EVALUATION OF ACTUAL AND PERCEIVED LEVEL OF SERVICE OF URBAN MID-BLOCK SECTIONS AND INTERSECTIONS

PROJECT REPORT

Submitted by

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of

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DEPARTMENT OF CIVIL ENGINEERING

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DECLARATION

I undersigned hereby declare that the project report "Evaluation of Actual and Perceived Level of Service of Urban Mid-Block Sections and Intersections", submitted for partial fulfilment of the requirements for the award of degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of Prof. Karthik S, Assistant Professor. This submission represents my ideas in my own words and where ideas or words of others have been included; I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/ or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

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CERTIFICATE

Certified that this report entitled **'EVALUATION OF ACTUAL AND PERCEIVED LEVEL OF SERVICE OF URBAN MID-BLOCK SECTIONS AND INTERSECTIONS'** is the report of project presented by **SHUHAIB M C, Roll No.: TKM20CETE14** during **2021-2022** in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Transportation Engineering of the A P J Abdul Kalam Technological University.

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ABSTRACT

The continuously increasing population of our country also showcases a corresponding or in fact a multi-fold increase in vehicle population. Unfortunately, the transportation facilities are not well developed to cater this huge demand. Many a times the traffic flow through these existing facilities exceed the design capacity. This results in reduction in the design speed of the facility, increased delays and bottlenecks, increase in travel time, reduced comfort and convenience. These ill characteristics causes poor operating conditions and consequent decrease in the user satisfaction of these facilities. Therefore, it is of prime importance to measure the effectiveness of these facilities from time to time. Level of Service (LOS) is such a measure which can be used to analyse the efficiency of such facilities. This study determined the LOS of two midblock sections and two intersections by collecting factors like average travel speed and free flow speed for the former, and delay and V/C ratio for the latter. The user perceived LOS of these facilities are also processed from 400 responses. Comparisons were made between these values of LOS. The study concludes that that the LOS perceived is higher than actual LOS. Obstructions to traffic flow and visibility of the signal and proper display of signal timing are the most important factor affecting the service of a road and a junction respectively. The results of this analysis can be utilized to bring out timely development to these facilities and subsequently improve the efficiency and user satisfaction.

Keywords: Level of Service (LOS), Average Travel Speed (ATS), Free Flow Speed (FFS), Highway Capacity Manual, Clustering Analysis, User Perception, Likert Scale.

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LIST OF ABBREVIATIONS

LOS	Level Of Service
FFS	Free Flow Speed
ATS	Average Travel Speed
PCU	Passenger Car Unit
V/C	Volume / Capacity
HCM	Highway Capacity Manual
GPS	Global Positioning System
FCM	Fuzzy C-Means
HAC	Hierarchical Agglomerative Clustering
DIANA	Divisive Analysis
HardCL	Hard Competitive Learning
CLARA	Clustering Large Applications
LCV	Light Commercial Vehicle
HV	Heavy Vehicle
TAT	Two/Three Axled Truck
MAT	Multi Axled Truck

CHAPTER 1
INTRODUCTION

1.1 General

For emerging nations, the rapid urbanisation and growth of large cities with rising populations presents significant challenges. In India, the number of motorised vehicles has significantly expanded over the past ten years along with the country's rapid urbanisation. India had about 25 million urban residents in 1901, or roughly 10.84 percent of the country's total population. The population of urban regions has grown to almost 285 million people, or 28 percent of the overall population, in the next century (Babit et al, 2016). This sturdy increase in population has been a challenge for the evolvement of modern society by causing a consequent increase in population of vehicles too. According to statistics provided by the Ministry of Road Transport & Highways (MoRTH), the Government of India, and Compound Annual Growth Rate (CAGR), the number of motor vehicles in India increased at a rapid rate of around 10.5 percent per year between 2002 and 2012. Between the many types of vehicles, cars, cabs, and jeeps registered the highest CAGR (11 percent), followed by two-wheelers (10.7 percent) (Babit et al, 2016). In India, the nature of the traffic flow is non-lane based and heterogeneous. Indian urban areas include a wide variety of large, developed, and underdeveloped cities, as well as small towns. Unfortunately, not all of these cities or towns are endowed with reliable and adequate transit infrastructure. The transportation industry has always had to deal with constant carelessness, ignorance, and unpredictability. Therefore, it is difficult to predict how traffic would behave on urban roadways given the current heterogeneous state, which makes the flow of traffic extremely complex. The most important things to watch out for on Indian urban roads are the driver's comfort, convenience, safety, traffic volume, and trip delay. It has become vital to monitor traffic volume and Level of Service (LOS), which are indicators of high-quality transportation.

In most cities and towns, rising traffic congestion, which leads to a poor level of service and has an impact on the local economy and environment, has been a major problem during the past several years. Better transportation infrastructure is needed since it is essential to the expansion of India's economy. A key factor in determining the current state and even being able to predict the future state of traffic volume is determining the current amount of traffic. The following variables frequently contribute to a declining level of service: journey time, travel speed, traffic jams, and limits. This decline in service quality has grown to be a serious problem since it makes driving more difficult. The issue of air and noise pollution brought on by idling vehicles in traffic jams is another result of traffic congestion. These have a significant impact on the country's economic development.

This report aims to develop a sound understanding of Level of Service (LOS) on urban roads in Indian conditions from the previous studies conducted. The detailed information on various parameters that are used to define LOS for both homogenous and heterogenous traffic conditions are also reported and presented. The classifications of LOS grades along with its operating characteristics are also provided.

The LOS of two urban midblock sections and intersections in the Indian state of Kerala has been found out using methodologies prescribed in the Indo HCM 2017 by collecting the data regarding the various parameters required for the respective LOS evaluation. The observed details of a user questionnaire survey conducted for the same facilities and the comparison and conclusions made are presented.

1.2 Problem Statement

The always increasing population of our country also showcases a corresponding or in fact a multi-fold increase in vehicle population. Unfortunately, the transportation facilities are not well developed to cater this huge demand [00]. Many a times the traffic flow through these existing facilities exceed the design capacity. This results in reduction in the design speed of the facility, increased delays and bottlenecks, increase in travel time and reduced comfort and convenience. These causes poor operating conditions and consequent decrease in the user satisfaction of these facilities. Hence it is important to measure the effectiveness of these facilities from time to time. Level of Service (LOS) is such a measure which can be used to analyse the operating conditions. By carrying out LOS evaluation we can determine if a particular facility is performing satisfactorily or not.

1.3 Objectives

- To evaluate LOS as per methodology prescribed in Indo HCM for heterogenous traffic conditions.
- To obtain the LOS perceived by the user of the facility and to analyze the difference between actual measured LOS and perceived LOS.
- Study the effect of heterogenous nature of traffic on LOS.

1.4 Scope

- The results of this evaluation can be utilized to bring out timely development to these facilities and subsequently improve their efficiency and user satisfaction.
- A minimum LOS of LOS ‘C’ is required for a highway section. Accordingly, we can evaluate if a particular facility is performing satisfactorily or not.
- It provides a basis for determining the extent of future expansion of the facility to cater the increasing traffic load on these facilities.

CHAPTER 2
TERMINOLOGIES

2.1 Capacity

Under prevailing traffic and roadway conditions, capacity expresses the highest hourly rate at which people or vehicles can reasonably be expected to go a distance in a given amount of time. Vehicles per Day (VPD) are commonly used to describe capacity for various types of routes. Highway capacity analysis is used in transportation planning studies to determine if existing highway networks are enough to handle current traffic volumes or to project a future period when traffic growth may exceed a highway's capacity.

2.2 V/C Ratio

By dividing the volume (VPD) of traffic (current or anticipated) by the route's capacity, the Volume-to-Capacity ratio (V/C) calculates the degree of congestion on a given roadway. Example: If a road segment's capacity is 17400 VPD and the volume of traffic on it is 10,000 VPD, then the segment's V/C ratio is 10,000/17,400, or 0.57. The relative degree of congestion on a stretch of road can be calculated using the V/C ratio.

2.3 Free Flow Speed (FFS)

The average speed of the passenger automobiles on a uniform freeway segment that can be accommodated given the absence of traffic control systems, low to moderate traffic volume, and the existing roadway conditions. Vehicle stream composition, lane width, sideways clearance, number of lanes, interchange density, and geometric designs all have an impact on FFS. The speed that happens at a place when the flow density is zero is known as the free flow speed (FFS). FFS can be calculated using an analytical model or by taking measurements in the field.

2.4 Average Travel Speed (ATS)

A vehicle's average speed is determined by dividing its total distance travelled by the time it took to cover that distance. Typically, average speed refers to the speed of moving objects like cars, trains, and aircraft. It is frequently expressed in mph (miles per hour) or kmph (kilometres per hour). It is calculated during both peak and off-peak times.

2.5 Peak Hour

The period of the day when traffic congestion on the roads and crowding on public transportation are at their peak is known as a peak hour (or rush hour). Every weekday, this typically occurs twice: once in the morning and once in the afternoon or evening, when the majority of people commute. The phrase is frequently used to describe an extended period of peak congestion. Peak hour volume is the amount of traffic that is present during that time.

2.6 Passenger Car Unit (PCU)

In transportation engineering, the terms "passenger car equivalent" (PCE) and "passenger car unit" (PCU) are used to measure how fast traffic moves along a route. The effect a form of transportation has on traffic characteristics (such headway, speed, and density) when compared to a single car is referred to as a passenger car equivalent. Cycles and motorcycles are regarded as half-car units, while one automobile is considered to be a single unit. Due to their size, buses and trucks are quite inconvenient and are compared to three automobiles or three PCU (4 in some case).

2.7 Traffic Density

The quantity of vehicles using a given length of road is referred to as traffic density. Consider an aerial shot of a highway segment to get a better idea of traffic density. Count the number of cars inside a single lane's 1 km. The density per lane-km will be this. Traffic densities range from zero (no flow) to numbers that depict stopped, congested traffic. Depending on the traffic density and the amount of space between vehicles, this upper limit, known as the jam density, is typically between 185 and 250 vehicles per lane-km.

2.8 Traffic Flow

The number of vehicles passing a spot in a predetermined amount of time is referred to as flow rate, and it is typically stated as an hourly flow rate. Over time, the word "volume" has been substituted with "flow" or "flow rate." We must define the flow rate as well as the time frame during which it was observed because flow rate changes over time. Assume, for instance, that we saw a rate of 1000 automobiles per hour in 15 minutes. This indicates that we measured the number of vehicles as 250 during a period of 15 minutes and expressed the flow rate as an hourly rate. Existing traffic demand, service volume, capacity, and saturation flow rate are the four most significant flow measuring applications.

2.9 Traffic Volume

Traffic volume is the actual number of vehicles that are seen to pass a specific location on the roadway in a specific amount of time. Vehicles/unit time make up its units. Based on the volume of peak traffic, we determine the width of the road. Studies of traffic volume are carried out to gather information on the volume of traffic that passes through a certain location on a highway facility during a predetermined period of time.

2.10 Headway

The headway between cars in a transportation system is the separation measured in both space and time. The shortest such distance or time that a system may achieve without reducing vehicle speed is known as the minimal headway. Depending on the application, the exact definition varies, but the distance between the front end of one vehicle and the next vehicle behind it, is the one that is most frequently measured. The distance between the cars or the amount of time it will take the trailing vehicle to travel that distance can be used to express it. The vehicles are spaced closer apart when the headway is "shorter." A crucial factor in determining a transportation system's overall route capacity is headway.

2.11 Arterial Road

An arterial road, also known as an arterial thoroughfare, is a high-capacity urban road that, in terms of traffic flow and speed, is below freeways and motorways on the road hierarchy. An arterial road's main purpose is to transport traffic at the highest quality of service between metropolitan centres and from collector roads to freeways or expressways. As a result, numerous arteries have limits on private access or are limited-access roads. Many important roads experience heavy land usage and urban growth due to their relative high accessibility, making them key urban areas.

2.12 Likert Scale

A psychometric scale called a Likert scale is frequently used in studies that use questionnaires. The phrase is considered to be synonymous with rating scale, despite the fact that there are other kinds of rating scales because it is the most generally used method for scaling responses in survey research. Respondents to Likert items rank their level of agreement or disagreement with a set of assertions on a symmetric agree-disagree scale. As a result, the range reflects how strongly they feel about a certain item. Likert scales have applications in business, marketing, statistics, psychology, and the social sciences.

2.13 Saturation Flow Rate (SF)

It is the constant rate at which backed-up vehicles are released from a signalised intersection with a never-ending green light. It is determined by measuring the maximum pace of backed-up vehicles leaving an approach during the green period at the stop line under the prevailing circumstances. It is measurement in PCU/hour of green and is based on the intersection's declared base conditions of traffic, geometry, and control.

2.14 Control Delay

Typical delay a vehicle encounters as a result of signal control. This includes the time wasted from queue moves up, slowing down to a stop, and speeding back up to the target speed. Control lag is measured in seconds per vehicle or seconds per PCU.

2.15 Intersection Capacity

It is defined as the highest volume of traffic that can undertake a certain non-priority movement under the given conditions of traffic flow on all the other approaches. It is determined for each non-priority movement. Generally indicated in PCU/hr.

2.16 Critical Gap

Critical gap is defined as the least gap available in the priority stream of traffic, which is acceptable or satisfactory for a driver undertaking a non-priority movement. It differs between drivers and always lies between the maximum rejected gap and the accepted gap. It is measured in seconds.

2.17 Major and Minor Street

A road with higher priority is termed as major street and road with lower priority is termed as minor street. Hierarchy of road network is considered while classifying a road as major or minor. In the absence of a definite hierarchy, the wider road among the two or the one with the heaviest traffic is taken as the major road.

CHAPTER 3
LITERATURE REVIEW

3.1 General

Level of Service (LOS) is a metric used by transportation planners to gauge how well-run particular transportation facilities—like roads, lanes, intersections, and intersection approaches—are during "peak" traffic periods. LOS describes the facility's operating characteristics in terms of speed, transit duration, manoeuvrability, traffic delays, comfort, and convenience. LOS varies from A (least crowded) to F (most crowded). The differentiation among the levels-of-service A through F is subjective in nature. Here we discuss level of service, LOS in urban areas, LOS as per various versions of HCM, methodology for defining LOS based on HCM (2000), a case study of evaluation on a particular road section, a review of LOS analysis of urban streets and different clustering techniques applicable to determine the ranges of FFS for urban street classes and ranges of ATS for LOS categories. Papers discussing the perceived LOS of a facility and its determination through survey questionnaire from the users is also reviewed.

