ESTIMATING DELAY TIME AT PALESTINE STREET INTERSECTIONS IN BAGHDAD CITY USING HCM AND SIDRA MODELS

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ABSTRACT

The objective of this paper is to the estimate delay time at two important intersections in Baghdad City using Highway Capacity Manual Model (HCM) ,which is widely used for estimating delay at signalized intersections in Iraq, and Signalized and Unsignalized Intersection Design and Research Aid (SIDRA INTERSECTION 4) Model. Field traffic volumes and control delay were measured during peak and off-peak periods. Data on geometric design elements and signal timings and phasing were measured through a field survey. The results of the analysis indicated that SIDRA INTERSWCTION4 using HCM model was found to be the best in the comparison with the field values by observed percent of difference. Therefore a proposed model is build by derive a new parameters of the uniform delay term (d1) and random delay term (d2) for non-lane state. This model is validated on Art College Intersection. The results show that the predicted model cannot be used for other intersections. Then a proposed model is build for Art College Intersection.

Keywords: HCS, HCM, SIDRA, SIDRA INTERSECTION4, Signalized Intersections, Delay.

تخمين زمن التأخير في تقاطعات شارع فلسطين في مدينة بغداد باستخدام موديلات HCM و SIDRA

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الخلاصة

الهدف من هذا البحث هو تخمين قيم زمن التأخير في تقاطعين مهمين في مدينة بغداد باستخدام موديلي سعة الطرق (HCM)، الشائع استخدامه في تخمين قيم زمن التأخير في التقاطعات العاملة بنظام الاشارة الضوئية في العراق، و (SIDRA INTERSECTION 4). تم مسح الحجوم المرورية وقيم زمن التأخير الحقلية في موقع التقاطعات في ساعات الذروة وغيرها. وتم أيضاً مسح الخصائص الهندسية وعناصر زمن الدورة الضوئية وأطوارها لكل تقاطع. نتائج التحليل بينت أن برنامج (SIDRA INTERSECTION 4) باستخدام موديل (HCM) أعطى أفضل النتائج بعد المقارنة مع القيم الحقلية لزمن التأخير بنسبة اختلاف واضحة. لذلك تم استنباط موديل بمعايير جديدة لمتغير زمن التأخير المنتظم (d1) ومتغير زمن التأخير العشوائي (d2) لحالة جريان غير منتظمة. تم تدقيق صحة النتائج لهذاالموديل بتطبيقه في حساب زمن التأخير في تقاطع كلية الفنون الجميلة. بينت النتائج ان الموديل لايمكن تطبيقه على تقاطعات أخرى. لذا تم استنباط علاقة أخرى لتقاطع الفنون الجميل.

INTRODUCTION

Vehicle delay is the most important parameter used by transportation professionals to measure the performance of signalized intersections. This importance of vehicle delay is reflected in the use of this parameter in both design and evaluation practices. For example, delay minimization is frequently used as a primary optimization criterion when determining the operating parameters of traffic signals at isolated and coordinated intersections (Garber and Hoel 1997).

The Highway Capacity Manual (TRB 2000) further uses the average control delay incurred by vehicles at intersection approaches as a base for determining the level of service provided by the traffic signals located at the downstream end of the these approaches. The popularity of delay as an optimization and evaluation criterion is attributed to its direct relation to what motorists experience while attempting to cross an intersection.

However, delay is also a parameter that is not easily determined, for instance, indicated that a perfect match between field-measured delay and analytical formulas could not be expected. The difficulty in estimating vehicle delay at signalized intersections is also demonstrated by the variety of delay models for signalized intersections that have been proposed over the years (Garber and Hoel 1997).

Despite differences between the proposed delay models, very little research has been concerned with the consistency of delay estimates from one model to the other. This paper addresses this problem by comparing the delays that are estimated by analytical delay models with that computed from the field.

To achieve this goal, the paper first presents some background material on vehicle delays at signalized intersection, followed by a description of the two famous delay models that are being compared (HCS and SIDRA models). Evaluations of the consistency of delay estimates from these models are conducted by using them to evaluate delays on both under-saturated and over-saturated signalized intersection approaches. Then proposed model is build to compute the delay time at signalized intersection.

DELAY TIME MEASUREMENT

Delay is the time lost while traffic is impeded by elements over which the driver has no control. Delay results from two factors (Garber and Hoel 1997):

a- Operation delay: it may be caused by interference between and within traffic streams.

b- Fixed delay: it is caused by traffic control devices.

DELAY TIME TYPES

There are several types of delay that can be measured at an intersection, and each serves a different purpose to the transportation engineer. Intersection delays may include two components: *queue delay* and *control delay*. *Queue delay*, or stop delay, is difficult to quantify due to its stochastic nature affected by random arrivals. Sophisticated techniques may work better in estimating queue delays, but are often impractical for planning models due to intense data requirements. It is often difficult to find a well-balanced queue delay model for integration into a planning model. The signalized intersection capacity and LOS estimation procedures are built around the concept of average control delay per vehicle. *Control delay* is the portion of the total delay attributed to traffic signal operation for signalized intersections (TRB 2000) and (Ding 2007). Control delay (overall delay) can be categorized into deceleration delay, stopped delay and acceleration delay (TRB 2000):

a- Stopped delay is easier to measure, Typically, transportation professionals define stopped delay as the delay incurred when a vehicle is fully immobilized,

b- The delay incurred by a decelerating or accelerating vehicle is categorized as deceleration and acceleration delay, respectively.

In HCM2000 (TRB 2000), control delay is comprised of initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay, though in earlier versions it included only stopped delay.

Besides the control delay, there is another type of delay which vehicles experienced at signalized intersection. This type of delay is identified as *geometric delay* which is the time lost due to the intersection geometry. Geometric delays may be large for turning movements. *Total delay* of a vehicle is the sum of control delay and geometric delay (Darma *etal* 2005).

DELAY TIME MEASUREMENT METHODS

Two methods have been used to measure the delay time at signalized intersection, field measurement and theoretical measurement.

Field Measurement

There are a number of techniques for making field measurement of control delay, including the use of test-car observations, path tracing of individual vehicles, and the recording of arrival and departure volumes on a cycle-by-cycle basis.

For oversaturated conditions, other methods may be considered, such as an input-output technique or a zoned-survey technique. In the input-output technique, different observers count arrivals separately from departures and vehicles in queue are calculated as the accumulated difference, subject to in-process checks for vehicles leaving the queue before they reach the stop line. The zoned-survey technique requires subdividing the approach into manageable segments to which the observers are assigned; they then count queued vehicles in their assigned zone. Both of these techniques require more personnel and are more complicated in setup and execution(TRB 2000).

HCM field delay measurement method is applicable to situations in which queues are long or the demand to capacity ratio is near 1.0 with care must be taken to continue the vehicle-in-queue count past the end of the arrival count period. The method does not directly measure delay during deceleration and during a portion of acceleration, which are very difficult to measure without sophisticated tracking equipment. However, this method has been shown to yield a reasonable estimate of control delay. The method includes an adjustment for errors that may occur when this type of sampling technique is used, as well as an acceleration-deceleration delay correction factor. The acceleration-deceleration factor is a function of the typical number of vehicles in queue during each cycle and the normal free-flow speed when vehicles are unimpeded by the signal(TRB 2000).

