

A Study on Factors for Travel Time Variability in Dhaka City Corporation Area

A.H.M. Mehbub Anwar*

Abstract

Knowledge of travel time variability is valuable for improving the reliability of traffic information services and increasing the accuracy of travel time predictions. The paper attempts to explore the travel time variability in Dhaka city with the data collected by the probe vehicle. A comprehensive investigation of travel time distribution was conducted in terms of various time windows. With respect to travel time variability, approximately each mean travel time level has a certain variability associated with it. It has been observed that the higher travel times in the morning off-peak and afternoon peak have the lower coefficient of variance but the smaller mean travel time in the morning peak has the higher variability than other times of the day. The travel time variability has also been investigated by multiplicative nonlinear regression model. To establish the model, delay time (delay), volume-capacity (V/C) ratio and congestion index (CI), which is actual travel time divided by free flow time, were considered as explanatory variables while logarithm of travel time was used as dependent variable.

Introduction

The intention of this article is to develop an econometric model that predicts travel time variability. Prior to the discussion on econometric models, some general information about travel time variability has been assessed. The results presented in this paper gave insights in the empirical relationship between travel time variability and mean travel times as well as other variables, such as delay, congestion index, volume-capacity ratio etc. A reliable traffic system indicates that travelers can anticipate their travel times accurately before their trip, based on the experience gained from the past trips. In that sense, the measurement of reliability is how stable rather than severe the congestion is from day to day. Therefore, travel time variability can be used for evaluating the reliability of transportation systems. A high degree of variability indicates that the travel time would be unpredictable and the traffic service is less reliable (Turochy and Smith, 2002). From the traveler's perspective, a decrease in travel time variability reduces the uncertainty in decision-making about departure time and route choice as well as the anxiety and stress caused by such uncertainty (Sun, *et al.* 2003).

Previous qualitative studies found that users value the reliability of a transport system more highly than other features (Lam and Small, 2001, Bates *et al.* 2001). Bates, *et al.* (2001) pointed out that a reduction in variability is as valuable as the reduction of mean travel time or even more valuable in some situations. They further proposed that the median and the distribution of travel times are better measures than the mean travel time. However, the extent of research into the travel time variability is rather small compared to the efforts that have been done in analyzing mean travel time and measuring

* Associate Professor, Urban and Rural Planning Discipline, Khulna University, Khulna 9208, Bangladesh. Email: ahmma324@uowmail.edu.au, mehbub30@yahoo.com

behavioral reactions to the change of travel time variability. This is due, at least partly, to the fact that there is limited knowledge regarding the distribution of travel time because of the lack of a large enough sample of real travel time data.

In reliable transport system, the travellers can anticipate required travel time to complete the trips. But if the traffic system is composed with severe traffic congestion like Dhaka city, it is unpredictable to make trip schedule for travellers. Due to severe traffic congestion in Dhaka city, it is assumed that transport system is not trustworthy and the travellers loss many work hours which is directly related to national development. Therefore, this is the right time to analyze the factors that put significant effects on travel time variability in quantitative way in the severe traffic congestion condition.

In the above context, the objective of this paper is to analyze travel time variation/distribution properties from various time windows and identify the contribution of factors to travel time. The nonlinear regression methodology has been used to identify the sources of travel time variability.

Previous Studies

So far, only little research has been done in the field of explaining travel time variability. Uncertainty and variability in travel times related to them have attracted the attention of researchers and practitioners only in recent years. But this kind of work has not been done before for Dhaka City. As a result, the policy makers as well as transport planners will be benefitted from the outcome of this research.

