DEVELOPMENT OF A DELAY MODEL FOR ROUNDABOUTS IN KHULNA METROPOLITAN CITY, BANGLADESH

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ABSTRACT

The purpose of this research was to develop a model for estimating roundabout delay as a function of the influencing traffic and geometric factors. Nine roundabouts were selected from different areas in Khulna Metropolitan City (KMC). Circulating volume, entry volume, and entry delay were measured during peak and off-peak periods using video cameras. Data on geometric design elements including circulating width, entry width, and roundabout diameter were measured through field survey. An empirical approach was used to develop a delay model as a function of the influencing factors based on a time interval of 15 min. The analysis indicated that geometric variables have significant effects on the roundabout entry delay. Diameter of the roundabout island has the greatest influence, whereas the subject approach volume has the least influence. In the regression analysis the value of R^2 is 0.99 which is quite satisfactory. From the analysis it is observed that with the increase of Roundabout Island diameter, total stopped delay is decreased. Again with the increase of width of the circulating roadway and width of the subject entry approach, total stopped delay is also decreased.

Keywords: *Roundabout, delay, regression, SPSS, Khulna metropolitan city.*

1. INTRODUCTION

The traffic performance of a roadway network is greatly influenced by the traffic flow through intersections. Many types of traffic control are being used worldwide at intersections; including yield signs, stop signs, roundabouts, and signals. Roundabouts work better than traffic signals at intersections with low to medium traffic volumes. They reduce the overall delay, better handle intersections with high volumes of right turns, reduce fatal and injury accidents, reduce the speeds of approaching vehicles to the intersection, have lower maintenance costs, and provide an opportunity for landscaping inside the central island (Delray Beach Environmental Services, 2001).

The history of traffic circles is almost as long as that of signalized intersections. The first traffic circle concept was introduced in 1877 by French architect Eugene Henard (DeArgao, 1992). For more than three decades modern roundabouts have been used successfully throughout the world as a junction control device (Akcelik, 1997).

Roundabouts are widely used in Europe, Australia, and recently have received more acceptances in the United States and other countries like Bangladesh. Similar to other intersection control types, it is necessary for traffic engineers to have a methodology for estimating capacity and delay at roundabouts for the purpose of operational, design, and planning analyses (Al-Omari, 1996).

In Khulna Metropolitan City (KMC) traffic volume and congestion are two major problems that are severely seen at junctions at peak hours in the morning and evening. Hence traffic police need to intervene in the situation to regulate the traffic flow by over-riding the traffic control devices. Otherwise, it would be practically impossible to have normal traffic flow, especially at roundabout intersections, which is more dependent on driver behaviour and balanced traffic flow between the approaches. This Problem will continue and it may worsen in future due to the rapid growth of population and vehicle numbers in Khulna Metropolitan city.

There are about nine important roundabouts in Khulna Metropolitan City and most of them have served more than 20 years. Few studies on roundabout have been conducted on their capacity in Khulna metropolitan city; however less attention has been given to delay.

The problems associated with the delay of the roundabouts are necessarily geometric features of roundabouts such as flare and apron do not exist; in some roundabouts, there are visibilities problems caused by plants or elevated masonry and billboard. This causes the entering driver to hesitate on entering the circulating traffic, affecting the delay of the roundabouts. Besides roundabouts central islands are accessed by pedestrians and road marking signs and lights are also absent.

In this research, an effort will be made to develop an empirical model for estimating roundabout entry delay as a function of the influencing traffic and geometric factors.

2. LITERATURE REVIEW

Modern Roundabouts were first introduced in the early 1960s in England. These facilities were introduced in order to solve the problems of the existing rotaries and traffic circles. Using the principal that entering traffic yields to circulating traffic, or the "give way" rule, roundabouts proved to be a much more efficient intersection than the rotaries, and in many cases, signalized intersections (Seiberlich, 2001). Traffic delay is used for evaluating the performance of at-grade intersections controlled by stop signs, traffic signals, and roundabouts. Many studies have been conducted to develop delay models for stop signs and traffic signals, and less attention has been given to roundabouts.

The research on delay at roundabout began with the introduction of the yield-at-entry element. Tanner (1962) studied the delays at the minor stream on the basis of gap acceptance models and the analogy of traffic flow to the Poisson distribution.