Figure (1) show a worksheet that can be used for recording observations and computation of average time-in-queue delay.

More details about the procedure that has been used in collect field control delay at signalized intersection are explained in Appendix A at Highway capacity manual HCM 2000(TRB 2000).

Theoretical Method

Several models for estimating vehicle delay at signalized intersections have been used. However, it seems that the exploration on the method for estimating the delay is still continuously conducted. This is may be due to the consideration of various variables which could affect the delays.

The change of the primary factor for measuring the LOS at signalized intersection from stopped delay (HCM1994) to control delay (HCM1997 and 2000) depicts the continuing improvement by incorporating current research findings (Darma *etal* 2005) and (Hadiuzzaman 2008) .

The research of traffic engineering design several models, Dion *et al* (Dion et al 2004) and Akgungor (Akgungor & Bullen 2007) illustrated five delay models for signalized intersection: deterministic queuing model, shock wave delay model, steady-state stochastic delay model (For example Webster Model(Pretorius *etal* 2004)) , time-dependent stochastic delay model (Xuegang *etal* Model (Xuegang *etal* 2008) and Kimber and Hollis model (Pretorius *etal* 2004), and finally, microscopic simulation delay model (like TRANSYT and CORISIM models) (Rahim *etal* 2001) and (Pretorius *etal* 2004).

Webster classical formula is the oldest and the most popular deterministic model, which has been originated in UK. numerous studies were conducted in the field of estimating delays at signalized intersections that a result of them, a number of delay models based on deterministic queuing theory were proposed to suite different field conditions (Luttinen 2003). Among these, the most notable are the models developed by Miller (1963) and Akcelik (1981) in Australia, the models developed for use in HCM 1985 (TRB 1985), HCM 1994 (TRB 1994) and HCM 2000 (TRB 2000) in United States, the model developed by Teply et al. (1995) in Canada, and Sierpiński Model (Sierpiński & Janusz 2007). However, these models are analytically superior to Webster's classical model in the sense that they can successfully deal with oversaturated conditions and the effect of progression and platooning (Shamsul and Asif 2007) and (Ding 2007).

Highway capacity model HCM 2000 (TRB 2000) model is the most widely used in Iraq and the world. Other models are used also, for example SIDRA (Akçelikl 2009) and TRANSYT models.

Highway Capacity Manual (HCM2000) Model

Highway Capacity Manual (HCM2000) (TRB 2000) is widely used for the design of signalized intersection in North America and other developed countries.

In this manual, control delay is the principal service measure for evaluating LOS at signalized and unsignalized intersections. Control delay involves movements at slower speeds and stops on intersection approaches, as vehicles move up in the queue or slow down upstream of an intersection (TRB 2000).

HCM and other works assume homogeneous and lane based traffic for analysis, which exists in those countries, but traffic flow in countries like Iraq consists of different classes of vehicles having no lane disciplined.

The capacity analysis method for signals in this manual is the most recent edition since the procedure was converted from a v/c-based to a delay-based method in the HCM85, and has retained basically the same fundamental delay model since. The delay computation procedure, founded on the Webster delay model developed in 1958, which has stood the test of time as a fundamental method for traffic signal analysis. The delay model is comprised of two elements (Dennis *etal* 2006):

1. "*The First Term*" (d1): Produces the average delay per vehicle in the average cycle, assuming that traffic arrivals and departures are completely uniform, both within each signal cycle and across all cycles during the analysis period.
2. "*The Second Term*" (d2): Produces the incremental delay due to randomness in arrivals from cycle to cycle. The incremental delay assumes steady state conditions.

Several structural changes (with significant impact) have been made that resulted in the methods employed by the 1985 and subsequent updates of the HCM (1994, 1997, and 2000), but the basic structure of the method has remained unchanged. These changes are explained in ((Dennis *etal* 2006):

In the HCM 2000, the average delay per vehicle for a lane group is given by equations 1 to 4 (HCM 2000) (TRB 2000).

$$d = d1(PF) + d2 + d3 \quad (1)$$

Where
d = control delay per vehicle (s/veh);
d1 = uniform control delay assuming uniform arrivals (s/veh);
PF = uniform delay progression adjustment factor, which accounts for effects of signal progression;

d2 = incremental delay to account for effect of random arrivals and oversaturation queues, adjusted for duration of analysis period and type of signal control; this delay component assumes that there is no initialqueue for lane group at start of analysis period (s/veh); and

d3 = initial queue delay, which accounts for delay to all vehicles in analysis period due to initial queue at start of analysis period (s/veh).

$$PF = \frac{(1-P)f_{PA}}{1-(g/C)} \tag{2}$$

Where

PF = progression adjustment factor,

P = proportion of vehicles arriving on green,

g/C=proportion of green time available, and

f_{PA} = supplemental adjustment factor for platoon arriving during green.

$$d1 = \frac{0.5\,C\,(1-\frac{g}{C})^2}{1-[\min(1,X)g/C]} \tag{3}$$

Where:

d1 = uniform control delay assuming uniform arrivals (s/veh);

C = cycle length (s); cycle length used in pretimed signal control, or average cycle length for actuated control (see Appendix B for signal timing estimation of actuated control parameters);

g = effective green time for lane group (s); green time used in pretimed signal control, or average lane group effective green time for actuated control , and

X = v/c ratio or degree of saturation for lane group.

$$d2 = 900T[(X-1)+\sqrt{(X-1)^2+\frac{8kIX}{cT}} \tag{4}$$

Where

d2 = incremental delay to account for effect of random and oversaturation queues, adjusted for duration of analysis period and type of signal control (s/veh); this delay component assumes that there is no initial queue for lane group at start of analysis period;

T = duration of analysis period (h);

k = incremental delay factor that is dependent on controller settings;

I=upstream filtering/metering adjustment factor;

c = lane group capacity (veh/h); and

X = lane group v/c ratio or degree of saturation.

$$d3 = (1800Qb(1+u)t)/Ct \tag{5}$$

Where

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

c=adjusted lane group capacity (veh/h),

T = duration of analysis period (h),

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

u = delay parameter

The details of these calculation have been shown in chapter 16 at highway capacity manual 2000 (TRB 2000).

The Signalized and Unsignalized Intersection Design and Research Aid (SIDRA) Model

(SIDRA) software (Akçelikl 2009) used as an aid for design and evaluation of signalized intersection (fixed-time/pretimed and actuated), roundabouts, two-way stop sign control, all-way stop sign control, and give-way (yield) sign-control (Al-Omari and Ta'amneh 2007) .

SIDRA uses detailed analytical traffic models coupled with an iterative approximation method to provide estimates of capacity and performance analyzes signalized and unsignalized intersections and roundabouts. It computes average control delay, geometric delay, level of saturation, and level of service (Sabra *etal* 2000).

