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EVALUATION OF CAPACITY OF ROUNDABOUTS USING ANALYTICAL MODEL IN MIXED TRAFFIC FLOW CONDITIONS

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ABSTRACT: Capacity is the main determinant of analysing the traffic performance of roundabouts. The movements of the vehicles were observed at 2 roundabouts in Varanasi. Gap acceptance and follow up time were estimated for cars for one hour analysis. The relation between a roundabout performance measure and capacity is expressed in terms of degree of saturation (volume – Capacity ratio). The capacity analysis is done based on gap acceptance method that is adopted by Tanner based on the HCM 2010. The traffic movement data with vehicle characteristics were collected from 2 roundabouts in Varanasi. These 2 roundabouts are directly related to their approach leg numbers.Approach entry capacity has been analysed for all 2 roundabouts at their legs. Effective capacity verses entry flow relationship have been developed in order to find out the causes of their over Saturation (v/c ratio greater than 0.85) And the result indicates; number of entry lanes, number of circulatory lanes and high traffic flow are the major causes of their over saturation.

Key words: [Roundabouts, capacity, vehicles.]

1. INTRODUCTION

A roundabout is an alternative form of intersection traffic control. Roundabouts are generally circular in shape, characterized by yield on entry and circulation around a central island. Roundabouts are appropriate for many intersections including locations experiencing high number of accidents, traffic delays, and approaches with relatively balanced traffic flows. Roundabouts have the potential to resolve various traffic flow problems. Traffic volume on one approach is significantly higher that it prevents vehicles at any other approach from entering the roundabout especially at a downstream approach or the next following approach. Evaluation of junction capacity of roundabout is very significant since it is directly related to delay, level of service, accident, operation cost, and environmental issues. There are three legs, four legs, five legs and six legs roundabouts in Varanasi and most of them have served more than 15 years. Since little attention has been paid to the design and capacity evaluation of the roundabouts, no one knows knows their capacities or level of services.

Tanner model uses the gap-acceptance theory (or critical headway) to simulate the behaviour of entering vehicles and vehicles circulating within the roundabout. Finding a safe gap (or headway) within circulating traffic stream to enter the roundabout is the controlling variable that determines the ability of

approach vehicles to enter the roundabout. Current research work on roundabout models mostly concentrates on determining the capacity of an approach based on the entering and circulating flows. Approach capacity is calculated as a mathematical function of critical headway and follow-up headway. This method is not sensitive to roundabout geometric parameters such as inscribed circle diameter, entry angle, etc. In addition, the level of traffic stream performance itself can influence driver behaviour and increasing the complexity of modelling roundabout operations.

Critical headway and follow-up headway are two important parameters to perform operational analyses of roundabout. Critical headway at roundabouts represents the minimum time interval in circulating flow when an entering vehicle can safely enter the roundabout. A driver would enter the roundabout when faced with any headway equal to or greater than the critical headway. Follow-up headway is the minimum headway between two entering vehicles, which can be calculated by the average difference between passage times of two entering vehicles accepting the same mainstream headway under a queued condition. In other words the follow-up headway is equal to the inter-vehicle headway on an approach at capacity. Increasing the follow-up time and critical gap decreases capacity.

Several roundabout capacity models exist and can be classified into two broad categories - theoretical and empirical. The Tanner model is based on gap- acceptance theory with gap-acceptance parameters. **The Highway Capacity Manual (HCM 2010)** roundabout tanner capacity model is an analytical (exponential regression) model with clear basis in gap-acceptance theory. **The NCHRP Report 572model** is based on empirical exponential regression) capacity model with no explicitly.

Therefore, road authorities and other concerned bodies need to conduct a comprehensive capacity and delay study of every roundabout. so they can think with solutions for the traffic congestions, traffic delays, queue length, Degree of Saturation and level of services.

Vehicle Safety:

Roundabouts have fewer conflict points than traditional intersections and also require lower operating speeds for both the driver entering the roundabout and the driver driving in the roundabout. A conflict point is defined as a location where the paths of two motor vehicles or a vehicle and pedestrian queue, diverge, merge, or cross each other. The following figure is used to illustrate the reduction in conflict points:

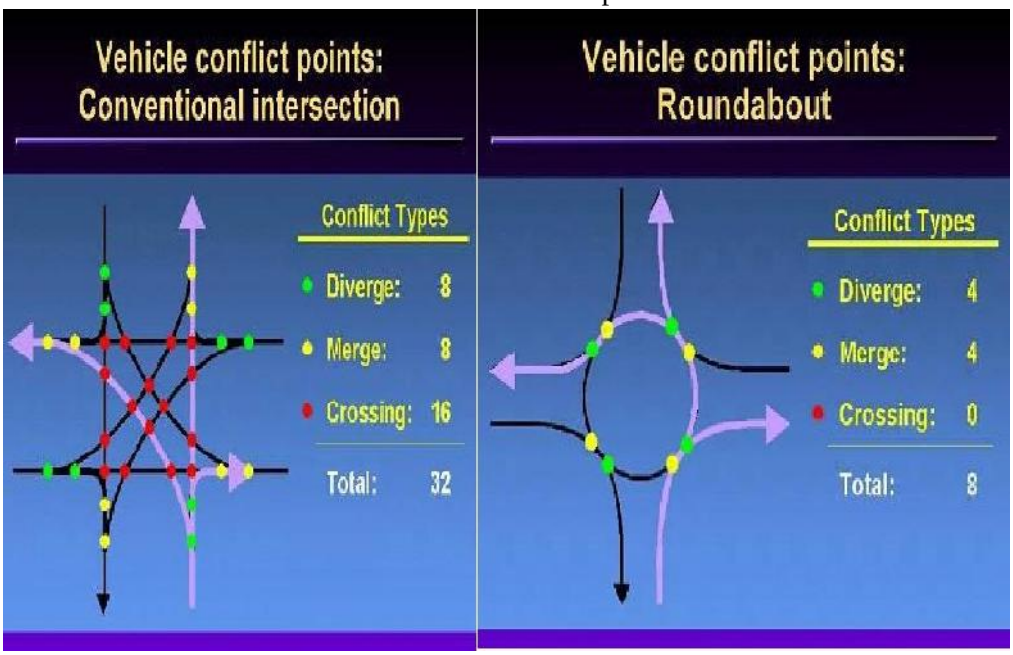

Figure 1- Vehicle Conflict Point Comparison

At four-way stop roundabouts have about a 75% decrease in vehicle conflict points compared to a traditional intersection. Three types of conflicts are defined in the report: merge and diverge conflicts, and crossing conflicts. Crossing conflicts are frequently the most serious in terms of vehicular injuries and fatalities. At a traditional intersection accidents are frequently happen when a driver neglects to stoplight or stop sign. By eliminating crossing conflicts, roundabouts were designed dramatically lower the incidents of injuries and fatalities associated with conflict points.

2. REVIEW OF LITERATURE

Roundabout capacity and delay analysis can be performed at several levels of detail.

Morlok (1978) states that behavioural studies of motorists indicate that motorists will choose their route based on the minimum travel time. This is compliments Fisk's statement of minimizing travel time. Minimizing travel time appears to be the most appropriate method to determine lane utilization for this formulation. Fisk describes the problem to be a mini-traffic assignment problem. For this model to be implemented into a travel forecasting model.

Akcelik (1998) mentions three methods for measurement capacity. These include analysis by total approach flow used in ARCADY, the British empirical regression based on simulation. Akcelik uses the lane-by-lane method for the purpose of allowing improved geometric modelling of the intersection. He points out that recognition of unequal lane utilization is important because it affects the capacity and performance of the roundabout.

Fisk (1991) states the lane utilization for entering lanes should be determined using travel time minimization or by equalizing queue lengths. It is also mentioned that the left lane will be served at a faster rate than the right lane and because of this travel time minimization would be a better predictor. Akcelik's use of dominant and subdominant lanes .so this is problem from a different angle. Fisk and Akcelik both recommend using a different critical gap and follow uptime for each lane. In Akcelik's model lane utilization ratio is determined by the degrees of saturation of the lanes. Lane group capacity is then calculated and flow rate for each lane is determined.

3. METHODOLOGY

There are basically two type of models in roundabouts capacity analysis:-

- Analytical Model
- Empirical Model

Analytical models works on the gap acceptance parameter while empirical model works on the geometric parameters of roundabouts. Some of analytical roundabout models are.

