Estimation of Vehicle Stops Based on Modified Canadian Capacity Guide Formula Under Non-Lane Based Road Traffic Condition

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Abstract: Vehicle stops estimation is one of the important parameters to assess the performance of a signalized road intersection. Canadian Capacity Guide provides a formula that can estimate number of vehicles that stops at least once due to the traffic signal. This study reviews the applicability of this formula for non-lane based traffic. The formula is segmented into two periods to check the estimation of stops during red period and green period. It is found that the formula underestimates the number of stops during red period. Also, the formula estimated number of stops is significantly higher during the green period. As traffic operation and vehicle maneuver of non-lane based traffic are much different from lane based disciplined traffic, the formula cannot predict vehicle stops accurately. Therefore, the estimation of vehicle stops by Canadian Capacity Guide formula is found to deviate considerably from field observed number of stops of vehicles. Thus, a modified regression formula is provided that can estimate the number of stops of vehicles for non-lane based traffic operation. The modified formula fits fairly good with the local traffic condition.

Keywords—Canadian Capacity Guide, Number of Stops, Non-Lane based traffic, Regression Analysis

1. Introduction

Various parameters exist to assess the performance of a signalized intersection. Delay, Queue length, vehicle stops are some much used parameters to assess this performance. Similar to other parameters mentioned, vehicle stops can be directly measured by performing field survey. Alternatively, analytical models are also found that can estimate number of stops of vehicles in an approach. Among various models, Webster [1] developed relationship between stop and delay based on uniform arrival of vehicles. Webster and Cobbe [2] developed a model based on random arrivals that can estimate the numbers of stops of vehicles. Cronje [3] explained the number of stops from queue diagram and also developed a model to estimate vehicle stops based on markov process. Rakha [4] reviewed the existing models of vehicle stops and proposed two approaches for estimating vehicle stops at under saturated and oversaturated condition. Canadian Capacity Guide [5] provides a model that is developed based on Webster and Cobbe [2] provided model. The Canadian Capacity Guide model estimates the number of vehicles that stops at least one time due to signal. This model is developed from uniform queue build
up model and a progression adjustment factor (P.F.) is multiplied to get the estimate of number of stops. However, traffic situation of Dhaka city of Bangladesh is much different from western lane based traffic. Traffic does not follow any lane behaviour in Dhaka city. This is why vehicle queue formation is different from lane based traffic. Vehicles are found to form cluster near approach. Lateral gaps between vehicles are very less during queue building as gaps are filled up by small sized vehicles like motor bike. During discharge of vehicles, irregular pattern of movement is found. Vehicles even tend to change direction laterally to move faster. As a result, the model does not predict the number of stops properly in case of non-lane based traffic. To estimate number of stops properly, Hadiuzzaman et al. [6] proposed two approaches in case of non-lane based mixed traffic operation. One approach computes vehicle stops based on microsimulation technique and other one is based on analytical approach. Both the approaches to estimate vehicle stops are quite useful for non-lane based traffic. Specially, the analytical approach deals to compute stops for oversaturated condition.

Yet, a simpler approach to estimate number of stops for both under saturated and oversaturated condition was necessary. This fact led the study of analysing Canadian Capacity Guide provided formula for number of stops of vehicles. Applicability of this formula is checked with field traffic condition. Field traffic condition includes both under-saturated and over-saturated condition. After analysing the formula and comparing it with observed field values, a modification is provided to this simple formula. The modified formula can be used to estimate number of stops of vehicles in case of non-lane based traffic. However, non-lane based heterogeneous traffic (Presence of Non-motorized vehicle) is beyond the scope of this study.

