PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume 25 No. 1 March 2021 pp: 21-31

Analysis of Speed Hump Effect on Signalized Intersection Performance

Marwa S. Elbany [1], Mohamed S. Serag [2]

Received: 8 January 2020; Accepted: 23 August 2020

ABSTRACT

Intersections have primary importance in urban networks because most of travel time is wasted at the intersection specially signalized category. Popular solutions of intersection control need to use artificial objects such as speed hump or signals. If both solutions were used together, it causes a manifestation of the delay problem. The study aims at analyzing the impact of speed hump on signalized intersection act in case of traffic mix nature. Quality features such as delay, level of service, and saturation flow rates had been measured and compared for the two consecutive signalized intersections that have approximately the same geometric and operation features in Port Said city. The first intersection has a speed hump and the other is without a speed hump. The study investigates that the existence of speed hump causes the increasing of the average delay by 4.3 %. Also, about half of green time is spent to pass the speed hump. Moreover, the saturation flow rate decreases by about 7 %. The speed hump adjustment factor is 0.93 that declares the harmful impact of speed hump on the saturation flow rate thus it effects on the whole performance of the intersection.

Keyword: Signalized intersections, speed hump, delay, saturation flow rate.

1. INTRODUCTION

Using signals in controlling intersection is one of safe and efficient control tools. Signalized intersections are the important points or nodes within a system of highways and streets. The most common measures of effectiveness are the average delay per vehicle, the average queue length, and number of stops [1].

Among those three measures, delay is the most frequently used measure of the effectiveness of signalized intersections for the directly perceived by a driver. There are many factors affected the delay such as the on-road traffic congestion, road infrastructure and number of lanes. At intersections, the average queue length at any time is a useful measure, and is critical in determining when a given intersection will begin to impede the discharge from an adjacent upstream intersection. Number of stops made is an important input parameter, especially in the environmental feasibility studies.

Why estimation of delay is complex? This question can be answered when studying the geometric characteristics of roads and the shape of movements due to random arrival of vehicles, lost time due to stopping of vehicles, and over saturated flow conditions.

[1] *A lecturer of transportation planning and traffic engineering, Civil Engineering Department, Faculty of Engineering, Port-Said University, Egypt, email: mr_elbany@eng.psu.edu.eg*

[2] *Professor of transportation planning and traffic engineering, a:Civil Engineering Department, Faculty of Engineering, Port-Said University, b: Giza Higher Institute of Engineering and Technology, Egypt, email: sadek1234@hotmail.com*

DOI : 10.21608/pserj.2020.22086.1027

Previous researchers concentrated on a natural pavement condition that changes by time causing deterioration and roughness or by external effects; weather. The speed hump's effect until now still has no attention intended to help the traffic manager decision either prevent or keep this kind of speed control way within a signalized intersection.

Furthermore, the average delay is a basic parameter when measuring the Level of Service LOS. In methodical models for predicting delay, there are three distinct components of delay, namely, uniform delay, random delay, and overflow delay [2]. Uniform delay has been calculated for uniform arrivals while the inter-vehicle arrival time between vehicles is constant. Assuming no pre-existing queue, arriving vehicles can move instantaneously when the signal is green. For signalized intersections, there are many types of delay measures such as stopped time delay, approach delay, travel time delay, time-in-queue delay, and control delay. Each of them had been used depending on the goal of the available data but control delay is proven to give the nearly results because that its components simulate the real profile of movement [1].

There are some driving imitations at signalized intersections especially in mixed traffic cities, including:

- Driver unexcitable left-turning movement which have right of way as they obstruct with opposite through movements causing exceeded delay
- Invisible lane discipline because of the road deformity that prevents the driver's perception over considering the huge number of vehicles and concentrates on avoiding that deformity

- Huge numbers of pedestrians waiting for taxis and side road movement near to intersections which causes more delays

- The existence of some artificial impediments such as industrial humps

The latest problem is the issue that driven by this study. After preparations to make control on intersection movement, speed hump effect is still un-noticeable that can influence the vehicle's delay and saturation flow rates.

This study compares between two cases of signalized intersections in Port Said city as one of an urban cities in Egypt with its mixed traffic features. It involves two scenarios of consecutive signalized intersections; with and without speed hump that have approximately same features of geometric characteristics, traffic characteristics, and signal interval times. Delay, Level of Service LOS and saturation flow rates are the factors expressed to present the intersection performance.

For a signalized intersection, many of studies have estimated the safety and operational performance during 1980,s. In 1990,s, some calculated the delay for different case studies and other proposed delay models. Most of them concentrated on the development of operational models. In the last five years, they focused on studying factors affecting the level of operational performance such as pavement condition affected by weather condition and traffic situations [3]. Some studies were concentrated on delay determination as it is the primary indication factor of performance in urban networks.