This software is compatible with the US Highway Capacity Manual (HCM) to a good extent. The US HCM versions of SIDRA INTERSECTION do not claim to be a simple replication of the HCM procedures. This means that generally (for all types of intersection), SIDRA INTERSECTION4 uses more advanced models and methods, including lane-by-lane analysis rather than analysis by lane groups, modeling of short lanes, detailed modeling of geometric delays, and the use of drive cycles (cruise, acceleration, deceleration and idling) for detailed modeling of delay and travel time components as well as operating cost, fuel consumption and emission estimation.

A key construct used in developing the SIDRA INTERSECTION delay definitions given above was a clarification of whether the delay estimated by a traditional analytical delay model includes any acceleration and deceleration delays. The SIDRA INTERSECTION method assumes that the analytical model delay is a stop-line delay that includes the main stop-start delay to queued vehicles, and does not include the geometric delay. In determining control delay for individual movements, control delay values for the lanes used by the movement are not aggregated directly. The stop-line delay values for the lanes used by the movement are aggregated first, and then the geometric delay for the movement is added. Geometric delay and other statistics for movements combined using the same movement number are the flow-weighted average values for individual origin-destination movements.

The use of control delay (overall delay with geometric delay) is the recommended method for consistency in comparing alternative intersection treatments. Stop-line delay given in the Lane Delays table in the Detailed Output report is recommended only for comparison of SIDRA INTERSECTION results with those from software packages that estimate delay without the geometric delay, or when the survey method used produces a delay that does not include the geometric delay. The delay models used by SIDRA INTERSECTION when the HCM Delay option is applicable (Model Defaults-Model General) differ from the standard SIDRA INTERSECTION models although the model structures are similar. For signal coordination (platooned arrivals), the HCM progression factor method is used for delay prediction. In SIDRA INTERSECTION, an additional progression factor is used for the prediction of queue-related performance statistics. The color code used for movements in the Control Delay display under Movement Displays is based on the Level of Service (LOS) values as indicated by the legend of the display

More details about the SIDRA models in SIDRA INTERSECTION4 User Guide (Akçelikl 2009) and (Abdy 2000), and more details in the differences between HCS and SIDRA packages are studied by (Freeman *etal* 1999), (Petraglia 1999), (Abdy 2000), (Transportation Research Board / National Research Council 2000), (Turley 2007), and (Darma 2005).

OBJECTIVES AND SCOPE

The specific objectives of this paper are summarized as follows:

1- Estimation delay time at Palestine street intersections in Baghdad City based on field delay data and using two software (HCS and SIDRA models) , and determine the most suitable software which represents the Baghdad conditions in estimating the signalized intersection delay,
2- Find out delay time model, which represent Palestine street intersections in Baghdad City conditions.
3- Validate this model by using it in the estimating of delay time at Art College intersection in Baghdad city.

STUDY AREA SELECTION

Three signalized intersections were selected at two important locations in Baghdad City to perform this study. They are Palestine Street Intersections (Palestine Intersection 1 and 2), and Art College Intersection. The study area that were selected for this study in Baghdad City, that's Palestine Street and Al-Wazeria have high degree of important and the characterized as CBD area. **Figure 2** and **Figure 3** show the satellite image of the area study.

DATA COLLECTION

Beside of the field delay time, the basic data that collected for calculating theoretical delay time are categorized into three categories: geometric, volume, and phasing signal.

Geometric Data

The details of lane geometric include number of lanes, Lane widths, existing and location of curb parking lanes and bus stops. **Table 1** shows the existing the geometric conditions of the selected sites.

Traffic Volume Data

Traffic volumes for the intersections must be specified for each movement on each approach. Data are gathered during weekday and clear weather for all the intersection of the selected sites .The period of the volume counting was divided into 15-minute intervals distributed over the best time of data counting. The vehicles volume surveys are classified into two types:

1. Small vehicles: any vehicles move on four wheels includes the PC.
2. Large vehicles: any vehicles move on more than four wheels.

Because the two models are not considered the variety in large vehicle capacity, then the small passenger car equivalent to large vehicle is calculated manually at each of the selected intersection with equivalent factor of 1.5 for large vehicle with average capacity of 20 pass/veh and 2 for truck vehicles and buses of more than 40 pass/veh.

Table 1 shows the existing the Traffic conditions of the selected sites.at peak and off peak periods.

Signal Phasing and timing

In Baghdad City, to control the traffic, fixed time traffic signals are being used for a significant number of years. Unfortunately, rather than using any traffic engineering knowledge, these signals have been timed by traffic police from arbitrary judgment only. As a result, they became ineffective to serve the purpose properly and efficiently. Therefore, this research assumed that the selected intersection work actuated system by traffic police and four phases signals (each approach with one phase) and use the maximum actual green time, that are assumed as a default value in SIDRA model, equal to 50 second.

Field Delay Time Measurement

Table (2) show a sample of field delay time survey at Palestine Intersection**, and Figure 4** to **9** show the field measurement at the selected intersection at peak and off peak periods. It should be noticed that field delay measurements were conducted for under-saturated, saturated, and oversaturated traffic flow conditions to be consistent with the HCM standard method of field delay data measurement.

ESTIMATING OF THEORITICAL DELAY TIME

The collected traffic, geometric and timing data were used as inputs to the HCS and SIDRA software and the control delay was obtained. **Figure 4** to **9** show these results by bar chart graphics.

Past research investigated different approaches for studying the uncertainty of the HCM delay model caused by uncertainty in input variables by several methods (Xiaojin 2006).

In this paper, The software results were compared with the measured field control delay using graphs, regression analysis and paired t-test.

Graphical Comparison

This method of statically comparison has been used in many research to validate the theoretical models results with the actual value (Al-Omari 2007), (Michael etal 2000), and (Shamsul & Imran 2007).

In order to verify HCM and SIDRA models, the field control delay, as resulted in HCS and SIDRA INTERSECTION4 Software, were plotted against the actual control delay time produced from the field. A regression line was fitted through the data points. Note that such plots were constructed for each theoretical model,

The results of calculation for the three intersections at peak and off peak hours with the graphical comparison of those with field-measured delay are shown in **Figures 4 to 9**, and the results of the degree of saturation (v/c) calculation with the graphical comparison delay are shown in **Figures 10 to 15.**

Figure 16 show the relationship between the theoretical delay that are calculated by the three models with the degree of saturation (v/c). It is noted that the theoretical models are nearly present equal values of delay when v/c is less than (1.0) and trend to be different at slightly higher value when v/c is greater than (1.0).

Figure 17 show the relationship between the differences between the theoretical delay that are calculated by the three models and field delay with the degree of saturation (v/c). it is noted that HCM model using SIDRA has smaller difference from field measurement in delay value than HCM model using HCS and SIDRA model in all values of v/c. in general all models gives high difference range when v/c is greater than (1.0).

Figure 18 presents the graphical comparison between the field delay and HCS model, From these results it can be seen that, for field delay ranges up to 80 seconds, HCS tends to be equal to estimate control delay. For higher delay ranges, it has under-estimations.

