Influence of Roadside Impedance on Speed and Capacity of Urban Streets

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Abstract. The elements of roadside friction have been defined as those activities that are taking place on the side of the road or even on the road, and which may affect on the uninterrupted traffic flowing. These elements are usually very common in highly populated regions in the developing countries, while they are random and low in the developed countries. In this research, the roadside friction elements were limited to on-street parking of vehicles first and the second side, vehicles stopping temporary and pedestrians crossing. Three links of arterial streets were chosen in the city of Baghdad; Palestine Street and Palestine Street, Zayouna region and 14-Ramadan Street, AL Mansoor. The data had extracted during two periods: the peak period and the non-peak period. The flow-density relationship was plotted and the values of the correlation coefficient (R²) were extracted for the two periods. A comparison was made between the empirical and extracted free-flow speed from the field. The percentage difference in FFS for Palestine Street was the maximum, as it reached 29.13%. The percentage reduction results in the capacity values display that Palestine Street, Zayouna Region has a maximum result which was 33.92%. While the minimum percentage 4.07% was for 14-Ramadan Street, AL-Mansoor region. This study spotlights through the results obtained the need to include side friction elements in traffic-related studies, especially for proper planning of urban roads.

Keywords: Capacity; Friction factors; Traffic impedance urban streets; Traffic speed; Statistical analysis.

1. Introduction and Literature Review

Transport plays an essential part in the economic development of countries. Traffic performance is influenced by many factors such as: the surface of road, shoulder, driver skills, width of the road, terrain, side friction or side activities, road maintenance, etc.

Highway capacity manual (2010) [1] defined the capacity of the road as the maximum hourly flow rate at which vehicles or persons can traverse a point or a segment of the roadway under prevailing conditions. Also, the manual mentioned the impact of roadside friction on the urban roads and should be included intuitively in the classification system of the highway. Arterial streets in many developing countries display deterioration in capacity and weak in operational performance. In some developing countries, various researches have been conducted on this problem and found that because of the urbanization, there are often many activities on the side of these streets. Side friction is a necessary component to be considered in the capacity analysis of urban streets. In this concern, the present study is an attempt to analyze the side friction elements impact on the vehicles speed and capacity of urban arterial streets.

In his study about estimating the capacity of two-lane roads, Chandra took consideration six variables into consideration: lane width, shoulder condition, roughness, directional splitting, terrain condition, percentage of slow-moving vehicles [2]. While Chinguma [3] studied the impact of side friction factors on speed and capacity and its effect on urban traffic performance. Frequent vehicles stopped and frequent
pedestrian movements on the side of the roads, especially at shopping malls had been observed, these cases had led to reduction in the average speed and capacity, also the entry and exit of the vehicles from the access points causes disturbance in the traffic flow Side frictions can be in the form of buses stopped at bus stops, pedestrians walking along the sides of carriageways and crossing at random, on-street parking, exits and entries from approach roads, slow-moving vehicles. Munawar Ahmad [4] has analyzed the effect of side friction on capacity and speed. A comparison was made in his research between the capacity observed and the capacity and speed suggested by IHCM. Munawar has determined that when the side friction has severe, there is a significant difference between the speeds predicted by Indonesian Highway Capacity Manual (IHCM) and the observed speed. Also, in his research suggested that the side friction should be measured as a factor in reducing capacity.

Rao A. and Rao K. [5] studied the impact of the side friction in the roads on the capacity in the Indian capital and reported a reduction in the average speed of vehicles by 49-57% of the sections with bus stop locations and 45-67% of the segments that the provision of on-street parking is available.

For local studies, Alkaissi Z.A [6], studies a selected two links of Palestine arterial street that are most congested, the commercial and educational land-use surrounded in this street created a potential pressure of additional attraction and production daily trips that produce the oversaturation conditions in traffic flow where the demand exceeds the design capacity of streets. The results obtained for the heavy congestion conditions for the south direction of the link (1) and north direction for Link (2) with a V/C ratio of 1.2 and 1.4 respectively. Also, the saturation conditions occur at Link (1) and (2) at jam density of approximately (100veh/km, 58veh/hr, 60veh/hr, and 70veh/hr) for south and north directions respectively. Alkaissi Z.A [7] predicted the time headway distribution under heavy flow conditions for Palestine Arterial Street. Collected field data for two links; Link (1) from Al-Mawal intersection to Bab AlMutham intersection 1.03 km length and link (2) from Zayona intersection to Mayslone intersection. The data obtained at two different time periods to conform the variation of time headway under congestion periods. The variation in time headway for Link (1) had reduced and more constant state, this obtained due to heavy flow conditions at congestion peak periods.

