Delay Time Analysis and Modelling of Signalised Intersections using Global Positioning System (GPS) Receivers

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Abstract. Delays at signalised intersection are considered the most important measure of effectiveness (MOE) for signalised intersections as these are used to determine the level of service (LOS). Thus, the aim of this research is the estimation of total delay and modelling of signalised intersections in Baghdad along the Palestine arterial street. Global Positioning System (GPS) receivers provide an opportunity to accurately measure intersection delay in terms of deceleration delay, stopped delay, and acceleration delay. The field data were collected for the selected sections of Palestine arterial street for Bab Al Moatham; AlSakaha; Beirut; and Maysaloon intersections respectively. Congestion of traffic conditions takes place during peak hours of the day, so from 12:00 to 3:00 p.m. on Mondays and Tuesdays in May 2019 were selected to study the variations of total travel time and travel delay times for each intersection in the selected sites. GPS essential measurement equipment running on cell phones was applied to compute the delay components for each group’s set of data points recorded at peak periods on each selected intersection corridor. A total of 60 test runs were carried out in the north and south direction in each case. The obtained results indicated that the stopping time for vehicles represents the major part of total control delay reaching about 88% of the control delay at some signalised intersections (Beirut and Bab Al Moatham intersections) at peak hours. The acceleration delay time was also higher than the deceleration delay time. GPS was also shown to be an effective field tool to accurately measure intersection delay as composed of deceleration delay, stopped delay, and acceleration delay for oversaturated traffic conditions.

1. Objective of the Research

The delay models for signalised intersections used most widely are the Webstar's Delay model and the HCM Model. These models are effective, though most realistic when the signals are operated with fixed timings. The oversaturated conditions of traffic flow, including the static and dynamic characteristics of most vehicles’ movement in accessible lanes, means that the reliability of predictions of control delay are less accurate, however. The objective of this research is thus to estimate and predict total delay of signalised intersections by utilising a more convenient method and common tools in order to reflect the
Discrepancies mentioned above and to obtain a more realistic delay time model. Global Positioning System (GPS) receivers now provide an opportunity to accurately measure intersection delay, composed of deceleration delay, stopped delay, and acceleration delay.

2. Introduction

Control delay at a signalised intersection is defined as the delay due to the operation of traffic signals at signalised intersections. Control delay is just a part of the total delay, which includes the control delay (acceleration, stopping and deceleration), geometric delay, volume delay, and incident delay [7]. Figure 1 shows the components of delay more clearly.

![Figure 1. Delay Component of Signalised Intersection [7].](image)

Delay at signalised intersections is an important factor inducing arterial street delays and affecting their operations. The performance measures of effectiveness for signalised intersections are also based on total control delay. Several studies have thus focused on the modelling of delay using various algorithms: Dion et.al. (2004) used the deterministic queuing model, shock wave model, time dependant stochastic delay model, and steady-state stochastic delay model [4], while Ceylan (2013) utilised the DE algorithm for signal controlled road networks and indicated an optimal design using Genetic Algorithms and Harmony and based search models [3].

Alkaissi (2017) developed different predicted models for the three link sections of Palestine streets based on field data. The best fit was presented with the observed field travel time data for all the models of studied links as compared to the predicted models, which illustrated that the predicted models did represent the actual field data. Stopped delay compromised the major part of intersection delay for all links studied, while the acceleration time delay was higher than deceleration time due to conflicts between vehicles in the intersections [1]. Alkaissi (2018) also studied the variation of headway time for selected links (Palestine arterial street) and demonstrated the fluctuating effects of higher observed flow rates. The results showed that the shape of probability density distribution functions was skewed to the right, with rising peaks for link (1) that were higher than for link (2) [2]. Ko, Hunter, and Gentler (2007) also presented a methodology to estimate the control delay using GPS data by defining the control points for acceleration and deceleration profiles based on speed differences in test vehicles [5],[6].
3. Study Area
The selected study area was Palestine Street, located in Baghdad in Iraq. It includes eight intersections: Bab Al Moatham, Alsakhir, Beirut Square, Al Muhandissein, Al Nakheel Mall, the Interior Ministry, Al Rubaie and Maysaloon square. Figure 2 shows the intersections along Palestine Street. The measured locations of these intersections are listed in Table 1 per World Geodetic System 1984 (WGS 1984) datum and Universal Transverse Mercator (UTM) map projection zone 38 north. Thirty runs of data were observed, divided into fifteen runs in each direction. The first set is in the direction of Maysaloon Square and the second is in the direction of Al-Mawal place.