3.2 Level of Service

The term Level of Service (LOS) has been introduced by the Highway Capacity Manual (HCM) which represents the level of facility a particular user can derive from a road under various operating characteristics and traffic volumes. When a road is carrying traffic in equal volume to its capacity, or say volume to capacity ratio near to one, under ideal traffic and roadway conditions, the operating conditions become poor. Dropping of speed and the frequency of delays or stops mount up. The service which is offered by a roadway to the users can differ under different traffic volumes. The term level of service is defined as a qualitative measure which describes the operational conditions within traffic stream, and their observation by motorists and/or travellers.

The following are the factors which might be considered in evaluating the LOS:

1. Traffic restrictions or obstructions, with important consideration to the frequency of stops made in a kilometre, speed variations and delays incurred.

2. Speed and travel time, comprising the actual travelling speed and the total amount of time spent in traversing a given stretch of road way.

3. Reflecting the road and traffic conditions in as much as they have an impact on the driver's comfort and convenience while driving.

4. Freedom to manoeuvre and the ability to maintain the desired operating speeds. (Babit et al, 2016)

While level of service provides a qualitative assessment of traffic, capacity provides a quantitative one. The road's capacity might remain constant, but the actual traffic rate will vary on different days and at different times during the day. Based on various operating conditions based on v/c ratio and travel speed, HCM describes six levels of service, labelled LOS 'A' to LOS 'F,' which are shown in from Figure 1 to Figure 6. The finest operating circumstances are indicated by a road with LOS 'A,' while the worst operating conditions are indicated by a road with LOS 'F.

i) **LOS A**: With free-flowing traffic and an average vehicle speed of 90% of the free-flowing speed, this grade represents the ideal operating circumstances for a user. For this grade, the volume to capacity ratio is less than 0.125.

ii) **LOS B**: In this grade, users can go at their preferred speed and there is a steady flow of traffic. For this grade, the volume to capacity ratio ranges from 0.125 to 0.276, and the typical speed is between 70 and 80 percent of free flow speed.

iii) **LOS C**: This grade also denotes a steady flow of traffic. The level of comfort gradually declines and the average speed ranges between 50% and 60%. For this grade, the volume to capacity ratio ranges from 0.276 to 0.479.

iv) **LOS D**: This rating suggests that there is a high vehicle density and nearly unstable traffic flow. Vehicles travel at an average speed of 40 to 50 mph. This grade's volume to capacity ratio, which ranges from 0.479 to 0.715, implies poor comfort. The flow is approaching unstable flow.

v) **LOS E**: Given the high vehicle density and the fact that the average vehicle speed has fallen to between 30 and 40 percent. The volume to capacity ratio for this grade ranges from 0.715 to 1.0, which provides passengers with incredibly poor comfort and convenience. The flow is unstable in nature.

vi) **LOS F**: This grade signifies very heavy traffic, and the average speed has reduced to 25% to 35%, indicating very little comfort and convenience for the motorist. For this grade, the volume to capacity ratio exceeds 1.000. Vehicles in a traffic jam represents this condition. (Pala Gireesh Kumar et al, 2020).

Fig. 1. Level of service category A

Fig. 2. Level of service category B

Fig. 3. Level of service category C

[*Source*: Pala Gireesh Kumar et al. (2020)]

Fig. 4. Level of service category D

Fig. 5. Level of service category E

Fig. 6. Level of service category F

[*Source*: Pala Gireesh Kumar et al. (2020)]

3.3 Level of Service in Urban Areas

Urban streets (including arterial and collector streets) are placed below multilane suburban and rural highways in the hierarchy of street transportation infrastructure. The primary determinants of the difference are street function, control circumstances, and the type and level of roadside development. The main purpose of arterial streets is to accommodate longer through trips. However, another crucial role of arterials is to provide access to adjacent business and residential land uses. Within residential, commercial, and industrial districts, collector routes provide both land access and traffic circulation. Urban Street LOS is based on the average through-vehicle travel speed for the segment or for the entire street under consideration (vehicles travelling directly through a street segment and not turning). The primary performance indicator for urban roadways is travel speed. The running times on the urban roadway and the control delay of through movements at signalised junctions are used to calculate the ATS. The fraction of the overall delay for a vehicle approaching and entering a signalised intersection that is due to traffic signal operation is known as the control delay. Initial deceleration, move-up time in the queue, stops, and re-acceleration delays are all included in control delay. The number of lights per kilometre and the intersection control delay both affect the LOS for metropolitan roadways. The LOS can be severely compromised by improper signal timing, inadequate progression, and rising traffic flow. These variables are more likely to affect streets with medium-to-high signal density (i.e., more than one signal per kilometre), and low LOS may be noticeable even before serious issues arise. However, lengthy metropolitan roadway segments with busy intersections can still offer a respectable degree of LOS, even when a particular signalised intersection may be running at a lesser level. (Bhuyan and Rao, 2011)

HCM defines four urban roadway grades (2000). The classes, which are identified by numbers (I, II, III, and IV), showcase various intersections of roadway function and design. Principal arterial and minor arterial are the two subcategories of the functional component. There are four categories for the design element: high-speed, suburban, intermediate, and urban. The computation of a facility's LOS for the immediate or distant future is a frequent use of the LOS analysis. An urban street LOS analysis's planning-level goal is to determine the facility's operating circumstances. Addressing growth management is a crucial application for this kind of analysis. (Das and Bhuyan, 2017)

3.4 LOS in Highway Capacity Manual

The National Academies of Science published the Highway Capacity Manual, which offers principles, rules, and instructions for determining the capacity and level of service of highway facilities. The highway capacity manual's 1965 edition was the first to establish the level of service (LOS) concept for highways (HCM, 1965). Following its inception, there were numerous research on LOS measurement that looked at how users assessed the quality of the road service. The definition of LOS in this version of the manual is based on the combination of travel time and the ratio of traffic flow rate to the capacity of road sections. LOS was described by six classes from "A" to "F," which indicate a range of operating situations. This concept was redefined in relation to several traffic conditions in the 1985 version of the HCM (1985). The measures of LOS adopted in the HCM (1985) include travel speed, traffic flow rate, and traffic density, for each type of road. The LOS is defined as "a qualitative measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to manoeuvre, traffic interruptions, comfort and convenience" in the 2000 version of HCM (2000). According to HCM (2000), LOS is a quantitative stratification of performance measures or measures that represent quality of service (QOS) designated six LOS for each type of facility, from 'A' to 'F', with LOS 'A' representing the best operating conditions and LOS 'F' the worst. However, the 2010 edition of HCM (2010) states that there are numerous techniques to gauge the effectiveness of a transportation facility or service, as well as numerous viewpoints that can be taken into account when determining which measurements to take. Everyone has a different opinion on how a route or service should operate and what constitutes "excellent" performance, including the organisation responsible for maintaining it, drivers of cars, walkers, cyclists, and bus passengers, as well as decision-makers and the general public. Therefore, there is no one correct method for determining and interpreting performance. Classes (A-F) of LOS have not changed since their debut in 1965 up through the 2010 version of HCM, while new criteria have been taken into account when defining LOS. (Bhuyan and Nayak, 2013)

Factors considered to define LOS in various versions of HCM:

- **HCM (1965)** - Travel time and traffic flow (v) to capacity (c) ratio.
- **HCM (1985)** - Traffic flow, travel speed and traffic density.

- **HCM (2000) -** Travel time, travel speed, user's freedom to manoeuvre, comfort and convenience and interruption from traffic. (HCM 2000)
- **HCM (2010) -** No emphasis has been given to a particular measure of effectiveness (MOE) and kept it open for the users to decide based on their own assessment through qualitative measures. (HCM 2010)

3.5 Methodology for Defining LOS of A Road Section

Robin Babit et al. (2016), stated that the slow development of transportation facilities compared to the vehicle volume and population growth rate has resulted in poor operating conditions. Hence defining the LOS of urban street classes are of prime importance. The author explains the steps to be followed for defining the LOS based on HCM (2000).

1. Recognizing the study area.

Identifying the study area where L.O.S must be defined is a prerequisite for identifying L.O.S. The road or segment that will be used to identify L.O.S. is chosen so that it has a minimum length of 3 kilometres. The chosen segment should be broken up into manageable stretches so that the running and delay times at the conclusion of each stretch may be calculated.

2. Finding the peak hour volume and peak hour factor.

It is necessary to conduct a traffic volume count along the selected segments in order to estimate peak hour volume. Both automatic and manual counting techniques can be employed to get the traffic count. People are used in the manual count method to count the traffic, which is recorded. To determine the peak hour factor, traffic counts should be conducted mostly during peak hours. The ratio of the volume happening during the peak hour to the maximum rate flow during a specific time period inside the peak hour is known as the peak hour factor. A 15-minute time frame is typically utilised to estimate flow, and a maximum value equal to the hourly rate is used to estimate peak hour factor.

3. Calculating the Free Flow Speed.

The term "free flow speed" (FFS) refers to the average speed of traffic when volumes are sufficiently low for drivers to be unaffected by the presence of other vehicles and when intersection traffic control (such as a signal or sign) is absent or sufficiently far away to have no bearing on drivers' speed choices. In non-peak hours, or when there are no restrictions prompting vehicles to slow down, the free flow speed is set in the middle of the roadway. Two lines are drawn in the middle of the road block, spaced by, say, 100 metres, to determine the FFS. When a vehicle reaches the first marked line during low density, the stopwatch is started and kept running until the vehicle leaves the second marked line; at that point, it is stopped, and the time is recorded on the diary. As a result, FFS can be calculated by simply timing the time it takes the vehicle to cover the designated distance using a stopwatch. The urban street class and an estimate of the segment's running time are both based on the free-flow pace. Less than 200 vehicles per hour should be moving along the lane when this measurement is made.

4. Categorizing urban street type and class.

The classification of urban street types will be based on information gathered from surveys of the roads and from the functional characteristics of the segment or road. Functional parameters can be used to determine if a street is a primary arterial or a minor arterial as shown in Table 1.

Table 1. Urban Street Based on Functional Parameters

Criterion	**Functional Category**	
	Principal arterial	**Minor arterial**
Mobility function	Very important	Important
Access function	Very minor	Substantial
Points connected	Freeways, important activity centres, major traffic generators	Principal arterials
Predominant trips served	Relatively long trips between major points and through- trips entering, leaving, and passing through the city.	Trips of moderate length within relatively small geographical areas.

[Source: Robin Babit et al. (2016)]

Urban street classification is done based on design category in addition to functional factors. In order to categorise urban streets according to design categories, road surveys are conducted. The road survey includes the posted speed limit, the number of driveways and access points, the number of signals, and other design elements as given in Table 2. A brief examination of the roads taken into consideration will provide an indication of the street's high-speed, sub-urban, intermediate, or urban type for the purpose of classifying urban street type through design specifications. Urban street types will be established using data from table 2 and information gathered from road surveys.

Table 2. Design Parameters for Classifying Urban Street Type

Criterion	**Design Category**			
	High Speed	**Suburban**	**Intermediate**	**Urban**
Arterial type	Multilane divided; undivided or two-lane with shoulders	Multilane divided; undivided or two-lane with Shoulders	Multilane divided or undivided; one- way, two- lane	Undivided one-way, two-way two or more lanes
Driveway/Access Density	Very low density	Low density	Moderate density	High density
Parking	No	No	Some	Significant
Separate left turns	Yes	Yes	Usually	Some
Signals/Km	0.3 – 1.2	0.6– 3.0	2- 6	4 - 8
Speed limit (Km/h)	75 - 90	65 - 75	50 - 65	40 - 55
Pedestrian activity	Very little	Little	Some	Usually
Roadside Development	Low density	Low to medium density	Medium to moderate density	High density

[Source: Robin Babit et al. (2016)]

Urban street class must be determined following the definition of urban street type with functional and design criteria. As illustrated in Table 3, the classes offered in HCM are numbered (I, II, III, and IV) and represent various combinations of street function and design.

Table 3. Urban Street Class Based on Functional and Design Parameters

Design Category	Functional Category	
	Principal Arterial	**Minor Arterial**
High Speed	I	N/A
Suburban	II	II
Intermediate	II	III or IV
Urban	III or IV	IV

[Source: Robin Babit et al. (2016)

5. Calculating running time, delay time and average travel speed

Urban section LOS is derived from field data and is mostly determined by the travel speed along segments. The method of using a floating automobile is the one that is most frequently utilised to collect speed information for the section. The running time and delay time are recorded at predetermined check points by two passengers while the driver operates the vehicle, necessitating a minimum of three people. Either an audio recorder, pen and paper, or a small data recording device can be used to keep track of the passing time. The floating car method has several advantages because it just needs novice technicians and inexpensive tools. It is to be carried out during both peak and nonpeak hours to know the changes in running time, delay time and average travel speed.

6. Analysis of data to finalize the LOS

Based on urban street class and average travel speed, as shown in Table 4 below, urban street L.O.S. is calculated. The average travel speed calculated may not be a suitable indicator of the L.O.S. if the demand volume at any point exceeds the segment's capacity.

Table 4. Urban Street LOS by Class

Urban Street Class	I	II	III	IV
LOS	**Average Travel Speed (Km/h)**			
A	> 72	> 59	> 50	> 41
B	> 56-72	> 46-59	> 39-50	> 32-41
C	> 40-56	> 33-46	> 28-39	> 23-32
D	> 32-40	> 26-33	> 22-28	> 18-23
E	> 26-32	> 21-26	> 17-22	> 14-18
F	≤ 26	≤ 21	≤ 17	≤ 14

[Source: Robin Babit et al. (2016)]

3.6 Case Study of LOS Evaluation

Pala Gireesh Kumar et al. (2020) found the LOS of four different corridors in and around Bhimavaram, Andhra Pradesh to define LOS for different types of roads, in which two corridors fall under the categories of urban roads and two corridors fall under those of rural roads. Andhra Pradesh's Bhimavaram is a town with a large population. 21 metres of section length was taken into account. They sought to assess the amounts of cars in each corridor, the composition of each corridor's traffic during peak and off-peak hours, the average speed of vehicles in each corridor, and finally, the differences in LOS slopes between urban and rural locations. They might also assess the state of these roads so that remedial action could be conducted.