2. Problem Statement
Traffic congestion has become a really significant problem in urban areas, due to the fact that these areas have been expanded without any planning and controlling. For urban arterial streets in Baghdad city, sometimes, the disturbance amount of normal traffic flow resulting from the side friction elements and the number of resource of friction is too large. The side friction elements may include: temporary vehicles stopping, on-street parking, loading and unloading (specifically public transport vehicles), non-motorized vehicles, pedestrians walking in the roadway or crossing it, trading on street and the number of access points in the street and the number of vehicles using them. In result, traffic flow is considerably discontinuous, and subsequently detraction the performance of traffic operations and damage in the capacity and functional safety of the road.
3. **Objective of the Research**

The main purpose of this research is:

1. To estimate the impact of the roadside friction elements on the main traffic characteristics of urban arterial streets in Baghdad city, namely (Palestine Street, 14th- Ramadan Street / ALMansoor, Palestine Street / Zayouna region).

2. To develop statistical models for the speed and density relationship of the three urban arterial roads in Baghdad city.

4. **Study Area**

Three links of arterial streets are chosen in the city of Baghdad; two of them in the AL-Rusafa district and the other in AL-Karkh district. A site has been selected far from traffic control facilities such as traffic signals, turning, junctions, etc. Also, the locations nearby the intersections, which are able of congestion, were kept off because the idea was to observe the continuous flow.

![Aerial photos for study links](Source: Baghdad Municipality / Geographic Information Division source)

5. **Data Collection**

Traffic volume data were collected for two consecutive months, from June to July of 2019. The data collected every five minutes and converted to one-hour equivalent flow (veh/hr). A manual field method was applied in the collection process for all study sites, and also it was used in collecting the roadside friction elements data. As for the speed data, spot speed aggregated by using speed gun device (Bushnell Speedster III), Figure (2) illustrated the speed gun device that used in the field.
6. Results and Discussions

6.1 Flow-Density Relationship for Urban Roads

The flow-density diagram is used to determine the traffic condition of a roadway. To estimate the value of capacity during peak and non-peak periods for the three selected study segments, the relationship of flow with density has been plotted.

The density limits in Figure (3, a) are approximately stable with low values ranged up to 30 and 60 veh/km for free-flow conditions. On the other hand, the flow rate values were high for about 1488 veh/hr and continued to rise until it reached a maximum value of 2064 veh/hr. In peak time the density values start with 107.61veh/km and the value keeps rising until reach to jam density 282.4veh/km. As for the flow rate values, they began to gradually decrease, after their value is 1980 veh/hr, it became 852 veh/hr. The value of the correlation coefficient ($R^2$) for flow-density relation has been determined, for the unsaturated zone the $R^2$ result was 0.947, while the value of this coefficient decreased in the saturated zone, where it reached its value 0.8793.

In the Figure (3, b) the flow data showed an increase in its values in the free flow region, where the flow values increased from 1440 veh/hr to 2304 veh/hr (the maximum capacity). On the other hand, the density values also witnessed an increase, because the relationship between flow and density during the non-peak period was positive, so the initial value of density was 40.62 veh/km, and it rising to 121.84 veh/km. in peak period, the density values have ranged from 84.2 veh/km to reach the highest density of 170.67 veh/km (jam density). As for the flow rates, they are 1992 veh/hr at the highest point and 1248 veh/hr at the lowest point. The regression line for the saturation region is more curved, with the value of R-square reaching 0.8019, while the congested region shows a more linear pattern than a curve where it is noticed that the value of R is 0.6362.

It’s noticed in the Figure (3,c), that the flow rate value began with value 1428 veh/hr and continues increase until reached to 2724 veh/hr and the density values ranged between 31 veh/km and 107 veh/km. When the flow data reached its maximum value (maximum capacity), the relationship between the flow and the density began to become inverse, as it was noticed from the figure that the value of the flow rate 1800 veh/hr and gradually decreased to reach the value of 1140 veh/hr with a clear increase in the density values from 145.87 veh/km to 225.74 veh/km. the value of $R^2$ for the non-peak period was higher than its value during peak period, where its value during peak is 0.7173 while in non-peak is 0.9098. It is noticed, the coefficient of determination increases in its value when there are more points that located on the regression line.
Determination of Free-Flow Speed (FFS) from Field Measurement

Highway Capacity Manual (2010) describes the free-flow speed as the average speed of vehicles on a dedicated facility, measured under low traffic volume conditions when the drivers tend to drive at their wished speed and are not constrained by control delay. The value of free-flow speed in field obtained from spot speed data during uninterrupted flow. FFS can either be determined using direct field measurements or estimated using a model. Each segment of the study arterial street has been extracted two values of free-flow speed (from an analytical model for speed-density model and from the field). Table (1) illustrated the value of FFS for each link; free-flow speed empirical and from the field, and their percentage difference.

