Capacity Estimation Approaches for Roundabouts: A Review

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Abstract

The vehicle ownership is increasing day-by-day with the population growth. The traffic scenario is also changing along with this change. Roundabout has been widely adopted alternative as a type of intersection in many parts of the world due to its convenience for operation with lesser conflict points than the other unsignalized intersections. The capacity of roundabout intersection is the important or we can say key parameter to check the performance of roundabout intersection. The capacity of the roadway roundabout depends on the flow at different legs approaching the roundabout. The performance of roundabouts in terms of queues, delays and saturation index typically depends on entry capacity. This paper discusses and reviews the capacity estimation of roundabout which have done in past by various methods by different research scholars from various parts of the world. This study can contribute to an improved understanding of one of the parameter of performance of roundabout i.e. capacity of roundabout.

Keywords: Roundabout; Headways; Capacity

I. INTRODUCTION

Rapidly and continuously increasing population is a broad challenge for traffic engineers. As traffic engineer, we have to reduce number of accidents by reducing number of conflict points in existing and new transit networks & to give the transit user full safety and convenience while using any transit path. Roundabouts are a major form of at-grade intersection. Roundabout is a kind of intersection or a junction mostly in circular shape in which the road traffic slowed and moves almost continuously in one direction around a circular shaped area or we can say Central Island to many exits onto the various intersecting roads. Roundabouts have been used successfully in the cities throughout the world. This type of intersection generally builds in suburban areas where traffic volumes do not approaching saturation. Roundabout offers safety advantage over other signalized intersections. The modes of transportation also increasing along with the rapidly growing population in the cities which are resulting in congested traffic in the roads. Due to this much of modes of transportation, when they pass through the roundabout intersection then they need enough capacity of roundabout junction for vehicular movements, pedestrian safety, aesthetics and other safety purposes. Various studies have been made on capacity of roundabout all over the world. The capacities of roundabouts are calculated in terms of practical capacity of each weaving section or entry capacity. Capacity models for roundabouts are based on at least one or more of the major methodologies: empirical approaches based on observed roundabout intersection capacity measurements and gap acceptance theories based on theoretical models of driver behaviour characteristics and vehicular characteristics at intersections (Yok Hoe Yap et.al. 2015). The critical gap is an important input in the calculation of the capacity of roundabouts and is the smallest gap that a driver is willing to accept to merge with the circulating traffic and mainly determines the gap acceptance behaviour of the driver. The Transport and Road Research Laboratory (U.K.) recommends the formula for practical capacity of the weaving section of the roundabout in PCUs per hour which is the modification of War drop formula (IRC: 65-1976). The Highway Capacity Manual (HCM) (TRB 2000) model which is based on gap acceptance theory is used to estimate the entry capacity (Serhan Tanyel et.al. 2005 & 2007; Weiqi Wang et.al. 2012; Xiaobo Qu et.al. 2014). Another method used to evaluate entry capacity is Federal Highway Administration (FHWA) method which is based on empirical linear regression analysis (Osama A. Abaza et.al. 2009 & 2012; Xiaobo Qu et.al. 2014). NCHRP Report 572 recommended a model for the capacity of roundabout (Osama A. Abaza et.al. 2009 & 2012; Taylor W.P. Lochraneet.al. 2014). Tanner (1967) also gave a capacity formula for unsignalized intersections (Serhan Tanyel et.al. 2007).

II. LITERATURE SURVEY

Serhan Tanyel et.al. (2005) discussed the applicability of HCM 2000 procedure for roundabouts and suggested that the approaches to determine the capacity of roundabouts such as- gap acceptance based methods, linear regression based methods etc.  
Serhan Tanyel et.al. (2007) discussed applicability of various capacity models such as- HCM 2000, Tanner capacity model, Troutbeck etc. for single lane roundabouts.
Rui-jun Guo et al. (2009) discussed iterative calculation for full capacity of roundabouts. They suggested that the entry capacity can be calculated by use of the equation based on the gap acceptance theory. They analyzed the difference of the calculations between single-lane roundabout and double-lane roundabout.

Prof. Osama A. Abaza et al. (2009) compares the capacity analysis suggested by federal highway administration (FHWA) roundabout guidelines with those of transportation research board (TRB draft report, 2006) and national highway cooperative research program (NHCRP report 572).

Weiqi Wang et al. (2012) estimated the capacity of roundabout by modeling weaving gap acceptance at the weaving sections. They proposed a new method based on gap acceptance theory to estimate the capacity of roundabouts. They suggested that capacity estimation with weaving section vehicles result in improved prediction of the actual capacity of a roundabout & the geometrical design of roundabout is another important factor which influences the capacity of roundabout.

