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Development of Delay Models for Roundabouts

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Abstract

The purpose of this research is to develop an empirical model for total delay time prediction at roundabouts as a function of influence traffic and geometric features. Four roundabouts of fifteen approaches with different characteristics are selected in Karbala City. The traffic parameters are measured using video recording technique. Geometric elements are measured through field survey and satellite image. A statistical approach is used to develop three delay models (linear regression models with 95% and 50% confidence level, and polynomial regression model with 95% confidence level). The statistical analysis indicates that both geometric and traffic variables have a significant effect on delay time. The entry radius and circulating traffic have the greatest influence. These models have been compared with SIDRA delay model. It is found that although SIDRA delay overestimates delay time at high delay range, but it does not have a significant difference with the field delay at 95% confidence level.

الخلاصة:

الغرض من هذا البحث هو لاستحداث نموذج تجريبي للتنبؤ بقيم التأخير الكلية للدوارات كدالة للتأثيرات المرورية و عوامل التصميم الهندسي. فقد تم اختيار أربعة دوارات بـ(١٥) مقترب ذات خصائص مختلفة من مدينة كربلاء. كما تم حساب العوامل المرورية باستخدام تقنية تصوير الفيديو، أما البيانات الخاصة بعوامل التصميم الهندسي فقد تم حسابها من خلال المسح الحقلي وبالاستفادة من الصورة الفضائية. استخدمت الطريقة الإحصائية لاستحداث ثلاث موديلات للتأخير (موديلات الارتداد الخطي بمستوى ثقة ٩٥% و ٥٠%، و موديل الارتداد المتعدد الحدود بمستوى ثقة ٩٥%). أوضحت نتائج التحليل الإحصائي بأن كلاً من المتغيرات المرورية والهندسية لها تأثيرات هامة على قيم التأخير، حيث نصف قطر الاستدارة والحجم المروري المستدير لها التأثير الأكبر من بين العوامل الأخرى. كما تم مقارنة نتائج هذه الموديلات مع النتائج المحسوبة من برنامج (SIDRA)، فقد وجد بان على الرغم من ان هذا البرنامج يعطي قيم تأخير أعلى عند قيم التأخير الحقيقية العالية، لكنه لا يختلف اختلافاً ذا دلالة إحصائية مع قيم التأخير المحسوبة موقعياً بمستوى ثقة ٩٥%.

Keyword: Traffic Delay Model, Roundabout, SIDRA

1. Introduction

Roundabout delay is defined separately for each entry approach. The delay for any entry approach is composed of two distinct components: queuing and geometric delay. Queuing delay occurs when drivers are waiting for an appropriate gap in the circulating traffic. Geometric delay results from vehicles slowing down, when traversing the roundabout [1].

Control delay defined by the highway capacity manual (HCM2000) as the time that a driver spends decelerating to a queue, queuing, waiting for an acceptable gap in the circulating flow while at the front of the queue, and accelerating out of the queue [2].

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 [3].The difficulties in a theoretical approach are in the basic parameters (driver behavior in term of headways and its distribution function) which cannot be often directly observable due to the following reasons:

1. Operational conditions in which they are observable rarely occur.
2. Traffic operations do not usually last long enough to make reliable measurement.

The analytical model of average control delay for a given lane is a function of the lane`s capacity and degree of saturation as illustrated in the HCM model for delay at unsignalized intersection [2,4,5,6,7]:

$$d = \frac{3600}{c} + 900T\left[x - 1 + \sqrt{(x-1)^2 + \frac{\left(\frac{3600}{c}\right)x}{450T}}\right] + 5 \times min[x, 1] \quad \text{....................} \quad \textbf{(1)}$$

where:

d: average control delay (sec/veh),

x: volume to capacity ratio of the subject lane,

c:capacity of subject lane (veh/hr), and

T: time period (hr).

Control delay can be considered to be the overall time loss that includes all delays experienced in traveling through an intersection with reference to approach and exit cruise speeds (including all acceleration and deceleration delays, delay due to cruise at a lower speed, and stopped delay). Geometric delay is the delay experienced by a vehicle going through (negotiating) the intersection in the absence of any other vehicles [**8**].

