

Developing an Analytical Model and Simulation of The Contraflow Left-Turn Lane at Signalized Intersections

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Abstract

At some intersections, excessive queue lengths may spill out of the left-turn bay and block the through lanes, jeopardizing level of service for the entire intersection. One of the most effective plans recently presented by the researchers is the "Contraflow left-turn lane" (CLL) In this method, left-turn vehicles will use the nearest lane in the opposite direction in addition to the usual left-turn lane. The most important principle in this design is that all vehicles which go into the opposite direction for left-turn movements should be definitely discharged during the left-turning phase. This issue prevents vehicles from a head-on collision when the other traffic signal turns green. Therefore, the number of vehicles entering the lane should be limited by a traffic signal. Accordingly, in this study, while determining the left turning capacity of the intersection with the CLL design based on vehicle traffic with generalized Poisson distribution, optimal CLL length and appropriate timing of the incoming traffic signal were determined. The goal of this study is to examine the effects of the CLL design on intersection performance. Therefore, the simulation of three real intersections in AIMSUN software was performed in two conventional and CLL designs. Comparison of the simulation results of the two designs showed that the CLL design at the intersections while reducing the travel time by 6 to 16 percent, resulted in an 8 to 24 percent reduction in vehicle delay. Also, according to the results of the study, the CLL scheme increased the number of stops for vehicles from 7 to 18%.

Keywords: Signalized intersection; delay, left-turn movement, contraflow left-turn lane design

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1. Introduction

One of the most complex issues in at-grade intersections are the safe and effective inclusion of the left-turn in all directions of the intersection. Studies show that the highest percentage and the most common cause of accidents at the signalized intersection are related to left-turn movement [Choi, 2010; Wang & Abdel-Aty, 2008]. This problem becomes more complicated as the traffic of the left-turn vehicles increases. Many unconventional solutions have been proposed by the researchers, including U-turn, Jug-handle, Continuous-flow intersection, Quadrant roadway, Bowtie, Parallel-flow intersection and so on. Generally, these solutions eliminate the left-turning phase and increase the capacity by removing or transmitting the left-turn interference point with a direct flow of the other side in the intersection. But these solutions often increase travel time for the left-turning vehicles by leading them to a mazed path or force them to cross intersection multiple times. Also, the implementation of these methods requires extra and accessible land, as well as the construction of a new route for left-turn movement [Li, 2018].

When it is not possible to provide any of the conditions required for implementing these solutions, alternative methods can be applied to manage the left-turn movement. Such approaches improve the intersection capacity without removing left-turn movements and creating a fairly expensive new left-turn route.

One of the most recent designs presented by the researchers is Contraflow left-turn lane. In this method, left-turning vehicles can use the nearest lane of opposite direction in addition to left-turn lane. In fact, the use of the opposite lane for left-turn movement enables more vehicles to discharge during the left-turning phase. The design manipulates the vacant opposite lane dynamically. Therefore, it provides additional

capacity for the left-turn movement. Increasing left-turn capacity reduces the left-turning phase and, as a result, increases the total intersection capacity. Figure 1 illustrates the signal timing plan for the main signal and pre-signal at a signalized intersection with the CLL design.

The signal phase sequence associated with the CLL design is also depicted in Figure 1. In the first phase, the through movements on the minor street are allowed to move (Movements 1 and 5 in Figure 1) Meanwhile, all left-turning vehicles on the major street are queuing in the conventional left-turn lane. When the opposing through lanes on the major street are vacant, the pre-signals on the major street turn green to allow left-turning vehicles to enter the contraflow lanes through the median opening (Movements 9 and 10) Only those left-turning vehicles that are waiting beyond the pre-signals can get access to the contraflow lanes. The left-turning vehicles in the contraflow lanes depart together with the left-turn movement in the traditional lanes (Movements 2, 6, 13, and 14) in the exclusive left-turn phase on the major street. The last two phases are similar to the first two phases. A field video is available to help better understand the signal phase sequence [Wu J. , 2017].

To avoid the collision of the left-turning vehicles while releasing the flow of opposite direction, the vehicles in the CLL must be fully discharged during the left-turn phase [Wu, Liu, Tianand Xu, 2016]. By limiting the arrival of vehicles to the CLL using the pre-signal, the number of inbound vehicles can be controlled in such a way as to ensure their fully discharge during the green interval. In addition to pre-signal for limiting the number of vehicles entering the CLL, there should be a limited length of the opposite lane for the left-turn movement, so that all vehicles in it can be fully discharged. On the other hand, to achieve the maximum possible capacity, this length should be chosen to fit the maximum number of vehicles that

can be safely discharged during the left turning phase. Therefore, the location and timing of the pre-signal are key factors that influence the operations of the CLL design [Wu, Liu, Tianand Xu, 2016].