![Palestine Street Image](image)

**Figure 2.** Palestine Arterial Street with Signalised Intersections.

| Intersections              | Easting (m)  | Northing (m)  |
|---------------------------|--------------|---------------|
| Bab Al Moatham Intersection| 445258.42    | 3691712.02    |
| Alsakhir Intersection     | 445651.08    | 3691348.91    |
| Beirut Square             | 446110.04    | 3690914.39    |
| Al Muhandissein Intersection| 447017.17    | 3690061.19    |
| Al Nakheel Mall Intersection| 447514.75    | 3689600.07    |
| Ministry of Interior Intersection| 448702.27    | 3688470.19    |
| Al Rubaie Intersection    | 449348.61    | 3687861.14    |
| Maysaloon Square          | 450571.82    | 3686718.72    |
4. Data and Application
The GPS Info mobile application was used for data measurements in this study. The data gathered included the location, speed, and measurement time. The locations were measured according to WGS 1984 datum. Figure 3 illustrates the GPS Info application and a screenshot taken during measurements. The distances along the routes were determined based on measured GPS locations. Four readings were taken at each intersection in the two directions along the track and in the reversed direction. These readings were used to calculate deceleration time, stopping time, and acceleration time, although no stopping occurred at some intersections.

Figure 3. GPS Info Application and Data Measurement.

5. Analysis of Vehicle Speed Profile, Travel Time and Trajectories
The delay time components are deceleration, stopping, and acceleration time, and there were estimated for each signalised intersection along the Palestine arterial street (from Al-Mawal to Maysaloon Square) based on the data from GPS obtained during 60 test runs in the south and north directions at peak hours (12:00 - 3:00 p.m.) on a Monday and Tuesday in May 2019. Figures 4 and 5 show the speed profile along the Palestine arterial street in both directions. The maximum speed was about 60 km/hr, which represents the posted speed limit for Palestine street.

Figures 6, 7, 8, and 9 present the travel time and trajectories over the studied roadway segment. The total travel time varied, from 17.3 min. to 14.4 min. for the north and south directions, respectively. Figure 10 demonstrates the components of delay, including deceleration, stopping, and acceleration delay time. It is clear that stopping time for vehicles presents the major part of total control delay, reaching about 88% of the control delay at some signalised intersections (Bairut and Bab Al Moatham intersections) at peak hours. The acceleration delay time is higher than deceleration delay time for most studied intersections, however, due to the long queues of vehicles generated and poor driver behaviour.
Figure 4. Speed Profile along Palestine Arterial Street (South Direction).

Figure 5. Speed Profile along Palestine Arterial Street (North Direction).
Figure 6. Travel Time Profile along Palestine Arterial Street (South Direction).

Figure 7. Travel Time Profile along Palestine Arterial Street (North Direction).
Figure 8. Space-Time Trajectories along Palestine Arterial Street (South Direction).

Figure 9. Space-Time Trajectories along Palestine Arterial Street (North Direction).
6. Delay Model Development
A statistical model was used to predict the control delay as a dependent variable for the signalised intersections along Palestine arterial street using IBM SPSS ver.21. The independent explanatory variables included the deceleration, stopping and acceleration delay time based on field data collected over 60 test runs. The statistical distribution study of the delay components (deceleration delay, stopping delay and acceleration delay) is presented in Figure 11.

**Figure 10.** Proportions of Delay Components: Acceleration, Stopped and Deceleration for 60 Test Runs during Peak Hours.
These variables were entered in a stepwise regression linear method. In this method, the acceleration, stopping and deceleration delay time were introduced in the regression model, and entering the stopping delay time value gives an adjusted $R^2$ of 0.909, as presented in Table 2. Details of regression models for Independent Variable Control Delay and Dependant Explanatory Variables: Acceleration, Stopping and Deceleration Delay Times and their correlations coefficients are presented in Tables 3 and 4, respectively.

**Figure 11.** Statistical Distributions of Control Delay Components.

![Histogram](image)

(c) Acceleration Delay Distribution.

| Model Summary |
|---------------|
| **Model** | **Change Statistics** | **Durbin-Watson** |
| **R Square** | **F Change** | **df1** | **df2** | **Sig. F Change** |
| Change | | |
| 1 (single) | .909^a | 279.182 | 1 | 28 | .000 |
| 2 (Multi-variables) | .086^b | 483.128 | 1 | 27 | .000 |
| 3(Multi-variables) | .005^c | . | 1 | 26 | 1.681 |

a. Predictors: (Constant), Stopping
b. Predictors: (Constant), Stopping, Acceleration
c. Predictors: (Constant), Stopping, Acceleration, Deceleration
Table 3. Details of the Regression Models for Independent Variable Control Delay and Dependant Explanatory Variables; Acceleration, Stopping and Deceleration Delay Times.