Flannery et al. [**9**] developed an analytical model for stopped time delay estimation at single lane roundabouts by making use of Little`s law for queue length. Their model requires a value for the average accepted gap for individuals, the headway distribution (lognormal) of the circulating stream, and the arrival rate to the roundabout approach.

$$L_q = \lambda\, E(T) + \frac{\lambda^2\left[(E(T))^2 + VAR(T)\right]}{2(1-\lambda E(T))} \qquad \text{................................}\mathbf{(2)}$$

where:

E (T) : the expected service time,

VAR (T) : the variance of a random variable, *T*.

L_q : queue length, and

λ : the mean arrival rate to the queue.

Hummody [**1**] developed a simulation models for estimation the average control delay for through and left turning movement from the micro-simulation model, developed in his study (RONDSIM) The model for left turning vehicles with adjusted R^2 equals to 0.984 was:

$$Average\ Car\ Delay = \sqrt{Left\ TurnVolume} \qquad \text{................................}\mathbf{(5)}$$

Al-Omari et al. [**3**] developed an empirical stopped delay model as a function of the influencing factors based on a time interval of 15 min. The model has an adjusted R^2 of 51.8% as follows:

$$D_s = 0.0027V_s + 0.0056V_c - 0.1802\, ID + 0.8048W_c - 0.3083W_e \ \text{...........}\mathbf{(3)}$$

where:

D_s: stopped delay (s/veh),

V_s: volume of vehicles in the subject entry (pcuph),

V_c : volume of vehicles in the circulating roadway (pcuph),

ID: diameter of the roundabout island (m),

W_c : width of the circulating roadway (m), and

W_e: width of the subject approach entry (m).

The models for determining the geometric delay for each intersection type is a function of the intersection geometry, and negotiation and exit cruise speed. Since the negotiation distance and speed parameters depend on the intersection size, the geometric delay varies with the intersection size. It is also depends on approach and exit cruise speed values.

Hagring [10] stated that geometric delay is a function of the approach speed. It's assumed that the acceleration and deceleration rates are equal.

$$d_g = 0.0012v^2 + 0.0254v + 1.5 \qquad \text{.................................(6)}$$

where:

d_g : Average vehicle geometric delay (sec),and

v : average approach speed (km/hr)

A systems analysis of a roadway network may include geometric delay because of the slower vehicle paths required for turning at intersections [7].

When comparing a roundabout's operation with that of a traffic signal, it is important to recognize that outside the intersection's peak hours (i.e., traffic demands are lower), roundabouts result less delay to motorists, whereas a signal will always result more delay, even under extremely low traffic flow.

Sisiopiku and Oh [11], and Mishra [12] indicated that roundabouts capacities are higher than capacities of signal controlled intersections with two- and three-lane approaches for any proportion of left-turning traffic volume.

Kakooza et al.[13] noted that under light traffic, roundabout intersections perform better than unsignalized and signalized intersections in terms of easing congestion.

Collins [14] stated that, if the objective is to minimize mean vehicle or pedestrian delay, decision-makers can be confident that total vehicle delay will be significantly reduced through implementation of a roundabout.

Local studies on traffic performance measure should be conducted, because the developed delay models are not always applicable accurately for all sites, due to the effect of driver behavior, geometric features, and environment.

2. Study Objective

The purpose of this study is to develop a statistical model for the prediction of total vehicle delay at roundabouts based on 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 15 approaches were selected from four different roundabout characteristics in Karbala city. The locations of these roundabouts are illustrated in **Figure (1)**.

Figure (1) Roundabouts Location in Karbala City

In this research, the statistical approach will be followed to develop models for estimating roundabout 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 (entry and circulating traffic volume (Ve, Vc), weaving and non-weaving traffic volume (Vw, Vn-w) , and percent of turning movements (Pl, Pth, Pr). Geometric features is the features that believed to have a significant impact on total delay such as (central island diameter (ID), width of entry and circulating of the subjected approach (We, Wc), weaving length (Lw), and entry radius (Re)) have been included in model building**.** The definitions of these terms are shown graphically in **Figure (2)**.

