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CAPACITY ANALYSIS OF ROUNDABOUT

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ABSTRACT

Roundabouts are a form of unsignalised intersections where the vehicles are forced to slow down and moves around the central island in a clockwise direction. The capacity of roundabouts is higher, compared to other uncontrolled intersections. The geometry of roundabout itself forces the vehicles to slow down before entering and reduces the severity of crashes. Operating cost is lesser than signalised intersections and delay is lesser than unsignalised intersections. The capacity of the roundabout is a function of various factors that have a significant influence on it. The effect of identified traffic and geometric factors are taken for the study. Two types of analysis are available for the capacity estimation of an intersection, namely, analytical methods and empirical methods. Empirical methods rely on field data which develop the relationship between geometric variables and performance measures. However, analytical methods which are based on gap acceptance theory develop the relationship between driver behaviour and performance measures, such as capacity and delay. For this study, the data is collected for two roundabouts by video recording, from the Hyderabad city. The gaps in the traffic stream and traffic volume count data were extracted from the video. Critical gap is a traffic parameter that is used in the analytical model, which is more preferred for the capacity estimation. In this study, the critical gaps were estimated for various vehicle types separately and the effect of circulating flow on critical gap was analyzed.The critical gap is a complex variable to estimate, as it cannot be measured directly in the field and whose value changes from driver to driver, time to time, between intersections, type of movement (Right, Left or Through) and vehicle type. A comparison was made between Raff's method and Maximum Likelihood Estimation (MLE) method of critical gap estimation from the data of two roundabouts (in Hyderabad).The capacity of the roundabout is estimated using three models were considered to compare the better method among Raff's method and MLE method. Three capacity models were HCM 2010 model, ARRB model and ARRB model for Indian condition. The validated results are given in Root Mean Square Error (RMSE) values.

Key words: Comparing the methods of Critical gap estimation, and calculating the capacity of roundabout.

I. INTRIDUCTION

Roundabout is a type of intersection, at which traffic streams moves around a central island in a clockwise direction, after first yielding (giving way) to the circulating traffic. It is generally circular shape, and there is yield control of all entering traffic. The geometric curvature and features are designed to induce desirable vehicular speeds. It serves to calm the traffic that crosses the inter section area. Essentially, all the major conflicts at an intersection, the collision between through and right-turn movements are converted into milder conflicts namely, merging and diverging. The vehicles entering the roundabout are gently forced to move in a clockwise direction in an orderly fashion and then move out of the roundabout to the desired direction. Moreover, in order to reduce the number and severity of the crashes, the entry speeds are to be reduced. This is done by reducing the central island diameter of the roundabout so that vehicles are forced to slow down and enter the roundabout.

II. OBJECTIVE AND SCOP OF WORK

The objectives of the study is to identify the suitable method for critical gap estimation, by comparing Raff's and (MLE) method and estimate the capacity of a roundabout for heterogeneous traffic conditions, by incorporating traffic and geometric variables.

The Scope of the work includes the following:

- The scope of this study is limited to a comparison of Raff's and Maximum Likelihood critical gap estimation methods only. Limited number of traffic and geometric factors are considered while analysing the capacity of the roundabout and the effect of environmental factors was completely omitted.
- The analysis is performed using data on traffic flow on two roundabouts at Hyderabad.
- The influence of pedestrians on traffic flow was not considered in this study, as the number of pedestrians at the study locations was less

III. REVIEW OF LITERATURE

The literature review on capacity reveals that the research work carried out on the capacity estimation of roundabout by incorporating the geometric variables is less. Also, at some places depending on the traffic behaviour, empirical models predict the entry capacity more than the analytical models. The review of literature on critical gap reveals that Raff's method is the earliest method for critical gap estimation while Maximum Likelihood Estimation (MLE) is the most recommended. However, the study about the method to be followed for critical gap estimation in heterogeneous traffic conditions is lacking.

IV. METHODOLOGY

Suitable roundabout locations were identified from the Hyderabad city, where traffic and geometric data is collected from two roundabouts. The two roundabouts collected were signalised and with zero gradient. The pedestrian traffic is also negligible. During the data collection, it was observed that most of the roundabouts in Hyderabad were converted as signalised roundabouts, as the traffic flows at those places exceeded the roundabout capacity. However, the data for this study was collected from the roundabouts without any signals. To identify the best method among Raff's method and MLE, for estimating the critical gap, secondary data that is available is used (Ashraf, 2015). The data available is from two roundabouts in Hyderabad with 3 legs each, during the morning and evening peak hours from 8:30 AM to 11:00 AM and 3:30 PM to 6:00 PM for two days. The data such as geometric details, gaps, follow-up time and Intrabunch headway are available from the two roundabouts.

