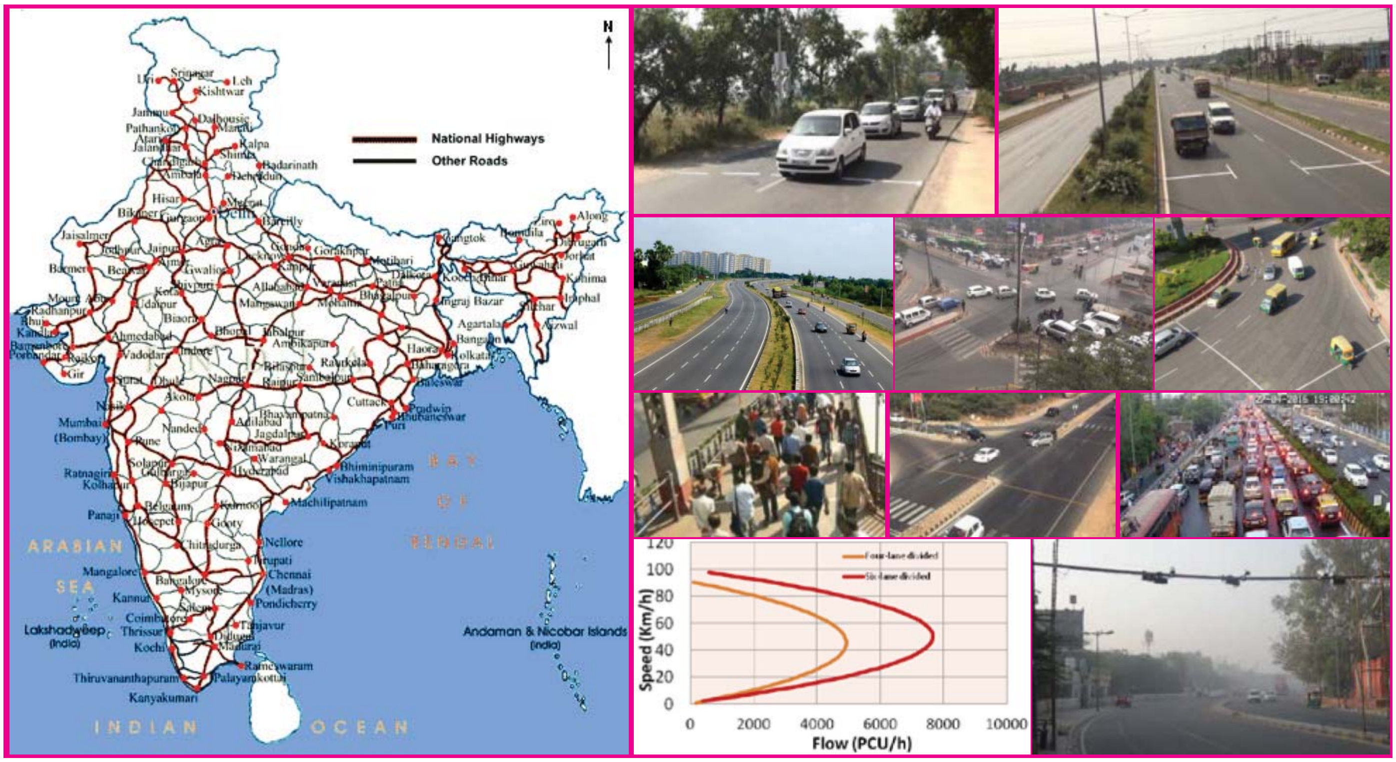
Indian Highway Capacity Manual
(Indo-HCM)

Sponsored by
Council of Scientific and Industrial Research *(CSIR)*, New Delhi

2012-2017



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December, 2017

Nodal Organisation:

सी एस आई आर – केंद्रीय सड़क अनुसंधान संस्थान, नई दिल्ली–110025

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About the Manual

The need for an Indian Highway Capacity Manual *(referred as Indo – HCM)* has been felt for a long time by researchers, policy makers and planners in the country. Hence a maiden attempt was made by CSIR - Central Road Research Institute *(CRRI)*, New Delhi to network with academic institutes *(by including IITs / NITs/ Central/ State Universities)* on the lines of HCM *(2010)* of USA. This mission mode project led by CSIR - CRRI was completed on time with regular monitoring at different levels to achieve the desired quality which has showcased once again the technical prowess and management expertise of CSIR - CRRI in handling large size projects.

Chapter-1 presents a bird's eye view of the structure of the manual and definition of generic terminologies related to traffic engineering and planning. Each of the subsequent nine chapters deals with the procedure for the estimation of capacity and Level of Service *(LOS)* through a series of steps and culminates with typical illustrative examples. These examples are expected to be of immense use for the analysts in understanding the essence of the Indo - HCM towards the estimation of capacity and Level of Service *(LOS)* of various types of roads *(both midblock sections and various types of intersections)* and different forms of urban pedestrian facilities dealt in this manual. Moreover, this manual would provide a much-needed reliable source to update the IRC documents and standards for evolving new guidelines to address the missing links. Further, it is expected that this document can serve the society as a basic guide for the practicing engineers and decision makers towards capacity augmentation of various types of road and pedestrian facilities in India.

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Mathura Road, New Delhi-110025

http://www.crridom.gov.in

Price: ₹ 3500

in association with

Indian Institute of Technology *(IIT)* Roorkee, Roorkee

Indian Institute of Technology *(IIT)* Bombay, Mumbai

Indian Institute of Technology *(IIT)* Guwahati, Guwahati

School of Planning and Architecture *(SPA)*, New Delhi

Sardar Vallabhai Patel National Institute of Technology *(SVNIT)*, Surat

Indian Institute of Engineering and Sciences University *(IIEST)*, Shibpur

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TABLE OF CONTENTS

FOREWORD

The need for an Indian Highway Capacity Manual has been felt for a long time by researchers, policy makers and planners in the country. It was emphasized by the Government of India also in 2012 when the then Planning Commission expressed the immediate need for initiating a comprehensive research study focusing on scientific estimation of the roadway capacity in India in their *Eleventh Five Year Plan 2007-12 document*. Accordingly, the Council of Scientific and Industrial Research (CSIR) sponsored a research project entitled **"Indian Highway Capacity Manual"** ***(referred as 'Indo-HCM' in this manual)*** to CSIR - CRRI in 2012 in the form of mission mode project.

The development of Indo - HCM was not an easy task considering the vast size of the country and variety of roads and traffic mix. Therefore, CSIR - CRRI identified seven prominent academic institutes located in different regions in the country to provide technical support for all the Work Packages as well as to assume the role of Regional Coordinators for one or two work packages depending upon their expertise. The seven academic institutions identified are Indian Institute of Technology Roorkee, Indian Institute of Technology Bombay, Mumbai, Indian Institute of Technology, Guwahati, School of Planning and Architecture, New Delhi, Indian Institute of Engineering and Science and Technology, Shibpur, *(Howrah)*, Sardar Vallabhai Patel National Institute of Technology, Surat and Anna University, Chennai. This was the maiden attempt made to network with such a large number of academic institutes on the lines of HCM of USA. This mission mode project led by CSIR - CRRI was completed on time with regular monitoring at different levels to achieve the desired quality which has showcased once again the technical prowess and management expertise of CSIR - CRRI in handling large size projects. Transportation and Highway professionals can now follow the realistic capacity values evolved in this manual while undertaking the projects of evaluation of existing road facility or planning of any new road facility. Each chapter deals with the procedure for the estimation of capacity and Level of Service *(LOS)* through a series of steps and culminates with typical illustrative examples. It is expected that this document can serve the society as a basic guide for the practicing engineers and decision makers towards capacity augmentation of various types of road and pedestrian facilities in India.

18.12.2017

(Satish Chandra)
Director, CSIR – CRRI

ACKNOWLEDGEMENTS

The team of CSIR - CRRI would like to place on records its profound gratitude to Council of Scientific and Industrial Research *(CSIR)*, New Delhi for sponsoring this long-awaited research study. Further, the CSIR - CRRI led team extends its gratitude to the experts who served as Session Chairs during the review meetings for extending their immense technical help. Largely, their presence has helped to monitor the progress achieved in each of the Work Packages *(which is rechristened as Chapters in the manual)* during various national level workshops and Task Force Committee *(TFC)* meetings. Champion and Co-Champion of Indo-HCM project conducted these meetings in close coordination with the identified faculty from reputed academic institutes. The faculties representing the respective institutes have been assigned the role of Regional Coordinators *(RCs)* cum Local Organizing Secretary *(LOC)* for the conduct of the national workshops and TFC meetings. The first workshop in the above series was conducted in January, 2013 titled, **'Methodology for Indian Highway Capacity Manual'** (***MIHCaM)***. This was followed by yearly review workshops *(3 numbers)* conducted in March, 2014, February, 2015 and March, 2016 titled, **'RIHCaM-2014', 'RIHCaM-2015', and 'RIHCaM-2016' i.e. 'Review workshop of Indian Highway Capacity Manual'.**

During each of the above workshops, the identified experts in the capacity of Session Chairs have made invaluable contributions. Their contributions encompassed critical appraisal of the incremental progress made by the Work Package *(WP)* Leaders / members of CSIR - CRRI as well as by the seven Regional Coordinators *(RCs)* by highlighting shortfalls *(if any)* in the WPs and thereby necessary course corrections have been done by the concerned team*(s)*. Moreover, a total of nine Task Force Committee *(TFC)* meetings chaired by Director, CSIR - CRRI was also convened by Champion and Co-Champion during the course of the Indo - HCM Project which comprised of WP Leaders from CSIR - CRRI and RCs serving as principle members. The above workshops and TFC meetings were conducted by various RCs. The RCs who conducted the above include SVNIT, *(Surat)*, Anna University, *(Chennai)*, IIT *(Guwahati)*, IIEST *(Shibpur)*, IIT Bombay, Mumbai and IIT Roorkee, Roorkee. Basically, the above national workshops as well as the deliberations during the TFC meetings the concerned teams to gear up themselves for the finalization of the chapters dealt by them and facilitated in streamlining each of the chapters leading to the development of indigenous manual for Indian traffic conditions.

