2nd Conference of Transportation Research Group of India (2nd CTRG)

Methodological Framework towards Roadway Capacity Estimation for Indian Multi-Lane Highways

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Abstract

Since transport industry is essentially a service sector component, it is of paramount concern for the traffic engineers, transport planners and policy-makers alike to understand and evaluate the “quality” of service being provided by the transport facilities designed by them. US Highway Capacity Manual (HCM), with all its revisions since 1950, is the pioneer document in this respect as it quantified the concept of capacity for a transport facility and laid the foundations for estimating the level of service (LOS) being provided by that facility to its users. Unfortunately, the HCM methods developed in US are not directly applicable directly around the world due to the heterogeneities arising out of markedly varying local conditions. Recognizing this, several countries have developed their indigenous versions of HCM. Likewise, Indian highways, due to the heterogeneous traffic conditions and vastly unique driver behavior found on these roads, are also not conducive to the application of US HCM methods. Identifying this huge gap in knowledge, efforts were initiated by CSIR-CRRI to develop the Highway Capacity Manual for Indian roads (Indo-HCM). This paper, thus, presents a review of significant methodological issues that need to be specifically addressed to enable accurate estimation of roadway capacity for multilane highways, and based on the same, methods that can deployed for roadway capacity estimation in Indian conditions have been discussed.

Keywords: Indo-HCM; Methodological Issues; Mixed Traffic; Multi-lane Highways

1. Introduction

Since transport industry is essentially a service sector component, it is of paramount concern for the traffic engineers, transport planners and engineers alike to understand and evaluate the “quality” of service being provided by the transport facilities designed by them. In this regard, it is imperative to understand first the capacity of such facilities. U.S. Highway Capacity Manual (US-HCM), first published in 1950, has been the
pioneer document in this respect as it quantified the concept of roadway capacity for a transport facility, and has been widely referenced and used by the researchers from many countries in their pursuit to develop the indigenous methods for capacity estimation. Since then, this manual has undergone significant improvements with major restructuring and rewrites in 1965, 1985, 2000 and the recent publication in 2010.

Unfortunately, in the absence of adequate knowledge on roadway capacity estimation methods applicable for the roads in India, the highway engineers and planners in India refer to the US-HCM for solving indigenous problems. It is an established fact that, due to the prevalence of high degree of heterogeneity in the Indian traffic scene and also vastly unique driver behavior on Indian roads which even differs significantly from other developing countries like China and Indonesia, the standards evolved for other countries cannot be readily translated for Indian traffic conditions by simply developing some adjustment factors. Considering this huge gap in knowledge, efforts have been initiated by CSIR-Central Road Research Institute (CSIR-CRRI) to develop the Highway Capacity Manual for Indian condition under a project titled “Indo-HCM”. The scope of Indo-HCM includes the total spectrum of roadway facilities available across the Indian nation in its ambit.

Considering the vast scope of the work being undertaken, a need is felt for consolidating the already available knowledge emanating out of the vast body of research undertaken towards estimation of roadway capacity. This paper, therefore, reviews the literature on methods of capacity estimation deployed in India as well as abroad with special emphasis on their suitability for the mixed traffic conditions as observed on Indian roads. To further refine the meaningfulness of this exercise, the paper limits its scope only to the methods developed specifically for multi-lane highways covering four-lane, six-lane and eight-lane divided carriageways.

During the literature review, several key methodological issues were identified that need to be addressed in the direction of developing some capacity estimation procedures for Indian multi-lane highways. Thus, the next section presents these issues and a review of studies that dealt with them. For the purpose of comparison, results from the US-HCM are also provided to enable the reader to appreciate the difference in approaches from the standard procedures adopted in the developed world for homogeneous traffic conditions. Finally, the paper ends with an assessment of the methodologies reviewed and recommendations about the best ones to be adopted for Indian conditions.