V. RESULTS

A comparison was made between Raff's method and MLE method of critical gap estimation from the data of two roundabouts (in Hyderabad). It can be inferred that the RMSE of Modified ARRB model developed by Ashraf (2015) for Indian traffic conditions is less than the other two models HCM 2010 model and ARRB model. It can be observed that the RMSE values of MLE method in all the three capacity models is comparatively less than the Raff's method values (except in three cases).From these results it can be concluded that MLE is the best method for the estimation of the critical gap.

5.1 Design and Analysis

The traffic data collected through traffic video recordings from traffic police station at Basherbagh from traffic survey data of the year 2017 and was calculated as per HCM 2010 guidelines. But, there are no particular guidelines available for the capacity estimation of roundabouts in India.

5.2 Critical Gap Calculation

The critical gap is an important parameter in gap acceptance behaviour. The definition of the critical gap has undergone significant modifications over the years. It is the minimum gap that is acceptable to a driver, intending to cross a conflicting stream (*Ashalatha and Chandra, 2011*). For a consistent driver, its value lies between the largest rejected gap and the one finally accepted gap. The critical gap cannot be directly measured in the field. Its value differs from driver to driver, from time to time, between intersections, type of movement and traffic situations. All these factors make the estimation of the critical gap a difficult process and have led to the development of different models/techniques, each having its own advantage and disadvantage and making their own assumptions. This study uses Raff's method and Maximum Likelihood Estimation Method for calculation of critical gap and makes a comparison of the results. Both the methods are briefly explained here.

5.2.1 Raff's method

It is one of the earliest methods for estimating the critical gap and easiest to use. This method estimates the mean critical gap by drawing the cumulative distribution function of accepted gaps $F_a(t)$, and reverse cumulative distribution function of the rejected gaps $F_r(t)$. The gap value for which both the density functions attain same value is defined as the critical gap and is shown in Figure 5.1.

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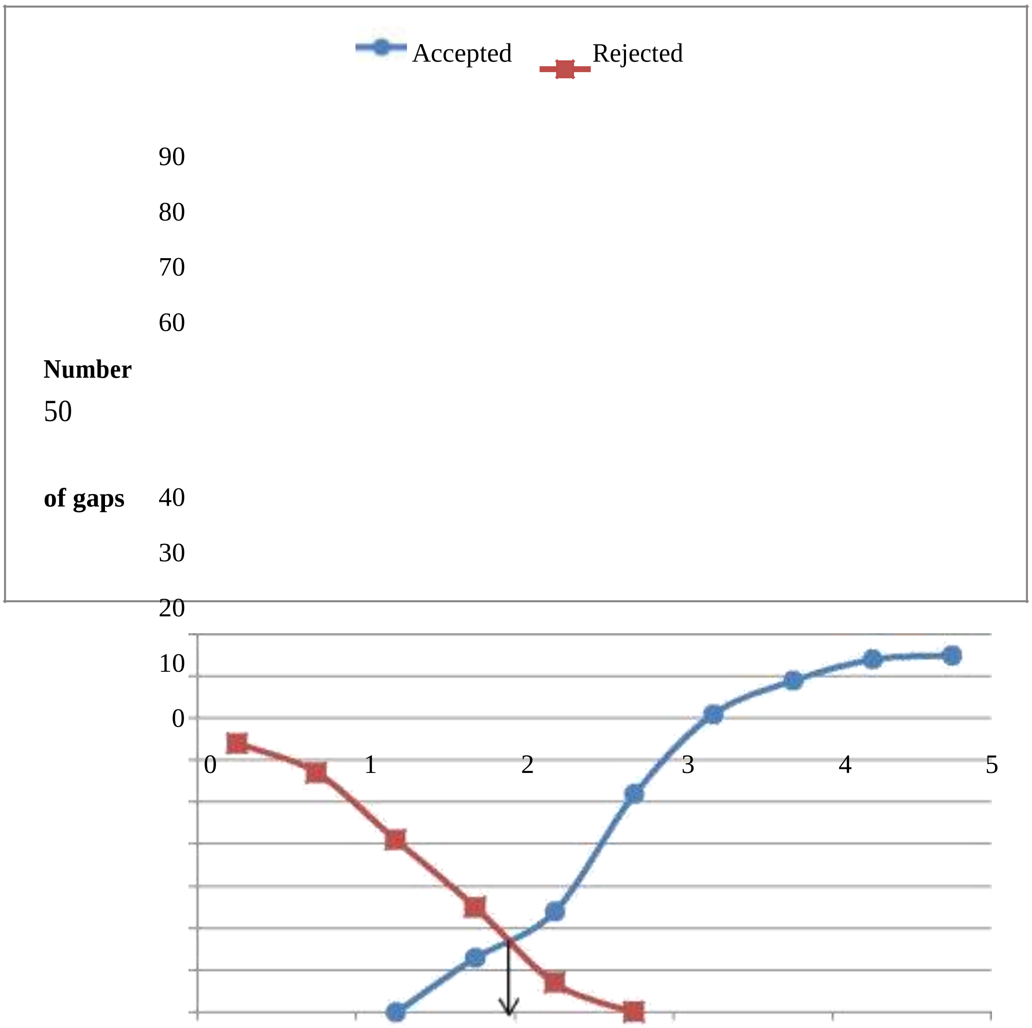

