Available online at www.sciencedirect.com

ScienceDirect

Procedia - Social and Behavioral Sciences 111 (2014) 252 – 261

Procedia
Social and Behavioral Sciences

EWGT2013 – 16th Meeting of the EURO Working Group on Transportation

Investigation of Cyclic Vehicle Queue and Delay Relationship for Isolated Signalized Intersections

Yetis Sazi Murat[a,]* , Sabit Kutluhan[a], Ziya Cakici[a]

[a]*Pamukkale University, Engineering Faculty, Dept. of Civil Engineering, 20070, Denizli, Turkey.*

Abstract

Delay is the one of the design criteria that has been used for performance evaluation of signalized intersections. In pre-timed control, vehicle delays can be minimized or reduced by proper design of signal timings and phasing. But vehicle delays include many parameters such as signal timing, number of phases, vehicle headways, saturation flow, queueing etc. Among these parameters vehicle queue is formed by unbalanced signal timings or unexpected demand values. On the other hand, headways of vehicles can be effective on queue forming especially in discharging case. It is also related to driver behaviors.
In this paper, relationship of cyclic vehicle queue and vehicular delay is investigated considering different signal timings and phase sequencing. The data are obtained from observations that are made at urban intersections of Denizli city, Turkey. Regression analysis is used for relationship and statistical tests are applied. The MuLReD (Multiple Linear Regression Analysis based Delay Estimation) model is developed and significance of the model is proved by statistically. Adjusted R^2 value of MuLReD Model is obtained as 0,95. On the other hand, delay values obtained from the MuLReD Model and Akcelik Vehicle Delay Formula are compared with each other. As a result of comparisons, Mean Square Error (MSE) values for Akcelik Equation and the MuLReD Model are determined as about 112 and 7 respectively. These results show that outcomes obtained by the MuLReD Model are closer to field observations. Discussions about the present delay formulas, are also reported in the paper.

Selection and/or peer-review under responsibility of Scientific Committee

Keywords: traffic signal control; vehicle queue; delay; intersection; cycle time.

1. Introduction

Modeling vehicle delay is one of the interesting issues that traffic engineers dealt with. Measurement of delay is a sensitive procedure that takes long time. On the other hand, it should be repetitive for different time periods.

* Corresponding author. Tel.: +90-258-2963357; fax: +90-258-2963460.
E-mail address: ysmurat@pau.edu.tr

1877-0428
Selection and/or peer-review under responsibility of Scientific Committee
doi:10.1016/j.sbspro.2014.01.058

Therefore, basic and useful approaches are preferred by researchers to estimate vehicle delay at signalized intersections.

Webster, Akcelik and Transportation Research Board (Highway Capacity Manual) methods are used commonly in calculation of vehicle delays. In these methods, delay parameter includes uniform and random components. As the uniform component expresses the delays which occurs owing to existing red signal and lost time, random component represents vehicle arrival headways, vehicle queuing, discharging regime of the intersection and etc. Despite the delay equations give results near to actual values, these equations can not converge sufficiently to actual values all the time due to the random component especially.

In the scope of this study, the relationship between delay and red signal time, number of vehicle in queue, average discharging headway, average entering time to intersection were investigated. In the second part, delay calculation and Akcelik delay formula were explained. As field observations and data collected from the intersections were presented in the third part of the study, in the fourth part, the parameters which were considered in the regression analysis and the regression model were introduced. In the fifth part, the delay value obtained from regression model equation was compared with that of Akcelik delay equation and field observations. In the final part, the results of this study were commented.

2. Delay Calculation

The Webster (1958), HCM (TRB, 1985) or the Akcelik's (1981) delay calculation methods have been preferred by traffic engineers for many years. In 1965, the Transportation Research Board (TRB) published the Highway Capacity Manual (HCM), and it has subsequently been updated several times. In the HCM method, the average delay of vehicles is calculated based on a lane of an approach leg. The Webster delay formula cannot be used for over-saturation cases. Therefore, only the Akcelik's (1988) delay formula is considered in this study.