Palcharia, Neson, HCM, Chen, and Younas,s approaches had been proposed to estimate delay depending on many factors such as demand, weather, and saturation flow. Younas comprised the road condition as a factor of delay. The research was depended on fuzzy concept that ascertains the level of traffic congestion on a road leading to a road junction [4].

There was a model for calculating delays at signalized intersection that produced by Hashim ib. and Shawky M. who studied the effect of the green indicator countdown number of drivers with a validation of the real time. They found that the start-up delay of the first four queued vehicle is reduced by about 9.2% in case of "with" countdown device. Also, they found that the installation of the countdown timers does not have any significant impact on the number of red light violations [5].

Nikiforos St. studied 32 intersections before/after signal installation and explored that about 19 of 32 intersections had a negative operational performance because of un-met the appropriate warrants [6]. The performance of traffic had been studied by Asamer J. who simulated road traffic performance by a microscopic simulator VISSIM that are sensitive to snowy road conditions and indicated valid parameter subspaces with observed saturation flow rates and start up delays. The study had concluded that saturation flow rate and start up delay are essential for correctly estimating road capacity for combination with green time of a signalized intersection. As desired speed decreases, the saturation flow rate decreases as well. The higher the free speed, the longer the acceleration phase will last and the higher the start-up delay will be [7].

Othayoth D. and Krishna K.V.used HCM approach for signalized intersection LOS analysis used a delay as a service measure and does not incorporate the users' perception. They made the Importance-Satisfaction analysis and recognized the most important and satisfying factor. They found out that the most important and least satisfied factor by the users was the waiting time at the signal followed by the pavement surface quality [8].

Most of previous studies focused on driver perception and operational performance depending on weather condition or intersection geometric but no one give attention to the impact of the speed hump in the signalized intersection. So, this study takes care about that issue by monitoring two cases of intersection with/without speed hump effects and illustrates the methodology of achieving the performance dependable standards; delay, LOS and saturation flow rate. The first standard has to be illustrated is a control delay that is the most commonly used scale of signalized intersection's effectiveness.

Control delay is the delay caused by a control device, either a traffic signal or a STOP sign. It is equal to delay when stopping at red sign in addition to the acceleration-deceleration delay component. LOS depends on control delay that includes initial deceleration delay, in-queue delay, stopped delay and final acceleration delay [9].

Average control delay measures can be stated for a single vehicle, as the average additional time for all vehicles over a specifi1ed time period or as an aggregate total value for all vehicles over a specified time period. Aggregate delay is measured in overall vehicle-seconds, vehicle- minutes or vehicle-hours for all vehicles in the particular time interval. Average individual delay is generally stated in terms of seconds per vehicle for a particular time interval. The signalized intersection control delay can be defined as the sum of three components [10]:

• Stopped Delay: is the time throughout which the vehicle is in a stop location.

• Deceleration Delay: is the time that average location at which vehicles gradually stops before intersection stop line from a normal speed.

• Acceleration Delay: is the time calculated when vehicle begins to move achieving its normal speed.

This study examines the impacts of speed hump on the key traffic parameter of the signalized intersection, namely, control delay. It will concentrate on speed hump reseated on the signalized intersection approaches. This kind of speed control method may be existed before installation of traffic at the intersection. There is a question if keep or remove it. To answer this question, there is a need to make more research about the effect of such object on the intersection performance by following the next decided control delay calculation methodology.

2. METHEDOLOGY

To reach the optimum values of delay, many factors should be analyzed such as, traffic volumes and the intersection geometry. Many studies use the traffic volume delay approach and others use geometric intersection delay approach; here the fusion of both approaches is used in a form of average delay estimation model.

Highway Capacity Manual HCM or traffic volume delay model, one of signalized intersection delay estimation models, uses the traffic volume to be the effective reason for control delay *(d_c)*. Others use the effect of geometric design of the intersection presenting in turning movements and any stops before approaches that is called a geometric delay (d_{ad}) such as McShane and Roess model [11].

2.1 Average Delay Model

Here, the proposed model sets a combined equation to calculate the average delay *(D)* and is called average delay model. It divides into two parts; the first is the time dependent stochastic delay of traffic volume model that gives a control delay *(d_c)* and the second deals with a geometric intersection delay approach that estimates a geometric delay (d_{ad}) as shown in the following equation:

$$\textit{Average Delay } (D) = d_c + d_{ad} \qquad (1)$$

The traffic volume delay approach measures a control delay *(d_c)* for a steady state traffic flow as a sum of three components d_1, d_2, and d_3 (sec./veh). It depends on traffic demand and saturation of approaches as will illustrate in the following paragraphs. The geometric intersection delay approach produces a geometric delay (d_{ad}) as a sum of acceleration delay d_a and deceleration delay d_d affected by a speed hump. All components will be identified in the following equations and illustrated step-by-step in the following figure:

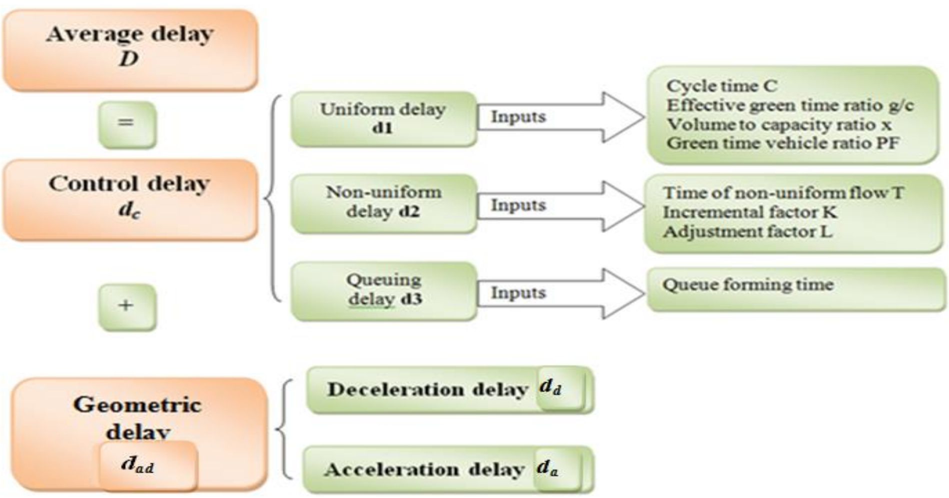

Figure 1: Average delay components flowchart

2.2 Traffic volume delay (d_c) approach

Traffic volume delay approach is driven by HCM delay model for all flow conditions based on empirical calculations as shown in figure 1. This model assumes steady-state traffic conditions and estimates a delay under stochastic equilibrium conditions [12]. It supposed that:

- The arrival and departure flow rates have been stationary for an indefinite period of time,

- The number of arrivals in a given interval follows Poisson distribution, and

- The headway between departures has a known distribution with a constant mean value.

The most important aspect here, that the location of noticeable must cover all the queue length. It splits into three components as shown in the following equation:

$$d_c = d_1\,(PF) + d_2 + d_3 \qquad (2)$$

Component d_1: a delay assuming uniform arrival *(sec/veh.) that is calculated by:*

$$d_1 = 0.5C\ \frac{(1-\lambda)^2}{(1-\lambda x)} \qquad (3)$$

Component d_2: a delay assuming random arrival *(sec/veh.) that is calculated by:*

$$d_2 = 900T\left[(X-1) + \sqrt{(X-1)^2 + \frac{8kIX}{cT}}\right] \qquad (4)$$

Component d_3: a delay depending on the initial queue from the beginning of data collection *(sec/veh.)*. It is assumed to be zero at most cases.

$$d_3 = \text{queue forming time} \qquad (5)$$

Where:

C is cycle length (sec.),

X is the volume to capacity ratio

λ is the total number of vehicles

Progression adjustment factor PF

$$PF = \left(\frac{(1-P)}{(1-(\frac{g}{c})}\right) * f_p \qquad (6)$$

Where:

c is the capacity of lane (vph)

f_p is a delay adjustment factor for quality of progression and control type equal to 1.0 for pre-timed non-coordinated signals

To determine delays and other features, field data including traffic volumes, surface conditions and others were collected for the two intersections 1 and 2 that perform two cases, first is signalized intersection with speed hump and the second is signalized intersection without speed hump (base case) in the same roadway. The site pictures are shown in figures 2, 3, 4and 5from which various traffic parameters were extracted from vehicle trajectories. The two intersection's approaches have 15 m width with the same number of lanes; three lanes at each direction.

k is an incremental delay adjustment factor and depends on signal controlling mode equal to 0.5 for pre-timed signals, and less than 0.5 for intersections with high efficiency

T is the minimum time of evaluations (hr) and x is *min* (1, X), if the data collected for 15 min. then T= 0.25

I is the upstream effect on randomness of arrival factor equal to 1 for completely random and less than 1 for a lower variance

2.3 Geometric intersection delay (D_{ad}) approach

The empirical delay model; D_{ad} is a sum of acceleration delay d_a and deceleration delay d_d due to the existence of speed hump at intersection approaches (sec/pcu). An acceleration and deceleration delay model, for extra delay causing by turn or any stopping reasons, is formed by the following equations [13]:

$$d_{ad} = d_a + d_d \qquad (7)$$

$$d_{ad} = [\,(1-P_s) * P_{ar} * 6\,] + [P_s * 4] \qquad (8)$$

Where:

d_g is acceleration and deceleration delay

P_s is the number of stopped vehicles per the total number of vehicles

P_{ar} is the number of vehicles turning right per the total number of vehicles

Also, they have approximately the same traffic volumes as they are two following intersections of the same roadway. The previous similarities have been predicted to give approximately the same delay values for only NB and SB directions that have the speed hump in case 1 and don't have one in case 2. The geometric-characteristics of both intersections are shown in Table 1. The existence of the speed hump in one of them is expected to have an impact that will be studied in this study.

