Estimation of BPR Function for Dhaka City by Incorporating the Influence of Illegal On-Street Parking and Street-Occupancy

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1. Introduction

Illegal on-street parking on a major arterial within the city decreases road capacity and increases delays and accidents due to the physical occupation of the space, manoeuvres, pedestrians appearing in between vehicles and other activities associated with parking and street occupancy. The capacity reduction factors for adjacent lanes resulting from parking manoeuvres are given in the Highway Capacity Manual. For example, on average 20 manoeuvres reduces capacity by 20% on one lane, 11% on two lanes and 7% on three lane roads (TRB, 2000). Therefore, if the lane is occupied by illegal parking or occupancy so it has a significant impact on the road capacity reduction. Illegal on-street parking and street occupancy accounts for a substantial fraction of the traffic stream in many regions and is often the source of localized traffic congestion. Use of travel demand models to identify transportation projects that can improve air quality and mobility requires the effective treatment of illegal on-street occupancy in travel demand forecasting. Many urban areas especially in developing country is now suffering from illegal on-street occupancy and include the explicit treatment of illegal on-street occupancy as a part of the overall modeling process. However, it is difficult to measure the influence of illegal on-street parking and street occupancy on overall traffic flow as well as travel time quantification.

Paratransit or the informal public transport modes have been developed to fill the gaps left among private cars, buses and fixed track systems. They provide a flexible and frequent service to small settlements and through narrow streets, where no other services are available at a relatively low fare. In developing countries, the lower standard of living, high population density, availability of cheap labor force etc., have together provided a bewildering array of transport modes bridging the gap between public bus and private automobiles. In addition, the urban paratransit sector generates a considerable number of employment opportunities, as much as 10%-20% of the total employment in some cities (ESCAP/UNCHS, 1987).

Though it has some economical advantages to the poor people, it bears also some positive and negative effects. Basically, employment generation is the positive effect of paratransit and the effect on speed or capacity of road traffic including accident is its negative impact. In the urban area, the transport sector including storage and/or communication provides a great number of job opportunities which accounts for 2% to 20% of the total labor force at the national level. In India and Bangladesh the share of transport sector is remarkably high, 12% in India and 12.9% in Bangladesh, due to the labor intensive cycle rickshaw. In Dhaka, about 380,000 people are directly employed as rickshaw pullers, and another 80,000 are employed in ancillary services related to rickshaws, together accounting for nearly one fourth of all employment in metropolitan Dhaka (Shimazaki, and Rahman, 2010). Thus, paratransit accounts for the large share in providing employment for unskilled low income workers. The accident rate of paratransit modes which may be considered as its negative effect too is often claimed to be excessive in developing countries. In Dhaka, it was reported that rickshaw contributed to only 2.3 % traffic accidents as against the motorized modes such as cars (45.5%), buses (21.5%), trucks (18.6%), auto rickshaws (5.9%) and motorcycles (5.5%) (Islam, 1990). But the actual figure of accidents involving rickshaw was unreported because of illegal status of rickshaw themselves and lack of insurance claims. Other negative effect is traffic congestion due to reduction of the vehicle speed and decrease of the capacity of road owing to on-street illegal occupancy by the paratransit as well as other illegal occupiers.

The most common approach to reflecting the overall impact of congestion in travel demand models is the Bureau of Public Roads (BPR) type curve. One advantage of the BPR curve is that the parameters of the curve can be calibrated to reflect locally observed volume–delay relationships that may vary depending on roadway class and driver behavior. A disadvantage of the standard BPR formulation is that it does not realize the illegal on-street parking and street occupancy and how that illegal occupancy can contribute to congestion which is very common scenario in developing city like Dhaka. Thus, the common and traditional BPR function does not work properly under severe traffic congestion due to influence of illegal on-street parking and street occupancy in case of developing cities. So to overcome this disadvantage, this research has introduced a new BPR function named as travel time – volume (TTV) function by incorporating illegal on-street parking and street occupancy and this is the first time that the influence of illegal on-street parking and street occupancy has been considered to develop such kind of TTV function.

This paper examines travel time – flow relationship, travel time variability, volume delay function and finally new TTV function for Dhaka city by considering illegal on-street parking and street occupancy.