Vehicles were divided into four groups: heavy vehicles, pedestrians, cars/autos, and powered two-wheelers. The V/C ratio and the average speed method were used in this project to define the LOS grades. These two approaches were cited as the most popular and effective ways to define LOS in suburban and rural settings. There were no bus stops, parking spaces, or pedestrian activity along any of the four corridors.

Field research was done manually. For the purpose of gathering volumetric data, the number of passing cars was counted and recorded. Both peak and off-peak traffic data were gathered, and the traffic composition was identified. Using the stop-watch approach, the average journey speed was calculated. Additionally, it was done during peak and off-peak hours. The average speed was then calculated using speed v/s frequency curves, of which Figure 7 provides an example (of corridor-4).

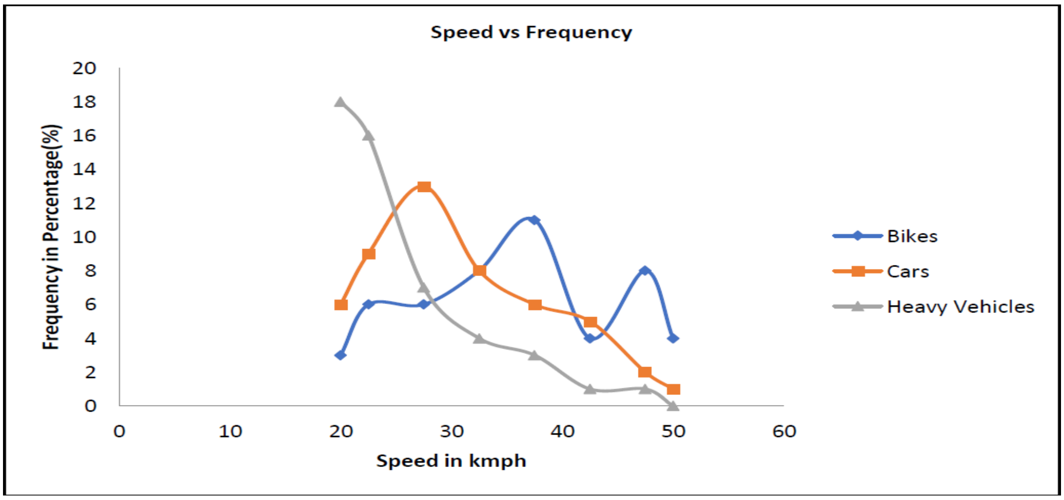

Fig. 7. Average speed of vehicles at corridor-4 in Peak hour

[*Source*: Pala Gireesh Kumar et al. (2020)]

These values of V/C ratio and average travel speed was compared to standard values given in HCM (2000) and the corresponding LOS grades were found out as given in Table 5 below.

Table 5. LOS of Selected Corridors Based on V/C Ratio and Average Speed

Corridor	Speed (Km/h)	V/C ratio	LOS
Corridor 1	31.65	0.48	D
Corridor 2	24.46	0.96	E
Corridor 3	28.51	0.48	D
Corridor 4	25.84	0.73	E

[Source: Pala Gireesh Kumar et al. (2020)]

The authors concluded that the lesser no. of vehicle data was a limitation to obtain better results and thus the result could be improved otherwise.

3.7 Defining FFS Ranges of Urban Street Classes and ATS Ranges of LOS Categories

This section discusses about the various cluster analysis techniques applied by various authors on a large set of Free Flow Speed and Average Travel Speed data collected from a study corridor in Mumbai city. These cluster analysis techniques were applied on free flow speed data to find the FFS ranges of urban street class and on the average travel speed data to find the ATS ranges of LOS categories.

3.7.1 Study corridor

Five important urban road corridors of the city of Mumbai of Maharashtra State, India are selected for their study. Grater Mumbai is an Island city with a linear pattern of transport network having predominant North-South commuter movements. Passengers move towards south for work trip in the morning hours and return towards north in the evening hours. Hence four north-south corridors and one east-west corridor were chosen. Major roads like Eastern express highway extending up to south (Corridor-1), LBS Road extending up to south via Ambedkar Road (Corridor-2), Western express highway extending up to marine drive (Corridor-3), SV road extending up to south via Veer Savarkar Road (Corridor-4) and Versova- Andheri- Ghatkopar- Vashi (VAGV) (Corridor-5) are included.

3.7.2 Data collection

Mid-sized vehicles were the research team's chosen probe vehicle. Trimble Geo-XT GPS receiver was installed in this car, and it was configured to continuously record speed information (at time intervals of one second). Travel time, halted time, travel speeds (instantaneous and average), and different congestion indices were all calculated from the GPS data, which also gave spatial information. They employed three mid-sized automobiles and three drivers on various survey work days in order to obtain unbiased data set.

Details on the inventory of roads made up the first category of data gathered. This study included information on segment length, number of flyovers, lanes, types of medians, pedestrian activity, roadside development, access density, construction activity, speed limit, distinct right turn lane, and access density. The suitable segmentation approach, which is the directional stretch of road section immediately after signalised intersections to the location point immediately after the next signal, was used during the collection of inventory details.

To determine free flow speed, a second kind of study was carried out. The time period during which the traffic volume is less than or equal to 200 cars per lane per hour should be known before starting the free flow speed data collecting. Prior to the collection of FFS, a thorough 24-hour traffic volume count survey was done for that. Data on the amount of traffic were gathered from 45 stations on seven screen lines. For routes entering the study area, traffic volume per lane per hour was determined using survey data. Free flow traffic circumstances (less than 200 vehicles per hour) were discovered to be arriving at 12 a.m., and they last from 1 a.m. to 5 a.m. on all route segments. Therefore, during these hours, free flow speeds for all of these highways were measured using a GPS receiver mounted on a probe car. On a large majority of the observed street segments, the probe vehicle was seen to have maintained free flow speed between 40 and 65 km/h, with only a small number of segments maintaining free flow speed below 40 or beyond 65 km/h.

Congested travel speed was the third category of information gathered. Congested travel speed surveys were done on all corridors in both directions during peak and off-peak hours. At least three and occasionally as many as six trips are covered for each direction of travel and for the different study hours (peak, off-peak, and free-flow). Using Pathfinder version 3.00, data that has been gathered in the field has been transmitted back to the office computer. Using differential correction, field data accuracy was greatly increased.

3.7.3 Clustering techniques applied

3.7.3.1 Fuzzy C- Means (FCM) clustering:

Prasanta Kumar Bhuyan, K.V. Krishna Rao. (2010)

Fuzzy cluster analysis and fuzzy logic are typically only related through the application of the membership coefficient, not the more thorough theory. In their investigation, the FCM clustering algorithm, which was developed by Bezdek and is regarded as one of the most well-liked and reliable cluster analysis or pattern recognition algorithms, was used.

Based on principles, centres are as dissimilar from elements in other clusters as possible and as similar to one another inside a cluster as possible.

3.7.3.2 Hierarchical Agglomerative Clustering (HAC):

Prasanta Kumar Bhuyan and K. V. Krishna Rao. (2011)

Data segmentation, often known as cluster analysis, serves many objectives. All of these methods involve classifying or segmenting a set of objects (also known as observations, individuals, cases, or data rows) into smaller groups or "clusters," where objects assigned to the same cluster are more likely to be related to one another than objects assigned to different clusters. The idea of the degree of similarity (or dissimilarity) between the individual items being clustered is fundamental to all of the objectives of cluster analysis. A statistical technique for locating relatively homogeneous clusters of cases based on measured attributes is called hierarchical agglomerative cluster analysis. Each case is initially placed in a different cluster, which is then gradually combined. At each stage, the number of clusters was lowered until only one cluster was left with.

The statistics toolbox in MATLAB was used in the following three phases to perform Hierarchical Agglomerative Clustering (HAC) on free flow speed data to categorise urban streets into four classes and average travel speeds into six levels of service category.

Step 1: Finding the Similarity between Objects

Step 2: Defining the Links between Objects

Step 3: Creating Clusters

In their study, the cluster function was applied five times; once for the free-flow speed data and four times on the speed data of urban street classes.

3.7.3.3 K-means and K-medoid clustering:

Prasanta Kumar Bhuyan & Kurra Venkata Krishna Rao. (2012)

K-means clustering is one of the most used hard partitioning techniques. It works well when generating a few groups out of a huge number of observations. It requires continuous variables without outliers. The k-means function divides the observed data into k mutually exclusive clusters and outputs an index vector indicating which of the k clusters each observation belongs to. K-means employs an iterative method that seeks to reduce the total distances between each object and the centroid of the cluster. Up until the total can no longer be decreased further, this algorithm shifts objects between groups. However, because we receive different results with randomly selected beginning clusters, k-means does not ensure unique grouping. Only when the initial partitions are reasonably near to the final solutions does the k-means algorithm produce better results. In each cluster, this method aims to reduce the overall distance between the items. There are two stages in the algorithm's progression. By choosing representative objects one at a time until k representative objects are found, an initial clustering is created in the first phase. The first representative object is the one whose sum of differences from all other things is as low as it can be. This typical object is located in the middle of the assortment of things. A fresh object is picked at each succeeding level. Centres for the k-medoid cluster analysis are chosen from the data set itself. If not, k-medoid is identical to the k-means method. These methods typically offer a wide range of statistics that allow for a thorough analysis of the clustering results, especially when used in conjunction with validation parameters. to run a data set using a k-means cluster analysis. The processes below were carried out after selecting the number of clusters ($1<N$) and initialising random cluster centres from the data set.:

Step 1: From a data set of N points, k-means algorithm allocates each data point to one of c clusters to minimize the within-cluster sum of squares:
Step 2: Selecting points for a cluster which are having the minimal distances from the centroid.
Step 3: Calculating cluster centres.
Step 4: Calculating fake cluster centres.
Step 5: Choosing the nearest data point to be the cluster centre.

3.7.3.4 Neural gas clustering:

A. K. Das et al. (2013)

Martinez and Schulzen proposed the neural gas method in 1991. This approach makes it possible to identify a generalisation for a collection of data that is represented as a group of related elements. The algorithm for Neural gas is as follows:

Step1: Initialize the set A to contain N units Ci.

Where A= {C1, C2, ..., Cn}

With reference vectors Wci ε Rn chosen randomly according to expected distribution of 'X' samples. Also initialize the time parameter t as t=0

Step 2: A random input 'X' is provided.

Step 3: Order all elements of A according to their distance to X, i.e., find the sequence of indices (i0, i1, …., iN-1) such that Wi0 is the reference vector closest to X, Wi1 is the reference vector second closest to X and Wik, K=0, ..., N-1 is the reference vector such that k vectors Wj exist with X - Wj < X - Wk. We denote Ki (X, A) the number k associated with Wi.

Step 4: Adapt reference vectors according to ΔWi= e(t). hλ (ki (X, A)). (X-Wi), with the following time dependencies:

λ(t)=λi (1)

e(t)=ei (2)

hλ(k)= (3)

Step 5: Increase the time parameter t:

t=t+1

Step 6: If t<tmax., go to step 2.

3.7.3.5 Divisive Analysis (DIANA):

Vivek Kumar Gope and Prasanta Kumar Bhuyan. (2016)

A hierarchical clustering method called DIANA builds the hierarchy in reverse. It comes close to the Agglomerative Hierarchical Clustering reversal algorithm. All n objects are grouped together into a single sizable cluster. The largest cluster that is still available is divided into two clusters at each succeeding stage until all clusters are eventually made up of a single item. The hierarchy is thus constructed in n-1 steps. All conceivable fusions of two items are taken into account in the first stage of an agglomerative approach, resulting in n (n-1)/2 combinations. There are 2n-1-1 alternatives to divide the data into two clusters when using the divisive approach, which is based on the same theory. In comparison to an agglomerative approach, this figure is significantly higher. To bypass such complex computations, the following steps were done:

Step-1: The DIANA clustering is followed by Agglomerative Hierarchical Clustering up to the cluster contains all the objects. Then the Divisive Analysis Clustering (DIANA) follows the top-down approach assuming it single cluster having level L (0) =n and sequence number m= 0.

Step-2: The most dissimilar pair of clusters in the current cluster is found out; that is (r), (s) in which d [(r), (s)] =min d [(i), (j)], where min is the complete pairs of clusters in the current cluster.

Step-3: The sequence number is incremented in the manner m= m+ 1. The cluster is broken into clusters (r) and (s) to form next cluster to make the level of clustering: L (m1) =d [(r)] and L (m2) = d [(s)].

Step-4: The distance matrix (D) is updated by adding the rows and columns corresponding to clusters (r) and (s).

3.4.3.6 Hard competitive learning (Hardcl) method:

Amit Kumar Das and Prasanta Kumar Bhuyan. (2017)

Step 1: The set C is initialized to contain k (k<<N) units cj: C = {c1, c2, …, ck}, with centre vectors $wcj \in Rd$ chosen randomly from the data set. The iteration counter is set to zero.

Step 2: A pattern xi is drawn from the data set.

Step 3: The winner s (xi): s (xi) = arg min$c$∈C__ xi −wc__ is determined.

Step 4: The centre vector of the winner is moved along the gradient of ___ xi −ws _xi____ toward xi. In case of Euclidean norm this becomes Δws _xi_ = _ t _xi −ws _xi__, where _ t is a suitable chosen learning rate is.

Step 5: t is set as t:t + 1; if t < $t$max, return the loop to step 2.

3.7.3.7 Clustering Large Application (CLARA):

A. K. Das and P. K. Bhuyan (2014)

Kaufman and Rousseeuw created the CLARA algorithm [20]. Partitioning Around Medoids (PAM) technique is used in CLARA clustering. PAM is based on finding k representative objects among the data set's objects. Medoids are the representative objects in the PAM algorithm. Clustering using CLARA is done in two steps. The k-medoid approach is used to first take a sample from a set of data and cluster it into k subsets. The k representative objects come from these k subsets. The nearest of the k representative objects is given to each object that is not a member of the sample. The entire data set has now been clustered. The clustering quality is determined by the average distance between each data set object and its representative object. then randomly. After random samples have been drawn and clustered, the sample which provided the least average distance was selected.

