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Impact of Delay and Queue on the Length of Left-Turn Storage at Palestine Intersections in Baghdad city, Iraq

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Abstract. At intersections, Left-turning vehicles seek to occupy the same physical space as close to the stop line as possible. These result in high conflicts, delays, and blockage of vehicles by turning vehicles and vice versa. The impact of the lengths of Left-turn lanes on intersection delays is considered to optimize the lengths of the Left-turn lanes. Data for traffic counts, queue lengths, and signal timing are collected from three intersections in Baghdad city in Iraq. The methodology involves the development of estimation models using traffic Simulation SIDRA INTERSECTION 8.0 and simulating various scenarios by varying traffic signal conditions to evaluate delays and queues caused by varying lengths of the Left-turn Lane. Optimal lengths are computed and compared to existing lengths in intersections. No differences in delay, queue, and lengths of the Left turn lane are found using t-test analysis for significance. Outputs from the three models were compared to the maximum observed in the field from the selected intersections. Data analysis involved determining the R^2 and the standard error mean between the model output and the observed data. In general, SIDRA INTERSECTION 8.0 overestimated queue vehicles and length of storage for approaches with a high degree of saturation ratios and underestimated it for those with a high degree of saturation ratios.

Keywords: Queue length; delay; Left-turn storage; analysis models; SIDRA

1. INTRODUCTION

Several studies have been carried out in the past related to Left-turn movement and the related need for Left-turn Lane. One of the key needs is to identify and study conflicts. Conflicts, in turn, affect both safety and traffic flow near intersections. Typically, there are three types of conflicts – crossing, merging, and diverging conflicts. As far as Left-turn movements are considered, the conflicts to deal with are merging and diverging conflicts. Both merging and diverging conflicts can potentially result in rear-end or side-swipe conflicts [1-3]. The length of the turn lanes includes three components: taper, deceleration length, and storage length, as shown in Figure 1 [4,5]. The turn lane begins with a taper, the design of which depends on location and traffic characteristics. The AASHTO [6], the HCM 2010 [7], and the other guidelines specify the taper length as 8:1 and 15:1 for design speeds up to 30 mph and up to 50mph, respectively. Based on this recommendation, the length of the taper should be 96 to 180ft for low-speed and high-speed roadways, respectively (the width of the turning lane is considered 12ft). The use of taper length, such as 100ft for a single-turn lane and 150ft for a dual-turn lane for urban streets, is mentioned in the AASHTO guideline. Provided that the deceleration distance is determined in the high-speed conditions, the recommendation of the shorter taper design from 100ft to 130 ft is mentioned in Traffic Engineering Handbook. Queue length estimation is essential in signalized intersections to design the optimum turn lane length with no congestion appearing [8].

Traffic simulation models are effective tools for evaluating the impacts of changes in system parameters where the situations are too complex for analytical methods or field observations. This approach provides the freedom to modify the different traffic parameters within the model and observe the changes without disrupting the traffic flow or altering the infrastructure. Simulation models can be classified according to the level of detail at which they represent the traffic stream [9]. Delay to a vehicle is the difference between interrupted and uninterrupted travel times through the intersection, as seen in Figure 2, which shows the delay experienced by a through vehicle stopping and starting at traffic signals [10,11].

The average delay predicted by SIDRA INTERSECTION 8.0 is for all vehicles, queued and unqueued. Based on this definition, the total delay (vehicle hours per hour) is the product of the average delay and the total demand flow rate. The total delay for a movement (or lane group) is the sum of total delays for all lanes that are used by the movement (or belong to the lane group), allowing for the proportion of movement demand flow in each lane [13,14].

