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Optimum Cycle Time Prediction for Signalized Intersections at Baghdad City

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Özet. Bu araştırma, sinyalize kavşaklarda araç davranışı ve gecikmesi üzerine bir çalışmayı anlatmaktadır. Amaç, gözlenen trafik hareketlerinden geliştirilen simülasyon modeline dayalı bir regresyon modeli geliştirmektir. Geliştirilen simülasyon modelinin çok çeşitli uygulamaları vardır. Bunları, bu araştırma kapsamında örneklemek için, sinyalize kavşaklarda araç gecikmesini en aza indiren optimum döngü zamanı tahmini için regresyon modeli geliştirilmiştir. Geliştirilen regresyon modeli dolaylı olarak, halen Bağdat'ta kullanılan sürüş pratiği örneklemlerine dayanmaktadır.
Araç gecikmesi için geliştirilen modelin çıktılarını doğrulamak ve ayarlamak için OSCADY/3 yazılım paketi kullanılmıştır. Gözlenen sonuçlar bu makalede sunulmaktadır. Kıyaslama, üretilen ve tahmin edilen sonuçların uyumlu olduğunu göstermektedir. Son olarak, tahmin edilen model, varolan bir kavşaktaki trafik performansını, buradan gözlenen verilerin simüle edilmesiyle, değerlendirmek için kullanılmaktadır. Gözlenen sonuçlara dayanarak, bu özel işlevdeki araç gecikmesini azaltacak önerilerde bulunulmaktadır.[1]

Anahtar Kelimeler. Trafik davranışı, optimum döngü zamanı, simülasyon modeli, gecikme.

Abstract. This research describes a study of vehicle behavior and delay at signalized intersections. The objective was to develop a regression model based on simulation model developed from observed traffic behavior. The developed simulation model has reasonably wide range of applications. To illustrate that within the scope of this research a regression model for the prediction of optimum cycle times, which minimizes vehicle delay at signalized intersection, was developed. The developed regression model is implicitly based on the sampled driving practice currently used in Baghdad.

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Bu makale, 26-27 Nisan 2012 tarihlerinde Çankaya Üniversitesi'nin Ankara Merkez yerleşkesinde yapılmış olan *5. Çankaya Üniversitesi Mühendislik ve Teknoloji Sempozyumu*'nda sunulan ve sadece geniş bildiri özeti bölümü hakem sürecinden geçerek bu sempozyum kitapçığında yayımlanan bir makalenin revize edilmiş şekli olup Sempozyum Değerlendirme Komitesi tarafından yayımlanmak üzere *Çankaya University Journal of Science and Engineering* dergisine gönderilmesi önerilmiş ve derginin bağımsız hakem değerlendirmeleri sonucunda yayıma kabul edilmiştir.

[1]Türkçe özet ve anahtar kelimeler, orijinal İngilizce metindeki ilgili kısmın doğrudan tercümesi olup *Çankaya University Journal of Science and Engineering* editörlüğü tarafından yazılmıştır. | Turkish abstract and the keywords are written by the editorial staff of *Çankaya University Journal of Science and Engineering* which are the direct translations of the related original English text.

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The OSCADY/3 software package was used to verify and calibrate the developed model outputs of vehicle delay. The obtained results are presented in this paper. The comparison suggested the existence of harmony between the produced and predicted results. Finally the predicted model is used to evaluate the traffic performance at an existing intersection by simulating its observed data. Based on the obtained results, suggestions were made to reduce vehicle delay at this particular function.

Keywords. Traffic behavior, optimum cycle time, simulation model, delay.

1. Introduction

Delay that individual vehicles may experience at a signalized intersection is usually subject to large variation because of the randomness of traffic arrivals and interruption caused by traffic signal controls. On the other hand such variation may have important implications for the planning, design, and analysis of signal controls [1]. Predicting the optimum cycle time will minimize delay and will result in an efficient performance of the signalized intersections.

The main objective of this paper is to develop a general regression model for the prediction of optimum cycle time at signalized intersections depending on the application of a simulation model developed for vehicle behavior at signalized intersection.

The information presented here is divided into two parts. In the first part, the simulation model is applied to typical situations by assuming typical four-arm signalized intersections with different geometries, flow, and cycle times. The main objective of this part was to develop a general regression model for the prediction of optimum cycle time at signalized intersections. The optimum cycle time calculated by the predicted model is then compared with that calculated by OSCADY/3 program. In the second part a congested signalized intersection in an urban area at Baghdad City was selected as a case study. Alternatives for improving its performance were suggested based on the developed simulation model results.

2. Development of the Optimum Cycle Time Regression Equation

This section describes the steps, assumptions, and procedure that is followed for the application of the developed simulation model to the calculation of the cycle time. This cycle time minimizes vehicle delay at signalized intersections. To achieve this purpose, three typical intersections with different geometries were assumed and examined by simulation of vehicle delay for a range of signal timing under various flow conditions. Vehicle behavior and movement were simulated on the basis of the following assumptions:

1. Vehicles arrive at the intersection approaches at random with negative exponential distribution of vehicle inter-arrival times.
2. A range of mean lost time for each signal phasing of (1, 1.5, 2, 2.5 seconds) was assumed for each flow variation.
3. Saturation flow was calculated for each approach by the simulation model on the basis of the predictive equations developed by Kimber, McDonald, and Hounsell for road intersections controlled by signals [2].
4. Vehicle movement types are straight through only.

The assumed simulated intersections are described below.

2.1. 4-Arm signalized intersection with one lane of traffic flow. The geometric layout and the stage diagram used in this simulation experiment are shown in Figure 1. The traffic composition was assumed to be 100% passenger cars.

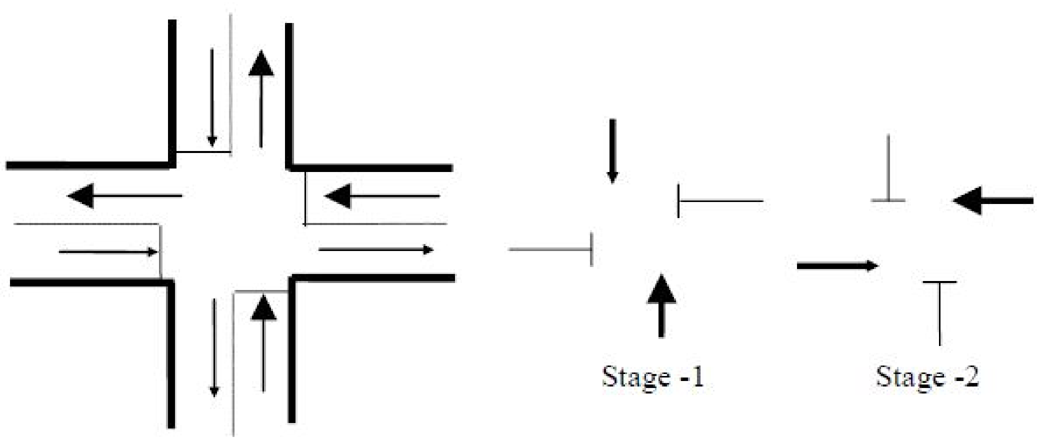


FIGURE 1. Geometric layout and stage diagram of the 4-arm simulated intersection.