Length of Gap (in seconds)

Figure 5.1 Critical gap obtained from Raff's plot

5.2.2 Maximum Likelihood Estimation (MLE) Method

With reference to *Tian et al. (1999)*, in this model, only the accepted gap and the maximum rejected gap of each vehicle are treated pair wise. For one individual minor street driver *i*, the observed accepted gap is assumed as a_i and the corresponding maximum rejected gap as r_i.The maximum rejected gap is the largest value of all rejected gaps for one minor street driver. It is observed from the literature review, as well as from the available data, that the gaps follow a log-normal distribution. The MLE is based on the assumption that minor stream drivers behave consistently. It means that each driver will reject every gap smaller than his critical gap and will accept the first gap larger than the critical gap. Under this assumption, the distribution of the critical gaps lies between distributions of largest rejected and accepted gaps. The parameters of the distribution function of the critical gaps, the mean, 'μ' and variance 'σ^2', are obtained by maximizing the likelihood function. The literature review, as well as from the available data, that the gaps follow a log-normal distribution. The MLE is based on the assumption that minor stream drivers behave consistently. It means that each driver will reject every gap smaller than his critical gap and will accept the first gap larger than the critical gap. Under this assumption, the distribution of the critical gaps lies between distributions of largest rejected and accepted gaps. The parameters of the distribution function of the critical gaps, the mean, 'μ' and variance 'σ^2', are obtained by maximizing the likelihood function. The likelihood function is defined as the probability that the critical gap distribution lies between the observed distribution of the maximum rejected gaps and the accepted gaps. The likelihood function is given by Equation 1

$$L = \prod_{i=0}^{n} [F(a_i) - F(r_i)] \qquad (1)$$

Where

L - Maximum likelihood function,

a_i - Logarithm of the accepted gap of driver i,

r_i - Logarithm of the maximum rejected gap of driver i,

$F(a_i)$ - Cumulative normal distribution functions for accepted gaps

$F(r_i)$ - Cumulative normal distribution functions for maximum rejected Gaps

The logarithm of the Equation 2 is

$$L = \sum_{i=1}^{n} \ln[F(a_i) - F(r_i)] \qquad (2)$$

Likelihood parameters 'μ' and 'σ^2' are the solutions of the Equation 3 when its partial derivation is equal to zero. The partially derivate Equations w.r.to μ and σ^2 are as follows

$$\left.\begin{aligned} \sum_{i=1}^{n} \frac{f(a_i) - f(r_i)}{F(a_i) - F(r_i)} = 0 \\ -\frac{1}{2e^2} \sum_{i=1}^{n} \frac{(a_i - \mu).f(a_i) - (r_i - \mu).f(r_i)}{F(a_i) - F(r_i)} = 0 \end{aligned}\right\} \qquad (3)$$

$f(a_i)$, $f(r_i)$ – probability density functions for the normal distribution with parameters 'μ' and 'σ^2'Parameters 'μ' and 'σ^2' can be calculated from *Equation 3* by numerical and iteration technique. The mean $E(t_c)$ and variance $V(t_c)$ of the critical gap can be derived from *Equation* 4 is

$$\left.\begin{aligned} E(t_c) = e^{\mu + 0.5\sigma^2} \\ V(t_c) = [E(t_c)]^2.(e^{\sigma^2} - 1) \end{aligned}\right\} \qquad (4)$$