According to this method, the queue length must be calculated primarily to determine the average delay of vehicles in a traffic flow. The queue length value is calculated by the following equation.

$$N_0 = \frac{QT_f}{4}\left(z + \sqrt{z^2 + \frac{12(x+x_0)}{QT_f}}\right) \quad (1)$$

If $x_0 > x$, $N_0 = 0$

Where;
N_0: Average queue length (The vehicle numbers on all lanes)
Q: Capacity (vehicle/hour)
Tf: The flow period
QTf= The maximum number of vehicles which can be discharged during the flow period
x=q/Q : (degree of saturation)
Z=x-1,
x_0 = Maksimum value of degree of saturation (the average overflow queue is approximately zero)

x_0 is calculated by equation 2.

$$x_0 = 0.67 + sg/600 \quad (2)$$

Where ;

s= saturation flow (vehicle/second)
g= effective gren time (second)

Total delay (value) is calculated by the following formula;

$$D = \frac{qc(1-u)^2}{2(1-y)} + N_0 x \quad (3)$$

Where;
D: Total delay (second)
q: Flow (vehicle/second)
c: Cycle time (second)
u: Green time ratio (g/c)
y: Flow ratio (q/s)

In addition, the average delay time per vehicle can be expressed as;

$$d = D/q \quad (4)$$

Where;
D: Total delay (second)
q: Flow (vehicle/second)

The queue length is considered as a significant component in Akcelik delay equation.

3. Data Collection

The data were collected from isolated and signalized intersections in Denizli city, Turkey. The data which are directly obtained by the observations include the average entering time to intersection, average discharging headway, cyclic queuing length, red signal time and vehicle delay time. The data were collected by cyclic basis and more than three hours for each intersection. Morning and evening peak hours and off-peak hours (afternoon) are selected as observation periods. All of those data were obtained simultaneously by a table that is designed for this aim. The data were collected by aid of two observers for each lane of the approach legs at selected signalized intersections. While one of the observers was observing vehicles coming to intersection approach leg, the other recorded the time measurements by using the chronometer. Illustration of observers' location at an intersection is depicted in Figure 1.

4. Regression Analysis and the MuLReD Model

Multiple linear regression analysis approach was taken into consideration in modeling. Vehicle delays at signalized intersections were estimated considering signal timing and traffic flow parameters by multiple linear regression analysis. Multiple Linear Regression Analysis based Delay Estimation (MuLReD) model was developed in this study.

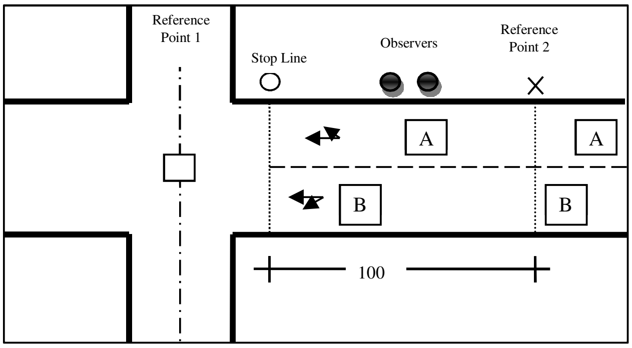

Fig. 1. Location of observers at an intersection

4.1 Average Entering Time to Intersection (AET)

Average entering time to intersection, number of vehicle in queue, average discharging headway and red signal time were regarded as effective parameters in the MuLRed model.

Average entering times of vehicles have an importance on vehicle delay. This variable makes some contributions on randomness of the process. It can be affected by traffic conditions, locations and signal timings of neighbor intersections.

4.2 Red Signal Time (RT)

The red signal time can be described as uniform component of the delay. Assigning red signal times inappropriately or unnecessarily can increase the delay (Washburn and Larson, 2002, Mazloumi, 2008, Ban et al, 2009). Thus, the red signal time was considered as an effective variable in the regression model.

4.3. Number of Vehicles in Queue (NVQ)

The number of vehicles in queue depends on entering and discharging time of vehicle and red signal time. However, the queue formation is affected by locations and signal timing of neighbor intersections. If the vehicle queue is long with respect to green signal time, vehicle discharging from the queue is very difficult and this condition causes to increase the average vehicle delay (Murat, 2006; Su et al., 2009). Therefore, vehicle queuing is considered more effectively in designing of the intersection signal timing.

4.4 Average Discharging Headway (ADH)

The queue can be dissipated depending on signal timing and driver behaviors. Discharging headway is another important variable on delays of vehicles. Average discharging headway is a term of the saturated flow (Cetin and Murat, 2013). It shows discharging regime of vehicles. This parameter which depends directly on driver behaviors includes randomness and is influential on delays of vehicles (Dion et. al, 2003, Mousa, 2002).