The simulation experiment was made by starting with an input vehicle flow of 100 pcu per approach. The minimum possible lost time was input, together with other necessary input parameters. A minimum cycle time of 22 seconds composed of 7 seconds green, 3 seconds yellow and one second all red was selected. This selection is based on safety requirements for minimum green and yellow [3].

The vehicle delay which corresponds to 22 second cycle time was simulated. The simulation time was 5 hours. The saturation flow which corresponds to this simulation condition was also obtained from the simulation model. The cycle time is increased in 5 seconds intervals and the calculations described as above are repeated. The objective is to obtain a database showing the listed below information for each value of vehicle flow.

1. Cycle time.
2. Vehicle delay.
3. Vehicle lost times.
4. Vehicle saturation flow.

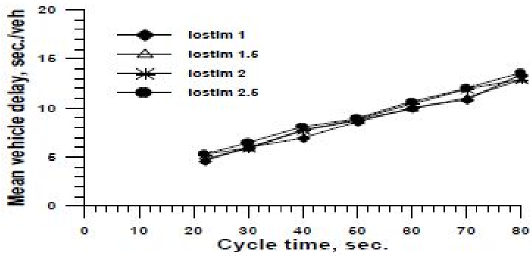
Typical results are presented in Table 1. The variable X computes from the degree of saturation (Y) which is computed for each approach as $X = (\text{total lost time})/(1-Y)$.

TABLE 1. 4-Arms simulated intersection with one-lane traffic flow.

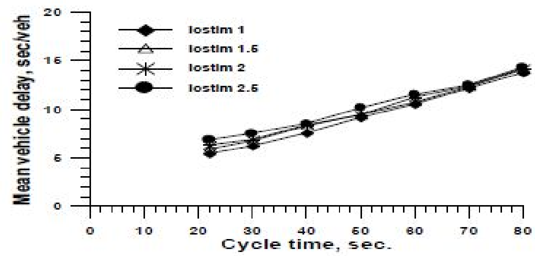
Flow	Lost time 1 sec.			Lost time 1.5 sec.			Lost time 2 sec.			Lost time 2.5 sec.		
Vph	Co	S.flow	X	Co	S.flow	X	Co	S.flow	X	Co	S.flow	X
100	22	1766	3.18	22	1528	4.52	22	1766	5.30	22	1766	6.36
200	22	1700	3.40	22	1680	4.54	24	1650	5.69	28	1645	6.83
300	22	1640	3.67	22	1648	4.89	32	1688	6.08	34	1623	7.36
400	30	1624	3.98	30	1640	5.29	35	1650	6.60	40	1650	7.92
500	40	1645	4.31	40	1650	5.74	45	1673	7.13	45	1662	8.58
600	45	1750	4.56	45	1680	6.22	50	1698	7.73	55	1645	12.6
700	50	1605	9.42	50	1565	10.5	50	1238	11.5	60	1566	12.3

Following that, the cycle time which resulted in the minimum vehicle delay was selected together with other necessary information for later regression analysis. The variation of cycle time with the increase in vehicle demand flow is presented graphically in Figure 2.

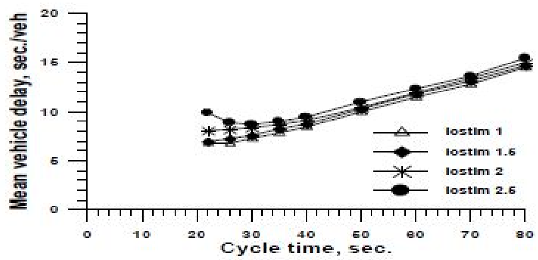
2.2. 4-Arm signalized intersection with two lanes of traffic flow. The purpose of this application is to examine the optimum cycle time by simulating a range of signal phasing with demand flow variations for a 4-arm intersection with two lanes for each approach.



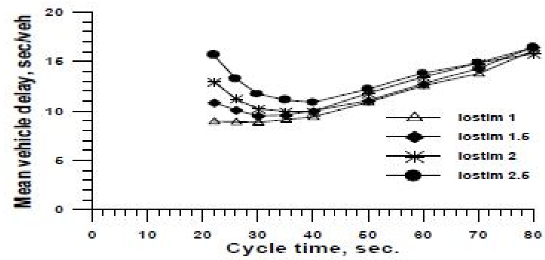
(a) flow 100 vph



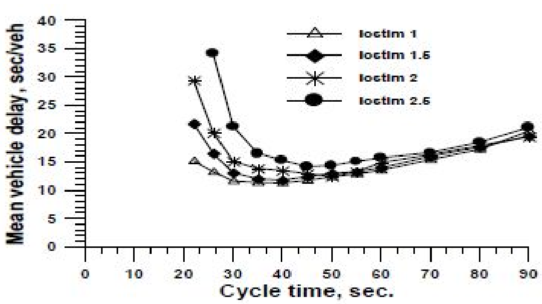
(b) flow 200 vph



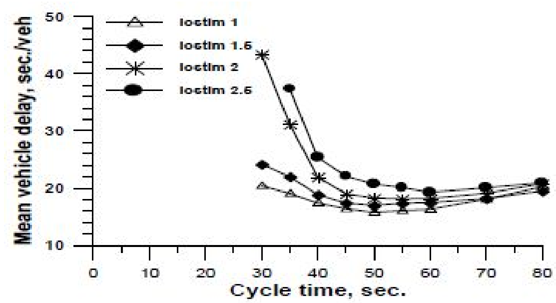
(c) flow 300 vph



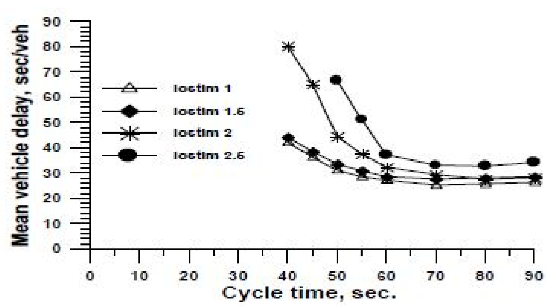
(d) flow 400 vph



(e) flow 500 vph



(f) flow 600 vph



(g) flow 700 vph

FIGURE 2. Model application at four arms signalized intersection with one lane approaches.