A research that is similar in its focus as this one has been done by Eliasson (2006). He uses an econometric model and finds a nonlinear relationship between the relative standard deviation of travel time (standard deviation divided by travel time) and the relative increase in travel time (travel time divided by free-flow time) on urban roads. Interestingly, he shows that these two variables are not positively related for all congestion levels. If congestion is very severe, relative standard deviation is a decreasing function of the relative increase in travel time. Other explanatory variables are not included in the model as their contribution in increasing the explanatory power of the model was only minor. Gilliam (2008) also researched on travel time variability in an urban context by means of regression models. He relates a coefficient of variation of travel times (defined as standard deviation divided by mean travel time) and a congestion index (actual travel time divided by free flow time) to each other, using GPS (Global Positioning System) data. Not only do they find a positive relation between these two factors, but also between the coefficient of variation and the length of the road stretch. Li (2004) uses individual car data on urban toll roads to investigate vehicle-to-vehicle variability (travel time variability between drivers who depart within the same time slot) and variability between different time slots. Latter, he again decomposes into variability induced by demand and supply related factors. He finds that during morning peak, demand related factors play a major role, whereas in the afternoon peak, supply related factors become more important. As intended in this paper, Kouwenhoven *et al.* (2005) also use regression analysis as a mean to predict travel time variability. They find that variability is strongly correlated to mean speed but do not find a correlation between variability and exogenous factors such as incidents or weather. However, the latter shows to influence mean speed resulting in an indirect effect on travel time variability.

Fosgerau (2008) does not use regression models to explain travel time variability. Instead, he uses Jensen's inequality to theoretically prove that whenever mean travel times are increasing between two time periods, the standard deviation of travel times increases as well during the same time. As this is also the case at the point where mean travel time peaks, a loop comes into being as soon as mean travel time decrease. Hence, Fosgerau provides a theoretical explanation for the looping phenomenon that is often observed in travel time distributions (Eliasson, 2006, Franklin and Karlstrom, 2008).

Another line of research that is more technical in its origin is not to forecast travel time variability by regression models but rather to find ways of predicting it directly within traffic assignment models. Although in most cases traffic assignment models with the ability to forecast travel time variability have not become fully operational yet, considerable advancement can be seen in this area (Li, 2009). The results presented in later sections of this paper are empirical. Emphasis is not put on modeling structural relationships between single events (e.g. weather conditions, incidents) and congestion pattern but rather on the analysis of aggregate travel time distributions.

Data Sources and Methodology

Most of the data of this research was collected from primary source. Nevertheless, a substantial amount of information regarding this research was also collected from secondary sources. However for primary data relating to traffic count survey, the following features were emphasized:

- Identification of links of Dhaka city;
- Traffic volume;
- Travel time with a probe vehicle;
- Link length and road width (no. of lanes); and

The field study was carried out in Dhaka city from the early August 2009 to mid-September 2009. For the traffic count survey, the 30 links (Figure 1) over Dhaka City Corporation (DCC) area were selected randomly by considering the characteristics of main corridor, connected to commercial, educational and residential areas and it was also intention to cover entire Dhaka city approximately. The traffic count survey was implemented in work days i.e. from Sunday to Thursday. Two links were surveyed each day and traffic was counted for four hours per link. Each hour was divided into four time segments as follows:

| 08:00 to 09:00* | 12:00 to 13:00 | 17:00 to 18:00* | 21:00 to 22:00 |
|-----------------|----------------|-----------------|----------------|
| 1. 0800 – 0815 | 1. 1200 – 1215 | 1. 1700 – 1715 | 1. 2100 – 2115 |
| 2. 0815 – 0830 | 2. 1215 – 1230 | 2. 1715 – 1730 | 2. 2115 – 2130 |
| 3. 0830 – 0845 | 3. 1230 – 1245 | 3. 1730 – 1745 | 3. 2130 – 2145 |
| 4. 0845 – 0900 | 4. 1245 – 1300 | 4. 1745 – 1800 | 4. 2145 – 2200 |

* During Ramadan, a changed survey times 08:30 – 9:30 and 15:30 – 16:30 were applied only in morning and afternoon respectively.

