Modelling of the Gap Phenomena at U-turn Provisions on the Median Openings of Inter-Urban Highway Corridors

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Abstract: In India, most of the capacity augmentation activities have been carried through expansion of the existing bi-directional carriageways into four lane divided carriageways, which has brought the practice to provide the median opening at every 2 km and the same has been brought in the form of an ordinance by the concerned authorities as well. U-turn median openings considered among the most hazardous locations on highways. It is essential to understand the gap phenomena occurring at the median openings. This paper reviewed gap acceptance phenomena occurring at U-turn median openings studied by various researchers in India and abroad. In this study, gap acceptance behaviour on the candidate test sections was evaluated by employing different gap acceptance modeling methods. Based on the results, it was observed that the critical gap of 4.5 seconds is optimum for designing the median opening on inter-urban corridors in India.

Keywords: Gap Acceptance, Median Openings, U-Turn, National Highways,

1. INTRODUCTION

During the last decade, India has accorded top priority towards the development / augmentation of its road infrastructure and has almost completed some of its very ambitious projects like the Golden Quadrilateral, North - South and East - West corridors spanning the envisaged length of 13,000 km. During the course of this expansion, it is noted that more than 90% of the capacity augmentation activities have been carried through expansion of the existing bi-directional carriageways into four lane divided carriageways. This practice has brought in the need to provide the median opening at every 2 km and the same has been brought in the ordinance of the National Highways as well. However, this phenomenon of providing median openings at frequent intervals has resulted in severe road crashes at such locations on the Indian road network. As the economy has again shown glimpses of growth, it is anticipated more number of capacity augmentation projects will be undertaken in the foreseeable future. But the mere capacity augmentation alone will not serve the purpose since it is essential to understand the gap phenomena occurring at the median opening and based on the same needful measures can be undertaken so as to provide reasonable operating speed.
U-turn median openings considered among the most hazardous locations on inter-urban highways. The behavior of the driver when turning is governed by the gap acceptance behavior. Drivers usually do not care much about the conflicting traffic and they attempt to enter median openings, even if a conflicting vehicle is about to collide. All these non-standard conditions create very complex travel behaviour at unsignalized median openings, which are the causes of increase in accident on the roads. Studies of U-turn Gap Acceptance on Inter Urban highway corridors had been neglected. Very few studies in the literature have focused on estimating critical gap values at U-turn median openings of intercity highway corridor (Datta S, 2014). There is need for development of a gap acceptance model for U-turn median openings of intercity highway corridor which will give the accurate value of critical gaps near the median openings and can be adopted for efficient median gap design for the heterogeneous traffic conditions and current traffic volumes. The traffic in India is exceedingly heterogeneous. Vehicles are having wide variations dimension of the vehicles and engine technology. Smaller size vehicles often squeeze through any available gap between large size vehicles and move into the median opening area in haphazard manner. This forced gap acceptance significantly affects the entry capacity of the lower priority stream and causes substantial delay to higher priority movements. It makes gap acceptance an extremely unpredictable phenomenon. Understanding the driver behavior is essential for selecting the prone locations and finding solutions to minimize crash problems. Gap acceptance study at U-turn median openings has not been addressed in the US Highway Capacity Manual (HCM 2010). The detailed Gap acceptance study will be beneficial to Indian highways, in designing the proper median gap and further this will reduce the number and the severity of the road crashes on the Indian Highways.

The objective of the study is to estimate critical gap for U-turn median openings of Inter-Urban Highways. For this a study section on National highway 8(NH8) was identified and videography data has been collected to study the effect of driver waiting time on critical gaps of U-turn vehicles. Reviewed various gap acceptance studies in the literature and identified seven Gap acceptance models estimate critical headway and follow-up headway of U-turn movements from the field data for upstream direction of the traffic flow and downstream of the traffic flow.

