Development of Delay Model for Selected Signalized Intersections at CBD in Sulaymaniyah City

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Abstract

The purpose of this research is to develop an empirical model for delay prediction at Signalized Intersections as a function of influence traffic and geometric features. Two Signalized Intersections with different characteristics are selected in Sulaymaniyah city. Field traffic volumes, signal timings and phasing and control delay were measured during peak and off-peak periods using video recording technique. Geometric design elements were measured through a field survey and satellite image. A statistical approach is used to develop delay model (linear regression model with 95%). The statistical analysis indicates that both geometric and traffic variables have a significant effect on delay time. The regression model, developed to estimate delay, shows the good correlation with field values. The ratio of total width of exit roadway of intersection for traffic departing straight forward to total width of lane groups departing to the same exit roadway at the same phase at stop line (We/Ws) appear to affect the delay. The ratio has a negative effect on delay time when the ratio is less than 1.0. The model has been compared with SYNCHRO delay model. It is found that although SYNCHRO delay overestimates delay at high (v/c) range, but it does not have a significant difference with the field delay at 95% confidence level.

Keyword: Traffic Delay Model, Signalized Intersection, SYNCHRO

تطوير نموذج التأخير لتقاطعات مختارة في المنطقة التجارية المركزية في مدينة السليمانية

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الخلاصة

الغرض من هذا البحث هو لاستحداث نموذج تجريبي للتنبؤ بقيم التأخير للتقاطعات العاملة بالإشارة الضوئية كدالة للتأثيرات المرورية وعوامل التصميم الهندسي. فقد تم اختيار تقاطعين ذات خصاص مختلفة من مدينة السليمانية. كما تم حساب الحجوم المروية وعناصر زمن الدورة الضوئية واطوارها لكل تقاطع والتأخير الحقلي خلال وخارج أوقات الذروة باستخدام تقنية تصوير الفيديو. وتم أيضا مسح عوامل التصميم الهندسي باستخدام حقليا وبالاستفادة من الصورة الفضائية. استخدمت الطريقة الإحصائية لاستحداث موديل للتأخير (موديل ارتداد خطي بمستوى ثقة 95 %). أوضحت نتائج التحليل الاحصائي بأن كل من المتغيرات المرورية والهندسية لها تأثيرات هامة على قيم التأخير. هذا الموديل المطور لتخمين التأخير يبين علاقة جيده مع القيم الحقلية للتأخير. نسبة العرض الكلي لمخرج التقاطع والمستخدم للمرور الى العرض الكلي للخطوط التي يتجه فيها حركة المرور للمخرج نفسه وفي نفس الطور (We/Ws) أظهرت تأثير على التأخير. وهذه النسبة يكون تأثيرها سلبي عندما تقل عن 1. كما تم مقارنة نتائج هذا الموديل مع النتائج المحسوبة من برنامج مع القيم الحقلية فقط وجد ان بالرغم من ان هذا البرنامج يعطي قيم تأخير اعلى عن قيم التشبع العليا، لكنه لا يختلف اختلافا ذا دلالة إحصائية مع قيم التأخير المحسوبة موقعيا بمستوى ثقة 95 %.

1. Introduction

Delay is one of the key parameters that is utilized in the optimization of traffic signal timings and it in computing the level of service provided to motorists at signalized intersections. Delay, however, is a parameter that is difficult to estimate because it includes the delay associated with decelerating to a stop, the stopped delay and the delay associated with accelerating from a stop [1].

In developing delay models for different types of at-grade intersections, researchers followed the theoretical approach, the empirical approach, or computer simulation. The theoretical approach relies on the theoretical understanding about driver behavior and vehicle performance at the intersection. This approach may enable the researcher to extrapolate results to a wide range of cases; however, its theoretical assumptions limit its validity to represent real-traffic conditions. The simulation approach is similar to the theoretical approach in the sense that it is based on some theoretical assumptions about driver-traffic behavior. However, the simulation approach allows more flexibility to include certain driver-traffic behavior and make the models more realistic. The empirical approach relies on a more accurate understanding of the local driver-traffic behavior in the field, because it covers factors that affect the driver’s behavior that may be cannot represented in a theoretical equation or computer simulation. The main shortcoming for this approach, however, is that it is largely dependent on the data used in building the models and it may become limited to the ranges of that data [2]

Webster, F.V. (1958) [3] developed a model for estimating the delay incurred by motorists at under-saturated signalized intersections that become the basis for all subsequent delay models. The mathematical form of the model is:

$$d = \frac{C\,(1-1)^2}{2(1-\lambda X)} + \frac{X^2}{2v(1-X)} - 0.65\left(\frac{C}{v^2}\right)^{\frac{1}{3}}[x^{2+51}] \qquad \text{(Eq. 1)}$$

where:

d = average overall delay per vehicle (seconds),

λ= proportion of the cycle that is effective green (*g/C*),

C = cycle length (seconds),

v = arrival rate (vehicles/hour),

c = capacity for lane group (vehicles/hour),

g = effective green time (seconds).