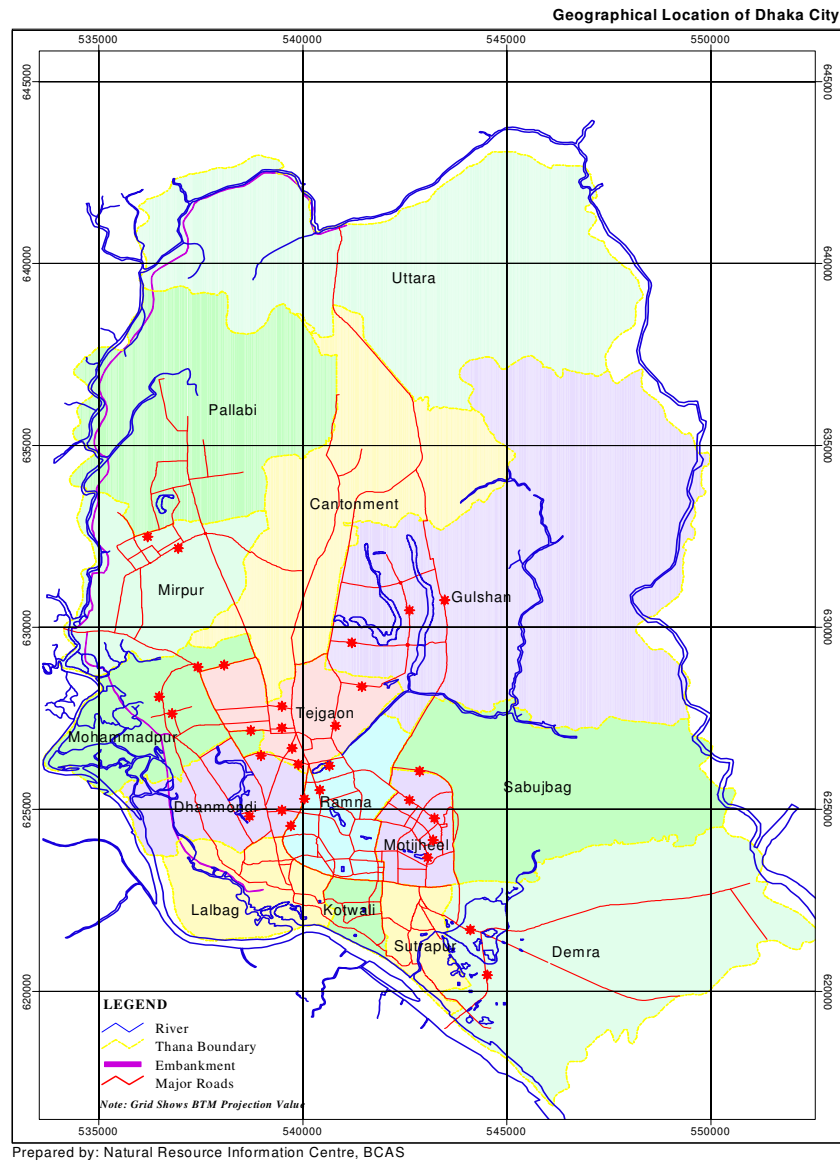


Fig. 1: Location of surveyed links on Dhaka City map

In terms of travel time survey, a car was rented as probe vehicle. The car was driven through all the selected links and the travel time was counted by the author at the same 16 times as traffic count survey a day in between 8:00 to 22:00. On the other hand, 100 sample households were interviewed to know the travel time variability for a common trip such as school trip or work trip. The households were selected randomly around the selected links.

In this research, relevant and required factors were investigated i.e. (i) travel time variability; (ii) congested travel time; (iii) free flow travel time; (iv) traffic volume; (v) traffic capacity; and (vi) link length and road width. With these collected data, the delay time was calculated by deducting the congested travel time from free flow travel time. In

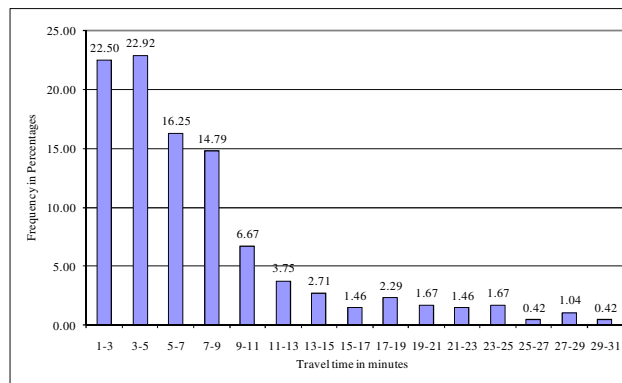
this research, 60km/hr was assumed as free flow speed. Multiplicative nonlinear regression model was applied in this study to examine the travel time variability by estimating the parameters. Amount of travel time depends on free flow time, systematic delay and unexplained delay which have been discussed in the later part of this paper. Among these variables, systematic delays caused by for example peak and off-peak hours and unexplained delays caused by for example congestion are directly involved to determine the travel time variability. Again, the level of volume-capacity ratio postulates the congestions. So, to examine the travel time variability, delay, congestion index and V/C were inputs as independent variables, whereas travel time variability was considered as dependent variable using multiplicative nonlinear regression model.