The MuLReD model was developed regarding to the parameters mentioned above. 180 data were used in developing stage and 100 data were used in testing the model. Sample data used in the model are given in Table 1.

Multiple Linear Regression analysis was applied to data and the following equation was obtained for vehicle delay calculation.

$$D = -0{,}260-0{,}919b+1{,}017c+1{,}113d+0{,}651e \quad (5)$$

where;
D: Average delay of vehicles (sec/veh)
b: Average entering time to intersection (AET) (sec.)
c: Red time (RT) (sec.)
d:Number of vehicle in queue (NVQ) (veh.)
e: Average discharging headway (ADH) (sec.)

Table 1. Sample data used in the MuLReD model

Average Entering Time to Intersection (sec.)	Red Time (sec.)	Number of Vehicle in Queue (veh.)	Average Discharhing Headway (sec.)	Average Delay (sec./veh.)
40,70	65	10	2,89	40,50
33,50	65	8	2,29	46,38
50,50	65	12	3,00	36,83
55,17	65	12	2,91	32,67
60,25	65	12	3,09	27,67
43,21	65	14	2,54	41,29
50,57	65	14	2,69	37,50
43,69	65	13	3,08	42,31
39,67	65	9	2,25	37,89
48,67	65	9	3,38	32,33
52,22	65	9	3,00	30,11
42,25	65	8	3,14	39,13
46,77	65	9	2,50	33,33
47,94	65	16	2,53	39,50
45,27	65	15	2,71	43,07
34,17	65	6	2,00	44,17
32,83	65	6	2,20	44,33

Descriptive statistics, correlations, model summary, analysis of variance (ANOVA), coefficients and collinearity diagnostics are given in Table 2, Table 3, Table 4, Table 5, Table 6 and Table 7 respectively.

Table 2. Descriptive statistics

	Mean	Std. Deviation	N
DELAY	42,6977	10,1047	180
AET	42,8293	9,7144	180
RT	70,9611	8,4028	180
NVQ	7,6333	3,0543	180
ADH	2,5009	,6504	180

The correlation coefficients between dependent variable and independent variables are seen in Table 3. It is required that the correlation coefficients between the independent variables must be less than 0,5 to avoid the internal dependence in the model. In the analysis, it is obtained that, the correlation coefficients between the independent variables is less than 0,5 for the proposed model.

Table 3. Correlations

		DELAY	AET	RT	NVQ	ADH
Pearson Correlation	DELAY	1,000	-,586	,436	,245	-,349
	AET	-,586	1,000	,379	-,100	,253
	RT	,436	,379	1,000	-,206	-,150
	NVQ	,245	-,100	-,206	1,000	-,119
	ADH	-,349	,253	-,150	-,119	1,000
Sig. (1-tailed)	DELAY	,	,000	,000	,000	,000
	AET	,000	,	,000	,092	,000
	RT	,000	,000	,	,003	,022
	NVQ	,000	,092	,003	,	,055
	ADH	,000	,000	,022	,055	,
N	DELAY	180	180	180	180	180
	AET	180	180	180	180	180
	RT	180	180	180	180	180
	NVQ	180	180	180	180	180
	ADH	180	180	180	180	180

Table 4. Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin - Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	,977[a]	,955	,954	2,1783	,955	919,186	4	175	,000	1,295

a. Predictors: (Constant), ADH, NVQ, AET, RT
b. Dependent Variable: DELAY

In the model, coefficient of multiple determination (R^2) is calculated as 0,955 and adjusted coefficient of multiple determination is 0,954 in Table 4. These values show that the variance of dependent variable can be explained by independent variables in high level.

Table 5. Analysis of variance (ANOVA)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	17446,229	4	4361,557	919,186	,000[a]
	Residual	830,379	175	4,745		
	Total	18276,608	179			

a. Predictors: (Constant), ADH, NVQ, AET, RT
b. Dependent Variable: DELAY

F indicator (919,186) in ANOVA table shows that the model is meaningful completely at all levels (Sig.=0,000). The coefficients of regression and t statistics relating to these coefficients are seen in Table 6. t statistics values show that all variables in the model are separately meaningful. Additionally, tolerance and VIF values near to 1,0 show that there is no multicollinearity between independent variables.

