# DEVELOPMENT OF INDIAN HIGHWAY CAPACITY MANUAL (INDO-HCM): AN OVERVIEW

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## ABSTRACT

Over the years Highway Capacity Manual were developed by different countries and undergone the changes / re-writes such as United States Highway Capacity Manual (US-HCM) which was first developed in 1950. Since then, this manual had undergone significant improvements with major restructuring and rewrites in 1965, 1985, 2000 and including the recent publication in 2010. Like in US, Finland and Norway and other South Asian countries like Indonesia, China, Malaysia etc., have developed their own Highway Capacity Manual suiting their conditions. It is evident from the above that the existing capacity manuals from such countries cannot be transformed for Indian traffic conditions by developing any adjustment factors. From the above discussion, it is obvious that the development of Indo - HCM (Indian Highway (Indo-HCM) Capacity Manual) has to be undertaken on priority in the form of mission mode project in India by considering the various categories of Indian roads like Expressways, National Highways (NH), State Highways (SH), Major District Road (MDR), Other District Roads (ODR) and Urban Roads (UR) separately. The principle goal of this research envisages to study the nationwide characteristics of road traffic and to bring out a manual for determining the roadway capacity and Level Of Service (LOS) for varying types of inter-urban roads and urban roads separately by including Controlled and Uncontrolled Intersections coupled with addressing the pedestrian facilities existing on the relevant type of roads. The Indo-HCM project was approved on 8th October, 2012 for funding by Council of Scientific and Industrial Research (CSIR) under the Planning Commission Grants, Government of India. Moreover, the Indo-HCM project has been categorized as Supra Institutional Network Project [*SINP])* wherein CSIR-CRRI is the nodal organization for overseeing the execution of the various project related tasks.

To summarize, the Indo-HCM project is being accomplished by CSIR-CRRI in coordination with the prominent academic institutes in the country which includes, Indian Institute of Technology (Roorkee), Indian Institute of Technology (Bombay), Indian Institute of Technology (Guwahati), School of Planning and Architecture (Delhi), Sardar Vallabhai Patel National Institute of Technology, (Surat), Bengal Engineering & Science University, Shibpur, (Howrah) and Anna University (Chennai). The above listed institutes have been entrusted the

role of Regional Coordinators representing the respective region in this endeavour. This paper highlights the modus operandi of the Indo-HCM project execution.

*Keywords: Indian Highways 1, Indo-HCM, ,. CSIR-CRRI 3. Regional Coordinators 4*

# 1.0   INTRODUCTION

The most quoted and referred capacity manual is the United States Highway Capacity Manual (US-HCM) first developed in 1950. Since then, this manual had undergone significant improvements with major restructuring and rewrites in 1965, 1985, 2000 and including the recent publication in 2010. For example, the US-HCM 2000 (TRB, 2000) suggested that a maximum flow rate that can be achieved on a multilane highway is 2200 Passenger Car Units (PCU)/hour/lane. The Danish method is also a modification of US-HCM to suit Danish conditions. The adjustment factors in the Danish method caused steeper capacity reduction than in US-HCM 2000 as the conditions become less ideal and therefore, the capacity under ideal conditions on a four-lane highway has been estimated as 2300 PCUs / hour/ lane on Danish highways (Nielsen and Jorgensen, 2008). Similarly, in Finland and Norway too, US-HCM 2000 (TRB, 2000) has been followed with minor modifications to suit the local conditions and the roadway capacities obtained by the Finnish and Norwegian methods for multi-lane highways is 2000 PCU/hour/lane The Australian method for analysis of roadway capacity is basically same as that of US-HCM method with the basic difference being additional modification has been suggested for specific problems. Under ideal conditions, the average minimum headway of 1.8 seconds is considered and maximum flow of 2000 vehicles per hour per lane has been assumed. However, it is borne in mind that these evolved manuals coexist with roadway design and traffic control practices prevailing in a specified country and cannot be simply transferred to India for direct applications. On the contrary, Indonesian Highway Capacity Manual (I-HCM) evolved the capacity of multi-lane highways as 2300 Light Vehicles (LV)/hour/lane. In the case of Chinese HCM, based on the field data collected, VTI highway simulation model developed under Swedish conditions has been calibrated and validated and this model has been deployed for the determination of Passenger Car Equivalents (PCE) and development of speed - flow relationships for different terrain types in conjunction with multiple regression analysis of empirical speed-flow data. The results showed that the free-flow speeds of vehicles are somewhat low and that the roadway capacity was also marginally lower (2100 PCEs per lane on four-lane divided carriageways) under Chinese conditions as compared with the values obtained for Indonesian multi-lane highways. Further, Yang and Zhang (2005) have established based on their extensive field survey of traffic flow on multi-lane highways in Beijing and subsequent empirical model development that the average roadway capacity per hour per lane on four-lane, six-lane and eight-lane divided carriageways is 2104, 1973 and 1848 PCUs/lane/direction respectively. This is unlike HCM results obtained in many developed countries which prescribe that average capacity per lane on different highways is equal as they assume that highway capacity is constantly proportional to the number of lanes on multi-lane divided carriageways.