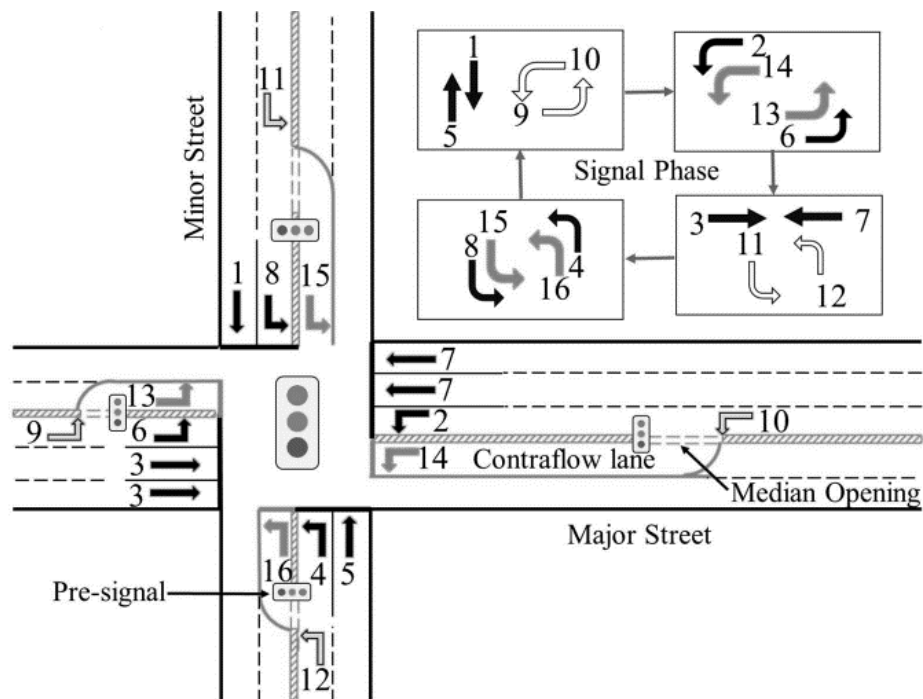


Figure 1. Geometric layout and signal phase sequence of the CLL design at a signalized intersection [Pan Liu, Wu, Zhou, Baoand Yang, 2019]

This study was conducted with the goal of improving performance and increasing the capacity of intersections in which making geometrical changes are not possible. For this purpose, the left-turning capacity of the intersection with the CLL design, optimal CLL length, and proper timing of the pre-signal were determined by assuming generalized Poisson distribution for the arrivals of vehicles.

The use of opposite lanes for movement is not a new topic. Reversible roadways have been used throughout the world to mitigate the effects of congestion and optimize roadway performance for more than 80 years. They have been applied on a variety of roadway types using many different methods of control to address an assortment of needs, including the movement of unbalanced directional traffic associated peak commuter periods, emergency evacuations, roadway construction work zones, and other major gatherings and events [Wolshon & Lambert, 2006]. In this situation, all or part of the vehicles in one of two directions are periodically guided in the opposite direction to

continue their path. In other words, the temporary movement of vehicles in the other direction is done bilaterally.

But applying the Dynamic Reversible Lane at intersections/interchanges is a relatively new topic [Su, Krause, Hale, Baredand Huang, 2016]. Krause et al. (2014) simulated this method using the VISSIM software to reduce the delay at signalized diamond interchange. The results of this simulation show a decrease in network delays by up to 60% in different geometric and traffic conditions [Krause, Kronpraset, Baredand Zhang, 2014].

Zhao et al. (2013) presented the CLL design by the name of "Exit lanes for left-turn" (EFL) as a strategy to reduce the queue at the signalized intersection. They conducted numerical analysis and simulation with VISSIM software to evaluate the performance of the CLL design and compare it with the usual intersection in various traffic and geometric conditions. According to the results of this study, the CLL design, in all circumstances, leads to an increase in intersection capacity compared with the usual

intersection. It also reduces average vehicle delay and queue lengths at all traffic levels. Notably, the highest reduction is achieved at the highest demand level by as much as 49.8% (delay) and 72.6% (queue), respectively [Zhao, Ma, Zhang and Yang, 2013].

Su et al. (2016) determined the optimal CLL length based on the 95th Percentile of left-turn queue length. Using the 95th percentile of the left-turn queue length, the optimal contraflow lane length is 1/2 of that value [Su, Krause, Hale, Bared and Huang, 2016].