Eventually, the above streamlined review process culminated with the 2-day national level dissemination workshop organized by CSIR - CRRI in their premises on 20th and 21st February, 2017 which is again engineered by Champion and Co Champion of Indo - HCM Project. During this dissemination workshop, an executive summary of the manual was published by the CSIR - CRRI led team with each of the RCs and Work Package Leaders from CSIR - CRRI presenting the salient findings included in various chapters of the manual. The issues raised by the Session Chairs and the 150 odd invited delegates during the Workshop have been appropriately incorporated in the present manual. The experts who have extended immense contributions during the above national level workshops in the capacity of Session Chairs are:

1. **Prof. M.R. Madhav,** Chairman, Research Council, CSIR - CRRI, New Delhi; Prof. Madhav showered immense praise on the modus operandi followed by CSIR - CRRI team led by Champion / Co-Champion for project execution in a couple of Research Council meetings convened at CSIR - CRRI as well as in the RIHCaMs.
2. ***(Late)* Dr. L.R. Kadiyali;** Dr. Kadiyali was the author of famous book on 'Traffic Engineering and Transportation Planning' printed by Khanna Publishers. The support extended by him to the team is fondly remembered.
3. **Dr. S. Gangopadhyay,** Former Director, CSIR - CRRI; He gave his contribution initially as Director till 30.11.2015 and subsequently as Session Chair in RIHCAMs. Moreover, Dr. Gangopadhyay

played a pivotal role in convincing the then **Director General, CSIR, Prof. S.K. Brahmachari** to award this project to CSIR - CRRI. Though the project was approved for funding later by CSIR due to his above efforts, Dr.S. Gangopadhyay asked the Champion to organize a Kick-off Meeting at CSIR - CRRI *(sourcing from Laboratory Reserve of CRRI even before the award of the research study)* on 21.09.2012 by inviting all the involved institutes to discuss the modus operandi. This contribution is placed on records.

4. **Prof. Partha Chakroborty,** IIT, Kanpur.
5. **Dr. T.S. Reddy,** Scientist-G *(Retired)*, CSIR - CRRI and Consultant, M/s. Lea Associates Limited.
6. **Prof. V. Thamizh Arasan,** IIT, Madras, Chennai *(Retired)* and Vice Chancellor, Vels University, Chennai.
7. **Prof. P.K .Sikdar,** IIT, Bombay, Mumbai *(Retired)* and President *(Traffic and Transportation)*, M/s. ICT Private. Limited, New Delhi.
8. **Prof. A. Veeraragavan,** Department of Civil Engineering, IIT, *(Madras)*, Chennai.
9. **Prof. B .K. Katti,** SVNIT, Surat, *(Retired)*.
10. **Sh. D. Sanyal,** Managing Director, M/s. CRAPHTS Consultants *(I)* Pvt. Ltd. Faridabad, Haryana.

The encouraging words of appreciation remarking on the modus operandi followed for the Indo - HCM execution by the then Chairman, Research Council *(RC)* of CSIR - CRRI namely, **Prof. M.R. Madhav,** IIT, Kanpur *(Retd.)* during the course of national level workshops and RC meetings is gratefully acknowledged.

The study outputs derived from the dissertation works of more than a dozen Doctoral Students and about 36 Masters students *(which included Masters Dissertation as well as Internship program outputs)* as well as Project Fellows / Assistants *(their names given in the respective chapters)* have been appropriately incorporated in the manual and hence all their contributions is gratefully acknowledged.

During this 5-year journey of Indo - HCM project, many Scientists and Technical Staff working in the Traffic Engineering and Transportation Area *(TTP)* and other support divisions of CSIR - CRRI have rendered all types of technical and logistic assistance. This included the present serving staff of CSIR - CRRI namely, **Dr. Anuradha Shukla, Dr. S. Padma** *(for serving as an excellent anchor during the dissemination workshop at CSIR - CRRI)***, Mr. Vivek Dubey, Mr. Mariappan, Mr. S. Kannan, Mr. Satyabir Singh, Mr. Ambrish Saurikhia** and **Ms. Nidhi Agarwal** as well as some of the retired staff namely, **Mr. S.K. Ummat, Mr. B.M. Sharma** and **Mr. T.K. Amla.** Similarly, the logistic assistance rendered by the staff of Civil and Electrical Sections of CSIR - CRRI *(especially, **Mr. Gautam Pande**)* during the conduct of Workshops and TFC meetings at the Council Hall of CSIR - CRRI are placed on records. Further, the contributions rendered by more than 50 staff engaged on daily basis during the traffic data collection, data collation and analysis phase of the Indo - HCM project is acknowledged.

The spouses and families of CSIR - CRRI Work Packages *(WP)* Leaders as well as Regional Coordinators *(RCs)* had to bear the brunt of the scientists and faculty burning the midnight oil to complete the project in record time and hence many sacrifices that have been made by their family members is fondly remembered at this hour.

Last but not the least, the team of CSIR - CRRI would like to place on records their gratitude to **Sh. D.P. Gupta,** Former Director General, Ministry of Road Transport and Highways *(MoRT&H)* for rendering his essential technical inputs and effecting many essential editorial corrections in the final report prepared by the teams. His inputs have helped in improving the readability of the manual to a great extent.

- Team CRRI and Regional Coordinator led by Director, CSIR - CRRI,
Champion, *(Indo - HCM)* and Co-Champion (Indo - HCM)

EXECUTIVE SUMMARY

INTRODUCTION

The main hypothesis behind conceiving this project was that Indian traffic characteristics are fundamentally different from those in the developed countries and even the driver behaviour is vastly different from even the developing economies like China, Taiwan, Malaysia and Indonesia. Consequently, the development of an indigenous manual was undertaken on priority in the form of a mission mode project by considering the various categories of roads like Expressways, National Highways *(NHs)*, State Highways *(SHs)*, Major District Roads *(MDRs)*, Other District Roads *(ODRs)* and Urban Roads *(UR)* as well as various forms of pedestrian facilities on urban roads. The project was approved in October, 2012 for funding by CSIR under the Inter Agency Project *(IAP)* category of CSIR through Planning Commission grants. The principal goal of this research is to study the nationwide characteristics of road traffic and to develop a manual for determining the capacity and Level of Service (LOS) for varying types of interurban roads and urban roads separately by including controlled intersections *i.e. signals and roundabouts* and uncontrolled intersections coupled with addressing the capacity and Level of Service (LOS) of urban pedestrian facilities. To accomplish the stated goal, the project is aimed at analyzing the characteristics of the heterogeneous traffic flow and identifies appropriate distributions of the various variables influencing the traffic stream and pedestrians' characteristics by examining the traffic flow characteristics through extensive field data collection and analysis. This summary highlights the maiden attempt undertaken by CSIR - CRRI at the national level to develop an indigenous manual addressing the traffic heterogeneity prevalent on Indian roads. The report has been published by CSIR - CRRI with its title, **"Indian Highway Capacity Manual *(henceforth referred as 'Indo-HCM')***. This project was executed by CSIR - CRRI in coordination with reputed academic institutes in the country which included Indian Institute of Technology *(Roorkee)* Roorkee, Indian Institute of Technology, *(Bombay)*, Mumbai, Indian Institute of Technology, *(Guwahati)*, Guwahati, School of Planning and Architecture, New Delhi, Sardar Vallabhai Patel National Institute of Technology, Surat, Indian Institute of Engineering and Sciences University *(IIEST)*, Shibpur and Anna University, Chennai. The project was executed by Champion and Co-Champion in close coordination with Work Package Leaders as well as the faculty from the above reputed academic institutes have been assigned the role of Regional Coordinators *(RCs)*.

STRUCTURE OF INDO - HCM

The findings of the Indo-HCM project is presented under the following ten chapters in this manual:

- Chapter 1: Basic Concepts and Structure of the Manual
- Chapter 2: Two Lane, Intermediate and Single Lane Roads
- Chapter 3: Multilane Interurban Highways
- Chapter 4: Inter urban and Urban Expressways
- Chapter 5: Urban Roads
- Chapter 6: Signal Controlled Intersections
- Chapter 7: Roundabouts
- Chapter 8: Uncontrolled Intersections
- Chapter 9: Pedestrian Facility
- Chapter 10: Reliability as a Performance Measure for Inter-urban and Urban Arterials

As the title suggests, Chapter -1 presents an overview of the structure of the report, definition of generic terminologies related to Traffic Engineering and Planning followed by an overview of the types of road and pedestrian facilities considered and also vehicle types and other salient features. Chapters 2 to 8 focus on varying types of road facilities. Pedestrian facility is dealt in Chapter 9 and Chapter 10 focuses exclusively on Travel Time Reliability of urban and interurban corridors. Illustrative examples and a list of references are included in each chapter.

NEW CONCEPTS IN INDO-HCM

The new concepts evolved or published works of the team have been included in various chapters of Indo-HCM are breifly highlighted in the succeeding sections.

Capacity and Level of Service of Mid Block Sections

Chapters 2 to 5 discuss the capacity and level of service analysis on interurban and urban roads with varying typologies. The PCU value of a vehicle type is found to be sensitive to traffic and roadway conditions. Hence, a single set of PCU could not be recommended for all types of traffic conditions. A small change in either traffic volume or traffic composition may change PCU factors substantially, especially for large size vehicles. Hence the PCU for a given vehicle type is estimated using Equation 1.

$$PCU_i = \frac{V_c/V_1}{A_c/A_i}$$ Equation 1

Where,

V_c and V_i are speed of standard car and vehicle type 'i' respectively and

A_c and A_i are their projected rectangular area on the road.