The traffic composition was assumed to be 96% passenger cars and 4% heavy vehicles. The geometric layout and signal-stage diagrams for the simulated intersection are shown in Figure 3. The variation of cycle time with the increase in vehicle demand flow is presented graphically in Figure 4. The method of analysis used is similar to that described for 4-arm signalized intersection with one lane of traffic flow. The typical results obtained are presented in Table 2.

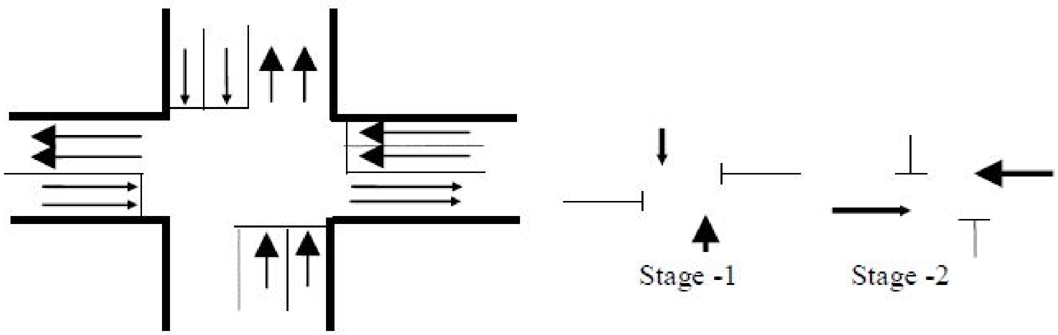
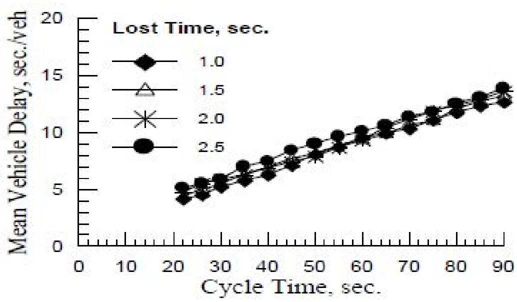


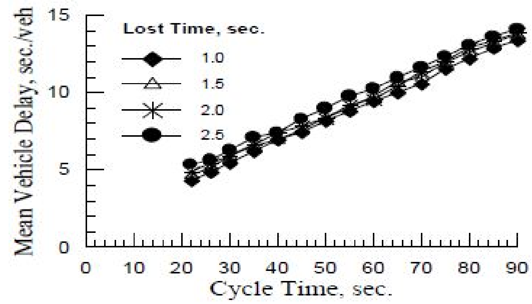
FIGURE 3. Layout and stage diagram of the 4-arm simulated intersection.

TABLE 2. 4-Arm simulated intersection, two lanes.

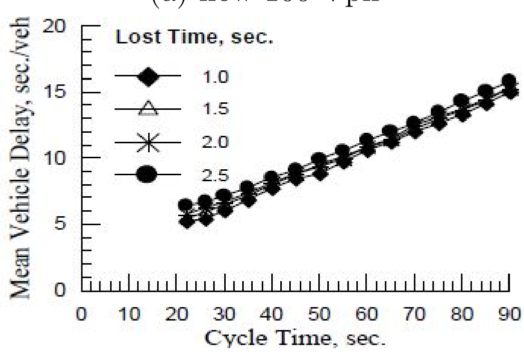
Flow	Lost time 1 sec.			Lost time 1.5 sec.			Lost time 2 sec.			Lost time 2.5 sec.		
Vph	Co	S.flow	X	Co	S.flow	X	Co	S.flow	X	Co	S.flow	X
100	22	2099	3.15	22	2004	4.21	22	2004	5.25	24	2099	6.18
200	22	1866	3.36	22	1866	4.48	24	1866	5.60	29	2046	6.65
300	22	1800	3.60	24	1800	4.80	28	1800	6.00	31	1775	7.22
400	30	1748	3.89	30	1733	5.20	32	1733	6.47	32	1733	7.8
500	30	1719	4.23	30	1734	5.62	32	1734	7.05	35	1729	8.44
600	28	1711	4.62	30	1711	6.16	38	1711	7.72	38	1711	9.24
700	30	1714	5.07	32	1700	6.80	38	1700	8.52	40	1724	10.1
800	26	1698	5.67	30	1703	7.54	38	1703	9.42	40	1705	11.3
900	32	1696	6.39	38	1696	8.52	42	1696	10.6	44	1705	12.7
1000	34	1699	7.29	42	1724	9.52	46	1724	11.9	44	1731	14.2
1100	37	1722	8.30	42	1719	11.1	52	1719	13.8	55	1728	16.5
1200	42	1738	9.69	45	1739	12.9	65	1739	16.0	65	1745	19.2
1300	45	1753	11.6	52	1756	15.4	75	1756	18.9	75	1840	20.4
1400	60	1730	15.7	68	1797	18.1	80	1797	22.4	80	1880	23.5



