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# DEVELOPMENT OF DELAY MODELS FOR ROUNDABOUT WITH HETEROGENEOUS TRAFFIC FLOW CONDITION

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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. Three roundabouts were selected in Hyderabad.

a) A 4-legged roundabout intersection named as "Prasad Imax Junction"
b) A 4-legged roundabout intersection named as "Narayanguda Junction"
c) A 4-legged roundabout intersection named as "Barkathpura Junction"

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. correlation was done by taking average delay as dependent variable and Entry width, circulating width, Island diameter, approach volume and circulating volume as independent variables, where the coefficient of correlation(r) value shows the level of dependence. The goodness of fit of the model was assessed by the coefficient of determination ($R^2$) value and the other statistic measures like F-ratio, t-statistic.

The analysis indicated that geometric variables have significant effects on the roundabout entry delay. The entry width has the greatest influence, whereas the circulating width has the least influence. A comparison between delay models produced using different time intervals showed that, as time interval increases, the stronger the correlation.

***Keywords*****:** Intersections; Hyderabad; Delay time; Traffic flow.

## I. Introduction

### I.I. General

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. Transportation is an infrastructure facility for the economic, social, cultural and administrative development of a nation. But in order to see that interaction materialize in practice, a provision of suitable transportation system is imminent. The rapid urbanization and growth of private ownership have caused an increase in road traffic congestion and delays in most of the urban areas in India. Generally road network links in the urban areas frequently intersect thus leading to conflicts between opposing flows of traffic and to delays and accidents. As the intersections are vital points in a transportation network, their efficiency of operation greatly influence the entire networks performance. The operation of at-grade intersections may often be the critical factor in determining overall capacity and performance of city road network. In addition to that it is complicated by the fact that each intersection has its unique characteristics of physical layout, vehicle flow rates, turning movements, pedestrian movements and so forth.

Roundabouts are widely used in Europe, Australia, and recently have received more acceptances in the United States and other countries. Roundabouts work than traffic signals at intersections with low to medium traffic volumes. They reduce the overall delay, better handle intersections with high volumes of left 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.

### I.II. Delays at Roundabout Intersection

Roundabout intersections are the intersections which function without any priority assigned to the traffic on any of the intersecting roads, no control (neither STOP signs nor Police-controlled) and the traffic is of heterogeneous nature. These intersections are vital nodal points on urban roads, the performance of which will influence the traffic flow on entire network.

Delays to vehicles at urban uncontrolled intersections depend on several factors. The most important among these being the major road approach volume, type of turning movement, and vehicular composition. The extent of intersection of these factors and their collective effect on delay caused to vehicles need to be studied in detailed for better traffic management at these intersections. Field studies due to resources constraint may not include all these, the limited samples that might be obtained will be sufficient to evaluate the effect of various parameters.

Moreover, queuing theory and other mathematical relationships that had been used in most of earlier studies to estimate delay to vehicles at intersections, are not appropriate for the conditions (absence of queue) prevailing at urban uncontrolled intersections under mixed traffic condition.

### I.III. Need for the Study

The recent steep growth of traffic in and around urban areas in India created an urgent need for better management of vehicles movements along the main streams, in general, through uncontrolled intersections, in particular. In India, the problem of traffic congestion, delay, and queuing are more complex than that in western countries. This is mainly due to

- Heterogeneity of traffic flow
- Unrestricted mixing of various vehicles without their physical segregation
- Irregular lateral and longitudinal spacing among the vehicles while in queue.
- Lack of lane discipline
- Haphazard movement of vehicles and pedestrians.
- The various factors affecting the delay caused to the vehicles approaching the intersections are:
- **Physical factors**: Number of lanes, width, grades, access control, channelization and transit stops
- **Traffic factors**: Volume on each approach, turning movements, vehicle classification, driver characteristics, approach speeds, parking and pedestrians.
- **Traffic controls**: Type of control (Signals/Stop-Yield signs / police control / uncontrolled), parking regulations, prohibition of certain turning movements.

For this purpose, it is necessary to develop a model which will be useful to analyze the traffic delay and apply the results to evolve appropriate traffic management measures for safe, fast and economic movement of traffic.

### I.IV. Objectives of the Study

Based on the above discussion, the present study was taken up with the following objectives:

- To identify the study area
- To collect data on
    i. Geometric characteristics
    ii. Traffic volume study for delay studying using video photography.
- To develop a model for estimating roundabout delay as a function of the influencing traffic and geometric factors.
- 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.