CLARA algorithm:

Step 1. For i=1 to 5, repeat the following steps.

Step 2. Draw a sample of objects randomly from the entire data set, and call Algorithm PAM to find k medoids of the sample.

Step 3. For each object O j in the entire data set, determine which of the k medoids is the most similar to O j. O j denotes other non-medoid objects that may or may not need to be moved, and is not efficient in dealing with medium and large data sets.

Step 4. Calculate the average dissimilarity of the clustering obtained in the previous step. If this value is less than the current minimum, use this value as the current minimum, and retain the k medoids found in Step 2 as the best set of medoids obtained so far.

Step 5. Return to Step 1 to start the next iteration.

3.7.3.8 Genetic algorithm fuzzy clustering:

Smruti Sourava Mohapatra et al. (2012)

In their study, a hybrid algorithm based on fuzzy c-means in conjunction with genetic algorithm (GA) is employed to obtain a nearly optimal solution. This hybrid method can solve the clustering problem more effectively because it combines the global search capabilities of GA and the local search capabilities of FCM. The fuzzy c-means algorithm's local minimum and global minimum frequently diverge. Realizing the search for the global minimum of function J is challenging due to the high volume of calculations involved. For optimization problems, GA that leverages the survival of the fittest produces good results. Although GA cannot promise that a global solution will ever be found, they are effective at doing so in a short amount of time with a "sufficiently good" answer. FCM clustering:

Step 1. Set Algorithm Parameters: c - the number of clusters; m - exponential weight; - Stop setting algorithm.

Step 2. Randomly generate a fuzzy partition matrix F.

Step 3. Calculate the centers of clusters.

Step 4. Calculate the distance between the objects of the X and the centers of clusters. Here X is the observation matrix.

Step 5. Calculate the elements of a fuzzy partition.

Step 6. Check the condition. If "yes", then go to step 7, otherwise go to step 3.

Step 7. End.

3.7.4 Cluster validation parameters

Verifying the accuracy of clustering results is the focus of cluster validity. The ideal number of clusters is obtained using validation procedures. The number of groups a data set needs to be divided into is shown by the optimal number of clusters. The most typical use of cluster validity has been to determine the appropriate number of clusters in a data collection. These variables are solely used to validate statistical clusters; they are not utilised to validate any models. The validation parameters used in the above clustering techniques are grouped in Table 6.

Table 6. Different Clustering Techniques and Validation Parameters Used

Sl No.	Clustering Technique	Validation Parameters
1	Fuzzy C-Means (FCM)	Partition coefficient, Classification entropy, Partition Index, Separation Index, Xie and Beni's Index, Dunn's Index.
2	Hierarchical Agglomerative Clustering	Silhouettes.
3	K-means and K-medoid	Partition Index, Separation Index, Xie and Beni's Index, Dunn's Index, Silhouettes.
4	Neural gas	Duda Index, McClain Index, PtBiserial Index, Gplus Index, Tau Index, Ratkowsky Index.
5	Divisive Analysis (DIANA)	Silhouettes.
6	Hard competitive learning (Hardcl)	Duda Index, McClain Index, PtBiserial Index, Gplus Index, Tau Index, Ratkowsky Index.
7	Clustering Large Application (CLARA)	Calinski-Harabasz Index, Connectivity Index, Avg. Proportion of Non-overlap (APN) Index, Avg. Distance (AD) Index, Avg. Distance b/n Means (ADM) Index, Figure of Merit (FOM) Index.
8	Genetic algorithm fuzzy	C-Index, Weighted inter-intra Index, Hargitan Index, R-squared Index, Krzanowski-Lai (KL) Index.

[Source: P.K. Bhuyan et al., (2015)

3.8 LOS Based on User Perception

3.8.1 Urban roads

3.8.1.1 LOS based on user perception

V. Aparna & S. Salini (2019) stated that Level of Service (LOS) is a major scale of performance of highways facilities. It is a fundamental consideration in important choices about the use of public finances. The degree to which users approve of the facility is shown by how they perceive the LOS. Since there are many options accessible and there is a strong mix of traffic, especially during rush hours, urban road users choose their routes based on their own assessment of the service level given by various roadways. Their study evaluated how users perceived the length of sight (LOS) of urban roads by calculating the LOS score they arrived at based on their own perceptions of travel speed, road surface quality, and delay, as well as the relative importance of each of these measurements. Using fuzzy c means clustering, the percentage LOS scores derived from their responses were then divided into six separate LOS groups. The boundary values generated from the clustering were used to evaluate the average LOS scores of the routes under consideration and select the appropriate LOS categories. The user-perceived LOS was found to be lower than the IRC LOS category. It has been determined that percentage speed reduction (PSR) from free flow speed (FFS) is a superior performance metric for assessing line of sight (LOS) under circumstances of heterogeneous traffic flow. Using the K means clustering approach, PSR of discrete vehicles from FFS were estimated and divided into six LOS groups. It was discovered that the user's perceived LOS and the LOS obtained from PSR were comparable.

3.8.1.2 Modelling user response pattern to find LOS

Suprava Jena, Debu Kumar Pradhan, Prasanta Kumar Bhuyan (2017) presented a qualitative method to assess the quality of the transportation service provided under the circumstances of the heterogeneous nature of traffic flow based on the reaction patterns of vehicle users. Using data sets gathered through a survey questionnaire from 34 urban street segments of three medium-sized Indian cities, the Automobile Users' Satisfaction Index (AUSi) was created. In the traveller's intercept survey, about 977 responses were gathered from a suitable merge of gender, age, driving experience, etc. In order to evaluate the combined process of measuring the service quality and the degree of driver satisfaction, the Rasch Model (RM) was utilised to identify a set of statistical parameters. With the aid of six-dimensional variables including roadway geometry, traffic facilities, traffic management, pavement quality, safety, and aesthetics, their research understood the multidimensional user perception traits to estimate AUSi. Every user and each dimensional element received a standard score value from RM coupled with a common continuum. This improved the ability to distinguish between harder qualities that serve satisfaction and the responses of various types of transportation. The key findings of their research were that respondents reported being less satisfied, particularly as a result of the lack of segregated lanes for bike/bus pull-out, inadequate parking facilities, and disruptions from non-motorized vehicles, public transportation, or wayside business activity. For each street section, they used Fuzzy C-Means (FCM) clustering to divide the AUSi scores into the six vehicular LOS categories (A-F). They used a significant match between expected Automobile user LOS (ALOS) categories and the same user's perceived Overall Satisfaction (OS) scores for fourteen randomly selected street segments to verify the model. Their prediction model, which makes use of language information and actual driver concerns on the quality of services, is the first of its kind in the context of diverse traffic flow state. They argued that their method will assist decision-makers with persistent planning and constructing of road networks on a preferential basis by being more dependable than conventional models.

3.8.2 Signalized intersections

3.8.2.1 Perceived LOS at signalized intersections

Darshana Othayoth, K.V. Krishna Rao & B.K. Bhavathrathan (2020) stated that the Highway Capacity Manual (HCM) approach for determining the LOS at signalized crossings uses control delay as the measure of efficacy and leaves out the users' perceptions. Since LOS represents the degree of customer satisfaction, it is crucial to factor in users' perspectives. This becomes important since consumers at signalized intersections come from all over the world. They attempted to investigate how a user's vehicle type affected the perceived LOS at these intersections in their article. They did not take into account the perceptions of pedestrians or other non-motorized users in their study. 8500 users who were travelling in motorized two-wheelers, three-wheelers, vehicles, and buses contributed responses to the database. These statistics were gathered from 15 signalized crossings in India. From this database, they created aggregate and disaggregate ordered probit models for perceived LOS. At the aggregate level, the model was a thorough user-judged LOS without any distinction for the user's vehicle type. They came to the conclusion that in addition to the perceived waiting time, other elements such as the quality of the road surface, the visibility of the traffic signal from the line, the presence of signs and road markings, the presence of pedestrians and large vehicles, obstructions, and aesthetics also play an important role in determining how far away the user perceives the line of sight. Their conclusions spotlighted the importance of integrating qualitative factors in the analysis of LOS besides the traditional delay measurement.

3.8.3 Roundabouts

3.8.3.1 Driver's perception of quality of service

Efterpi Damaskou, Ioannis Karagiotas, Maria Perpinia, and Fotini Kehagia (2019) stated that modern roundabouts are being accepted more widely because of their superiority in terms of geometrical and operational characteristics that increase their traffic capacity, significantly reduce delays, and improve safety, which benefits the users. When compared to conventional signalised intersections, these structures outperform them in terms of both economic and environmental benefits. It has been established what Level of Service (LOS) and Quality of Service (QoS) notions are. While LOS measures a facility's ability to handle traffic and is calculated using specific procedures, QoS assesses how well a transportation facility is operating based on how its customers see it. They provided a QoS description of roundabouts in their study. In order to acquire information, they conducted a questionnaire study among Greek roundabout users. In order to learn more about the factors that affect drivers' pleasure while navigating a roundabout, researchers in Greece performed a questionnaire survey of those who utilise roundabouts. Their research showed that a variety of factors, such as the presence of on-street parking, lightning, and clear visibility of road signs, affect how well service is perceived at roundabouts in both urban and rural areas.

3.9 Findings

- The FFS ranges for different urban street classes and the ATS ranges for different LOS categories are found to be lower than those suggested by HCM-2000.
- Good LOS can't be expected from urban street segment for which physical and surrounding environmental characteristics are not good.
- It is important to integrate qualitative factors and user perception in the analysis of LOS besides the traditional modes of measurement.

3.10 Summary

- Here we discussed the concept of LOS, LOS in urban areas, LOS characteristics in various versions of HCM, the methodologies of LOS evaluation based on HCM (2000), a case study of evaluation on a particular road section, a review of LOS analysis of urban streets and different clustering techniques applicable to determine the ranges of FFS for urban street classes and ranges of ATS for LOS categories. It was found that determination of LOS in urban areas is very much different from the concept applied in rural areas or uninterrupted roads. Rural LOS is based on density, flow, space headway etc. while urban street LOS is based on average travel speed, delay time, running time and urban street type and class.
- LOS is found to be low for the test section in Andhra Pradesh and some remedial measures were given in order to increase its Los grades towards better satisfaction of traffic conditions.
- It was found that with the application of an intelligent transportation system, the LOS of urban streets can be analyzed more dynamically. The free flow speed ranges for different urban street classes and average travel speed ranges for different LOS categories are found to be lower than that suggested by HCM 2000. It was evident that good LOS can't be expected from urban street segment for which physical and surrounding environmental characteristics are not good.
- The methodology to characterize level of satisfaction of road users using hierarchical fuzzy inference system (HFIS) by Suprava Jena et al. (2016) offers unique and significant approach to define service quality provided by the transportation infrastructure. It may defeat the constraints of customary delay-based methods to some extent.

- Studies on user perceived LOS of traffic facilities highlighted the importance of integrating user's perception on several qualitative and quantitative parameters in to the determination of LOS of a facility. This will assist decision-makers with persistent planning and constructing of road networks on a preferential basis by being more believable than conventional models.

3.11 Gaps Identified

- The LOS estimation procedure adopted in the previous studies were based on HCM 2000, which was formulated for homogenous lane-based traffic conditions. Hence it is not appropriate for the heterogenous non-lane-based traffic conditions prevailing in India.
- No study has been undertaken to evaluate LOS based on Indo HCM standards for heterogenous traffic conditions.
- Difference of LOS for the same facility under the different LOS ranges of homogenous and heterogenous flows has not been analyzed.
- Researches regarding measurement of perceived LOS of a facility by the user and comparison of the actual perceived LOS are scarce.

CHAPTER 4

METHODOLOGY

4.1 General

Based on the procedure for LOS evaluation described in Indo HCM 2017. Appropriate for the highly heterogenous nature of traffic in Indian conditions. LOS is evaluated for 2 midblock sections, one signalized intersection and an unsignalized intersection.

4.2 Midblock Section

Midblock section is that section of the urban road which is fairly away from any upstream or downstream intersection so that the vehicle movement is not influenced by the control mechanism and the vehicles are in a normal cruising mode.

4.2.1 Basis for choosing of standard road segment

For the purpose of traffic flow recording, urban road segment of length 50 to 75 meters, also known as trap are selected. The selected segment shall adhere to the following conditions:

- It should be part of an urban road section situated in a plain terrain void of any curves.
- It should be lacking wayside frictions such as the presence of on-street parking, bus stops and access points.
- There should be crossing/pedestrian motion on the street and allows ingress to adjoining properties, side roads etc.
- Should be placed 500 meters away from the upstream intersection to make sure that vehicles are in a cruising mode.