Figure 19 presents the graphical comparison with theoretical delay which is calculated by SIDRA INTERSECTION4 using HCM model and its defaults value and **Figure 20** presents the graphical comparison with theoretical delay, which is calculated by SIDRA INTERSECTION4 using SIDRA model and defaults value. In this figures, it can be seen that, for delay ranges up to 50 seconds, SIDRA delay value has a good estimation of the control delay. In the range of (50 to 200) sec/veh, SIDRA has mix of under-estimations and over-estimations with some points that are severely over-estimated. SIDRA delay value has a severely over-estimated in the range greater than 200sec/veh.

Regression Analysis

The measured field delays were regressed against the predicted models producing the results shown in **Table 3**.

From this table it is observed that SIDRA model gives lower value of R^2 and higher Standard error of estimation (SEE) while HCM model using SIDRA INTERSECTION4 gives higher value of R^2 and lower value of (SEE).

Paired T-Test

The paired t-test results, as shown in **Table 4**, showed the mean of differences with a P-value. It was also used to see if the average deviations between filed and predicted control delay are significantly far from zero. These results shows the HCM model using HCS have less standard deviation and standard error mean from the field delay with p value equal to 0.00.

Software Calibration

The basic saturation flow rate was measured following the HCM standard procedure (TRB 2000) using the through movement on the intersection approaches that were believed to be the closest to ideal conditions. So a calibration was conducted for the HCS (which has a default value of 1900 pcphgpl) and SIDRA INTERSECTION4 software (which has a default value of 1900 pcphgpl for HCM model and 1950 pcphpgl for SIDRA model) regarding the basic saturation flow rate.

In this paper the basic saturation flow rate was averaged to values greater than the default value of the models but not higher than 2300pcphpgl which is the maximum saturation flow value for HCS. This high value can be explained by knowing the aggressive driver behavior in Iraq which results in reducing the vehicle headways leading to an increase in the saturation flow rate.

The field delays were regressed against the predicted ones, producing the results shown in **Table 5**. At all values of v/c the R^2 value indicated that HCS explains about 66.5% of the variability in the control delay at saturation flow equal to 2000 pcphpgl. This is higher than the R^2 value obtained using default values by 4%. While the default value gives the higher R^2 at under and over saturation state.

The R^2 value indicated that SIDRA INTERSECTIO4/HCM model explains about 76.6% of the variability in the control delay at default value of saturation flow. This is higher than the R^2 value obtained using values greater than it. While the saturation flow of 2200pcphpgl gives the higher R^2 at under and over saturation state.

When using SIDRA INTERSECTIO4 / SIDRA model, The R^2 value indicated that 69%% of the variability in the control delay at default value of saturation flow. This is higher than the R^2 value obtained using default value by 10%. While the saturation flow of 2300pcphpgl gives the higher R^2 at under and over saturation state.

BUILDING OF DELAY TIME MODEL

Estimation of delay at signalized intersections is a complex process and depends on a number of parameters, among which the degree of saturation (x = v/c) is the most important (Akgungor 2007).

The urban road traffic situation of Baghdad City is quite different from that of developed city. The traffic is mixed with a wide variation in the operating and performance characteristics of vehicles. The vehicles which travel in the same right of way also vary in size, maneuverability, control and dynamic characteristics. Another striking feature of the road traffic operating condition is that most of the time lane discipline is not followed no matter whether non-motorised vehicles are present or not. At intersections, there is notable lateral movement and vehicles tend to use lateral gaps to reach the front of the queue.

HCM 2000 delay model takes into account effect of signal coordination and uncoordinated surrounding intersections and is selected to modify in order to be able to estimate control delay for non lane based traffic condition. Details about HCM 2000 equation are shown above**.** Control delay which includes initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay is given by:

$$d = d1(PF) + d2 + d3 \quad (1)$$

Past studies (Al-Omari 2007), starting time survey is selected in such a way that there is no residual delay and hence d_3 is zero. For the purpose of regression analysis above delay equation can be written as:

$$df = ax1 + bx2 \quad (6)$$

Where,

df = field delay, x1 = d1 * PF, x2 = d2/900, a and b = calibration parameters.

to find suitable value of constant in the equation for d1and d2 which are currently 1 and 900 respectively, delay estimation equation has been proposed based on regression analysis.

Proposed Delay model along with statistics is build with input field control delay time of two selected intersection , Palestine Intersection (1) and (2) because they have the same conditions. The proposed model is:

$$d = 1.43161 + 0.75301d1 + 241.446d2 \quad (7)$$

and the statistical analysis results of the model are shown in **Table (6).** This results shows that since the P-value is less than 0.01, there is a statistically significant relationship between the variables at the 99% confidence level. The R-Squared statistic indicates that the model as fitted explains 86.6241% of the variability in actual control delay time. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is 84.1921%. The standard error of the estimate shows the standard deviation of the residuals to be 28.1029

VALIDATION OF THE PROPOSED MODEL

In order to validate the proposed model of control delay time prediction at Palestine Street Intersection at another site, the input parameters of Art College Intersection are used to investigate the estimated delay time at it. The results of the validation are shown in **Table (6)**.

CONCLUSIONS AND RECOMMENDATIONS

The basic concluded remarks are as follow:

1. The results of the analysis showed that HCM model using HCS and SIDRAINTERSECTION4 with HCM model give a predicted control delay that is best agreement with the field data that SIDRA model.
2. On the other hand, the HCM model gives different delay time values when using HCS than SIDRA INTERSECTION4 with HCM model by a small percent.
3. It was found that the SIDRA model can be improved significantly and used for traffic analysis in Baghdad conditions by calibrating the basic saturation flow rate.
4. This study showed that traffic software, which are being used in the developed countries, should not be used in Iraq or other developing countries before calibrating their parameters that are believed to be different from those in developed countries such as the ones related to driver behavior.
5. a proposed model is build by derive a new parameters of the uniform delay term (d1) and random delay term (d2) for non-lane state. This model is validated on Art College Intersection. The results show that the predicted model cannot be used for other intersections. Then a proposed model is build for Art College Intersection.

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Table *(1) Existing Traffic and Roadway Condition of Selected intersection

		Lane width (ft.)	No. of lanes	At Peak hour*		Off peak hour*	
				PHF*	Volume (vph) (Lv+1.5Mv+2.0Hv)	PHF*	Volume (vph) (Lv+1.5Mv+2.0Hv)
Palestine intersection (1)							
North bound	L	11	1	0.90	505	0.90	288
	T	11	3	0.91	862	0.95	329
	R	11	1	0.90	798	0.92	128
South bound	L	11	1	0.83	359	0.97	424
	T	11	3	0.91	1001	0.94	643
	R	11	1	0.95	445	0.92	330
East bound	L	13	1	0.84	723	0.82	567
	T	13	3	0.95	4507	0.89	1690
	R	13	1	0.96	873	0.91	657
West bound	L	13	1	0.92	589	0.89	789
	T	13	3	0.92	2302	0.85	889
	R	13	1	0.93	389	0.85	272
Palestine intersection (2)							
North bound	L	12	1	0.92	631	0.94	265
	T	12	3	0.90	3121	0.92	1040
	R	12	1	0.94	451	0.93	256
South bound	L	12	1	0.88	637	0.96	270
	T	12	3	0.92	3039	0.92	1119
	R	12	1	0.88	3332	0.86	1203
East bound	L	11	1	0.86	728	0.96	174
	T	11	3	0.92	866	0.80	427
	R	11	1	0.93	436	0.94	279
West bound	L	11	1	0.90	197	0.92	66
	T	11	3	0.94	178	0.91	117
	R	11	1	0.94	154	0.90	86
Art College Intersection							
North bound	L	12	4	0.95	916	0.95	768
	T	12	4	0.95	894	0.95	720
	R	12	4	0.95	372	0.95	232
South bound	L	12	4	0.94	141	0.94	101
	T	12	4	0.94	1211	0.94	988
	R	12	4	0.94	361	0.94	243
East bound	L	12	4	0.97	657	0.97	468
	T	12	4	0.97	1006	0.97	925
	R	12	4	0.97	368	0.97	220
West Bound	L	12	4	0.98	720	0.98	567
	T	12	4	0.98	593	0.98	444
	R	12	4	0.98	1180	0.98	897