Moreover, it was felt that the dynamic PCUs evolved in this manual in the case of midblock road sections are not sufficient to understand the complete variation in PCU for a vehicle type. Therefore, a new concept of Stream Equivalency Factor (S_e) is introduced in this manual to take care of dynamic nature of PCU. Stream Equivalency Factor (S_e) is defined as the ratio of flow in PCUs per hour to the flow in vehicles per hour which is given in Equation 2.

$$S_e = \frac{\text{Flow in PCU/hour}}{\text{Flow in vehicles/hour}}$$ Equation 2

The factor S_e is an overall equivalency factor for the entire traffic stream. It is correlated with traffic volume and its composition on the road.

Capacity of a two-lane road is influenced by the road conditions and drivers' behaviour. Hence a linear relation as typically presented in Equation 3 is observed to exist between capacity and operating speed () of standard cars plying on varying typologies of interurban and urban roads. In this context, the operating speed on a road is taken as the 85th percentile of free flow speeds of standard cars. A vehicle travelling with headway 8 seconds or more is considered as free flowing.

$$\text{Base Capacity} = A + B * V_{OS}$$ Equation 3

Where,

V_{OS} = Operating Speed of Standard Cars, km/hr

In general, it is an established fact that the term 'capacity' and 'LOS' will have a close relationship. Capacity refers to the quantitative measure of road section and LOS represents the qualitative measure of the road section. Speed has been considered as the principal factor affecting the LOS of an urban road segment under ideal conditions. Stream speed has been considered as the basic parameter for the estimation of LOS in the present study and hence clustering technique has been used for grouping of the speed data. The suggested LOS for the range of stream speed, Volume - Capacity Ratio and percentage of free flow speed is subsequently presented.

Several new measures are suggested in the manual to define LOS on undivided and divided road sections. For example, on a two-lane road, level of service is defined in terms of number of followers. A vehicle is taken in the following state if it moves with a gap less than or equal to critical gap with lead vehicle. The critical gap *(CG)* is related with traffic volume by Equation 4. The critical gap value is expected to vary with the traffic volume on the road and hence the relationship established between the two for two lane two way roads is presented in the above equation.

$CG = 74.8 * Q^{-0.45}$ Equation 4

Where,

Q = Two-way traffic volume, *(in veh/h)*

CG = Critical Gap value, *(in seconds)*

Critical gap value decreases with the increase in traffic volume on the road. Eventually, the number of followers as part of the road capacity *(NFPC)* is found to be related with two-way two-lane traffic volume as presented in Equation 5.

$NF = 1.1742 * Q^{0.9306}$ Equation 5

Where,

Q = Two-way traffic volume, PCU/h

NF = Number of followers, PCU/h

Further, LOS parameter is taken as the number of followers as part of the road capacity *(NFPC)*. Therefore, NF in the above equation is considered in PCU/hour to avoid any mismatch of units while calculating NFPC.

Saturation Flow and Capacity of Signalized Intersections

In the case of signalized intersections given in Chapter 6, the analyst has the option of measuring the saturation flow in the field by following the prescribed procedure or estimating the saturation flow using the model given in this manual. PCUs for converting the observed vehicle types into equivalent passenger cars are furnished in this chapter. The estimated base saturation flow can be adjusted by applying adjustment factors to get the saturation flow under prevailing geometric, traffic and control conditions. The capacity of each approach and that of the overall intersection can then be calculated based on the saturation flow, effective green time and the cycle time. Control delay is prescribed as the measure of effectiveness for determining the level of service of signalized intersections. The stopped delay measured in the field is converted into control delay using the prescribed conversion factors.

Critical Gap and Capacity of Roundabouts

In the case of roundabouts presented in Chapter 7, the critical gaps are estimated based on the technique related to the accepted and maximum rejected gaps using Root Mean Square Method. Root Mean Square *(RMS)* is an analytical model where the minimization of square root of the mean squared deviation of predicted value from a given baseline or fit gives the absolute measure fit. Critical gap estimation requires information about the accepted gap and the maximum rejected gap for each driver. RMS model minimizes the square root of the mean squared deviation of Rejected gap value R_i and Accepted gap value A_i from expected critical gap value T_c to give the average critical gap value. The function depicting the estimation of critical gap has been written as given in Equation 6.

$$Min\left[\sum_{i=1}^{n}\sqrt{\frac{(A_i - T_c)^2 + (T_c - R_i)^2}{2}}\right]$$ Equation 6

Where,

A_i = Accepted gap of the i^{th} entering vehicle *(seconds)*,

R_i = Highest Rejected gap of the i^{th} entering vehicle *(seconds)* and

T_c = Critical gap value *(seconds)*.

Critical Gap and Capacity of Unsignalized Intersections

In the case of Unsignalized intersections presented in Chapter 8, since the gap acceptance theory is primarily dependent on critical gap value, a method termed as Occupancy Time Method *(OTM)* has been conceived for the calculation of critical gaps. Unlike the other methods of critical gap estimation, OTM also incorporates actual driver behaviour observed on unsignalized intersections largely. As such, OTM accounts for the actual clearing pattern of the conflict area and the traffic interaction that occurs within this region. Thereafter, the capacity for various movements observed at an unsignalized intersection is carried out through a series of steps as detailed out in this chapter.

Capacity of Pedestrian Facilities

In the case of pedestrian facilities in urban areas presented in Chapter 9, capacity and LOS of Footpaths, Stairways and Foot Over Bridges *(FOBs)* have been presented in this chapter. For the purpose of the above estimation, a simplified body ellipse of 0.35 m by 0.51 m *(total area 0.18 m^2)* is used as the basic space for a pedestrian in this chapter. This represents the practical minimum space for standing pedestrians. Eventually, the required space for various forms of pedestrian facility in Indian context has been determined in this chapter. Thereafter, macroscopic modelling approach to build the empirical equation aimed at quantifying the flow of pedestrians and the capacity of various forms of pedestrian facilities. The relationship among density, speed and directional flow for pedestrians is similar to that for vehicular traffic streams and the same is presented in Equation 7.

$Q_p = V_p \times K_p$ Equation 7

Where,

Q_p = Unit flow rate *(ped/min/m)*

V_p = Pedestrian speed *(m/min)*, and

K_p = Pedestrian density *(ped/m^2)*

Further, Pedestrian Level of Service *(PLOS)* is a measure for assessing the operating condition of facilities in a quantitative manner. It denotes the level of comfort offered by the type of facility to pedestrians while using the facility. Pedestrian Level of Service *(PLOS)* is defined based on fundamental pedestrian flow parameters for five different land uses as test sections considered in this chapter encompassed varied land uses. Eventually, 6 types of LOS are defined starting from LOS A to LOS F for the following types of pedestrian facilities namely, footpaths, stairways and foot over bridge based on the varying types of type of land uses. On the other hand, LOS for Crosswalks is evolved based on pedestrian delay observed at the study locations. In addition to the above, Quality of Service *(QOS)* of the footpaths *(in terms of Walkability Index)* has been captured through a detailed questionnaire survey by understanding the perception of the pedestrians. Thus, the Walkability Index *(WI)* is calculated using Equation 8:

Walkability Index: QOS = $\sum_{i=1}^{10} A_i * B_i$ Equation 8

Where,

A_i: Importance weight for physical and user characteristics

B_i: Satisfaction rating for physical and user characteristics

Travel Time Reliability as a Performance Measure for Interurban and Urban Corridors

Travel time reliability is considered as a useful tool for the road users as well as for the public transit system planners. As such, Travel Time Reliability concept was introduced by Asakusa by considering selected network of roads in Japan and the same has found a found a place in the fifth edition of HCM *(2010)* published by Transportation Research Board. It is defined as the probability that the trip between a given Origin - Destination *(O-D)* pair can be made with a certain degree of reliability under varying time periods of the day and specified Level of Service. This measurement is found to be useful while evaluating network performance under normal daily flow variations and various uncertainties. Considering the above, methodology for the travel time reliability analysis for uninterrupted and interrupted urban arterial roads and interurban highway corridor has been conceived in this chapter for the Indian traffic conditions based on the estimation of travel time reliability measures and development of LOS based on reliability measures. The present chapter provides the methodology to deploy travel time reliability as a performance measure of urban arterial corridors which encompasses only the uninterrupted and interrupted flow corridors as well as interurban corridors. It also provides a procedure to determine the Level of Service *(LOS)* of the candidate test sections considered in this study. In the case of uninterrupted in urban corridor, the length of the selected uninterrupted section ranges from 2.5 to 3 km. However, in the case of interrupted flow in urban corridor, the length of the interrupted section is around 1.5 km to 3 km whereas the location of controlled intersection is at least 500 m away from the start and the end points of the study section. At the same time, in the case of interurban uninterrupted corridor, since such a test section invariably exists beyond the urban periphery on the National Highways or State Highways connecting major cities, the length of the test section considered for analysis is at least 3 km. Such road sections should not have influence due to the aforesaid urban conditions except for catering to insignificant proportion of Left-in and Left-out traffic from minor road. The assessment of operational performance for the above types of road environs has been done for both public transport and private vehicles. In this regard, LOS based Travel Time Reliability for cars, two wheelers, Public Transit System *(both conventional and BRTS corridor)* has been framed in this chapter.

Innovative Process of Manual Development

This project of development of Indo-HCM itself is innovative as there has not been any such attempt in the past in India. The development of Indo - HCM was not an easy task considering the vast size of the country and variety of roads and the heterogeneous traffic mix. Therefore, CSIR - CRRI identified seven prominent academic institutes located in different regions in the country to provide technical support for all the Work Packages as well as to assume the role of Regional Coordinators *(RC)* for one or two work packages depending upon their expertise. As mentioned earlier, the seven academic institutions identified are Indian Institute of Technology Roorkee, Indian Institute of Technology Bombay, Mumbai, Indian Institute of Technology, Guwahati, School of Planning and Architecture, New Delhi, Indian Institute of Engineering and Science and Technology, Shibpur, Howrah, Sardar Vallabhai Patel National Institute of Technology, Surat and Anna University, Chennai. The methodology for collection and analysis of traffic data was finalized in the common meeting of Regional Coordinators. Each RC collected traffic flow data on various types of facilities in the respective regions of the country and provided to the respective Work Package *(WP)* in charge for analysis. The identified institutes as well as Work Package leaders from CSIR – CRRI performed traffic data collection at pan-India covering all types of road network *(Expressways, National Highways. State Highways, Major District Roads and Other District Roads)* including various forms of urban pedestrian facilities.