Any segment of urban road fulfilling the prescribed norms is considered as a standard road segment. (Indo HCM 2017)

4.2.2 Passenger car unit value

Cars, buses, trucks, motorized two-wheelers, auto rickshaws, buses, light commercial vehicles, large commercial goods vehicles (such two axle and multi-axle trucks), tractors with trailers, bicycles, cycle rickshaws, animal-powered carts, and other vehicle types make up India's traffic stream. The maneuverability and speed characteristics of these vehicles vary. On Indian urban roadways, more than a dozen different vehicle kinds are seen, but the make-up of traffic differs from region to region. While an auto rickshaw's size is practically identical to that of a tiny automobile, the latter can accelerate more quickly than the former. However, two-wheelers offer exceptional steering and acceleration capabilities. The movement of traffic is a highly complex phenomenon as a result of all these combinations in a mixed traffic environment. In light of the aforementioned, it has been decided that the Passenger Car Units (PCUs) will be used to express the flow in a single unit. Using the dynamic PCU technology, PCUs for the automobiles operating on Indian roads have been established. In the dynamic PCU approach, the PCU of the subject vehicle is calculated as the proportion of the ratio of subject vehicle's speed to that of a standard vehicle and ratio of its plan area to that of the standard vehicle. The term "standard vehicle" refers to car, and the typical plan area of cars is used as the standard vehicle's plan area. (Indo HCM 2017)

The recommended PCU values based on the aforementioned concept are shown in Table 7. One can select the median PCU values for divided and undivided roads for the purpose of research and planning. (Indo HCM 2017)

Table 7. Suggested PCU Values for Divided and Undivided Urban Roads

Sl No.	**Vehicle Type**	**Undivided roads**		**Divided roads**	
		Range	**Median**	**Range**	**Median**
Motorized Traffic					
1.	Two-Wheeler (TW)	0.10 - 0.31	0.20	0.10 – 0.45	0.22
2.	Auto rickshaw (Auto)	0.33 – 2.65	0.73	0.38 – 2.11	0.90
3.	Car	1.00	1.00	1.00	1.00
4.	Bus (B)	1.79 – 6.5	3.77	1.99 – 6.00	4.60
5.	Mini Bus (MB)	1.36 – 3.11	1.80	1.62 – 4.10	2.07
6.	Light Commercial Vehicle (LCV)	2.10 – 3.49	2.30	2.10 – 4.50	2.38
7.	Two/Three Axle Truck	2.70 – 4.81	3.70	2.70 – 7.50	3.90
8.	Multi Axle Truck	-	-	3.30 – 7.90	5.90
9.	Tractor Trailor Combo.	-	4.50	2.51 – 5.89	5.40
Non-motorized Traffic					
10.	Bicycle	0.34 – 0.50	0.39	0.30 – 0.80	0.42
11.	Cycle Rickshaw	-	1.80	0.88 – 3.16	2.04

[Source: Indo HCM (2017)]

4.2.3 Methodology

The overall procedures to be undertaken to compute the LOS are shown in Figure 8.

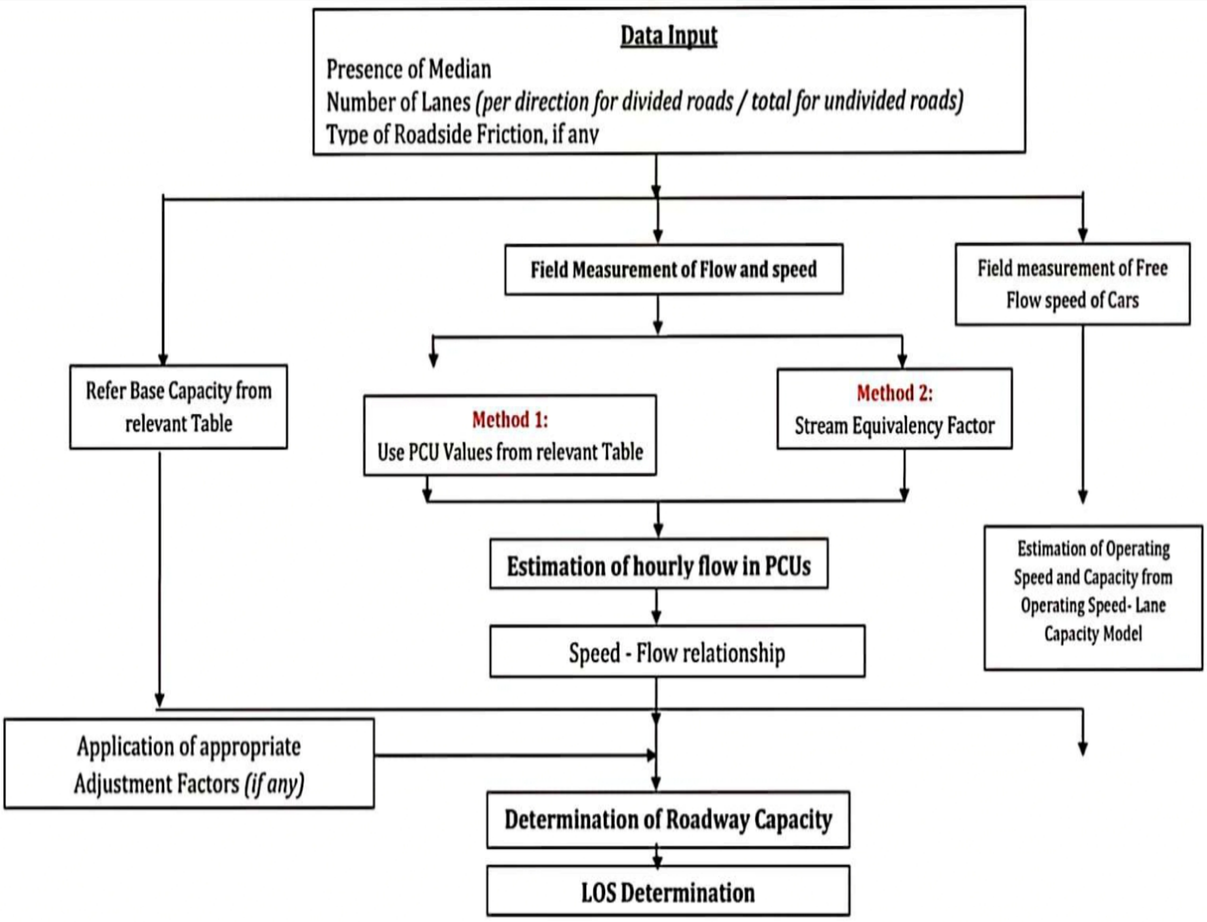

Fig. 8. Methodology for the Determination of LOS of Urban Roads

[*Source*: Indo HCM (2017)]

4.2.3.1 Data input

Data input includes presence of median, no. of lanes, 24-hour traffic flow recording of the subject midblock section to determine the peak hour and hours of free flow condition. This is done by using videography technique or any other suitable techniques.

4.2.3.2 Determination of free flow hour and peak hour

The video graphic data collected is played on a computer to extract the traffic volume data on an hourly basis. This traffic volume is converted into equivalent PCU by using the table provided in the later section. This volume data is analyzed to determine the peak hour and free flow hour. Peak hour indicates the hour during which the heaviest traffic flow occurs in terms of PCU. It usually occurs during the morning or evening rush hours. Free flow hour is the hour during which the flow is less than 450 vehicle per hour [xx]. Vehicles can move freely without any interruption from other traffic or controls during this condition.

4.2.3.3 Measurement of free flow speed and average travel speed

Once the free flow hours and peak hour are determined, vehicle speed data is collected from the field. This is achieved by video taping a specific length of the road segment called trap length, during the peak and free flow hours. The time taken by each vehicle to traverse this specific trap length is then extracted from the video data by using a stop watch. From the known data of length and time, we can determine the speed of each vehicle. The harmonic means of the speed values observed during peak hour is considered as ATS, while the harmonic means of the speed values observed during free flow hours is taken as FFS.

4.2.3.4 Determination of level of service

LOS represents the qualitative aspect of the road segment. Actual flow for a particular road facility will vary based on the time of day. The goal of LOS determination is to correlate the traffic service level with a specific traffic flow rate. It is a term that describes a number of operational circumstances on a certain kind of facility. Under ideal circumstances, speed is considered to be the main element affecting the LOS of an urban road segment. In the current study, stream speed as the percentage was employed as the fundamental parameter for estimating LOS. The suggested LOS for the range of average travel speed in percentage of free flow speed are presented in Table 8.

Table 8. LOS of Two-lane Undivided Urban Roads based on V/C Ratio and Stream Speed in % of FFS

Level of Service	ATS in percentage of FFS
A	≥ 89
B	88 – 55
C	54 – 21
D	20 – 12
E	11 – 6
F	< 6

[Source: Indo HCM (2017)]

4.3 Signalized Intersection

Signalized intersections are intersections which work with the aid of a traffic signal. The right-of-way is allocated at a time to a single movement or a group of movements. In an ideal signalized intersection, the time share allocated to each movement reduces the travel time and delay and/or the stopping frequency while traversing the road network and allot the capacity ideally.

4.3.1 Base intersection

An intersection is recognized as a base intersection if it satisfies the following situations:

- Uniform approach width reaching at the stop line.
- No bus stop in the neighbourhood (within 75 m) from the closest stop line of the intersection.
- Negligible pedestrian movement, or there is a separate phase for pedestrian crossing.
- No longitudinal gradient for all the approaches.
- Through vehicles are not obstructed by right turning vehicles while utilizing the same approach awaiting their phase.

If the considered intersection does not confine to the stated conditions, then adjustment factors are to be applied for the changes in base characteristics. (Indo HCM 2017)

4.3.2 Methodology

The procedure adopted for the assembling of field data succeeded by the calculation of capacity and LOS analysis of signalized intersections are shown in Figure 9. The saturation flow can be computed from the field following the procedure prescribed or by utilizing the saturation flow model shown in Indo HCM 2017. Passenger Car Unit (PCU) values for transforming the detected vehicle classes into corresponding equivalent passenger cars are given. The computed base saturation flow is modified by multiplying with applicable adjustment factors to obtain the saturation flow happening at the current geometric, traffic and control characteristics. This saturation flow, effective green time and the cycle time are then used to compute the capacity of each approach and that of the total intersection in general. Control delay is defined as the key factor for evaluating the LOS of signalized intersections. The control delay can be calculated utilizing the calibrated delay model provided or by direct measurement of the same from the field using the methodology mentioned. The stopped delay obtained in the field is transformed into control delay utilizing the provided conversion factors. (Indo HCM 2017)

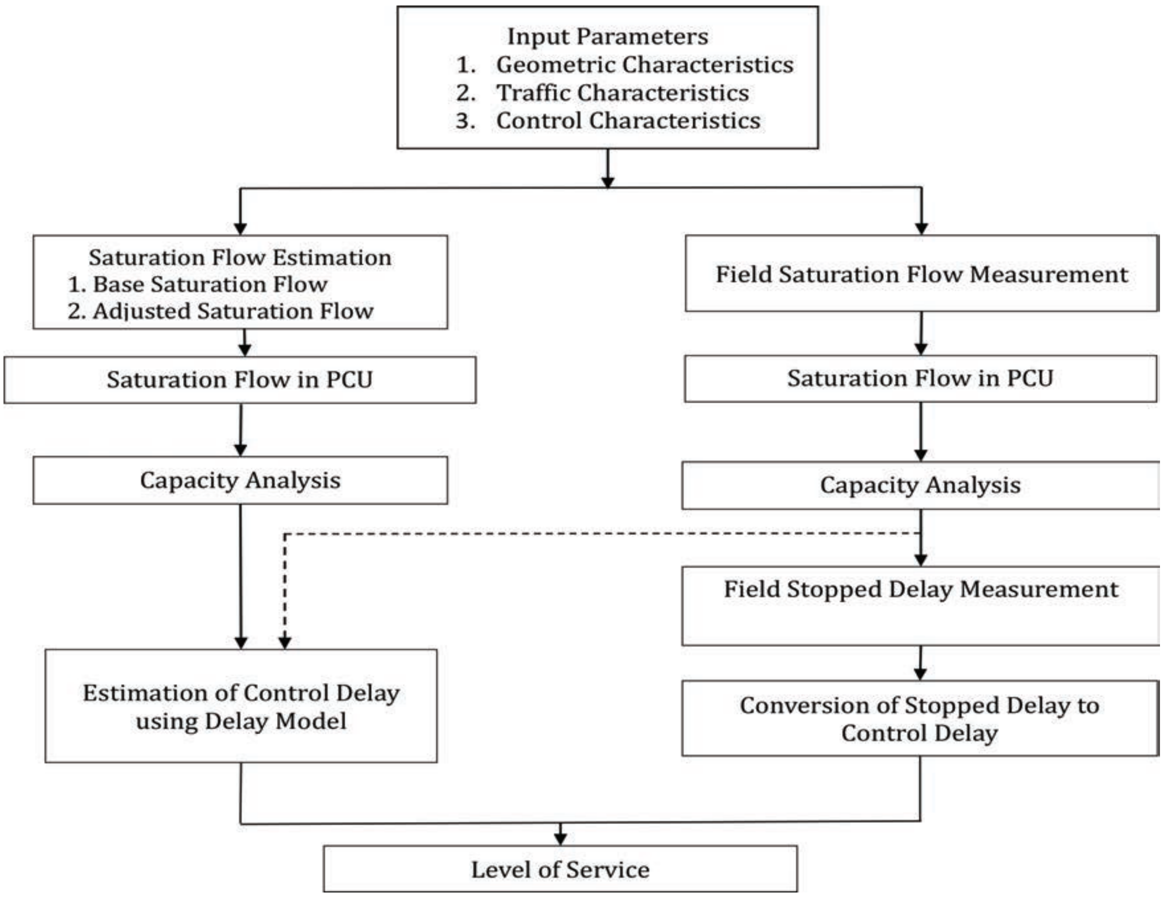

Fig. 9. Methodology for Estimation of Capacity and LOS for a Signalized Intersection [*Source*: Indo HCM (2017)]

4.3.2.1 Geometric characteristics

Geometric Characteristics includes identifying the type of intersection, approach width ‘w’ in metres. Presence of unique lanes for an exclusive right turning phase or free left turn and presence of bus bays or curb side bus stops are also examined.

4.3.2.2 Traffic characteristics

4.3.2.2.1 Traffic volume (V)

The traffic volume of each movement on each approach of the intersection is collected by means of a classified turning movement count during the peak hour. This categorized turning vehicle counts are changed into equivalent PCU utilizing the values provided.

4.3.2.2.2 Passenger Car Unit (PCU) values

For the calculation of capacity and LOS of signalized intersections, the traffic flow recorded at a signalized intersection is to be categorized into suitable vehicle classes and the volume of each vehicle type is to be converted into equivalent volume of PCU. Saturation flow has been applied as the foundation for getting the PCUs of all types of vehicles. The concept is to get the constant value for the saturation flow when vehicle volumes with different compositions are converted into equivalent passenger car volumes using these PCUs.

The PCU values to be used is given in Table 9. These values are commonly applicable, given that the proportion of heavy vehicles are less than 15% of the total traffic volume of the approach considered (Indo HCM 2017). The data regarding the number of buses stopping during the peak period within 75 m locality of the approach stop line (upstream or downstream) is required to modify the base saturation flow to accommodate the effect of obstruction to flow of traffic by them.