Table 1 geometric characteristic of the two intersections

Geometric characteristics	I1				I2			
Directions	*NB*	*SB*	*EB*	*WB*	*NB*	*SB*	*EB*	*WB*
No. of lanes near approaches	3	3	3	3	3	3	-	3
Approach lane width (m)	3.5	3.5	3.42	3.6	3.5	3.56	-	3.45
Median width (m)	4	4	4	4	3.1	3.1	-	-

Figure 2: Intersection 1 with speed hump (East-West movement)

Figure 3: Intersection 1 with speed hump (North-South movement)

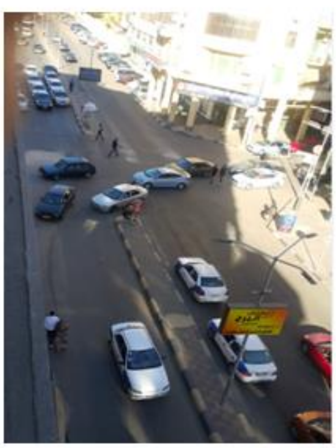

Figure 4: Intersection 2 without speed hump (East-West movement)

Figure 5: Intersection 2 without speed hump (North-South movement)

3. DATA COLLECTION

Real-time delay (cycle-by-cycle) is calculated using manual monitoring technique as follows:

- Collecting traffic signal timing data (total cycle length and green time of each phase)
- Collecting traffic volume data (Volume during green & clearance, Total occupancy during green, arrival type and;
-Average headway

Estimating control delay is the first step followed the procedure within accumulation of the HCM model and other empirical models. The second step is calculating LOS which depends on the computed average delay values. Estimation of saturation flow rate of each cycle using headway measurements will be briefly illustrated as the last step of analysis.

Field survey data using manual traffic counts was carried out for 15 minutes during a day in the morning and evening peak hours then converted in passenger cars unit. There is a mixed flow; cars, mini-buss, motorbikes, bicycles and pedestrians.

Table2: Data collection time period

	Intersection 1,2	
	AM	**PM**
Data collection time	1:00-1:15	8:00-8:15

At the roof of building near the two intersections, a camera was mounted focused to cover one leg of the intersection. Also, it covers all performed queue length at the red time interval for each approach. The recording was done for about 15 minutes during two peak hours; AM and PM. For the two intersections, data was recorded from 1:00 AM to 1:15AM and another one at 8:00 PM to 8.15 PM. Vehicles count and delays was obtained from the video records. NB and SB movements have the same traffic values but interrupted with a speed hump in intersection 1 before reaching the intersection with about 6 m. All movements are illustrated in figure 6.

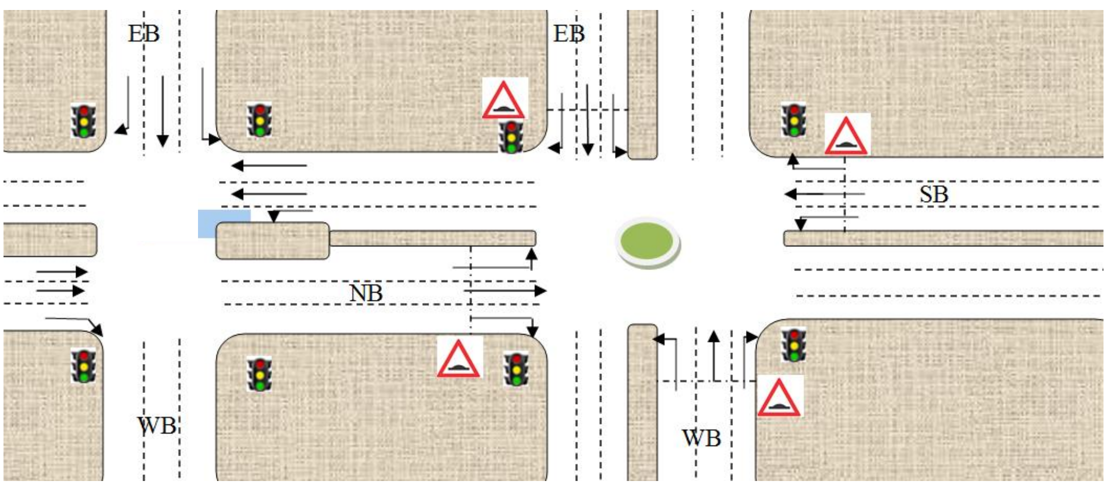

Figure 6: Intersections' layout and movements

Data on signal timing:

- Number of cycles and cycle length,
- Number of phases,
- Signal timing,
- Queue forming time collected manually,
- Time of stop and time of move using a stop watch, and
- Stopped and non-stopped vehicles data

Through and right movements in the intersections are taken as one group. For intersection 2, the left turn is prevented, so, the left turn is illuminated from the study. Data analysis and calculated features of performance are illustrated in the following sections.

4. DATA ANALYSIS AND RESULTS

4.1 Average delay

The traffic, in the two studied intersections, has features of traffic mix containing cars, trucks, buses, motor bikes, and pedestrians. Each of control and geometric delay is calculated for the allowed movements; through and right as illustrated in table 3. The difference between calculated and observed delay values, for the two cases, is shown in figure 6.

Table 3: Calculated average delays (sec.)

Movement	Vehicle type	Average control Delay Sec./veh.		Average Geometric Delay Sec./veh.						Average delay Sec./veh.	
		d_c		Acceleration delay		Deceleration delay		D_{ad}		$D=d_c+d_{ad}$	
		I1	I2	I1	I2	I1	I2	I1	I2	I1	I2
Through and right	Car	10.13	8.31	5.32	1.34	13.23	11.2	18.55	11.2	28.68	19.51
	Truck	8.82	5.77	7.49	7.41	19.31	16.35	26.8	23.72	35.62	31.49
	Bus	13.25	12.36	5.36	5.22	8.21	6.39	15.49	11.75	26.74	24.11
	Motor-bike	4.91	4.82	6.26	4.65	6.25	5.21	9.91	9.77	15.82	13.59

As seen in the previous table, the control delay has small values of variation between the two selected intersections. The difference can be observed among the traffic classification categories depending on their movement features. For cars, buses, and motor bikes, the variation on control delay values is less than 2 seconds where it is more than 3 seconds for trucks because of their special movement characteristics. Intersection 2 increases in delay values than the other one and the difference can be noticed in acceleration and deceleration delay values.

It is reasonable when a driver notices the speed hump, he should slow down his speed (deceleration) and then he intends to increase his speed to move (acceleration) even though there is no signal. There is dissimilarity from mode to another, for example cars, trucks, buses, and motor-bikes the driver takes his reactions in about 7, 3, 4 and 0.2 seconds; respectively which is named as geometric delay d_g. It can be concluded that the speed hump has low effect on motorbikes because its capability to move with its speed on speed hump without slowing down. The average delay increases by 4.3% due to speed hump. The existence of speed hump has a high effect on cars delay and medium effect in trucks and buses. The comparison between observed and computed delay values for intersection with speed hump is shown in figure 7.

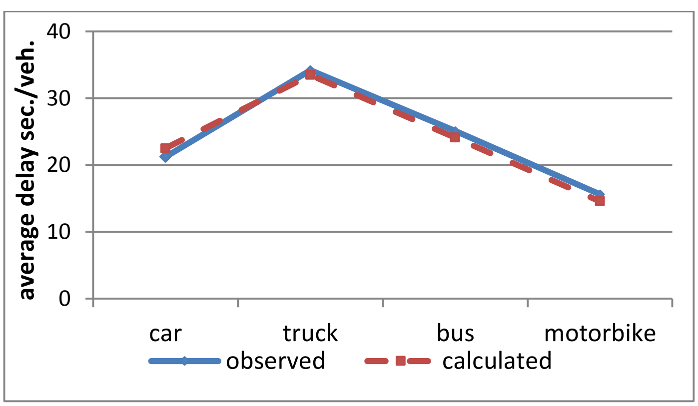

Figure 7: The comparison between observed and calculated average delay for intersection with speed hump (sec./veh.)

4.2 Delay profile distribution

The average travel time data was collected for the 12 cycles through the two intersections and illustrated as travel time profile shown in figure 8. The percent of average delay influenced by the speed hump is calculated by equation 9. Delay profile distribution is estimated by equation 10 and presented by the area between travel times of both intersections as shown in figure 8.

$$D_o = T_{I1} - T_{I2} \quad (9)$$

$$D\% = d_0 / G \quad (10)$$

Where:

D_0 is the average delay time influenced by the speed hump

T_{I1} is the travel time through intersection 1

T_{I2} is the travel time through intersection 2

G is the green time equal to 30 seconds

Table 4: Average delay of 12 cycles (sec./veh.)