Prof. Satish Chandra, Director, CSIR – CRRI spearheaded the entire Indo - HCM team with the project execution performed under the leadership of **Dr. S. Velmurugan, Champion** and aided by **Dr. K. Ravinder, Co-Champion**. As mentioned earlier, this was the maiden attempt by CSIR - CRRI to network with such a large number of academic institutes on the lines of HCM *(2010)* of USA. The project was completed on time with regular monitoring at different levels to achieve the desired quality. This mission mode project led by CSIR - CRRI was completed in time with regular monitoring at different levels to achieve the desired quality, which has once again displayed the technical prowess and management expertise of CSIR - CRRI in handling large size projects. Largely, the various national level workshops and task force committee meetings conducted by Champion and Co-Champion of Indo - HCM Project in close coordination with faculty from reputed academic institutes who have been assigned the role of Regional Coordinators *(RCs)* cum Local Organizing Secretary *(LOC)* for the conduct of the national workshop has helped this cause. The first workshop in the above series was conducted in January, 2013; it was followed by yearly review workshops *(three numbers)* conducted in March, 2014, February, 2015 and March, 2016 in different academic institutes involved in this study.

During each of the above workshops, the identified experts in the capacity of Session Chairs were invited for critical monitoring of the incremental progress made by the Work Package *(WP)* Leaders / members of CSIR - CRRI. All the suggestions of the learned experts were considered positively and the concerned teams in their chapters did necessary course corrections. Moreover, a total of nine Task Force Committee *(TFC)* meetings chaired by Director, CSIR - CRRI were also convened by the Champion and the Co-Champion during the course of the Indo - HCM Project which comprised of WP Leaders from CSIR - CRRI and RCs serving as principle members. The above national workshops as well as the deliberations during the TFC meetings aided the concerned teams to gear up for the finalization of the chapters dealt by them and facilitated in streamlining each of the chapters leading to the development of indigenous manual for India. Eventually, the above streamlined review process culminated with a 2-day national level dissemination workshop organized by CSIR - CRRI in its premises on 20th and 21st February, 2017 which was again engineered by Champion and Co Champion of Indo - HCM Project. During the above workshop, an executive summary of the manual was published by the CSIR - CRRI led team with each of the RCs and Work Package Leaders from CSIR - CRRI presenting salient findings included in various chapters of the manual. The issues raised by each of the Session Chairs and the 150 odd invited delegates during the Workshop have been appropriately incorporated in the present manual. During the execution of the project, several new concepts were evolved considering the unique traffic behavior on Indian roads. A few of them are listed below:

- Modus Operandi followed for the execution of Indo - HCM is itself innovative as there has not been any similar attempt made in the past in the country.
- Dynamic Passenger Car Unit *(DPCU)* based on Area and Speed of a vehicle.
- Development of Stream equivalency factor for readymade estimation of capacity
- Relationship between Operating Speed and Capacity that can be used to estimate the capacity of any given road provided Free Flow Speed *(FFS)* of a minimum sample size of 200 standard cars be collected for any type of road.
- Estimation of Level of Service on Interurban Undivided carriageways through the Number of Followers per Capacity *(NFPC)*.

- Level of Service *(LOS)* estimation for Signalized Intersection through User Perception Surveys
- Gap acceptance model for analysis of roundabouts
- Occupancy time method for estimation of critical gap, estimation of capacity *(of movements)* and Level of Service of unsignalized intersections and
- Concept of travel time reliability for interurban and urban arterial roads.

Societal Benefits

Engineers / Planners / Bureaucrats can look to follow the realistic capacity values evolved in this manual during the planning of new facilities instead of using either the obsolete values available in the relevant Indian Roads Congress *(IRC)* documents or directly adopting the values given in US-HCM *(2010)* or other manuals, which are not directly applicable to Indian road scenario.

It is expected that the manual would serve as a basic guide for the practicing engineers and decision makers towards capacity augmentation of various types of roads, *(both at mid-block sections and intersections of varied typologies)* as well as pedestrian facilities. Efforts are already in place from the scientists of CSIR - CRRI as well as Regional Coordinators *(RCs)* associated with the various Indian Roads Congress *(IRC)* technical committees to incorporate the study findings from this manual in the appropriate documents of IRC for their revision. In this context, the following guidelines of IRC need either immediate revision or formulation of new guidelines based on the above results derived in the Indo - HCM project and efforts are in place for the same as mentioned above:

- IRC:64 *(1990)* Guidelines for Capacity of Rural Roads in Plain Areas
- IRC:106 *(1990)* Guidelines for Capacity of Urban Roads in Plain Areas
- IRC:65 *(1976)* Recommended Practice for Roundabouts
- IRC 93 *(1985)* Guidelines on Design and Installation of Road Traffic Signals
- IRC:103 *(2012)* Guidelines for Pedestrian Facilities
- New Capacity Guidelines for Unsignalized Intersections
- New Guidelines for Travel Time Reliability on Urban and Interurban Corridors.

Chapter 1:

Basic Concepts and Structure of the Manual

TABLE OF CONTENTS

1.1 PREAMBLE

This chapter is the starting point for learning to use the maiden edition of the 'Indian Highway Capacity Manual'. The chapter covers the purpose, objectives, methodology adopted, proposed use as well as target users of the manual. It also provides definition of terminologies and a brief on each of the subsequent chapters of the manual.

The main hypothesis behind conceiving this research project is that traffic characteristics on Indian roads are fundamentally different from those in the developed economies and even the driver behaviour is quite different from the developing economies like China, Malaysia and Indonesia. Several countries have developed their own highway capacity manuals reflecting the traffic pattern prevalent in their respective countries. Obviously, the capacity manuals from these countries cannot be transformed for Indian traffic conditions by developing any adjustment factors. Moreover, based on the communicated views of CSIR – CRRI *(in 2010)*, the immediate need for initiating a comprehensive research study focusing on scientific estimation of the roadway capacity was aptly emphasized in 2012 by the Planning Commission, Government of India *(refer Volume III: Agriculture, Rural Development, Industry, Services and Physical Infrastructure of the Eleventh Five Year Plan 2007-12 document)*.

Considering the importance attributed by the Government of India *(GoI)* on this issue, it was felt essential to develop an indigenous highway capacity manual by considering the Indian traffic scenario as this would be of immense use to the engineers, bureaucrats and planners. The development of such a manual would certainly help policy makers in deciding allocation of budget for capacity augmentation of roads and enhancing productivity of road transport through increased Level of Service *(LOS)*.

Accordingly, this research was classified by the Council of Scientific and Industrial Research *(CSIR)* under the theme entitled, ***"Knowledge / Technology space where we do not have expertise and we would like to achieve"***. This CSIR sponsored research study project is entitled as **"Indian Highway Capacity Manual"** ***(henceforth referred to as 'Indo-HCM' in this manual)*****.** Subsequently, the development of Indo - HCM was undertaken on priority in the form of a mission mode project by CSIR – CRRI. In this study, various categories of roads in India like Expressways, National Highways *(NHs)*, State Highways *(SHs)*, Major District Roads *(MDRs)*, Other District Roads *(ODRs)* and Urban Roads *(UR)*, as well as various types of intersections *(i.e. Signalized, Roundabout and Unsignalized Intersections)* and pedestrian facilities seen on urban roads in the country have been considered.

1.2 STUDY OBJECTIVES AND SCOPE

The objectives of the Indo-HCM are:

- To study the nationwide road traffic characteristics and
- To bring out a manual for determining the capacity and Level of Service *(LOS)* for various categories of interurban and urban roads and intersections as well as roundabouts and also various forms of pedestrian facilities on urban roads.

In order to accomplish the above stated objectives, the study has addressed analysis of the heterogeneous traffic flow characteristics under varying environs. In this regard, an attempt has been made to address the appropriate distribution of the various variables influencing the traffic stream characteristics on various categories of roads, intersections and pedestrian facilities through extensive field data collection spread over the country and the associated analysis.

1.3 MODUS OPERANDI

The study project was approved in October, 2012 for funding by CSIR under the Inter Agency Project *(IAP)* category of CSIR through Planning Commission grants. CSIR - Central Road Research Institute *(CRRI)*, New Delhi was the nodal research organization. Seven prominent academic institutes located in different regions in the country were made partners to this project to provide technical support in all the Work Packages *(WPs)* and thus assigned the role of Regional Coordinators *(RCs)* for one or two WPs depending on their expertise. The academic institutions identified are:

1. Indian Institute of Technology, *(Roorkee)*,
2. Indian Institute of Technology, *(Bombay)*, *Mumbai,*
3. Indian Institute of Technology, *(Guwahati)*,
4. School of Planning and Architecture, *(New Delhi)*,
5. Indian Institute of Engineering and Science and Technology, Shibpur, *(Howrah)*,
6. Sardar Vallabhai Patel National Institute of Technology, (*Surat)* and
7. Anna University, *(Chennai)*.

1.4 PURPOSE OF INDO-HCM

Transportation and Highway fraternity can look to follow the realistic capacity values evolved in this manual while undertaking evaluation of existing road facility or planning of any new road facility without relying on obsolete or adhoc capacity values as well as procedures given in some of the Indian Roads Congress *(IRC)* documents. Moreover, indigenous manual would obviate the need to direct adoption of the capacity values given in HCM of USA *(2010)* or manuals of other countries *i.e. Chinese HCM (2005) or Indonesian HCM (1999).* It is worthwhile to mention here that the values given in the above-referred manuals evolved for other countries cannot be translated for Indian traffic conditions through evolving adjustment factors, as these would not be replicating Indian traffic scenario. In this regard, this manual is expected to provide a much-needed reliable source to update the above IRC documents and standards as well in addition to evolving new guidelines to address the missing links.