2. Travel Time – Flow Relationship

The figure 1 portrays the raw data with the v/c ratio on the horizontal axis and the travel time per kilometer in minutes on the vertical axis. Each point represents a 15-minute observation, i.e. average travel time within the given minute. It is evident that there is not so wide distribution of travel time at various v/c ratio, with most concentration at v/c less than 0.8. The relationship between travel time and v/c ratio is positive. In terms of the regression equation in the figure 1, the rate of change of travel time is 5.62 as a function of changes in v/c which is moderately acceptable with the level of significance of R-squared = 44%.

* Keywords: Traffic network analysis, BPR function, TTV function, Illegal occupancy, Dhaka City
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Figure 2 presents the travel time and delay time information with the time of day on the horizontal axis and the travel and delay time in minutes on the vertical axis. The horizontal axis has been categorized into four time points such as morning, noon, afternoon and night. Two points (morning and afternoon) of them corresponds to a peak time observation. The other two points corresponds to an off-peak observation. It is evident that there is an upward direction from morning to afternoon and downward direction from afternoon to night. Therefore, it implies that the travel time and delay time is higher during the day time than night time. On the day time, trip demand is higher owing to simultaneous combination of work trip, business trip, shop trip, educational and recreational trips. As a result, since trip demand is increased so speed is reduced due to traffic congestion and eventually travel time is increased on the day time than night time.

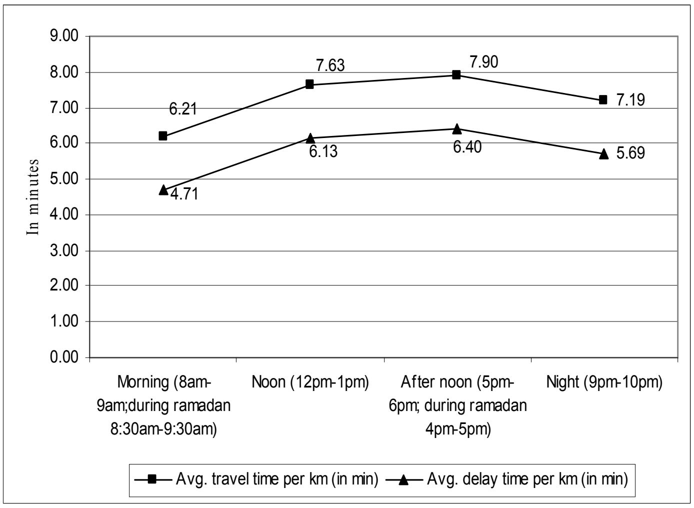

Figure 2: Travel time and delay time by time period

Figure 3 delineates percentages with time segment a day on horizontal axis and percentages on vertical axis. The time segment has been also categorized into four time slots. Two (morning and afternoon) of them are treated as peak time and others (noon and night) are off-peak time. From the figure it is apparent that afternoon is mostly affected by the illegal on-street parking and street occupancy because of floating shops and resting vehicle on the streets. Figure 4 exhibits the illegal occupancy in percentages by various vehicles and shops according to time segment a day. From Figure 3, it was found that afternoon is mostly affected by illegal occupancy. From Figure 4, it was found that most of the illegal occupants are microbus in afternoon. On the other hand, CNG, car and rickshaw are the highest as illegal occupants in morning, noon and night respectively.

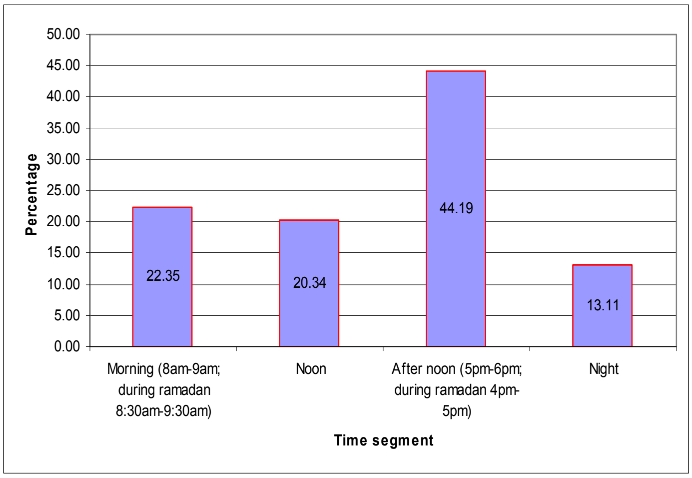

Figure 3: Distribution of illegal occupancy by time period

Table 1 illustrates the relationship by analyzing the co-efficient of correlation between illegal occupancy and some selected TTV factors in percentages. From Table 1, it can be observed that the strength of relationship is very strong between illegal occupancy and other factors. The changes of average delay time (which is related to travel time) have the highest coefficient of correlation (0.983) which was also highly significant as P-value < 0.05. On the other hand, the changes of average speed and changes of average travel time didn't meet the minimum significance level statistically.