Cycles	T_{I1}(sec.)	T_{I2}(sec.)	Delay	delay%	%delay from ordinary case
C1	24	16	8	0.27	0.50
C2	12	10	2	0.07	0.20
C3	14	8	6	0.20	0.75
C4	26	9	17	0.57	1.89
C5	10	8	2	0.07	0.25
C6	40	11	29	0.97	2.64
C7	24	10	14	0.47	1.40
C8	11	9	2	0.07	0.22
C9	11	6	5	0.17	0.83
C10	48	15	33	1.10	2.20
C11	42	7	35	1.17	5.00
C12	39	9	30	1.00	3.33

From the previous table, it can be noticed that the minimum value of delay is two seconds and the maximum is 35 seconds which is the delay value caused by the speed hump. Using such profiles is better than using travel time profile because although the maximum travel time through intersection with speed hump is 48 seconds, the delay is only 33 seconds. So, using the difference between travel time values is more reliable than using delay values. The average difference between cycle time and each values of delay, presents the problem of using any of obstacles through movement. This also appears in value of delay exceeds the green time (30 seconds) as it is the time of movement permission in cycles 6,10,11 and 12. So, the vehicle should stop for the next cycle and causes over traffic volume. The other standard is the difference of delays from the ordinary case (without hump) which seems as similar to delay percent values. It is calculated to assure the delay caused by speed hump during time of observation.

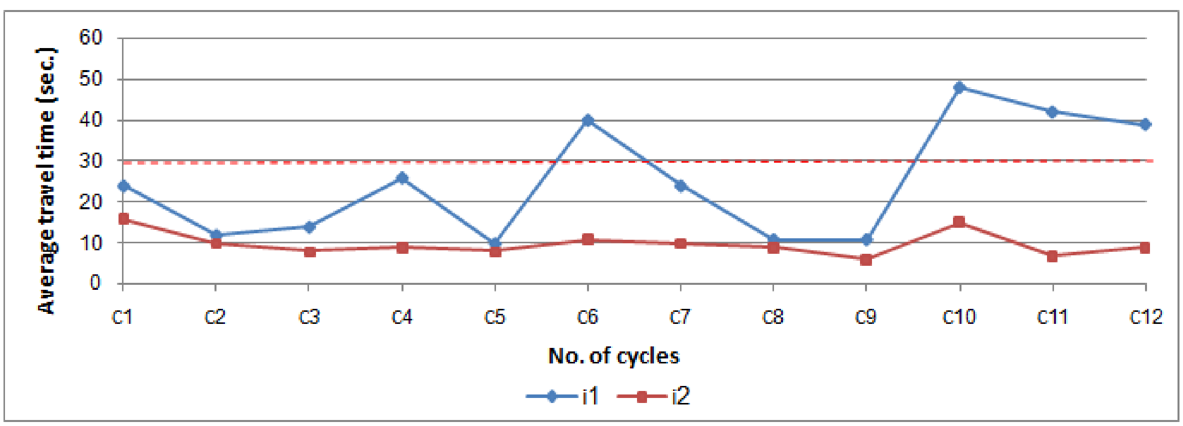

Figure 8: Travel time profile

The delay percent *D%* is calculated by equation 10. It describes the dissimilarity of congestion during the time of observation that displayed by delay distribution profile shown in figure 9. It various in ranges from 7 to 117% that indicates the effect of the existence speed hump on delay. It can be noticed that the value of delay percent exceeds 100% in c10, c11, and c12 that exceeds the green time which happens when there are another effects; existence of bicycles and pedestrian. The average delay percent of the twelve cycles is 51% which indicates that about half of green time is spent to skip the speed hump region .

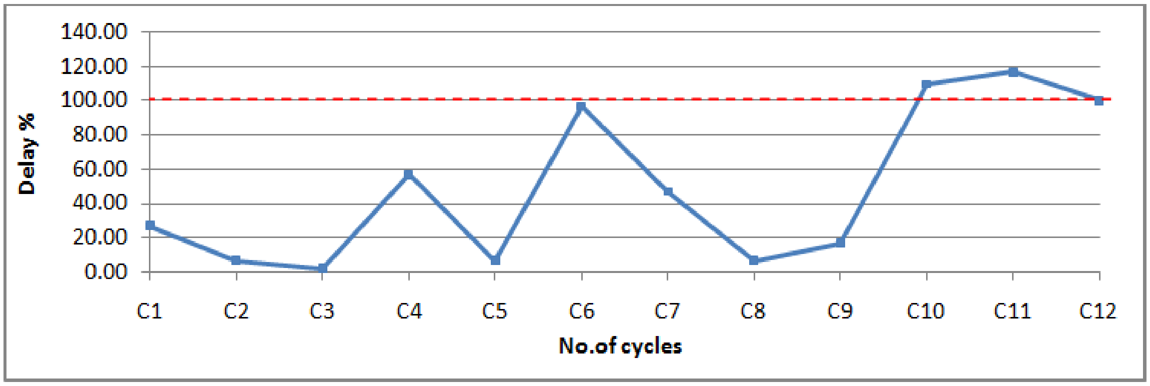

Figure 9: Delay distribution profile

4.3 The performance of intersection operation

For signalized intersections, LOS can be evaluated using table 5. There are six LOS regions different by control delay per vehicle [14]. Using the pre-calculated control delay values, LOS was estimated for both intersections .