1.5 DEFINITION OF TERMINOLOGIES ...

Chapter 2:

Single Lane, Intermediate Lane and Two Lane Interurban Bidirectional Roads

TABLE OF CONTENTS

2.1 INTRODUCTION

Interurban highways in India include single lane roads, intermediate lane roads, two lane roads, multi-lane highways and expressways. Single lane, intermediate lane and two lane roads are undivided, facilitating two-way movement of traffic, whereas multi-lane highways and expressways have divided carriageways with two or more lanes in each direction. On the other hand, traffic operations on undivided roads are vastly different from that on divided highways. Hence, the capacity and LOS of undivided roads and multilane divided highways have been dealt with separately in this manual. A substantial proportion of National Highways *(NHs)* and State Highways *(SHs)* in the country are still either two lane or intermediate lane carriageways. Similarly, majority of Major District Roads *(MDRs)* are with either two lane or intermediate lane carriageways, while the Other District Roads *(ODRs)* and Village Roads *(VRs)* are generally provided with single lane and only in few cases with intermediate lane carriageways. Single lane roads have 3.75 m wide carriageways whereas intermediate lane roads have carriageways between 5.5 m and 6.0 m wide carriageways. The existing single lane roads are upgraded to intermediate lane roads where funds are not sufficient to widen from single lane to two lane roads immediately. Traffic operations on two lane or intermediate lane roads are unique in nature. Lane changing and overtaking manoeuvres are possible only in the face of oncoming traffic in the opposing lane. The overtaking demand increases while passing opportunities decline rapidly as the traffic volume increases. Therefore, flow in one direction influences the flow in the other direction. This problem is more acute in the case of mixed traffic where speed differential amongst different vehicle types is significant. It increases the desire for overtaking manoeuvres considerably whereas number of opportunities to overtake is limited. As a result, operating quality deteriorates as demand flow increases, and operations can become 'unacceptable' at a volume, which is much below the capacity of the road. Single lane roads are normally provided to connect the villages to district roads and state highways. These are generally feeder roads and experience low traffic volume. Traffic operations on single lane roads are very much influenced by the condition and width of the shoulders as vehicles are forced to use them during passing or overtaking operations. This chapter presents methodologies for the estimation of capacity, operating speeds and Level of Service of single lane, intermediate lane and two lane roads operating under mixed traffic flow conditions.

2.2 DEFINITIONS AND TERMINOLOGIES

- **Annual Average Daily Traffic *(AADT)*:** It is the annual average daily traffic when measurements are taken for the entire 365 days *(366 days in case of leap year)* of the year and averaged out.
- **Average Daily Traffic *(ADT)*:** It is the average daily traffic when measurements are taken for a few days *(less than one year such as monthly or weekly)*, averaged by the number of days for which the measurements have been taken.
- **Capacity:** It is the maximum hourly volume *(vehicles per hour)* at which vehicles can reasonably be expected to traverse a point or a uniform section of a lane or roadway under the prevailing roadway, traffic and control conditions. Following two definitions of capacity are used in this chapter:
    - **Base Capacity:** It is the maximum number of vehicles that can pass a given point on a lane or roadway during one hour, under the most nearly ideal roadway and traffic conditions, which can possibly be attained.
    - **Adjusted Capacity:** It is the maximum number of vehicles that can pass a given point on a lane or roadway during one hour under the prevailing roadway and traffic conditions. It is obtained by adjusting the base capacity for the roadway and traffic conditions present at site.

- **Composition of Traffic Stream:** It is the proportional share of different types of vehicles in the traffic stream.
- **Design Hourly Volume:** Design Hourly Volume *(DHV)* is usually the 30th highest hourly volume. This hourly volume is exceeded only during 29 hours in a year.
- **Design Service Volume *(DSV)***: It is defined as maximum service volume at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during one hour under prevailing roadway, traffic and control conditions while maintaining a designed Level of Service**.**
- **Design Speed:** Design speed depends on the function of the road and terrain classification. It is the basic parameter, which determines all other geometric design features.
- **Free Flow Speed:** The mean speed of any vehicle type that can be accommodated under low to moderate flow rates on a road segment under prevailing roadway and traffic conditions. This signifies that the Free Flow Speed (FFS) of any given vehicle type, when the traffic flow is such that the time gap between two consecutive vehicles is more than 8 seconds. Alternatively, FFS is defined as the maximum speed that can be achieved by any given vehicle type when there are no interruptions other vehicle types in the traffic for the given road width and terrain conditions.
- **Flow *(or Volume)*:** It is the number of vehicles that pass through a given point on a road during a designated time interval. Since roads have a certain width and the required number of lanes is accommodated within the available width, flow is always expressed in relation to the given width *i.e. per lane or per direction etc.* The time unit selected is one hour.
- **Interurban Roads:** These roads help in achieving enhanced mobility of traffic between any adjoining cities or towns. National Highways *(NHs)*, State Highways *(SHs)*, Major District Roads *(MDRs)* and Other District Roads *(ODRs)* all fall under the category of interurban roads.
- **Level of Service *(LOS)*:** It is defined as a qualitative measure, describing operational conditions within a traffic stream and their perception by drivers/passengers**.** LOS definition generally describes these conditions in terms of factors such as speed and travel time, freedom to manoeuvre, traffic interruptions, comfort, convenience and safety. Six levels of service are recognized and these are designated from A to F, with LOS A representing the best operating condition *i.e. free flow* and the LOS F, the worst *i.e. forced or breakdown flow*. A typical illustration of LOS is given in Section 2.10.
- **Number of Followers as Percent of Capacity *(NFPC)*:** NFPC is the number of vehicles in following state on a section of two lanes or intermediate lane road, divided by its capacity. It is used to define Level of Service on two lane and intermediate lane roads.
- **Operating Speed *(V_{OS})*:** It is the 85th percentile of free flow speed of standard passenger cars *(small cars)* on a road. A vehicle travelling at headway 8 seconds or more is considered to be operating under free flow conditions in this manual.
- **Passenger Car Unit *(PCU)***: It is the amount of interaction *(or impedance)* caused by the vehicle to a traffic stream with respect to a standard passenger car. It is used to convert a heterogeneous traffic stream into a homogeneous equivalent to express flow and density in a common unit.
- **Peak Hour Flow:** Peak rates of flow are related to hourly volumes with peak hour factor. This factor is defined as the ratio of total hourly volume to the peak rate of flow within the hour.

- **Speed:** It is the rate of motion of individual vehicles or of traffic stream. It is measured in metres per second *(m/s)* or kilometres per hour *(km/h)*. The types of speed measurements used in traffic engineering are Space Mean Speed and Time Mean Speed.
    - **Space Mean Speed *(SMS)*:** It is the mean speed of vehicles in a traffic stream at any instant of time over a certain length of the road. It is the average speed based on average travel time of vehicles to traverse a known segment of a roadway. It is generally slightly less than the time mean speed.
    - **Time Mean Speed *(TMS)*:** It is the mean speed of vehicles observed at a point on the road over a period. It is the arithmetic mean of spot speeds.
- **Terrain Classification:** Terrain is classified based on the general cross slope of the country across the highway alignment. Cross slope is the slope approximately perpendicular to the road. Terrain is classified as plain, rolling, mountainous and steep as per the criteria given in Table 2.1.

Table 2.1: Terrain Classification

S.No.	Terrain Classification	Percent cross slope of the country
1	Plain	0 - 10
2	Rolling	10 - 25
3	Mountainous	25 - 60
4	Steep	More than 60

2.3 FUNCTIONAL CHARACTERISTICS

The traffic on Indian roads is composed of slow and fast moving vehicles with substantial differences in their static and dynamic characteristics including their size and engine power. A wide range of motorized and non-motorized traffic *(NMT)* uses the same roadway space resulting in heterogeneous traffic. The bi-directional traffic on these roads shares the same road space without physical segregation and occupies any lateral position on the road depending on the availability of space. The vehicles on these roads rapidly change their positions to obtain a clear view of the oncoming traffic or to find an opening to perform an overtaking manoeuvre.

2.3.1 Two Lane Roads ...

Chapter 3:

Multilane Divided Interurban Highways

TABLE OF CONTENTS

3.1 INTRODUCTION

This chapter provides the capacity and Level of Service *(LOS)* values evolved for vehicular traffic plying on uninterrupted flow segments of multilane divided interurban highways under mixed traffic conditions observed in Indian roads. Uninterrupted flow here refers to the flow conditions observed on roadway segments with no fixed causes of delay or interruption external to the traffic stream. This implies that the uninterrupted flow facilities referred to in this manual include such types of multilane divided interurban highway segments which are have median openings that are spaced at least 1 *(one)* km apart, and moreover, there are no major access roads connecting to the highways in those segments. At the same time, minor access roads or driveways joining such highway segments and catering to a substantially low volume of traffic throughout the day can be tolerated while defining a facility as an uninterrupted flow facility. Apart from the stated major objective of specifying the Capacity and LOS values for segments with uninterrupted flow on multilane divided interurban highways, there are a few other objectives covered in this chapter as well. These are summarized below:

- Establishin g a relationship between capacity and operating speed for base sections
- Estimation of dynamic Passenger Car Unit *(PCU)* values for different vehicle-types and Stream Equivalency Factors (S_e) encompassing varying widths of multilane divided interurban highways
- Estimation of adjustment factors for various road characteristics affecting traffic flows on multilane divided interurban highways

3.1.1 Scope and Limitation ...

Chapter 4:

Interurban and Urban Expressways

TABLE OF CONTENTS

4.1 INTRODUCTION

4.1.1 Interurban Expressways

An expressway is defined as an arterial highway for motorized traffic having divided carriageways for high speed travel with full control of access and provided with grade separators or interchanges at locations of intersections. These are the highest class of roads in the Indian road network with design speeds ranging from 100 to 120 km per hour in plain terrain. In the case of interurban expressways connecting cities and towns, vehicle types like motorised two-wheelers and auto rickshaws are generally be prohibited from entering due to their vulnerability to road crashes. Because of access control, traffic flow behaviour on expressways is significantly different from other multilane interurban roads which are faced with mixed traffic conditions prevailing on Indian roads. Hence, this category of roads is dealt with separately in this manual. Normally, expressways have at least two lanes in each direction of travel and depending upon the traffic demand it can be divided carriageways of six-lane, eight-lane or more number of lanes.