Instead of calculating the critical gap by iteration technique, EXCEL spreadsheet is used to make the calculation easier. All accepted gaps except the first accepted gaps and maximum rejected gaps are considered in the analysis in MLE, whereas, first accepted gaps are also included in the RMS method. Initially, two cells are allotted for calculating the mean (m) and standard deviation (S) of the critical gap and an arbitrary integer value is given to them. Then the likelihood value of each sample is calculated by as given in *Equation 5 is*

$$L = \ln\left[\begin{pmatrix} lognormal \\ distribution\ of \\ accepted\ gaps \end{pmatrix} - \begin{pmatrix} lognormal \\ distribution\ of \\ maximum \\ rejected\ gaps \end{pmatrix}\right] \quad (5)$$

The total likelihood is calculated by summing up the likelihood of all the samples calculated by *Equation 5*. But, to calculate the lognormal distribution the parameters μ and σ^2 are necessary and are calculated with the help of the following *Equation 6 is*

$$\left.\begin{aligned} \sigma^2 &= \ln\left(\frac{s^2}{m^2}+1\right) \\ \mu &= \ln m - 0.5\sigma^2 \end{aligned}\right\} \quad (6)$$

By using the SOLVER add-in in EXCEL, the mean and standard deviation values which will maximize the likelihood L is estimated

5.3 Capacity Estimation Models

Three capacity estimation models were considered to compare the better method among Raff's method and Maximum Likelihood Estimation (MLE). The three capacity models were:

5.3.1 HCM 2010 Models

According to HCM 2010 (TRM 2010), the approach capacity of the roundabout can be estimated as shown in Equation 7 is

$$C = \frac{3600}{(t_f)} * e^{-\left(\frac{t_f - 0.5t_f}{3600}\right)v_c} \quad (7)$$

Where

C - Capcity of the roundabout (veh/hr.)

v_c – Circulating flow (veh/hr.) t_c – Critical gap

(sec)

t_f – Follow-up time (seconds)

5.3.2 ARRB Model

The capacity equation as given by Australian Road Research Board (ARRB) is as given in Equation 8 is

$$Q_e = \frac{3600 * \alpha * q_c * e^{-\lambda(t_c - \Delta)}}{1 - e^{-\lambda(t_f)}} \quad (8)$$

Where

Q_e – Entry Capacity (veh/hr)

q_c – Circulating Flow (veh/hr) t_c – Critical gap

(seconds)

t_f – Follow-up time (seconds)

Δ - Intra bunch headway (seconds) $\lambda = 0.75 * q_c$

α – proportion of free vehicles with headway greater than Δ seconds = 0.75*(1-

Δq_c)

5.3.3 ARRB model for Indian condition

A modified ARRB model was developed for Indian conditions by Ashraf (2015) is given by Equation 9 is

$$Q_e = \frac{3600 * \alpha * q_c * e^{-\lambda(t_c - \Delta)}}{1 - e^{-\lambda(t_f)}} \quad (9)$$

Where-

Q_e – Entry Capacity (veh/hr)

q_c – Circulating Flow (veh/hr) t_c – Critical gap

(seconds)

t_f – Follow-up time (seconds)

Δ - Intra bunch headway (seconds) $\lambda = 0.75 * q_c$

α – proportion of free vehicles with headway greater than Δ seconds = $0.214*(1-\Delta q_c)$

Table 5.1 Critical gap (in seconds) at roundabout A (Birla Mandir)

Intersection	Leg	Method/ Samples	2W	3W	bus	car	goods auto	LCV	Mini Bus	Truck
Birla Mandhir	Leg 1	MLE	1.67	1.95	2.49	2.21	2.21	2.73	2.61	2.37
		Raff	1.35	1.75	2.5	2.05	1.8	2.35	2.5	2.25
		Samples	81	28	12	71	13	19	7	13
	Leg 2	MLE	1.67	2.05	2.9	2.41	2.26	2.83	2.54	2.94
		Raff	1.35	1.8	2.75	2.25	1.85	2.5	2.5	2.8
		Samples	92	53	8	51	27	31	3	11
	Leg 3	MLE	1.68	1.99	2.43	2.3	2.2	2.53	2.64	3.16
		Raff	1.4	1.75	2.25	2	1.85	2.25	2.5	2.85
		Samples	84	37	4	59	12	17	5	10