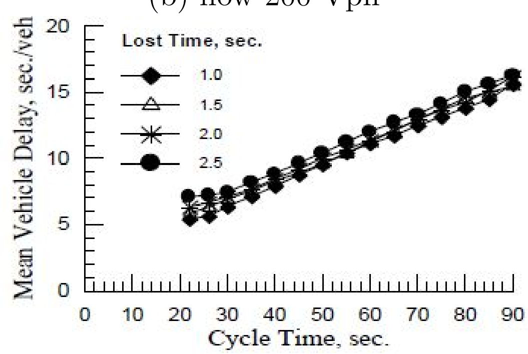
(a) flow 100 Vph



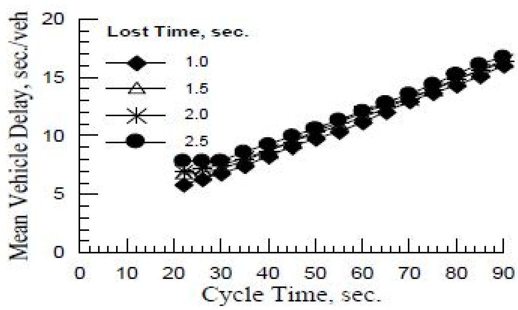
(b) flow 200 Vph



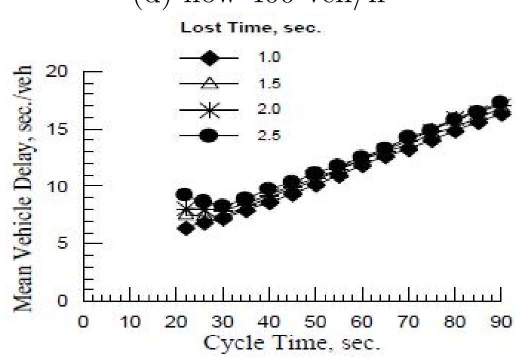
(c) flow 300 veh/h



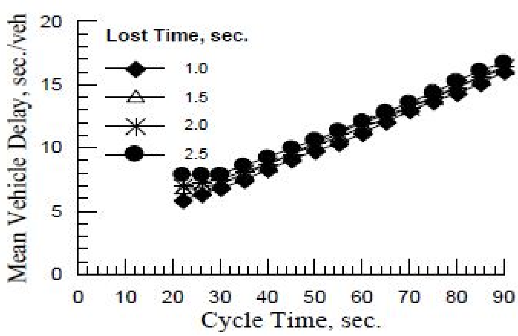
(d) flow 400 veh/h



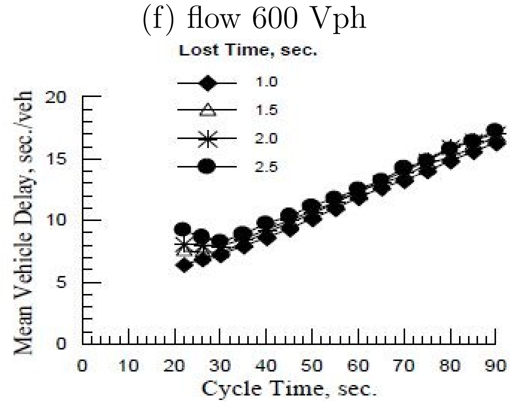
(e) flow 500 Vph



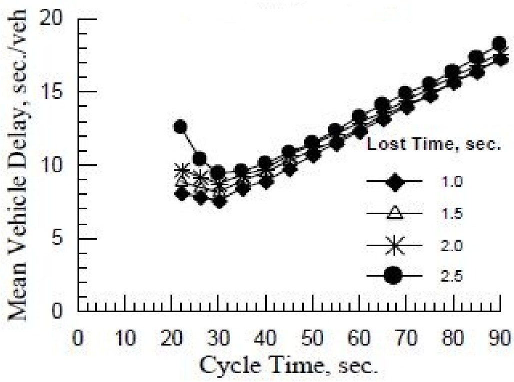
(f) flow 600 Vph



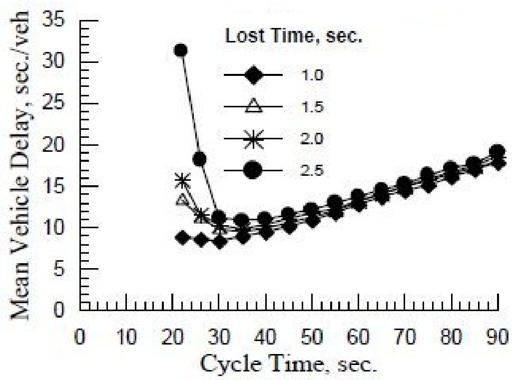
(g) flow 700 Vph



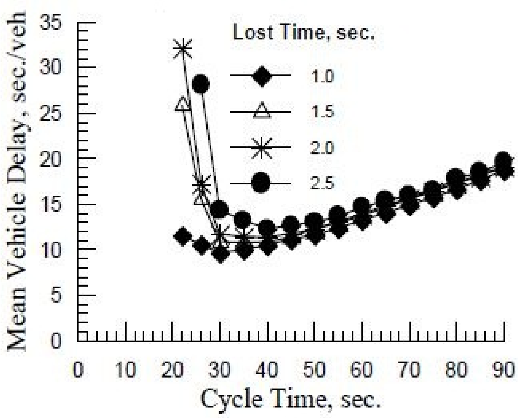
(h) flow 800 Vph



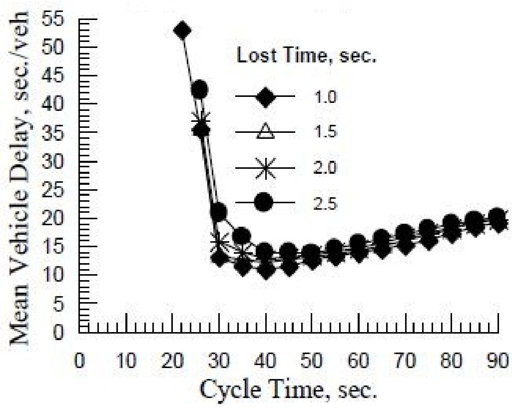
(i) flow 900 Vph



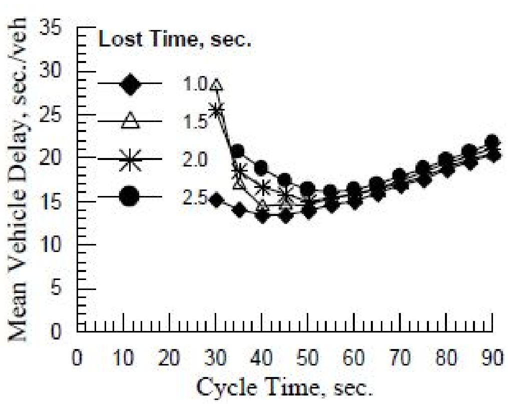
(j) flow 1000 Vph



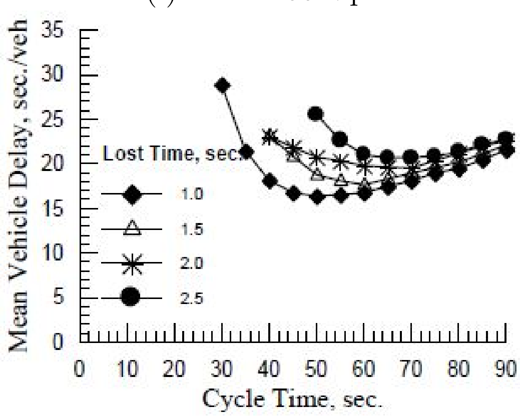
(k) flow 1100 Vph



(l) flow 1200 Vph



(m) flow 1300 Vph



(n) flow 1400 Vph

FIGURE 4. Model application at signalized intersection, two lane approaches.

2.3. 4-Arm signalized intersection with three lanes of traffic flow. The objective of this simulation experiments is the determination of optimum cycle times of a 4-arm signalized intersection with three lanes of traffic flow. The used geometric layout and stage diagram are presented in Figure 5. The traffic composition was assumed as 98% passenger cars and 2% heavy vehicles. The method of analysis used is similar to that described for the 4-arm signalized intersection with one lane of traffic flow. The typical results obtained are presented in Table 3. The variation of cycle time with the increase in vehicle demand flow is presented graphically in Figures 6.