Following this classical work, numerous studies were conducted in the field of estimating delays at signalized intersections. As a result of these studies, a number of delay models based on deterministic queuing theory were proposed to suite different field conditions. Among these, the most notable are the models developed by ***Miller (1963)*** [4]**,** the models developed for use in HCM 1985 ***(TRB, 1985)***, HCM 1994 ***(TRB, 1994)*** and HCM 2000 in United States[5] and the model developed by ***Teply et al. (1995)*** in Canada[6]**.**

In the **HCM 2000**, average delay per vehicle for a lane group is given by equation [5]**:**

$$d = d1 * PF + d2 + d3 \qquad \text{(Eq. 2)}$$

$$d1 = 0.5C\,\frac{\left[1-\frac{g}{C}\right]^2}{\left[1-Min\,(1,X)\frac{g}{C}\right]} \qquad \text{(Eq. 3)}$$

$$d2 = 900\,T\left[(X-1) + \sqrt{(X-1)^2 + + \frac{8KIX}{cT}}\right] \qquad \text{(Eq. 4)}$$

$$d3 = \frac{1800\,Q_b(1+u)t}{cT} \qquad \text{(Eq. 5)}$$

$$PF = \frac{(1-P)f_p}{1-\frac{g}{C}} \qquad \text{(Eq. 6)}$$

where:

d = average overall delay per vehicle (second/vehicle),

*d*1 = uniform delay (second/vehicle),

*d*2 = incremental, or random, delay (second/vehicle),

*d*3 = residual demand delay to account for over-saturation queues that may have existed before the analysis period (second/vehicle),

PF = adjustment factor for the effect of the quality of progression in coordinated systems,

C = traffic signal cycle time (second),

g = effective green time for lane group (second),

X = volume to capacity ratio of lane group,

c = capacity of lane group (vehicle/hour),

k = incremental delay factor dependent on signal controller setting (0.50 for pretimed signals; vary between 0.04 to 0.50 for actuated controllers),

I = upstream filtering/metering adjustment factor (1.0 for an isolated intersection),

P = proportion of vehicles arriving during the green interval,

f_p = progression adjustment factor.

Qb = initial queue at the start of period T (vehicle),

T = duration of analysis period (hour),

t = duration of unmet demand in T (hour), and

u = delay parameter.

Shamsul Hoque and ***Asif Imran*** [7] modified Webster's delay formula under non lane based mixed road traffic condition by adding an empirical adjustment term with the sum of first and second terms, which has been calibrated based on field observations of delays. Hence, the general pattern of the modified Webster's delay formula will be, as follows:

$$d = \frac{C(1-\lambda)^2}{2(1-\lambda X)} + \frac{X^2}{2q(1-X)} + adj \qquad \text{(Eq. 7)}$$

$$adj = \beta_o + \beta_1 * q + \beta_2 * c + \beta_3 * x + \beta_4 * lamda + \beta_5 * pnmv \qquad \text{(Eq. 8)}$$

where:

adj = Adjustment term for model.

q = Vehicle arrival rate (PCU/sec).

c= Cycle length (seconds).
x= Degree of saturation.
$lamda$ = Effective green ratio.
$pnmv$ = Percentage NMV in traffic.
β_0 = Constant term in the model.
β_1 = Coefficient corresponding to q.
β_2 = Coefficient corresponding to c
β_3 = Coefficient corresponding to x.
β_4 = Coefficient corresponding to $lamda$.
β_5 = Coefficient corresponding to $pnmv$.

2. Study Objective

The purpose of this study is to develop a statistical model for the prediction of total vehicle delay at signalized intersection based on existing traffic and geometric conditions.

3. Data Collection and Abstraction

In order to achieve the objective of this study, traffic and geometric data have been collected. A total of 9 lane groups were selected from two intersections in Sulaymaniyah city. The locations are illustrated in **Figure (1)**.