Travel Time Distribution

Travel time distribution properties provide a valuable basis for travel time prediction and estimation models based on statistical techniques, as well as traffic and driver behavior simulation. The study of travel time distribution has attracted research interest for many years. The early research mainly suggested two kinds of travel time distribution; namely, the normal distribution (Smeed and Jeffcoate, 1971) and the lognormal distribution (Richardson and Taylor, 1978). However, due to the limited capacity to collect travel time data at the time of these earlier studies, the data used to derive the travel time distribution was collected over different links during different time windows over the day.

Recently, Kwon, *et al.* (2000) analyzed the daily pattern of travel times observed from probe vehicles. Their analysis revealed that the distribution of travel time was skewed to the right. One drawback in their research approach is that the sample size of travel time collected from probe vehicles was so limited that they had to interpolate the values of travel time between two consecutive runs. Work performed by Sun, *et al.* (2003) investigated the distribution of travel time in a one and a half hour travel time window (8-9.30am) on one day by analyzing 500 samples from two video detectors spaced 130m apart. The study found that the travel time distribution was not symmetrical, indicating that the mean and median value would not be same.

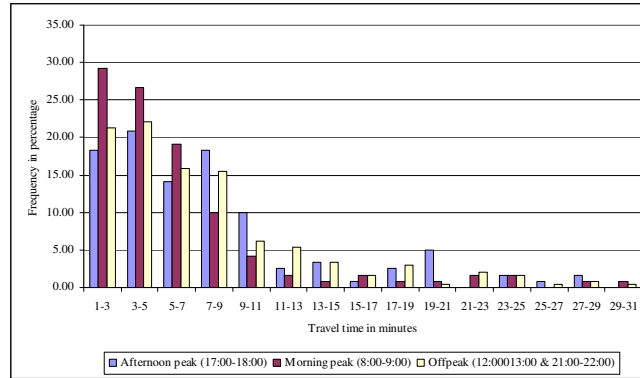
Figure 2 shows the distribution of car travel times per kilometer in Dhaka City over 15-days duration in all weekdays in August – September, 2009. Observations conducted between 8:00 to 9:00, 12:00 to 13:00, 17:00 to 16:00 and 21:00 to 22:00 have been included in this analysis. It is clear that this distribution is highly skewed with a flat and long right tail.



Source: Field survey, 2009

Fig. 2: Distribution of car travel time per km in minutes: all weekdays over 15-day duration

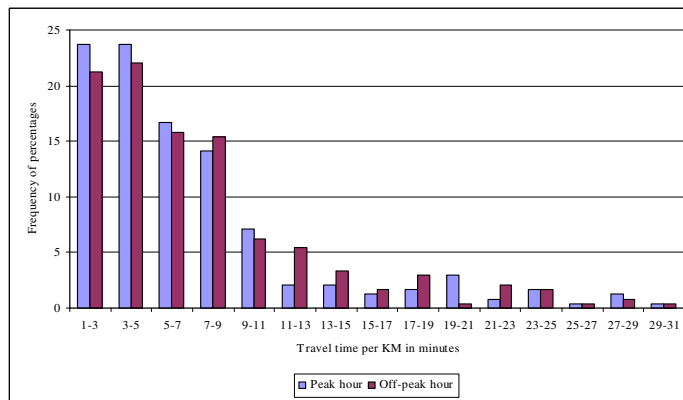
Figure 3 shows the distribution of car travel time for different time periods. It can be seen that in a comparative sense, the distribution of travel times under morning peak condition has the long right tail, whereas the travel times in the afternoon peak and off-peak presents the most skewed distribution also. This highlights that the variability between peak and off-peak travel times show the lowest variability for this area.