## II. Literature

### II.I. Roundabout Intersections

A roundabout is a type of circular intersection or junction in which road traffic flows almost continuously in one direction around a central island.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. Roundabout delay has received less attention from researchers as compared to roundabout capacity.

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.

### II.II. Case Studies

The 1994 HighwayCapacityManual (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 modelfor estimating the roundabout delay.

Flannery et al. (1998) Madea 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.

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.

Oh and Sisiopiku (2001) made a comparison between the performance of different types of intersection control-roundabouts, yield, and two- and four-way stopcontrol—using the SIDRA(Southwestern Idaho Desert Racing Association.) 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 State.

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 analyse the traffic behavior at roundabouts assuming that vehicles enter the roundabout based on the gap acceptance concept.

### II.III. Studies with Mixed Traffic Conditions in India

Aggarwal et al. (1994) developed a simulation model for intersection of flows for mixed traffic. In this study, an attempt has been made to simulate the mixed traffic flow for a four-legged right-angled uncontrolled intersection, to estimate the total delay and queue lengths of all approaches.

Thamizh Arasan (2005) described a modeling methodology adopted to simulate the flow of heterogeneous traffic with vehicles of wide ranging static and dynamic characteristics. The simulation framework for the traffic-flow model was prepared in such a way that the absence of lane discipline in mixed traffic flow conditions is taken into account.

Satish Chandra et al. (2009) introduced a service delay model, based on microscopic analysis of delay data under mixed traffic conditions.Service delay (or Service time) is mainly depends upon the conflicting traffic volume and the priority of the movement.The mathematical relations for service delay to the different types of vehicles for a priority movement at uncontrolled intersections based on microscopic analysis are established.The proportion of heavy vehicles in the conflicting traffic was found to be greatly affect the service delay.The comparison of the proposed delay model with Kyte’s linear model shows that the linear variation of service delay is valid up to a conflicting traffic volume of 0.20 veh/s (720 veh/hr), beyond which it is exponential.The proposed model is developed for mixed traffic conditions of the type prevailing on Indian roads and can be used to better estimate the service delay to various priority movements at uncontrolled intersections.

Raghava Chari et al. (1993) developed a simulation model to study the interaction between pedestrian and vehicles at an unsignalized intersection in terms of delay suffered at an urban uncontrolled intersection under mixed traffic conditions.

Satish Chandra and Ashalatha (2010) developed a simulation model capable of simulating heterogeneous traffic flow conditions at a TWSC intersection. Driver behavior was incorporated in the model through intersection clearing time distributions. This simulation model is used for studying the effect of conflicting traffic as well as its composition on the service delay of various priority movements.

### II.IV. Multiple linear regression

Multiple linear regression attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data. Every value of the independent variable x is associated with a value of the dependent variable y. MLR is based on least squares.

Regression has long been used in dendroclimatology for reconstructing climate variables from tree rings. A few examples of dendroclimatic studies using linear regression are reconstruction of annual precipitation in the Pacific Northwest (Graumlich 1987), reconstruction of runoff of the White River, Arkansas (Cleveland and Stable 1989), reconstruction of an index of the El Nino Southern Oscillation (Michaelsen 1989), and reconstruction of a drought index for Iowa (Cleaveland and Duvick 1992). The model expresses the value of a predicted (dependent) variable as a linear function of one or more (independent) predictor variables.

$$\mathbf{Y = a_0+a_1X_1+a_2X_2+\ldots\ldots+a_nX_n}$$

Y = dependent variable

$a_0$ = regression constant

$x_1$ , $x_2$ = independent variables

$a_1$ , $a_2$ = regression coefficients

### II.V. Correlation

Correlation is a statistical measure for finding out degree of association between two or more variables.

### Coefficient of correlation

The extent or degree of relationship between two variables measured in terms of another parameter is called the coefficient of correlation.

It is denoted by r.

Let X and Y denote two variables and r denote the coefficient of correlation between X and Y. depending on the value of r, we can classify correlation as follows

(a) If r = 1 both the variables X and Y increase or decrease in the same proportion. In this case we say that there is perfect positive correlation.

(b) If r = -1 both the variables X and Yare inversely proportional to each other. We say that there is perfect negative correlation.

(c) If r = 0 we say that there is no relation between X and Y.