***NOTE**. NO Percent of grade, Pedestrain flow in each approach assumed 50 ped/hr., No Pedestrian Button, No existing of curb parking lanes; storage bays, and buses stops.

PHF =PHV/4(highest volume/interval of 15min.) ,

Peak hour is: 8:00-9:00 am for Palestine Street Intersections and 7:45-8:45 am for Art College Intersection

Off Peak hours: 11:15am-12:15 pm for Palestine Street Intersections and 11:00am -12:00 pm for Art College Intersection

Table (2), Sample of the Results of Delay Survey

Input Field Data											
N(No. o lane)=5 Vstop=161 , Vtot=161 , Is=15sec. ,											
Clock time	**Cycle no.**	**No of veh. In queue Control interval (I=15 sec.)**									
		1	2	3	4	5	6	7	8	9	10
7:45 am	1	16	39	13	39						
	2	18	36	12	42						
	3	20	31	16	40						
	4	22	42	18	39						
	5	24	40	22	36						
	6	28	36	24	33						
	7	33	33	26	31						
	8	36	24	31	28						
	9	42	22	33	24						
7:55 am	10	40	16	36	18						
Total		280	321	234	334						
Viq=1169 , No of cycle = 10, dvq = (Is *Viq/Vtot) * 0.9=98 sec. No. of vehicles stopping per lane each cycle =Vstop/(N*Nc)=3.22 , Accel/Decel correction factor, CF (Ex.A16-2)=-1 Number of cycles surveyed, Nc =10 , Fraction of vehicles stopping, FVS=Vstop/Vtot.=100% , Accel/Decel correction delay, dad = FVS * CF=-1 Control delay/vehicle, d = dvq + dad = 97sec											

Table (3) R^2 Comparison of Actual and Theoretical Control Delay Prediction.

Model	R^2	Std. Error of the Estimate
HCS (HCM Model)	0.676	38.80111
SIDRA INTERSECTION 4/ HCM Model	0.766	33.55110
SIDRA INTERSECTION 4/ SIDRA Model	0.634	48.47451

Table (4) Paired t-test Comparison of Actual and Theoretical Control Delay Prediction.

Model	Paired Differences			t	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean		
HCS (HCM Model)	-154.86364	159.18312	33.93796	-4.563	.000
SIDRA INTERSECTION 4/ HCM Model	-102.91667	176.36225	35.99979	-2.859	.009
SIDRA INTERSECTION 4/ SIDRA Model	-441.20833	763.00704	155.74816	-2.833	.009

Table(5) Calibration of the theoretical models using Regression analysis

Saturation Flow (pcphpl)	HCS (HCM Model)			SIDRA INTERSECTION 4/ HCM Model			SIDRA INTERSECTION 4/ SIDRA Model		
	All values of v/c	v/c<1	v/c>1	All values of v/c	v/c<1	v/c>1	All values of v/c	v/c<1	v/c>1
Default value*	0.640	0.9158	0.5093	0.7658	0.3842	0.7305	0.6344	0.0134	0.5708
2000	0.6653	0.8156	0.4873	0.7609	0.372	0.7216	0.6367	0.0006	0.5888
2100	0.6609	0.8979	0.4733	0.759	0.5255	0.6976	0.4827	0.1813	0.5756
2200	0.6577	0.8718	0.483	0.6575	0.5567	0.7338	0.6204	0.1549	0.5701
2300	0.6283	0.8276	0.4665	0.6589	0.367	0.6941	0.6908	0.3248	0.6308

* 1900 pcphpln in HCM model and 1950 pcphpln in SIDRA model

Table (6) Statistical Analysis Results of the Predicted Delay Time Model

Multiple Regression Analysis Results					
Dependent variable: Field delay time					
		Standard	T		
Parameter	Estimate	Error	Statistic	P-Value	
CONSTANT	1.43161	126.672	0.0113017	0.9912	
d1	0.75301	1.56618	0.480796	0.6401	
d2/900	241.446	35.586	6.78487	0.0000	
Analysis of Variance					
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	56261.4	2	28130.7	35.62	0.0000
Residual	8687.52	11	789.775		
Total (Corr.)	64948.9	13			
R-squared = 86.6241 percent					
R-squared (adjusted for d.f.) = 84.1921 percent					
Standard Error of Est. = 28.1029					
Mean absolute error = 18.6672					
Durbin-Watson statistic = 1.50625					

INTERSECTION CONTROL DELAY WORKSHEET

General Information | Site Information

Input Initial Parameters

Input Field Data

Computations

Figure (1) the worksheet of delay time field measurement at signalized intersection source (TRB 2000).

Figure (2) the satellite Image of Al-Funoon College Intersection

Figure (3) the satellite Imag of Palestine street Intersections.

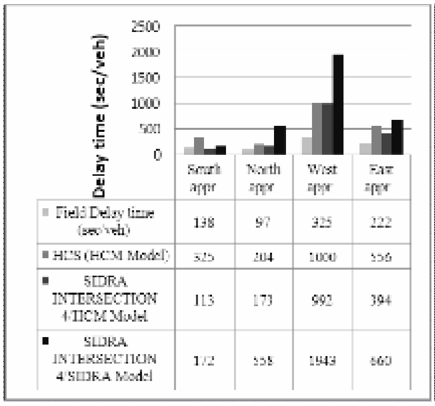

Figure (4) Average Control Delay per Approach\Palestine street Intersection 1 (at peak hour)

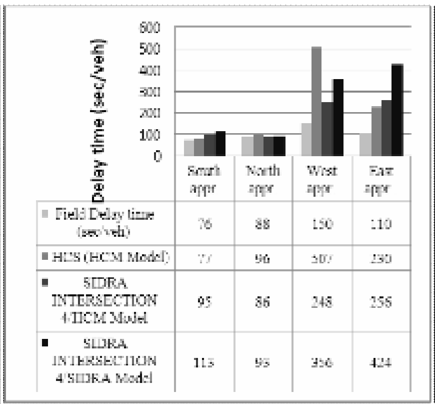

Figure (5) Average Control Delay per Approach\Palestine street Intersection 1 (at off peak hour)