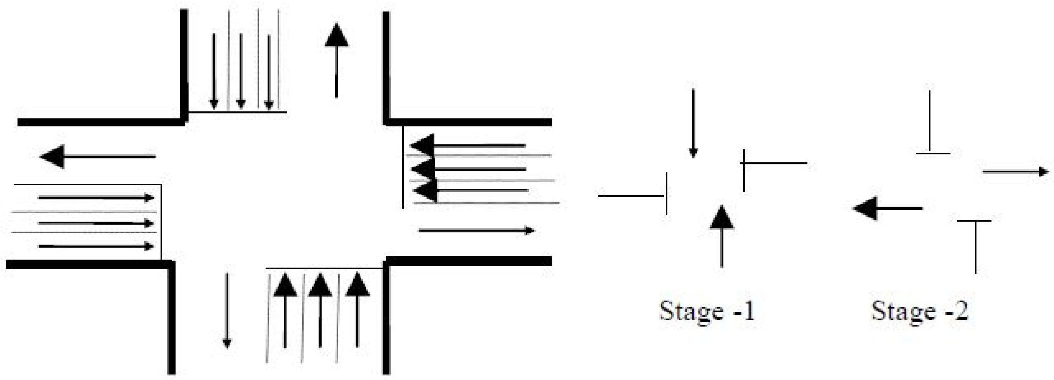
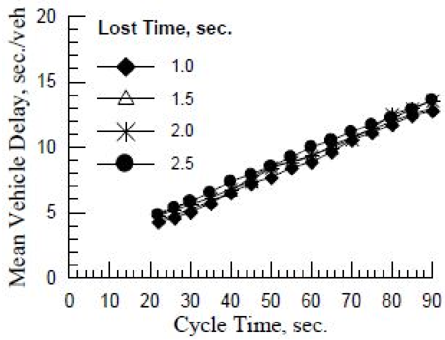


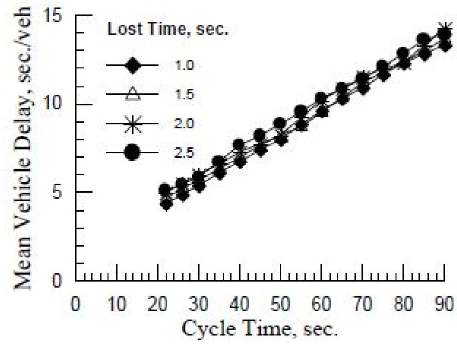
FIGURE 5. Geometric layout and stage diagram of the 4-arm simulated intersection.

TABLE 3. Data for 4-arm simulated intersection with three lanes.

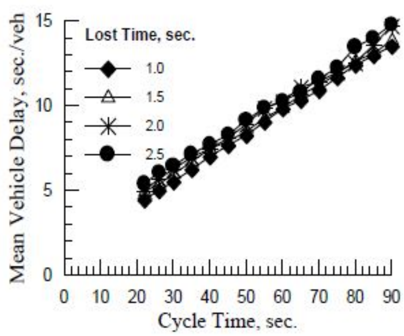
Flow	Lost time 1 sec.			Lost time 1.5 sec.			Lost time 2 sec.			Lost time 2.5 sec.		
Vph	Co	S.flow	X	Co	S.flow	X	Co	S.flow	X	Co	S.flow	X
100	22	2099	3.15	22	2004	4.21	22	2100	5.25	22	2035	6.31
200	22	1866	3.36	22	1866	4.48	24	1866	5.6	26	1866	6.72
300	22	1878	3.57	22	1858	4.77	25	1846	5.97	28	1865	7.15
400	24	1828	3.84	25	1828	5.12	28	1828	6.40	30	1828	7.68
500	24	1815	4.14	26	1815	5.52	32	1815	6.90	33	1815	8.28
600	26	1800	4.50	28	1812	5.98	30	1814	7.47	33	1812	8.97
700	27	1793	4.92	30	1793	6.56	35	1786	8.22	35	1774	9.91
800	28	1775	5.46	30	1775	7.28	35	1763	9.15	42	1779	10.9
900	30	1765	6.12	35	1765	8.16	42	1765	10.2	45	1770	12.2
1000	35	1763	6.93	42	1761	9.25	45	1757	11.6	48	1759	13.9
1100	42	1758	8.01	42	1766	10.6	46	1762	13.3	57	1760	16.0
1200	45	1779	9.21	48	1785	12.2	56	1782	15.3	66	1780	18.4
1300	45	1781	11.1	50	1781	14.8	62	1774	18.7	76	1803	21.5
1400	58	1820	13.0	64	1711	17.6	76	1806	22.2	80	1880	23.5