McDonald and Noon (1978) studied the impact of geometric factors to delay. Mean speed and turning angle were found to be the main contributing factors and an equation to estimate delays was suggested.
The 1994 Highway Capacity Manual (HCM) (TRB 1994) used delay models for intersections controlled by stop signs and traffic signals and did not include any model for roundabouts. The 1997 HCM update (TRB 1997) and the HCM 2000 (TRB 2000) added a methodology for estimating the capacity of roundabouts, but they did not include any model for estimating the roundabout delay.

Roundabout delay has received less attention from researchers as compared to roundabout capacity. Flannery et al. (1998) made a before-and-after study to compare the entry delay for five intersections converted from stop control to roundabouts, and they found that roundabouts caused significant reductions in the entry delays. In a similar study, Garder (1999) investigated the effect of converting intersection control from a two-way stop to a roundabout at a main junction in the United States. The results indicated that the construction of the roundabout reduced the average minor streets delay by about 83% in the morning peak and by 76% in the afternoon peak. Sisiopiku and Oh (2001) made a comparison between the performances of different types of intersection control—roundabouts, yield, and two- and four-way stop control—using the SIDRA package for various volume levels, turning volume splits, number of approach lanes, and lane widths. They concluded that ''roundabouts are the best alternative design for intersections with two lane approaches that carry heavy through and/or left turning traffic volumes''.

Flannery and Datta (1997) used 16 h of field data collected by video camera to determine the critical gap for roundabout entry based on the graphical method as 3.7 s, and that based on the likelihood technique method as 3.89 s. They also derived the probability density function for the gap acceptance of roundabouts in the United States. Troutbeck (1986) utilized a dichotomized distribution to represent the roundabout headway distribution and developed a group of models for roundabout capacity and delay.

The Institute of Transportation Engineers (ITE) Technical Council Committee (Yagar, 1992) has summarized the current practice related to the use and analysis of roundabouts based on the U.K. and Australian procedures. The U.K. procedure estimates vehicle delay as a function of entry capacity, entry degree of saturation, and distribution of arrivals and services. The Australian procedure divides the traffic stream into two groups, the group of vehicles that stop and the group of vehicles that need not stop, and uses the probabilistic approach to calculate the geometric delay for each group. The ITE recommended procedure (Yagar, 1992) is based on calculating the average stopped vehicle delay on each approach as a function of the volume on the approach and the estimated capacity for that approach using an empirical formula.

Kimber and Hollis (1979) conducted a comprehensive research on traffic delay and queues at road junctions in Great Britain. They estimated vehicle delay as a function of entry capacity, entry degree of saturation, and distribution of arrivals and services.

Akcelik and Troutbeck (1991) developed a comprehensive Australian method for analysis of the capacity and performance of roundabouts. The method allows for the effects of circulating flows, entry flows, and roundabout geometry on gap acceptance parameters. The method was implemented in the SIDRA package. SIDRA was developed by Australian Transport Research Ltd. (Akcelik and Troutbeck, 1991) as an aid for design and evaluation of signalized intersections, roundabouts, two-way stop control, all way-stop control, and yield control. The software uses detailed analytical traffic models coupled with an iterative approximation method to provide estimates of capacity and performance statistics (delay, queue length, stop rate, etc.).

Most of the analytical procedures for roundabout operational analysis have been implemented in computer software. Examples for such software are (Robinson et al., 2000): ARCADY (British), RODEL (British), SIDRA (Australian), HCS-3 (American), KREISEL (German), and GIRABASE (French). There were a number of studies (Munawar, 1994; Pursula et al.,1997; Pearce et al., 2000) that used traffic simulation to analyze the traffic behavior at roundabouts assuming that vehicles enter the roundabout based on the gap acceptance concept.

