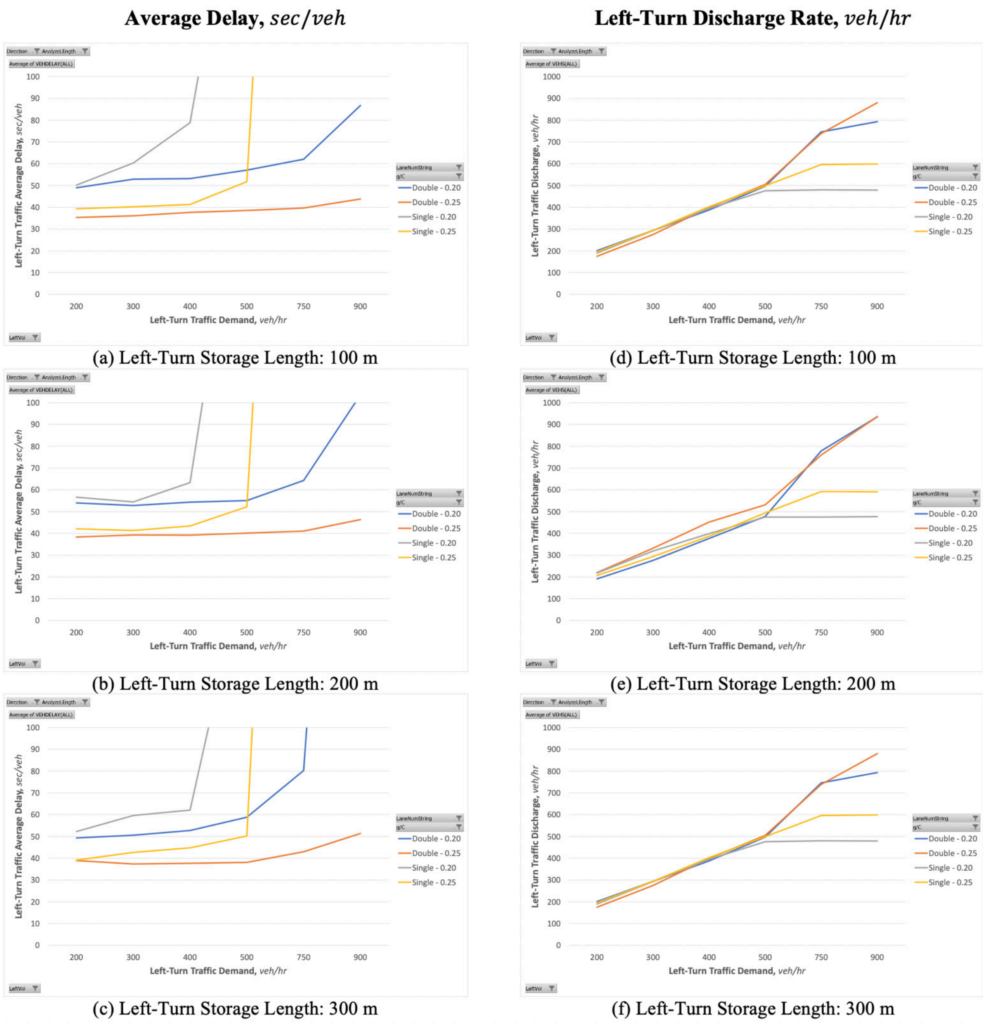


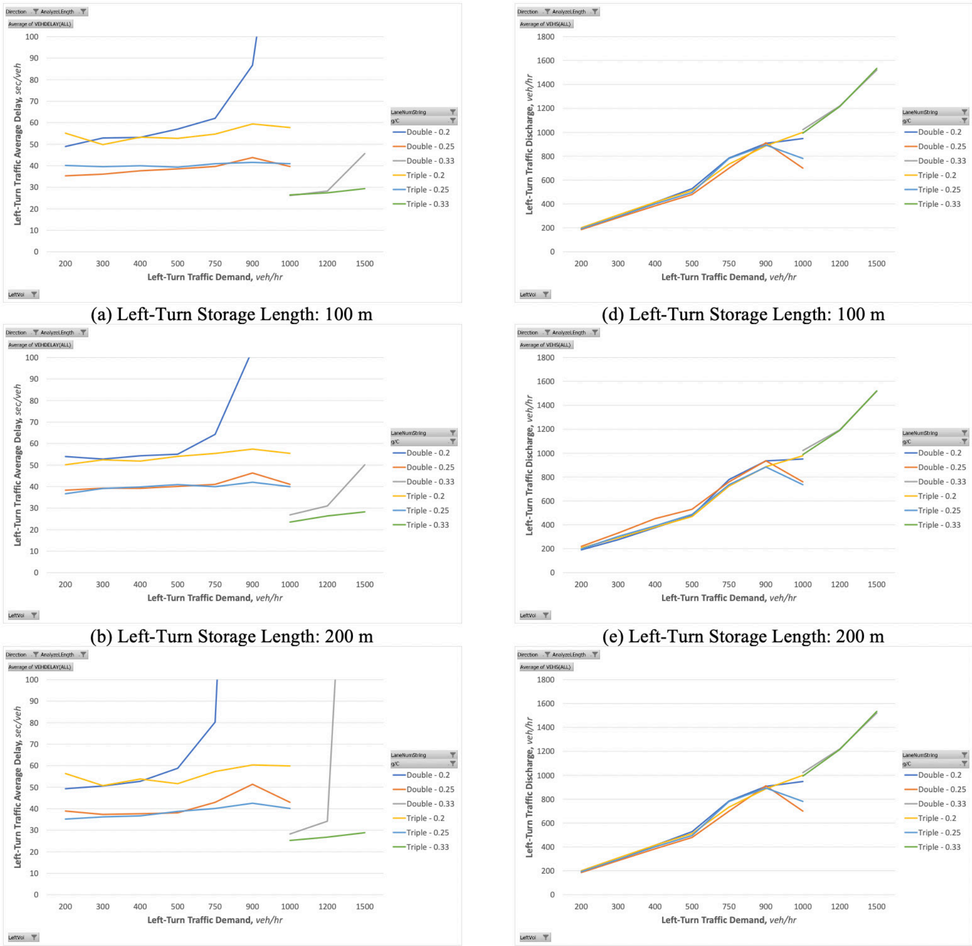
Figure 2: Left-Turn Movement Average Delay and Discharge Rate (Single Lane vs Double Lanes)

4.2 Double Lane vs. Triple Lane Comparison

The second comparison illustrated in this research is the comparison between the double and triple left-turn lanes. Unlike the single lane, both lane configurations (i.e., double and triple lanes) resulted in lower delay values and accommodated higher discharge rates. Because of this, a third g/C ratio of 0.33 is introduced to represent the operational performance at a higher demand rate that reaches 1,500 veh/hr. The simulation results are summarized in Figure 3.

Contrary to the expected, both double and triple lanes configurations perform similarly at low traffic volumes. For instance, and for g/C ratio of 0.25, it can be seen that the average delay is between 35 and 40 *sec/veh* for both configurations regardless of the storage length. This observation can be attributed to the fact that there is a significant variation in lane utilization. While the queue length is relatively low (due to the low arrival rate), there was a significant gain of using the third lane in the triple lanes configurations. However, by increasing traffic demand, it can be seen that double lanes configuration starts to experience significant delay increase when the demand exceeds 750 veh/hr (for g/C of 0.2 and 0.25) and 900 veh/hr (for g/C of 0.33).

Average Delay, sec/veh **Left-Turn Discharge Rate,** veh/hr



(a) Left-Turn Storage Length: 100 m (d) Left-Turn Storage Length: 100 m