(d) If $0< r < 1$ , there is moderate (partial) positive correlation between X and Y

(e) If $-1< r < 0$ , there is moderate (partial) negative correlation between X and Y

### II.VI. Scope of the Work

From the review of the literature, it is clear that the most of the studies pertain to stop-sign controlled intersections handling homogeneously traffic; and only limited work has been done so far to comprehensively analyze traffic delay at roundabout intersection under mixed traffic conditions.The recent steep growth of traffic in and around urban areas in India created an urgent need for better management of vehicle movement at roundabout in particular.For this purpose, it is necessary to develop models which will be useful to analyze the traffic delay and apply the results to evolve appropriate traffic management measures for safe, fast and economic movement of traffic.

## III. Methodology

### III.I. Study Area

Hyderabad City is the 1st biggest city in the Telangana Region. It has a population of nearly 87.4 lakhs. The phenomenal increase in population coupled with growth of road vehicles has created considerable traffic problems. In addition to this, there is mixed traffic where light vehicles (2 wheelers, cars or jeeps, auto-rickshaws), heavy vehicles (buses, trucks, tractors, mini-buses or tempo-vans) and slow-moving non-motorized vehicles (bullock-carts, bicycles, cycle-rickshaws) are operating together.The potential roundabouts intersections identified for the study are:

a) A 4-legged roundabout intersection named as “Prasad Imax Junction”

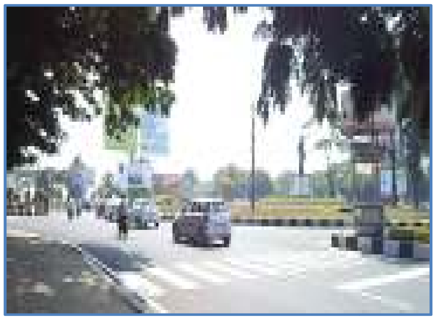

Figure 3.1 Site image of Prasad Imax Junction

b) A 4-leggedroundaboutintersection named as "Narayanguda Junction"

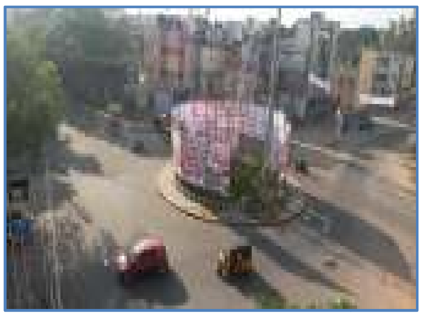

Figure 3.2 Site image of NarayangudaJunction

c) A 4-legged roundabout intersection named as "Barkatpura Junction"

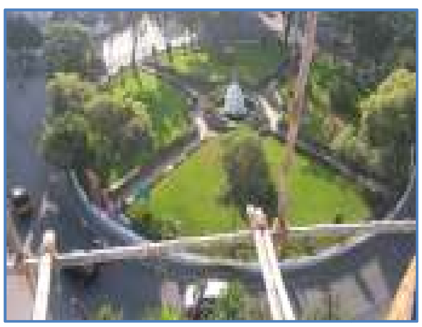

Figure 3.3 Site image of barkatpura Junction

For the purpose of modeling, three four-legged intersections with each leg of two-lane (or more) two-way traffic roads (which are more common type of intersections) were considered. For any vehicles approaching the intersection, there will be four possible turning movements of traffic, namely left turn (LT), straight or through turn (TH), right turn (RT) and U-turn.

Locations were selected based on maps and information provided by the cities' municipalities. Geometric characteristics were obtained through field measurements during off-peak periods. Roundabout geometry included the island diameter, circulating roadwaywidth, and entry width. Data were collected on sunny days in the spring 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.

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.

### III.II. Generation of Vehicle Characteristics

Mixed traffic, as already emphasized, consists of variety of modes ranging from heavy commercial vehicles to light powered bicycles. Each mode has its own distinct physical and operational characteristics which affects its behavior in the traffic. The dimensions of the vehicle, acceleration and deceleration characteristics and the mode of operation of the vehicle very much influence its behavioral properties. The traffic at these intersections in most Indian cities is highly heterogeneous comprising vehicles with different static and dynamic characteristics falling on the wide range. For the purpose of the study, the vehicles based upon the size, speed and acceleration or deceleration characteristics were grouped into the following types:

i. Cars (car/jeep/passenger van)

ii. Motor cycles (motorcycle/scooter/moped)

iii. Auto-rickshaws

iv. Heavy vehicles (bus/truck/tractor/mini-bus)

v. Non-motorized vehicles (cycle/cycle-rickshaw)

The average dimensional attributes of the five proposed vehicle categories are given in the Table-3.1.