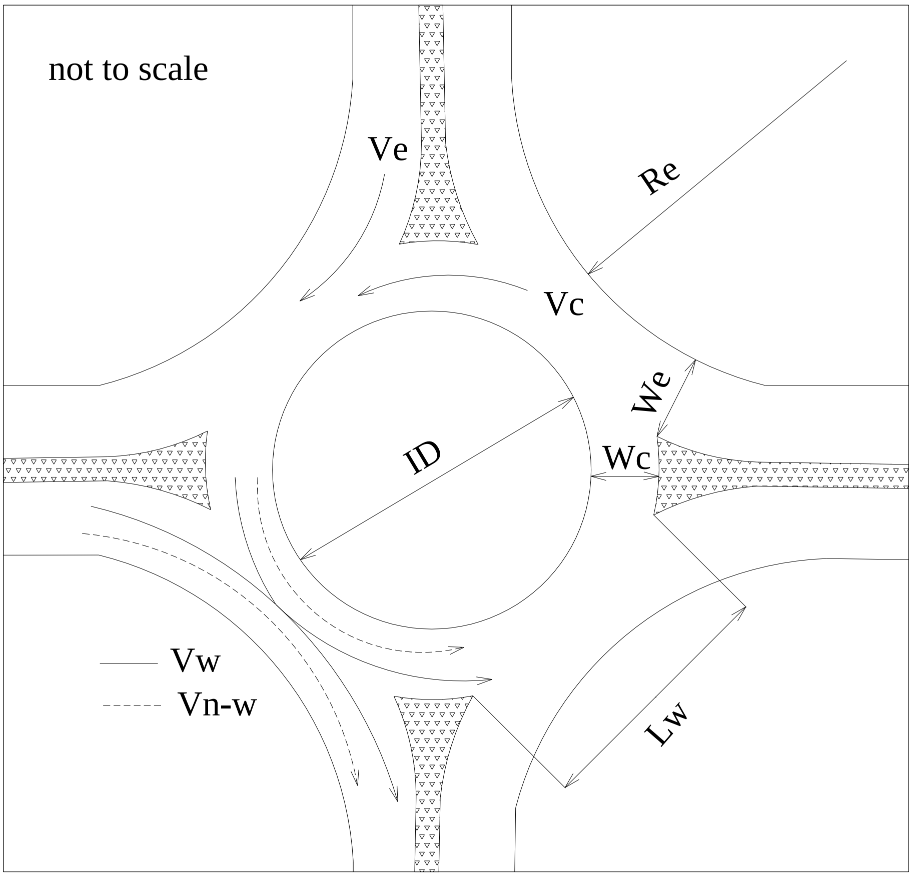

Figure (2) Variables Definition

3.1 Traffic Volume

The traffic volume data were collected on sunny days in May / 2010 from locations with good pavement conditions and during times when there were no holidays or occasions. The video recording technique was used for this purpose. The selected roundabout 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 roundabout intersection in a day.

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 Features

The geometric data have been collected through field survey and the measurements with the aid of GIS tools from the available satellite image. The geometric features used for models building are presented in **Table (1)**.

Table (1) Geometric Features for the Selected Approaches

Node	**Approach**	**Entry Width (*We*)**	**No. of Entry lanes (n_e)**	**Exit Width**	**Entry Radius(*Re*)**	**Circulating Width (*Wc*)**	**No. of Circulating Lanes (n_c)**	**Splitter Island Width**	**Inscribed Circle Diameter (*ICD*)**	**Central Island Diameter (*ID*)**
		(m)	**No.**	**(m)**	**(m)**	**(m)**	**No.**	**(m)**	**(m)**	**(m)**
1	**East**	18	5	21.5	35	20	3	8	65	25
	West	18	5	22.7	22.5	20	3	6.3	65	25
	North	---	---	---	---	---	---	---	---	---
	South	10	2	11.5	22.5	20	3	2.5	65	25
2	**East**	18	5	21.5	35	20	3	8	67	27
	West	18	5	22.7	22.5	20	3	6.3	67	27
	North	15	3	---	18	20	3	7.5	67	27
	South	10	2	11.5	22.5	20	3	2.5	67	27
3	**East**	15	5	17	45	17	3	17	102	68
	West	15.5	3	16	55	17	3	25	102	68
	North	17	3	17	55	17	3	14	102	68
	South	16.5	3	16.5	55	17	3	23	102	68
4	**East**	9	2	7	37.5	16.5	3	13.7	48.5	21
	West	13	2	12.7	14.5	13	3	9.8	40.5	21
	North	10.5	2	17.5	56	9	2	8.5	38	21
	South	7	2	13.3	16	11.5	2	13.7	48.5	21

3.3 Delay Time

The average delay time were adapted to measure the total approach travel time with the aid of the abstracted data from video films using EVENT program, which have accuracy of 0.01 second. A 'travel zone' was defined by a known point upstream of any queuing to the yield bar. Approach travel time was measured for each vehicle completing the travel zone trip. By definition, geometric delay caused by the roundabout was added to the approach delay. The geometric delay is measured for vehicles at off-peak periods. When, the vehicle transverse the intersection alone, and not affected by the others. Average delay was then calculated by subtracting the free flow time from the measured travel time determined from this equation.