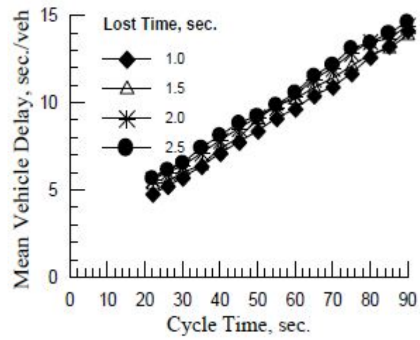
(a) flow 100 Vph



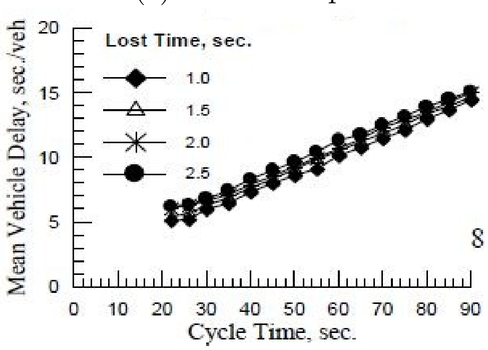
(b) flow 200 Vph



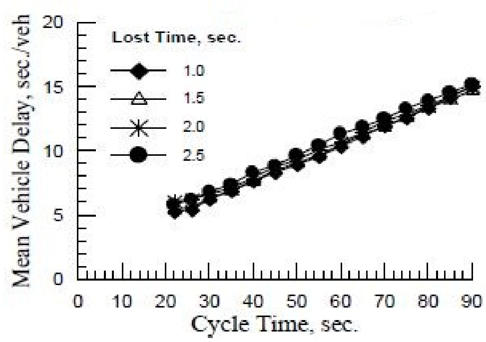
(c) flow 300 Vph



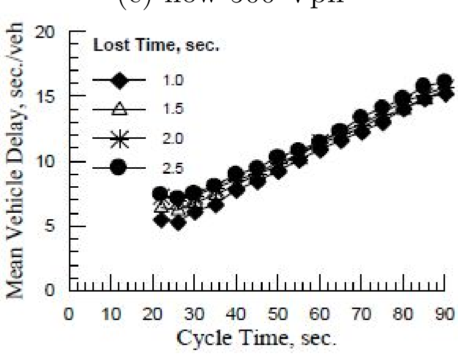
(d) flow 400 Vph



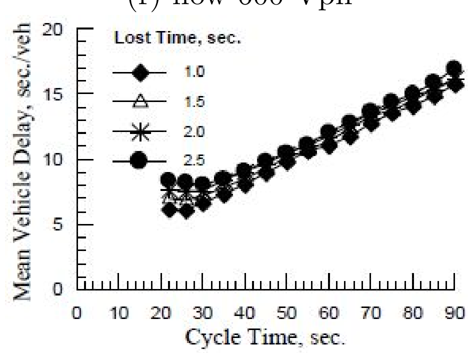
(e) flow 500 Vph



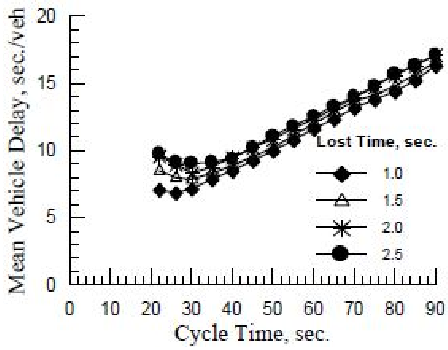
(f) flow 600 Vph



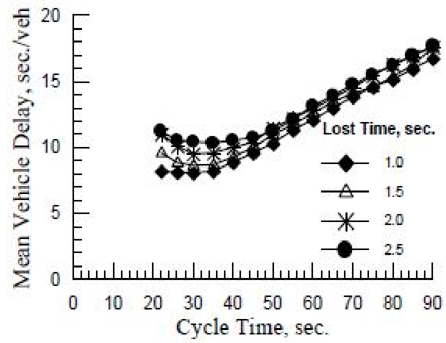
(g) flow 700 Vph



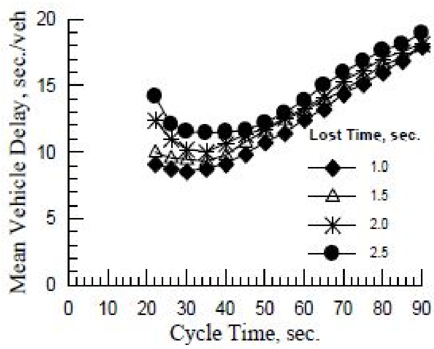
(h) flow 800 Vph



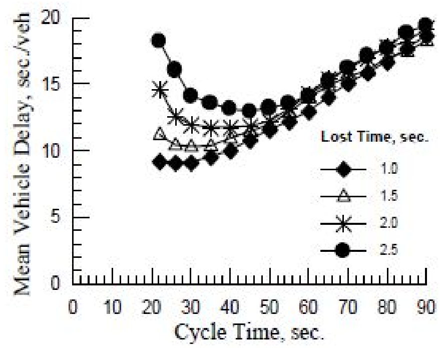
(i) flow 900 Vph



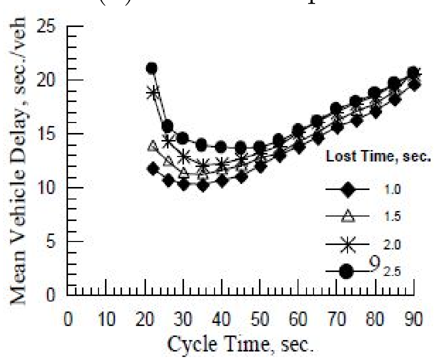
(j) flow 1000 Vph



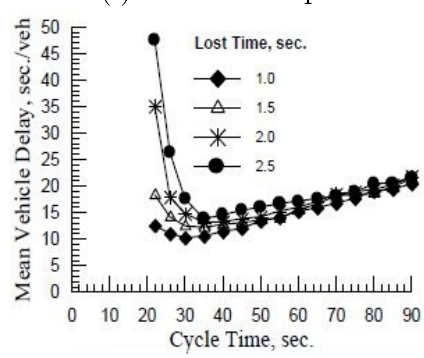
(k) flow 1100 Vph



(l) flow 1200 Vph



(m) flow 1300 Vph



(n) flow 1400 Vph

Figure 6. Model application at four arms intersection, three lane approaches.

3. Determination of Optimum Cycle Time

The data obtained from the simulation experiments made in the previous section are analyzed statistically using linear regression technique. The objective was development of a statistical model for the prediction of cycle times which minimizes vehicle delay.

The general from of the adopted model for linear regression analysis was as below

$$\text{Cycle time} = aX + b$$

where

$$a = \text{coefficient of } X$$
$$b = \text{constant, and}$$
$$X = \text{the independent variable.}$$

Furthermore, the independent variable was assumed to be a function of the total lost time per cycle and the average degree of saturation of the intersection. Speaking mathematically, the general form of the X-equation is as below

$$X = \frac{L}{1 - Y}$$

where L is the total lost time per cycle in seconds ($L = nl + R$) and Y is the average degree of saturation of an intersection ($Y = q/s$). Here, n is the number of phases, l is the average lost time per phase (excluding any all-red periods), R is the time during each cycle when all signals display red, q is the vehicle demand flow for an approach Vph, s is the saturation flow for an approach.

Following this mathematical transformation the linear regression technique was applied and the resulting equation is as described below

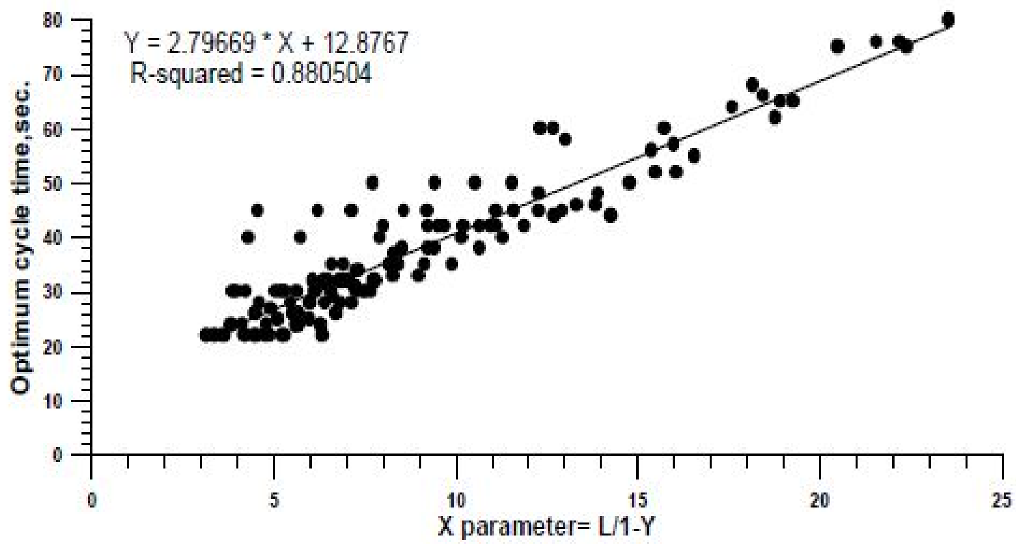
$$C_{\text{o}} = 2.97\,X + 12.87,$$

thus

$$C_{\text{o}} = \frac{2.79L}{1 - Y} + 12.87$$

is the developed regression model. Here C_o is the optimum cycle time.