In developing delay models for different types of at-grade intersections, researchers followed the theoretical approach, the empirical approach, or computer simulation. The theoretical approach (Al-Omari, 1996) relies on the theoretical understanding about driver and vehicle behaviour at the intersection. This approach may enable the researcher to extrapolate results to a wide range of cases; however, its theoretical assumptions limit its validity to represent real-world conditions. The simulation approach is similar to the theoretical approach in the sense that it is based on some theoretical assumptions about driver-traffic behaviour. However, the simulation approach allows more flexibility to include certain driver-traffic behaviour and make the models more realistic. The empirical approach relies on a more accurate understanding of the driver-traffic behaviour in the field, because it covers factors that affect the driver's behaviour that may not be represented in a theoretical equation or computer simulation. The main shortcoming for this approach, however, is that it is largely dependent on the data used in building the models and it may become limited to the ranges of that data. In this research, the empirical approach will be followed to develop models for estimating roundabout delay as a function of the influencing traffic and geometric factors.

3. METHODOLOGY

To achieve the objectives of this study, roundabout's traffic data at peak periods and geometric data were required. The geometric data should be measured correctly since geometric design will improve not only capacity and safety but also reduce delay, which is major concern for road design. A total of nine roundabouts were selected from Khulna Metropolitan City: Hotel Royal Mor, Rupsa Traffic Mor, Sat-Rasta Mor, Notun Rasta Mor, Zero-Point Mor, Power house Mor, Ferighat Mor, Moylapota Mor and Shibbari Mor. These roundabouts were chosen based on the principle of possible representative of the target population of the roundabouts in terms of size and numbers. The other roundabouts in KMC are more or less similar to each other, so these roundabouts can represent all the roundabouts in the city. Traffic volumes on circulating roadways, and both traffic volumes and queue lengths on entry approaches (for one entry at a time) were recorded simultaneously using a video camera. A camera that was located in a position to observe the queue activity of the subject entry approach and the volumes of both the entry and circulating approaches was used to videotape each sample site. Traffic volume data were collected for each separated lanes. This produced a total of 18 h of data. The locations of the roundabouts and video recording time for each roundabout are summarized in Table 1.

Table 1: Selected Roundabouts and Their Locations

Roundabout Number	Roundabout name	Location	Hours
1	Rupsa Traffic Mor	Rupsa	2
2	Hotel Royal Mor	Hotel Royal Mor	2
3	Sat-Rasta Mor	7-Rasta Mor	2
4	Notun Rasta Mor	Notun Rasta	2
5	Zero-Point Mor	Zero-Point	2
6	Power house Mor	Power house mor	2
7	Ferighat Mor	Ferighat	2
8	Moylapota Mor	Moylapota	2
9	Shibbari Mor	Shibbari	2

Geometric characteristics were obtained through field measurements during off-peak periods. Roundabout geometry included the island diameter, circulating roadway width, and entry width. Data were collected on sunny days in the summer of the year 2015 from locations with good pavement conditions and during times when there were no policemen in the area. It was not possible to collect data during congested conditions because traffic police control roundabouts during such conditions. The collected geometric data are summarized in Table 2.

Table 2: Summary of Intersection Geometry

Sl. No.	Roundabout name	No. of Legs	Number of circulatory lane	Island Diameter (m)	Circulatory roadway width (m)	Average Entry width (m)
1	Rupsa	4	2	1.9	8.3	5.7
2	Hotel Royal mor	3	2	6	9	7.4
3	7-Rasta Mor	5	2	4.9	9.95	6.1
4	Notun Rasta mor	3	2	14.5	9.8	6.4
5	0-Point	4	2	29	8.6	8.3
6	Power house mor	4	2	1.8	6.8	6.4
7	Ferighat	3	2	1.8	6.8	6.2
8	Moylapota mor	4	2	7	11	7.6
9	Shibbari	4	3	19	17	9.5

The volumes of traffic on the subject entry and circulating roadways were counted while observing the videotapes. At the same time, the queue length (number of vehicles between the entry stop line and the end of the standing queue) for the subject approach was measured based on a time interval of 15 s. A vehicle was considered as having joined the queue when it approached within one car length of a stopped vehicle and was itself about to stop (TRB 2000). The counting process was repeated every 15 s during the study period using a countdown-repeat timer on a digital watch to signal the count time. Observations were then averaged for each one minute (four observations per Minute) to calculate the average queue length. Also, the average queue lengths for other time intervals were estimated by grouping the 1 min data to obtain the 5, 10, 15, 30, and 60 min data. The average stopped delay was then calculated using the following Little's formula (Salter and Okezue 1988):

$$D=L/\lambda \tag{1}$$

where D= stopped delay time (sec); L= queue length (veh); and λ= mean arrival rate (veh/sec).