2. Methodology for the study

The formula provided by Canadian Capacity Guide [5] to estimate number of stops of vehicles for at least once during signal operation is as follows:

$$ N_s = \frac{P.F. \cdot t_e \cdot v \cdot (C \cdot g)}{60 \cdot C \cdot (1 - y)} $$

(1)

Where,

- $N_s$ = Number of vehicles that stops at least once during the evaluation time. The maximum value must be less than the following:

$$ N_{s(max)} = \frac{v \cdot t_e}{60} $$

- $P.F.$ = Progression Adjustment Factor
- $v$ = Arrival Flow Rate (vehicles/hour)
- $C$ = Cycle time (seconds)
- $g$ = Effective green time (seconds)
- $S$ = Saturation flow rate (vehicles/hour)
- $y = \frac{v}{S}$ capped at $y \leq 0.99$
- $t_e$ = Evaluation time (minutes)

Now, formula (1) can be simplified more if the evaluation time is considered same as the cycle time. Therefore, simplification of formula (1) while considering consistency of units produce the following version:

$$ N_s = \frac{P.F. \cdot v \cdot (C \cdot g)}{(1 - y)} $$

(2)

Where,

- $v$ = Arrival flow rate (vehicles/hour)
- $C \cdot g = r \cdot C_{r}$ = Red signal phase period (hour)

Cronje [3] explained number of stops from the queue diagram. If there is an initial queue at the beginning and no overflow at the end of cycle, the total number of stops per cycle is as follows:

$$ N_s = Q_{B} + r \cdot v + \frac{(Q_{B} + r \cdot v) \cdot v}{S - v} $$

(3)
Where, $Q_B = \text{Initial Queue (vehicles)}$

If there is no initial queue at the beginning and no overflow at the end of cycle, then total number of stops per cycle:

$$N_s = r \times v + \frac{(r \times v) \times v}{S - v}$$  \hspace{1cm} (4)

The first term of the equation (4) represents number of stops during red period while the later term represents number of stops during green period. By simple mathematical operation and replacing $r$ by $(C-g)$, it can be shown:

$$N_s = \frac{v \times (C-g)}{1-y}$$  \hspace{1cm} (5)

So, the equation (5) is simply the same as equation (2) except the term progression adjustment factor which is absent in equation (5). Thus, the formula provided by Canadian Capacity Guide in equation (1) is just an improved version of equation (4).

Therefore, the study focuses on the equation (4) as it splits the number of stops in two distinct periods. This equation is used to determine number of stops in red period and green period consecutively by applying appropriate values of traffic parameters. Parameters are found from performing a traffic survey on selected road intersection. The following diagram of Figure 1 provides a clear understanding of procedure followed for the research study (analysis and model development parts are not shown):

![Figure 1. Diagrammatic representation of the methodology](image)

**Estimation of vehicle Stops by Canadian Capacity Guide Formula**

- Determination of Traffic Parameters from Selected Site:
  - Arrival Flow Rate
  - Saturation Flow Rate
  - Cycle Time
  - Red Period
  - Green Period
  - Progression Adjustment Factor

- Vehicle stops during red interval are estimated using parameters determined from site survey

**Field Determination of Stops of Vehicles at a selected approach of an intersection**

- Counting starts from the onset of red period.
- Vehicles that stop at least once are included in the counting.
- Counting continues until the queue dissipates.
- Total arrival of vehicles are counted during the cycle
- Vehicles that arrive during green period are counted
- All vehicles during red must stop. Thus:

  **Stops of vehicle during red** = Total Arrival Volume - Vehicles arrival in green

  **Stops of vehicle during green** = Total Stops - Stops of vehicle during red period
The methodology explained above in Figure 1 is followed to conduct this study. At first, traffic parameters are determined form the site. Traffic parameters such as signal timings, arrival flow rate, saturation flow rate, Progression Adjustment Factor are measured as follows: Signal timings are measured directly from video recording. Average arrival flow rate is determined by Mcshane et al. [7] provided procedure. Vehicles that depart during the green period and form queue at the end of green period are the total arrival period during that cycle. This total arrival volume is divided by cycle time to get the average arrival flow rate (v) in vehicle per hour unit. Road Note 34 [8] is used to estimate saturation flow rate. Road Note 34 is applied to each cycle of traffic flow in terms of PCU per hour. PCE values required for estimation of saturation flows are taken from Hadiuzzaman et al. [9]. Saturation flow in PCU per hour is then converted into equivalent saturation flow in vehicle per hour unit using the procedure mentioned in Canadian Capacity Guide [5]. A total of thirty (30) cycles are used to estimate the average saturation flow (in vehicle per hour unit). Lost times are also determined by Road Note 34 [8]. Average of Initial lost times and final lost times from 30 cycles have been used. Average lost times are used to determine effective green time. Another important parameter is Progression Adjustment Factor (P.F.), it is determined by Strong et al. [10] provided formula. This formula is much better suited than using default values of Highway Capacity Manual 2000 [11]. After determining the above mentioned parameters, number of stops is estimated. Next, counting of number of stops is conducted that provide the actual number of stops of vehicles. After that, results of formula is compared with the observed results. Deviation of the formula from the observed value justifies the need of modification. Thus a modification is performed for the existing formula.

So, the rest of the paper explains data collection procedure followed by statistical analysis of vehicle stops. After that a linear regression model development is shown. The later portion describes the major findings and limitations of the study.

3. Data Collection

Data for this study is collected from Hotel Intercontinental intersection (Previously known as Hotel Sheraton intersection) of Dhaka City of Bangladesh. Few attributes of the intersection are shown in Table 1-

| Intersection Name | Approach Name | Road Width (meter) | Traffic Stream Type | Pedestrian behavior | Road Side friction |
|-------------------|---------------|--------------------|---------------------|---------------------|-------------------|
| Hotel Intercontinental | East          | 12.21              | Only motorized vehicle is present | Relatively disciplined | Low               |
|                    | South         | 12.11              | Only motorized vehicle is present | Relatively disciplined | Low               |
|                    | North         | 10.23              | Only motorized vehicle is present | Relatively disciplined | Low               |

Based on the information given on Table 1, it is understandable that this intersection has some advantages over other intersections of Dhaka city. Thus, data collection was performed on this selected site and it was done using video camera recording. Some techniques were needed to be followed such as: for long queue where a single camera cannot capture the entire queue, two video cameras were used simultaneously keeping a common overlapping portion. Also, some considerations were applied during video data transcription. As the East approach of the intersection has exclusive left turning facility, left turning vehicles were not supposed to stop due to signal. However, queued vehicles sometimes block the passage as they don’t follow any lane behavior. These additional vehicle stops were not considered into the statistical comparison. This is due to the fact that the analysis is
focused for queued vehicles only and the formula is not supposed to recognize the stops of vehicles of other lanes. This consideration is also applied for North approach and South approach of the intersection.

4. Comparative Analysis of Vehicle Stops

Data collected from site survey is used to compare between observed stops and formula stops. These data with corresponding traffic parameters are shown below in Table 2:

Table 2. Comparison between Formula estimated number of stops and Observed number of stops