2. Methodological Issues to be considered in Capacity Estimation for Indian Multi-Lane Highways

2.1. Base Conditions for Capacity Estimation

The base conditions are defined to estimate the highest operating level of multi-lane rural and suburban highways. Under these base conditions, the full speed and capacity of a multi-lane highway are achieved. The US HCM (2000) has defined the following conditions as the ideal ones:

- 3.6-m minimum lane widths;
- 3.6-m minimum total lateral clearance in the direction of travel—this represents the total lateral clearances from the edge of the traveled lanes to obstructions along the edge of the road and in the median (in computations, lateral clearances greater than 1.8 m are considered in computations to be equal to 1.8 m);
- Only passenger cars in the traffic stream;
- No direct access points along the roadway;
- A divided highway; and
- Free-flow speed (FFS) higher than 100 km/h.

In addition to that, the highways must be operating under good weather, good visibility and no accidents/incidents conditions. These base conditions were redefined in the 2010 version of the US HCM where it was understood that the highway segment should also not be having any work zone activity, and any pavement defects that would adversely affect operations. The HCM (2010) rephrases the “only passenger cars in the traffic
stream” requirement as “No heavy vehicles, such as trucks, buses, and recreational vehicles in the traffic stream”. It also recognizes that a driver’s familiarity with a facility encourages him to drive at higher speeds and hence has a positive impact on capacity. So it includes amongst the base conditions that the driver population must be composed primarily of regular users who are familiar with the facility.

The Indonesian HCM (1993) accounts for the heterogeneous traffic conditions prevalent on the Indonesian highways. It defines the base conditions for its multi-lane highways a bit differently as below:

- Traffic lane widths of 3.5-m;
- Shoulders of effective width of 1.0 m for each carriageway (measured as the mean of inner shoulder and outer shoulder widths) (unpaved shoulders, not suitable for moving traffic);
- A divided highway;
- Flat terrain;
- No roadside developments;
- Very low side friction;
- Functional class of the road as Arterial road; and
- More than 70% of the segment with sight distance>300 m.

The difference here lies in the fact that the Indonesian HCM allows for certain roadside events on the segment, such as the presence of pedestrians, stops made by public transport and other vehicles, vehicles entering and exiting roadside premises, and slow-moving vehicles, however restricting the weighted frequency of such events to less than 50. Also, considering the local conditions, the Indonesian HCM is explicit about the sight distance requirements which do not feature in the US-HCM.

2.2. Determination of Units of Traffic Flow

Traditionally, passenger cars have been taken as the basis of traffic flow measurement and hence the Passenger Car Units (PCU) has been the widely adopted metric for assessing flow rate. Owing to the mixed traffic conditions, however, the analysts in Asian countries have come up with either their own standard values of PCU or have adopted some other class of vehicles as the new basis for flow measurement. Indonesian HCM (1993), for example, has adopted the following classification scheme conforming to their conditions as presented in Table 1.

Table 1. Vehicle Classification adopted in Indonesian HCM (1993)