Average Delay=Measured Travel Time – Free Flow Travel Time

Free flow travel time was measured by timing vehicles that encountered no obstacles to entering the roundabout. This value was compared to the theoretical free flow time, obtained by dividing the approach distance by the speed limit at the site. The total approach delay is a sum of stop time delay and geometric delay. The total delay at each approach is presented in **Table (2)**.

Table (2) Measured Approach Delay

Node	Approach	Average Vehicle Delay (sec/veh)
1	East	12.0
	West	9.6
	North	---
	South	16.1
2	East	9.8
	West	17.4
	North	7.8
	South	10.7
3	East	47.3
	West	36.6
	North	211.2
	South	88.9
4	East	31.8
	West	27.6
	North	40.6
	South	64.2

4. Model Development

The stepwise regression method is used for total delay time prediction. The variables are entered in a stepwise manner to build the models.

4.1 Linear Regression Model

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 the volume of circulating traffic and entry radius are entered the model, and gives an adjusted R^2 equals to 0.582, to produce model (A), with *F*-statistics of 10.7 corresponds to *P*-value of 0.002, the regression results and the ANOVA test are shown in **Tables (3, and 4)**. It can be drawn that the simple linear regression does not predict vehicle delay accurately.

$$Delay = 0.04\,Vc + 1.55\,Re - 51.35 \qquad \text{..........................}\textbf{(A)}$$

R^2=0.642 SEE=35.4

where:

Vc : volume of vehicles in the circulating roadway (veh/hr),and

Re : entry radius of the subjected approach (m).

Table (3) Regression Results for Model (A)

	Beta	Std.Err.	B	Std.Err.	t(12)	p-level
Intercept			-51.3546	24.62236	-2.08569	0.059025
Vc	0.548311	0.179806	0.0393	0.01290	3.04946	0.010095
Re	0.451439	0.179806	1.5508	0.61769	2.51070	0.027373

Table (4) ANOVA Test for the Regression Model (A)

	Sums of Squares	df	Mean	F	p-level
Regress.	27027.72	2	13513.86	10.75909	0.002106
Residual	15072.49	12	1256.04		
Total	42100.22				

The stepwise regression (based on *F*- to enter equals to 1) was used to find the most influencing variables on the total delay. It was found that the circulating traffic volume, weaving traffic volume, percent of left turning traffic volume, entry radius, and circulating width had significant effects on the total delay.

The correlation matrix in **Table (5)** and the regression results in **Table (6)** show that the circulating traffic volume of the subjected approach has the greatest linear association with delay time, with a correlation coefficient of (0.674), whereas the weaving traffic and the entry radius have the less correlation coefficient, of (0.605 and 0.604), respectively. It can also be noticed that the percent of left turning vehicles and circulating width have less linear associations with delay time, with correlation coefficients of (0.427and -0.405), respectively.

Considering the aforementioned variables, the following regression model was produced for estimation of the total delay time (sec/veh):

$$Delay = 0.03\,Vc + 0.65\,Re - 6.05\,Wc + 1.03\,Pl + 0.015Vw + 42.854 \quad \text{......} \textbf{(B)}$$

$R^2=0.81$ SEE=29.5

where:

Vc : volume of vehicles in the circulating roadway (veh/hr),

PL: percent of left turning vehicles in the subject entry (veh/hr),

Vw: volume of weaving vehicles in the subject entry (veh/hr),

Re : entry radius of the subjected approach (m), and

Wc: width of the circulating roadway (m).