Table 6. Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	Constant	-,260	1,832		-,142	,887	-3,875	3,355					
	AET	-,919	,019	-,884	-47,738	,000	-,957	-,881	-,586	-,964	-,769	,758	1,320
	RT	1,017	,022	,846	45,589	,000	,973	1,061	,436	,960	,735	,754	1,327
	NVQ	1,113	,055	,337	20,178	,000	1,004	1,222	,245	,836	,325	,933	1,071
	ADH	,651	,272	,042	2,388	,018	,113	1,188	-,349	,178	,038	,844	1,185

a. Dependent Variable: DELAY

Table 7. Collinearity diagnostics

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions				
				(Constant)	AET	RT	NVQ	ADH
1	1	4,785	1,000	,00	,00	,00	,01	,00
	2	,134	5,966	,00	,02	,00	,75	,04
	3	4,960E-02	9,822	,00	,09	,04	,03	,72
	4	2,666E-02	13,398	,06	,82	,07	,07	,00
	5	4,714E-03	31,858	,94	,07	,89	,15	,23

a. Dependent Variable: DELAY

In Table 7, Condition Index values less than 100 also show that there is no multicollinearity between independent variables.

In the following histogram, mean and standard deviation of standardized residual are zero and 0,99 respectively (Fig 2). It can be said that residuals are normally distributed. Normal P-P graph of standardized residuals can be seen in Fig 3. In this graph, clustering of the points on or around the line also shows that residuals are normally distributed.

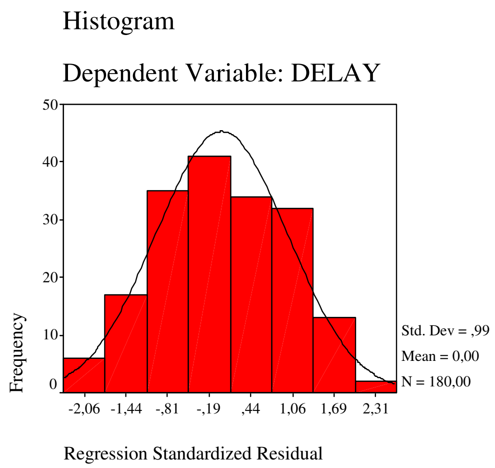

Fig. 2. Illustration of Mean and Standart Deviation of Standardized Residuals

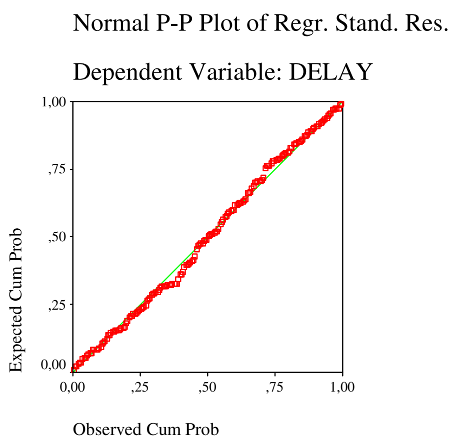

Fig. 3. Illustration of Normal P-P Graph of Standardized Residuals

The scatterplot of dependent variable (delay) versus standardized residual is shown in Fig 4. Distributing the residuals randomly around the zero shows that the normality assumption is verified.