Table 5: LOS for signalized intersection [14]

Level of Service	Control Delay per Vehicle (sec)
A	<10
B	10 to 20
C	20 to 35
D	35 to 50
E	50 to 80
F	>80

The calculated average control delays for intersections with and without speed hump are 12.3 and 10.9 seconds; respectively. It is found that the two cases are in state LOS B (from table 4).

4.4 Saturation flow rate

Saturation flow rate is one of the fundamental determinants in intersection design of signalized intersections and capacity analysis depending on the vehicle mix in the traffic stream and intersection geometry. It is a macro performance measure of junction operation.

This concept is un-acceptable in Egypt because its traffic characteristics and road environment which is different from those of the American and the European cities. In this study, another model of saturation flow rate for mixed traffic had been taken [15]. It concluded the observation region for middle lane varies from 3rd queue vehicle position to 7th which is called effective region.

Conventional theory supports that saturation flow is the steady maximum queue fulfill rate of traffic across the stop-line.

Typical theory supporting that saturation flow is the steady maximum queue discharge rate of traffic across the stop-line during the green time [12]. It depends on the *Highway Capacity Manual 2000* (TRB, 2000) that concludes that saturation flow rate is achieved and kept after the fourth vehicle discharged by time measurement

Different degrees of saturation are calculated using the observed headways during the twelve cycles (peak and non-peak hours). The effective headway for a specific vehicle is calculated by taking the time recorded when that vehicle's rear wheels crossed the stop bar and subtracting the corresponding time for the preceding vehicle [13]. The average headway is calculated by the following equation: (using headway data collection).

$$h^{\backslash} = (h_3 + h_4 + \ldots + h_i)/n \qquad (11)$$

Where:

$h^{\backslash}$: is the average headway

n: is the number of queued vehicles beginning with the third queue

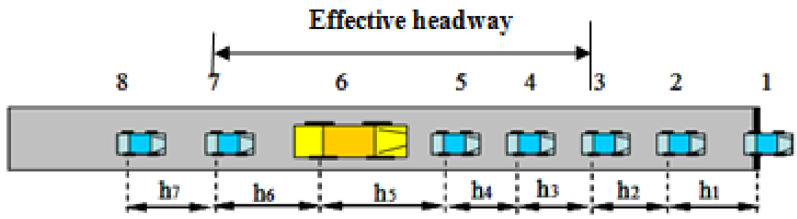

Figure 9: Example of headways measurement for mixed traffic in one cycle

Saturation flow is calculated for NB and SB directions by dividing 3600 seconds by the average headway for both intersections (with and without speed hump) as seen in equation12. It is usually given in terms of vehicles per hour of green (vphgl).

$$S = 3600/h^{\backslash} \qquad (12)$$

Table 6: Average headway and saturation flow

Intersection	Average headway (Sec.)	Saturation flow S_o (pcu/hr green)
I1	1.65	2169
I2	1.59	2256

Saturation flow rate is determined for the two intersections which given 2256 and 2169 pcu/hr green for I1 and I2; respectively. The difference between the two cases is a result of the existence of the speed hump that causes an extra delay in travel time. As there are adjustment factors for heavy vehicles, right turn, left turn, etc, adjustment factor for speed hump was calculated. All factors except the speed hump factor are used to calculate the adjustment flow rate as in table 7. The change percent between saturation flow rates in both intersections is the impact of speed hump that's called speed hump adjustment factor(F_{SH}).

Table 7: Calculated adjustment saturation flow rates

Intersection	Phase	Approach	So (pcu/h green)	Adjustment factors						S (pcu/h green)
				F_{cs}	F_{sf}	F_g	F_p	F_{rt}	F_{lt}	
I1	1	E-W	2169	0.94	0.94	1.00	1.00	1.00	1.00	1917
	2	N-S	2169	0.94	0.94	1.00	1.00	1.13	1.00	2165
I2	1	E-W	2256	0.94	0.93	1.00	1.00	1.16	1.00	2288
	2	N-S	2256	0.94	0.94	1.00	1.00	1.16	1.00	2312

Saturation flow of I2 is considered to be the base saturation flow rate [16]. But saturation flow rate of I1 is considered to be the adjustment flow rate because it has an extra value caused by the existing of speed hump. For EB and WB directions, the impact is neglected because of the changes in geometric and traffic characteristics. The calculated speed hump adjustment factor (F_{SH}) is 0.93 From N-S directions. This means that the capacity of intersection is reduced by 7%. The speed hump has an impact such as the case of right turn, left turn, heavy vehicles and other factors affecting the saturation flow but with difference dealing. Sometimes such movements and traffic characteristics is imposed by the situation and cannot be changed.