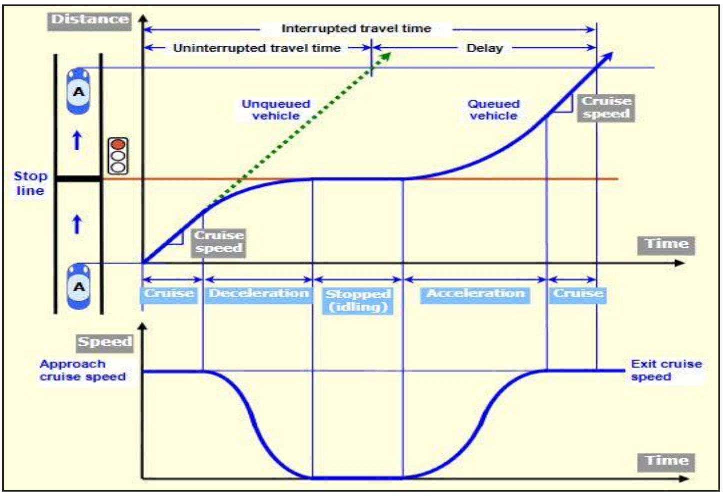


Figure 1: Definition of delay experienced by a vehicle stopping at traffic signals [12].

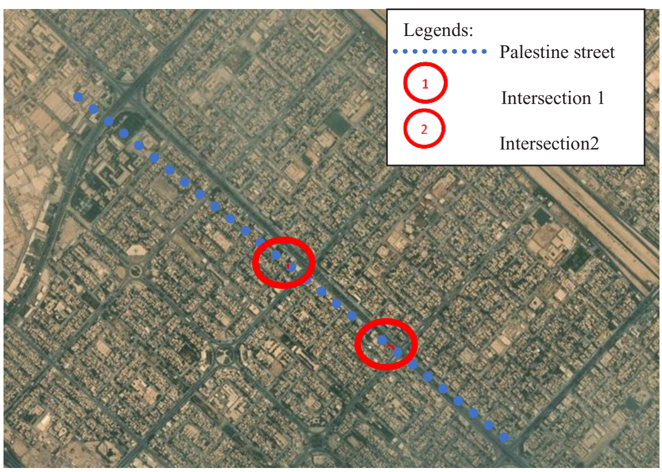


Figure 2: Overall study site map, source: Bing map 2023.

2. DATA COLLECTION METHODOLOGY

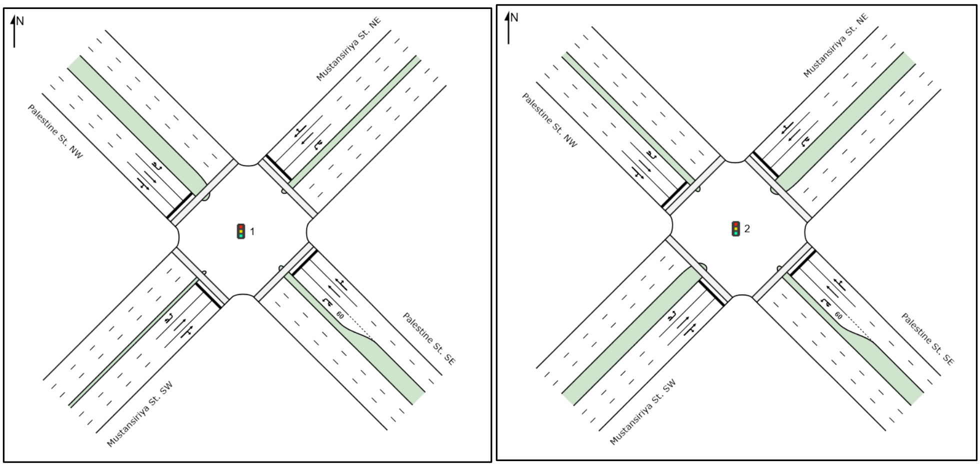
After the preliminary surveys are conducted on the sites initially chosen for the study, the left-turn queue storages at Palestine intersections are selected for the study. Figure 2 shows the overall map of the site. It is observed that the intersections are congested during the evening peak hour, and left-turn lanes overflow most of the time. To study the area, the following criteria are shortlisted for selecting the study site:

- Existence of left-turning vehicles overflowing onto the through lanes during peak hour periods.
- Existence of through vehicles blocking the entry of left turn during peak hour period.
- Having a single left turn on the approach leg under study.