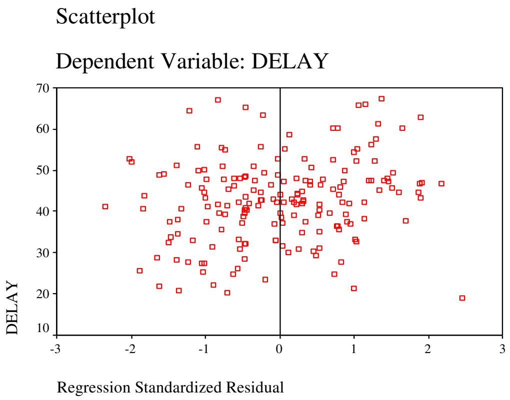

Fig.4. Illustration of Scatterplot of Delay versus Standardized Residual

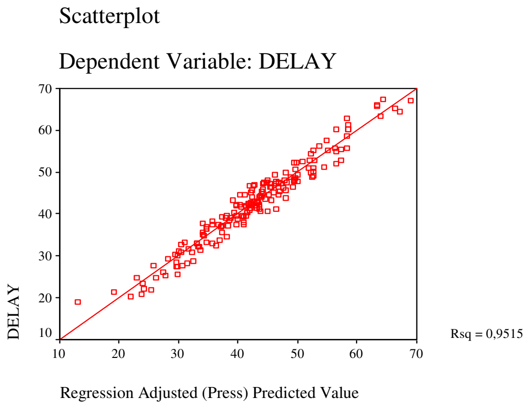

Fig.5. Illustration of Scatterplot of Predicted Delay Values versus Observation Delay Values

The scatterplot of actual delay values used in the model versus delay values predicted by regression model is shown in Fig 5. In this figure, clustering of the points on or around the line indicates the power of the model. R^2 value is about 0,95 in Fig 5.

5. Validation Research of the MuLReD Model (Comparisons)

Validation research of the MuLReD model is made by comparing results of the model to the observations by field studies and calculations by Akcelik Delay formula.

The validity of the model was investigated over a hundred data which were devoted for the test. The delay values calculated with Akcelik equations, MuLRed Model results and observation values were compared with each other in the study. Comparisons of the results is shown in Fig 6.

As a result of the comparisons, Mean Square Error (MSE) values for Akcelik Equation and MuLReD Model were determined as about 112 and 7 respectively. Sample error calculations and MSE values are given in Table 8. Based on these calculations and comparisons, it was understood that MuLReD Model results were compatible with observation values. In addition, it was concluded that MuLReD Model results were also compatible with the results of Akcelik Equation which was approved by the transportation researchers.

It can be said that the MuLReD Model is an effective model on delay estimation. Besides, according to results obtained from the comparisons, the MuLReD Model can be defined as a reliable model.