This formula has proved (Zonghong et al. 1997) to give reliable delay estimates at unsignalized intersections. In Bangladesh, According to the MoC, 2001 for conversion into passenger car units (PCU); single unit trucks and buses were rated at 3.0 PCU, Rickshaws and vans were rated at 2.0 PCU, Light Good Vehicles were rated at 1.0 PCU, Auto-Rickshaws and Motorcycles were rated at 0.75 PCU, Bicycles were rated at 0.5 PCU. Larger heavy vehicles were not available in the data. An effort was spent to cover a wide range of data for each of the measured variables to make use of the empirical procedure for model development as efficient as possible.

4. MODEL DEVELOPMENT

The accuracy of the produced delay models is affected by the sampling time interval used in data collection and reduction. The sampling time interval must be capable of handling the possible variation in delay time and providing stable intersection traffic flows. The larger the sampling time interval, the better the estimation of the average delay will be but worse the estimation of the traffic flows will be. Thus, a sampling time interval that strikes some balance should be chosen. Since the 15 min time interval is the most popular for delay analysis all over the world, it was adopted for the development of the proposed delay model. This is also consistent with HCM procedures. Table 3 shows the data ranges and their statistical characteristics based on the 15 min time interval.

Based on the 15 min time interval, and as can be seen from the correlation matrix in Table 4, diameter of the roundabout island has the greatest linear association with delay time, with a correlation coefficient of 0.847, whereas the subject approach volume Vs and circulating volume Vc have less linear associations with delay time, with correlation coefficients of 0.392 and 0.434 respectively. It can also be seen that the Subject approach volume has the lowest correlation coefficient, of 0.392.

Table 3: Data Ranges and Their Statistical Characteristics

Variable	Symbol	Mean	Standard deviation	Minimum	Maximum
Subject approach volume (pcu/h)	Vs	1394	731.859	573	2776
Circulating volume (pcu/h)	Vc	1273	646.623	510	2446
Diameter of central island (m)	Di	9.544	9.431	1.8	29
Circulating width (m)	Wc	9.694	3.073	6.8	17
Entry width (m)	We	7.067	1.239	5.7	9.5

Table 4: Correlation among Estimated Stopped Delay and Other Variables (for 15 min Time Interval Model)

Variable	Ds	Vs	Vc	Di	Wc
Vs	0.392				
Vc	0.434	0.997			
Di	-0.847	-0.616	-0.631		
Wc	-0.575	-0.381	-0.378	0.439	
We	-0.751	-0.238	-0.249	0.727	0.753

From regression analysis, it was found that the entry traffic volume, circulating traffic volume, roundabout island diameter, circulating width, and entry width had significant effects on the stopped delay, and none of them could be excluded from the model. And the following regression model was produced for estimation of the average stopped delay time,

$$Ds=81.483-0.265Vs+0.285Vc-3.117Di-5.6Wc+9.214We \quad (2)$$

where Ds= average stopped delay (sec/veh); Vs=volume of vehicles in the subject entry (pcuph); Vc=volume of vehicles in the circulating roadway (pcuph); Di=diameter of the roundabout island (m); Wc=width of the circulating roadway (m); and We=width of the subject approach entry (m), with an adjusted R^2 of 99.0% and a standard error of the estimate (SEE) of 3.031.

Table 5: Regression Results for Delay Model Using 15 min Time Interval

Predictor	Coefficient	Standard Error	T-Ratio	P-Value
Vs	-0.265	0.021	-12.421	0.001
Vc	0.285	0.024	11.703	0.001
Di	-3.117	0.290	-10.745	0.002
Wc	-5.600	0.722	-7.755	0.004
We	9.214	2.506	3.677	0.035
Constant	81.483	8.875	9.181	0.003

Note: R^2= 99.0%; SEE= 3.031

The intercept, the variables, and the regression model were all significant at 95% confidence. Regression details are as shown in Tables 5 and Tables 6.