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Full-form</th>
<th>Description</th>
<th>Light Vehicle Unit (LVU) values (speed-based)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV</td>
<td>Light Vehicle</td>
<td>Two-axle motor vehicle on four wheels with an axle spacing of 2.0 – 3.0 m (including passenger car, micro bus, pick-up and micro truck)</td>
<td>1.0</td>
</tr>
<tr>
<td>MHV</td>
<td>Medium Heavy Vehicle</td>
<td>Two-axle motor vehicle with an axle spacing of 3.5-5.0 m (including small buses, 2-axle truck with six wheels)</td>
<td>1.5</td>
</tr>
<tr>
<td>LT</td>
<td>Large Truck</td>
<td>Three-axle trucks and truck combinations with axle spacing (first to second axle) &lt; 3.5 m</td>
<td>2.7</td>
</tr>
<tr>
<td>LB</td>
<td>Large Bus</td>
<td>Two- or three-axle buses with an axle spacing of 5.0 - 6.0m.</td>
<td>1.2</td>
</tr>
<tr>
<td>MC</td>
<td>Motor Cycle</td>
<td>Motor vehicles with two or three wheels (including motorcycles and 3-wheeled vehicles)</td>
<td>Their impact is considered separately in capacity estimation</td>
</tr>
<tr>
<td>UM</td>
<td>Non-motorized Vehicle</td>
<td>Non-motorized traffic element on wheels (including bicycles, horse carriages and pushcarts)</td>
<td>Their impact is included in the side-friction component in capacity estimation</td>
</tr>
</tbody>
</table>
Thus, the Indonesian HCM makes use of Light Vehicle Units (LVU) for expressing flow rate (LVUs/h). For specific grades a different set of values is used, where the LVU value for LV and LB remain constant at 1.0 and 1.5 respectively, while those for MHV and LT are estimated according to the specific gradient value (in %) and the length of gradient segment (in km). Bang et al. (1998) used a vehicle classification quite similar to the one found in Indonesian HCM and estimated passenger car equivalents (PCE) as a function of the terrain type and volume of traffic (in veh/h). However, unlike Indonesian HCM, they did not consider the effect of motorcycle traffic separately and provided PCEs for motorcycles as well. Rotwannasin and Choocharukul (2005) defined vehicle classifications based on vehicle length (in m) for measuring traffic flow on Bangkok multi-lane highways. A passenger car or such vehicle with a length less than 5 m (including light Bus, pick up etc.) was considered as having a Passenger Car Equivalent (PCE) value of 1. Similarly, PCE values for motorcycles (length< 3m), bus, medium and heavy trucks (length< 12 m), semi-trailer (length< 16 m) and full-trailers (>16 m long) were estimated.

Tanaboriboon and Aryal (1990) classified the vehicles into three major types while estimating the PCE values for capacity estimation for uninterrupted flow on highways in Thailand, namely; small (S), medium (M), and large vehicles (L). They estimated the Passenger Car Equivalents (PCE) by a method using mean headways between various vehicle types as factors. This method had been advocated for use by Krammes and Crowley (1987). For heavy vehicles, their formula possessed the following functional form as given in Equation (1):

\[
PCE = \frac{1-p(H_L-S+H_S-L-H_S-S)}{H_S-S} + p(H_L-L)
\]

where,
- \(p\) = proportion of large vehicles in the mixed-traffic stream
- \(H_L-S\) = average minimum headway time for large vehicle followed by small vehicle (in s)
- \(H_S-L\) = average minimum headway time for small vehicle followed by large vehicle (in s)
- \(H_S-S\) = average minimum headway time for small vehicle followed by small vehicle (in s)
- \(H_L-L\) = average minimum headway time for large vehicle followed by large vehicle (in s)

Using the above formula, they obtained the PCE values for large and medium vehicles in each lane in peak and off-peak hours. Using weighted averages, they arrived at the final PCE values.

The above reported studies have considered static values of PCU. Chandra and Sikdar (2000) argue that in a mixed traffic situation, there is a greater degree of interaction amongst the different vehicle types, which is quite different from the type of interaction between two vehicles of same type. Thus, many researchers have also tried to estimate what is called dynamic passenger car units. The dynamic PCU models tend to establish the effect of factors such as pavement width, shoulder width and condition, percentage of slow moving traffic in the stream, grade and its length, pavement surface characteristics etc. on the PCU values for different vehicle classes.

Do et al. (2010) used simulation methods to calculate the dynamic PCEs for motorcycles on a four-lane divided road. They adopted three scenarios for determining the PCE values. First, they developed two simulation models with 100% car traffic and 100% motorcycle traffic respectively. They monitored the input volumes of the two vehicle types (i.e. cars/motorcycles entering the system per minute) till the system reached its saturation levels. In the third scenario, they used the above two models to develop two more models that considered the system at saturation levels under mixed traffic conditions. From their results, they identified that the PCE values for motorcycles are normally distributed with mean = 23.279 and standard deviation = 1.539.