Table 1: Correlation co-efficient (r) between illegal occupancy in percentage and some selected factors

Variables	Illegal occupancy (%)	Change of avg. travel time per km in min in %	Change of avg. speed (km/hr) in %	Change of volume-to-capacity (v/c) in %	Change of avg. delay time min/km in %	Change of avg. PCU lane/15 min in %
Illegal occupancy (%)	1.00	0.841	0.815	0.974 *	0.983 *	0.977 *
p-value	-	0.159	0.185	.026	0.017	0.023

* Correlation is significant at the 0.05 level

3. Travel Time Variability

Chen et al. (2003) stated that the travel time variability is proportional to the mean travel time. Figure 5 shows the relationship between the coefficient of variation and mean travel time for different time segments a day over the weekdays. Having observed line plots of mean travel time and coefficient of variation in different time slots, it was found that approximately each mean travel time level has a certain variability associated with it. Figure 5 shows the mean travel time and variability as a function of time of day using data from all weekdays. The mean and variability of travel times are calculated by observations in the same 15-minute time window across all weekdays. It can be seen that the higher travel times in the morning off-peak and afternoon peak have the lower variability but the smaller mean travel time in the morning peak has the higher variability than other times in the day.

4. Volume – Delay Function

Travel time (per unit distance) is the inverse of speed. Thus, delays rise as speeds fall. And, speeds fall as density/capacity rises. Density or capacity rises as more and more users compete for limited road space, entering the facility and reducing inter-vehicle spacing, causing speeds to fall. Fortunately, densities can rise fast enough to offset reduced speeds, so that their product (i.e., flow) rises. But flow can increase only so far: in general, it cannot exceed capacity. As soon as demand for travel across a section of roadway exceeds capacity, flow at the section "exit" will equal capacity, and a queue will form upstream, causing average travel times across the congested section to rise. Unfortunately, these travel times tend to rise exponentially, as a function of demand for the scarce road space. Thus, only moderate additions to demand can dramatically impact travel times. And if the resulting queuing impedes other system links, the delay impacts can be even more severe.

Referred to as the "BPR (Bureau of Public Roads) Formula" (FHWA 1979), the following is a common travel-time assumption:

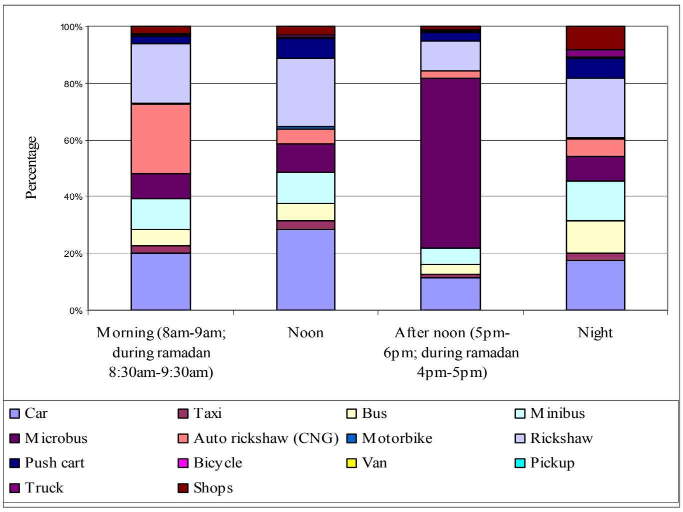

Figure 4: Percentage of illegal occupancy by vehicles

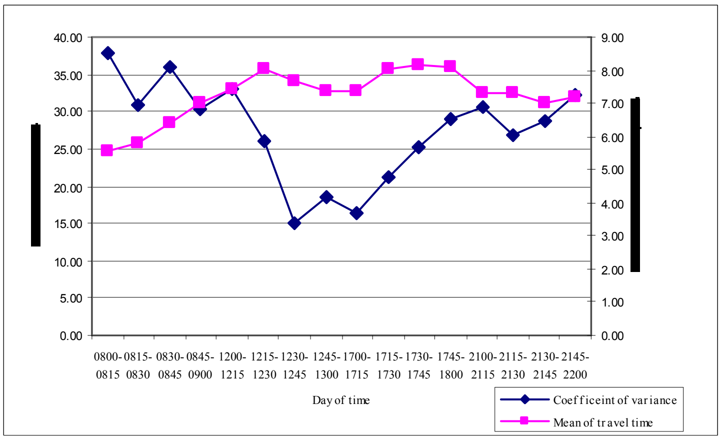

Figure 5: Mean travel time and coefficient of variance

$$T_a = T_0 \left(1 + \alpha (V/C)^{\beta}\right) \qquad (1)$$

where, T_a indicates the congested travel time, T_0 refers to free-flow travel time, V is link traffic volume, C is link capacity, α and β are parameters (generally $\alpha = 0.15$ and $\beta = 4.00$ in case of USA).