2. REVIEW ON GAP ACCEPTANCE AT MEDIAN OPENINGS

U-turn gap is the time headway between two vehicles on the major road into which a U-turn vehicle may choose to run. Ashworth and Green (1966) measured gap from the rear of one vehicle to the front of the following vehicle. Adibesi (1982) defined gap as the major stream headway wholly available to a waiting vehicle from the minor road. Polus (1983) defined it as the time interval between two successive vehicles in the major road stream. Solberg and Oppenlander (1966), Adibesi (1982), Polus (1983) defined Lag time, as the time interval between the arrival of a vehicle on the minor road at the stop line and the arrival of the next (first) vehicle on the major road to a point opposite this line. Conventionally, Gap is defined as the time or space headway between two successive vehicles in the through traffic stream (Uber, 1984). United States of America (USA) Highway Capacity Manual (HCM 2000) defined Gap is the time, in seconds, for the front bumper of the second of two successive vehicles to reach the starting point of the front bumper of the first. Further HCM (2010) defined Gap as the space or time between two vehicles, measured from the rear bumper of the front vehicle to the front bumper of the second vehicles. HCM (2010) defined gap acceptance
as the process by which a driver accepts an available gap in traffic to perform a maneuver. Gap acceptance is the process through which a driver has to evaluate the gaps and judge whether they are enough or not for merging (Turki I. Al-Suleiman Obaidat, 2013).

2.1 Definitions of Critical Gap

Critical gap is an important parameter in gap acceptance behavior. It is the minimum gap that is acceptable to a driver, intending to cross a conflicting stream. The definition of critical gap has undergone significant modifications over the years in the literature. Greenshield defined it as the gap range that has equal number of acceptances and rejections. Raff and Hart (1950) defined critical gap as the size of the gap whose number of accepted gaps shorter than it is equal to the number of rejected gaps longer than it. Drew (1968) defined critical gap as the gap for which the percentage of traffic that will accept a shorter gap is equal to the percentage of traffic that will reject a longer gap. Miller (1974) defined critical gap as the minimum gap to make a manoeuvre (left turn, right turn, or lane merge), which varies from driver to driver. HCM (1985) defined critical gap as the median time headway between two successive vehicles in the major street traffic stream that is accepted by a driver in a subject movement who intends to cross and/or merge with the major street flow. HCM (1994 and 2000) modified the definition of critical gap as the minimum length of time interval that allows intersection entry to one minor stream vehicle. HCM (2010) defined critical gap as the minimum time interval in the major-street traffic stream that allows intersection entry for one minor-street vehicle.

2.2 Work done in India and Abroad

Al-Masaeid (1999) developed a linear regression model to estimate the capacity of U-turn movement and to investigate the effects of different factors that might affect the estimated capacity. This study showed that the critical gap is strongly correlated with the average total delay and conflicting traffic speed at U-turn sections. This study used regression equation to analyze the relationship between U-turn critical gap and delay. Also, this study estimated the critical gap and follow-up time for U turns and used them to calculate capacity based on the gap acceptance model provided by the HCM (1994). Ebisawa et.al. (2001) modeled the gap acceptance function of a U-turn in Bangkok as a binary choice problem. Xiao et.al (2001) explored the critical gap of U-turn at median openings using Raff’s method and Logit model. Hussein (2008) used both empirical and simulation approaches to estimate capacity of U-turn movement at median openings of divided arterials. Liu et al. (2006, 2007 and 2008) have conducted a series of research relating to capacity of U-turn at median opening. They estimated the parameters critical headway and follow-up headway of U-turn movements from the field data. This study validated the capacity estimation from the model with the field capacity. The model provides reasonable estimated capacity for U-turn movement at median openings. The HCM (2010) utilizes the values of these parameters of U-turn movement for the capacity analysis in the US. Thakonlaphat et.al (2013) evaluated the gap acceptance capacity model and proposed an adjustment method by Volume by Capacity (V/C) ratio. Turki and Mohammad (2013) studied the driver’s gap acceptance behavior at U-turn median openings. Datta S (2014) introduced a concept of merging behaviour of U-turn vehicles for evaluation of gaps by drivers. Most of the Gap acceptance studies in India focused on Gap Acceptance behaviour at Unsignalised Intersections (Ashalata and Satish Chandra, 2011).
Factors Affecting Gap Acceptance Behaviour

HCM (2000) listed various factors that affect driver gap acceptance characteristic which are turning movements, number of lane in the major roadway, adequacy of intersection sight distance and corner radii, etc. The factors affecting gap acceptance analysis at U-turn provisions and models considered in the previous studies are presented in Table 2.