From the above discussion, it is obvious that the development of Indo - HCM has to be undertaken on priority in the form of mission mode project in India by considering the various categories of Indian roads like Expressways, National Highways (NH), State Highways (SH),

Major District Road (MDR), Other District Roads (ODR) and Urban Roads (UR) separately. The main hypothesis behind conceiving this project is that Indian traffic characteristics are fundamentally different from those in developed countries and even the driver behaviour is vastly different from developing countries like China and Indonesia. Therefore, the existing capacity manuals from such countries cannot be successfully implemented in India by developing any adjustment factors. Consequently, the principle goal of this research envisages to study the nationwide characteristics of road traffic and to bring out a manual for determining the roadway capacity and Level Of Service (LOS) for varying types of inter-urban roads and urban roads separately by including Controlled and Uncontrolled Intersections coupled with addressing the pedestrian facilities existing on the relevant type of roads. In order to accomplish the above stated goal of this study, the proposed research work would aim at analyzing the characteristics of the heterogeneous traffic flow so as to identify appropriate distributions of the various variables influencing the traffic stream characteristics by examining the traffic flow characteristics through extensive field data collection and analysis.

Above all, the appropriateness and the immediate need for the initiation of this comprehensive research study focusing on judicious estimation of the roadway capacity has been aptly emphasized in the Volume III: Agriculture, Rural Development, Industry, Services and Physical Infrastructure of the Eleventh Five Year Plan 2007-12 document (vide pp. 298) published by the Planning Commission, Government of India (GOI). Considering the importance attributed by the GOI on this aspect, there is an urgent need to develop the Indo-HCM explained in this research proposal which would be of immense use to the engineers, bureaucrats and planners as the manual would help the policy makers in the government to make the appropriate allocation of budget for the road sector development. This paper describes the study undertaken by the CSIR-CRRI at the national level towards the Development of Indian Highway Capacity Manual (termed as 'Indo-HCM'). A brief description of this research endeavor undertaken by CSIR-CRRI has been discussed in the next section. In section 2, the goal and objectives are presented. A brief on the methodology being followed is discussed in section 3 and finally study deliverables expected out of this study is presented in Section 4.

## 2.0   PRIMARY GOAL AND OBJECTIVES

### 2.1   Statement of the Study

The most quoted and referred capacity manual is the United States Highway Capacity Manual (US-HCM) which was first developed in 1950. Since then, the document had undergone significant improvements with major restructuring and rewrites in 1965, 1985, 2000 and including the recent publication in 2010. The concept of six levels of service to describe the quality of highway operations using the Level of Service (LOS) concept in the form of A - F letter scale first appeared in the 1965 HCM. Since then, many concerted efforts were carried out aimed at periodical updation during the last five to six decades which illustrates how the US-HCM has evolved over the years. The main hypothesis behind conceiving this project is based on the fact that the Indian traffic characteristics are fundamentally different from those in developed countries and even the driver behaviour is

vastly different from developing countries like China and Indonesia. Therefore, the existing capacity manuals from such countries cannot be successfully implemented in India by developing any adjustment factors. The study is aimed at analyzing the characteristics of the heterogeneous traffic flow so as to identify appropriate distributions of the various variables influencing the traffic stream characteristics which can enable to examine the traffic flow characteristics through extensive field data collection and analysis.

Moreover, this project falls under the CSIR theme titled, "Knowledge / Technology space where we do not have expertise and we would like to achieve" warranting the need for the development of exclusive Indo - HCM for the Indian traffic conditions. Eventually, the development of Indo - HCM has been undertaken on priority in the form of mission mode project by considering the various categories of Indian roads like Expressways, National Highways (NH), State Highways (SH), Major District Road (MDR), Other District Roads (ODR) and Urban Roads (UR) separately.

## 2.2    Primary goal

- To study the nationwide characteristics of road traffic and to bring out a manual for determining the roadway capacity and Level Of Service (LOS) for varying types of inter-city roads and urban roads separately including Intersections coupled with assessment of pedestrian needs on the relevant type of roads.

## 2.3    Objectives of the study

In order to accomplish the above stated goal of this study, the following objectives have been formulated:

- Study and characterization of the basic road traffic flow characteristics such as speed, flow, density which can eventually lead to the development of Speed -Flow and Speed - Density relationships for different categories of Indian roads under varying conditions.
- Development of capacity and level-of-service determination procedure and evolving guidelines for different categories of Indian roads including quantification of the impact of various roadway, traffic, climatic and control factors on the capacity and level of service.
- Development of capacity and LOS determination procedure and evolving guidelines for different types of intersections (uncontrolled and controlled intersections separately) including quantification of the impact of various roadway, traffic and environmental factors on the capacity of the different types of intersections.
- To examine the fundamental characteristics of travel time reliability and development of reliability as a performance measure for inter-city as well as urban corridors.
- To establish a pedestrian flow profile by determining pedestrian traffic peak times and off-peak times on urban roads and thus evolve the relationships between the time of the day and pedestrian volumes and speeds for different categories of urban roads.
- To determine the existence of correlation between vehicular volumes, pedestrian volumes and pedestrian speeds on varying categories of urban roads.