Arasan and Arkatkar (2011) studied the effect of variation of traffic volume, road width, magnitude of upgrade and its length on PCU values for various vehicle categories using simulation. For finding out the dynamic PCU values for the different types of vehicles, they ran the simulation model at different v/c ratios while replacing a certain percentage of cars by the subject vehicle type in the traffic stream in each case, such that the average stream speed remained constant. For each flow level, the number of cars removed divided by the number of subject-vehicle type introduced gave the PCU value of that vehicle type. An average of PCU values for three runs of the model was taken as the final value with different seeds. Table 2 gives the PCU values at level stretches. It can be seen from the table that the PCU values are greatly affected by the traffic volume levels. PCU values for
six-lane highways are consistently higher than the four-lane highways; this is indicative of the fact that higher speeds are possible due to the increased width of the pavement on six-lane highways.

Table 2. Variation of PCU value for the different types of vehicles on four-lane and six-lane roads (Arasan and Arkatkar, 2011)

<table>
<thead>
<tr>
<th>V/C ratio</th>
<th>PCU values for Four-lane roads</th>
<th>PCU values for Six-lane roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.125</td>
<td>2.00</td>
<td>2.25</td>
</tr>
<tr>
<td>0.250</td>
<td>1.95</td>
<td>2.20</td>
</tr>
<tr>
<td>0.375</td>
<td>1.90</td>
<td>2.15</td>
</tr>
<tr>
<td>0.500</td>
<td>1.80</td>
<td>2.10</td>
</tr>
<tr>
<td>0.675</td>
<td>1.70</td>
<td>1.90</td>
</tr>
<tr>
<td>0.750</td>
<td>1.80</td>
<td>1.95</td>
</tr>
<tr>
<td>0.875</td>
<td>2.20</td>
<td>2.10</td>
</tr>
<tr>
<td>1.000</td>
<td>2.70</td>
<td>2.50</td>
</tr>
</tbody>
</table>

2.3. Speed-Flow Relationships

From the fundamental diagram of traffic flow, we know that speed-flow curve is parabolic in shape. However, in US-HCM (2000), for uninterrupted flow on multi-lane highways, the speed-flow relationships were represented by a family of parallel curves for differing Free-Flow Speeds (FFS) rather than a single speed-flow relationship (Figure 1). This was basically done as a generalization of the empirical results and did not represent any theoretical equation (Hall, 1996). As is evident from Figure 1, the space-mean-speed for passenger cars remains constant over flows below 1400 pc/h/ln, where it corresponds to the FFS on the segment. Beyond a flow of 1400 pc/h/ln, however, the space-mean-speeds decrease until they become the lowest at capacity.

Because of the introduction of multiple speed-flow curves corresponding to differing values of FFS, the bivariate form of the speed-flow relationship was modified to a multivariate form. Thus, for flow rates greater than 1400pc/h/ln, the functional form of the equation for FFS between 90 and 100 km/h (only upper limit inclusive) became as shown in Equation (2). Similar equations were developed for other FFS ranges.

\[
S = FFS - \left( \frac{9.3}{25} FFS - \frac{630}{25} \right) \left( \frac{V_p - 1400}{15.7 FFS - 770} \right)^{131}
\]

where, 
\[S = \text{space-mean-speed of passenger cars (km/h)};\]
\[V_p = \text{traffic flow on the segment (pc/h/ln)}.\]
Bang et al. (1999) have also given a family of speed-flow curves for differing values of free-flow speeds. However, the difference here is that the curves, as shown in Figure 2, are not parallel to each other. Moreover, the free-flow speeds do not remain constant for a range of v/c ratios (degree of saturation, DS) and are constantly decreasing in nature.

The Indonesian HCM (1993) maintained the single regime structure of the speed-flow relationship (Figure 3) while determining capacity values for Indonesian multilane highways. They assumed the shape of the curve to be a parabola that was defined by the Equations (3) and (4):

\[ V = FV \left[ 1 - \left( \frac{D}{D_j} \right)^{l-1} \right]^{1/(l-m)} \]  \hfill (3)

\[ \frac{D_c}{D_j} = \left[ \frac{(1 - m)/(l - m)}{l} \right]^{1/(l-1)} \]  \hfill (4)

where,
- \( D \) = density (LVU/km) (calculated as \( Q/V \));
- \( D_j \) = jam density;
- \( D_c \) = density at capacity;
- \( l, m \) = constants.