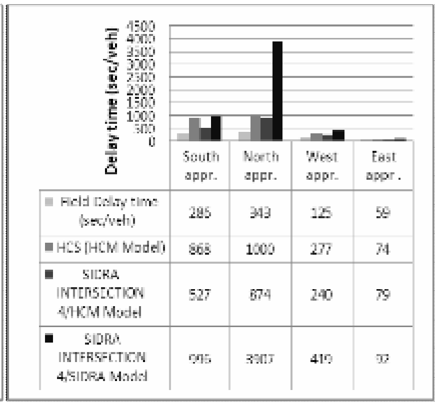

Figure (6) Average Control Delay per Approach\Palestine street Intersection 2 (at peak hour)

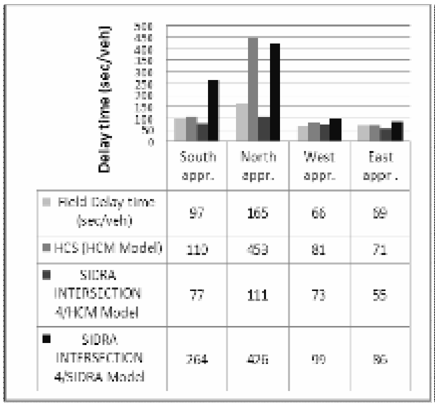

Figure (7) Average Control Delay per Approach\Palestine street Intersection 2 (at Off peak hour)

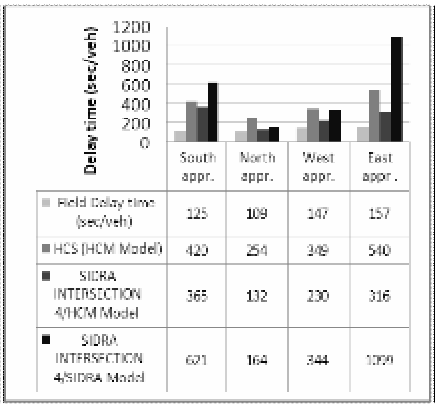

Figure (8) Average Control Delay per Approach\Art College Intersection (at Peak Hour)

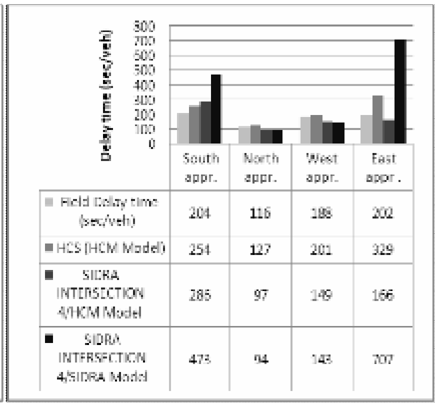

Figure (9) Average Control Delay per Approach\Art College Intersection (at Off Peak Hour)

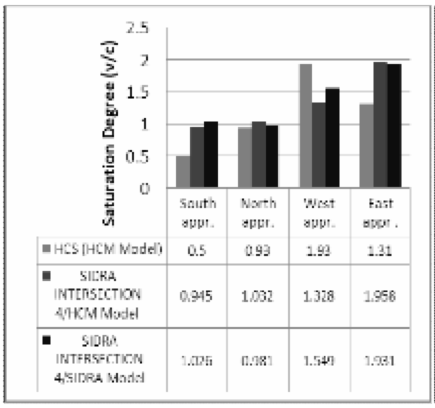

Figure (10) Saturation Degree (v/c) per Approach\Palestine Street Intersection 1 (at Peak Hour)

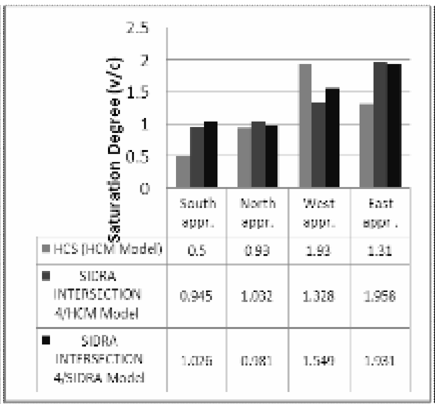

Figure (11) Saturation Degree (v/c) per Approach\Palestine Street Intersection 1 (at off Peak Hour)

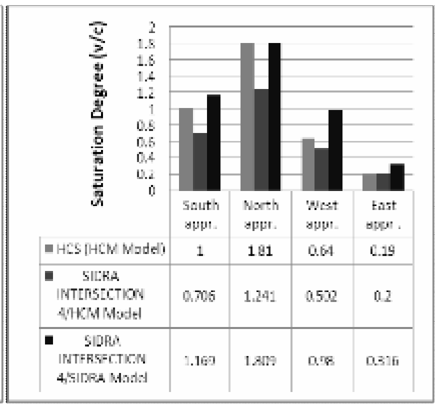

Figure (12) Saturation Degree (v/c) per Approach\Palestine Street Intersection 2 (at Peak Hour)

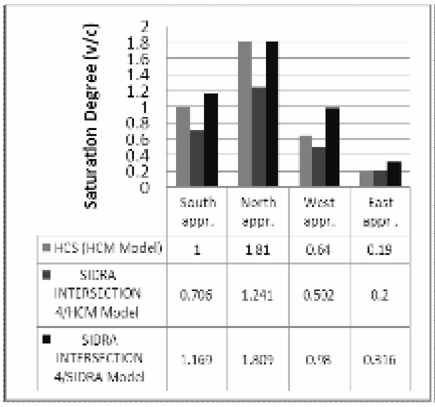

Figure (13) Saturation Degree (v/c) per Approach\Palestine Street Intersection 2 (at off Peak Hour)

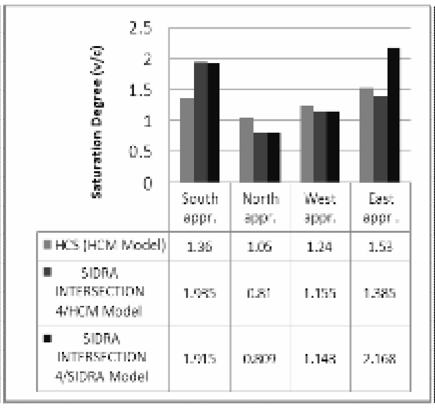

Figure (14) Saturation Degree (v/c) per Approach\Art College Intersection (at Peak Hour)

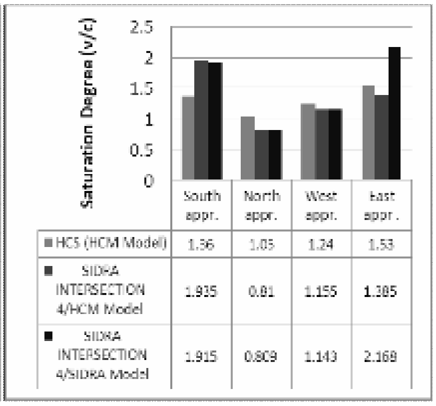

Figure (15) Saturation Degree (v/c) per Approach\Art College Intersection (at off Peak Hour)