Table (5) Correlation Matrix for the Selected Parameters

	Ve	**Vc**	**ID**	**WC**	**We**	**Re**	**L w**	**Vn-w**	**Vw**	**WR**	**PL**	**PTH**	**PR**	**Delay**
Ve	1.00													
Vc	-0.30	1.00												
ID	0.27	0.60	1.00											
WC	-0.06	-0.05	0.07	1.00										
We	0.21	0.14	0.32	0.56	1.00									
Re	0.24	0.28	0.66	-0.27	0.12	1.00								
Lw	0.25	0.32	0.66	0.58	0.57	0.35	1.00							
Vn-w	0.52	0.15	0.48	0.16	0.47	0.35	0.54	1.00						
Vw	0.34	0.60	0.52	-0.23	0.01	0.27	0.18	-0.07	1.00					
W R	-0.27	0.32	-0.05	-0.26	-0.41	-0.13	-0.24	-0.78	0.63	1.00				
PL	0.33	0.19	0.63	0.24	0.10	0.42	0.63	0.62	0.06	-0.45	1.00			
PTH	0.00	-0.14	-0.48	-0.08	0.27	-0.28	-0.33	-0.08	-0.09	-0.02	-0.61	1.00		
PR	-0.29	0.00	0.03	-0.10	-0.40	-0.02	-0.15	-0.46	0.04	0.43	-0.15	-0.69	1.00	
Delay	0.09	0.67	0.62	-0.41	0.00	0.60	0.17	0.23	0.61	0.16	0.43	-0.41	0.12	1.00

Table (6) Regression Results for Model (B)

	Beta	**Std.Err. of Beta**	**B**	**Std.Err. of B**	**t(9)**	**p-level**
Intercept			42.85394	57.18464	0.74940	0.472751
Vc	0.4169	0.184354	0.02991	0.01323	2.26155	0.050050
Re	0.1901	0.178682	0.65319	0.61383	1.06412	0.314988
WC	-0.36867	0.165817	-6.04812	2.72024	-2.22338	0.053270
PL	0.34478	0.173537	1.02826	0.51755	1.98680	0.078199
Vw	0.2004	0.185742	0.01456	0.01349	1.07892	0.308690

Table (7) lists the results of the simple ANOVA test, for the delay model (B), showing that the regression model is statistically significant ($p \approx 0$).

Table (7) ANOVA Test for the Regression Model (B)

	Sums of Squares	**df**	**Mean**	**F**	**p-level**
Regress.	34260.59	5	6852.118	7.866325	0.004192
Residual	7839.63	9	871.070		
Total	42100.22				

4.2 Polynomial Regression Model

The stepwise regression data transformation method was used in order to obtain the optimum combination set for the predictors to model the total delay time. In this case the variables that passed the selection criteria for inclusion in the equations are: the ratio of circulating traffic volume to the circulating roadway width (Vc/Wc), the entry radius (Re), the ratio of weaving traffic to the weaving length (Vw/Lw), and the weaving ratio (WR). The coefficients for the stepwise regression models for total delay at roundabout and some of the analysis results are summarized in **Table (8).**

The model obtained from a stepwise regression is:

$$Delay = -7.45 + 0.015\left(\frac{Vc}{Wc}\right)^2 - 2.26\left(\frac{Vc}{Wc}\right) + 0.025\,(Re)^2 + 0.01\left(\frac{Vw}{Lw}\right)^2 + 88.25(WR)$$

Adjusted $R^2 = 0.929$ SEE= 14.63 **(C)**

where:
Vc : volume of vehicles in the circulating roadway (veh/hr),
Wc: width of the circulating roadway (m),
Re : entry radius of the subjected approach (m),
Vw: volume of weaving vehicles in the subject entry (veh/hr),
Lw: Length of weaving section (m), and
WR: weaving ratio= weaving traffic/ (weaving +non weaving traffic).

Table (8) Regression Results for Model (C)

	Beta	Std.Err.	B	Std.Err.	t(9)	p-level
Intercept			-7.453	14.015	-0.531	0.607
$(Vc/Wc)^2$	2.318	0.387	0.015	0.002	5.978	0.000
$(Re)^2$	0.536	0.082	0.025	0.003	6.466	0.000
$(Vw/Lw)^2$	0.405	0.085	0.010	0.002	4.758	0.001
(Vc/Wc)	-1.864	0.418	-2.260	0.507	-4.453	0.001
WR	0.332	0.114	88.247	30.399	2.902	0.017

Referring to **Table (8),** all the variables are significant for the total delay time prediction, where the *p*-value for each of the parameters is less than 0.05, so these parameters can be included in the model for estimating total delay time at roundabouts. The standard error contains the same units as the coefficients. In general, the smaller the values of the standard error in relation to the test coefficient, the better results will be produced.