The determination coefficient (R^2) for this model is 0.88. This value suggests that the obtained regression model explain about 88% of the observed scatter in the simulated data. The remaining 12% unexplained scatter was attributed to the random nature of other variables, for example vehicle arrival flow distribution. On the basis of the above analysis result, it may be reasonable to use the developed linear regression model for the prediction of optimum cycle time. Figure 7 shows the scatter plot and the developed regression model for the relationship between the optimum cycle time and the X parameter.



Model Summary,

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	0.938	0.88	.880	1.6743

FIGURE 7. Relationship between the optimum cycle time and X parameter value.

The OSCADY/3 program was adopted to calibrate the regression model outputs. To achieve this purpose, cross signalized intersection was selected. The geometric layout and signal stage diagram is represented in Figure 8. The following assumptions were considered for this test:

- vehicle movement type is straight through only,
- flow varied from 100 to 1400 Vph,
- saturation flow was 1940 Vph according to Kimber, Macdonald and Hounsell equation for prediction the saturation flow,
- lost time for each phase is 1.5 seconds,
- traffic composition is 98% passenger cars, and 2% are heavy vehicles.

The regression model was used to calculate the optimum cycle time which corresponds to each level of vehicle flow. The same intersection parameters were used as an input data for OSCADY/3 program [4]. The produced optimum cycle time

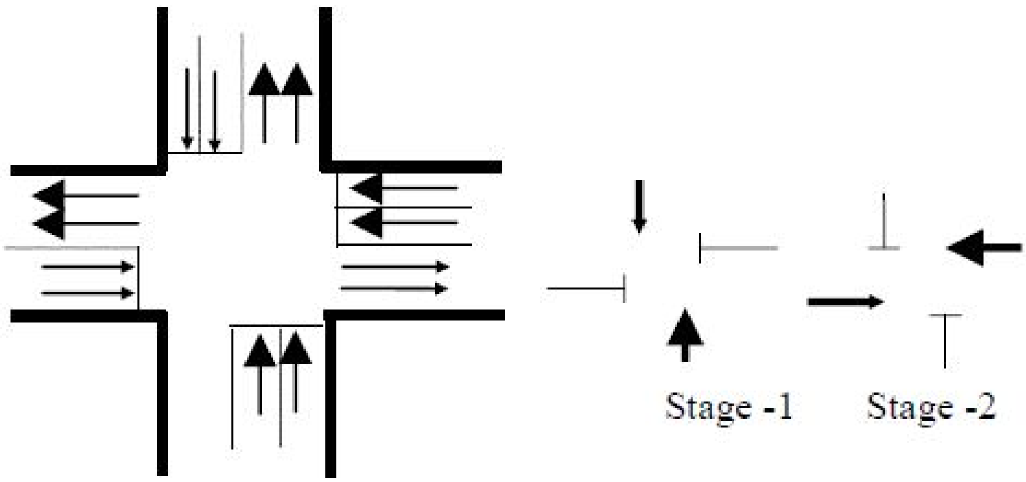


FIGURE 8. Geometric layout and stage diagram of 4-arm intersection used for model calibration.

values were then compared with that predicted by the regression model. Comparison of results is presented in Figure 9. The produced optimum cycle time for the regression model and that predicted by OSCADY/3 was plotted against the flow variation as shown in Figure 10.

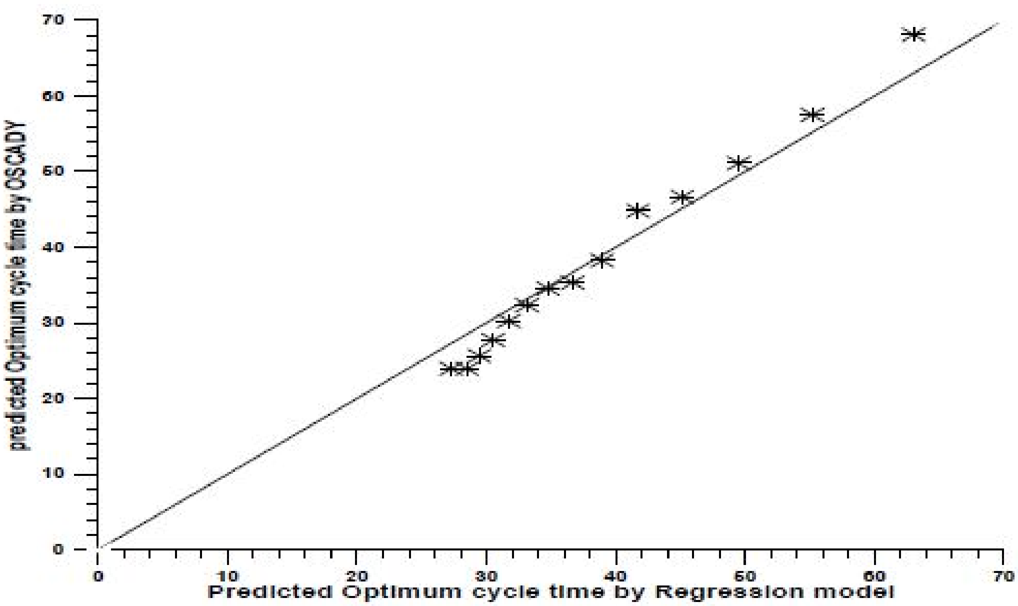


FIGURE 9. Comparison of regression model and OSCADY/3 outputs.

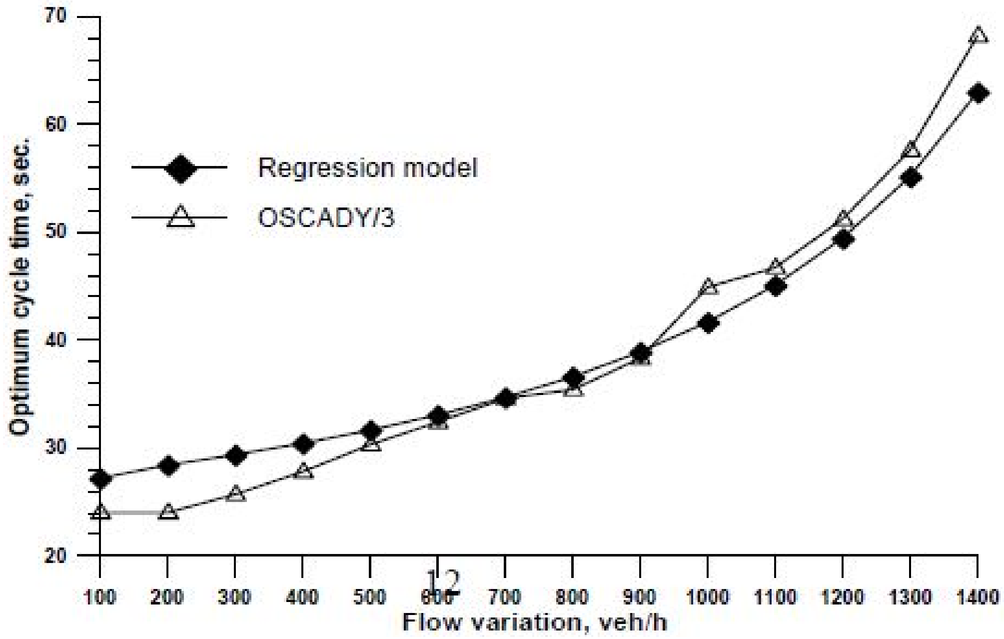


Figure 10. Effect of vehicle flow variation on optimum cycle time.