Debashish Das et al. (2014) analyzed the performance of rotaries based on various parameters such as total entry traffic volume, weaving traffic, capacity of weaving section and distances from CBD boundary. They calculated the necessary parameters from the existing guidelines specified by IRC: 65–1976 & compared relative performance with respect different rotary location.

Xiaobo Qu et al. (2014) estimated the entry capacity for single lane modern roundabout using the HCM Model (TRB 2000) and developed a new roundabout capacity model. They also discussed gap acceptance theory. The also took into account the impact of exiting vehicles.

Mitesh Kumar N. Damor et al. (2014) evaluated practical capacity of roundabout using modification of Wardrop formula which is given in IRC-65(1976). Traffic data were collected from video-graphic survey. The practical capacities for different weaving sections of roundabout were obtained.

A. Jianjun Shi et al. (2014) estimated the capacity of roundabout by modeling radius of roundabout, width of circulating roadway, and gap acceptance at the weaving sections. They have proposed a new concept of “Quasi-saturation state of roundabout”. They found that the method of estimating the capacity of roundabouts by modeling weaving gap acceptance at the weaving sections is proved to be feasible.

Taylor W.P. Lochrane et al. (2014) studied mini-roundabout capacity in U.S. & their study provided design recommendations and a simulation approach for capacity models of mini-roundabouts from U.S. data. They found out that the linear regression models estimate the capacity of roundabout intersection to be lower than that of the single-lane roundabout.

III. LITERATURE ON EXISTING METHODS TO ESTIMATE CAPACITY OF ROUNDABOUT

There are various methods to estimate capacity of roundabout are proposed in past which are useful for evaluation purposes. The capacity of a roundabout is directly estimated by the practical capacity of each weaving section. IRC: 65-1976 formula to estimate the capacity of roundabout:

\[
Q_p = \frac{280 w \left(1 + \frac{e}{w} \left(1 - \frac{p}{3} \right) \right)}{1 + \frac{w}{l}}
\]

Where

\[Q_p\] = Practical capacity of the weaving section of the roundabout (rotary) in passenger car units, PCUs per hour.

\[w\] = width of the weaving section in meters.

\[e\] = average entry width of the roundabout in meters.

\[l\] = length of the weaving section between the ends of the channelizing island in meters.

\[p\] = proportion of weaving traffic, i.e. ratio of sum of crossing streams to the total traffic on the weaving section.

\[
p = \frac{b + c}{a + b + c + d}
\]

as in Figure-1,

Figure-1: Relevant dimensions of weaving section and proportion of weaving traffic for use in capacity formula of roundabout.
Mitesh Kumar N. Damor et.al. found the capacity of weaving sections using the IRC-65:1976 approach is presented in chart-1. CHART-1: Capacity of weaving sections of Anjali roundabout.

Weiqi Wang et. al. worked on following parameters:
1) Critical gaps.
2) Follow-up time.
3) Entry capacity.
4) Weaving section capacity.

They found that the entry capacity at roundabout decreases if the circulating flow increases due to less headway for entering vehicles.

Debashish Das et.al. found peak hour entry traffic volume and minimum weaving section capacity of all roundabouts are presented in chart-2.

CHART-2: Entry traffic volume and minimum weaving section capacity of roundabouts at peak hour.
The HCM Model (TRB 2000) is used to estimate the capacity of single lane roundabouts for their research. The formulation of HCM Model is as follows:

\[ C_e = \frac{q \cdot e^{\left(\frac{-ae}{5600}\right)}}{1 - e^{\left(\frac{-ae}{5600}\right)}} \]

Where

- \( C_e \) = Entry Capacity (veh/h),
- \( q \) = Circulating Flow (veh/h),
- \( T \) = Critical gap(s),
- \( T' \) = Follow-up time(s).

The capacity of the weaving Section of roundabout is given by:

\[ C_w = C_e + q \]

Serhan Tanyel et al. worked on various models to estimate capacity of roundabout including HCM Model (TRB 2000) and found that HCM 2000 has the highest capacity values than the other model used and this procedure can be used for an initial approach in design of single lane roundabout.