Table 6: ANOVA

Source	DF	SS	MS	F	P
Regression	5	7285.905	1457.181	158.659	0.001
Residual	3	27.553	9.184		
Total	8	7313.458			

Note: R^2= 99.0%; SEE= 3.031

From the previous model, it can be seen that delay increases as the entry volume increases. This refers to the increase in probability of forming a queue at the roundabout entry while drivers are waiting for suitable gaps in the circulating roadway traffic. Also, the delay time increases as circulating volume increases. This is because as circulating volume increases, shorter gaps are produced, and as a result, the probability of gap acceptance for the entering drivers decreases.

The delay time has an inverse proportional relationship with circulating width. This is explained by the fact that, the drivers found sufficient space at the larger circulating width of the roundabout entries. When entry drivers look for gaps in parallel streams of traffic on the circulating roadway, they need less time to find suitable gaps and enter the roundabout.

As entry width increases, delay time decreases. This is explained by the fact that, as the number of entry lanes increases, a larger group of parallel vehicles can benefit from the same accepted gap and enter the roundabout simultaneously.

The delay time has an inverse proportional relationship with the roundabout island diameter. This is explained by the fact that, as the island diameter increases, the speeds of circulating vehicles increase, and as a result, the roundabout capacity will be increased and the delay at the roundabout entry will be decreased.

5. MODEL VALIDATION

Validation process is determining whether the selected model is appropriate for the given conditions and for the given task; it compares model prediction with measurements or observations (TRB 2005). The objective of validation is to assess the adequacy of the proposed prediction models, and measure the error or accuracy of the prediction for the validation range. There are several methods used for models validation. One of these methods is to compare the model with another data set that was not included in model building.

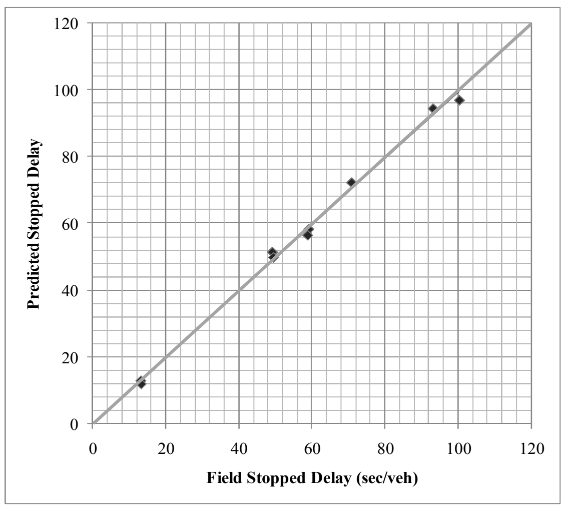

Figure 1: Proposed model versus field stopped delay

Figure 1 shows the validation of the predicted model. It is seen that the observed and predicted stopped delay are scattered around the diagonal line. This suggests that the model predicts well. Because the produced model was based on a wide range of data from different roundabout in Khulna Metropolitan City, covering different areas, the proposed model can be used in predicting roundabout delays for similar sites in other parts of the country, which has similar driver behaviour as in Khulna Metropolitan City.

6. CONCLUSIONS

The main objective of this research was to develop models for estimating the average stopped delay time at roundabouts as a function of traffic and geometric conditions. A total of 18 h of field traffic and geometric data were collected from 9 roundabouts, covering different regions in Khulna metropolitan City: Hotel Royal Mor , Rupsa Traffic Mor, Sat-Rasta Mor, Notun Rasta Mor, Zero-Point Mor, Power House Mor, Ferighat Mor, Moylapota Mor and Shibbari Mor. The study shows that the major problems are related to entry width, circulating width, high traffic flow and unbalanced traffic on the approaches which in fact, not recommended on the roundabouts. Besides, the roundabouts are built when the traffic flow was lower and without considering future traffic extension.

Using 15 min time intervals, an empirical model was developed to estimate the entry stopped delay time as a function of the entry traffic volumes, circulating traffic volumes, roundabout island diameter, circulating width, and entry width. It was found that entry delay increases with an increase in entry volume and circulating volume, and with a decrease in island diameter, circulating width and entry width. Diameter of the roundabout island has the greatest influence on the estimated entry stopped delay time, while subject approach volume has the least influence.

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