Detailed studies are being carried on straight / mid-block roadway sections and uncontrolled intersections with adequate coverage of all possible combinations of geometry

and operating conditions. Similarly, the capacity and level of service guidelines for the controlled intersections falling in the urban areas would be studied separately. To accomplish the same, it is proposed to consider the test sections speed over the length and breadth of the country.

## 3.0  METHODOLOGY

Ironically, most of the models developed are applicable for homogeneous traffic conditions and hence are not applicable for the heterogeneous traffic prevalent on Indian roads. Eventually, the first major research effort in India in this direction was done as part of the RUCS-1982 and this was followed by URUCS-1992 and URUCS-2001. For instance, IRC-64 (1990) suggested a tentative DSV of 40,000 PCUs for the four-lane divided carriageway in plain terrain which is significantly lesser than the values evolved in most of the developing countries and therefore the need was felt for revisiting the DSV values evolved under IRC-64. Consequently, many research studies (Kadiyali, et. al., 1991, Tiwari, et. al., 2000, Velmurugan et. al., 2002, Chandra S. and Kumar U., 2003, Reddy, et. al., 2003, Chandra, 2004, Errampalli, et. al., 2004, Velmurugan, et. al., 2004, Dey, 2007, Errampalli, et. al., 2009, Velmurugan et. al., 2009, Velmurugan, et al, 2010, Madhu, 2011) aimed at assessing the roadway capacity for varying carriageway widths including single lane, intermediate lane, two-lane bi-directional and multi-lane divided carriageways (i.e. four lane to eight lane) covering different terrains have been carried out during the last two decades. Unfortunately, these piece meal research efforts have not culminated towards the development of Indo - HCM and hence this important research study has been proposed. In view of the formulated objectives, the framework for the present study has been designed by identifying the key elements required for the development of Indo - HCM. The methodology outlined for the development of the Indo-HCM can be regarded as unique as the ongoing research work aims at analyzing the characteristics of the heterogeneous traffic flow so as to identify appropriate distributions for various traffic variables influencing the traffic stream characteristics which can enable to examine the traffic flow characteristics and vehicular interactions occurring on the different typology of road sections. In this regard, it may be noted that there are different approaches employed to estimate the roadway capacity namely, direct empirical and indirect empirical approaches (Minderhoud et al. 1997). There are four different methods available for capacity estimation under the direct empirical approach as shown in Figure 1. On the other hand, the roadway capacity estimation guidelines by TRB (HCM), Indian Roads Congress (IRC) and similar agencies are based on indirect empirical methods using appropriate techniques like traffic simulation. Outputs from the appropriate traffic flow simulation models would be used to construct fundamental diagrams of flow thereby making it possible to estimate the capacity of a facility. Though there are traditional macroscopic modelling methods are available for the estimation of roadway capacity, as indicated in Figure 1, the microscopic simulation models is being deployed extensively in this research study in addition to the traditional methods as this is regarded as one of the most effective analytical tools to estimate the roadway capacity of Indian highways (Velmurugan et al 2010). This is because, these models, once validated, can be used to study the traffic flow characteristics over a wide range of the associated

variables which would enable to get more acceptable results and thus could be useful for assessing the effectiveness of traffic management measures.
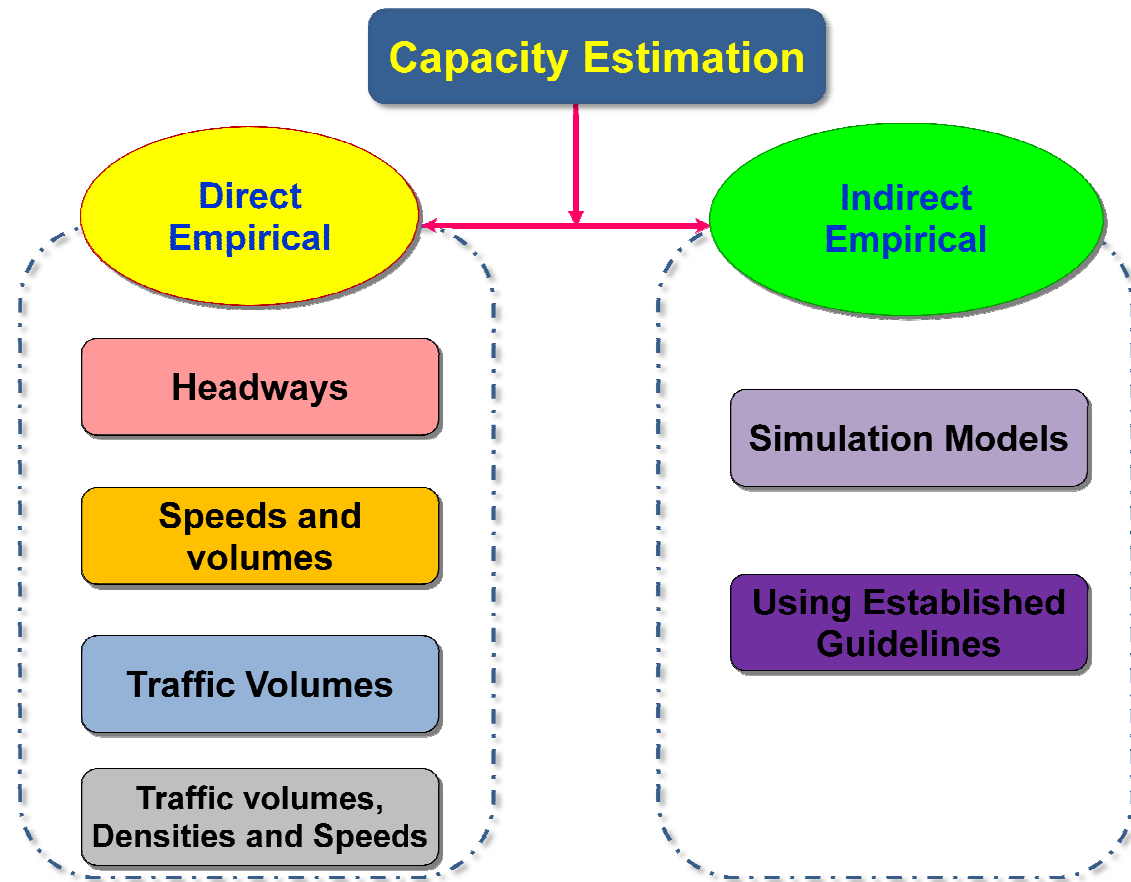