Alpha (α) is the scale parameter and beta (β) is the shape parameter. These α and β can vary city to city. This equation assumes that parameter α is the ratio of travel time per unit distance at practical capacity to that at free-flow, and parameter β determines how fast the curve increases from the free-flow travel time.

Modifications in BPR factors and the underlying formulae can have dramatic impacts on travel time estimates, travel demand predictions and policy implications. Yet actual travel time relationships remain poorly understood in developing cities like Dhaka. Illegal on-street parking and shops occupy edge of road sections which makes complexity of traffic flow and eventually it precedes higher travel time.

Example of Temporary Lane Loss

If capacity of 10,000 vehicles per hour corresponds to a four-lane high-design freeway, then the loss of one of these four lanes (by a crash or creation of a construction work zone or illegal occupancy, for example) results in an effective capacity of 7,500 vehicles per hour. At a demand of 13,000 vehicles per hour, travel times will jump by 115 percent, from 2.0 minute per mile to 4.3 minute per mile. This is now 330 percent longer than travel time under free-flow conditions. Under this dramatic situation, speeds would be just 14 mile per hour – far less than the free-flow speed of 60 mile per hour and well below the four-lane speed of 30 mile per hour (Kockelman, 2003).

The reason that travel times rise so dramatically once demand exceeds capacity or congestion is severe, and/or capacity is reduced caused by illegal occupancy, is that a roadway can accommodate no more flow. It behaves much like a funnel or pipe that can release only so much fluid per unit of time. Any additional users will be forced to form a slow-moving queue, backing up and impacting the rest of the system. This is a classic bottleneck situation, where demand exceeds supply or unexpected traffic congestion due to poor traffic management. Capacity-reducing incidents can affect supply instantly, leading to essentially the same low-speed, high-delay conditions for which recurring bottlenecks are responsible. Unfortunately, there is no guarantee that congestion can be altogether avoided; supply disruptions, through incidents and the like, can occur at most any time.

5. A New Travel Time – Volume (TTV) Function with Illegal On-Street Parking and Street Occupancy

As discussed earlier, BPR function proposed by Federal High Way Administration of US Transport Department uses to achieve the effect of capacity restraint and it does not consider the illegal occupancy. So this traditional BPR function can not work properly under the severe traffic congestion due to influence of illegal on-street parking and street occupancy. In this consequence, a new BPR function named as TTV function has been introduced in this study.

(1) Function and Factors

The most widely used delay function has been modified to illustrate the TTV function parameters incorporating the illegal on-street parking and street occupancy.

The new TTV function has been explained by incorporating the illegal on-street parking and street occupancy in the volume-to-capacity ratio part considering peak and off-peak time together. It infers that the illegally occupied lane has been deducted so eventually the capacity has been reduced in this case.

The new TTV function is expressed by the following equation:

$$\text{TTV Function:} \quad T_a = T_0[1 + \alpha(V/(C - C_{io}))^{\beta}] \qquad (2)$$

where, T_a refers to congested travel time, T_0 is free-flow travel time, V is link traffic volume, C is link capacity, C_{io} is capacity occupied by illegal occupancy lane, α and β are parameters.

Networks originally prepared with the default coefficients of the volume-delay function (α=0.15 and β=4.0). With these coefficients, link capacity was set to design capacity, normally taken to be level-of-service C in earlier editions of the Highway Capacity Manual. More recent travel forecasting packages have generally retained these traditional coefficients and definition of link capacity. Technically, design capacity should be interpreted as the volume that causes free speed to drop by 15 percent. There are valid reasons for trying to retain this definition of capacity in previously calibrated networks. These coefficients/parameters are applicable/suitable for highway roads of developed countries. In previous analysis related to BPR function, the severe congestion condition due to illegal on-street parking and street occupancy is not considered.