Table 3.1 Dimensions of the vehicles

| S.NO | Vehicle Type | Length(m) | Width(m) |
|---|---|---|---|
| 1 | Heavy Vehicles (Bus/Truck) | 7.5 | 2.4 |
| 2 | Cars | 4.4 | 1.65 |
| 3 | Auto-rickshaws | 2.5 | 1.25 |
| 4 | Motorcycles | 2.0 | 0.7 |
| 5 | Bicycles | 1.9 | 0.5 |

### III.III. Delay Study at roundabout Intersection

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 15min interval data. The average stopped delay was then calculated using the following The average stopped delay was calculated using the following Little's formula (Salter and Okezue 1988).This formula has proved (Zonghong et al. 1997) to give reliable delay estimates at unsignalized intersections.

let

*D*=stopped delay time (s);

*L*=queue length (veh); and

λ=mean arrival rate (veh/s).

$D=L/\lambda$

The data of interest for each approach are the entry flow and the circulating flow. Entry flow is simply the sum of the through, left, and right turn movements on an approach. Circulating flow is the sum of the vehicles from different movements passing in front of the adjacent upstream splitter island. At existing roundabouts, these flows can simply be measured in the field. Right turns are included in approach volumes and require capacity, but are not included in the circulating volumes downstream because they exit before the next entrance

VEB,circ = VWB,LT + VSB,LT + VSB,TH + VNB,U-turn + VWB,U-turn + VSB,U-turn

VWB,circ = VEB,LT + VNB,LT + VNB,TH + VSB,U-turn + VEB,U-turn + VNB,U-turn

VNB,circ = VEB,LT + VEB,TH + VSB,LT + VWB,U-turn + VSB,U-turn + VEB,U-turn

VSB,circ = VWB,LT + VWB,TH + VNB,LT + VEB,U-turn+ VNB,U-turn + VWB,U-turn

### III.IV. Proposed Methodology

The suggested methodology is presented below through a flow chart, as shown in Figure-3.1.

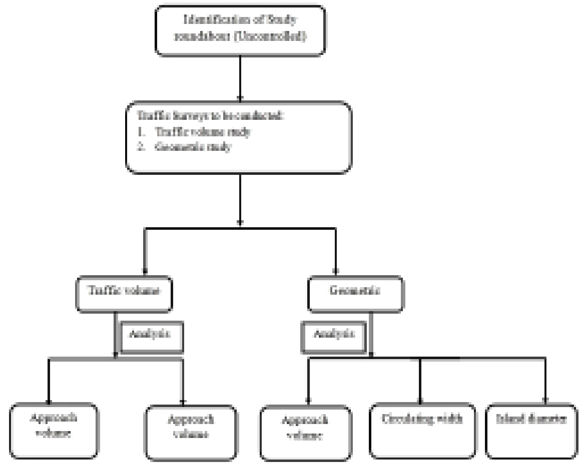


Fig 3.4Proposed methodology

For the purpose of model development, three four-legged intersections with each leg of two-lane (or more) two-way traffic roads (which are more common type of intersections) were considered. For any vehicles approaching the intersection, there will be four possible turning movements of traffic, namely left turn (LT), straight or through turn (TH), right turn (RT) and U-turn.For all the three intersections, classified turning movement (CTM) volume study and the delay study suggested by Little's formula (Salter and Okezue1998) will be carried out. From the CTM volume study, turning movement volumes, approach flow rates and vehicular composition will be estimated.The analysis will be done separately for different categories of vehicles: two wheelers, cars, autos, buses and truck vehicles and for four types of movements i.e., right turn (RT), left turn(LT), straight moving(TH) and U-turn at roundabout-intersection.The service delay models will be developed using correlation and regression statistical techniques.The goodness of fit of the models will be assessed by the coefficient of determination ($R^2$) value and the other statistic measures like F-ratio, t-statistic.

## IV. Data Collection

### IV.I. General

This chapter details about the classified turning movement volume and delay studies conducted for this work and the data extracted for the analysis.