4.1.2 Urban Expressways

An urban expressway is a multi-lane road in urban areas with divided carriageway for high speed travel having full control of access and provided with grade separators and interchanges at locations of intersections. At the location of entry to exit from the expressway, it is provided with on-ramp and off-ramp facility respectively. Urban expressways are the highest class of urban roads in the road network in Indian metropolitan cities with the design speed ranging from 80 to 100 km per hour in plain terrain. In the case of urban expressways in India, vehicle types like motorised two-wheelers and motorized three-wheelers are generally permitted to ply despite their vulnerability to road crashes. This may be attributed to the fact that the travel mode usage in a city may warrant entry of these vehicles on urban expressways which are very few in the country. Moreover, the entry and exit points on urban expressways are more frequent compared to interurban expressways. At the same time, the traffic flow behaviour on urban expressways is significantly different from other urban roads and streets. An urban expressway shall have at least two lanes in each direction of travel and depending upon the traffic demand can have six lanes, eight lanes or more in both directions of travel. The primary difference with respect to interurban expressway is that it serves a particular urban area, radiating out from the urban centre to serve the surrounding region. It also provides connectivity for urban traffic to the rural highways or interurban expressways. Urban expressways can also be elevated or below the ground.

This chapter presents methodologies for the estimation of capacity and LOS values evolved for vehicular traffic plying on fully access controlled four-lane and six-lane divided interurban expressways as well as eight lane urban expressways catering to somewhat different traffic conditions observed on Indian expressways as compared to developed economies.

4.2 DEFINITIONS AND TERMINOLOGIES ...

Chapter 5:

Urban Roads

TABLE OF CONTENTS

5.1 INTRODUCTION

Urban road is the one with a relatively high density of driveway access located in an urban area and having traffic signals with a minimum spacing of one kilometer. The term 'Urban Road Segment' refers to the length of road with control arrangements at both of its ends, i.e. the upstream and downstream intersections are controlled intersections. This chapter describes the procedures for calculation of capacity and performance measures of two lane undivided and four to ten lanes divided urban roads in India for the given roadway, traffic and environmental conditions.

5.1.1 Study Objectives

- 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 varying widths of urban roads.
- Development of capacity norms and Level of Service *(LOS)* and for varying road widths of urban roads including quantification of the friction due to bus bays, on-street parking and access roads.

5.1.2 Scope and Limitation

Urban roads are generally classified based on the functional characteristics and configuration. However, as the functional classification varies from city to city. In this context the standard road width per lane considered is 3.5 m with an additional shyness of 0.25 m provided on either edge of the road. Hence the typology of roads considered in this manual includes the following:

Divided Roads (in each direction of travel with 0.25 m kerb shyness on either edges of the road):

- 7.5 m road width *i.e. Four-lane Divided Road*
- 11 m road width *i.e. Six-lane Divided Road*
- 14.5 m road width *i.e. Eight-lane Divided Road*
- 18.0 m road width *i.e. Ten-lane Divided Road*

Undivided Roads: (Road width of 7.0 m plus 0.25 m kerb shyness on either edge)

- 7.5 m road width *i.e. Two-lane Undivided Road*

The scope of the chapter includes capacity and LOS analysis for the above class of roads only in this manual. The number of base and non base sections considered across varying road widths selected in different metropolitan cities of the country namely, Delhi, Mumbai, Kolkata, Chennai, Jaipur, Chandigarh, Surat, Ahmadabad, Thiruvanthapuram and Guwahati is presented in Table 5.1.

Table 5.1: Number of Test Sections considered across Varying Road Widths

S.No.	Type of Road	Number of Road Sections	
		Base	Non Base
1	Four lane Divided Urban Road	11	26
2	Six Lane Divided Urban Road	11	6
3	Eight Lane Divided Urban Road	4	2
4	Ten lane Divided Urban Road	3	1
5	Two Lane Undivided Urban Road	2	1

5.2 DEFINITIONS AND TERMINOLOGIES ...

Chapter 6:

Signalized Intersections

TABLE OF CONTENTS

6.1 INTRODUCTION

Intersections are the critical points of any road network, where delay normally occurs due to sharing of space and time between conflicting streams / movements of vehicles. Depending upon the type of control employed at the intersection, hierarchically can be termed as uncontrolled, stop controlled, roundabout, signalized, grade separated intersection *i.e. flyover* and interchange. This chapter deals with the methodology devised for determination of capacity and Level of Service *(LOS)* of signalized intersections. It is imperative to study the varying typologies of signalized intersections to arrive at the capacity and LOS norms under different operating conditions.

Accordingly, this chapter describes the methodology for the estimation of saturation flow, capacity, delay and LOS for varying typologies of signalized intersections. The models developed deal primarily with fixed time isolated signal controlled intersections. The methodology considers a variety of prevailing operating conditions such as traffic composition, flow movements, geometric characteristics and signal settings at such intersections.

Using this methodology, the saturation flow and delay can be estimated for existing signalized intersections or for a newly planned intersection. Moreover, in the case of existing signalized intersections, the users have the option of either using the models developed for the estimation of saturation flow and control delay or directly obtain these parameters through field measurement procedures prescribed in this manual. Further, adjustment factors accounting for the ground conditions existing at any non-base intersections are also proposed in the manual which can be used to obtain the prevailing saturation flows and capacity.

6.2 DEFINITIONS AND TERMINOLOGIES ...

6.3 BASE INTERSECTION

In this manual, an intersection is categorized as base intersection if it conforms to the following listed conditions:

- Each approach is uniform in its width leading to the stop line.
- There is no bus stop *(far side or near side)* in the vicinity *i.e. within 75 m from the nearest stop line of intersection*.
- The pedestrian flow is negligible, or phasing plan allows protected pedestrians crossing at the intersection.
- The longitudinal gradient of all the approaches is almost zero.
- Through vehicles are not hindered by the right turning vehicles sharing the same approach and waiting for their phase.

If the candidate intersection considered by the analyst does not conform to the aforesaid conditions, then such intersections are to be classified as non-base intersections and adjustment factors need to be applied for the deviations from the base conditions.

6.4 SCOPE AND LIMITATION

This chapter presents concepts and procedures for the estimation of capacity and LOS offered by the fixed time isolated signal controlled intersections. For the purpose of estimation of saturation flow and capacity, 23 signalized intersections possessing varying typologies located in 8 cities of the country namely; Delhi, Mumbai, Kolkata, Chennai, Ahmedabad, Vadodara, Surat and Noida have been considered for analysis. In the case of delay and Level of Service *(LOS)* estimation, perception data of the vehicle users on the quantum of delay encountered as well as basic socio-economic aspects of the respondents has been collected at 18 signalized intersections located in Delhi, Mumbai, Kolkata and Noida. The above perception data has been collected by interviewing the respondents both at the approach arms of the intersections as well as by intercepting the respondents at the parking lots / fuel stations located adjacent to the above 23 intersections selected for saturation flow and capacity analysis.

6.5 METHODOLOGY ...

Chapter 7:

Roundabouts

TABLE OF CONTENTS

7.1 INTRODUCTION

At grade intersections are the critical points of a road network where delay normally occurs due to sharing of space and time between conflicting streams / movements of vehicles. Depending upon the type of control employed, intersections can be termed as uncontrolled intersections, stop-controlled intersections, roundabouts, signal controlled / signalized intersections and grade separated intersections or interchanges. It is necessary to study them to arrive at various capacity and Level of Service (LOS) norms under different operating conditions. This chapter presents concepts and procedures for estimating the capacity and LOS of Roundabouts.

A roundabout is a specialized form of at-grade intersection where vehicles from the converging arms are forced to move round a central island in one direction in an orderly and regimented manner and move/weave out of the roundabout into their desired direction. In a conventional roundabout, traffic at entry seek suitable gap in the circulating stream to negotiate at the roundabout.

Roundabouts are categorized according to size and environment to facilitate analysis of specific performance or design issues. There are three basic categories based on environment, number of lanes and size.