Table 5.2 Critical gap (in seconds) at roundabout B (Cancer hospital)

Intersection	Leg	Method/ Samples	2W	3W	bus	car	goods auto	LCV	Mini Bus	Truck
Cancer Hospital	Leg 1	MLE	1.84	2.12	2.27	2.47	2.24	2.65	2.94	3.39
		Raff	1.7	2	2.35	2.25	2	2.4	2.75	3.1
		Samples	105	85	4	69	25	20	6	6
	Leg 2	MLE	1.76	1.98	2.32	2.37	2.54	2.61	2.99	NA
		Raff	1.6	1.75	2	1.85	2.3	2.35	2.75	NA
		Samples	43	39	3	38	10	11	4	0
	Leg 3	MLE	1.83	2.19	2.71	2.39	2.45	2.81	3.31	2.71
		Raff	1.7	2	2.5	2.25	2.25	2.55	3	2.5
		Samples	104	73	4	59	19	13	7	7

The entry capacities calculated using these critical gaps by the three capacity models were compared with the entry capacity observed in the field. The error between the observed and estimated capacity is found using the Root Mean Square Error (RMSE) value, which is calculated by Equation 5.1 and 5.2

$$RMSE = \sqrt{\frac{(C_{observed} - C_{calculated})^2}{n}} \qquad (10)$$

Where

$C_{calculated}$:Observed capacity (veh/hr)

$C_{calculated}$:Caculated capacity (veh/hr)

n: Number of samples available for calculating the RMSE value.

The RMSE values were calculated for each leg separately. The RMSE values of the three roundabouts calculated from the three capacity models were shown in the Table 5.3, Table 4.4respectively.

Table 5.3 RMSE values at (Birla Mandhir) roundabout A

Intersection	Leg	Critical Gap Method	RMSE of Estimated Capacity		
			HCM 2010	ARRB	ARRB (Ashraf)

Birla mandhir	Leg 1	MLE	231.522	215.014	206.952
		Raff	240.974	221.543	208.690
	Leg 2	MLE	137.938	96.381	85.568
		Raff	158.145	108.161	88.553
	Leg 3	MLE	149.916	114.319	98.053
		Raff	164.979	123.521	100.361

Table 5.4 RMSE values at (Cancer hospital) roundabout B

Intersection	**Leg**	**Critical gap Method**	**RMSE of Estimated Capacity**		
			HCM 2010	**ARRB**	**ARRB (Ashraf)**
Cancer hospital	Leg 1	MLE	72.156	23.094	22.658
		Raff	82.955	27.729	23.942
	Leg 2	MLE	26.532	18.183	18.336
		Raff	33.175	18.952	18.256
	Leg 3	MLE	152.457	63.861	58.357
		Raff	177.296	73.680	60.959

From the Table 5.3, Table 5.4 it can be inferred that the RMSE of Modified ARRB model developed by Ashraf (2015) for Indian traffic conditions is less than the other two models. Moreover, it can be observed that the RMSE values of MLE method in all the two capacity models is comparatively less than the Raff's method values (except in three cases). Also it is understood from the literature review that the MLE method is most preferred for critical gap estimation. Hence, from these results it can be concluded that MLE is the best method for the estimation of the critical gap.

VI. DISCUSSIONS AND CONCLUSIONS.

- It is observed that the number of samples available for bus, goods auto, mini-bus, truck and LCV were less From the other three vehicle types i.e. 2W, 3W, Car; for which adequate samples are available. It is observed that the critical gap of 2W is less than that of 3W, which in-turn is less than critical gap of car.
- It is observed that the critical gap in seconds at roundabout A (Birla mandhir) and roundabout B (Cancer Hospital) is less for MLE method when compared with Raff's method at all three legs.

- The critical gap at roundabout B with 30.8 m central island diameter have comparatively larger critical gap than roundabout A with 14.2 central island diameter. Hence is can be concluded that central island diameter increases the critical gap also increases.
- It can be inferred that the RMSE of Modified ARRB model developed by Ashraf (2015) for Indian traffic conditions is less than the other two models HCM 2010 model and ARRB model.
- It can be observed that the RMSE values of MLE method in all the three capacity models is comparatively less than the Raff's method values (except in three cases).
- From these results it can be concluded that MLE is the best method for the estimation of the critical gap.

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