Wu et al. (2016) also provided a methodology for randomly entering vehicles with the assumption of "Poisson distribution" and with the goal of maximizing intersection capacity to determine the optimum CLL length and green time for pre-signal. In addition, they proposed two analytical models for estimating left-turn capacity and delay in the intersection with the CLL design. The capacity model was calibrated and validated using field data collected at six approaches at five signalized intersections in the city of Handan, China [Wu, Liu, Tian and Xu, 2016]. Simulation analyses were conducted to compare the delay experienced by the left-turn and through movement at the signalized intersections with the conventional left-turn lane, the CLL, and the tandem design. The results showed that both CLL and tandem designs outperformed conventional left-turn lane design, and the CLL design generated less delay for both the left-turning and through vehicles as compared with the tandem design [Wu, Liu, Tian and Xu, 2016].

Zhao et al. (2018) provided an analytical model based on nine different scenarios for estimating the capacity of the CLL design. Nine different scenarios were created to form queues and occupy lanes by a random entry of vehicles with the assumption of Poisson distribution in two different time intervals (green and red phase of pre-signal), as well as the random selection of the left-turn lane (normal and CLL) by motorists

with "negative binomial distribution." For each of the nine possible scenarios, the model calculates the expected capacity "loss" due to suboptimal use of the pocket lane. As a result, the real capacity of the CLL is slightly less than the capacity of a single lane. In other words, during the left-turn phase of the main signal, vehicles are discharged less than the amount, which was expected [Zhao, James, Xiao and Bared, 2018].

According to previous studies, the assumption of the arrival rate was adopted as a Poisson, and it was stated in other research that this assumption was not realistic [Mauro, 2015]. The research contribution was therefore adopted as a generalized Poisson for the arrival rate pattern and, following this assumption, the intersection capacity with the CLL was determined analytically.

2. Methodology

In order to determine the optimal timing of the pre-signal and the optimal CLL length, it is necessary first to determine the left-turn capacity with the CLL design, and then with the goal of maximizing the capacity, to determine the optimal value of these two important parameters. Due to the control of vehicles entering the CLL, this capacity is highly influenced by the type of vehicle's arrival. So, it is necessary to determine the "arrival pattern" of vehicles to the CLL, before determining the left-turn capacity.

2.1. Arrival Pattern

The phrase $X(t)$ is defined as a discrete random variable in order to express the number of vehicles passing through a given section in the time interval of 0 to t . Table 1 shows the most widely used probability mass function (PMF) of various statistical distributions related to vehicle traffic [Mauro, 2015]. Indeed, $P(X(t) = x; t)$ represents the probability in which x vehicles pass through a particular cross-section over time t .

Table 1. Probability mass functions of different distributions along with its parameters [Mauro, 2015]

Distribution	Binomial	Poisson	Negative binomial
PMFs	$\binom{n}{x} p^x (1-p)^{n-x}$	$\frac{\mu^x}{x!} e^{-\mu}$	$\binom{x+k-1}{k-1} p^k (1-p)^x$
Mean (μ)	$n \cdot p$	μ	$\frac{k \cdot (1-p)}{p}$
Variance (σ^2)	$n \cdot p \cdot (1-p)$	μ	$\frac{k \cdot (1-p)}{p^2}$
μ/σ^2	$(1-p)^{-1} > 1$	1	$p < 1$
Parameter Estimation	$p = (\bar{x} - s^2)/\bar{x}$ $n = \bar{x}^2 / (\bar{x} - s^2)$	$\mu = \bar{x}$	$p = \bar{x}/s^2$ $k = \bar{x}^2 / (s^2 - \bar{x})$
Traffic condition	Congested traffic	Light traffic	Cyclic variation in flow

If the mean \bar{x} and variance s^2 of the number of vehicles entering the CLL are almost equal, then the measured counting distribution is assumed to be consistent with a Poisson distribution [Mauro, 2015].

But if the mean \bar{x} is greater than the variance s^2 , it can be inferred that measurement variability of surveyed counts is lower than that expected for Poisson arrivals of an equal mean. In this case, the "positive binomial" or "generalized Poisson" models can be used to adapt to the arrival of vehicles. The circumstance in which Poisson

arrivals. In that case, the negative binomial distribution is selected [Mauro, 2015].

The summary of the above discussions is presented in Table 2 as a criterion for choosing the type of vehicle distribution by means of mean and variance.