Table 1. Factors affecting Gap Acceptance at U-Turn Provisions

<table>
<thead>
<tr>
<th>Studies</th>
<th>Factors Affecting Gap Acceptance Modeling</th>
<th>Models Considered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suprabeet Datta (2014)</td>
<td>Mixed traffic conditions, speed, manoeuvrability, effective dimensions, Power-weight ratio</td>
<td>Harder’s and “INAFOGA”</td>
</tr>
<tr>
<td>Turki I. Al-Suleiman Obaidat (2013)</td>
<td>Waiting time, Gender, Age</td>
<td>Multi Linear Regression (MLR)</td>
</tr>
<tr>
<td>Thakonlaphat Jenjiwattanakul (2013)</td>
<td>Conflicting headway distribution</td>
<td>Maximum likelihood method</td>
</tr>
<tr>
<td>Hussein Kariem Mohammed (2008)</td>
<td>Average total delay of U-turning vehicles, conflicting traffic flow delay, travel time, critical gap, follow-up time</td>
<td>Regression analysis, Simulation Approach</td>
</tr>
<tr>
<td>Jian John (2007)</td>
<td>Properties of the traffic, configuration of the intersection, number of lane crash rate, delay, travel time, queue discharge time, critical gap, follow-up time</td>
<td>Simulation Approach</td>
</tr>
<tr>
<td>Pan liu (2006)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NCHRP-524 (2004)</td>
<td>Location of median openings, spacing of median openings, safety of median openings, median width, median opening length, median treatments (Raised/Depressed/Flushed), median acceleration lanes, sight distance at median openings and effects of adjacent traffic Signals</td>
<td>AASHTO</td>
</tr>
<tr>
<td>Ryoichi Ebisawa (2001)</td>
<td>Waiting time, speed, acceleration, critical gap, distance between signalised intersection and U-turn and number of lanes</td>
<td>Binary Logit Model</td>
</tr>
</tbody>
</table>

Findings from Literature

Critical gap is an important parameter in gap acceptance study and it is difficult to measure directly in field. Because the measurement varies for different drivers and with time instants depending upon manoeuvres of the U-turn vehicles under mixed traffic conditions prevailing on the median openings. In the literature many researchers were tried to calculate the accurate value of critical gap and they proposed different models for finding the accurate value of critical gap. Most of the studies in the literature considered the accepted and rejected gaps as
the key parameters in estimation of critical gaps. HCM (2010) also estimated critical gap on the basis of observations of the largest rejected and smallest accepted gap corresponding to a given transportation facility. Raff (1950) gave macroscopic model which was the earliest method for estimating the critical gap which is widely used in many studies because of its simplicity. Harder’s (1968) makes only use of gaps data i.e he excluded lags data for the calculation of critical gap. Siegloch (1973) had given the procedure for the estimation of critical gap and follow-up time which was closely related to the subsequent capacity theory. But this method can only be applied for saturated conditions which are difficult to find in many practical cases. Troutbeck (1999) corrected the Raff’s model and concluded that this method gave suitable results for light-to-medium traffic but is not acceptable in heavy traffic conditions. Turki I. Al–Suleiman Obaidat (2013) proposed a model for the estimation of time gap needed by a U-turn driver based on driver’s age, gender and the elapsed time between arriving and experiencing the gap. From the literature it can be inferred that the maximum likelihood procedure and Hewitt’s method gave the best results than the other methods. The gap rejection behaviour mainly depends on the various factors namely, time of the day, manoeuvre, time waiting for an acceptable gap, average size of available gap, Vehicle classification, point of departure, etc.

Gap acceptance analysis for median openings under heterogeneous traffic conditions has not been given proper attention in the literature. The recent US HCM (2010) also did not address the gap acceptance study for median openings. In India there is no study focused on operational effects of U-turn movement on Inter urban highways. In the literature very few studies focused on the effect of the distance between the U-turn and the nearest signalized intersection on the behaviour of the drivers maneuvering the U-turn. Because of non-availability of accurate critical gaps value for the present traffic volume and heterogeneous condition on Indian roads, the existing methods of design of roads are either underestimated or overestimated. Underestimated design will provide parameters value (no of lane, geometries of intersection, gap length in median openings, etc) lesser than the required, which will lead to the earlier congestion problems, slow movement of vehicles on the road, irritating driving behavior and increase accidents on the roads. Overestimated design will provide parameters value more than the required, which is not economical.