**Figure 1: Methods of Roadway Capacity Estimation**

To facilitate the timely and smooth execution of the project as per the envisaged time line, the Indo-HCM project is being accomplished by CSIR-CRRI in coordination with the prominent academic institutes in the country which includes, Indian Institute of Technology (Roorkee), Indian Institute of Technology (Bombay), Indian Institute of Technology (Guwahati), School of Planning and Architecture (Delhi), Sardar Vallabhai Patel National Institute of Technology, (Surat), Bengal Engineering & Science University, Shibpur, (Howrah) and Anna University (Chennai). Further, in order to have uniformity in the analysis method, a standardized methodology has been devised during the **National Level Workshop** which was held in January, 2013 at Sardar Vallabhai National Institute of Technology, Surat (SVNIT). The methodology was finalized during this workshop is being uniformly adopted by all the academic institutions. To accomplish the above stated objectives, the entire study has been sub-divided into nine different packages and the same is explained in the succeeding section.

## 3.1 BRIEF DESCRIPTION OF WORK PACKAGES

Each of the above envisaged Work Packages (WP) is briefly described in the succeeding sections.

**WP-1: Roadway Capacity Estimation of Two Lane, Intermediate and Single Lane Carriageways**

Under this category, the normal roadway section as they exist in India is categorized as follows:

1       Undivided roads

    (i)       Single-lane roads

(ii)      Intermediate-lane roads

    (iii)      Two-lane roads with earthen or paved shoulders

The factors considered while developing the capacity norms for the above types of roads are discussed in the succeeding sections. Although the roads in India are categorized based on the lane width as single-lane (3.5m to 3.75m), intermediate lane (5.5m to 6.0m) and two-lane (7.0m to 7.5m), it is invariably noted that the Indian roads have non-standard widths that are not conforming to any discrete number of lanes. Hence, the basic concept of lane width would be dealt by considering the existing carriageway width perspective. This is true for the operational features as well, as the vehicles (road users) seldom obey lane markings. Though based on the administrative classification of roads, the inter-urban roads are categorized as National Highways (NH), State Highways (SH), Major District Roads (MDR), Other District Roads (ODR) and Village Roads (VR) (and lately, Expressways), the capacity are being studied based on engineering features only. Considering the above scenario, the road sections are studied accounting for various geometric and operational conditions as listed below:

•     Main carriageway width

•     Type and condition of Shoulder

•     Roadway surface condition

•     Gradient

•     Horizontal curvature and their frequency

•     Vertical curvature

•     Roadside obstructions

•     Traffic volume and composition

•     Directional distribution of traffic

•     Assessment of free speeds of different vehicle types across varying road widths

•     Influence of Pedestrians

•     Impact of Non-Motorized Traffic

•     Traffic regulation and Control measures such as speed limit, type of movement (one way or two way traffic as the case may be)

•     Environmental factors like weather and land use development in the form of adjoining land use

This analogy will be applicable for the mid block sections considered under the single, intermediate and two lane bidirectional carriageways. The above varying lane widths would be considered on the typical inter-urban corridors located preferably in the vicinity of the cities like Delhi, Mumbai, Kolkata, Chennai, Surat, Dehradun, Guwahati, Trivandram and

Calicut so as to get the geographical spread across the country representing plain, rolling and hilly terrains.

## WP-2: Roadway Capacity Estimation of Multi-lane Inter City Highways

In addition to the factors listed for single and two-lane roads, factors like lateral clearance, width of median, number of lanes, auxiliary lanes, width and type of shoulders would be considered in the test sections in the vicinity of the cities mentioned above. Based on the collected data, adjustment factors would be derived wherever deemed necessary.