Table 2. Selection criteria for distribution [Mauro, 2015]

Suggested distribution	Value of \bar{x}/s^2
Binomial or generalized Poisson	> 1
Poisson	$\cong 1$
Negative binomial (Pascal)	< 1

Probability mass function of generalized Poisson distribution is shown in Equation (1)

$\bar{x} > s^2$, has frequently been observed in traffic conditions away from the free flow, where traffic volumes are generally very high. The generalized Poisson distribution can be used as a mathematical counting model, also for high traffic volume values, on condition that flow stationarity is maintained during an observation time interval T. Finally, if the observed mean \bar{x} is less than the observed variance s^2 , the mean being the same, then there are more dispersed counts than those deriving from

$$P(X = x) = \sum_{i=1}^k \frac{e^{-\lambda} \cdot (\lambda)^{x \cdot k + i - 1}}{(x \cdot k + i - 1)!} \quad (1)$$

A rough approximation of k is that ($k = \bar{x}/s^2$) Using \bar{x} between k and λ , there will be an equation which is given below:

$$\lambda = k \cdot \bar{x} + 0.5(k - 1) \quad (2)$$

Given the average and variance of passing vehicles, the k value can be obtained for any positive number. But due to complex mathematical calculations, k value obtained from observed data processing is generally rounded off to the nearest integer in engineering practice. Integer values between 1 and 3 for flow q intervals ranging between 0 and 1,500 veh/h

can be attributed to k , in an approximate but often acceptable manner for applications. Table 3 shows the different values of k and λ for different intervals of arrival flow to the intersection.

Table 3. Values of k and λ base on the flow rate
[Mauro, 2015]

Flow q (veh/h)	k Value	λ Value
0-500	1	$\lambda = \bar{x}$
501-1000	2	$\lambda = 2\bar{x} + 0.5$
1001-1500	3	$\lambda = 3\bar{x} + 1$

In the low traffic volume, the flow rate of fewer than 500 vehicles per hour, the generalized Poisson distribution function is equal to the Poisson distribution.

2.2 Determining Capacity

The capacity of the left-turn movement at the intersection with contraflow left-turn lanes design includes two general parts. The first part is the capacity of the normal left-turn lane and the second part is the capacity of CLL. The capacity of normal left turn lane can be easily calculated based on intersection main signal features and by the HCM equation:

$$c_{NLL} = 3600 \times s_L \cdot \left(\frac{g_L}{C} \right) \quad (3)$$

Where;

c_{NLL} : Capacity of the normal left-turn lane (veh/h);

g_L : Effective green time of left-turn phase in the main signal (s);

s_L : Saturated flow rate of left-turn traffic in normal lane (veh/s)

Determining the capacity of CLL due to the control for entering is more complicated than the capacity of normal lanes. All vehicles entering to CLL must be fully discharged in order to provide safety and avoid blockage during the left-turning phase. So, theoretically, it can be assumed that the number of vehicles entering the opposite direction lane is the capacity of CLL. The number of vehicles that can enter the CLL depends on different factors which are as follows [Wu, Liu, Tianand Xu, 2016]:

Location of median opening; this value determines the maximum number of vehicles that can be stopped between stop lane and pre-signal (n);

a) All left-turn vehicles that reach intersection before finishing the green phase of the traffic signal (x);

b) The queue of vehicles remained of the previous phase (initial queue) in normal left-turn lane (Q_l);

c) Effective green time of pre-signal (g_p);

d) The saturated flow rate of entering traffic to CLL under control of pre-signal (s_p);

So, according to the factors mentioned above, the number of vehicles during a cycle through CLL which pass intersection depending on the number of all left-turn entering vehicles can be calculated by using the Equation(4) [Wu, Liu, Tianand Xu, 2016].

$$V_{CLL} = \min(s_p \cdot g_p, \max(x - n + Q_l, 0)) \quad (4)$$

In other words, the above equation can be expanded to the Equation (5) [Wu, Liu, Tianand Xu, 2016] In the Equations above, V_{CLL} is the number of vehicles that can be discharged through CLL during a cycle. So, as it is cleared, CLL capacity is dependent on arrival pattern. In this case, if p_0 is the probability of $x < n - Q_l$, p_1 is the probability of $n - Q_l < x < n - Q_l + s_p \cdot g_p$ and p_2 is the probability of $x > n - Q_l + s_p \cdot g_p$, then CLL capacity equals the Equation(6).

Since CLL design is considered with the aim of improving intersection situation in the conditions of heavy left-turn traffic volume, the possibility of low entering of vehicles that means the occurrence of p_0 is very insignificant and almost equals to zero. As a result, it can be said that in this case the sum of possibilities p_1 and p_2 is almost equal to one [Wu, Liu, Tianand Xu, 2016]. So, by omitting the phrase p_0 and with adding and subtracting the phrase p_1 .