Analysis of variance (ANOVA) test consists of calculations that provide information about levels of variability within a regression model and form a basis for tests of significant. The

ANOVA portion of the statistical software output is shown in **Table (9).** The *P*- value for the *F* test statistics of 37.5 equals to 0.000, it shows that this model provides valuable information for predicting delay and it's statistically significant.

Table (9) ANOVA Test for the Regression Model (C)

	Sums of Squares	df	Mean	F	p-level
Regress.	40172.33	5	8034.466	37.50747	0.000009
Residual	1927.89	9	214.210		
Total	42100.22				

5. Model Analysis

From the previous model, it is obvious that delay time increases as circulating volume increases, as it produce shorter gaps, and as a result, the probability of gap acceptance for the entering drivers to merge decreases.

The weaving traffic needs larger gaps to cross or change lanes as compared with non-weaving traffic. Also, the weaving traffic in the circulatory road may submit to produce bunched or forced gaps to the entry flow and cause an excessive delay, so the increase in weaving traffic or weaving ratio cause increase in total delay times. While the increase in weaving length cause decrease in delay time due to the increase in vehicle speed at longer sections and consequently reduce geometric delay. Since the geometric delay depends mainly on vehicle speed at weaving section.

The delay time has a proportional relationship with entry radius. This is due to the longer vehicles path for through and left turning movement and the reduced speed at the curvature section. The delay time has an inverse proportional relationship with the circulating width. This is explained by the fact that, as the number of circulating lanes increases, the circulating traffic will produce high probability of accepted gaps. Since the circulating traffic tends to drive at the inner lane and keeps the outer lane for merging maneuvers.

6. Model Limitation

The produced models were based on traffic and geometric characteristics of four roundabouts (15 approaches) in urban area of Karbala city. The traffic and delay data used in model building are the weighted average of one hour data abstracted from the video recording films for typical weekdays. The variables that have significant impact on total delay are explained in **Tables (10)** for the linear and polynomial regression model, with their statistical characteristics. The developed models will be applicable within the range of traffic parameters values present in this Table.

Table (10) Data Range and Their Statistical Characteristics for Models

(B)

Var.	Mean	S.D	Min.	Max.
Vc	1228.6	764.3	168	2832
Wc	17.2	3.3	9.5	20.0
Re	34.7	15.9	14.5	56.0
Vw	1651.8	754.9	0	3232
PL	28.1	18.3	0.0	54.1
Delay	50.8	34.7	7.8	211.2

(C)

Var.	Mean	S.D	Min.	Max.
Vc	1228.6	764.3	168.0	2832.0
Wc	17.2	3.3	9.5	20.0
Lw	44.2	14.3	19.6	67.2
Vn-w	949.6	566.5	292.0	2208.0
Vw	1651.8	754.95	0.0	3232.0
WR	0.633	0.206	0.0	0.874
Re	34.7	15.9	14.5	56.0

S.D: Standard Deviation

7. 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 [2]. 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 range. There are several methods used for models validation. One of these methods is to compare the model with another data set that was not included in model building.

The data used for this purpose is one hour data abstracted from video recording films at different time for the same roundabouts in the network. The average delay from one hour is regressed with the delay time predicted by the model. The regression results are shown in **Figure (3)** and **Table (11)**.