## WP-3: Roadway Capacity Estimation of Inter - City and Urban Expressways

In addition to the factors listed for multilane highways, the capacity of expressway sections will be examined considering the adequacy of ramp provision, weaving sections and merge / diverge sections. Obviously, the test sections on expressways will be selected in accordance with the availability of the same in the vicinity of the cities mentioned above. Additional test sections are also considered in the vicinity of other cities in case, sufficient number of expressways is not available near the above listed cities under WP-1.

## WP-4: Urban Roadway Capacity Estimation for Arterials / Sub- Arterials / Collectors

As proposed for the Inter-Urban roads (i.e. WP-1), the roads classified under Arterial, Sub-Arterial, and Collector streets in the case of Urban Roads is being studied by selecting road sections in the cities like Delhi, Mumbai, Kolkata, Chennai, Surat, Dehradun, Guwahati, Trivandram and Calicut for determining the roadway capacity.

Another important aspect of highway capacity analysis is the term EPCU (Equivalent Passenger Car Units) used to express all the vehicles in the stream in common units. Following the practice of developed countries, EPCU was published for different types of vehicles by the Indian Roads Congress (IRC) in the form of two Codes namely, Guidelines for Capacity of Roads in Rural Areas (IRC: 64-1990) and Guidelines for Capacity of Roads in Urban Areas (IRC: 106-1990) which are extensively referred by the practicing engineers and planners in the country but at the same time these are rather outdated now. Due to the obsoleteness of the above codes, when the EPCU listed in the above codes are employed to express the traffic flow and thus work out the Volume - Capacity (V-C) ratios from the capacity figures, sometimes unacceptable traffic figures emerge and this may be attributed to the usage of outdated EPCU values. The research studies carried out in India and abroad have evolved EPCU for urban as well as for rural roads and intersections in Indian context. These research works have provided significant insight on mixed traffic operations and have resulted in recommending changes to the static PCU values for different roadway and control conditions.

In this regard, it is to be borne in mind that the PCU of a vehicle type for a roadway facility is assumed to be unaffected by traffic volume and its composition. Sometimes, such assumption may be misleading while estimating service volume of a facility or formulating

traffic management measures. Further, the presence of slow moving vehicles in traffic stream would impede the free flow of traffic. Realizing the above, unique attempts have been made in India (both in urban roads and inter-urban road context) to determine dynamic EPCU values (Arasan, 2000 and 2008, Chandra, 2004) for different types of vehicles operating on different categories of road. It is recognized that EPCU of a vehicle type is not a constant value. It changes with all factors influencing the behavior of vehicles in the traffic stream. Considering the above, EPCU of a vehicle has been proposed to be estimated from field data using the following equation (Chandra, et al, 2004).

$$PCU_i = \frac{V_c / V_i}{A_c / A_i}$$

(1)

Where,
Vc = Speed (or clearing speed for intersection) of a car
Vi = Speed (or clearing speed for intersection) of a vehicle type i
Ac = Projected rectangular area of a car, (length x width)
Ai = Projected rectangular area of vehicle type i on the road (length x width)
In this study, the applicability of the above equation to determine EPCU for varying types of carriageways are being studied and based on the acceptability of the above formulation for traffic plying on different types of carriageways, the need for refinement would be finalized for both Inter-Urban and Urban roads.

## WP-5: Capacity Estimation of Controlled Intersections

The other important area of capacity analysis is related to the various types of intersections. As intersections are the critical nodal points of any road network, where normally delay is caused to traffic, it is imperative to study the intersections to arrive at the various LOS and capacity norms under different operating conditions. The intersections on urban roads are studied critically because of the presence of slow-moving traffic including pedestrians. The capacity of intersections further gets reduced due to the presence of other roadside commercial and social activities. Two broad categories of intersections i.e. uncontrolled and controlled (i.e. signalized) intersections are studied in detail in and around the cities listed above. The various factors relating to roadway, traffic, control and environmental aspects that are relevant for capacity and LOS estimates are discussed in the following section under controlled and uncontrolled intersections which would include roundabouts as well.
Signalized intersections are present on roads of different widths including the undivided / divided carriageways and therefore, the following factors would be considered:
(i)      Roadway Factors
•          Number of intersecting legs
•          Approach width
•          Approach gradient
•          Approach curvature
•          Safe stopping sight distance
•          Intersection sight distance
•          Channelization
(ii)     Traffic Factors
•          Traffic volume and composition

- Directional (straight and turning) flow of traffic
- Peak and non-peak flow of traffic
- Parking regulation in the vicinity of intersection
- Location of bus stops near the intersection area
- Pedestrian traffic

(iii) Environmental Factors
- Weather
- Other environmental factors influencing the intersection operation

(iv) Control Conditions
- Speed limit
- Prohibition of overtaking
- Availability of traffic control devises such as signs, islands, markings, etc.

In the case of roundabout too, the above detailed analysis would be carried out separately by considering the parameters envisaged above for signalized intersections.