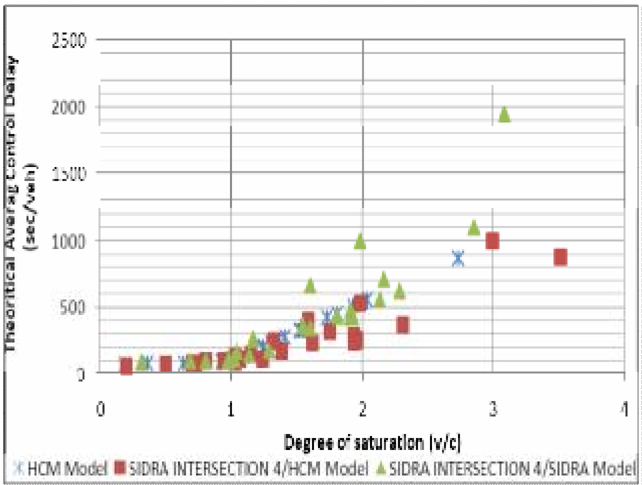

Figure (16) Theoretical delay calculated by the three models according to degree of saturation (v/c)

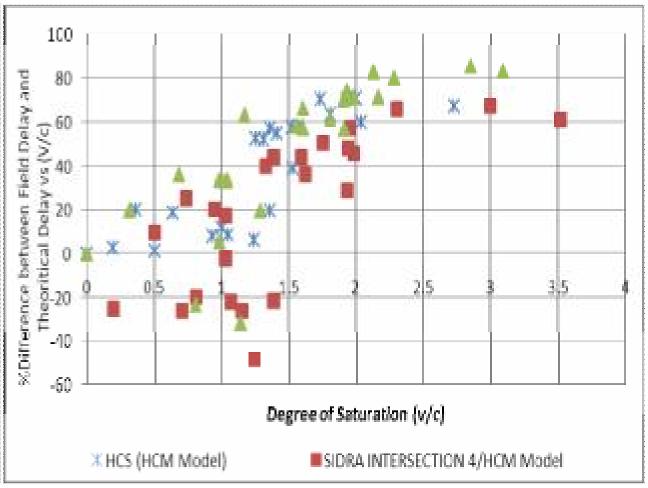

Figure (17) The differences between field delay and theoretical delay computed by the three models according to degree of saturation (v/c)

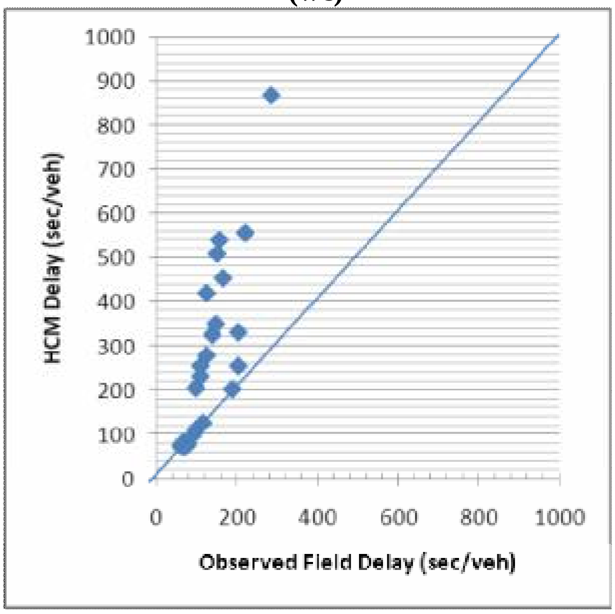

Figure (18) Observed field delay versus Theoretical delay (HCS Model)

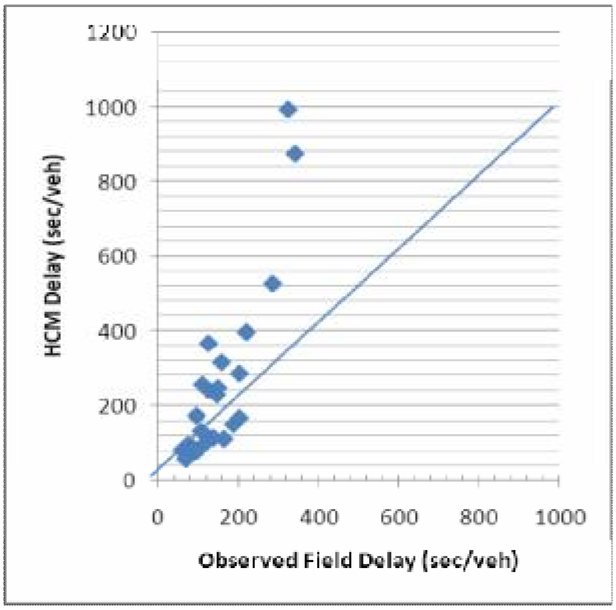

Figure (19) Observed field delay versus. Theoretical delay (SIDRA INTERSECTION 4/HCS Model)

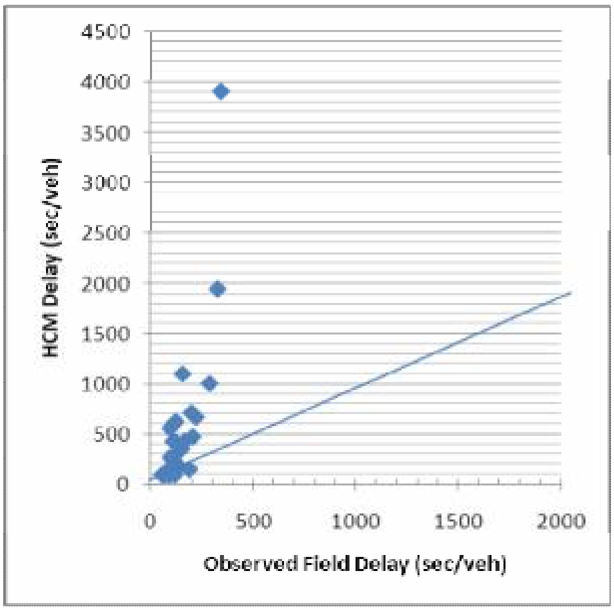

Figure (20) Observed field delay versus. Theoretical delay (SIDRA INTERSECTION 4/SIDRA Model)