- Mini Roundabouts
- Single Lane Roundabouts
- Multilane Roundabouts

7.1.1 Mini Roundabouts

Mini roundabouts are small roundabouts with a fully traversable central island. Figure 7.1 shows the features of a typical mini roundabout. They may be useful in environments where a conventional roundabout design is not possible due to constraints of Right of Way *(RoW)*. Mini roundabouts are relatively less expensive because they typically require minimal additional pavement at the intersecting roads and minor widening at the corner of kerb. They are generally recommended when there is insufficient RoW to accommodate the design vehicle with a traditional single-lane roundabout. They are small in diameter *(ranging from 4 m to 12 m)*. Mini roundabouts are perceived

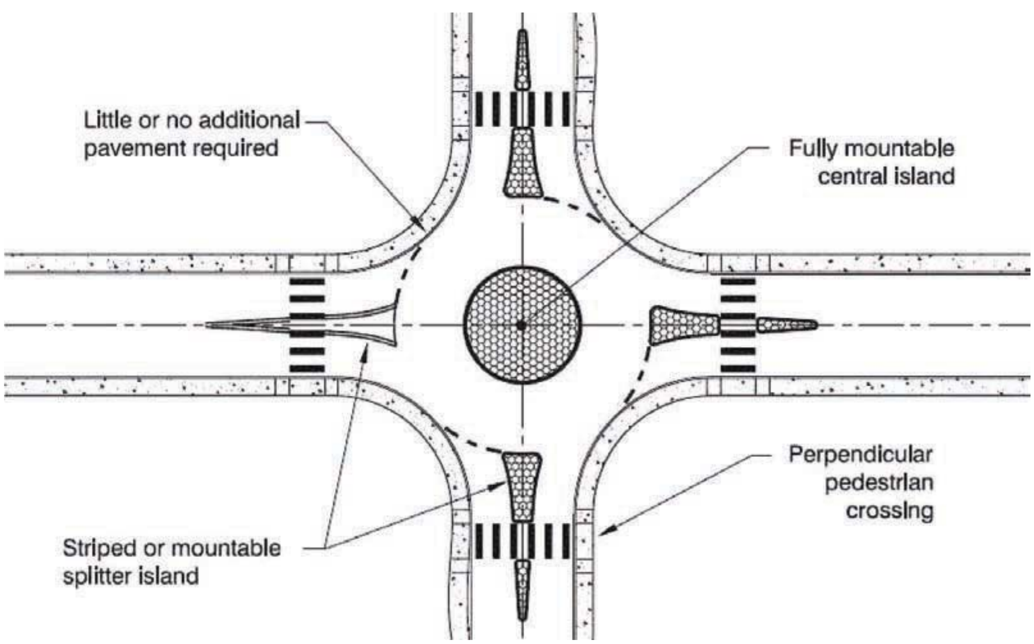

Figure 7.1: Typical Mini Roundabout

as pedestrian friendly due to short crossing distances coupled with low speed of vehicles on each of the entry and exit approaches. A fully traversable central island is provided to accommodate large vehicles and it serves as one of the distinguishing features of a mini roundabout. It is basically designed to accommodate passenger cars without requiring them to traverse over the central island accompanied by the basic philosophy of applicable for the roundabouts so as to provide *'priority to circulating traffic from the right'*. Vehicles entering the roundabout must give way to vehicles approaching from the right, circulating the central island. The capacity and LOS estimation of mini roundabouts has not been dealt within this manual due to non-availability of such roundabouts to study the traffic characteristics in Indian cities.

7.1.2 Single Lane Roundabouts

This type of roundabout is characterized as having a single-lane entry at all legs and one circulatory lane. Figure 7.2 shows the features of a typical single lane roundabout having a diameter ranging from 27 m to 55 m. They are distinguished from mini-roundabouts by their larger inscribed circle diameter and non-traversable central-islands. Their design allows slightly higher speeds at the entry, on the circulatory roadway and at the exit. The geometric design typically includes raised splitter islands, a non-traversable central island, crosswalks and a truck apron/ mountable area. The size of the roundabout is largely influenced by the choice of a design vehicle and available RoW. However, again the capacity and LOS estimation of single lane roundabouts has not been dealt in this manual due to inadequate representation of such roundabouts to study the traffic characteristics in Indian cities.

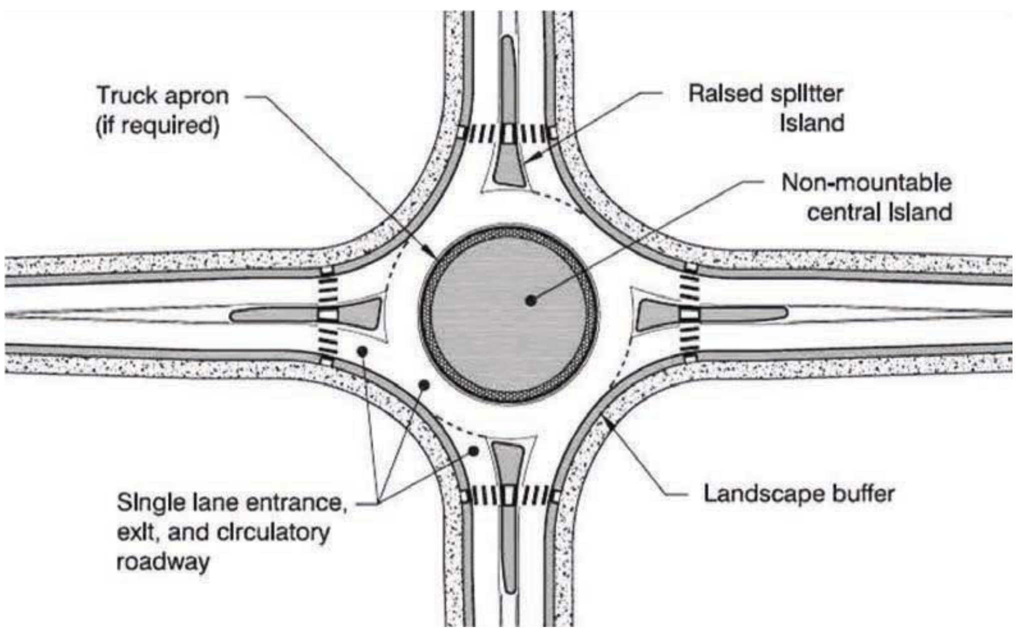

Figure 7.2: Typical Single Lane Roundabout

7.1.3 Multilane Roundabouts

Multilane roundabouts have at least one entry with two or more lanes. In some cases, the roundabout may have different number of lanes on one or more approaches *(e.g., two lane entry on the major approach and one lane entry on the minor approach)*. They also include roundabouts with entries on one or more approaches that flare from one to two or more lanes. These require wider circulatory roadways to accommodate more than one vehicle travelling side by side. Figure 7.3 shows the features of a typical multi-lane roundabout having a diameter ranging from 46 m to 90 m. The speeds at the entry on the circulatory roadway and at the exit are similar or may be slightly higher than those for the single lane roundabouts. The geometric design will include raised splitter islands, truck apron, a non-traversable central-island and appropriate entry path deflection.

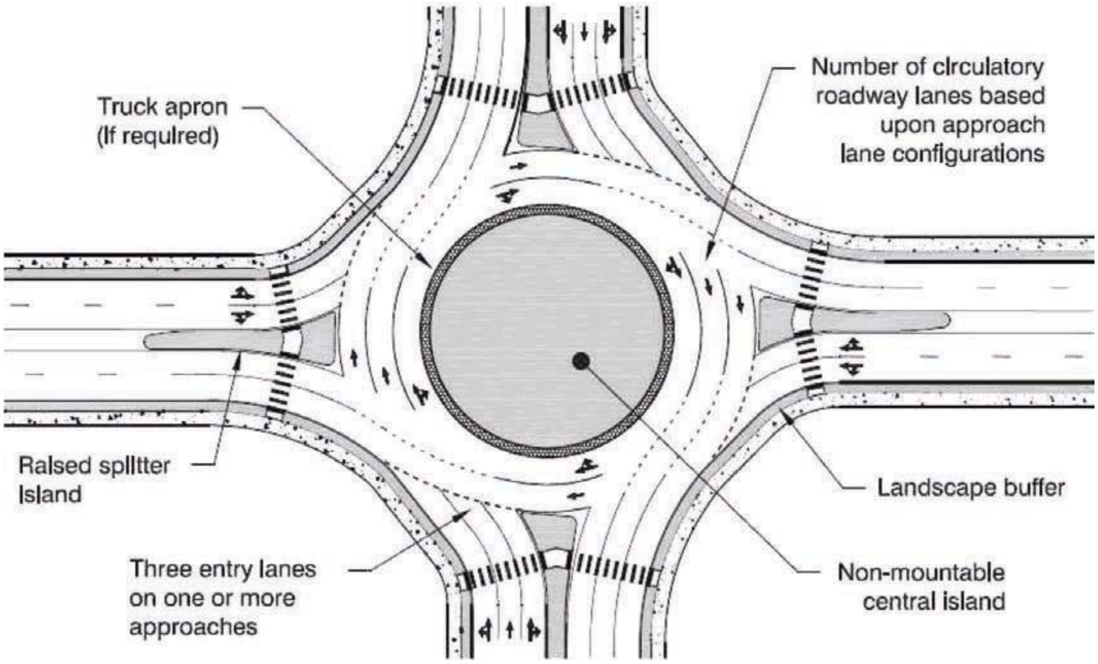

Figure 7.3: Typical Multilane Roundabout

7.2 BASE CONDITIONS FOR CAPACITY ESTIMATION

Based on the study of typology of over 350 roundabouts located in different parts of India, it is found that more than 70 percent roundabouts possess 20 m to 70 m diameter and average diameter of roundabouts in Indian cities / town is 35 m. This chapter presents concepts and procedures for the estimation of capacity and LOS of multilane roundabouts of diameter of 20 m to 70 m with two lane approach roads having mixed traffic flow conditions. The methodology proposed is applicable to base roundabouts satisfying most of the requirements mentioned below:

- Roundabouts at Four-arm intersection having two-lane approaches only.
- Roundabouts have circular shape of Central Island.
- Roundabouts shall have three-lane weaving width.
- Intersection angle shall preferably be at 90 degree +/- 10 degree.
- Central Island diameter in the range of 20 m to 70 m.
- Roundabouts catering to low percentage of two wheelers and less than 5 per cent heavy vehicles and Non-Motorised Traffic *(NMT).*

The methodology allows the analyst to assess the operational performance and capacity of existing or planned roundabouts based on the given traffic demand levels.

7.3 DEFINITIONS AND TERMINOLOGIES ...

Chapter 8:

Unsignalized Intersections

TABLE OF CONTENTS

8.1 INTRODUCTION

An unsignalized intersection refers to "an intersection without signal or manual control and also without any central island". It is formed when two roads intersect *(or join)* each other at grade. Based on the relative importance of the two roads, one of them is generally designated as major road and the other as minor road. When traffic on minor road is controlled by STOP signs, the intersection is called a Two-Way Stop Controlled *(TWSC)*. In case STOP signs are placed on all the approaches of an intersection, it is termed as an All Way Stop Controlled *(AWSC)* intersection. Due to weak enforcement of traffic regulations and lack of understanding of priority rules among road users in India, no distinction is made in this manual between a TWSC and AWSC intersection.