(b) Left-Turn Storage Length: 200 m (e) Left-Turn Storage Length: 200 m

(c) Left-Turn Storage Length: 300 m (f) Left-Turn Storage Length: 300 m

Figure 3: Left-Turn Movement Average Delay and Discharge Rate (Double Lanes vs Triple Lanes)

5 CONCLUSION AND RECOMMENDATIONS

The objective of this research is to evaluate the potential benefits of converting left-turn exclusive single lane bay into double or triple lanes configurations at signalized intersections. To do so, different left-turn demand levels and signal timing parameters were simulated and evaluated. A total of 540 scenarios were developed and analyzed using a VISSIM as a micro-simulation testbed.

The simulation results show that the operational benefits associated with lane configurations for exclusive left-turn bay depend on the level of left-turn demand. The results also reveal that the left-turn demand of 400 veh/hr can be considered as the highest demand level for single lane configurations. The double lanes is recommended for left-turn demand that does not exceed 750 veh/hr. While the study shows promising results regarding the benefits of multiple left-turn lanes, there is a significant potential of expanding the scope of this study to include additional variables such as the percentage of heavy vehicles and lane width.

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Cite this article as: Shaaban K., Ghanim M. S., "Evaluating the Operational Impact of Left-Turn Exclusive Number of Lanes: A Case Study from Qatar", *International Conference on Civil Infrastructure and Construction (CIC 2020)*, Doha, Qatar, 2-5 February 2020, DOI: https://doi.org/10.29117/cic.2020.0075