Source: Field survey, 2009

Fig. 3: Distribution of car travel time per km for different time windows flow: all weekdays over 15-day duration

Additional insight can be obtained by reducing the time window associated with the travel time distribution, to say, one hour. Figure 4 shows the distribution of travel times in one-hour time window reflecting peak and off-peak conditions. It can be seen that the travel times in a one-hour time window differ from a normal distribution for both flow conditions which illustrates the skewed distribution.



Source: Field survey, 2009

Fig. 4: Distribution of car travel time in a one-hour time window (peak and off-peak hour)

Table 1 shows the descriptive statistics of travel time distribution in different time windows. The high value of skewness indicates that the distribution is asymmetrical. The kurtosis value is used to measure the weight of tails relative to the rest of a distribution. The kurtosis will increase as the tails of a distribution become fatter and will decrease as the tails become thinner. A normal distribution has zero skewness and kurtosis of 3. It indicates that the distribution become asymmetrical.

Table 1: Travel time distribution in different time windows (in minutes)

| Distribution (per km in minutes) | Mean | Standard deviation | Variance | Skewness | Kurtosis |
|-----------------------------------|------|--------------------|----------|----------|----------|
| Peak hour travel time | 7.05 | 5.85 | 34.25 | 1.85 | 3.29 |
| Off-peak hour travel time | 7.41 | 5.75 | 33.06 | 1.62 | 2.63 |

Source: Field survey, 2009

Table 1 also shows the travel time differences between peak and off-peak hours. The difference of mean travel time of peak and off-peak hours is 0.36 minute, which is not substantial amount to distinguish peak and off-peak conditions. The author’s observation is that it is quite difficult to differentiate peak and off-peak in Dhaka city because of severe traffic congestion on the entire day. In the case of this research, theoretically peak hour was considered from 8:30am to 9:30am and 5:00pm to 6:00pm in weekdays which is very commonly assumed, considering office opening and closing times in the morning and afternoon respectively.

Van Lint, *et al.* (2004) analyzed the distribution of travel times in a small time window (1minute) and also found that it is approximately normal. But present results suggest that the analysis of travel time distribution in different time windows indicates that the distribution tends towards a skewed distribution in Dhaka City.

Travel Time Variability

The travel time variability in this research has been discussed as the decomposition of travel time into free flow travel time (the minimal travel time without congestion) and delay. Some delays can be anticipated and therefore does not cause uncertainty, e.g. the systematic variation with time of day (peak versus off-peak) or day of week (weekday versus weekend). Therefore, delay is further decomposed into systematic delay, which can be explained by observed characteristics of the trip, and unexplained delay, which cannot be foreseen and taken into account:

Responsible for occurring
travel time variation

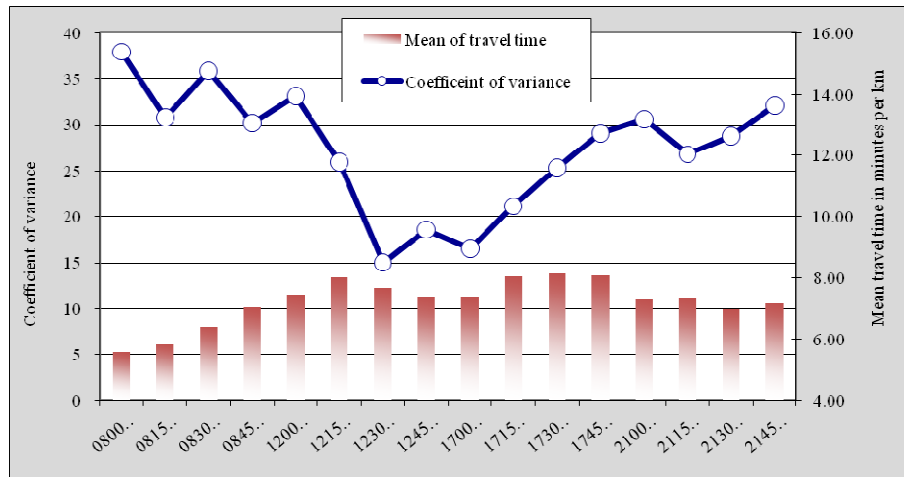
$$\underbrace{\hspace{15em}}_{\text{Responsible for occurring travel time variation}}$$

$$\text{Travel time} = \text{free flow time} + \text{systematic delay} + \text{unexplained delay} \tag{1}$$