### IV.II. Data Collection

The data set pertaining to the independent variable and the dependent variable were obtained by conducting the traffic surveys at study intersections.Classified turning movement volume counts of vehicles of each groups i.e., two-wheelers, cars, auto, buses, trucks, tractors, mini-bus/tempo vans) and, for each direction of movements (LT, RT,TH and U-turn) at each of the approaches were done simultaneously for 1hours in the morning session at

10 AM. It was observed that the traffic volume and vehicular composition of individual vehicles remained varied slightly during the survey period. For this turning movement volume and count study and approach volume, four videotapes are placed simultaneously at four corners of the roundabout intersection.

As a part of delay study, at each intersection, data were collected by video recording technique on a typical weekday. The video camera was placed at a suitable vantage point near the intersection to record an unobstructed view of all approaches and turning movements anddata were recorded for about 1hr to 2 hr depending upon the significant sample of vehicle type. The recorded video file wasplayed in the laboratory several times to get the conflicting traffic volume count and the queue length experienced by each subject vehicle.

### IV.III. Data Extraction

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):

$D=L/\lambda$

where

D=stopped delay time (s);

$L$=queue length (veh); and

$\lambda$=mean arrival rate (veh/s).

### IV.IV. Passenger Car Units Considered for the Analysis

As per IRC: 106-1990, “Guidelines for Capacity of Urban Roads in Plain areas”, urban roads are characterized by mixed traffic conditions, resulting in complex interaction between various kinds of vehicles. To, cater to this, it is usual to express the capacity of urban roads in terms of a common unit. The unit generally employed is the ‘Passenger Car Unit’ (PCU), and each vehicle type is converted into equivalent PCUs based on their relative interference value.

The equivalent PCUs of different vehicle categories do not remain constant under all circumstances. Rather, these are a function of the physical dimensions and operational speeds of the respective vehicle classes. In urban situations, the speed differential amongst different vehicle classes is generally low, and as such the PCU factors are predominantly a function of the physical dimensions of the various vehicles. Nonetheless, the relative PCU of a particular vehicle type will be affected to a certain extent by increase in its proportion in the total traffic. Considering all these factors, the conversion factors as shown in Table 4.1 are recommended for adoption.

Table 4.1 Recommended PCU factors for various types of vehicles on urban roads (IRC: 106-1990)

| Vehicle Type | Equivalent PCU Factors<br>Percentage Composition Of Vehicle Type In Traffic Stream | |
|---|---|---|
| | 5% | 10% and above |
| Fast Vehicles | | |
| 2w | 0.5 | 0.75 |
| 3w/Auto | 1.2 | 2.0 |
| Car/Van | 1.0 | 1.0 |
| LCV | 1.4 | 2.0 |
| Truck/Bus | 2.2 | 3.7 |
| Tractor | 4.0 | 5.0 |
| Slow Vehicles | | |
| Cycles | 0.4 | 0.5 |
| Cycle Rickshaws | 1.5 | 2.0 |
| Tonga | 1.5 | 2.0 |
| Hand Cart | 2.0 | 3.0 |

Data showing Average stopped delay models, Entry width, Circulating width, Island diameter, Approach volume and Circulating volume of three roundabout delay for 15min time interval are in the below table 4.2

Table 4.2 Total data for model development

| S No. | ASD | E W | CW | Is-Dia | AV | CV |
|---|---|---|---|---|---|---|
| 1 | 2.43 | 10.5 | 13.5 | 60 | 1273 | 477 |
| 2 | 1.76 | 10.5 | 13.5 | 60 | 1545 | 792 |
| 3 | 2.28 | 10.5 | 13.5 | 60 | 1460 | 842 |
| 4 | 2 | 10.5 | 13.5 | 60 | 1311 | 507 |
| 5 | 1.6 | 10. | 13.5 | 60 | 1460 | 768 |