Therefore, the current study has compensated this gap by incorporating illegal on-street parking and street occupancy resulting severe traffic congestion. The new TTV function parameters for Dhaka city were estimated using Constrained Non-linear Regression (CNLR) Model. To execute this model, the computer software SPSS (Statistical Package for the Social Sciences) was applied.

(2) Non-linear Regression Model

It is well organized that any type of statistical inquiry in which principles from somebody of knowledge enter seriously into the analysis is likely to lead to a "Nonlinear Model" (Seber and Wild, 1989). Such models play a very important role in understanding the complex inter-relationships among variables. A nonlinear model is one in which at least one of the parameters appears nonlinearly. More formally, in a nonlinear model, at least one derivative with respect to a parameter should involve that parameter. Nonlinear regression is a method of finding a nonlinear model of the relationship between the dependent variable and a set of independent variables. Unlike traditional linear regression, which is restricted to estimating linear models, nonlinear regression can estimate models with arbitrary relationships between independent and dependent variables. This is accomplished using iterative estimation algorithms.

(3) Nonlinear Regression Parameters

Parameters are the parts of this model that the nonlinear regression procedure estimates it. Parameters can be additive constants, multiplicative coefficients, exponents, or values used in evaluating functions. All parameters that are defined appear with their initial values. It is required to specify a starting value for the parameter, preferably as close as possible to the expected final solution. Poor starting values can result in failure to converge or in convergence on a solution that is local (rather than global) or is physically impossible.

(4) Choice of Initial Values

All the procedures for nonlinear estimation require initial values of the parameters and the choice of good initial values is very crucial. However, there is no standard procedure for getting initial estimates. The most obvious method for making initial guesses is by the use of prior information. Estimates calculated from previous experiments, known values for similar systems, values computed from theoretical considerations all these form ideal initial guesses.

(5) Goodness of Fit of a Model

For nonlinear regression model, this is generally assessed by the coefficient of determination, R-squared. However, as pointed out by Kvalseth (1985), eight different expressions for R-squared appear in the literature. One of the most frequent mistakes occurs when the fits of a linear and nonlinear model are compared by using the same R-squared expression but different variables. Thus, for example, a power model or an exponential model may first be linearized by suing a logarithmic transformation and then fitted to data by suing ordinary least squares method. The R-squared value is then often calculated using data points ($\log_e y_i$, $\log_e \hat{y}_i$). The R-squared is generally interpreted as a measure of goodness of fit of even the original nonlinear model, which is incorrect. Scott and Wild (1991) have given a real example where two models are identical for all practical purposes and yet have very different values of R-squared calculated on transformed scales.

Kvalseth (1985) has emphasized that, R-squared given below is quite appropriate even for nonlinear models.

$$\text{R-squared} = 1 - \Sigma(y_i - \hat{y})^2 / \Sigma(y_i - \bar{y})^2 \qquad (3)$$

(6) Parameters Estimation

To determine the parameters α and β, the functional form of TTV function was first transformed as follows:

$$\text{Log } (T_a/T_0 - 1) = \log \alpha + \beta \log(V/C - C_{io}) \qquad (4)$$

A constrained nonlinear regression analysis was performed assigning Log (T_a/T_0 -1) as dependent variable and log α, and β log(V/C) as independent variables. In this model, α and β were defined as parameters to be estimated. The information on road lane capacity *C* was borrowed from STP (Strategic Transport Plan for Dhaka City) report conducted by DTCB (Dhaka Transport Co-ordination Board) and the data on travel time and traffic volume used in the analysis were collected from the field survey directly in August and September in 2009.

It is already mentioned earlier that in the TTV function, alpha is the scale parameter and beta is the shape parameter. That means, the alpha value determines how much speed is less or how much travel time is increased compared with free flow condition when volume equals to the capacity. On the other hand, the beta value determines how fast the curve increases from the free-flow travel time. From Table 2, the value of alpha parameter is 3.59 and value of beta parameter is 0.40. The value 3.59 was found by incorporating the illegal on-street parking and street occupancy considering peak and off-peak together. So it can be commented that travel time is increased by 359% i.e. 3.59 times.

Table 2: Parameter estimation results of TTVF

Types	TTV function parameters (N = 480; free flow 60km/hour)		Goodness of fit
	Alpha (α)	*Beta (β)*	R^2
TTV Function	3.59	0.40	0.60

In terms of beta values, as it is not high for this case so it signifies that the speed does not drop abruptly. Indeed, it is already dropped due to severe traffic congestion in Dhaka city. With the parameters determined, the travel time – volume relationship (modified new BPR function) with considering the influence of illegal on-street parking and street occupancy can be represented by the following equation:

$$\text{TTV Function:} \quad T_a = T_0[1 + 3.59(V/(C - C_{io}))^{0.40}] \qquad (5)$$

By considering the statistical measures of the model for TTV function parameter estimation, the obtained R-squared shows better performance as a model. The overall fit of the model is reasonable with R-squared value more than 0.60 which means the estimated parameters in the model are statistically significant.