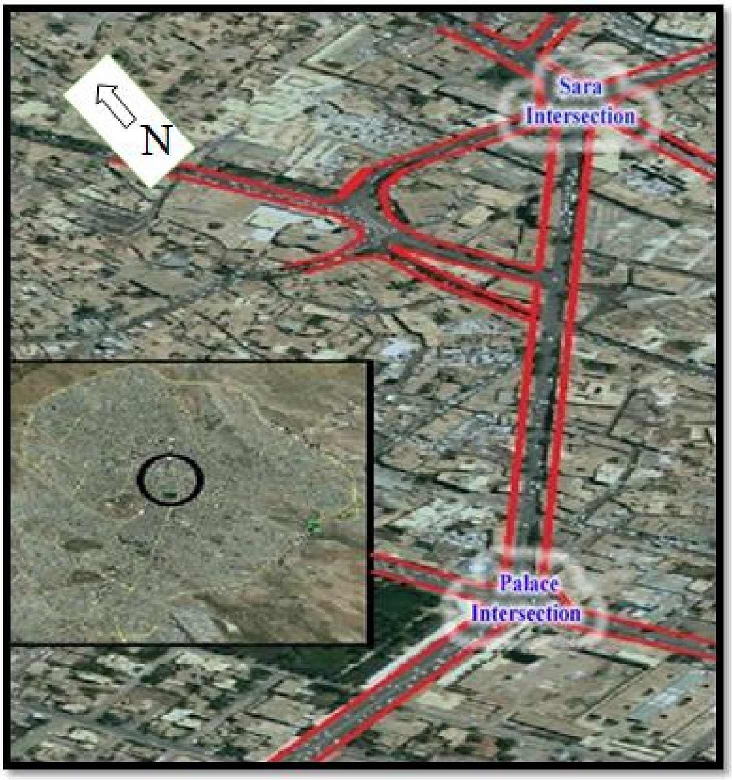

Fig .(1) Intersections Location in Sulaymaniyah. City

In this research, the statistical approach will be followed to develop model for estimating delay as a function of the influencing traffic and geometric factors. Several variables are used to simulate the geometric and traffic characteristics that affect total delay (geometric and control delay), it can be categorized as traffic conditions and geometric features. Traffic conditions such as { effective green time for movement or lane group(*g*), capacity of lane group (*c*), cycle length (C), vehicular flow rate (*v*)}. Geometric features such as { width of lane group at stop line (w), total width of lane groups departing to the same exit roadway, in the same phase at stop line (Ws), total width of exit roadway of intersection for traffic departing straight forward (We)}

3.1 Traffic Volume Data Collection

Traffic volumes for the intersections must be specified for each movement on each approach. Data are gathered during times when there were no holidays or occasions and clear weather for the intersections. The selected intersections were recorded four days in a week (Monday, Tuesday,

Wednesday, and Thursday) during peak and off-peak periods at four hours durations (two hours at A.M, two hours at P.M) for each intersection in a day. The period of the volume counting was divided into 15-minute intervals distributed over the best time of data counting. Video recording technique was adopted to collect traffic volume from vantage point nearby intersection. The recorded video films were played back many times to abstract the recorded data together with EVENT program. This program turns the computer into data capturing device, and provide digital representation of the selected data.

3.2 Geometric Data

The details of lane geometric include number of lanes, Lane widths are shown in **Table 1** for the selected intersections:

3.3 Field Delay Time Measurement

The method suggested by HCM 2000 is adopted in this study to collect field delay which based on direct observation of vehicles-in-queue counts at the intersection. This method does not directly measure delay during deceleration and during part of acceleration, which are very difficult to measure without sophisticated tracking instrument. However, this method has been seen to yield a reasonable estimate of control delay. A sample worksheet, used for recording retrieved data, is included in **Table (2).**

Table .(1) Geometric Features for the Selected Intersections

Intersection Name	Approach Name	Lane Group	Movement	Lane Width (m)	No. of Lanes	One Way or Two Way
Palace	Salim	1	LT+UT	3.2	1	Two way
	Salim	2	TH	3.2	1	Two way
	Salim	3	RT	4.5	1	Two way
	Baban	4	LT	2.4	1	Two way
	Baban	5	TH	2.4	1	Two way
	Baban	6	RT	2.4	1	Two way
	Mamostayan	7	RT	3.7	2	Two way
Sara	Mawlawi	1	LT	4.1	2	One way
	Kawa	2	TH	3.2	2	One way
	Kawa	3	LT	4.5	1	One way
	Sabunkaran	4	TH	4.8	1	One way
	Sabunkaran	5	RT	5.0	1	One way
	Piramerd	6	LT+UT	2.35	2	Two way
	Piramerd	7	RT	4.2	2	Two way