| S No. | ASD | E W | CW | Is-Dia | AV | CV |
|---|---|---|---|---|---|---|
| | | 5 | | | | |
| 6 | 1.65 | 10.5 | 13.5 | 60 | 1412 | 794 |
| 7 | 1.71 | 10.5 | 13.5 | 60 | 1263 | 627 |
| 8 | 2.12 | 10.5 | 13.5 | 60 | 1318 | 622 |
| 9 | 3.27 | 9.5 | 13.5 | 60 | 838 | 1466 |
| 10 | 3.49 | 9.5 | 13.5 | 60 | 748 | 1746 |
| 11 | 3.76 | 9.5 | 13.5 | 60 | 771 | 1535 |
| 12 | 2.41 | 9.5 | 13.5 | 60 | 780 | 1372 |
| 13 | 1.97 | 9.5 | 13.5 | 60 | 871 | 1667 |
| 14 | 3 | 9.5 | 13.5 | 60 | 810 | 1826 |
| 15 | 2.85 | 9.5 | 13.5 | 60 | 762 | 1729 |
| 16 | 2.53 | 9.5 | 13.5 | 60 | 748 | 1646 |
| 17 | 2.45 | 12 | 11.6 | 17 | 1500 | 628 |
| 18 | 2.37 | 12 | 11.6 | 17 | 1408 | 704 |
| 19 | 2.41 | 12 | 11.6 | 17 | 1275 | 702 |
| 20 | 2.76 | 12 | 11.6 | 17 | 1465 | 744 |
| 21 | 1.91 | 11.2 | 11 | 17 | 1299 | 701 |
| 22 | 1.98 | 11.2 | 11 | 17 | 1322 | 721 |
| 23 | 1.6 | 11.2 | 11 | 17 | 1268 | 820 |
| 24 | 1.61 | 11.2 | 11 | 17 | 1339 | 866 |
| 25 | 2.26 | 9.5 | 11.2 | 17 | 762 | 1350 |
| 26 | 0.19 | 9.5 | 11.2 | 17 | 601 | 1128 |
| 27 | 2.72 | 9.5 | 11.2 | 17 | 695 | 1263 |
| 28 | 2.9 | 9.5 | 11.2 | 17 | 823 | 1370 |
| 29 | 2.7 | 9.5 | 11.2 | 17 | 808 | 1456 |
| 30 | 3.22 | 9.5 | 11.2 | 17 | 865 | 1402 |
| 31 | 2.98 | 9.5 | 11.2 | 17 | 879 | 1290 |
| 32 | 3.26 | 9.5 | 11.2 | 17 | 914 | 1523 |
| 33 | 3.86 | 6 | 12.6 | 42 | 1241 | 300 |
| 34 | 3.02 | 6 | 12.6 | 42 | 1368 | 361 |
| 35 | 3.62 | 6 | 12.6 | 42 | 1215 | 356 |
| 36 | 2.72 | 6 | 12.6 | 42 | 1225 | 331 |
| 37 | 3.15 | 6 | 12.8 | 42 | 834 | 440 |
| 38 | 4.04 | 6 | 12.8 | 42 | 760 | 463 |
| 39 | 3.36 | 6 | 12.8 | 42 | 835 | 432 |
| 40 | 3.5 | 6 | 12.8 | 42 | 753 | 457 |
| 41 | 3 | 4.5 | 12 | 42 | 633 | 742 |
| 42 | 3.75 | 4.5 | 12 | 42 | 578 | 722 |
| 43 | 3.58 | 4.5 | 12 | 42 | 601 | 762 |
| 44 | 2.9 | 4.5 | 12 | 42 | 580 | 732 |
| 45 | 3.8 | 4.5 | 12.8 | 42 | 264 | 1388 |
| 46 | 4.61 | 4.5 | 12.8 | 42 | 237 | 1561 |
| 47 | 3.91 | 4.5 | 12.8 | 42 | 208 | 1374 |
| 48 | 4.81 | 4.5 | 12.8 | 42 | 242 | 1367 |
| Av | 2.7870 | 8.6 | 12.433 | 39.666 | 961.81 | 976. |

| S No. | ASD | E W | CW | Is-Dia | AV | CV |
|---|---|---|---|---|---|---|
| g | 8 | | 3 | 7 | 3 | 5 |

### IV.V. Geometric Characteristics

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 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.

Table 4.3 geometric characteristics of roundabouts

| Roundabout name | Island diameter (m) | Direction | Entry width (m) | Circulating width (m) |
|---|---|---|---|---|
| Barkathpura | 42 | BJP office | 4.5 | 12.8 |
| | | Kacheguda station | 6 | 12.8 |
| | | Narayanguda | 4.5 | 12 |
| | | Fewer hospital | 6 | 12.6 |
| Indira Gandhi circle | 60 | secretariat | 10.5 | 13.5 |
| | | imax | 9.5 | 13.5 |
| | | khairathbad signal | 10.5 | 13.5 |
| | | Necklace road | 9.5 | 13.5 |
| Narayanguda circle | 17 | barkathpura | 9.5 | 11.3 |
| | | kachegud a signal | 11.2 | 11 |
| | | king koti | 9.5 | 11.2 |
| | | narayanguda | 12 | 11.6 |

## V. Model Development of Average Stopped Delay

### V.I. General

The average stopped delay models for each subject approach based on parameters Entry width, circulating width, Island diameter, approach volume and circulating volume of Roundabout intersections are presented in this chapter.