## WP-6: Capacity Estimation of Uncontrolled Intersections

As different types of uncontrolled intersections practically exist on Indian Roads, the various factors influencing the roadway capacity of typical uncontrolled intersections are critically analyzed by considering the following parameters:

(i) Roadway Factors
- Number of intersecting legs
- Entry and exit width
- Carriageway width
- Turning radius
- Gradient
- Channelization
- Angle of intersection
- Safe stopping sight distance
- Intersection sight distance
- Availability of Exclusive lane for different modes of traffic (including non-motorized)

(ii) Traffic Factors
- Traffic composition
- Volume of straight and turning traffic
- Peak hour factor
- Distribution of gap in the major traffic stream
- Relative priority of the various streams at the intersection
- Presence of pedestrians
- Presence of on-street parking, hawkers
- Number and type of conflicts / interactions among different vehicle types (Combinations of car-car, car - pedestrian, car - two wheelers, car – goods vehicles, car - cycles etc.)

(iii) Environmental Factors
- Land use
- Weather

The scope of the WP is confined to the Uncontrolled intersections.

## WP-7: Capacity Estimation of Pedestrian Facility

Level of Service (LOS) is a term used which describes existing operating conditions (or suitability) for a mode of travel in the transportation system. Motor vehicle LOS is primarily based on speed, travel time and intersection delay whereas the calculation of Pedestrian LOS is a more complex, which represents the operating condition of pedestrian facility and level of comfort pedestrians experience in using these facilities.

Two methods are being deployed for the evaluation of the pedestrian facilities in urban areas namely, Capacity Based (HCM Method) and Roadway Characteristics Based Methods. In the case of Capacity based method, the principles of highway capacity is being accounted to evaluate pedestrian facilities which is expected to be helpful in planning pedestrian facilities but provide little information regarding acceptability by pedestrians. On the other hand, Roadway Characteristics Based Methods has been deployed for the evaluation of the characteristics of the existing walkways or pedestrian facilities. Further, this method also aids in assessing the pedestrian perceptions and thus an attempt to quantify the comfort level of pedestrians while encountering certain roadway characteristics. Both the two methods would be judiciously deployed depending on the requirements in each of the selected cities for assessing the pedestrian volume and their behavioral aspects.

## WP-8: Gap Acceptance Studies

Driver behaviour in conflict points between crossing vehicle movements at uncontrolled intersections is being studied from the video recordings conducted from vantage positions. The data obtained from these surveys comprise the following:

•         time headway at stop line passage;
•         behaviour in crossing conflicts (e.g., waiting for gaps, pushing, etc);
•         Accepted and rejected time gaps for minor road vehicles observing the right-of-way of the major traffic movements.

Based on the above collected data, the driver behavioral aspects would be critically analyzed by conducting appropriate experiments and based on the above data, gap acceptance models will be developed to understand whether vehicles that had a choice between "gapping" or "pushing" actually waited for a gap in the major road flow. This would ultimately help in assessing the intersection performance in the case of uncontrolled intersections considering different vehicle types.

## WP-9: Development of Reliability as a performance measure

Travel time reliability is increasingly recognized as an important mobility performance measure. Even the recently released US-HCM does not include a method to address travel time reliability. Therefore the objective of this work package is mainly focused on the development of travel time reliability as a performance measure in the Indo-HCM for expressways and multi lane highways and also to develop travel time reliability as a performance measure in the Indo-HCM for urban arterial roads.

## 3.2    Timeline of the Study

The proposed program schedule and targets for accomplishment at the end of every six months during the course of five year period starting from April 2012 is presented in Table 1.

**Table 1: Proposed Activity Schedule of the Indo - HCM Project.**

| S. No | Name of the Activity | Schedule of the program | |
|---|---|---|---|
| | | Start | Completion |
| 1 | National Level Workshop | October, 2012 | March, 2013 |
| 2 | State of the Art Report | September, 2012 | March, 2013 |
| 3 | Identification of the Basic Parameters for Evaluation, Preparation of Methodology, Inception Report, Test Section Identification | April, 2013 | September, 2014 |
| 4 | Planning of Field Studies, Collection of Secondary Data, Data Collation and Analysis ,Generation of Mid Block Traffic Characteristics for Varying Types of Carriageways | April, 2013 | March, 2016 |
| 5 | Development of Speed-density-volume relationships for Varying Types of Carriageways | October, 2013 | March, 2016 |
| 6 | Generation of Operational Characteristics of Varying types of uncontrolled intersections | April, 2014 | March, 2016 |
| 7 | Generation of Operational Characteristics of Varying Types of Controlled intersections including Roundabouts | April, 2014 | March, 2016 |
| 8 | Guidelines for roadway capacity and Level-of-Service *(LOS)* estimation for different categories of roads and intersections | April, 2014 | March, 2016 |
| 9 | Preparation of Draft Final Report and Draft Manual | March, 2016 | September, 2016 |
| 10 | Dissemination of Indo-HCM Manual Findings | October, 2016 | March, 2017 |
| 11 | Submission of Final Report & Manual to Planning Commission | October, 2016 | March, 2017 |

## 4.0   DELIVERABLES AND OUTCOMES OF THE STUDY

The tangible year-wise outputs that would be derived from this mission mode project during the various stages of the project are presented in Figure 2 in the form of a Bar chart.