$(s_p \cdot g_p)$, Equation (7) will be formed. So, Equation (7) will change into Equation (8).

$$\begin{cases} V_{CLL} = 0 & x < n - Q_I \\ V_{CLL} = x - n + Q_I & n - Q_I < x < n - Q_I + s_p \cdot g_p \\ V_{CLL} = s_p \cdot g_p & x > n - Q_I + s_p \cdot g_p \end{cases} \quad (5)$$

$$c_{CLL} = 3600 \left[p_0 \cdot (0) + p_1 \cdot (x - n + Q_I) + p_2 \cdot (s_p \cdot g_p) \right] / C \quad (6)$$

$$c_{CLL} = 3600 \left[s_p \cdot g_p + p_1 \cdot (x - n + Q_I - s_p \cdot g_p) \right] / C \quad (7)$$

$$c_{CLL} = 3600 \left[s_p \cdot g_p + \sum_{x=0}^{n+s_p \cdot g_p - Q_I} \left[P(x) (x - n + Q_I - s_p \cdot g_p) \right] \right] / C \quad (8)$$

The total capacity of the left-turn movement at the intersection with CLL design with considering normal lane capacity, according to Equation(9) equals the sum of the Equations(3) and (8)

2.3 Determining Principal Factors

As it is cleared from capacity equation (Equation(9)), values of n (maximum number of vehicles that can be stopped between stop line and pre-signal) and g_p (Effective green time of pre-signal) should be determined in a way that the capacity amount (c_L) reaches its maximum value. When n is obtained and with considering the average occupancy length of a vehicle, the optimum length of CLL can be calculated. In order to ensure the CLL is completely discharged during the left-turn phase, the number of vehicles entering the CLL during the pre-signal green phase with a saturated flow rate, should be at most equal to n value. It means, in this case, Equation (10) should be meaningful.

Value of T in Equation (11), is the number of left-turn vehicles that during only one cycle can

be discharged through normal left turn lane and CLL. In order to simplify calculations, Equation (11) instead of Equation (9) is used.

In this study, with regard to the heavy left-turn volume at the intersection with CLL design, entering of vehicles is considered with the assumption of generalized Poisson distribution. Therefore, by the combination of Equations (1) and (11), Equation (12) can be created.

Also, according to Equation (10), the equation above can be rewritten as Equation (13).

In order to solve the above equation and determine the optimum value for n in a way that T value and following that capacity of left-turn movement would be maximized, programming in MATLAB software is used. After obtaining the optimum value of n by MATLAB software, with the assumption of first queue equal to zero ($Q_I = 0$), using Equation(10) and by assuming a saturated flow rate equal to 1615 vehicle per hour, pre-signal optimum green time also can be calculated. Furthermore, the value of the CLL length area with considering the average occupancy length equals to 6 meters for each vehicle is determined.

$$c_L = 3600 \left[s_p \cdot g_p + \sum_{x=0}^{n+s_p \cdot g_p - Q_I} \left[P(x) (x - n + Q_I - s_p \cdot g_p) \right] + s_L \cdot g_L \right] / C \quad (9)$$

$$n \geq s_p \cdot g_p \quad (10)$$

$$T = s_p \cdot g_p + \sum_{x=0}^{n+s_p \cdot g_p - Q_I} \left[P(x) (x - n + Q_I - s_p \cdot g_p) \right] + s_L \cdot g_L \quad (11)$$

$$T = s_p \cdot g_p + \sum_{x=0}^{n+s_p \cdot g_p - Q_I} \left[\sum_{i=1}^k \frac{e^{-\lambda} \cdot (\lambda)^{x \cdot k + i - 1}}{(x \cdot k + i - 1)!} (x - n + Q_I - s_p \cdot g_p) \right] + s_L \cdot g_L \quad (12)$$

$$T = n + \sum_{x=0}^{2n - Q_I} \left[\sum_{i=1}^k \frac{e^{-\lambda} \cdot (\lambda)^{x \cdot k + i - 1}}{(x \cdot k + i - 1)!} (x - 2n + Q_I) \right] + s_L \cdot g_L \quad (13)$$

3. Simulation and Result Analysis

The proposed statistical analytical model is evaluated through a series of microscopic simulations completed in AIMSUN because there are no existing implementations of CLL intersections in Iran. The selected measures of effectiveness (MOEs) for this study are throughput and total delay of both the LT approach and the entire intersection. In order to check out and assess the capacity equation and basic parameters resulted from it, simulation of three intersections located at the city of Tehran in Iran has been done by AIMSUN software. These are the intersections of Modiriyaat-Saadatabad Boulevards, Farahzadi-Dadman, and Paknejad-Darya.