3. STUDY AREAS AND DATA COLLECTION

3.1 Study Area

Initially, a reconnaissance survey has been carried out on National Highway number 8 (NH8) to identify the study section to collect the data study. A section on NH-8 near Manesar, Gurgaon, Haryana, India has been identified. NH 8 is four lane divided carriageway and the identified study section is not influenced by any intersection. Also there is no storage lane for the U-turning vehicles at this study section. The physical characteristics of the study section are presented in Figure 1. The length of the median opening at this section is 38 m. A typical illustration of subject vehicle, lag vehicle, lead vehicle, follow up gap and critical gap are schematically presented in Figure 1.
3.2 Data Collection

Traffic data was collected on the study section through videography survey and the location of vantage point was carefully selected by considering variables of interest to be observed through the survey. Total seven hours traffic data was collected for both upstream direction (Delhi to Manesar) and downstream direction (Manesar to Delhi). Videography data extraction was done by considering Dartfish Software for slow motion scale of videography data. The study parameters namely rejected gap, accepted gap and waiting time of U-turn vehicles were recorded for modeling the gap acceptance behaviour at this study section. The sample size of U turning traffic on both directions of travel for the study period (total seven hours data) was presented in Table 2. Classified traffic Volume Counts (CVC) data was also extracted for both directions of travel for the study period and it was observed that the total traffic on upstream side and downstream directions are 12302 vehicles and 15992 vehicles respectively. Out of this, a total of 748 U-turning vehicles and 187 U-turning vehicles were observed on the upstream and downstream directions of travel and the same were considered for the gap acceptance analysis. The composition of the U-turning traffic at this median opening on the upstream and downstream directions of travel is presented in Figure 2. It can be inferred from Figure 2 composition of car (Small Car [up to 1400 cc] and big car [beyond 1400cc including Vans / Jeeps]) is the dominant mode (68%).

Table 2. Sample size of U turning Traffic on both Directions of Travel

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Upstream Direction (Delhi to Manesar)</th>
<th>Downstream Direction (Manesar to Delhi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantum of U-turning traffic</td>
<td>Traffic Volume (Veh/hr)</td>
</tr>
<tr>
<td>1st hour</td>
<td>129</td>
<td>1496</td>
</tr>
<tr>
<td>2nd hour</td>
<td>120</td>
<td>1747</td>
</tr>
<tr>
<td>3rd hour</td>
<td>141</td>
<td>1605</td>
</tr>
<tr>
<td>4th hour</td>
<td>147</td>
<td>1803</td>
</tr>
<tr>
<td>5th hour</td>
<td>97</td>
<td>2054</td>
</tr>
<tr>
<td>6th hour</td>
<td>56</td>
<td>1805</td>
</tr>
<tr>
<td>7th hour</td>
<td>58</td>
<td>1792</td>
</tr>
<tr>
<td>Total</td>
<td>748</td>
<td>12302</td>
</tr>
</tbody>
</table>
4. GAP ACCEPTANCE ANALYSIS

In this study, seven different gap acceptance model widely used in the literature have been considered for studying the gap acceptance behavior at median opening on present study section. Critical gap acceptance for upstream side and downstream side directions were also estimated in this study and results of this model are discussed in the following sub sections. Finally, a comparative evaluation between these models was made in the subsequent section.

4.1 Raff’s Method

Raff (1950) gave macroscopic model which was the earliest method for estimating the critical gap which is used in many countries because of its simplicity. Raff method defines the critical gap to be the size of gap that results in an equal number of accepted shorter gaps and longer rejected gaps. The critical gap is the intersecting point of accepted and rejected gap. Figure 3 presents the profile of accepted and rejected gaps at upstream direction (Figure 3a) and downstream direction (Figure 3b). The critical gap estimation for the study area is obtained as 4.9 sec and 4.3 sec for upstream and downstream directions of travel respectively. The main disadvantage of this method is that the useful gap acceptance and rejection data are omitted in this method. This shortcoming can be eliminated by combining the gap and lag data based on the notion that there is no statistical significance between lag and gap data.
b) Downstream direction (Manesar to Delhi)
Figure 3. Raff’s Method for Calculating the Critical Gap