**Figure 2: Year-wise Project Deliverables**

| S. No | Name of The Activity | Year of Accomplishment | | | | |
|-------|---------------------|:--:|:--:|:--:|:--:|:--:|
|       |                     | 1 | 2 | 3 | 4 | 5 |
| 1 | A **State-Of-the Art Report** *(SOAR)* highlighting the salient aspects of nationwide characteristics of highway traffic, operation and control and also Review of hierarchical functioning of inter-city and urban roads. | ■ | ■ | | | |
| 2 | **Generation and Updation of Traffic Database and Traffic Flow Characteristics** for Indian roads | | ■ | ■ | ■ | |
| 3 | **Fundamental Speed-Density-Volume relationships** for a wide range of roadway and traffic conditions in India | | | ■ | ■ | |
| 4 | Procedure for determining the **Operational Efficiencies** of different categories of Indian roads including intersections with all possible combinations of geometry and operating conditions evaluated adequately | | | | ■ | |
| 5 | **Guidelines for Roadway Capacity and LOS estimation** for different categories of roads and intersections *(including pedestrian facility). This includes the revision of existing IRC Codes like IRC-64, IRC-93, IRC-106, IRC-103, IRC-SP-30 and also evolving Guidelines for Expressways (New)* | | | | | ■ |

In addition, it is anticipated that significant number of Journal Publications *(a minimum of three per year)* is targeted for achievement during the project period and beyond.

As this research study envisages the formulation of indigenous manual *(termed as Indo - HCM)* based on the prevailing traffic scenario across the country, a fairly accurate picture of the overall traffic scenario in the country would be readily available once the manual is developed which can be used for forecasting the future traffic.

Further, the manual is expected to serve as a useful document for accomplishing the following aspects in the foreseeable next five years:

- Decision making tool for road development and management
- Comparison of alternative road infrastructures in terms of LOS
- To forecast LOS as a result of different transportation related policies
- Evaluate and prioritize planning / operational alternatives

Moreover, the developed manual can serve as a handy tool for the practicing engineers and planners to mitigate the traffic and infrastructural problems as the models evolved in this study would be calibrated and validated for different conditions prevailing on varying road widths *(by considering the mid block and intersections separately)* falling on plain, rolling and hilly terrains.

## ACKNOWLEDGEMENTS

## REFERENCES

Arasan V.T., and Reebu Zachariah Koshy (2002) "Simulation of Heterogeneous Traffic to Derive Capacity and Service Volume Standards for Urban Roads", Paper No. 500, A paper published in the Journal of Indian Roads Congress.

Arasan* V.T., and K. Krishnamurthy (2008) "Study of the Effect of Traffic Volume and Road Width on PCU Value of Vehicles using Microscopic Simulation", Paper No. 542, A paper published in the Journal of Indian Roads Congress.

Bang, K. L. and Heshen, A. (2000). "Development of capacity guidelines for road links and intersections for Henan and Hebei Provinces, PRC." Proc. 4th International Symposium on Highway Capacity, Transportation Research E-Circular, E-C018, ISSN 0097-8515, pp. 287-298.

Chandra S. (2004). "Capacity estimation procedure for two- lane roads under mixed traffic conditions." Journal of Indian Road Congress, Vol.65- 1, pp.139-170.

Chandra S. and Kumar U. (2003). "Effect of lane width on capacity under mixed traffic conditions in India." Journal of Transportation Engineering, ASCE, March/April 2003, pp 155-160.

CRRI (1982) "Road User Cost in India." A report submitted to Ministry of Surface Transport, Central Road Research Institute (CRRI), New Delhi.

CRRI (2001) "Updation of Road User Cost Data Volume-I and II." A report submitted to Ministry of Surface Transport, Central Road Research Institute (CRRI), New Delhi.

Dey, P. P., Chandra, S. and Gangopadhyay, S. (2006). "Speed distribution curves under mixed traffic conditions." Journal of Transportation Engineering, ASCE, Vol. 132 (6), pp 475-481.

Dey, P. P., Chandra, S. and Gangopadhyay, S. (2007). "PCU factors for two lane roads." HRB, Indian Road Congress, No.77, pp 111-119.

Errampalli, M., Reddy, T. S. and Velmurugan, S. (2004). "Updation of free speed models through mechanistic principles for Indian conditions." Journal of Advanced Transportation, Vol. 38 (2), pp 133-146.

Errampalli, M., Velmurugan, S., Ravinder, K. and Gangopadhyay, S. (2009). "Speed - flow characteristics of high speed corridors in India." Presented at 14th International Conference of Hong Kong Society for Transportation Studies (HKSTS), Hong Kong, Dec. 2009.

Hoban, C. J. (1987). "Evaluating traffic capacity and improvements to road geometry." World Bank, Washington, DC.

Ibrahim, A. T. and Hall, F. L. (1994). "Effect of adverse weather conditions on speed-flow-occupancy relationships." Transportation Research Record 1457, TRB, pp 184-191.

IRC (1990). "Guidelines for Capacity of Roads in Rural Areas" IRC-64 -1990, Indian Roads Congress, New Delhi.