Table 1. Free-Flow Speeds obtained from field measurements

| Site                        | Free-Flow Speed Empirical (km/hr) | Free-Flow Speed Field (km/hr) | The percentage difference in FFS (%) |
|-----------------------------|-----------------------------------|-------------------------------|-------------------------------------|
| 14-Ramadan Street, AL-Mansoor | 52.521                            | 58.76                         | 10.62                               |
Palestine Street 42.026 59.3 29.13
Palestine Street, Zayouna Region 52.258 58.02 9.93

6.3 Estimation of Capacity

Table (2) illustrates the value of the maximum flow for the studied arterial streets. After conducting the field aggregation of the segment, it was found that the value of the maximum capacity during the peak times in 14-Ramadan Street is 1980 veh/hr, while the value of the maximum flow increased during non-peak times and reached to 2064 veh/hr, in Palestine Street, its notice there is a drop in the value of capacity that calculated during peak time. Presence of side friction elements during peak period led to this result. The value of the maximum capacity decreases from 2304 veh/hr during the non-peak period to 1680 veh/hr during the peak period.

In Palestine Street, Zayouna Region the value of maximum flow during the non-peak period is more than the peak period, which appears that the presence of side friction element cause reduction in capacity. On-street parking for the first side had an effect considerable effect on traffic volume and which affects the capacity. Its shows in the Table (2) the capacity value drop significantly during measure with side impedances, As the value during the non-peak period, is 2724 veh/hr while during peak period is 1800 veh/hr.

Table 2. Capacity values with and without side friction elements

| Site                              | Capacity in non-peak time (without side impedance) (veh/hr) | Capacity during peak time (with side impedance) (veh/hr) | The percentage difference in Capacity (%) |
|-----------------------------------|-------------------------------------------------------------|---------------------------------------------------------|------------------------------------------|
| 14-Ramadan Street, AL-Mansoor     | 2064                                                        | 1980                                                   | 4.07                                     |
| Palestine Street                  | 2304                                                        | 1990                                                   | 13.63                                    |
| Palestine Street, Zayouna Region  | 2724                                                        | 1800                                                   | 33.92                                    |

The maximum percentage reduction in capacity was in Palestine Street, Zayouna region, where it reached to 33.92%; this is shown in Table (2) fourth column. While the percentage of reduction was in Palestine Street reached to 13.63%. The minimum percentage was in the street of 14 Ramadan, ALMansoor region as the percentage is 4.07%.

6.4 Impact of Roadside Friction on the Speed

Roadside friction elements have aggregated manually in study links. Figures (4.A, B and C) represented the variation of speed values according to the roadside friction elements for study links. It is noticed from Figure (4, a) that the value of speed decreased when the number of on-street vehicles parked in the first side reached more than 16 veh/5min. Whereas in Figures (4, b) and (4, d) the values of the side friction
elements for both periods (peak and non-peak period) were almost equal, with a significant variation in speed values. As for Figure (4, c), in spite of the increase in the number of vehicles stopped during the non-peak period, the speed values were not affected.

According to Figures (5, a) and (5, b), a stable variation in speed values is observed during the two study periods with nearly equal values of elements (OPF and OPS). As for Figure (5, c), it is noted that the speed variable is affected in the peak period, as its value decreases to reach 8.1 km/hr when the value of the VST element is greater than 6 veh/5min. It is noticed in Figure (5, d) the decrease in PC element in the non-peak period with a significant increase in the speed values, and with the increase of the PC value (greater than 6), the speed values decrease during peak period.

It is noticed through the figures (6, a), (6, b) and (6, c) in Palestine Street, Zayouna region, that the increase in the values of the side friction elements (OPF, OPS, VST) was stable, whether for the peak or non-peak period, with a significant variation in the speed values between the two periods. As for the figure (6, d), it notices an increase in the values of the PC element with an obvious decrease in the speed values.

![Variation of speed with on-street parking](image1)

![Variation of speed with stopping vehicles](image2)

![Variation of speed with pedestrian crossing](image3)

**Figure (4).** Variation in speed values with side friction elements for 14-Ramadan Street/ AL-Mansoor region.
Figure (5). Variation in speed values with side friction elements for Palestine Street
c. Variation of speed with stopping vehicles
d. Variation of speed with pedestrian crossing

Figure (6). Variation in speed values with side friction elements for Palestine Street, Zayouna region

7. Statistics Analysis by Program SPSS
SPSS (ver.23, 2015) was used for statistical analysis in this paper. Table (3) illustrated the values of the correlation coefficient for all study links and its model for with and without the elements of roadside impedance.