4.2 Greenshield’s Method

The main difference between Raff’s and Greenshield's method is that, Greenshield's method estimates the value of the critical gap using a frequency histogram which represent the total number of acceptances and rejections for each gap range (usually for each 0.5 s) whereas in the case of Raff's methods, the critical gap is the intersecting point of accepted and rejected profiles. The Critical Gap using Greenshield’s method is presented in Figure 4. The vertical axis of the frequency histogram represents the number of gaps accepted (positive value) or rejected (negative value) of a certain gap range and the horizontal axis represents the gap-size range. The gap range having an equal number of accepted and rejected gaps is the range of the critical gap size, and the mean of this range is the size of the critical gap. If none of the gap ranges have an equal number of acceptances and rejections, then the gap range that has the closest number of acceptances and rejections is used as the critical gap range, and the mean of this range is the critical gap. Similar critical gap of 4.5 sec was observed for both upstream and downstream direction. The limitation of this method is sample size, if sample size is small may affect critical gap.

a) Upstream direction (Delhi to Manesar)
4.3 Maximum Likelihood Estimation

Maximum Likelihood Estimation (MLE) method was initially introduced by Troutbeck (1992) for the estimation of Critical Gaps. MLE assumes the log-normal distribution of accepted and maximum rejected gaps. In this method only the accepted gap and the maximum rejected gap of each vehicle are treated pair wise. The maximum rejected gap is the largest value of all rejected gaps for upstream driver. The estimation of likelihood value of critical gap is presented at equation (1). 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. In the present study the estimation of likelihood value of critical gap was done by considering Ms Excel spread sheet and solver functions. The MLE is based on the assumption that upstream 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 were estimated.

\[ L = \sum \ln[F(b_i) - F(a_i)] \]  
*Eqn. (1)*

Where, \( L \) is likelihood for Critical Gap, \( F(a_i) \) is Cumulative Distribution Function (CDF) of the accepted gaps, \( F(r_i) \) is CDF of the largest rejected gaps, \( a_i \) is gap accepted and \( r_i \) is the largest gap rejected by a driver. The critical gap for upstream direction is 5.2 sec and downstream direction is 3.2 sec was observed by considering MLE method.

4.4 Acceptance Curve Method

Acceptance Curve method is used to estimate the value of the critical gap where the dependent variables of an “S-shaped” response variable curve, with \( y = 0 \) and \( y = 1 \) being the asymptotes, are the cumulative probability of accepting a gap of a specific length. The x-value corresponding to the 50% probability (median) is used as the critical gap. The acceptance curve method identifies the gap size with a 0.5 probability (50 percent chance) of acceptance by the drivers. Figure 5 presents the Accepted Curve method. The probability of acceptance is calculated by considering the Equation 2
\[ P_i = \frac{n_i}{N} \quad \text{Eqn. (2)} \]

Where \( P_i \) is the probability of accepting a gap (seconds) of length \( i \), \( n_i \) is the number of gaps accepted of length \( i \), \( N \) is the total number of events of gap acceptance.

**Figure 5. Acceptance Curve Method for Calculating the Critical Gap**

**4.5 Harder’s Method**

Harder (1968) has developed a method for critical gap estimation that has become rather popular in Germany and this method only makes the use of gaps. In Harder’s method, lags should not be used in the sample. The time scale is divided into intervals of constant duration, e.g. \( \Delta t = 0.5 \) seconds. The centre of each time interval is denoted by \( t_i \). For each vehicle queuing on the upstream, downstream gaps were observed. From these observations the proportions of accepted gaps were calculated using equation (3)

\[ a_i = \frac{A_i}{N_i} \quad \text{Eqn. (3)} \]

Where \( N_i \) is number of all gaps of size \( i \), that are provide to upstream vehicle, \( A_i \) is number of accepted gaps of size \( i \). These \( a_i \) values were plotted over period of time \( (t_i) \) and presented figure
6a and 6b for upstream and downstream respectively. The profile of proportion of accepted gaps has follows cumulative distribution function of critical gaps (F_c(t)). The critical gap of 7.11 sec and 5.55 sec were obtained for upstream and downstream respectively

![Graph](attachment:image.png)

**a) Upstream direction (Delhi to Manesar)**

![Graph](attachment:image.png)

**b) Downstream direction (Manesar to Delhi)**

Figure 6. Harder’s Method for Calculating the Critical Gap

### 4.6 Ashworth Method

Ashworth method (1968, 1970 and 1979) is based on the assumption of exponentially distributed of upstream and downstream gaps. This method states statistical independence between consecutive gaps and normal distributions for accepted gaps and average critical gap. This method found that the average critical gap form the mean of the accepted gaps and the standard deviation of the accepted gaps can be calculated by considering the Equation 4

\[ t_c = \mu_a - p \cdot \sigma_c^2 \]  

Eqn.(4)

Where \( t_c \) is the average critical gap (in seconds), \( \mu_a \) is the mean of the accepted gaps (in seconds), \( p \) is the major stream traffic volume (vehicle per second) and \( \sigma_c \) is the standard
deviation of the accepted gaps (in seconds). The critical gap of 4.5 and 3.1 sec for observed for upstream and downstream direction respectively.