![Fig. 3. Speed-flow relationship (Indonesian HCM, 1993)](image)

Velmurugan et al. (2010) considered two distinct regimes of flow, viz. uncongested and congested flows, while determining capacity values for Indian multilane highways. The uncongested (upper part of the speed-flow curve) and congested (lower part of the curve) flows were modeled separately and the capacity was taken to be the value of flow rate at the point of intersection of those two curves. However, to capture the effect of mixed traffic conditions, they developed individual speed-flow relationships for each class of vehicles as observed on Indian highways.

Also, owing to the non-observance of lane discipline on Indian roads, the flow values and the resultant capacity values were considered per direction instead of per lane. With respect to the functional form of the equation, for four lane highways, they considered the Bureau of Public Roads (BPR) form for the upper curve and a linear form for the lower curve. For six and eight lane highways, they considered only linear form for both the curves as other forms did not provide the required statistical validity. The speed-flow equations for cars on a four-lane highway are given in Equations (5) and (6) below for uncongested and congested flows respectively:

\[ y = \frac{110.761}{(1 + 1.564 \times (x/6999.968))} \]  \hfill (5)

\[ y = 0.004x + 21.29 \]  \hfill (6)

where,
- \( y \) = space-mean-speed (km/h);
- \( x \) = traffic flow on the segment (PCU/h/direction).

They also carried out a microscopic simulation experiment, and for the speed-flow data obtained from this experiment they used the following functional form (Equation (7)):
where, $y$ and $x$ carry the same meaning as above; $a_1$ and $a_2$ are two constants to be estimated.

### 2.4. Estimation of Free Flow Speed

For the purpose of estimation of capacity for new multi-lane highway facilities under development, where measurement of free-flow speed is implausible, the HCM (2000) provides for the estimation of the same by Equation (8).

$$FFS = BFFS - f_{lw} - f_{lc} - f_m - f_a$$  \hspace{1cm} (8)

where,

- $BFFS$ = base FFS (km/h);
- $FFS$ = estimated FFS (km/h);
- $f_{lw}$ = adjustment for lane width;
- $f_{lc}$ = adjustment for lateral clearance;
- $f_m$ = adjustment for median type (divided/undivided); and,
- $f_a$ = adjustment for access point density (no. of access points/km).

On the other hand, the Indonesian HCM (1993) provides the following equation for free flow speed estimation:

$$FV = FV_0 + FFV_W + FFV_{SF} + FFV_{RC}$$  \hspace{1cm} (9)

where,

- $FV$ = free flow speed for light vehicles for the actual conditions (km/h);
- $FV_0$ = base free flow speed for light vehicles for the studied road and terrain type (km/h);
- $FFV_W$ = adjustment factor for road width;
- $FFV_{SF}$ = adjustment factor for side friction conditions and shoulder width; and
- $FFV_{RC}$ = adjustment factor for road functional class and land use.

Bang et al. (1999) provide the following equation which includes a multiplicative adjustment factor for side friction and land use and, unlike Indonesian HCM, distinguishes between adjustment factors for road class and land use:

$$FV = (FV_0 + FV_{CW} + FV_{CLASS}) \times FFV_{LU}$$  \hspace{1cm} (10)

where,

- $FV_0$ = base free-flow speed for light vehicles (km/h);
- $FV_{CW}$ = adjustment for carriageway width (km/h);
- $FV_{CLASS}$ = adjustment for road function and road class (km/h); and
- $FFV_{LU}$ = adjustment factor for land use and side friction.