Table 9. Passenger Car Unit Values for Signalized Intersections

Vehicle Type	PCU
Two Wheelers (TW)	0.4
Auto rickshaws (Auto)	0.5
Passenger Cars	1.0
Light Commercial Vehicles	1.1
Heavy Goods Vehicles	1.6
Bus	1.6
Bicycle	0.3
Cycle rickshaw	1.8
Hand / Animal Drawn Cart	4.0

[Source: Indo HCM (2017)]

Number of buses stopping at intersection during the peak hour, presence of approach flare resulting in expected early discharge of vehicles causing initial surge and blockage of through vehicles by static right turning vehicles expecting their turn are also needed to be noted down.

4.3.2.3 Control characteristics

Control characteristics such as total cycle time ‘C’, green time ‘G’, change and clearance interval ‘Y’ of the intersection are recorded and a phase plan is created based on it. The analysis period ‘T’ is generally 15 minutes, i.e., T = 0.25 h.

4.3.2.4 Estimation of saturation flow

It has been identified that there is a fine correlation between the unit base saturation flow (USFo) and the width of the approach, w. Unit saturation flow is the saturation flow per unit width of approach. As the approach width of the base intersections varies between 7 m and 10.5 m, the relation provided is only valid within this range. The same is presented in below equation. (Indo HCM 2017)

$$\text{USFo} = \begin{cases} 630; & for \quad w < 7.0\ m \\ 1140 - 60w; & for \ \ 7.0 \leq w \leq 10.5\ m \\ 500; & for \quad w > 10.5\ m \end{cases}$$

where,

USFO = Unit base saturation flow rate (in PCU / hour / m)

w = effective width of approach in meters (m).

The actual saturation flow of the approach of the intersection considered is then computed as shown in below equation.

$SF = w \times USF_0 \times f_{bb} \times f_{br} \times f_{is}$

where,

SF = Existing saturation flow rate in PCU/hour.

w = Effective width of the approach in ‘m’ used by the movement group.

USF_o = Unit base saturation flow rate.

Fbb = Adjustment factor for bus blockage due to curbside bus stop.

Fbr = Adjustment factor for blockage of through vehicles by standing right turning vehicles waiting for their turn.

Fis = Adjustment factor for the initial surge of vehicles due to approach flare and anticipation effect.

Alternately, one can measure the saturation flow from the field other than computing the saturation flow using the given model.

4.3.2.5 Estimation of capacity and V/C ratio

4.3.2.5.1 Capacity

The capacity (C) of a movement group of an approach can be computed as given in below equation. (Indo HCM 2017)

$$C_i = SF_i \left(\frac{g_i}{CY_{Time}}\right)$$

where,

C_i = Capacity of movement group ‘i’ in PCU/hour.

SF_i = Existing saturation flow of the movement group in PCU/hour, after adjustments.

g_i = Effective green time for movement group ‘i’ in seconds.

CY_Time = Overall Cycle time in seconds.

4.3.2.5.2 Volume/Capacity ratio

The volume to capacity (v/c) ratio or degree of saturation (X) for a movement group of an approach can be calculated as shown below. (Indo HCM 2017)

$$X_i = (\frac{V}{C})_i = \frac{V_i}{SF_i\ (\frac{g_i}{CY_{Time}})} = \frac{V_i * CY\_Time}{SF_i * g_i}$$

where,

X_i = Volume to capacity ratio or degree of saturation for movement group ‘i’.

v_i = Volume of movement group ‘i’.

c_i = Capacity of movement group ‘i’ in PCU/hour.

SF_i = Existing saturation flow of the movement group in PCU/hour, after modification.

g_i = Effective green time for movement group ‘i’ in seconds.

CY_Time = Overall cycle time in seconds.

The critical volume to capacity ratio of the intersection can be computed utilizing the equation shown below. (Indo HCM 2017)

$$X_I = \sum \left(\frac{V}{SF}\right)_{ci} (\frac{CY_{Time}}{CY_{Time} - L})$$

Where,

X_I = Critical volume to capacity ratio for the intersection.

$\sum \left(\frac{V}{SF}\right)_{ci}$ = Summation of flow ratios for all critical movement groups ‘i’.

CY_{Time} = Cycle length in seconds

L = Total lost time per cycle

4.3.2.6 Calculation of delay

4.3.2.6.1 Control delay model

The control delay consists of three constituents:

d1: Uniform delay, the portion of delay when vehicles accumulate at a deterministic uniform rate.

d2: Incremental delay, the portion of delay that accounts for random nature of arrivals.

d3: The portion of delay which accommodates for the existence of initial queue before the beginning of period of analysis. (Indo HCM 2017)

Control delay is calculated as given in below equation.

d = 0.9 * d1 + d2 + d3

where,

d = control delay in seconds/PCU

$$d_1 = 0.50C \frac{(1 - \frac{g}{CY_{Time}})^2}{[1 - \frac{g}{CY_{Time}} \min(X, 1)]}$$

$$d_2 = 900T\,[(X - 1) + \sqrt{(X - I)^2 + \frac{4X}{C_{SI}T}}\ ]$$

$$d_3 = \begin{cases} 0, Q_b = 0 \\ \frac{1800 Q_b\,(1 + u)t}{C_{SI}T}, & Q_b \neq 0 \end{cases}$$

$$t = \begin{cases} 0, & Q_b = 0 \\ \min\left(T, \frac{Q_b}{C_{SI}[1 - \min(1, X)]}\right), & Q_b \neq 0 \end{cases}$$

$$u = \begin{cases} 0, \quad t < T \\ 1 - \dfrac{cT}{Q_b[1 - \min(1, X)]}, \quad otherwise \end{cases}$$

Where,

g = Effective green period in seconds.

CY_Time = Overall cycle time in seconds.

T = Analysis period in hours.

X = Degree of saturation.

Qb = Initial queue in PCU at the start of analysis period 'T'.

t = Duration of the demand met during the analysis period 'T' in hours.

u = Demand parameter.

C_{SI} = Capacity of the candidate signalized intersection in PCUs/hour.

4.3.2.6.2 Intersection delay

Intersection delay can be computed as the weighted average delay for each approach as shown in the below equation. (Indo HCM 2017)

$$d_I = \frac{\sum d_A \times V_A}{\sum V}$$

where,

d_I = Intersection delay in seconds.

d_A = Average control delay for a specific approach 'A' in sec/PCU.

V_A = Volume of a specific approach 'A' in PCU/ hr.

V = Total volume of the intersection in PCU/ hr.

Control delay can also be obtained from the field, apart from calculating it using the provided control delay model.

4.3.2.7 Estimation of level of service

Level of Service (LOS) is determined based on the control delay encountered as well as volume to capacity ratio of the candidate intersections considered in the study and the same are discussed in the succeeding sections. (Indo HCM 2017)

4.3.2.7.1 LOS based on control delay

The control delay is recognized as the service characteristic for the evaluation of LOS at signalized intersection. As the time wasted at the intersection expecting the green signal appeared as the most important factor from the user point of view, control delay is selected as the appropriate measure for deciding the LOS. The control delay and the corresponding LOS is given in Table 10.

Table 10. LOS based on Delay Criteria for Signalized Intersections

LOS	Control Delay (in seconds/PCU)
A	< 20
B	20 – 40
C	40 – 65
D	65 – 95
E	95 – 130
F	> 130

[Source: Indo HCM (2017)]

4.4 Unsignalized Intersections

4.4.1 Introduction

An unsignalized intersection is void of any signal or manual control and also any central island. It is configured when two roads meet each other at grade. One of them is normally deputed as major road (the road which is wider among the two or which bears larger volume of traffic) and the other one as minor road. If traffic on the minor road is regulated by STOP signs, the intersection is labelled as Two-Way Stop Controlled (TWSC). If STOP signs are shown on every approach of the intersection, it is known as an All-Way Stop Controlled (AWSC) intersection. But no distinction is usually observed in this regard due to poor implementation of traffic rules and poor knowledge about priority order among road users in India. An unsignalized intersection may be three-legged, four-legged or multi-legged type.

4.4.2 Base intersection

An unsignalized intersection is considered as standard/base intersection if it confines to th following nature:

- Number of intersecting approaches = 3 or 4
- Intersecting angle is 90 degrees with a compromise of +/- 10 degrees.
- Major road is 2-lane or 4-lane.
- Existence of non-motorized traffic, on-street parking, wayside vendors or any other activities requiring land space inside 75 m from the centre of the intersection is negligible.
- Gradient of approaches are zero.
- Availability of secure stopping sight distances.
- Speed breakers inside 75 m from the centre of intersection is not present on any approach. (Indo HCM 2017)

If any intersection does not confine to the above stated nature, then those intersections are to be termed as non-base and modification factors are required to be put in for difference from the standard conditions.

4.4.3 Methodology

Capacity calculation of an unsignalized intersection is dependent on the acceptance of gap by minor street vehicles. Gap acceptance theory is basically reliant on value of critical gap. Hence, a procedure known as Occupancy Time Method (OTM) has been employed for the estimation of the same. This method also includes real driver conduct noticed at unsignalized intersections to a greater extent. It also grounds for the genuine clearing nature of the conflict area and the traffic communication happening within the conflict area.

The procedure given in this section determines the capacity of right turn from major street, right turn from minor street and through movement on minor street. The methods to be pursued for the determination of capacity and LOS of a representative unsignalized intersection are given in Figure 10.

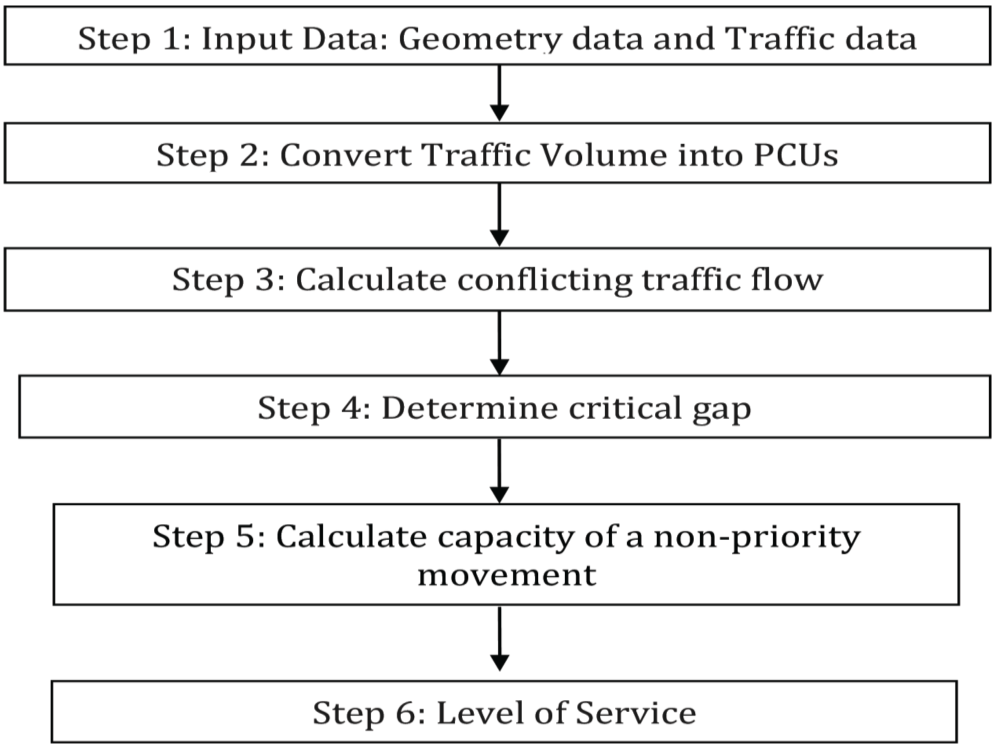

Fig. 10. Suggested Methodology for Finding LOS of Un-Signalized Intersection [*Source*: Indo HCM (2017)]

4.4.3.1 Input data

This step includes data collection of two types i.e., geometry data and traffic data. Data regarding the geometry include no. of lanes, lane width, whether divided/undivided and intersecting angle. Data regarding the traffic consists of classified traffic volume count during the peak hour at various movements of the intersection. (Indo HCM 2017)

4.4.3.2 Convert traffic volume into PCU

Traffic volume at each turning movement happening at the given intersection is to be transformed into corresponding number of passenger cars utilizing the PCU values provided in Table 11.

Table 11. Suggested Passenger Car Units

Vehicle Type	**PCUs**	
Motorized Two Wheelers	0.48	Through movement on major
	0.34	All other movements
Auto rickshaw	0.98	
Small / Standard Cars	1.00	
Big Cars and Vans	1.29	
Light Commercial Vehicles	1.70	
Buses	2.29	
Two / Three Axle HCVs	2.38	
Multi Axle HCVs	3.06	
Tractors	1.62	
Tractors with Trailor	3.13	
Cycles	0.42	
Cycle rickshaws	1.29	
Animal Drawn Carts	3.85	

[Source: Indo HCM (2017)]

4.4.3.3 Calculate conflicting traffic flow rates

Any subject movement dividing the right of way with movement of higher priority is considered as conflicting flow for that movement. Movement priority rules are hardly obeyed in India. Priority ranking is shown in Table 12. Therefore, lower priority movements may create obstructions to higher priority movements. Hence lower priority movement is also appraised while computing conflicting flow rate. Vehicles performing a certain movement may be needed to intersect many streams and join with the expected stream of traffic. In India, the conventional traffic functioning at uncontrolled intersection in India recognize merging to be a simple function and consequently left turning movements from major and minor roads do not counter much obstruction from other streams of traffic as the approaches are generally channelized for such movements. Process of gap acceptance is lacking for these movements and hence the capacity analysis become irrelevant for such movements. (Indo HCM 2017)

The impact that a certain movement cause on the subject vehicle differs with the type of movement. For multilane streets, turning movement join into the closest lane and only have to bear conflict from the traffic on that specific lane. Therefore, the donation to conflicting traffic is from the traffic flow on that specific lane only. Similarly, the unusual nature of traffic in various streams imparts various amounts of conflicts. The numbers allotted to each movement are shown in Figure 11.