Table .(2) Work Sheet for Field Measurement of Delay [5]

Intersection Control Delay Worksheet

Analyst : Saad Mohsen Khalil **Agency or Company : (–)** **Date Performed : 10/1/2012** **Analysis Time Period : 3:00 to 3:17**	**Intersection : Palace / Baban St.** **Area Type : CBD** **Analysis Year : 2012**

Input Initial Parameters

Number of Lanes , L : 1 **Total vehicle arriving, V_{tot} = 189**

Free – flow speed, FFS (Km / hr) : 38 Km / hr **Stopped vehicle count , V_{stop} = 93**

Survey count interval (s) : 15 sec

Input Field Data

Clock Time	Cycle Number	Count interval 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
3.00	1	0	4	10	10	10	16	18	18	11	5	0	0							
	2	3	8	9	13	21	12	22	20	12	9	6	2	0	0	0	0			
	3	3	3	3	6	6	8	11	12	16	17	21	19	12	11	5	0	0	0	0
	4	0	2	2	5	10	17	14	19	19	17	13	13	9	3	0	0	0	0	0
3.17																				
Total		6	17	24	34	47	63	70	71	68	59	45	34	26	16	5	0	0	0	0

Computations

Total vehicles in queue, ΣV_{iq} =585 **No. of cycle surveyed, N_c =4**

Time- in –queue per vehicle, $d_{vq}=(I*\Sigma V_{iq}/V_{Tot})*0.9=41.78$ sec

Fraction of vehicle stopping, FVS=Vstop/Vtotal= 0.492

Accel/Decel correction factor, CF =-1 **Accel/Decel delay, d_{ad} =FVS*CF = -0.492**

No. of vehicles stopping per each cycle = Vstop/N_cxL = 23.25 **Control delay = d_{ad} + d_{vq} =41.288 sec**

Table .(3) shows the existing traffic and geometric condition of selected intersection

Cycle	v/c	g/C	Field delay	We/Ws	Width	Volume
270	1.15	0.390	67.263	1.000	3.50	657
300	1.06	0.610	69.108	1.000	3.20	805
266	1.02	0.565	51.070	1.000	3.20	776
300	0.95	0.370	62.482	1.000	3.50	691
266	0.95	0.420	50.482	1.000	3.50	541
270	0.79	0.585	47.622	1.000	3.20	606
97	0.73	0.480	40.870	0.740	4.20	495
225	0.69	0.440	50.383	0.458	4.80	222
97	0.58	0.470	36.650	0.458	4.80	179
196	0.56	0.486	47.340	0.458	4.20	379
97	0.55	0.470	38.559	0.458	2.85	368
196	0.54	0.486	49.852	0.458	2.85	360
225	0.53	0.540	46.750	0.458	4.20	357
196	0.50	0.486	43.390	0.458	4.80	161
225	0.50	0.440	49.370	0.458	2.85	337

4. Model Development

The stepwise regression method is used for delay time prediction. SPSS software version 20 is used to develop the delay model. The variables are entered in a stepwise manner to build the models. In order to obtain a model with 95% confidence level, *F*-value is set to 3.84 (P=0.05) to enter and 2.71 (P=0.1) to remove. In this step only cycle length, (v/c) value and (We/Ws) are entered the model, and gives an adjusted R_2 equals to 0.995. The summary of stepwise regression delay model can be seen in **Table (4).**

Tables .(4) Stepwise Regression Models Summary for Delay Model (By SPSS, V.20).

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	R^2	$Adj.R^2$	SEE
		B	Std. Error	Beta					
	Cycle	0.102	0.020	0.457	5.192	0.000	0.995	0.993	4.175
	(1-We/Ws)	19.594	3.622	0.140	5.409	0.000			
	v/c	30.190	5.648	0.462	5.345	0.000			

The results of regression technique and selected developed delay model are shown in Equation (9).

$$d = 0.102\,C + 30.19\,v/c + 19.59\,(1 - We/Ws) \qquad (Eq.\ 9)$$

where:

d = Delay for lane group (sec/veh).

v = Vehicular flow rate (veh/h)

c = Capacity of lane group (veh/h),

C = Cycle length (sec),

Ws = Total width of lane groups departing to the same exit roadway, in the same phase at stop line (m).