The main goal of this paper is to determine the capacity of intersection with CLL by analytical approach. Simulation is used only for comparing the results of this study and the studies of others.

So, due to the comparative nature of this part of the work, the authors do not feel the need for calibration. The result of the comparison of the extra operational capacity obtained from CLL based on the assumption of entering with Poisson distribution and entering with generalized Poisson distribution shows that assuming generalized Poisson distribution results in a more operational capacity. Figure 2 shows the comparative chart of the operational capacity resulted from Poisson and generalized Poisson distributions.

Based on this comparison, as mentioned before, generalized Poisson distribution in heavy traffic conditions has a better performance than normal Poisson distribution.

The comparison of some important factors including delay, queue length and travel time for conventional and CLL design has been done. Tables 4 to 6 show the values of these factors in two modes.

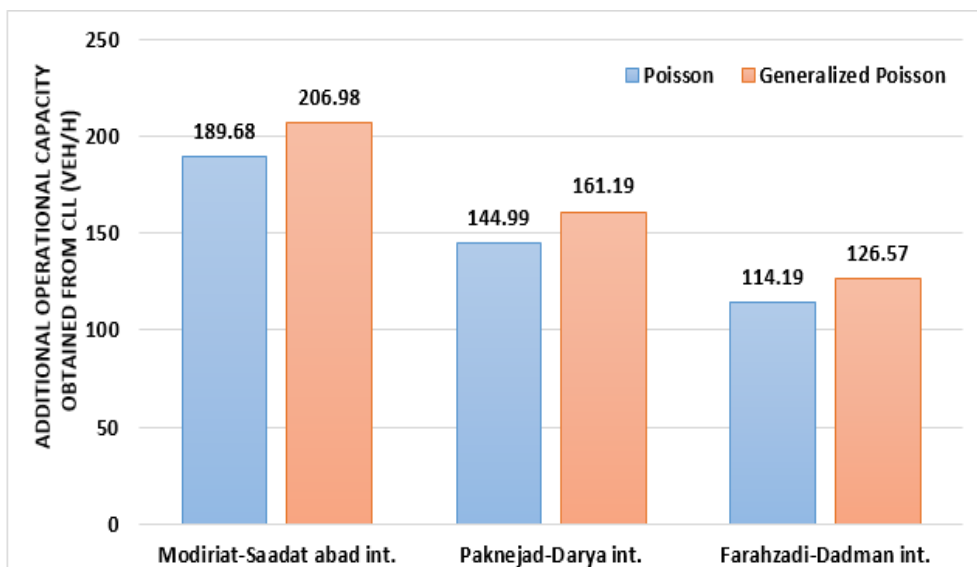


Figure 2. Comparison of CLL capacity in two entering modes of Poisson and generalized Poisson

Table 4. Simulation results of the intersection of Modiriat-Saadatabad for normal and CLL design

MOEs	Conventional			CLL design		
	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3
Vehicle delays (sec/km)	141.6	135.3	141.9	103.7	104.8	109.6
Mean Queue(veh)	27.4	27.56	29.3	22.2	23.9	25.2
Number of Stops(veh/km)	0.55	0.55	0.56	0.57	0.60	0.61
Travel Time(sec/km)	207.6	201.6	208.1	169.8	171.2	175.8

Table 5. Simulation results of the intersection of Paknejad-Darya for normal and CLL design

MOEs	Conventional			CLL design		
	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3
Vehicle delays (sec/km)	153.9	153.8	154.2	180.9	142.2	137.7
Mean Queue(veh)	23.2	33.1	23.2	35.7	36.7	34.8
Number of Stops(veh/km)	1.0	1.0	1.0	1.09	1.13	1.1
Travel Time(sec/km)	219.9	219.7	220.2	206.8	208.1	203.1

Table 6. Simulation results of the intersection of Farahzadi-Dadman for normal and CLL design

MOEs	Conventional			CLL design		
	Rep. 1	Rep. 2	Rep. 3	Rep. 1	Rep. 2	Rep. 3
Vehicle delays (sec/km)	178.8	167.1	175.55	177.24	148.1	155.3
Mean Queue(veh)	32.7	29.5	31.4	37.0	28.6	30.7
Number of Stops(#/veh/km)	0.93	0.88	0.90	1.10	0.97	1.10
Travel Time(sec/km)	245.1	233.2	241.7	243.4	214.2	221.4

Also, in Figures 3 to 5, the value of these factors (average of each three simulations) for normal and CLL design are compared with each other in the form of bar charts.