| Approach Name | Obs No. | Cycle Time, C (Seconds) | Effective green (Seconds) | Arrival flow rate, v (veh/hour) | Saturation flow rate, S (veh/hour) | Degree of saturation, X | P.F. | Canadian Capacity Guide Formula: Number of Stops in red (vehicles) | Observed Stops in red (veh) | Observed Stops in green (veh) |
|---------------|---------|------------------------|---------------------------|---------------------------------|---------------------------------|------------------------|------|---------------------------------------------------------------|-----------------------------|-----------------------------|
| East          | (1)     | (2)                    | (3)                       | (4)                             | (5)                             | (6)                    | (7)  | (8)                                                          | (9)                         | (10)                        |
| 1             | 306     | 130.57                 | 1906                      | 0.74                            | 0.99                            | 92                     | 42   | 92                                                           | 92                          | 36                          |
| 2             | 366     | 147.57                 | 2056                      | 0.84                            | 1.18                            | 147                    | 75   | 145                                                         | 145                         | 40                          |
| 3             | 165     | 86.57                  | 2444                      | 0.77                            | 1.44                            | 76                     | 51   | 73                                                          | 73                          | 7                           |
| 4             | 88      | 50.57                  | 2169                      | 0.62                            | 1.3                             | 29                     | 16   | 28                                                          | 28                          | 7                           |
| 5             | 131     | 57.57                  | 2226                      | 0.84                            | 1.38                            | 63                     | 37   | 61                                                          | 61                          | 2                           |
| 6             | 115     | 67.57                  | 2693                      | 0.76                            | 1.33                            | 47                     | 38   | 45                                                          | 45                          | 3                           |
| 7             | 209     | 67.57                  | 1809                      | 0.92                            | 1.12                            | 79                     | 34   | 79                                                          | 79                          | 0                           |
| 8             | 122     | 50.57                  | 2597                      | 1.03                            | 1.11                            | 57                     | 43   | 58                                                          | 58                          | 3                           |
| North         | (1)     | (2)                    | (3)                       | (4)                             | (5)                             | (6)                    | (7)  | (8)                                                          | (9)                         | (10)                        |
| 1             | 140     | 51.23                  | 900                       | 0.66                            | 0.84                            | 19                     | 6    | 19                                                          | 19                          | 0                           |
| 2             | 229     | 94.23                  | 2406                      | 1.58                            | 1                               | 90                     | 167  | 97                                                          | 97                          | 0                           |
| 3             | 146     | 12.23                  | 642                       | 2.07                            | 0.95                            | 23                     | 5    | 23                                                          | 23                          | 0                           |
| 4             | 98      | 44.23                  | 1690                      | 1.01                            | 0.93                            | 24                     | 20   | 24                                                          | 24                          | 0                           |
| 5             | 129     | 63.23                  | 2289                      | 1.26                            | 1.22                            | 51                     | 83   | 56                                                          | 56                          | 0                           |
| 6             | 110     | 62.23                  | 2455                      | 1.17                            | 1.07                            | 35                     | 69   | 36                                                          | 36                          | 0                           |
| 7             | 152     | 69.23                  | 1493                      | 0.89                            | 0.49                            | 17                     | 11   | 18                                                          | 18                          | 0                           |
| 8             | 119     | 38.23                  | 2269                      | 1.91                            | 0.98                            | 50                     | 79   | 57                                                          | 57                          | 0                           |
| 9             | 126     | 24.23                  | 1486                      | 2.09                            | 1.04                            | 44                     | 30   | 54                                                          | 54                          | 0                           |
| South         | (1)     | (2)                    | (3)                       | (4)                             | (5)                             | (6)                    | (7)  | (8)                                                          | (9)                         | (10)                        |
| 1             | 207     | 41.38                  | 661                       | 1.12                            | 1.08                            | 10                     | 43   | 10                                                          | 33                          | 3                           |
| 2             | 65      | 12.38                  | 554                       | 0.99                            | 0.86                            | 2                      | 9    | 7                                                           | 7                            | 0                           |
| 3             | 64      | 13.38                  | 844                       | 1.37                            | 0.09                            | 0                      | 1    | 2                                                           | 2                            | 0                           |
| 4             | 36      | 9.38                   | 600                       | 0.78                            | 0.43                            | 1                      | 3    | 2                                                           | 2                            | 0                           |
| 5             | 87      | 19.38                  | 663                       | 2946                            | 1.01                            | 0.88                   | 3    | 14                                                          | 11                          | 0                           |
| 6             | 78      | 11.38                  | 554                       | 1.29                            | 1.16                            | 3                      | 15   | 12                                                          | 12                          | 0                           |
| 7             | 39      | 10.38                  | 462                       | 0.59                            | 0.52                            | 0                      | 2    | 2                                                           | 2                            | 1                           |
| 8             | 73      | 15.38                  | 592                       | 0.95                            | 1.27                            | 3                      | 15   | 12                                                          | 12                          | 0                           |
| 9             | 69      | 7.38                   | 522                       | 1.66                            | 0.73                            | 1                      | 7    | 5                                                           | 5                            | 0                           |
| 10            | 55      | 29.38                  | 982                       | 0.62                            | 0.52                            | 2                      | 6    | 4                                                           | 4                            | 3                           |
| 11            | 54      | 12.38                  | 400                       | 0.59                            | 1.14                            | 1                      | 6    | 7                                                           | 7                            | 0                           |
Table 2 shows the summary of the collected data. Traffic parameters such as signal timings, arrival flow rate, saturation flow rate, Progression Adjustment Factor (P.F.) are measured by methods mentioned in the methodology. The first two columns describe the name of approach and observation periods. The column (3) provides cycle time which is determined from the survey. The effective green time (column 4) is determined by deducting lost times from Green + Amber time. Column (5) to column (8) show other traffic parameters necessary for number of stops calculation. Saturation flow listed in column (6) requires PCE factors. The following PCE values are used:

| Intersection Name | Approach Name | Pickup | Car | Bike | Auto-Rickshaw | Heavy vehicles |
|-------------------|---------------|--------|-----|------|---------------|----------------|
| Sheraton East     | East          | 1.211  | 1.0 | 0.108| 0.690         | 4,513          |
| Bangla Motor North| North         | 1.313  | 1.0 | 0.453| 0.338         | 2,252          |

PCE values shown on Table 3 are determined by following synchronous regression method by Hadiuzzaman et al. [9]. In this study, East approach and South approach uses the same PCE values of East approach as both the approaches have right turning vehicles only and also both of them are car dominated as found during this study. Average percentage of vehicles for East approach is found to be: Car-44%, Auto-Rickshaw-37%, Motor Bike-13%, HV-1% and Other vehicles-5%. South approach of the same intersection have: Car-56%, Auto-Rickshaw-23%, Motor Bike-15%, HV-2% and Other vehicles-4%. Thus, PCE values of East approach can be considered approximately same for these two approaches. On the other hand, North approach of the selected intersection is just at the downstream of Bangla Motor intersection. These two approaches have approximately same road width. Approach width of Bangla Motor is 10.6 meter which is pretty close to North approach (Width is 10.23 meter) of
Hotel Intercontinental. Also, vehicle composition for both the approaches is close. Therefore, it can be considered a reasonable approximation for PCE values.

Using all the parameters, number of stops is determined which is shown in the following column (9) and column (10) of Table 2. Number of stops is split into red and green interval as mentioned previously. It helps to analyse and interpret the values more deeply. Column (11) and column (12) express the number of stops counted from video recordings directly.

5. Regression Model Development

Again, Table 2 shows that the formula estimated number of stops during red period is much close to the observed value in case of East approach and South approach. However, it underestimates much in case of South approach. Overall, the formula does not predict accurately in red period. By analysing data of Table 2, it can be found that the average value of underestimation during red period is 5.5 vehicles with a standard deviation of ±6 vehicles. On the other hand, vehicle stops in green period are over-estimated by the formula. Average value of over estimation during green period is 25 vehicles with a standard deviation of ±30 vehicles. When the segmented periods are analysed combinedly, it is found that the formula overestimates the number of stops in total. Average number of over-estimation by the Canadian Capacity Guide Formula is 20 vehicles with a standard deviation of ±30 vehicles. So, it is clear that the formula does not estimate the practical results properly.

As the estimations of the Canadian Capacity Guide formula do not exactly match with field data, it is necessary to ensure whether the variation is great enough to modify the existing formula. A statistical t-test is performed to ensure the modification justification. For the t-test, differences between formula estimated vehicle stops and field observed vehicle stops are determined at first. For the Canadian Capacity Guide Formula to be applicable for non-lane based traffic, the difference should be statistically zero. So, the mean of differences should be zero in order to accept the hypothesis that the formula is okay. Now, using the mean of differences, standard deviation and number of observations, a t-test is performed which is shown in Table 4:

| Sample mean of differences | Sample standard deviation | Population mean of differences | Number of Observations | t-statistic | [Critical t] for 5% LOS | Comment |
|----------------------------|---------------------------|------------------------------|------------------------|------------|-------------------------|---------|
| Stops in green period      | -25.3                     | 30.04                        | 0                      | 41         | -5.39                   | -       |
| Stops in red period        | 5.54                      | 6.1                          | 0                      | 41         | +5.81                   | -       |
| Total number of stops      | -19.76                    | 30.27                        | 0                      | 41         | -4.18                   | 1.96    |