We = Total width of exit roadway of intersection for traffic departing straight forward (m),

The variables that have significant impact on total delay are explained in **Table (5**) for the linear regression model, with statistical characteristics. The minimum and maximum traffic parameters limits represent the range at which the model will be applicable.

Table .(5) Data Range and Statistical Characteristics for Delay Model (By SPSS, V.20).

	Minimum	Maximum	Mean	Std. Deviation
g/C	0.370	0.610	0.48253	0.068641
v/c	0.50	1.15	0.7395	0.230800
Cycle (sec)	97.0	300.0	215.067	70.1310
We/Ws	0.458	1.000	0.7298462	0.271017

The correlation coefficients between all of the variables are calculated and the correlation matrix is setup. This matrix can be seen in **Tables (6).**

Table .(6) Correlation Coefficient Matrix for Delay Model (By SPSS, V.20).

	Field delay	Cycle (sec)	g/C	v/c	We/Ws
Field delay	1.0	0.854	-0.022	0.759	0.659
Cycle (sec)	0.854	1.0	0.351	0.643	0.697
g/C	-0.022	0.351	1.0	-0.016	0.171
v/c	0.759	0.643	-0.016	1.0	0.719
We/Ws	0.659	0.697	0.171	0.719	1.0

5. Model Validation

Validation process is determining whether the selected model is appropriate for the given conditions and for the given task; it compares model prediction with measurements or observations [8]. The objective of validation is to assess the adequacy of the proposed prediction models, and measure the error or accuracy of the prediction for the validation period.

There are several methods used for models validation. One of these methods is to compare the model with another data set that is not included in model building. The data used for this purpose is peak hour data abstracted from video recording films at different times for the same intersections in the network [9]. The average field delay from peak hour is regressed with the delay time predicted by the model. The regression results are shown in **Table (7)** and **Figure (2).** It can be concluded from the models values of R^2 that the predicted values from models can represent estimation of the actual field values of delay.

Table .(7) Regression Results for the Delay Model (By SPSS, V.20).

Model	Model Fit	R^2-value	Adj. R^2-value	Sig.
Delay Model	0.958 * Field Delay + 3.36	0.922	0.911	0.000

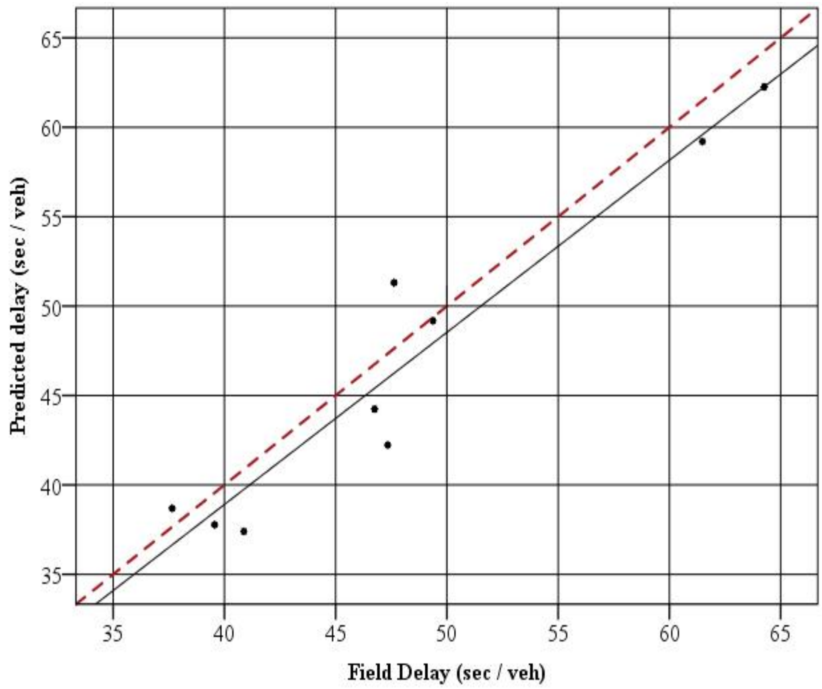

Fig .(2) Observed versus Predicted Delay (By SPSS, V.20).