APPENDIX A: SAMPLE OF HCS2000: SIGNALIZED INTERSECTIONS CALCULATION RESULTS

```
Analyst: abeer khudhir          Inter.:Palestine Intersection (1) intersectin
Agency:                         Area Type: CBD or Similar
Date:   7/28/2010               Jurisd

________________________SIGNALIZED INTERSECTION SUMMARY______________________
            | Eastbound   | Westbound   | Northbound  | Southbound  |
            | L   T   R   | L   T   R   | L   T   R   | L   T   R   |
            |_____________|_____________|_____________|_____________|
No. Lanes   |  0   5   0  |  0   5   0  |  0   5   0  |  0   5   0  |
LGConfig    |     LTR     |     LTR     |     LTR     |     LTR     |
Volume      |723  4507 873 |589  2302 389 |505  862  798 |359  1001 445 |
Lane Width  |    13.0     |    13.0     |    11.0     |    11.0     |
RTOR Vol    |        0    |        0    |        0    |        0    |
______________________________________________________________________________
Duration    0.25     Area Type: CBD or Similar
_____________________________Signal Operations_______________________________
Phase Combination 1    2    3    4 |      5    6    7    8
EB  Left       P                   | NB  Left   P
    Thru       P                   |     Thru   P
    Right      P                   |     Right  P
    Peds                           |     Peds
WB  Left            P              | SB  Left        P
    Thru            P              |     Thru        P
    Right           P              |     Right       P
    Peds                           |     Peds
NB  Right                          | EB  Right
SB  Right                          | WB  Right
Green          50.0  50.0                50.0  50.0
Yellow          4.0   4.0                 4.0   4.0
All Red         2.0   2.0                 2.0   2.0
                                  Cycle Length: 224.0   secs
___________________Intersection Performance Summary__________________________
Appr/   Lane      Adj Sat    Ratios      Lane Group   Approach
Lane    Group     Flow Rate  __________  __________   ___________
Grp     Capacity    (s)      v/c    g/C   Delay LOS   Delay LOS
______________________________________________________________________________
Eastbound
LTR     1746       7820      3.73  0.22         F           F
Westbound
LTR     1747       7828      2.04  0.22   556.0 F     556.0 F
```

Northbound
LTR 1568 7024 1.52 0.22 324.8 F 324.8 F
Southbound
LTR 1603 7180 1.25 0.22 204.1 F 204.1 F
Intersection Delay = 812.1 (sec/veh) Intersection LOS = F

APPENDIX B: SAMPLE OF SIDRAINTERSECTION4: SIGNALIZED INTERSECTIONS CALCULATION RESULTS

MOVEMENT SUMMARY

Site: Palestine Intersection - 1

New Site
Signals - Actuated Cycle Time = 216 seconds

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	95% Back of Queue Distance	Prop. Queued	Effective Stop Rate	Average Speed
		veh/h	%	v/c	sec		veh	ft		per veh	mph
South: RoadName											
3L	L	561	0.0	1.389	290.4	LOS F	94.4	2360.5	1.00	1.24	4.3
8T	T	947	0.0	0.743	92.3	LOS F	118.2	2955.1	0.97	0.83	10.5
8R	R	887	0.0	1.304	184.8	LOS F	118.2	2955.1	1.00	1.16	6.2
Approach		2395	0.0	1.389	173.0	LOS F	118.2	2955.1	0.99	1.05	6.6
East: RoadName											
1L	L	640	0.0	1.594	378.3	LOS F	127.6	3191.1	1.00	1.36	3.4
6T	T	2502	0.0	1.594	364.9	LOS F	133.7	3342.5	1.00	1.54	3.4
6R	R	418	0.0	1.594	336.5	LOS F	103.2	2580.3	1.00	1.29	3.7
Approach		3561	0.0	1.594	363.9	LOS F	133.7	3342.5	1.00	1.48	3.4
North: RoadName											
7L	L	433	0.0	1.071	165.6	LOS F	58.6	1464.0	1.00	1.04	6.9
4T	T	1100	0.0	0.799	96.9	LOS F	58.6	1464.0	0.96	0.85	10.1
4R	R	468	0.0	0.799	101.6	LOS F	39.7	992.3	0.66	1.01	10.0
Approach		2001	0.0	1.071	112.8	LOS F	58.6	1464.0	0.90	0.93	9.2
West: RoadName											
5L	L	861	0.0	3.001	1007.0	LOS F	318.9	7973.3	1.00	1.82	1.3
2T	T	4744	0.0	3.001	996.4	LOS F	329.7	8242.8	1.00	2.03	1.3
2R	R	909	0.0	2.998	954.8	LOS F	212.2	5305.0	1.00	1.58	1.4
Approach		6514	0.0	3.001	992.0	LOS F	329.7	8242.8	1.00	1.94	1.3
All Vehicles		14471	0.0	3.001	580.3	LOS F	329.7	8242.8	0.98	1.54	2.2

Level of Service (Aver. Int. Delay): LOS F. Based on average delay for all vehicle movements. LOS Method: Delay (HCM).
Level of Service (Worst Movement): LOS F. LOS Method for individual vehicle movements: Delay (HCM).
Approach LOS values are based on average delay for all vehicle movements.

Unlicensed Trial Version

MOVEMENT SUMMARY

Site: Palestine Intersection - 1

New Site
Signals - Actuated Cycle Time = 224 seconds

Movement Performance - Vehicles

Mov ID	Turn	Demand Flow	HV	Deg. Satn	Average Delay	Level of Service	95% Back of Queue Vehicles	95% Back of Queue Distance	Prop. Queued	Effective Stop Rate	Average Speed
		veh/h	%	v/c	sec		veh	m		per veh	km/h
South: RoadName											
1	L	555	0.0	1.335	424.4	LOS F	122.6	858.2	1.00	1.48	4.8
2	T	947	0.0	0.723	89.1	LOS F	295.8	2070.6	0.96	0.83	16.9
3	R	887	0.0	2.133	1144.5	LOS F	295.8	2070.6	1.00	1.81	1.8
Approach		2389	0.0	2.133	557.9	LOS F	295.8	2070.6	0.99	1.35	3.7
East: RoadName											

4	L	640	0.0	1.606	667.6	LOS F	188.3	1317.9	1.00	1.80	3.2
5	T	2502	0.0	1.606	657.5	LOS F	195.9	1371.2	1.00	2.11	3.1
6	R	418	0.0	1.606	665.8	LOS F	190.3	1332.1	1.00	1.81	3.1
Approach		3561	0.0	1.606	660.3	LOS F	195.9	1371.2	1.00	2.02	3.1
North: RoadName											
7	L	378	0.0	0.909	115.2	LOS F	42.2	295.6	1.00	0.95	14.6
8	T	1100	0.0	0.840	92.7	LOS F	112.9	790.3	1.00	0.87	16.5
9	R	536	0.0	1.290	381.0	LOS F	112.9	790.3	1.00	1.30	5.2
Approach		2014	0.0	1.290	172.3	LOS F	112.9	790.3	1.00	1.00	10.3
West: RoadName											
10	L	861	0.0	3.020	1950.1	LOS F	498.2	3487.3	1.00	2.62	1.1
11	T	4744	0.0	3.019	1940.9	LOS F	514.2	3599.2	1.00	3.01	1.1
12	R	909	0.0	3.020	1949.3	LOS F	496.7	3476.6	1.00	2.37	1.1
Approach		6514	0.0	3.019	1943.3	LOS F	514.2	3599.2	1.00	2.87	1.1
All Vehicles		14478	0.0	3.020	1153.1	LOS F	514.2	3599.2	1.00	2.15	1.8

Level of Service (Aver. Int. Delay): LOS F. Based on average delay for all vehicle movements. LOS Method: Delay (RTA NSW).
Level of Service (Worst Movement): LOS F. LOS Method for individual vehicle movements: Delay (RTA NSW).
Approach LOS values are based on average delay for all vehicle movements.