Table 4 clearly explains that is the null hypothesis is rejected at 5% level of significance. So, the Canadian capacity guide formula does not predict accurately enough for non-lane based traffic. So, the formula needs to be modified to suit non-lane based mixed traffic operation. In this study, a linear regression model is provided that can be suitable to estimate the actual number of stops of vehicles. The formula model is as follows:

\[
N_{S(\text{Field})} = a_1 \cdot N_{S(\text{formula})} + a_2
\]

(6)

Where,

\(a_1, a_2 = \) Regression Coefficients

\(N_{S(\text{Field})} = \) Field counted number of stops of vehicles
\(N_S\) (Formula) = Formula predicted number of stops of vehicles

After performing this simple linear regression based on the data provided on Table 2, the following regression model is found which is shown in Table 5:

| Proposed Model | \(N_S(\text{Field}) = 0.598 \cdot N_S(\text{Formula})\) |
|----------------|--------------------------------------------------|
| \(a_1\)       | 0.598                                            |
| \(a_2\)       | 0                                                |
| \(t_{a1}\)    | 184                                              |
| \(t_{a2}\)    | -                                                |
| F-value        | 337.4                                            |
| \(R^2\)       | 0.89                                             |

Table 5 provides a linear regression model that fits much well with the practical data. \(R^2\) value obtained in this model is 0.89 that shows a good correlation with field data. Coefficient obtained from the study is 0.598. So, formula predicts 40% higher than the actual number of vehicle stops.

Now, the calibrated regression formula is checked against another set of collected data from the same intersection. The relationship between modified formula predicted stops and observed field stops is shown in the following Figure 2.

![Figure 2. Correlation between Observed number of stops and Model predicted number of stops](image)

Observed number of stops fits very well with the model predicted number of stops as shown in Figure 2. So, correlation between the observed stops and model predicted stops is much better. Therefore, the calibrated formula just provides a multiplication of an Adjustment Factor (A.F.) to estimate number of stops properly:

\[
N_S = \frac{A.F. \cdot P.F. \cdot t_e \cdot v \cdot (C - g)}{60 \cdot C \cdot (1 - y)}
\]

Where, A.F. = 0.598
This calibrated formula can be used to estimate number of stops of non-lane based traffic. However, the selected intersection is much well-disciplined as mentioned previously. Thus, it may not provide proper results for traffic with many external interruptions to movement.

6. Conclusion and Recommendation

The study provides some valuable findings in context of non-lane based traffic operation. It is found out that the number of stops of vehicles estimated by Canadian Capacity Guide formula does not fit with the field observed number of stops of vehicles. Moreover, the formula estimates lower number of stops during red period. On the other hand, it estimates much higher number of stops during green period. Overall, the formula cannot be used to estimate number of stops of non-lane based traffic. Thus, the existing formula provided by Canadian Capacity Guide is modified to estimate actual number of stops of vehicles. The modified regression formula fits well with field data. The modified formula just provides an adjustment term (A.F. = 0.598). Thus, it is much easier to predict the actual number of stops. Also, the correlation coefficient (R² value) is 0.89 which indicates a very good fit with field data. So, this modified formula can be used to estimate number of stops of vehicles for non-lane based traffic. However, the findings are based on three approaches of a single intersection. The intersection is relatively well disciplined and traffic movement incurs less friction from pedestrian and roadside activities. The intersection is free from such disturbances which are very common in other intersections of Dhaka city. So, more study is necessary to establish a general model that will provide accurate results for every intersection with non-lane based motorized traffic. Also, the study excludes non lane based heterogeneous mixed traffic which is predominant in the city. The modified formula may not be suitable at all in predicting stops under such mixed traffic condition. Nonetheless, the findings from this study can provide a valuable base for further research into this area.

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