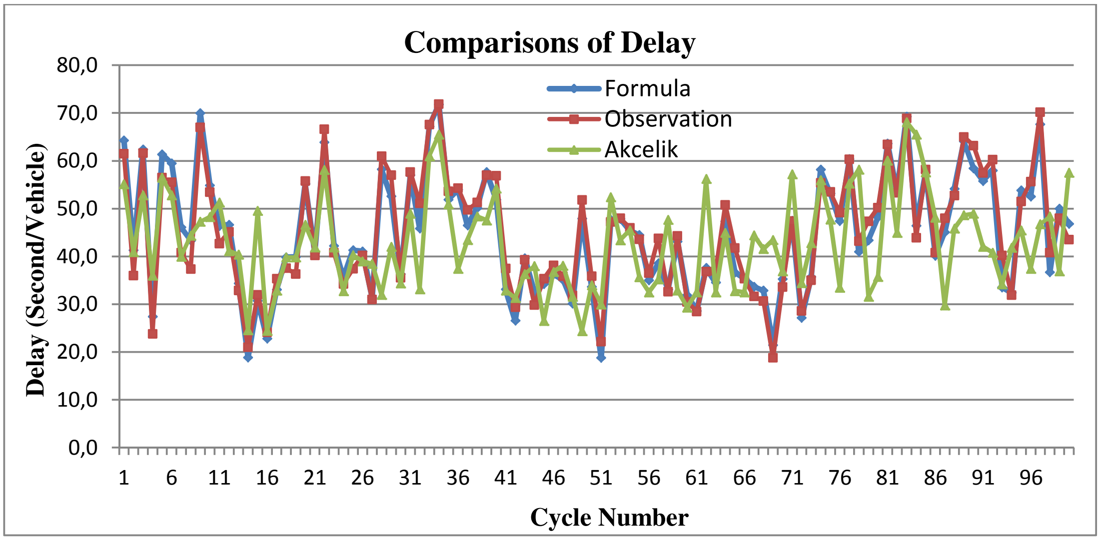

Fig. 6. Comparisons of Delay Values

Table 8. Sample MSE calculations

Data No	MuLReD (A)	Observation (B)	Akcelik (C)	Sq. Error (A-B)^2	Sq. Error (C-B)^2
7	46,09	40,80	39,96	27,98	0,71
8	43,36	37,38	44,36	35,76	48,72
9	70,02	67,00	47,26	9,12	389,67
10	54,89	53,44	48,28	2,10	26,63
11	46,40	42,71	51,30	13,62	73,79
12	46,67	45,13	41,13	2,37	16,00
--	--	--	--	--	--
--	--	--	--	--	--
29	52,59	57,00	42,04	19,45	223,80
30	36,35	35,57	34,37	0,61	1,44
--	--	--	--	--	--
--	--	--	--	--	--
95	53,87	51,50	45,48	5,62	36,24
96	52,51	55,67	37,44	9,99	332,33
97	67,68	70,20	46,74	6,35	550,37
98	36,71	40,80	48,37	16,73	57,31
99	49,98	48,00	36,89	3,92	123,43
100	46,83	43,50	57,52	11,09	196,56
			MSE	**6,95**	**111,54**

6. Conclusions

In scope of this study, the relationship between delay and vehicle queuing, signal timing was investigated. Multiple Linear Regression Analysis based Delay Estimation (MuLReD) model was developed. Descriptive statistics, correlations, model summary, analysis of variance (ANOVA), coefficients and collinearity diagnostics are applied to the model. Based on results of these tests and measurements, significance of the model is proved. It is also concluded that, AET, RT, NVQ are the most effective parameters on vehicle delays respectively regarding to t statistics.

Validity of the MuLReD model was investigated over a hundred data which were devoted for the test. The delay values calculated with Akcelik equations, MuLReD Model results and observation values were compared with each other in the testing stage. Mean Square Error (MSE) value of the MuLReD model is determined as 7.

It was concluded that delay value could be predicted by the MuLReD model. The MuLReD model can be used as a reliable estimation model for vehicle delays at isolated signalized intersections. Cyclic based data can be used practically for this purpose. On the other hand, the model can be used instead of existing delay formulas.

Further research can be made considering effects of other signal timing parameters on delays of vehicles and concrete values could be determined. In this research, average entering time to intersection was determined as the most effective parameters on delay, therefore remarkable improvement can be provided with addition of the average entering time parameter to existing delay formulas.

References

Webster, F. V. (1958). *Traffic Signal Settings*, Road Research Technical Paper, No 39, Road Research Laboratory, Her Majesty Stationary Office, London, UK.

TRB. (1985). *Special Report 209: Highway Capacity Manual*, Trasportation Research Board, National Research Council, Washington D.C., USA.

Akcelik R. (1981). *Traffic Signals: Capacity and Timing Analysis Research Report 123*. Australian Road Research Board, Melbourne, Australia.

Akcelik R. (1988). The Highway Capacity Manual Delay Formula for Signalized Intersections, *ITE Journal*, pp 23-27.

Washburn, S. S., Larson, N., (2002) Signalized Intersection Delay Estimation: Case Study Comparison of TRANSYT-7F, Synchro and HCS, *ITE Journal*, pp 30-35.

Murat Y.S. (2006). Comparison of Fuzzy Logic and Artificial Neural Networks Approaches in Vehicle Delay Modeling. *Transportation Research Part C-Emerging Technologies*, Vol 14/1 pp 316-334.

Su, Y., Wei, Z., Cheng, S., Yao, D., Zhang, Y., Lı, L. (2009). Delay Estimates of Mixed Traffic Flow at Signalized Intersections in China, *Tsınghua Science and Technology,* Vol 14/2 pp 157-160.

Cetin, M., & Murat, Y.S. (2013) A New Method for Determining Saturation Flow Depending on Driver Behaviour*, Chamber of Civil Engineers Technical Journal*, pp 6399-6414.

Dion, F., Rakha, H., & Kang, Y. S. (2004). Comparison of Delay Estimates at Under-Saturated and Over Saturated Pre-Timed Signalized Intersections, *Transportation Research Part B-Methodological,* Vol 38/2 pp 99-122.

Mousa, R. (2002). Analysis and Modeling of Measured Delays at Isolated Signalized Intersections, *J. Transp. Eng.,* 128(4), pp 347-354.

Mazloumi, E. (2008). A New Delay Function for Signalized Intersections, *Road and Transport Research,* Vol 17/3 pp 3-12

Ban, X., Herring, R., Hao, P., & Bayen A. M. (2009). Delay Pattern Estimation for Signalized Intersections Using Sampled Travel Times, *Transportation Research Board of the National Academies,* Vol 2130/2009 pp 109-119.