An unsignalized intersection can be three legged, four legged or multi-legged type. A typical three-legged intersection is formed when a side street joins a major street *(refer Figure 8.1)*. A four-legged intersection is formed when two roads cross each other. One of the two roads are generally a minor street but both streets can also be minor / major street *(refer Figure 8.2)*. A limited priority of movement is followed by road users in India. Considering the above circumstances, the road that is wider among the two or which carries heavy volume of traffic in an unsignalized intersection is considered as 'major' road and the other intersecting road is considered as 'minor' road. The methods presented in the manual are applicable for three legged and four legged unsignalized intersections only.

Figure 8.1: Typical Three-Approach Intersection with Four Lane Divided Carriageways on all Approaches

Figure 8.2: Typical Four-Approach Intersection with Two Lane Undivided Carriageways on all Approaches

8.2 DEFINITIONS OF TERMINOLOGIES ...

8.3 BASE INTERSECTION

In this manual, an unsignalized intersection is categorized as base intersection if it conforms to the conditions listed below:

- Number of intersecting approaches = 3 or 4
- Angle of intersection at 90 degrees on a three or four-legged intersection with a deviation of +/- 10 degrees.
- 2 or 4 lane divided major road
- Negligible presence of non-motorized traffic, on-street parking, hawkers or any other landuse activities within 75 m from the centre of the intersection
- No gradient on the intersecting approaches
- Safe stopping sight distance is available
- No speed breakers on any approach within 75 m from the centre of intersection

If the candidate intersection considered by the analyst does not conform to the previously mentioned conditions, then such intersections are to be classified as non-base intersections and adjustment factors need to be applied for deviations from the base conditions.

8.4 SCOPE AND LIMITATION

This chapter presents the concepts and procedures for the estimation of capacity and Level of Service *(LOS)* offered by the three legged and four legged unsignalized intersections only. In this context, 12 unsignalized intersections possessing varying three legged as well as four-legged configuration has been considered. These intersections are located in eight metropolitan cities of the country namely, Delhi, Navi Mumbai, Maraimalainagar *(on the outskirts of Chennai),* Thiruvanthapuram, Bhubaneshwar, Meerut, Faridabad and Noida.

8.5 METHODOLOGY ...

Chapter 9:

Pedestrian Facilities

TABLE OF CONTENTS

9.1 INTRODUCTION

9.1.1 Overview

The definition of 'Pedestrian' includes people who walk, sit, stand in public spaces or use mobility aids like walking stick, crutches or wheelchair, be they children, teenagers, adults, elderly persons, persons with disabilities, workers, residents, shoppers or people watchers *(IRC, 103:2012)*. Walking is the basic mode of travel. It is healthy and sustainable to human society. As compared to railways and vehicular transport, walking can happen anywhere: from roadside to covered shopping malls and from underground stations to foot over bridges. Walking is still the most universal means of travelling, especially for the first and the last trip leg of a journey. The importance of pedestrian movements is understood globally and need not be overemphasized. Hence the pedestrian facilities are analyzed by using factors like speed, pedestrian flow and density culminating with capacity and Level of Service *(LOS)* of various forms of pedestrian facilities. Apart from these quantitative factors, qualitative factors like pedestrian needs and perceptions of the pedestrians in the form of subjective data are also included in defining Walkability Index for Footpaths are also dealt in this manual.

9.1.2 Modal Characteristics ...

Chapter 10:

Travel Time Reliability as a Performance Measure for Interurban and Urban Corridors

TABLE OF CONTENTS

10.1 INTRODUCTION

The concept of reliability helps in understanding two operating states, implying thereby whether the road is connected or disconnected. This binary state approach limits the application to everyday situation where road links are operating in between these two extremities. Also, the aspects of this reliability are less useful to the road users than the transport system planners. This limitation, further led to the development of various network reliability measures such as travel time reliability, capacity reliability, parking reliability etc. Out of the various network reliability measures, travel time reliability is considered as a useful tool for the road users as well as for the public transit system planners. Since 1990, network reliability has been prominent research topic in transport planning in Japan, especially after the Kobe earthquake of 1990. In its immediate aftermath, measures have been undertaken on Japanese road network aimed at providing enhanced connectivity and reliability. Travel Time Reliability concept was introduced by Asakura *(Asakura and Kashiwadani 1991)* by considering selected network of roads in Japan. It was defined as the probability that the trip between a given Origin - Destination *(O-D)* pair can be made with a certain degree of reliability under varying time periods of the day and specified Level of Service. This measurement is found to be useful while evaluating network performance under normal daily flow variations and various uncertainties.

In this regard, travel time reliability is an important attribute of urban transportation services affecting choice of mode and route of travel. It is a measure of a roadway service quality in transport network. Reliability by its nature implies about the certainty or stability of travel time whereby it eliminates uncertainty for travelers in the sense that the travelling public does not have to travel with any degree of uncertainty in respect of the probable / reliable time of arrival at their respective destinations. This analogy is applicable to a large extent on the urban and interurban carriageways and their characteristics are discussed in the succeeding sections.

10.2 URBAN AND INTERURBAN CORRIDORS

10.2.1 Uninterrupted Flow in Urban Corridor

Uninterrupted urban arterial section is a typical ideal / base section. Vehicular speeds along this section does not get influenced due to merging or diverging traffic joining from the left-in and left-out access roads. Moreover, the candidate road section should not have influence due to any form of roadside friction *(like on-street parking, kerb side bus stops)* and presence of any sharp horizontal curves and steep vertical gradients. The length of the selected uninterrupted section ranges from 2.5 to 3 km. Figure 10.1 presents the typical uninterrupted flow section of an urban arterial corridor considered in this manual.

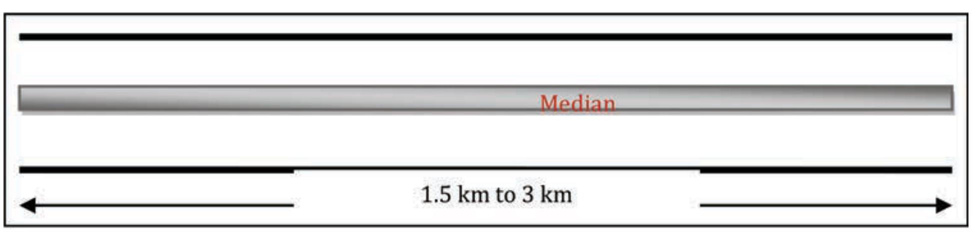

Figure 10.1: Typical Section of Urban Corridor of Uninterrupted flow section

10.2.2 Interrupted Flow in Urban Corridor

Interrupted Urban Corridor is a typical section of urban arterials witnessed in many of the metropolitan cities of India. This section is largely influenced by major controlled intersections *(ranging between one to two intersections)* and hence the speed of the vehicles along this section would get influenced due to merging or diverging traffic joining from the adjoining network. Moreover, the candidate road section should not have influence due to any form of roadside friction *(like the influence of on street parking, kerb side bus stops)* and should not have any influence due to the presence of any sharp horizontal curves and steep vertical gradients. The length of the interrupted section is expected to be 1.5 km to 3 km. The location of controlled intersection is at least 500 m away from the start and the end points of the study section. Figure 10.2 presents the typical interrupted flow section of an urban arterial corridor considered in this manual.

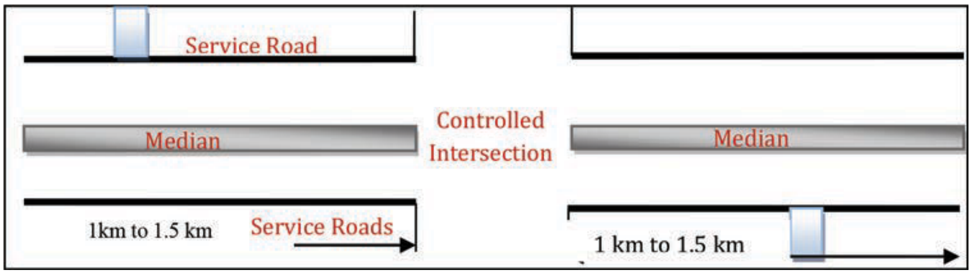

Figure 10.2: Typical Section of Urban Corridor of Interrupted flow section

10.2.3 Interurban Corridor

Such a test section invariably exists beyond the urban periphery on the National Highways or State Highways connecting major cities. Such road sections should not have influence due to the aforesaid urban conditions except for catering to insignificant proportion of Left-in and Left-out traffic from minor road *(Figure 10.3).* The length of the test section considered for analysis is at least 3 km which is termed as interurban corridor in this manual.

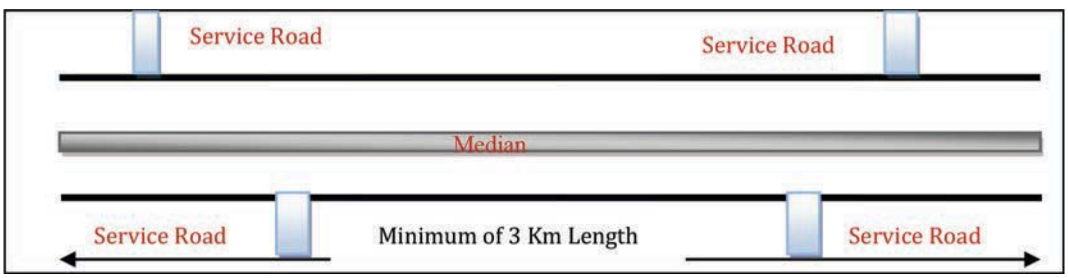

Figure 10.3: Typical section of Interurban Corridor of Interrupted Flow section

10.3 DEFINITIONS AND TERMINOLOGIES ...