### 4.7 Ning wu’s Method

This method is based on probability equilibrium of the accepted and rejected gaps are established to find the critical gap value. This method is robust and having theoretical concepts in terms of the Markov Chain and equilibrium of probabilities. This method requires neither predefined distribution function of the critical gaps nor the consistency nor the homogeneity of drivers. This model can take into account of all relevant gaps (not only the maximum rejected gaps) and yields the empirical probability distribution function of the critical gaps directly. This method is adopted and obtained critical gap of 3.40 sec for upstream direction and 2.72 sec for downstream direction.

### 4.8 Comparison of Critical Gap Values

The summary of critical gap obtained across all the seven gap acceptance methods for upstream direction and downstream direction are presented in Table 2. These Critical Gap values are estimated by considering different vehicle types including heavy commercial vehicles and Buses.

<table>
<thead>
<tr>
<th>Gap acceptance Methods</th>
<th>Critical gap values (sec)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Up Direction (Delhi to Manesar)</td>
<td>Down Direction (Manesar to Delhi)</td>
<td></td>
</tr>
<tr>
<td>Raff’s Method</td>
<td>4.90</td>
<td>4.30</td>
<td></td>
</tr>
<tr>
<td>Greenshield’s Method</td>
<td>4.50</td>
<td>4.50</td>
<td></td>
</tr>
<tr>
<td>Maximum likelihood Estimation</td>
<td>5.20</td>
<td>3.20</td>
<td></td>
</tr>
<tr>
<td>Acceptance Curve Method</td>
<td>3.80</td>
<td>2.10</td>
<td></td>
</tr>
<tr>
<td>Harder’s method</td>
<td>7.26</td>
<td>6.70</td>
<td></td>
</tr>
<tr>
<td>Ashworth Method</td>
<td>4.50</td>
<td>4.31</td>
<td></td>
</tr>
<tr>
<td>Ning Wu’s Method</td>
<td>3.40</td>
<td>2.72</td>
<td></td>
</tr>
</tbody>
</table>

### 5. CONCLUSIONS

The main objective this study is to study the behavior of gap acceptance at median opening for this study section on National Highway number 8 was identified and seven hours videography data was collected. Most widely used gap acceptance methods were considered in this study and critical gap acceptance for both upstream U-turn vehicles and downstream U-turn Vehicles were estimated. The Classified traffic volume counts data was also extracted for both directions for the study period and it was observed that the total traffic on upstream side and downstream directions of travel is 12,302 vehicles and 15992 vehicles respectively. Out of this a total of 748 U-turn vehicles data upstream direction and 187 U-turn vehicles downstream side direction were considered into gap acceptance analysis. The average difference between critical gap for the upstream and downstream traffic were determined by using various deterministic methods to understand Critical gap values. These include Raff's method, Greenshield’s method, Acceptance Curve method and Harder's methods which yields less variation in the estimated Critical Gap (CG) values. On the other hand, the stochastic models such as MLM and Ning Wu's methods yielded large variation. Based on the study
results, the CG values obtained by Greenshield and Ashworth’s methods are consistent due to the consistency in estimation of CG values in the upward and downward directions. Though the MLE method is developed based on robust mathematical concept, but the limitation of this model is that it is not considering the accepted gaps value smaller than the maximum rejected gap which generally occurs in mixed traffic condition due to forceful entry behavior resorted by the drivers under the conditions of traffic heterogeneity. Further study is required for quantification of the critical gap under varying sizes of median openings.

ACKNOWLEDGEMENTS

Authors are grateful to the Director, CSIR-Central Road Research Institute for allowing us to publish this paper. This study also acknowledges the resource of data collected for Development of Indian Highway Capacity Manual (Indo-HCM) project, a 12th Five Year Plan project of CSIR-CRRI, New Delhi, India.

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