### V.II. Model Development

The analysis was done separately for five categories of approach based parameters like Entry width, circulating width, Island diameter, approach volume and circulating volume. Correlation is a statistical measure for finding out degree of association between two or more variables. Taking average delay as dependent variable and Entry width, circulating width, Island diameter, approach volume and circulating volume as independent variables correlation was done where the coefficient of correlation(r) value shows the level of dependence.

The extent or degree of relationship between two variables measured in terms of another parameter is called the coefficient of correlation. It is denoted by r.Let X and Y denote two variables and r denote the coefficient of correlation between X and Y. depending on the value of r, we can classify correlation as follows

(a) If r = 1 both the variables X and Y increase or decrease in the same proportion. In this case we say that there is perfect positive correlation.

(b) If r = -1 both the variables X and Yare inversely proportional to each other. We say that there is perfect negative correlation.

(c) If r = 0 we say that there is no relation between X and Y.

(d) If 0< r < 1 , there is moderate (partial) positive correlation between X and Y

(e) If -1< r <0 , there is moderate (partial) negative correlation between X and Y.Multiple correlation was done for the above following data in Microsoft excel 2010 and following is the output data.

Table 5.1 Correlation

| Predictor | Delay | EW | CW | AV | CV | Is-Dia |
|---|---|---|---|---|---|---|
| Delay | 1 | | | | | |
| EW | -0.681 | 1 | | | | |
| CW | -0.146 | -0.136 | 1 | | | |
| AV | 0.588 | 0.678 | -0.010 | 1 | | |
| CV | 0.172 | 0.102 | 0.061 | -0.547 | 1 | |
| Is-Dia | -0.105 | -0.177 | 0.970 | -0.032 | 0.062 | 1 |

- Based on the 15 min time interval, as can be seen from the correlation matrix in table 5.1, the subject approach width has the greater linear association with delay time, with correlation coefficient -0.681. we see graph between Average stopped delay and entry width showing the relation

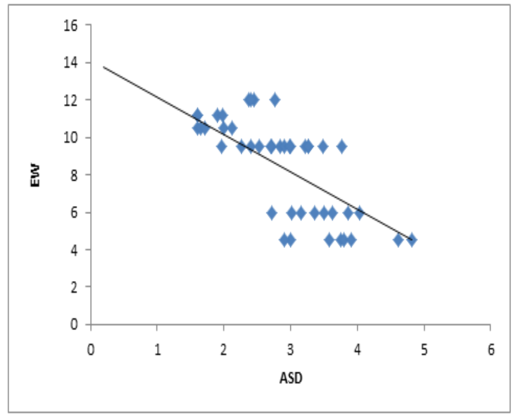


Fig 5.1 graph showing EW vs ASD

- Whereas the Island diameter and circulating width has less linear association with delay, with correlation coefficient of -0.105 and -0.146.
- Above correlation coefficient values show how the estimated average stopped delay depends geometric and traffic volume parameters.

### V.III. Regression model

The following regression model was produced for estimation of the stopped delay time by using above data. The stepwise regression was used to find the most influencing variables on the stopped delay. 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. By using Microsoft excel tools this regression model was generated.

$$D_s = -7.816 + 0.00708 V_s + 0.00818 V_c - 0.067 D_i + 0.8048 W_c - 0.383 W_e$$

With an adjusted $R^2$ of 60.2% and a Standard error of Estimate (SEE)of 0.55. The intercept, the variables, and the regression model were all significant at 95% confidence. Regression details are as shown in Tables 5 and 6.

- 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.

- 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 forthe entering drivers decreases.
- The delay time has a direct proportional relationship with circulating width. This is due to the confusion caused by a larger circulating width for the drivers at the roundabout entries. When entry drivers look for gaps in parallel streams of traffic on the circulating roadway, they need more 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 vehiclesincrease, and as a result, the roundabout capacity will be increased and the delay at the roundabout entry will be decreased.
- Because the produced model was based on a wide range of data from in Hyderabad, covering different areas and sizes, the proposed model can be used in predicting roundabout delays for similar sites in other parts of the country, and in any other developing country that has similar driver behaviors as in Hyderabad.