To develop the model, the traffic volume collected from the study sites at morning and evening peak hours that presented in tables from (7:00-10:00) and from (17:00-20:00) on the working day. As the control delays and queue lengths are collected from the field for calibration, the traffic counts from the field are collected to match the output control delays obtained from the model with the field control delays. They are input into the model during the morning and evening peak periods. The Traffic data is collected on Monday for a duration of 60 minutes. Table 1 and Figure 3 present the traffic count data summary.

Table 1: Traffic volume for 60 minutes for all designated intersections.

Intersection	Volume (vehicles)								Total Volume
	South-West Bound		North-West Bound		South-East Bound		North-East Bound		
	↰	↑	→	↷	↳	↓	←	↗	
Intersection 1	860	267	856	385	375	310	530	390	**3973**
Intersection 2	290	245	430	255	345	390	490	320	**2765**



(Intersection 1) (Intersection 2)

Figure 3: Geometric layouts for studied intersections.

3. QUEUE LENGTH AND CONTROL DELAY

In order to determine control delays, the HCM, 2010 method is used in this study. A field survey is conducted, and observations are recorded for every approach of the intersections that corresponds to the morning peak period. The flowing steps are followed to count the queue lengths and determine the control delays.

3.1 Counting Vehicles in the Queue

This step counts the vehicles queued on the Left Lane and through lanes. Successive 30-second intervals are used to count the vehicles in the queue at the intersection approach. The counts are started at the beginning of the red phase for a lane group for those cycles that had no vehicles remaining from the previous cycle. Each observer is used for counting the number of vehicles in queues for the Left-turning Lane and the through lanes. The observers counted the vehicles that arrived after the green phase ended. Table 2 presents the data for the queue lengths for the left-turn lane and two through lanes for Intersection 1 for 30 minutes, respectively.

Table 2: Queue length for left-turn lane for South-East approach for intersection 1.

Time	**Queue Lengths (vehicles)** for left-turn lane				Queue length for through lane			
	0 – 30 s	**30 - 60 s**	**60 - 90 s**	**90 -120 s**	**0 – 30 s**	**30 - 60 s**	**60 - 90 s**	**90 -120 s**
7:00:00	12	10	5	8	10	0	4	8
7:02:00	10	3	5	7	11	13	0	8
7:04:00	9	10	5	4	14	16	8	0
7:06:00	8	10	12	12	9	12	16	0
7:08:00	0	4	7	10	3	9	11	13
7:10:00	2	4	5	6	0	5	6	11
7:12:00	8	4	3	8	1	0	5	7
7:14:00	9	12	5	3	11	2	5	7
7:16:00	8	10	0	5	9	11	0	4
7:18:00	8	10	11	2	7	1	4	0
7:20:00	4	6	7	8	4	7	12	0
7:22:00	3	1	5	6	3	9	10	13
7:24:00	0	3	6	12	0	4	9	11
7:26:00	12	5	6	12	3	0	4	10
7:28:00	13	14	6	7	13	0	7	11
7:30:00	7	7	0	6	15	12	0	10
∑Viq	**430**				**428**			

3.2 Counting Vehicles That Stopped

In this step, the vehicles that stopped at the intersection at each cycle length are counted and recorded for 30 minutes. One observer each is used for counting the number of vehicles that stopped for the Left-turning Lane and the through lanes. Table 3 presents the data for Intersection 1 for one approach.

Table 3: Stopped and not-stopped vehicles for South-East for Intersection 1.

Cycle Length	Stopped (vehicles) (Left)	Stopped (vehicles) (Through)	Not-Stopped (vehicles) (Left)	Not-Stopped (vehicles) (Through)
1	10	20	2	5
2	7	22	0	6
3	8	23	1	3
4	7	24	0	6
5	7	20	2	3
6	4	23	2	7
7	7	22	0	7
8	5	20	2	10
9	9	23	1	8
10	9	23	2	6
Total	73	220	12	61

3.3 Computing Control Delay for Left-Turn Vehicles in Site

To compute control delay, the HCM (2010) method is used. The number of vehicles in the queue, the number of vehicles that stopped, and the number of vehicles that did not stop for the left-turn lane are obtained from Table 4.