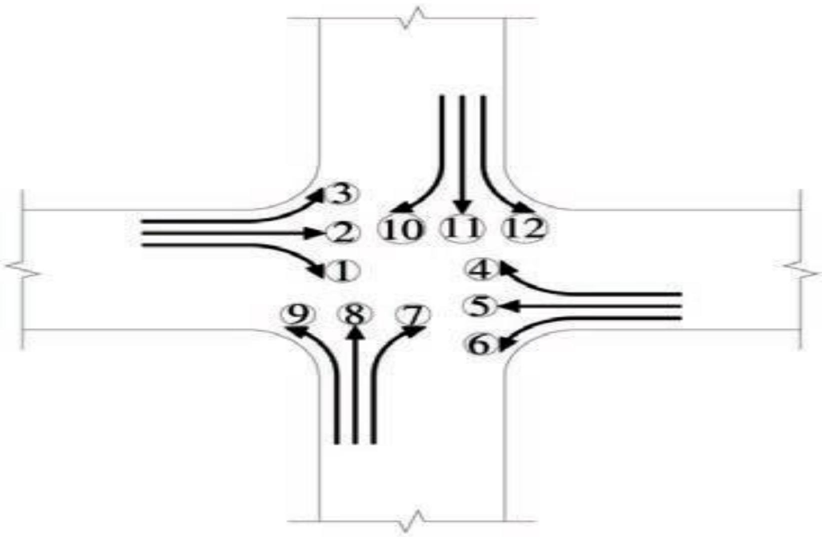

Fig. 11. Vehicular Movements at a Typical Four-Legged intersection

[*Source*: Indo HCM (2017)]

Table 12. Priority Ranks for Different Movements

Priority Rank	Movement
1	Movement 2
	Movement 3
	Movement 5
	Movement 6
2	Movement 1
	Movement 4
3	Movement 7
	Movement 10
4	Movement 8
	Movement 11

[Source: Indo HCM (2017)]

Movement 9 and 12 do not have notable influence on other movements as noticed on Indian roads. (Indo HCM 2017)

4.4.3.3.1 Rank 2 movements (movements 1 and 4):

Rank 2 movements are comparatively simpler to perform, as they have to intersect one course of through traffic only. If left turn is not separated, it is to be counted to the given equations while computing the conflicting flow.

For four-lane major streets:

$V_{c,1} = v_5$

$V_{c,4} = v_2$

When the major road is of two-lane undivided format, left turn movement is not isolated and so the left turning movements from major will also contradict with the subject movement. In addition to this, when divider is absent on the minor road approach, right turning movements from minor utilizes the right portion of the approach inflicting further obstruction to the subject movement. The effect through movement on major is amplified due to the unavailability of proper waiting area. Conflicting flows for two-lane major street are computed using given equations.

For two-lane major street:

$V_{c,1} = 1.5v_5 + v_6 + v_7$

$V_{c,4} = 1.5v_2 + v_3 + v_{10}$

4.4.3.3.2 Rank 3 movements (movements 7 and 10):

In India, right turn from minor is simpler to perform than the through motions from minor as the former requires conflicting only one stream of major road through traffic while the second one had to intersect two courses of through traffic (refer Figure 16). Right turn motions have to conflict the nearby through motions on major (V2 or V5) and also the right turning motions from major on their near side (V4 and V6) and at last unite with the median lane of major on the far side. If the major road has more than one lane, the subject movement contest with the flow on the lane nearer to the median only. Conflicting traffic flows for this movement can be estimated utilizing the given equations.

For four-lane major street:

$V_{c,7} = v_4 + v_5 + v_1 + 0.5v_2$

$V_{c,10} = v_1 + v_2 + v_4 + 0.5v_5$

In case of two-lane major roads, the complete flow on the joining road is to be added in the computation of conflicting rate of flow. Conflicting flow at intersections with two-lane approach for the rank 3 movements are given in below equations.

For two-lane major street:

$V_{c,7} = v_4 + v_5 + v_1 + v_2$

$V_{c,10} = v_1 + v_2 + v_4 + v_5$

4.4.3.3.3 Rank 4 movements (movements 8 and 11):

The most tough movement to perform at an unsignalized intersection is the through movements on minor roads, since it has to conflict with two courses of through traffic on the major road (refer Figure 8.11). This consists of right turning movements from far side of major road, right turning movements from minor road and ultimately unite with major road right turners from the close side and left turners from major road on the distant side. Left turn movements can be neglected in the computation of conflicting flows as the major road left turnings are divided at intersections, and the equation for finding conflicting flows at intersections with four-lane divided major road are given in below.

For four-lane major street:

$V_{c,8} = v_4 + v_5 + v_1 + v_2 + v_{10}$

$V_{c,11} = v_1 + v_2 + v_4 + v_5 + v_7$

On the other hand, for intersections with two-lane major road layout, conflicting flow is calculated using given equations.

For two-lane major street:

$V_{c,8} = v_4 + v_5 + v_1 + v_2 + v_3 + v_{10}$

$V_{c,11} = v_1 + v_2 + v_4 + v_5 + v_6 + v_7$

Table 13 shows the summary of conflicting movements faced by each set of non-priority subject movement.

Table 13. Calculation of Conflicting Traffic Flow

Rank	**Movement**	**Conflicting Flow (per hour)**	
		Two lane major street	**Four lane Major street**
1	v_2 v_3 v_5 v_6	--	--
2	v_1 v_4	$1.5v_5 + v_6 + v_7$ $1.5v_2 + v_3 + v_{10}$	v_5 v_2
3	v_7 v_{10}	$v_4 + v_5 + v_1 + v_2$ $v_1 + v_2 + v_4 + v_5$	$v_4 + v_5 + v_1 + 0.5v_2$ $v_1 + v_2 + v_4 + 0.5v_5$
4	v_8 v_{11}	$v_4 + v_5 + v_1 + v_2 + v_3 + v_{10}$ $v_1 + v_2 + v_4 + v_5 + v_6 + v_7$	$v_4 + v_5 + v_1 + v_2 + v_{10}$ $v_1 + v_2 + v_4 + v_5 + v_7$

[Source: Indo HCM (2017)]

4.4.3.4 Calculate critical gap value

The base critical gap values for different movements are shown in Table 14.

Table 14. Base Critical Gap Value (seconds)

Movement	Vehicle Type						
	Two-Wheeler	**Auto rickshaw**	**Standard Car**	**Big Car**	**LCV**	**Bus**	**TAT/ MAT**
Four lane Divided Intersection							
Right turning from major to minor street	2.5	2.7	2.7	2.9	3.3	3.6	3.8
Right turning from minor to major street	3.5	3.7	3.8	4.1	4.9	5.5	5.7
Through traffic on minor	5.8	5.9	6.8	7.6	7.9	7.9	8.6
Two lane Undivided Intersection							
Right turning from major to minor street	2.9	3.2	3.5	3.9	-	-	-
Right turning from minor to major street	3.2	3.5	3.8	-	-	-	-
Through traffic on minor	3.5	4.2	4.9	-	-	-	-

[Source: Indo HCM (2017)]

Critical gaps in the field for various movements is arrived at by taking the base values from the table and then modifying them for the quantity of heavy vehicles in the contradicting traffic flows. Critical gap for a specific movement is achieved using the given equation. (Indo HCM 2017)

$t_{c,x} = t_{c,base} + f_{LV} \times \ln(P_{LV})$

where,

$t_{c,x}$ = Critical gap (s) for vehicle type x.

$t_{c,base}$ = Base critical gap value for corresponding vehicle type executing the same movement.

f_{LV} = Adjustment factor for large vehicles (vehicle larger than big cars).

P_{LV} = Proportion of large vehicles in the conflicting traffic stream.

Large vehicle adjustment factors for various classes of vehicle, at intersections having major roads with four-lane and two-lane layouts are provided in the Table 15 given below.

Table 15. Adjustment Factor for Proportion of Large Vehicles in Conflicting Traffic Streams

Movement	Vehicle Type						
	Two-Wheeler	Auto rickshaw	Standard Car	Big Car	LCV	Bus	TAT/ MAT
Four lane Divided Intersection							
Right turning from major to minor street	0.25	0.27	0.46	0.55	0.48	0.53	0.74
Right turning from minor to major street	0.61	0.64	0.88	0.93	0.86	0.84	0.85
Through traffic on minor	0.34	0.38	0.58	0.45	0.44	0.44	0.27
Two lane Undivided Intersection							
Right turning from major to minor street	0.38	0.63	0.78	1.02	-	-	-
Right turning from minor to major street	0.07	0.07	0.01	-	-	-	-
Through traffic on minor	0.07	0.07	0.07	-	-	-	-

[Source: Indo HCM (2017)]

4.4.3.5 Calculate capacity of a turning movement

Capacity (Cx) in PCU/h of individual movement at an unsignalized intersection can be estimated utilizing the critical gap value for passenger cars (s), conflicting flow (PCUs/h) and assuming follow-up time as 60 % of critical gap, based on the model of gap acceptance given in the following equation.

The adjustment factors in the equation are to be selected from Table 16 depending on the geometry of the intersection. (Indo HCM 2017)

$$C_X = a \times V_{C,X} \frac{e^{-V_{C,X}(t_{c,x}-b)/3600}}{1 - e^{-V_{C,X}\, t_{f,x}/3600}}$$

where,

C_x = Capacity of movement ‘x’ in PCU/h.

$V_{c,x}$ = Conflicting flow rate corresponding to movement x in PCU/h.

$t_{c,x}$ = Critical gap of standard passenger cars for movement ‘x’ in seconds.

$t_{f,x}$ = Follow-up time for movement ‘x’ in seconds.

‘a’ and ‘b’ = Adjustment factors based on intersection geometry.

Table 16. Adjustment Factors for Capacity Model

Major Street Configuration	Adjustment Factors	Subject Movement		
		Right Turn from Major	Right Turn from Minor	Through on Minor
Four-lane Divided	a	0.80	1.00	0.90
	b	1.30	2.16	5.04
Two-lane Undivided	a	0.70	0.80	1.10
	b	-0.11	0.72	0.72

[Source: Indo HCM (2017)]

4.4.4 Level of service

Delay felt by users of non-priority movements is generally used to acknowledge the quality of traffic functioning at uncontrolled intersections. Minor vehicle drivers often force their way on to the priority stream of major road. This occurs as a result of aggressive and impatient behavior of drivers. LOS is determined based on the volume to capacity ratio for each movement. The LOS for V/C ratios are provided in Table 17.

Table 17. Level of Service at Unsignalized Intersection

Level of Service	Volume – Capacity Ratio
A	≤ 0.15
B	0.16 – 0.35
C	0.36 – 0.55
D	0.56 – 0.80
E	0.81 – 1.00
F	> 1.00

[Source: Indo HCM (2017)]

4.5 User Perception Survey

A user perception survey in the field was carried out among the users of the same mid-block sections, signalized intersection and unsignalized intersection to find out the user perceived LOS of those facilities. The survey was carried out by filling a Likert type questionnaire, while orally interviewing each vehicle user in and around the facility. The complete questionnaire form is given in the Appendix. It included the following sections:

a) Basic details such as gender, age group, type of vehicle used and driving experience.
b) Perceptions about Kacherippadi bypass regarding Average Travel Speed (ATS), surface quality, obstructions to traffic flow and safety.
c) Perceptions about Melakkam bypass regarding Average Travel Speed (ATS), surface quality, obstructions to traffic flow and safety.
d) Perceptions about Kacherippadi junction regarding the delay experienced, obstruction to movement and safety.
e) Perceptions about Jaseela junction regarding the delay experienced, obstruction to movement and safety.
f) General questions regarding the most important factor deciding the LOS of a road section as well as an intersection.

These factors were chosen since these factors represent the effective functioning of those facilities. The individual survey responses were processed to find the total LOS score provided by each user. This score is obtained by summing the response score of each question regarding a specific facility on a Likert scale of 1 to 5, for all factors except ATS. For ATS, the Likert scale is from 1 to 6. Then the aggregate individual LOS scores were subjected to K-means clustering to determine the suitable cluster intervals.

In the next step, the average LOS scores of the selected facilities were calculated and corresponding LOS categories were determined from the boundary values obtained by K-means clustering. The LOS perceived by the users of the facility were thus determined. Then a comparison will be made between the LOS measured on the field with the LOS perceived by the user while utilising these facilities. Finally, the difference between these two LOS will be analysed and conclusions will be made accordingly.

CHAPTER 5

STUDY AREA

5.1 Reconnaissance Survey

The midblock sections, signalized intersection and unsignalized intersection chosen for the study was identified after conducting an extensive reconnaissance survey on the major urban roads and intersections of Manjeri municipality.

Manjeri town (shown in Figure 12) in Malappuram district of Kerala, India is selected as the study area. Two bypass roads surrounding the city is considered for midblock level of service evaluation. They are:

1. Melakkam - Thurakkal bypass, shown in Figure 14.

2. Thurakkal - Kacherippadi bypass, shown in Figure 13.

A signalized intersection known as Jaseela Junction (shown in Figure 15) formed by the meeting of Melakkam - Thurakkal bypass with a national highway is considered for intersection analysis.

An unsignalized intersection known as Kacherippadi Junction (shown in Figure 16) formed by the meeting of the Thurakkal - Kacherippadi bypass with a major district road is considered for unsignalized intersection analysis.

These locations were found to be satisfying the criteria explained for them to be considered as a base road section, base signalized intersection and base unsignalized intersection, respectively.