IRC (1990). "Guidelines for Capacity of Urban Roads in Plain Areas" IRC-106 -1990, Indian Roads Congress, New Delhi.

Iwasaki, M. (1991). "Empirical analysis of congested traffic flow characteristics and free speed affected by geometric factors on an intercity expressway" Transportation Research Record 1320, TRB, pp. 242-250.

Kadiyali & Associates. (1992). "Study for Updating Road User Cost Data", A Report submitted to Ministry of Surface Transport and Asian Development Bank, Dr. L. R. Kadiyali & Associates, New Delhi.

Kadiyali, L. R., Lal, N. B., Satyanarayana, M. and Swaminathan, A. K. (1991), "Speed-flow characteristics on Indian highways" Journal of Indian Roads Congress, Vol. 52(2), pp. 233-251.

Luttinen, K. and Innamaa, H. (2000). "Traffic flow simulation for an inter-city freeway corridor." Proc. 4th International Symposium on Highway Capacity, Transportation Research E-Circular, E-C018, ISSN 0097-8515.

Errampalli, M., Velmurugan, S., Ravinder, K., Nataraju, J., (2011) "Development of Free Speed Equations for Assessment of Road User Cost on High Speed Multi-Lane Carriageways of India", Volume 100, No.9, A paper published in the Special Issue of Current Science Journal, on "Sustainable Transportation System for Cities of Developing Countries.

Minderhoud, M.M., Botma, H., and Bovy, P.H.L., (1997), "Assessment of Roadway Capacity Estimation Methods", Transportation Research Board, 1572, TRB, National Research Council, Washingdon D.C., 59-67.

Nielsen, O. A. and Jorgensen, R. M. (2008). "Estimation of speed - flow and flow - density relations on the motorway network in the Greater Copenhagen Region." 120/IET Intelligent. Transportation Systems, Vol. 2, doi: 10.1049/ iet-its:2007 0024, pp. 120-131.

Reddy, T. S., Velmurugan, S., Errampalli, M. and Ramalingaiah, A. N. (2003). "Updation of road user cost and revised software for evaluation of highway projects." Journal of Indian Roads Congress, 64 (2), 207-267.

Purnima Parida, Najamuddin and M.Parida, "Planning Design and Operation of Pedestrian Facilities in Delhi" published in Highway Research Bulletin, Oct 2007.

Purnima Parida, Najamuddin and M Parida,' Development of Qualitative Evaluation Methodology for Sidewalks in Delhi, published in ITPI Journal Vol. 4 No.3, July - September 2007.

Purnima Parida, Development of Qualitative Walkability Measures for Pedestrian Facilities in Delhi, Invited presentation at Transforming Transportation,, World Bank Washington, D.C. Jan 2009 (available on the website of WRI of World Bank).

Shukla, S. (2008) "Traffic flow modelling on multilane divided highways." Ph.D. Thesis submitted to IIT, Roorkee.

Shankar, V. and Mannering, F. (1998) "Modelling the endogeneity of lane-mean speeds and lane-speed deviations: a structural equations approach." Transportation Research, 32A, pp 311-322.

Tiwari, G., Fazio, J. and Pavitravas, S. (2000). "Passenger car units for heterogeneous traffic using a modified density method." Proc. 4th International Symposium on Highway Capacity, Transportation Research E-Circular, E-C018, ISSN 0097-8515, pp. 246-257.

TRB (2000). "Highway Capacity Manual 2000" 3rd Ed., National Research Council, Transportation Research Board, Washington, D.C.

Velmurugan, S., Errampalli, M. and Reddy, T. S. (2002). "Changing operating speeds on rural highways." Proc. Emerging Trends in Road Transport (RORTRAN), Vol. II, IIT, Kharagpur, India, Sep 2002, pp 5.29 - 5.40.

Velmurugan, S. Errampalli, M. and Reddy, T. S. (2004). "Evaluation of speed - flow characteristics on Indian highways." Proc. 10th World Conference on Transport Research (WCTR), CD-ROM, Istanbul, Turkey, Jul 2004.

Velmurugan, S., Errampalli, M., Ravinder, K. and Gangopadhyay, S. (2009). "Updation of road user cost for economic evaluation of road projects." Indian Journal of Traffic Management, Vol. 33 (3), July - September 2009, pp 205-225.

Velmurugan, S., Errampalli, M., Ravinder, K., Sitaramanjaneyulu K., Gangopadhyay, S., (2010) "Critical Evaluation of Roadway Capacity of Multi-Lane High Speed Corridors Under Heterogeneous Traffic Conditions through Traditional and Microscopic Simulation Models" Journal of Indian Roads Congress, Vol. 71(3), pp. 235 - 266.

Yang, X. and Zhang, N. (2005). "The marginal decrease of lane capacity with the number of lanes on highway." Proc. International Conference of Eastern Asia Society for Transportation Studies (EASTS), Vol. 5, pp. 739 - 749.

Yao, J., Teng, H., Wei, H. and, Hu, S. (2009). "Estimating roadway capacity using the simultaneous spline regression model." Journal of Transportation Systems Engineering and Information Technology, Vol. 9 (1), February 2009, pp 87-98.