Xiaobo Qu et al. proposed an analytical model based on gap acceptance theory. They estimated capacity from both the models and compared on the basis of four scenarios. The entry capacities under these conditions are given in table 1.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Capacity-HCM Model (TRB2000)(veh/h)</th>
<th>Capacity-New Model (veh/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1082.6</td>
<td>1048.2</td>
</tr>
<tr>
<td>2</td>
<td>991.7</td>
<td>945.9</td>
</tr>
<tr>
<td>3</td>
<td>560.8</td>
<td>575.1</td>
</tr>
<tr>
<td>4</td>
<td>1063.3</td>
<td>1081.5</td>
</tr>
</tbody>
</table>

The NCHRP Report 572 recommended following model based on gap acceptance theory for the Entry Capacity of Single-Lane roundabouts which is also discussed by Taylor W.P. Lochrane et al. and Prof. Osama A. Abaza et al.

\[ c = A \cdot \exp\left(-B \cdot v_c\right) \]

Where

- \( c \) = entry capacity (PCUs/h),
- \( v_c \) = conflicting flow (PCUs/h),
- \( A = \frac{3600}{t_f} \)
- \( B = \frac{t_c - tf}{3600} \)
- \( t_f \) = follow-up headway(s),
- \( t_c \) = critical headway(s).
Prof. Osama A. Abaza et. Al. compared three different methods in capacity analysis of roundabouts (veh/h). The comparison of estimated capacities (table-2) shows that TRB and NCHRP consider the gap acceptance theory which resulted in lower capacity.

<table>
<thead>
<tr>
<th>Methods</th>
<th>Capacity (veh/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCHRP 572 Method</td>
<td>562</td>
</tr>
<tr>
<td>FHWA Method</td>
<td>1312</td>
</tr>
<tr>
<td>TRB Method</td>
<td>501</td>
</tr>
</tbody>
</table>

Taylor W. P. Lochrane et.al. worked on capacity parameter for a Mini-Roundabout. Their result shows that the NCHRP 572 equation for single-lane roundabout predicted higher values for entry capacity than the other model proposed by them.

Tanner (1967) introduced a capacity formula for unsignalized intersections. As roundabout is a type of unsignalized intersections, this formula also applied to estimate the capacity of roundabouts in multiple studies. The model formulation is as follows:

\[ Q_e = \frac{3600 \cdot q_c \cdot (1 - \Delta \cdot q_c) \cdot e^{-q_c \cdot (t - \Delta)}}{1 - \exp\left(-q_c \cdot t_0\right)} \]

Where

- \( Q_e \) = entry capacity (veh/h),
- \( q_c \) = circulating flow in front of the entry approach (veh/h),
- \( \Delta \) = the minimum headway between the circulating vehicles (s),
- \( T \) = critical headway (s),
- \( T_0 \) = follow-up time (s).

Tanner Capacity Model discussed by Serhan Tanyel et.al. in their research. They worked on critical gaps, follow-up time, and capacity parameters. Their result shows that the Tanner Capacity Model estimated similar capacity values but less than HCM 2000.

Wu. N. et.al. proposed a formula for the entry capacity of the roundabouts which is modification of Tanner Capacity Model (1967) given by:

\[ C_e = \left(1 - \frac{\Delta \cdot q_c}{n_c}\right) \cdot \frac{n_c}{t_f} \cdot \exp\left[-q_c \cdot (t_0 - \Delta)\right] \]

Where

- \( C_e \) = Entry capacity (PCU/h),
- \( q_c \) = circulating flow in front of the entry approach (PCU/h),
- \( n_c \) = number of circular lanes,
- \( n_e \) = number of lanes in subject entry,
- \( t_0 = \left(t_e - \frac{t_f}{2}\right) \)
- \( t_e \) = critical gap (s),
- \( t_f \) = follow-up time (s),
- \( \Delta \) = the minimum headway between the circulating vehicles (s).

**IV. CONCLUSION**

A brief insight into various capacity estimation procedures for roundabout intersections has been provided. Based on the review, we can make following suggestions:

1) The weaving section of roundabout intersection has significant impact on capacity of roundabout. IRC: 65-1976 recommended formula for capacity of roundabout which focuses on capacity of each weaving section is used by many researchers across the India. But this formula has certain limitations based on its geometric layout and the percentage of weaving traffic.

2) The HCM Model (TRB 2000) of capacity estimation is mostly used method for single-lane roundabouts which considers both the gap acceptance behavior of the driver and weaving section of roundabout.

3) The NCHRP Report 572 recommended formula for entry capacity which is based on gap acceptance theory has limited applicability because it is only valid for single-lane roundabouts.

4) Tanner Capacity Model for roundabout which only focuses on gap acceptance theories can be used for capacity estimation of single-lane and double lane roundabouts.

5) Modified Tanner Capacity Model for roundabout which is based on both gap acceptance theory and geometric features of roundabouts can be used because it has no limitation for the number of entry lanes or number of circulating lanes.
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