Table 5.2Regression statistics

| Regression Statistics | |
|---|---|
| Multiple R | 0.803054899 |
| R Square | 0.64489717 |
| Adjusted R Square | 0.602623024 |
| Standard Error | 0.558288026 |
| Observations | 48 |

Table 5.3 Regression results for Delay model using 15 min time interval

| Predictor | Coefficients | Standard Error | T-ratio | P-value |
|---|---|---|---|---|
| Intercept | -7.814604461 | 3.720793293 | -2.10025224 | 0.04175162 |
| EW | -0.383091869 | 0.075315556 | -4.66161159 | 3.1688E-05 |
| CW | 0.804871376 | 0.359369289 | 3.309051201 | 0.00192738 |
| AV | 0.000780269 | 0.000599457 | 1.181518136 | 0.24404395 |
| CV | 0.008184150 | 0.000356863 | 2.293359485 | 0.02689916 |
| Is-Dia | -0.066672865 | 0.019692907 | -3.38562837 | 0.00155057 |

Table 5.4ANOVA

| ANOVA | | | | | |
|---|---|---|---|---|---|
| | DF | SS | MS | F | P |
| Regression | 5 | 23.77399983 | 4.754799965 | 15.2551199 | 0.00 |
| Residual | 42 | 13.09079184 | 0.31168552 | | |
| Total | 47 | 36.86479167 | | | |

## VI. Summary and Conclusion

### VI.I. Summary

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 12 h of field traffic and geometric data were collected from 3 roundabouts in Hyderabad. In this study, an attempt has been made to develop the average delay models for these roundabout intersections and to estimate the average delay caused to the different parameters like Entry width, circulating width, Island diameter, approach volume and circulating volume. Based on all roundabout intersection, an average delay model has been developed. This model is useful to estimate the average delay caused to vehicles, given the basic traffic data (which are easily measureable in the field) at roundabout intersections under heterogeneous traffic conditions.

Delay is a fundamental parameter in the economic analysis of highway investments. Delay caused to vehicles is important measure to evaluate the performance of roundabout intersections under mixed traffic conditions. Although the users' perception of quality of service may be difficult to measure, delay is a widely used quality of service measure for intersections. The vehicular composition, apart from traffic volume and proportion of turning traffic, is a vital factor in influencing the extent of delay caused to vehicles. Most of the earlier studies on delay to vehicles at urban uncontrolled intersections have been conducted under homogeneous traffic conditions, and the few studies that have been conducted under mixed traffic conditions being limited in scope. Therefore, there is a need to comprehensively analyze the delay caused to vehicles at urban uncontrolled intersections and develop the appropriate models to estimate the delay.

In this study, correlation was done by taking average delay as dependent variable and Entry width, circulating width, Island diameter, approach volume and circulating volume as independent variables, where the coefficient of correlation(r) value shows the level of dependence. The goodness of fit of the model was assessed by the coefficient of determination ($R^2$) value and the other statistic measures like F-ratio, t-statistic.

### VI.II. Conclusion

Based on the field studies and the modeling process, the following conclusions have been drawn:

- 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 the entry traffic volume, circulating traffic volume, roundabout island diameter, circulating width, and entry width had significant effects on the stopped delay.
- It was found that entry delay increases with an increase in entry volume, circulating volume, and circulating width, and with a decrease in island diameter and entry width.
- Entry width has the greatest influence on the estimated entry stopped delay time, while circulating width has the least influence.

### VI.III. Recommendations

The following recommendations have been suggested from the results obtained for the study undertaken:

- The service delay models developed can be used by practicing engineers to estimate the average delay for a roundabout intersection under mixed traffic where entry traffic volumes, circulating traffic volumes, roundabout island diameter, circulating width, and entry width are drawn through field survey.
- Since delay is the major problem in Hyderabad, while designing a roundabout delay influencing parameters should be taken into consideration.
- As the entry width has greater influence on the average stopped delay, while designing a roundabout a proper entry width should be considered to decrease its rate of influence.
- At all the three roundabout intersections in the Hyderabad city, the rules of priority are not fully respected by the drivers and vehicles found to be doesn't follow the lane movement. These conditions greatly affect the delay to the vehicles at uncontrolled intersections. So, to avoid the delays the rules of priority should be respected and follow the lane movement.

### VI.IV. Limitations of the present study

- The following limitations are found for the present study undertaken:
- 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.
- 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, the time intervals of 1, 5, 10, 15, 30, and 60 min were analyzed, to find the effect of different sampling time intervals on the produced models

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