Table 3. Model Summary for study sites without and with side friction elements

| Study Site                  | Period               | Model (Without Side friction) | R²   | Model (With Side friction) | R²   |
|-----------------------------|----------------------|--------------------------------|------|-----------------------------|------|
| Palestine street            | Non-Peak            | Y=43.398-0.227 D              | 0.872| /                           | /    |
|                             | During Peak         | Y=32.650-0.149 D              | 0.922| Y=33.250-0.142 D-0.433 OPS  | 0.942|
|                             | All (Non-Peak+      | Y=42.026-0.218 D              | 0.924| Y=40.921-0.182 D-0.236 VST-0.212 PC | 0.944|
|                             | During Peak         |                                |      |                             |      |
| Palestine Street, Zayouna   | Non-Peak            | Y=55.648-0.284 D              | 0.858| Y=68.871-0.338 D-0.793 OPF  | 0.921|
| Region                      | During Peak         | Y=23.399-0.082 D              | 0.899| Y=24.566-0.078 D-0.153 OPF  | 0.933|
|                             | All (Non-Peak+      | Y=52.258-0.234 D              | 0.970| /                           | /    |
|                             | During Peak         |                                |      |                             |      |
| 14-Ramadan, ALMansoor       | Non-Peak            | Y=62.796-0.446 D              | 0.885| /                           | /    |
|                             | During Peak         | Y=23.790-0.078 D              | 0.887| /                           | /    |
|                             | All (Non-Peak+      | Y=52.139-0.202 D              | 0.947| /                           | /    |
Where: \( Y = \) the dependent variable (Mean Speed)  
\( D = \) Density, \( \text{OPF} = \) On-Street Parking First Side, \( \text{OPS} = \) On-Street Parking Second Side  
\( \text{VST} = \) Vehicles Stopping Temporary, \( \text{PC} = \) Pedestrians Crossing

Figure (7, a) show the scatter plot and normal p-p plot for 14-Ramadan Street to check the normality for data. It is noticed from the figure that the data not normal, the small sample size in 14-Ramadan Street may cause non-normality shape in these plots. The data fall far from a line in normal p-p and taking a known uniform shape (U) in the scatted plot. While Figures (7,b) and (7,c) show that the data has been distributed normally, where the scatter plots demonstrated an irregular shape and the p-p normal plots show the data fall near the line.

a. 14-Ramadan Street, AL-Mansoor region

b. Palestine Street
8. The Validation of Model

The objective of validation is to evaluate the appropriateness of the proposed prediction model and measurement the error or accuracy of the forecasting for the validation period. The additional data for speed and density were collected for the validation operation. Figure (8) shows the scatter plots for validation of model for study links. Figures (8, a), (8, b) and (8, c) represented the relationship between the observed speed from the site and the expected speed. Depending on the values of the correlation coefficient R-squared, it is observed that there is a strong correlation between the two values since the value of R² exceeded 50%.

a. 14-Ramadan Street, AL-Mansoor region
b. Palestine Street
c. Palestine Street, Zayouna Region

Figure (7). Scatter and Normal P-P Plots for Study Sites
Figure (8). Scatter plots between the observed and theoretical speed for validation of model for study sites

9. Conclusions

1. The flow-density relation was plotted for all the study links, it was noticed in the diagrams, in the period of free-flow there was an increase in the flow of vehicles with an increase in the values of density and when the link reached to the maximum value of the flow (maximum capacity), the plotted shown an opposite relationship after it was a positive relationship. As the flow values decreased with an increase in the density values.

2. The free-flow speed was extracted from the field for each link in this study. The comparison was made between the FFS field value with FFS empirical value, where it was found that the maximum percentage difference value reached was in Palestine Street, where it reached to 29.13%.

3. Capacity was estimated for study links, it was found there was a dropping in its values. Where it was found that Palestine Street, Zayouna Region had the highest percentage decrease in capacity, which amounted to 33.92%, the percentage decrease was for Palestine Street 13.63%. As for 14 Ramadan Street, only the lowest percentage decrease in capacity occurred 4.07%.

4. According to roadside friction elements analysis with the speed-density relationship, the models for all study sites were developed. It’s found that in Palestine Street during peak time, OPS were the only element that has a negative effect on the speed. While when data are collected for the peak and non-peak periods, there were two elements that have a negative impact on the speed variable, VST and PC.

5. In Palestine Street, Zayouna region the OPF was the only element has a negative effect on the speed during peak and non-peak period. But in 14-Ramadan Street and according to the value of significant in regression analysis for each element, it was found there wasn't any element has a negative impact on speed variable.

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