While the distinction between free flow time and delay is straightforward, the distinction between systematic and unexplained delays is somewhat ambiguous. It depends on how much is known about the trip, and hence is a matter of perspective. From the traveler’s point of view, unexplained delay is everything he cannot foresee; such as additional travel time caused by random demand fluctuations or capacity reductions due to on-street occupancy, accidents, unannounced road works etc. However, travelers may differ in their perspective depending on how well they know the trip, as experienced travelers may be able to foresee a greater part of the demand variation or have knowledge about the likelihood of delays due to accidents or other reasons.

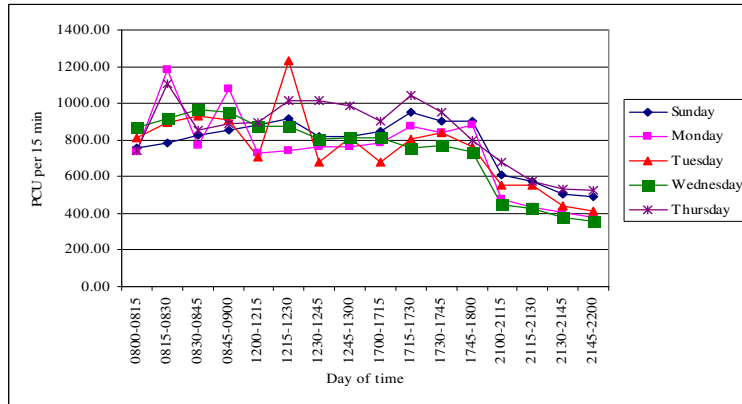
In the literature, systematic and unexplained delays are often referred to as recurrent and non-recurrent delays, respectively (Bates et al., 2001, Noland and Polak, 2002). Fosgerau *et al.* (2008) further decomposes non-recurrent delay into “usual” variability (random day-to-day variation, which causes travelers to use safety margins to reduce the risk of being late), and unpredictable long delays that are so long and infrequent that applying extra time margins to allow for them is unreasonable. This distinction has not been applied here as it is not very clear cut and as it is not apparent that it is meaningful from the point of view of the traveler.

Chen, *et al.* (2003) stated that the travel time variability is proportional to the mean travel time. Figure 4 shows the relationship between the coefficient of variance and mean travel time for different time segments a day over the weekdays. Having observed bar plots of mean travel time and line plots of coefficient of variance in different time slots, it was found that approximately each mean travel time level has a certain variability associated with it. The variation of demand results in the time to time flow fluctuations, whereas the variation of capacity results from the illegal street occupancy, roadwork etc. Figure 5 shows the mean travel time and variance 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 coefficient of variance but the smaller mean travel time in the morning peak has the higher variability than other times in the day.



Source: Field survey, 2009

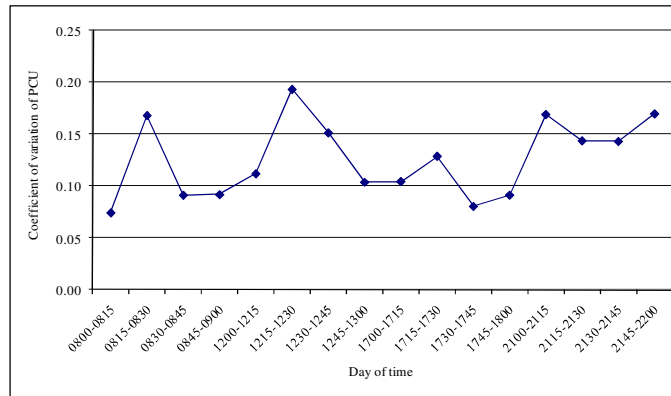
Fig. 5: Mean travel time and coefficient of variance according to the time of day over all the weekdays



Source: Field survey, 2009

Fig. 6: Flow of variability in PCU by day of week

The flow analysis, in Figures 6 and 7, shows that this high variability corresponds to high flow variability in the noon. The variability is not homogeneous over the day. The lowest variability is observed in morning time and it is gradually increasing and decreasing over the day. However, the overall variability is reduced due to severe traffic congestion. It is, therefore, important to consider the interaction between various factors when analyzing travel time variability.