CSIR-CRRI undertook Updation of Road User Cost Study (URUCS) in 2001, under which free speed equations were developed for four-lane divided highways. Errampalli et al. (2011) followed up this study by developing free speed equations for six-lane highways in addition to the four-lane highways. Road roughness (in mm/km) was chosen as the input parameter to model free speed in this study, as the chosen sections were at level. Here also the equations for different types of vehicle were linear in nature as URUCS-2001. However, only the equations for light commercial vehicles (LCV), buses and heavy commercial vehicles (HCV) showed good statistical fit.

### 2.5. Factors Affecting Roadway Capacity

As shown in Figure 1, HCM (2000) finds the free flow speed to be a factor determining the capacity in base conditions. Corresponding to the free-flow speeds of 100, 90, 80 and 70 km/h, the capacity values found were

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2 The lateral clearance value is the sum of clearance of roadside obstructions from the edge of the travel lanes and also that of obstructions in median from the travel lanes.
2200, 2100, 2000 and 1900 pc/h/ln, respectively. HCM (2000) also lists three categories of factors that can be said to affect the practical capacity on multi-lane highways such as:

- Roadway conditions: factors such as number of lanes, lane widths, shoulder types and widths, terrain and topography, the surroundings of the facility etc.
- Traffic conditions: the traffic stream characteristics such as the proportion of slow moving and heavy vehicles, the lane distribution of the vehicles etc.
- Control Conditions: The presence of intersections and their type.

Indonesian HCM (1993) determines capacity under mixed traffic conditions as given by Equation (11). An important point to note, which is also mentioned in Table1, is that the effect of the proportion of motorcycles in the traffic stream on capacity is considered by way of using an adjustment factor.

\[
C = C_o \times FC_W \times FC_{SP} \times FC_{MC} \times FC_{SF}
\]

where, 
\(C\) = practical capacity (LVU/h/ln);
\(C_o\) = base capacity (LVU/h/ln);
\(FC_W\) = adjustment factor for carriageway width;
\(FC_{SP}\) = adjustment factor for directional split;
\(FC_{MC}\) = adjustment factor for motorcycle traffic; and
\(FC_{SF}\) = adjustment factor for side friction.

The base capacities as per Indonesian HCM are 1900, 1850 and 1800 respectively for plain, rolling and hilly terrains. A similar equation has been used by Bang et al. (1998) for Chinese conditions, with the exception of the absence of adjustment factor for motorcycle traffic.

Tanaboriboon and Aryal (1990) studied the effect of the size of vehicles on the capacity of multi-lane highways in Thailand. The primary data utilized in the study was the mean headways between different classes of vehicles. Headways of 7 sec or greater were excluded from the study since headways of such magnitude were considered to be not exhibiting inter-vehicular interactions during peak flows. The basic capacity of the study section, which was a six-lane divided highway, was determined by considering the reciprocal of the average minimum headway adopted by small vehicles following small vehicles. They found out that if they considered the peak 15-minutes flow on the median lane, with no large vehicles present, the capacity values ranged from 2022-2338 pc/h, with a mean of 2180 pc/h. However, in case of a prevailing proportion of large vehicles in the traffic stream, the basic capacity fell down to 1856 pc/h, a reduction of 15% in capacity.

Xiao-bao and Ning (2007) undertook the investigation of the impact of number of lanes on highway capacity by collecting samples on urban multi-lane highways in China. From the empirical investigation they concluded that the mean capacity per lane for each type of highway was different and statistically validated their results by performing a single-factor ANOVA test. Rotwannasin and Choocharukul (2005) studied the lane distribution of traffic on multi-lane highways in Bangkok area. They tested several sets of single-regime models such as Greenshields, Greenberg and Underwood for each traffic lane and found that no one equation could define the speed-flow relationship for all the traffic lanes.

2.6. Methods of Traffic Data Collection and Extraction

Manual methods of traffic volume data collection are the traditional and also the most tedious of all methods. Moreover, since these methods require huge manpower and are error-prone, the researchers have been actively searching for alternative methods of traffic data collection. Many sophisticated methods for data collection using various types of sensors that are either intrusive (embedded into the pavement such as induction loops) or non-intrusive types (based on infra-red or radar technologies) are being used successfully on highways in developed countries.