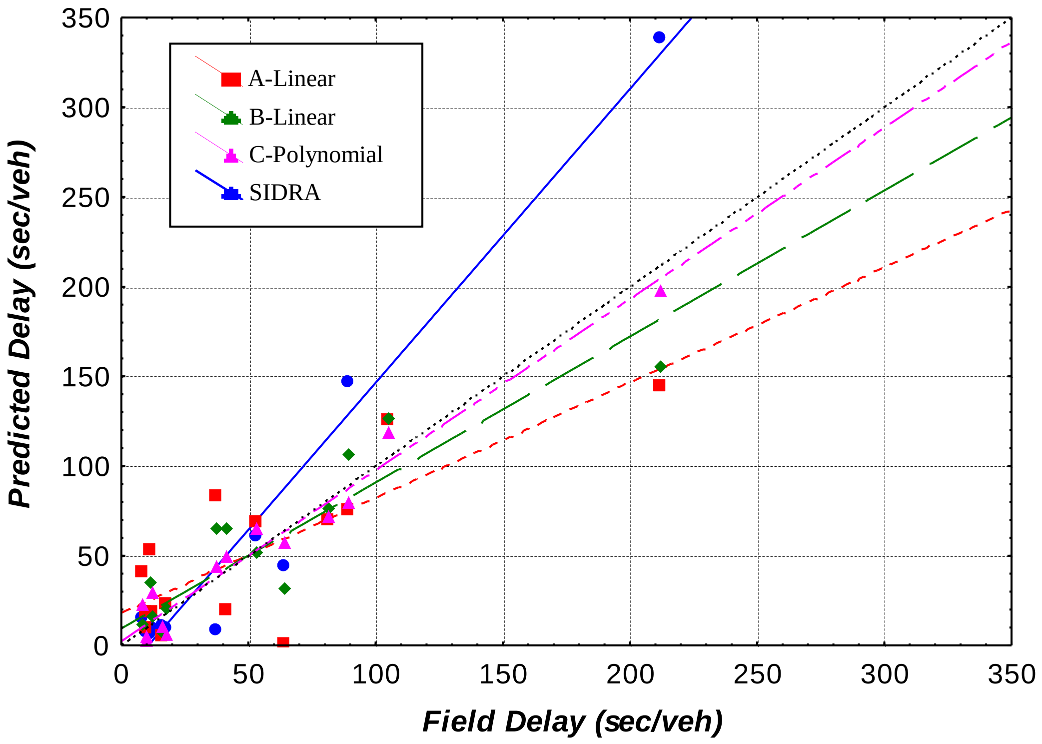

Figure (3) Observed Versus Predicted Delay Time for the Three Models

Table (11) The Regression Results for the Three Delay Models

Model	Model Fit	R^2-value
A- Linear	*18.2+0.64 × field delay*	0.80
B- Linear	*9.4+0.81 × field delay*	0.90
C- Polynomial	*2.3+0.95 × field delay*	0.97
SIDRA Model	*-9.4+1.50 ×field delay*	0.91

It is obvious from the analysis of different models, that the simple linear model with 95% confidence level is the simplest and easy to use as compared by other models, but it explains about 58.2% of variability. So, it cannot be used for accurate delay prediction, but it can give sense about the most variables affecting delay time and less sensitive to change in variable values. The second linear model with 50% confidence level is also easy to use and understandable, gives higher adjusted R^2 of 71%. But, it does not sensitive to each parameter within the model such as entry radius and weaving traffic. It can be used for delay time prediction with caution to lower traffic volume.

The polynomial model gives the highest adjusted $R^{2,}$ and explains about 92% of the variability. But it is complicated model, and depends on many variables which needed to be defined and measured. It is also very sensitive to traffic variation (circulating and weaving). **Table (11)** indicates that the intercept in model (C) is not significantly different from 0, as well as the slope is not significant different than 1. This is with coefficient of determination of

0.97, so the model can be considered acceptable and can be used for accurately delay time prediction within the model`s limit.

8. Comparison with SIDRA Software Model

SIDRA INTERSECTION 4.0 Software has been applied for these roundabouts. The delay results produced by SIDRA were compared with field delay. The comparison results are presented in **Figure (3).** This Figure shows that, for delay ranges (up to 20 seconds), SIDRA has a good representation of field delay. For higher delay ranges, SIDRA 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 (11).** The intercept is not significantly different from zero and the slope is not significantly different from 1 at 95% confidence. The R^2 value indicated that SIDRA explains about 91 % of the variability in the total delay. It can be drawn that SIDRA model can be applied to local traffic conditions with acceptable results within the models limits.

9. 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 not lead to high relationship model, while polynomial model and data transformation lead to better relationship with high significant variables.
2. The most significant parameters in delay time prediction are circulating volume and entry radius.
3. The traffic volume (circulating, weaving, and percent of left turning) as well as weaving ratio cause increase in delay time.
4. Geometric features (width of circulatory road and the length weaving section) reduce the delay time, except entry radius which cause increase in delay time.
5. The developed linear models slightly under estimate the delay time at high delay values.
6. The developed polynomial model predicts the total delay time accurately.
7. In comparison of delay time produced by SIDRA with field delay, SIDRA has a good representation of field delay at low to medium values, but it is overestimate at high delay range.
8. When the delay time produced by SIDRA with these developed models is compared, SIDRA delay is the lowest at low delay ranges up to 40 second. For higher delay values, SIDRA delay times are the highest, especially at very high delay values.

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