Source: Field survey, 2009

Fig. 7: Flow of variability in PCU by the time of day

Travel Time Variability Analysis by Multiple Regressions

The final component of the analysis focuses on identifying the factors of travel time variability. Multiple regressions were used to represent the variation in the dependent variable (travel time variability) as a function of the explanatory variables.

This section consists of multiplicative nonlinear regression models to determine the effects of selected relevant factors in travel time variability. The models including delay time (delay) determined as difference between free flow time and actual travel time, volume-capacity (V/C) ratio and congestion index (CI - actual travel time divided by free flow time) as explanatory variables are estimated. Later, some remarks are made about

the robustness of the results using models developed by the travel time observations conducted in Dhaka city.

It was found that a nonlinear multiplicative model of the following structure performs best in terms of predictive power:

$$\text{Travel time variability} = \beta_0 * (\text{delay})^{\beta_1} * (\text{CI})^{\beta_2} * (\text{V/C})^{\beta_3} \quad (2)$$

Considering natural logarithm on both side of equation 2, it transforms into:

$$\ln (\text{Travel time variability}) = \ln (\beta_0) + \beta_1 \ln (\text{delay}) + \beta_2 \ln (\text{CI}) + \beta_3 \ln (\text{V/C}) \quad (3)$$

Also, a linear model taking into account the same explanatory variables has been estimated. These alternative setups should give an indication on how much predictive power is lost if simpler model formulations are used as:

$$\text{Travel time variability} = \beta_0 + \beta_1 * \text{delay} + \beta_2 * \text{CI} + \beta_3 * \text{V/C} \quad (4)$$

Table 2 shows the results of these two regression models.

Table 2: Regression results of multiplicative non-linear and linear regression models

| Parameters | Multiplicative non-linear regression | | Linear regression | |
|-------------------------|--------------------------------------|----------------|--------------------------|----------------|
| | Standardized Coefficient | Standard error | Standardized Coefficient | Standard error |
| β_0 (const) | 0.981 | 0.059 | 0.997 | 0.124 |
| β_1 (delay) | 0.742 | 0.052 | 0.314 | 0.121 |
| β_2 (CI) | 1.211 | 0.059 | 0.756 | 0.024 |
| β_3 (V/C) | 0.596 | 0.063 | 0.814 | 0.071 |
| R ² | 0.597 | | 0.561 | |
| Adjusted R ² | 0.584 | | 0.547 | |

Source: Field survey, 2009

As expected, all four regressions including constant term are found to have a positive relationship between the dependent (travel time variability) and explanatory (delay, CI and V/C) variables. To generalize the parameters, the *standardized coefficients* have been considered in this model. In terms of non-linear regression model, congestion index is the most concerned variable to determine the travel time variability, whereas V/C factor is the most considerable aspect in linear regression model. From the non-linear setup, it becomes clear that the marginal effects of delay on travel time variability are decreasing in delay ($\beta_1 < 1$). The same are true for the CI and V/C ratio. These are positively related to travel time variability, exhibiting decreasing marginal effects.

Comparing the two linear regressions with each other, it is found indeed that in terms of non-linear regression model, congestion index is the most concerned variable to determine the travel time variability, while V/C factor is the most important consideration in linear regression model. As expected, the linear model is worse in predictive power compared to the non-linear models. The same is true for the explanatory power, as the R-squared falls from 59.7% to 56.1% when switching from the

non-linear models to a linear one. The overall fit of the models are reasonable with R – squared of 0.597 and 0.561, which means all variables included in the model are statistically significant.

Conclusion

Travel time distribution properties were investigated in term of various time windows. It was observed that the travel time distribution tends towards a skewed distribution whether the time window is introduced or not. This finding provides a constructive theoretical foundation for the modeling of travel times. Due to the variation in the sample, the results of the analysis can be used to predict travel times on other areas in Bangladesh. In order to yield similar results for other road types, the analysis as in this paper can be done using an appropriate data set.