| Model | Unstandardized Coefficients | Standardized Coefficients | B | Std. Error | Beta | t | Sig. | 95.0% Confidence Interval for B | Collinearity Statistics |
|-------|-----------------------------|---------------------------|---|------------|------|---|------|-------------------------------|------------------------|
|       |                             |                           |   |            |      |   |      | Lower Bound | Upper Bound | Toler | VIF |
| 1     | (Constant)                  |                            | 18.290 | 2.940      |       | 6.222 | 0.0 | 12.268 | 24.311 |       |     |
|       | Stopping                    |                            | 1.108 | 0.066 | 0.953 | 16.709 | 0.0 | .972  | 1.244 | 1.000 | 1.000 |
| 2     | (Constant)                  |                            | 6.865 | 0.863 |       | 7.956 | 0.0 | 5.094 | 8.635 |       |     |
|       | Stopping                    |                            | 0.988 | 0.016 | 0.850 | 59.983 | 0.0 | .954  | 1.021 | .890  | 1.124 |
|       | Acceleration                |                            | 1.088 | 0.049 | 0.311 | 21.980 | 0.0 | .986  | 1.189 | .890  | 1.124 |
| 3     | (Constant)                  |                            | 1.169 | E-013 | 0.000 | .000 | 1.000 | .000  | .000  | .000  |     |
|       | Stopping                    |                            | 1.000 | 0.000 | 0.861 | 253989 | 0.0 | 1.000 | 1.000 | .872  | 1.147 |
|       | Acceleration                |                            | 1.000 | 0.000 | 0.286 | 807785 | 0.0 | 1.000 | 1.000 | .797  | 1.255 |
|       | Deceleration                |                            | 1.000 | 0.000 | 0.073 | 219558 | 0.0 | 1.000 | 1.000 | .895  | 1.118 |

a. Dependent Variable: Control Delay
Table 4. Correlation Coefficients between Control Delay and Delay Components; Acceleration, Stopping and Deceleration Delay Times.

|                     | Control Delay | Deceleration Time | Stopping Time | Acceleration Time |
|---------------------|---------------|-------------------|--------------|-------------------|
| Pearson Correlation |               |                   |              |                   |
| Control Delay       | 1.000         | .318              | .934         | .105              |
| Deceleration Time   | .318          | 1.000             | .276         | .239              |
| Stopping Time       | .934          | .276              | 1.000        | .059              |
| Acceleration Time   | .105          | .239              | .059         | 1.000             |
| Sig. (1-tailed)     |               |                   |              |                   |
| Total Delay         | .000          | .007              | .000         | .212              |
| Deceleration Time   | .007          | .016              | .033         |                   |
| Stopping Time       | .000          | .016              | .326         |                   |
| Acceleration Time   | .212          | .033              | .326         |                   |
| N                   | 60            | 60                | 60           | 60                |

From the regression analysis, which is a set of statistical operations to predict the relationships among selected field variables in this research, that is, acceleration, stopping, and deceleration delay time, a travel delay model was developed.

dc = 18.29 + 1.108 ds  [Equ.1]

where
dc: Control delay time.
ds: Stopping delay time.

6.1 Model Validation

The best fit for the predicted delay model with the observed field delay data is presented in Figure 12 for the model of the studied arterial street. The predicted model represents the actual field data, and for building a general model with good performance, a 50% data splitting strategy was used. The goodness of fit for the predicted model and field data were thus checked using a chi-square test, as shown below. The scatter plot and normal P-P plot for the regression standardised residual are presented in Figures 13 and 14 respectively.

Chi-Square Test

\[ N = 60 \quad df = 58 \quad \text{significant level } \alpha = 0.05 \]
Figure 12. Predicted Delay Time Model Versus Field Delay for Palestine Arterial Street.

| Predicted Models        | $\chi^2$  | $\chi_{critical}$ |
|-------------------------|-----------|--------------------|
| Palestine Arterial      | 74.58142  | 77.931             |

As $\chi^2 < \chi_{critical}$, there are no significant differences between predicted model and observed field data. It can be concluded that the predicted delay model can represent the actual field values of the control delay.
Figure 13. Scatter Plot.

Figure 14. Normal P-P Plot of Regression Standarized Residual.
7. Conclusions

1. The stopping time for vehicles represents the major component of total control delay, reaching about 88% at some signalised intersections (Beirut and Bab Al Moatham intersections) at peak hours. The maximum speed is about 60 km/hr, which represents the posted speed limit for Palestine street.

2. The acceleration delay time is higher than deceleration delay time for most studied intersections due to long queue lengths of vehicles generated and poor driver behaviour.

3. The total travel time for Palestine arterial urban street varies from 17.3 min. in the northern direction to 14.4 min. in the southern direction.

4. The travel delay model thus developed is
   \[ d_c = 18.29 + 1.108 d_s \]
   This predicted delay model can offer relatively accurate estimation of the actual field values of control delay.

5. GPS provides an effective field tool to accurately measure intersection delay, composed of deceleration delay, stopped delay, and acceleration delay for oversaturated traffic conditions.

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