The control delay for the left lane is calculated as follows:

Total Number of Lanes (N) = 1; Free Flow speed = 60 kph (posted speed limit is taken as Free Flow Speed); Number of cycles surveyed (Nc) =10; Interval between vehicle on queue counts (Is) = 30 seconds; Total Number of vehicles arriving during survey period $\sum V_{total}$ =85; Total Number of vehicles stopped during survey period $\sum V_{stop}$ =73; and Total number of vehicles in queue = $\sum Viq$ =430

$$\text{Time in queue per vehicles} = \left(I_s * \frac{\sum V_{iq}}{V_{total}}\right) * 0.9$$

$$= \left(30 * \frac{430}{85}\right) * 0.9 = 136.5 \text{ sec.}$$

HCM, 2010 Exhibit A16-2 (TRB 2010) recommends an acceleration /deceleration correlation factor (CF) of 5 for the free flow speed of less than 60 kph and less than 7 vehicles in queue.

Acceleration / Deceleration correlation factor (CF) = 5

$$\text{Fraction of vehicles stopping (FVS)} = \left(\frac{\sum V_{stop}}{V_{total}}\right) \quad (1)$$

$$\text{(FVS)} = \left(\frac{73}{85}\right) = 0.85 \text{ sec.} \quad (2)$$

Acceleration / Deceleration correlation delay (dad) = FVS x CF (3)

$$= 0.85 * 5 = 4.25 \text{ sec.}$$

Control Delay per Vehicle (d) = dvq + dad (4)

$$= 136.5 + 4.25 = 140.75 \text{ sec.}$$

The control delay for the Left-turn Lane is calculated as 140.75 seconds/vehicle.

4. DEVELOPMENT OF LEFT TURN MODELLING

Each of the intersections was modeled with the selected traffic models by entering data pertaining to their respective geometry, signal timing, and traffic parameters. SIDRA INTERSECTION 8.0 Data input formed the basis for analysis. Thus, data about the geometry, signal phasing and timing, and traffic data were not coded but obtained from real existing data input. Default parameters in SIDRA INTERSECTION 8.0 were used; this study has not been calibrated yet. Table 4 shows the comparison between the queue in vehicles and distance with delay estimated by SIDRA Intersection 8.0 and the Maximum Observation Queue (MOQ), Maximum Observation Length (MOL), and Maximum Observation Delay (MOD).

Table 4: SIDRA Intersection 8.0 results vs. MOQ, MOL, and MOD.

Intersection	App.	Degree of Saturation	Queue (v.)	Queue (m.)	Delay (sec./veh.)	MOQ (v.)	MOL (m.)	MOD (sec./veh.)
Intersection 1	North	1.162	32.1	98.8	261.9	26	160	246.6
	South	1.216	24.1	68.6	261.9	18	60	171.0
	East	1.245	49.1	189.8	37.0	47	187	43.0
	West	1.284	41.9	111.4	295.1	39	100	312.0
Intersection 2	North	1.256	75.6	268.1	391.7	73	300	312.9
	South	1.215	84.7	219.1	1214.2	66	228	392.8
	East	1.422	48.3	138.0	497.3	43	194	512.0
	West	1.521	85.3	236.2	544.8	73	254	489.0

5. VEHICLES QUEUE ESTIMATES MODEL

The results of simulation runs for the existing condition (MOQ) show a comparison between SIDRA Intersection 6.0 and MOQ results using the paired samples t-test via SPSS. At the same time, the major measure of effectiveness is the queue. The results, as shown in Table 6 and Figure 4, show that the value of Correlation is 0.973 with a mean of difference in queue of 8.98 vehicles with Std. Error Mean of 4.2362, a Sig. (2-tailed) of 0.063, with a t-value of 2.12, so the hypothesis that there are no deviations is accepted at 95% confidence.