According to the chart in figure 3, CLL design led to a reduction in vehicle delay in all modes. Based on the results, the maximum value of delay's reduction (more than 24 percent reduction) is related to the intersection of Modiriat-Saadatabad boulevards, and also the minimum value of delay's reduction (7.8 percent reduction) is related to the intersection of Farahzadi-Dadman boulevards. The chart which is showed in Figure 4, expresses the travel time reduction of CLL design vehicles in

relation to normal design for all of the study conditions. Based on these results, the intersection of Modiriat-Saadatabad boulevards with a 16.3 percent reduction has the maximum value of travel time reduction. As it can also be seen in Figure 5, the queue length of CLL design vehicles at the intersection of Modiriat-Saadatabad boulevards in relation to normal design has decreased by 15.3 percent. While in two other intersections, vehicle queue length not only has not been decreased but also increased in a way that queue length at the intersection of Paknejad-Darya boulevards has been increased by 10.1 percent.

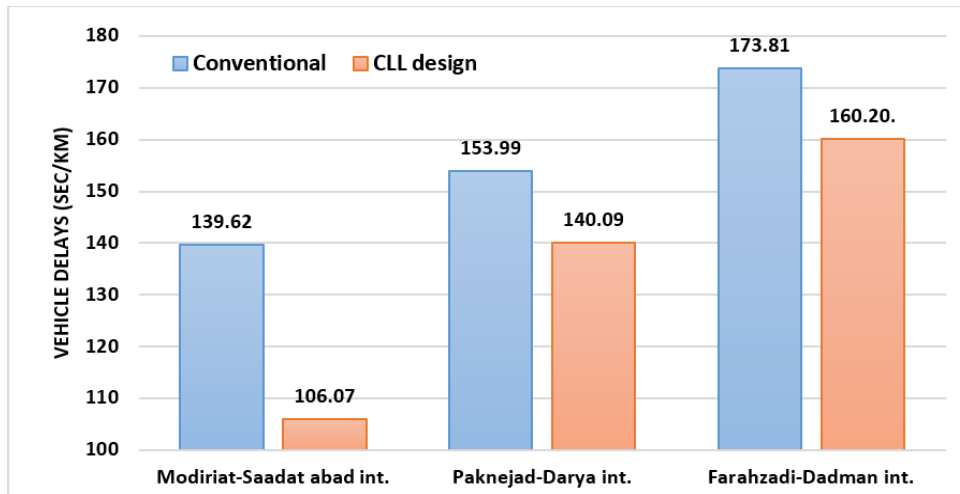


Figure. 3 Comparative chart of vehicles delay in two normal and CLL design for three intersections

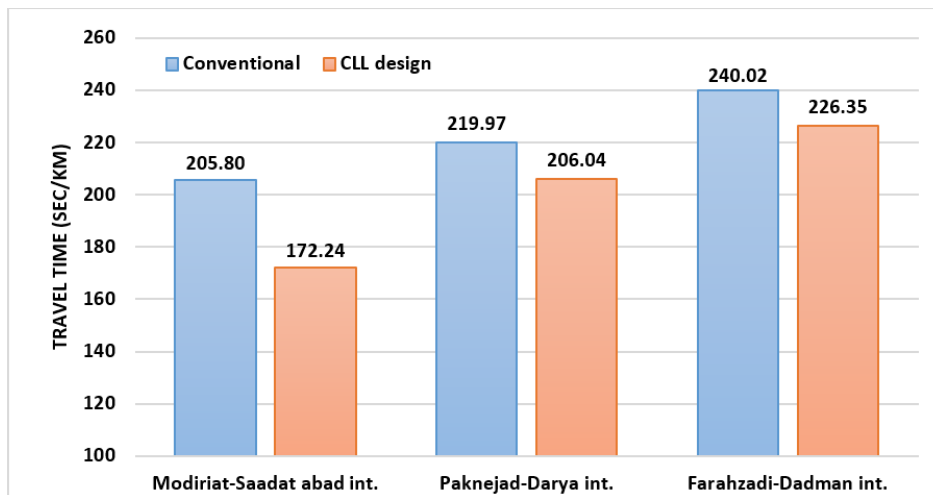


Figure. 4 Comparative chart of vehicles travel time in two normal and CLL design for three intersections