6. Implications of TTV Function Curves

Even with the introduction of the illegal on-street parking and street occupancy, the newly developed travel time – volume equation is still considered a variation of the standard BPR function but which is for developing countries. The most appealing feature of this type of equation is its simplicity. Traffic forecasting models must be able to analyze thousands of links in each model run. Use of a simple equation rather than a complex procedure to estimate link speed can reduce processing time. Also, the simple data requirements of the travel time – volume curve will facilitate data entry for modelers and planners.

The traffic forecasting models generally require that travel time be a monotonically increasing function of volume to ensure that a single user equilibrium solution can be found for the traffic assignment problem. Given that travel speed is the inverse of travel time, this means that the travel speed needs to be a monotonically decreasing function of volume. As discussed earlier, the functional form of the speed–flow curve satisfies this condition.

Figure 7 shows the comparison of TTV curve between developed (USA and

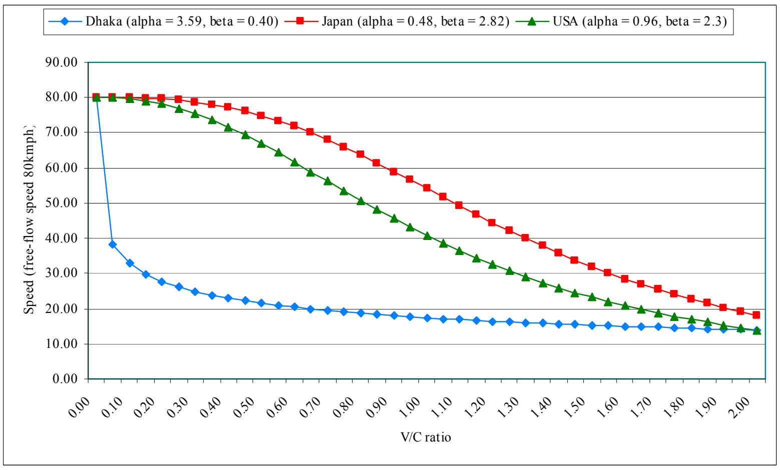

Figure 7: Comparison of TTV parameters between developed (USA and Japan) and developing (Dhaka, Bangladesh) countries

Japan) and developing (Dhaka, Bangladesh) countries. From this figure, it can be observed that there is a big difference between developed and developing country in case of scale parameter of the curve. The shape parameter of curve in case of USA and Japan implies the nature of abruptness of speed. On the other hand, steady shape in case of Dhaka implies lower value of beta (β) and speed is not dropped abruptly.

Some interesting properties of the speed–flow curves may be explored through considering the illegal on-street parking and street occupancy. First, the functional form performs reasonably under certain extreme conditions. For example, when V is close to zero, or $V \rightarrow 0$, indicating a near free flow condition, the congested travel time estimated from the equation is close to the free-flow travel time, or $T_a \rightarrow T_0$. Also, when illegal occupancy = 0, meaning there is no illegal occupancy, the functional forms of TTV becomes the standard BPR function, although the values of coefficients are different.

The BPR function represented by Equation 1, the multiplier is 0.15, indicating there is a 15% drop in speed when the volume approaches capacity. For the newly developed TTVF, the multipliers are a monotonically increasing function of illegal occupancy, which means the estimated speed will drop at the value of alpha when the V/C ratio is close to 1 or greater than 1. According to table 2 and equation 5, there is a 359% drop in speed when illegal on-street parking and street occupancy is considered under the severe traffic congestion condition. Finally, a smaller value of exponent β of V/C in the TTVF indicates that the speed is not abruptly dropped.

7. Concluding Remarks

This paper presented the new modified BPR function named as TTV function by incorporating the influence of illegal on-street parking and street occupancy and to make it authentic, Dhaka city was selected as study area. At the same time, it is also accounted for the impact of illegal on-street parking and street occupancy. The traditional BPR function representing the speed–flow relationships for roadway facilities is modified to TTV function specifically include impact of the severe traffic congestion condition caused by illegal on-street parking and street occupancy.

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