To model the value of queue lane for the Left-turns Lane, based on the regression analysis in SPSS, the following combinations of parameters are considered for the regression analysis:

a) Back of queue as a dependent function of queue.
b) Degree of saturation as an independent function of queue.
c) Overflow queue as an independent function of queue.
d) Queue storage ratio as an independent function of queue.
e) Probability of blockage as an independent function of queue.

$$\text{Queue (veh.)} = 1.698\ (\text{Overflow Queue}) - 26.689\ (\text{Degree of Saturation}) + 2.516\ (\text{Queue Storage Ratio}) - 0.184\ (\text{Probability of Blockage}\ \%) + 34.746 \quad (5)$$

Table 5: T-test analysis results between SIDRA Intersection 6.0 and MOQ.

<table>
<tr><th colspan="9">Paired Samples Statistics</th></tr>
<tr><th colspan="3"></th><th colspan="2">Mean</th><th>N</th><th colspan="2">Std. Deviation</th><th>Std. Error Mean</th></tr>
<tr><td colspan="3">SIDRA Intersection (veh.)</td><td colspan="2">55.580</td><td>10</td><td colspan="2">55.6540</td><td>17.5994</td></tr>
<tr><td colspan="3">MOQ (veh.)</td><td colspan="2">46.600</td><td>10</td><td colspan="2">50.0471</td><td>15.8263</td></tr>
<tr><th colspan="9">Paired Samples Correlations</th></tr>
<tr><th colspan="4"></th><th colspan="2">N</th><th colspan="2">Correlation</th><th>Sig.</th></tr>
<tr><td colspan="4">SIDRA Intersection (veh.) and MOQ (veh.)</td><td colspan="2">10</td><td colspan="2">0.973</td><td>0.002</td></tr>
<tr><th colspan="9">Paired Samples Test</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">Mean</th><th rowspan="2">Std. Deviation</th><th rowspan="2">Std. Error Mean</th><th colspan="2">95% Confidence Interval of the Difference</th><th rowspan="2">t</th><th rowspan="2">df</th><th rowspan="2">Sig. (2-tailed)</th></tr>
<tr><th>Lower</th><th>Upper</th></tr>
<tr><td>SIDRA Intersection (veh.) – MO (veh.)</td><td>8.980</td><td>13.3962</td><td>4.2362</td><td>-0.6030</td><td>18.5630</td><td>2.120</td><td>9</td><td>0.063</td></tr>
</table>

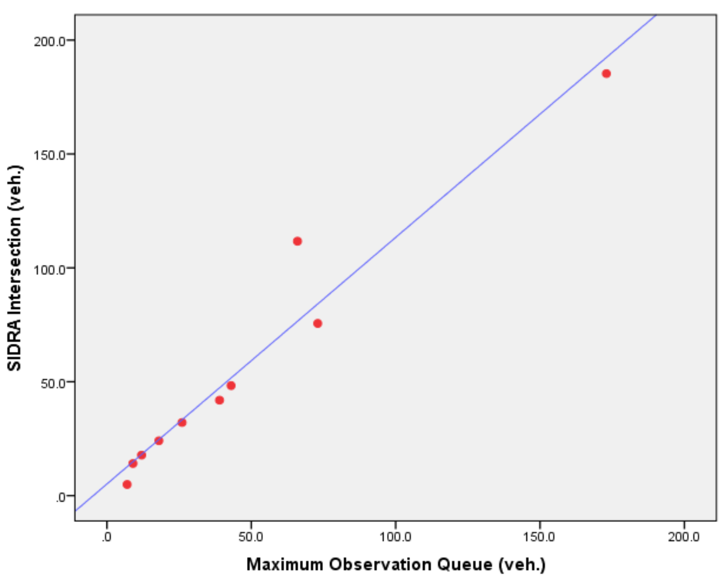


Figure 4: Comparison of queue vehicles estimated by SIDRA Intersection 6.0 with MOQ.

6. LENGTH OF QUEUE ESTIMATES MODEL

From the results of simulation runs for the existing condition (MOL), a comparison is made between SIDRA Intersection 6.0 and MOL results by using the paired samples t-test via SPSS. At the same time, the major measure of effectiveness is the queue length. The results, as shown in Table 6 and Figure 5, show that the value of Correlation is 0.973 with mean of difference in queue of 8.98 vehicles with Std. Error Mean of 4.2362, a Sig. (2-tailed) of 0.063, with t-value of 2.12, so the hypothesis that there are no deviations is accepted at 95% confidence.