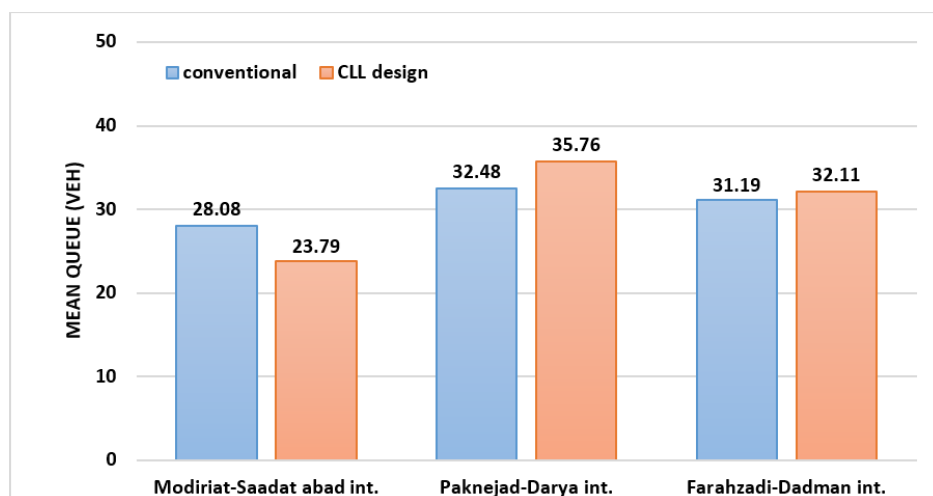


Figure. 5. Comparative chart of vehicles queue length in normal and CLL design for three intersections

3.1 Assessment of CLL Optimum Length

Figure 6 shows the vehicles' delay resulted from the simulation of different values of CLL length for the intersection of Modiriat-Saadatabad boulevards. These lengths are chosen based on the average occupancy length of each vehicle (6 meters), in a way that could be placed in the CLL area between 3 to 10 vehicles.

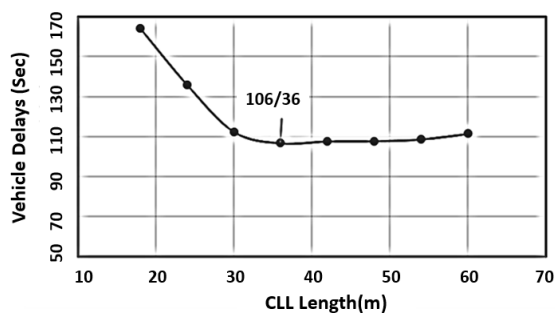


Figure 6. Changes in vehicles delay at the intersection of Modiriat-Saadatabad for different CLL values

According to the Figure above, at first, by increasing CLL length, vehicles' delay decreases with an almost steep slope till reaches its minimum value (for 36 meters length) Then by increasing more of CLL area length, vehicles' delay begins to increase. So, it can be said that CLL optimum length at this intersection equals the expected length of 36 meters (the length obtained in this study)

The important point is assigning CLL to the inappropriate length for doing left turn movement may not only cause not to improve the performance of intersection and decrease the delay but also cause worsen the situation and increasing the delay.

4. Discussion and Conclusion

Based on the comparison of results obtained from the simulation, in CLL design, travel time for 6 to 16 percent and vehicles' delay for 8 to 24 percent reduced in relation to conventional design. In addition to this, results showed that despite being effective of CLL design, this method in different conditions has not equal

effects on improving intersection performance. So, it is needed to compare the results more carefully to assess this design.

By observing and checking the results obtained from the simulation and vehicle traffic volume, it seems that the heavier left-turn vehicle volume tends to have the more desirable effects of the CLL design.

Therefore, CLL design at the intersection of Modiriat-Saadatabad boulevards that has the most volume of left-turn vehicles causes the maximum reduction rate of vehicles' delay and travel time. At this intersection, increasing vehicles' number of stops due to CLL design is less than the two other intersections, and also vehicles' queue length in this intersection, unlike the intersections of Paknejad-Darya and Farahzadi-Dadman has been decreased significantly. However, making CLL design at the intersection of Farahzadi-Dadman boulevards that has the lowest vehicle traffic volume brings fewer desirable effects.

Based on the observed results and the explanations stated about this case, it can be said that according to the past studies [Wu, Liu, Tianand Xu, 2016; Su, Krause, Hale, Baredand Huang, 2016; Zhao, Ma, Zhangand Yang, 2013; Zhao, James, Xiaoand Bared, 2018], in order to achieve the most desirable effects of CLL design, this method should be included at intersections with very heavy left-turn volumes. To conclude, this design does not have desirable effects on all traffic conditions.

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