5. CONCLUSIONS

The research proved that the existence of a speed hump in a signalized intersection is not recommended for a traffic control because its negative impact on delays, LOS and saturation flow rate. After studying the two selected cases of consecutive signalized intersections in Port Said city, the results shows the delay increasing and saturation flow rate reduction.

The average delay increases by 4.3% causing by speed hump which appears briefly in car delay and slightly in other studied modes. The average delay percent for intersection with speed hump is 51% of the green time interval which indicates that about half of green time interval is spent to pass the speed hump.

Also, the study is shown that, when using speed hump together with traffic signals, the saturation flow rate is reduced by 7% that gives an adjustment factor (FSH) equals to 0.93 due to speed hump. So, traffic signals are a sufficient method to control intersection and there is no need to install a speed hump. It is recommended for the future studies to investigate the impact of speed humps on the intersection performance by using simulation tools.

Credit authorship contribution statement

Elbany M. S.: Methodology, Conceptualization, Writing – original draft, Formal analysis. **Serag M. S.**: Methodology, Writing- review & editing, Supervision

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work in this paper.

REFERENCES

[1] T. V. Mathio, "Signalized Intersection Delay Models", Lecture Notes in Transportation Systems Engineering, 2018.

[2] R. Akcelik and N. M.Rouphail, "Estimation of delays at traffic signals for variable demand conditions", Transportation Research 27B (2), pp 109-131, 2012.

[3] Lu. Zhengyang, "Modeling, Simulation and Control of Signalized Intersections under Adverse Weather Condition, a master thesis presented to the University of Waterloo, Ontario, Canada, 2016.

[4] I. Younas and I. Rauf," Towards Traffic Delay Estimation using Fuzzy Logic", Conference Paper, Conference: 7th International Business Information Management, 2006.

[5] Ib. Hashim and M. Shawky," A before-and-after Study on Traffic Signal Countdown Control Device", 8th International Conference on Civil and Architecture Engineering ICCAE, 2010.

[6] St. Nikiforos, "Operational and Safety Efficiency of Traffic Signal Intersections", Research report for Kentucky Transportation Centre, KTC-08-09/SPR328-07-1I, 2008.

[7] A. Johannes, "Calibrating Car Following Parameters for Snowy Road Conditions in the Microscopic Traffic Simulator VISSIM", Mobility Department, Austrian Institute of Technology, 2009.

[8] D. Othayoth and K.V. Krishna," Statistical Analysis of User Perceived Level of Service at Signalized Intersection", Indian Institute of Technology Bombay 8 Mumbai 400076, India, 2016.

[9] T. A. Abdel-Wahed, "Measuring Control Delay at Signalized Intersections: Case Study from Sohag, Egypt, International Journal of Advance Research of Science and Engineering", Vol.No.5, 2018.

[10] Md. Hadiuzzaman and H. Tanweer, "Development of Delay Model for Non-Lane Based Traffic at Signalized Intersection", International Journal of Civil Engineering, Vol.No.2, 2014.

[11] W. McShane and R. Roess ," Evaluation of Intersection Performance Under Atc System in WuhanTraffic Engineering", Prentice Hall, New Jersey, Intelligent Information Management Journal, Vol.3 No.4, 1990.

[12] W. B. Jffery, "Real-Time Estimation of Delay at Signalized Intersection", PhD Dissertation, The University of FLORIDA, 2007.

[13] S. Siddiqui," Investigating Saturation Flow Rate of Dual Left Turn Lanes at Intersection Approaches", Journal of Advanced Research, pp. 19, 2015.

[14] M. Alfia, H.Nurul S. Ika, and S.Gotot, "the delays for signalized intersection using ATCS Data and Field Survey Method at Kerten-Intersection of Surakarta", the 5th International Conference of Euro Asia Civil Engineering Forum, 2015.

[15] R. Mizanur, O. Izumi, and N. Fumihiko," Determination of Saturation Flow Region of Queued Vehicles at Signalized intersections by Microscopic Approach", The International Conference of Transportation Methods, 2002.

[16] K. Hamad and H. Abuhamda, "Estimating Base Saturation Flow Rate for Selected Signalized Intersections in Doha", Qatar, Journal of Traffic and Logistics Engineering Vol. 3, 2015