To model the value of queue length for Left-turns Lane, based on the regression analysis in SPSS, the following combinations of parameters are considered for the regression analysis:

a) Back of queue as a dependent function of Queue Length.
b) Degree of saturation as an independent function of Queue Length
c) Overflow queue no. as an independent function of Queue Length.
d) Queue storage ratio as an independent function of Queue Length.
e) Probability of blockage as an independent function of Queue Length.

$$\text{Queue Length} = 158.816\ (\text{Degree of Saturation}) - 0.067\ (\text{Overflow Queue}) - 2.227\ (\text{Queue Storage Ratio}) - 0.045\ (\text{Probability of Blockage }\%) + 22.114 \quad (6)$$

Table 6: T-test analysis results between SIDRA Intersection 6.0 and MOL.

Paired Samples Statistics				
	Mean	**N**	**Std. Deviation**	**Std. Error Mean**
SIDRA Intersection (m.)	161.170	10	12.890	3.229
MOL (m.)	140.000	10	12.413	3.975

Paired Samples Correlations			
	N	**Correlation**	**Sig.**
SIDRA Intersection (m.) and MOL (m.)	10	0.967	0.005

Paired Samples Test								
	Mean	**Std. Deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**		**t**	**df**	**Sig. (2-tailed)**
				Lower	**Upper**			
SIDRA Intersection (m.) - MOL (m.)	21.170	3.014	10.1239	-1.73	44.07	2.091	9	0.066

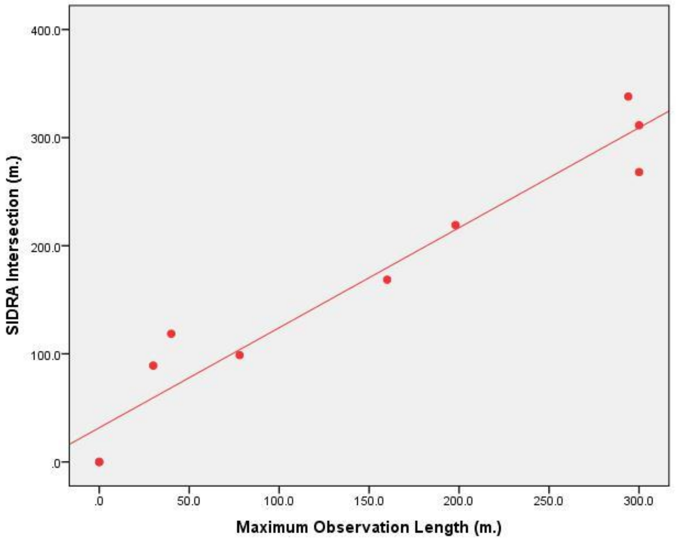


Figure 5: Comparison of queue vehicles estimated by SIDRA Intersection 6.0 with MOL.

7. CONTROL DELAY ESTIMATES MODEL

The results of simulation runs for the existing condition (MOD) show a comparison between SIDRA Intersection 6.0 and MOD results using the paired samples t-test. In contrast, the major measure of effectiveness is the delay. As shown in Table 8 and Figure 6, the value of Correlation is 0.994 with a mean difference in delay of 24.49 seconds per vehicle with Std. Error Mean of 12.03, a Sig. (2-tailed) of 0.072, with a t-value of 2.035, so the hypothesis that there are no deviations is accepted at 95% confidence.

To model the value of control delay for Left-turns Lane, based on the regression analysis, the following combinations of parameters are considered for the regression analysis according to following:

a) Average delay as a dependent function of control delay.
b) Degree of saturation as an independent function of control delay.
c) Stop-lane delay as an independent function of control delay.
d) Queue move-up delay as an independent function of control delay.
e) Stopped delay as an independent function of control delay.

$$\text{Control Delay} = 7.272\ (\text{degree of saturation}) - 0.684(\text{stop} - \text{lane delay}) + 0.99(\text{queue move} - \text{up delay}) + 0.991(\text{stopped delay}) + 5.854 \quad (7)$$

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Table 3: T-test analysis results between SIDRA Intersection 6.0 and MOD.