Traffic volume data collection in developing countries, however, poses some unique challenges. The traffic stream is composed of traffic with widely varying static and dynamic characteristics. The road space sharing
phenomenon on highways in developing world makes detection of vehicle types such as two and three-wheelers, and a host of other non-standardized ones, very difficult by devices such as inductive loops which can only effectively count and classify vehicles moving in lanes. Ravinder et al. (2010) demonstrated that infrared based techniques showed errors to the tune of 40% when the time headway between vehicles is less than 1 second on Indian highways. Such small headways can be commonly observed on Indian highways. Mallikarjun et al. (2009) state that this has led to a situation where the researchers only have the options of either using manual counts or video-filming based methods for data collection purposes. Vehicle detection and analysis through image processing software is becoming popular among researchers because of their ability to provide accurate data regarding both macroscopic traffic characteristics such as classified traffic volumes, average vehicle speeds and average occupancies, as well as microscopic characteristics such as individual vehicle trajectories, lateral, and longitudinal spacing. Moreover, the recorded videos also facilitate easy validation of the procured data. Velmurugan et al. (2010) and Arasan and Arkatkar (2011) used video-recording method for traffic data collection in their studies.

2.7. Use of Microscopic Simulation in Capacity Estimation

Velmurugan et al. (2010) have also attempted the capacity estimation on Indian highways through microscopic simulation. They argued that the random lane change behavior on Indian roads can severely affect the movements of vehicles and hence the overall capacity. They felt that microscopic simulation techniques can yield realistic estimates of speed-flow relationships because such models consider each and every vehicle movement on a roadway and hence the lane change behavior and vehicle interactions in mixed traffic can be better described.

Working in this direction, Arasan and Arkatkar (2011) utilized a traffic-flow simulation model HETEROSIM developed by Arasan and Koshy (2005) for estimating capacities for four- and six-lane highways in India. They developed certain speed-flow curves using the speed and flow values obtained from the model which fit the observed trend perfectly. Thus, they found that, for a representative traffic composition, the capacities for level stretches of four- and six-lane divided highways were 4600 PCU/h/direction and 7200 PCU/h/direction respectively.

Velmurugan et al. (2010) obtained capacity estimates for multi-lane highways using both traditional and microscopic simulation approaches. From the microscopic simulation approach, the capacity values obtained were 5574, 7733 and 9796 PCU/h/dir for four-lane, six-lane and eight-lane divided highways which were comparable to the capacity values of 6050, 6400 and 10500 PCU/h/dir obtained through traditional approach. It was also found that the traditional model for six-lane highways was under-predicting the capacity, the cause for which was attributed to the paucity of data. The authors then pointed out that overcoming the constraint of necessary availability of field data for developing good models was the biggest advantage of the simulation model over the traditional method, since in a microscopic simulation model the speeds can be estimated by substituting for any flow conditions.

3. Concluding Remarks

Based on the thorough literature review presented above, it was concluded estimating capacity for Indian multi-lane highways is going to be a unique exercise for the levels of complexity involved. For Indian multi-lane highways, the base conditions for capacity estimation could be adopted to be the same as the ones used in Indonesian HCM (1993). It is advisable to use the dynamic PCU concept for Indo-HCM as it better captures the heterogeneity arising out of varying static and dynamic characteristics of vehicles on Indian roads. Such a conversion of traffic flow into PCU shall greatly improve the accuracy of multi-regime speed-flow models which can be advocated for Indian conditions. Possibility of developing separate speed-flow equations for varying free-
flow speeds shall also be explored. Finally, it can be argued that considering the success of microscopic simulation in Indian scenario, such a technique shall be deployed for use in Indo-HCM using traffic data collected from the field through video-recording method. Image processing software such as TRAZER may be utilized for video data extraction purposes. It is believed that the above methodological framework will enable the Indo-HCM to reach its goals of accurate capacity estimation for Indian multi-lane highways.

Acknowledgements

We are very grateful to the Director, CSIR-Central Road Research Institute for according us the permission to publish this paper.

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