The model developed in this research is an improvement to existing rules-of-thumb on how to include the influential factors in travel time variability analysis. However, more research has to be undertaken to investigate relationships between variability and other factors (such as traffic management measures), which might have an impact on variability. Thus, less aggregate analyses need to be done taking into account spatial and temporal correlations among observations. An improved understanding of such underlying dynamics can then help to develop better prediction models. However, econometric prediction models based on delays, congestion index and V/C ratio as explanatory variables will hopefully not be the last step in this area of research, as they require using mean travel times predicted by traffic assignment models as an input. The travel time predictions generated by traffic assignment models have rather stringent underlying assumptions, for instance on the number of drivers using a highway. For obvious reasons, the number of drivers is based on forecasts not taking into account that more or less drivers might decide to use a road stretch depending on changes in travel time variability. It should, therefore, be an important goal of the research on travel time variability to develop models that allow predicting travel time variability in more elaborate ways rather than only on the basis of delay.

References

- Bates, J., Polak, J., Jones, P. and Cook, A. 2001. 'The valuation of reliability for personal travel', *Transportation Research Part E*, vol. 37, pp. 191-229, 2001.
- Chen, C., Skabardonis, A. and Varaiya, P. 2003. 'Travel Time Reliability as a Measure of Service', Proceedings of the 82nd Transportation Research Board Annual Meeting. Washington DC.
- Eliasson, J. 2006. 'Forecasting Travel Time Variability', Working Paper.
- Fosgerau, M. 2008. 'On the Relation between the Mean and Variance of Delay in Dynamic Queues with Random Capacity and Demand', MPRA Paper.
- Fosgerau, M., Hjorth, K., Brems, C. and Fukuda, D. 2008. 'Travel Time Variability Definition and Valuation', in URL http://www.dtu.dk/upload/institutter/dtu%20transport/rapporter/rap1_2008_travel%20time%20variability%20-%20report_v5.pdf retrieved on July 7, 2010.
- Franklin, J.P. and Karlström, A. 2008. 'Travel Time Variability for Stockholm Roadways: Modeling the Mean Lateness Factor', Working Paper.
- Gilliam, C. 2008. 'Forecasting and Appraising Travel Time Variability in Urban Areas', Association for European Transport and contributors.

- Kouwenhoven, M., Europe, R., Schoemakers, A., Transport Research Centre and Eric Kroes, R.V.G. 2005. 'Development of a Tool to Assess the Reliability of Dutch Road Networks', Association for European Transport and contributors.
- Kwon, J., Coifman, B. and Bickel, P. 2000. 'Day-To-Day Travel Time Trends and Travel-Time Prediction from Loop-Detector Data', *Transportation Research Record*, (1717), pp.120-129.
- Lam, T. C., and Small, K. A. 2001. 'The Value of Time and Reliability: Measurement from A Value Pricing Experiment', *Transportation Research E*, 37 (2-3), 231-251.
- Li, H. 2009. 'Reliability-based Dynamic Network Design with Stochastic Networks', PhD.Thesis, TRAIL Research School, Delft.
- Li,R. 2004. 'Examining Travel Time Variability Using AVI Data', paper presented at CAITR.
- Noland, R. and Polak, J. 2002. 'Travel time variability: a review of theoretical and empirical issues', *Transport Reviews*, vol. 22, pp. 39-54.
- Richardson, A.J. and Taylor, M.A.P. 1978. 'Travel Time Variability on Commuter Journeys', *High Speed Ground Transportation Journal*, vol. 12 (1), pp.77-99.
- Smeed, R.J. and Jeffcoate, G.O. 1971. 'The Variability of Car Journey Times on A Particular Route', *Traffic Engineering Control* (12).
- Sun, C., Arr, G., and Ramachandran, R. P. 2003. 'Vehicle Re-Identification as Method for Deriving Travel Time and Travel Time Distribution', *Transportation Research Record*, (1826), pp.25-31.
- Turochy, R.E. and Smith, B. L. 2002. 'Measuring Variability in Traffic Conditions By Using Archived Traffic Data', *Transportation Research Record*, (1804), 168-172.
- Van Lint, J. W. C., Tu, H. and Van Zuylen, H. J. 2004. 'Travel time reliability on freeways', Proceedings of 10th world conference on transport research (WCTR) [CD Rom], Istanbul, Turkey.