- Tanner model HCM 2010
- NCHRP report model
- German Linear Model

The examples of Empirical models are:-

- German Regression model
- UK model
- IRC model

4. TANNER HCM 2010 CAPACITY MODEL

The headway distribution functions can be used in conjunction with gap-acceptance parameters to derive the capacity estimation models. These models are macroscopic analytical models which express the capacity in an exponential function of the circulating flow. The exponential function is reasonable because the rate of reduction in capacity generally decreases as the circulating flow increases and capacity never reaches zero. For example, the capacity model adapted in the Highway Capacity Manual (HCM) 2000 (TRB,2000) assumes that headways follow an M1 distribution and is described as follows:

$$c_e = \frac{3600.q_c.e^{-q_c t_c}}{1-e^{-q_c t_f}}$$

Where
$\mathbf{c_e}$=the entry capacity (pcu/h)
$\mathbf{t_c}$= the critical headway (sec)
t_f= the follow-up time (sec)
This capacity model was revised in the HCM 2010 (TRB, 2010) as follows

$$c_e = \frac{3600}{t_f}.e^{-(\frac{t_c-0.5t_c}{3600})q_c}$$

The above capacity model is an exponential regression model developed based on a gap acceptance theory (Akçelik, 2011) .the HCM 2000 the critical headways were assumed to be different for different roundabout geometry. Geometry is classified in terms of the numbers of circulating lanes and entry lanes. In this model, shorter critical headways were used for a multi-lane roundabout than a one-lane roundabout.

UK Capacity Model

The UK roundabout capacity formula is based on **Kimber's study in 1980**. The first approach is a linear approximation used to determine the entry capacity of a roundabout.

$$\mathbf{C_e=F-f_c.q_c}$$

Where
F is a factor associated with the entry width, entry angle and width of the circulating flow and $\mathbf{f_c}$ is a constant that depends on the geometry of the circle (in particular, inscribed circle diameter).

Germany's Capacity Model

In Germany they use an approach similar to that of the UK. German researchers investigated both regression and gap theory and decided to utilize the UK regression analysis. UK linear approximation is an exponential regression line. It was used to describe the entry/circulating flow relationship between the entry capacity and the circulating flow based on the data collected from 10 roundabouts.

$$c_e = Ae^{\frac{-Bq_c}{10000}}$$

Where
A and B are the parameters associated with geometric factors including the number of circulating lanes, and the number of entrance lanes.

NCHRP report model

$$\mathbf{c_e=1130e^{-0.001q_c}}$$

Recently, continuing research from the federal government in Germany shows that the linear function instead of an exponential function has a better agreement of the variance of data. The new capacity formula is:

$$\mathbf{C_e=C+Dq_c}$$

Where
$\mathbf{c_e}$= entering capacity (vph)
$\mathbf{q_c}$=circulating flow (vph)
C and **D** are parameters show in table

5. STUDY AREA

Study area chosen for the research is a very congestional city of Varanasi.Traffic in Varanasi is way high due to its cultural heritage and tourism purposes.Two roundabouts are chosen from Varanasi to evaluate the capacity of roundabouts which are:

1. Lahurabir Chauraha
2. Maidagin Chauraha

The below table shows the traffic volume from each and calculated capacity from each model.

Round about	Leg No.	Traffic Count At Legs (V)	TANNER MODEL(Tanner)		NCHRP REPORT MODEL		GERMAN LINEAR MODEL	
			Capacity (C)	Degree Of Saturation (V/C)	Capacity(C)	Degree Of Saturation (V/C)	Capacity (C)	Degree Of Saturation(V/C)
Lahurabir Chauraha	E	649	713	0.91	422	1.54	489	1.33
	W	339	729	0.46	525	0.64	650	0.52
	N	931	1118	0.83	789	1.18	952	0.977
	S	765	1129	0.68	858	0.80	1014	0.75
Maidagin Chauraha	E	196	613	0.32	390	0.50	431	0.45
	W	458	776	0.60	426	1.07	496	0.92
	N	1227	1236	0.99	850	1.44	1007	1.22
	S	1432	1481	0.97	974	1.47	1108	1.29

Table 1- Estimation of Capacity on the Approach Leg

CONCLUSION

Varanasi roundabouts capacity analysis results indicate the most of the legs of roundabouts are in serious problems or over saturation. Based on observed actual field conditions it is common to see that at peak hours, the traffic police need to regulate the traffic at these roundabouts since traffic control devices cannot function or regulate the traffic. As the study uncovered the real issues are identified with deficiency of number of entry lanes, number of circulatory lanes, high traffic flow and unbalanced traffic on the approaches of roundabout. Besides most of the roundabouts were built more than 15 years ago with obscure service limits.

All the input parameters of empirical method for capacity analysis do not exist at Varanasi Roundabouts. Thus only analytical method was carryout the capacity analysis with parameter using Tanner Formula based on HCM 2010.

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