6. Analysis of Developed Delay Model Parameters

The delay model depends on many variables such as cycle length(C), degree of saturation(v/c) and Total width of exit roadway of intersection for traffic departing straight on divided by Total width of lane groups departing to the same exit roadway, in the same phase (We/Ws). From the previous model of delay, it is obvious that, delay time increases as cycle time and v/c value increase. The increase in delay is attributed mainly to the increase in the effective red and hence in waiting time for vehicles before the start of green. The delay time has a proportional relationship with the degree of saturation (v/c) which is based on flow rate and proportion of cycle time effectively green (g/c).The minimum of g/c and large flow rate cause high v/c value.

Delay time has an inverse relationship with (We/Ws). It is obvious that delay time increases when (We/Ws) is less than 1.0 . The limit of (We/Ws) adopted in the model should be $\leq$ 1.0, as in **Table (3)** for lane group width not for the whole approach.

7. Field Delay Comparison with SYNCHRO Software Model

SYNCHRO 8.0 Software has been applied for these intersections. The delay results produced by SYNCHRO were compared with field delay. The comparison results are presented in **Figure (3).** This Figure shows that, for delay ranges (up to 47 seconds), SYNCHRO has a good representation of field delay. For higher delay ranges, SYNCHRO has a mix of under-estimations and overestimations. The predicted delay variation increases with the increase of delay time. The field delays were regressed against the predicted ones producing the results shown in **Table (8).** The R^2 value indicated that SYNCHRO explains about 93 % of the variability in the total delay. It can be drawn that SYNCHRO model can be applied to local traffic conditions with acceptable results within the models limits.

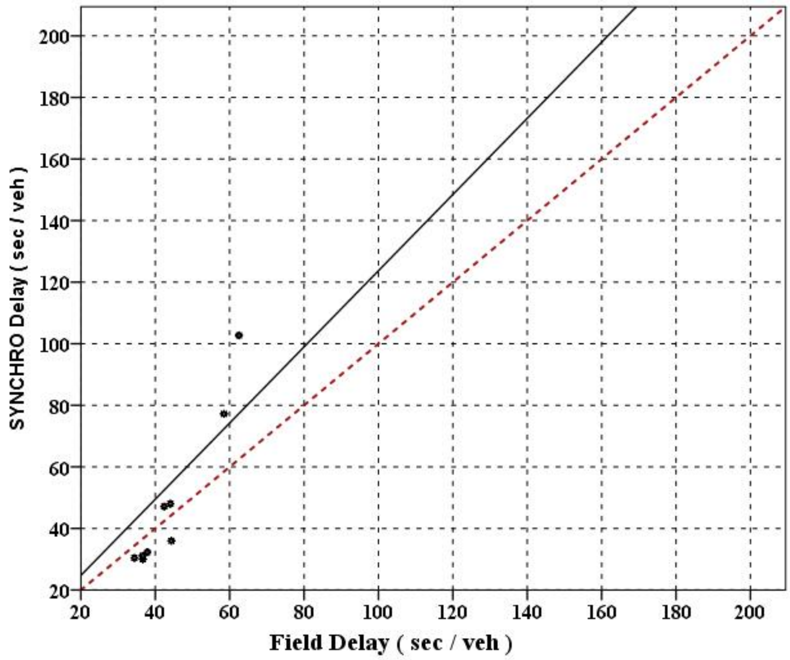

Fig .(3) SYNCHRO Delay Values versus Field (By SPSS, V.20).

Table .(8) Comparison of Actual and SYNCHRO Delay Prediction for Signalized Intersections (By SPSS, V.20).

Field delay	= 0.808*SYNCHRO Delay
R^2	0.933
Adj.R^2	0.924
Sig.	0.000
Paired Sample t-test	
Mean Difference in Delay (sec)	5.322
t	0.784
p	0.455
p-value greater than 0.05, so that there is no statistically significant difference	

8. Conclusion

Within the limits of traffic and geometric features of the study area, the main conclusions that can be drawn are as follows:

1- The simple linear regression used for total delay time prediction does lead to high relationship model.

2- Regression model, developed to estimate delay time, shows good correlation with field values. This model can used to estimate delay time at any intersections knowing signal timing, traffic volume, ratio of total width of exit roadway of intersection for traffic departing straight forward to total width of lane groups departing to the same exit roadway, in the same phase at stop line (We/Ws). This model may not be suitable for extreme range of input variable.

3- All signalized intersections suffer from long cycle length that causes high delay time values

4- The delay increases when the width of exit roadway is less than the width at stop line, as in the case of bottleneck.

5- Delay time for signalized intersections produced by SYNCHRO has a no significant difference with the delay time measured at field with 95% confidence level, SYNCHRO has a good representation of field delay at low to medium values, but it is overestimated at high delay range.

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