Paired Samples Statistics				
	Mean	**N**	**Std. Deviation**	**Std. Error Mean**
SIDRA Intersection (sec./veh.)	363.800	10	34.001	10.731
MOD (sec./veh.)	339.310	10	34.307	10.879

Paired Samples Correlations			
	N	**Correlation**	**Sig.**
SIDRA Intersection (sec./veh.) and MOD (sec./veh.)	10	0.994	0.005

Paired Samples Test								
	Mean	**Std. Deviation**	**Std. Error Mean**	**95% Confidence Interval of the Difference**				
				Lower	**Upper**	**t**	**df**	**Sig. (2-tailed)**
SIDRA Intersection (sec./veh.) - MOD (sec./veh.)	24.490	38.055	12.034	-2.73	51.71	2.035	9	0.072

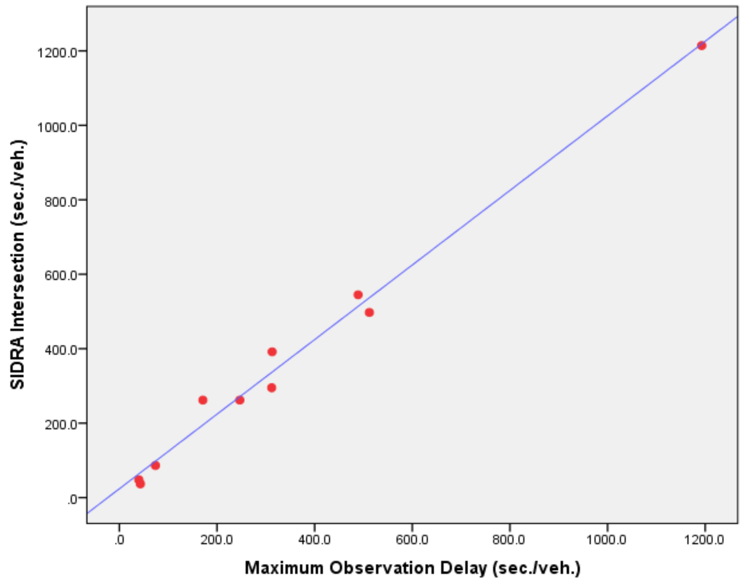

Figure 6: Comparison of queue vehicles estimated by SIDRA Intersection 6.0 with MOD.

8. CONCLUSIONS

This study performs analyses to evaluate the impact of queue and length of Left-turn lanes on signalized and un-signalized intersections delays. The optimum queue vehicles and length are determined using the principle of minimizing the delays. The delays corresponding to the optimum lengths and 95 percentiles are compared to evaluate the effectiveness of the optimum lengths of the left-turn lanes. This study analyzes protected and protected-permitted left-turn phasing for case study intersections. SIDRA INTERSECTION 8.0 software package has been developed and is available to the traffic engineer to design and estimate left-turn queues and delay models. However, these models vary from each other and how they replicate observed field data.

Paired t-tests were performed to determine the level of significance of the mean queue vehicles, distance, and delay computed SIDRA INTERSECTION 8.0. These were done by testing the null hypothesis that no significant difference exists between the estimated queues and delay by these models at a significance level of 0.05. The results of the test showed that there is no significant difference between the queue and delay estimated by SIDRA INTERSECTION 8.0. Regression analysis models were also performed to determine the relation between the queue and its depended variables and delay and its dependent variables. The variations in the queue estimated between the models are related to the degree of saturation, overflow queue number, queue storage ratio, and the probability of blockage. While the variations in the delay estimated between the models are related to the degree of saturation, stop-lane delay, queuing delay, queue move-up delay, and stopped delay.

Finally, the results of this study are based on a specific site's case study. The optimum lengths obtained from this study cannot be utilized for another site because the traffic conditions and geometric characteristics vary from site to site. Therefore, more sites should be studied to generalize the results and develop general guidelines that can be used for different intersection situations.

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