Figures 9 and 10 indicate reasonable agreement between the results produced by the OSCADY/3 program and with that predicted by the regression model under such working conditions.

4. Case Study

The objective of this part of simulation model application was to show the model capability to improve an existing signal controlled junction performance. The selected intersection is located in Ellwia District at Baghdad City. The cycle time of this intersection is long, in addition to that the distribution of effective green on approaches is not consistent with the degree of saturation for the approaches. This results in excessive vehicle delay at some approaches. The intersection geometric layout and existing signal stage timing diagram are presented in Figure 11.

Data of the intersection in its present state was collected using video camera technique, during the evening period from 6:30 to 7:30 pm. This period is one of the peak hours of the intersection. The EVENT computer program was used to abstract the data, while data processing was made with the aid of other computer programs developed for this purpose. To evaluate the present intersection performance, it was

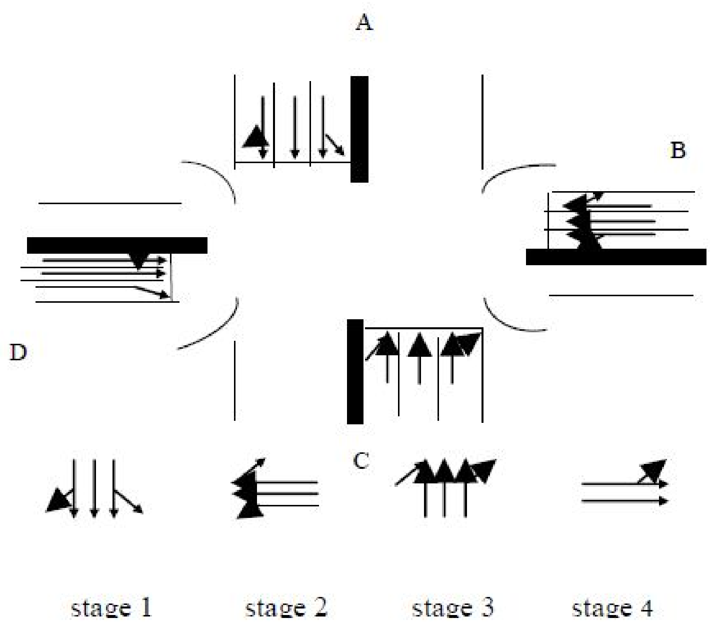


Figure 11. Geometric layout and stage diagram of the case study intersection.

essential to calculate its average delay. The observed delay for each approach and other essential information were found as presented in Table 4.

Table 4. Observed data for the case study intersection.

Approach	S. bound	W. bound	N. bound	E. bound
Effective green, sec.	25	26	24	13
Flow, Vph	650	800	840	400
Observed delay, s	35.6	36.8	53.11	48.76
Whole intersection average delay = 43.56 sec./veh. Existing cycle time = 112 sec.				

5. Assumptions for Solution and Alternative Using Model Application

Any traffic system has three components, the geometry, stage diagram, and the vehicle behavior. The changes or improvements for an intersection should be made on one or more of the above components. The prospect for geometric development at the examined intersection is limited because it is surrounded by buildings.

Alternatively, it was decided to focus on the possible improvement in stage diagram and signal timings. This objective was made in a number of steps. In the first step the intersection operation was examined using different sets of cycle time lengths and green splits. The intergreen periods adopted were 6 seconds for each phase. The resulting delay values were presented graphically in Figure 12.

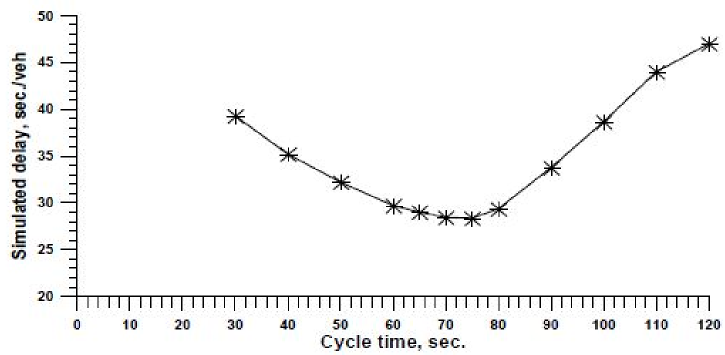


FIGURE 12. Variation of cycle time versus simulated delay.

In the second step the optimum cycle time was selected. The selection was based on the data presented in Figure 6. The optimum cycle was 72.5 second. This value is substantially lower than that currently in use which is 112 seconds. Other simulation results were reported in Table 5.

TABLE 5. Simulating data after intersection improvements.

Approach	S. bound	W. bound	N. bound	E. bound
Effective green, sec.	9.5	15.5	15.5	8
Simulated delay, sec.	31.24	25.04	25.25	29.65
Average delay for the intersection = 28.0 sec./veh., Obtained Co = 72.5 sec.				

Comparison between results in Tables 4 and 5 indicates the difference between the existing intersection performance and the possible performance when the proposed timings are employed. The proposed modifications result in decreases in the average delay for the intersection by about 40%. From this case study, the prediction model capability to support the best solutions for the signalized intersection can be concluded.

As the change in the signal timing resulted in an acceptable intersection delay, the researcher considered the decrease in the delay value (40%) is adequate and decided that the phasing diagram remains constant and no need to propose a new phasing diagram during this stage.

6. Conclusion and Recommendations

For the same traffic volumes, the obtained optimum cycle time values increased with the increase in the values of the total lost time in the intersection.

The optimum cycle time increased with the increase in traffic volume for a signalized intersection in case of considering no changes in other parameters such as the total lost time.

The developed regression model for the prediction of optimum cycle times can be used to obtain cycle times, which reduce vehicle delay. However, it is recommended to use it within the range of the simulated conditions.

It is recommended to examine the simulation model to predict a regression model representing wide range of simulated conditions to enable the model for wide application to play a main role for solving the traffic congestion in the signalized intersections.

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