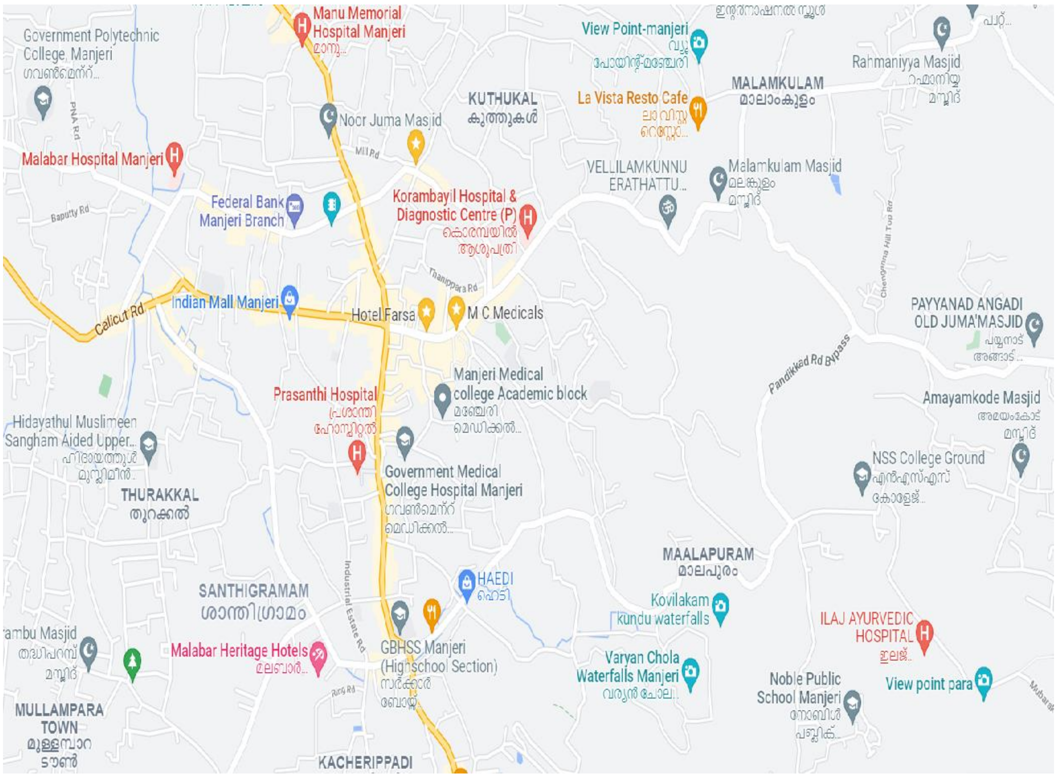

Fig 12. Google Map Image of Manjeri Town

(*Source*: Google)

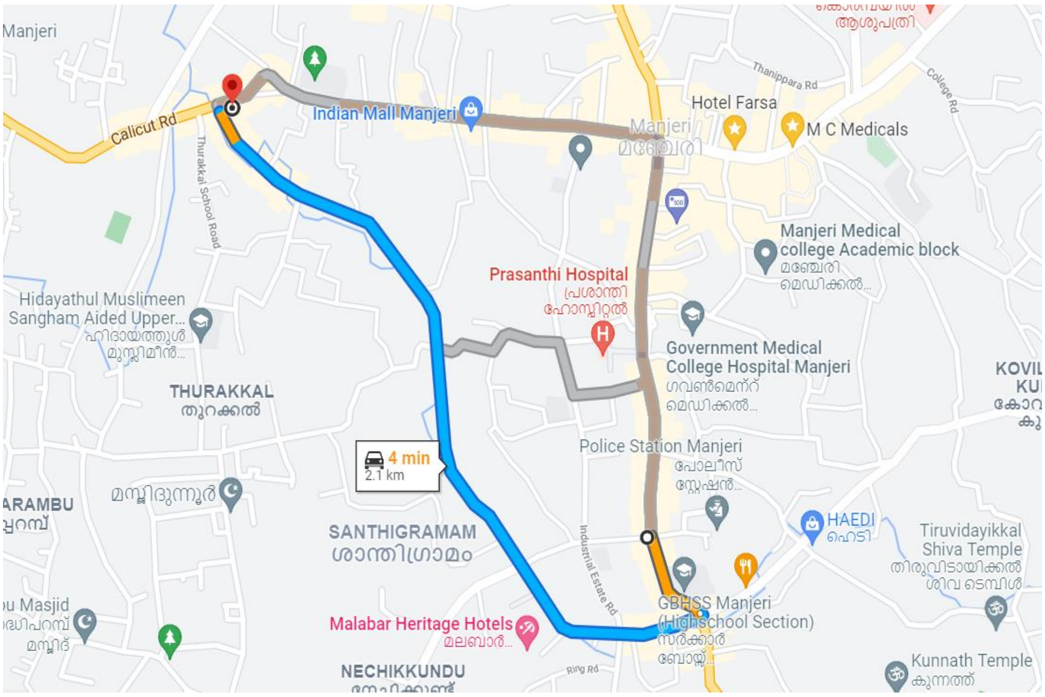

Fig. 13. Google Map Image of Thurakkal - Kacherippadi bypass

(*Source*: Google)

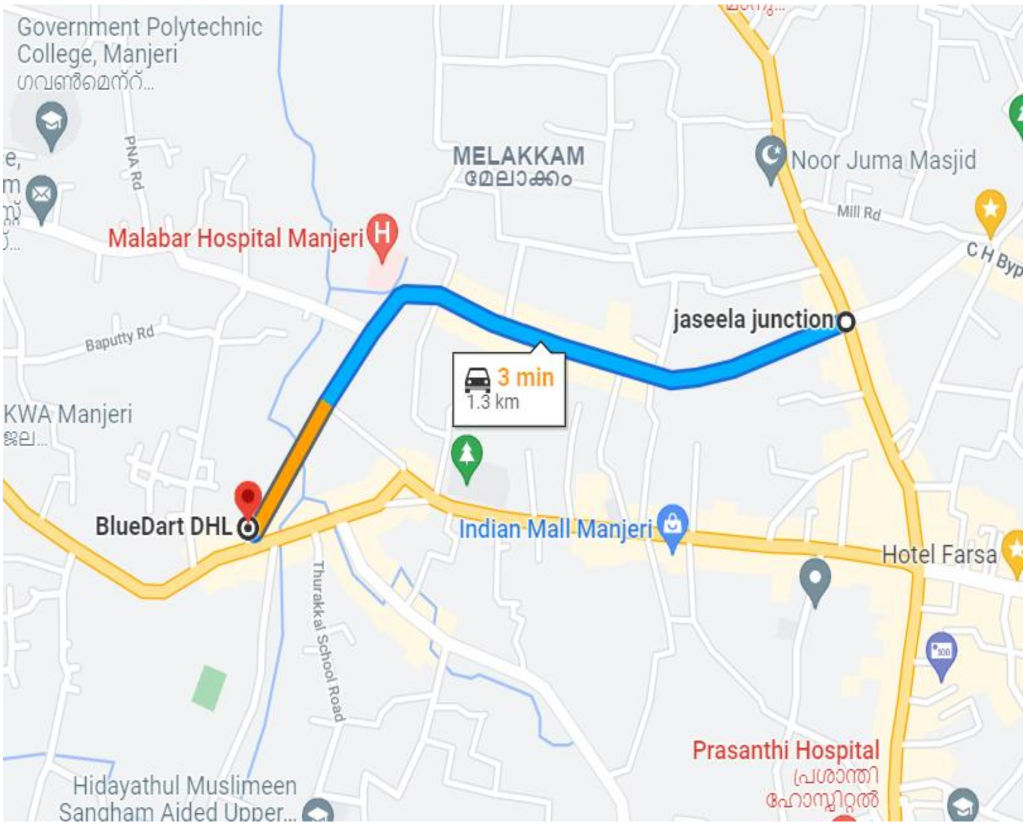

Fig. 14. Google Map Image of Melakkam - Thurakkal bypass

(*Source*: Google)

Fig 15. Google Map Image of Jaseela Junction

(*Source*: Google)

Fig. 16. Google Map Image of Kacherippadi Junction

(*Source*: Google)

CHAPTER 6

RESULTS AND DISCUSSIONS

The results of the study are explained in detail in below sections.

6.1 Midblock Sections

The research findings about the two midblock sections are provided one after the other.

6.1.1 Melakkam – Thurakkal bypass

6.1.1.1 Traffic flow

Video data recording of the Melakkam - Thurakkal bypass was conducted for a full 24-hour period covering entire day and night hours. A screenshot of the recording is shown in Figure 17.

Fig. 17. Screenshot of the Video Data Collection of Melakkam – Thurakkal Bypass

24-hour traffic volume data in vehicle/hour was extracted from the video data. The volume in vehicle/hour was then converted into equivalent volume in PCU/hour using the corresponding PCU values for each class of vehicle. The details of which are provided in Table 18.

Table 18. Traffic Volume Details of Melakkam – Thurakkal Bypass

Time	No. of Vehicles	Total PCU
6.00 - 7.00	446	345
7.00 - 8.00	802	695
8.00 - 9.00	1502	1172
9.00 - 10.00	1960	1386
10.00 - 11.00	1889	1497
11.00 - 12.00	1782	1501
12.00 - 13.00	1609	1424
13.00 - 14.00	1588	1377
14.00 - 15.00	1672	1420
15.00 - 16.00	1702	1464
16.00 - 17.00	1744	1435
17.00 - 18.00	2124	1504
18.00 - 19.00	2023	1419
19.00 - 20.00	1756	1236
20.00 - 21.00	1471	1041
21.00 - 22.00	1138	813
22.00 - 23.00	649	478
23.00 - 24.00	334	265
24.00 – 1.00	212	151
1.00 – 2.00	142	102
2.00 – 3.00	89	64
3.00 – 4.00	155	110
4.00 – 5.00	227	162
5.00 – 6.00	352	247

6.1.1.2 Peak hour and free flow hour

From the traffic volume details, it is observed that peak hour for Melakkam – Thurakkal bypass is from 17.00 to 18.00 hours during the evening rush hours. The peak hour traffic volume is found to be 1504 PCU/hour with a flow of 2124 vehicle/hour.

The free flow hours of this section is beginning from 23.00 at night and extends till 7.00 in the morning, as the traffic flow is less than 450 vehicle/hour during these hours.

6.1.1.3 Average travel speed and free flow speed

The ATS and FFS are obtained by extracting the time taken to travel a specific trap length by the vehicles during the peak hour and free flow hours respectively. The trap length used for this purpose is shown in Figure 18.

Fig. 18. Trap Length Used for Speed Data Extraction of Melakkam – Thurakkal Bypass

The ATS for each vehicle type and the overall ATS for this section obtained from the video is given in Table 19. The ATS of the section is found to be 26.9 Kmph.

Table 19. ATS Details of Melakkam – Thurakkal Bypass

Vehicle Type	Mean Speed (Kmph)	Average Travel Speed (Kmph)
2 – Wheeler	24.7	26.9
Auto	29.6	
Car	26.24	
Bus	28.74	
LCV	28.3	
TAT/MAT	24.5	

The FFS for each vehicle type and the overall FFS for the subject section obtained from the video is given in Table 20. The FFS of the section is found to be 67.8 Kmph.

Table 20. FFS Details of Melakkam – Thurakkal Bypass

Vehicle Type	Mean Speed (Kmph)	Free Flow Speed (Kmph)
2 – Wheeler	69.41	67.8
Auto	65.91	
Car	70.58	
LCV	69.36	
TAT/MAT	64.17	

6.1.1.4 Level of service

The ATS is found to be 39.7% of the FFS. Hence the LOS of Melakkam – Thurakkal bypass is determined as 'C' from the relevant table.

6.1.2 Kacherippadi – Thurakkal bypass

6.1.2.1 Traffic flow

Video data recording of the Kacherippadi - Thurakkal bypass was conducted for a full 24-hour period covering entire day and night hours. A screenshot of the recording is shown in Figure 19.

Fig. 19. Screenshot of the Video Data Collection of Kacherippadi – Thurakkal Bypass

24-hour traffic volume data in vehicle/hour was extracted from the video data. The volume in vehicle/hour was then converted into equivalent volume in PCU/hour using the corresponding PCU values for each class of vehicle. The details of which are provided in Table 21.

Table 21. Traffic Volume Details of Kacherippadi – Thurakkal Bypass

Time	No. of Vehicles	Total PCU
6.00 - 7.00	371	314
7.00 - 8.00	775	654
8.00 - 9.00	1471	1240
9.00 - 10.00	2176	1634
10.00 - 11.00	1936	1664
11.00 - 12.00	1792	1470
12.00 - 13.00	1414	1117
13.00 - 14.00	1386	970
14.00 - 15.00	1647	1185
15.00 - 16.00	1966	1533
16.00 - 17.00	2228	1671
17.00 - 18.00	2322	1729
18.00 - 19.00	2073	1492
19.00 - 20.00	1811	1249
20.00 - 21.00	1285	961
21.00 - 22.00	988	626
22.00 - 23.00	593	368
23.00 - 24.00	235	162
24.00 – 1.00	175	126
1.00 – 2.00	116	82
2.00 – 3.00	92	66
3.00 – 4.00	166	118
4.00 – 5.00	268	191
5.00 – 6.00	334	239

6.1.2.2 Peak hour and free flow hour

From the traffic volume details, it is observed that peak hour for Kacheripadi – Thurakkal bypass is from 17.00 to 18.00 hours during the evening rush hours. The peak hour traffic volume is found to be 1729 PCU/hour with a flow of 2322 vehicle/hour.

The free flow hours of this section begin from 23.00 at night and extends till 7.00 in the morning, as the traffic flow is less than 450 vehicle/hour during these hours.

6.1.2.3 Average travel speed and free flow speed

The ATS and FFS are obtained by extracting the time taken to travel a specific trap length by the vehicles during the peak hour and free flow hours respectively. The trap length used for this purpose is shown in Figure 20.

Fig. 20. Trap Length Used for Speed Data Extraction of Kacherippadi – Thurakkal Bypass

The ATS for each vehicle type and the overall ATS for this section obtained from the video is given in Table 22. The ATS of the section is found to be 32.04 Kmph.

Table 22. ATS Details of Kacherippadi – Thurakkal Bypass

Vehicle Type	Mean Speed (Kmph)	Average Travel Speed (Kmph)
2 – Wheeler	30.71	32.04
Auto	33.65	
Car	32.074	
Bus	33.9	
LCV	34.4	
TAT/MAT	28.37	

The FFS for each vehicle type and the overall FFS for the subject section obtained from the video is given in Table 23. The FFS of the section is found to be 72.17 Kmph.

Table 23. FFS Details of Kacherippadi – Thurakkal Bypass

Vehicle Type	Mean Speed (Kmph)	Free Flow Speed (Kmph)
2 – Wheeler	73.73	72.17
Auto	70.54	
Car	76.05	
LCV	72.7	
TAT/MAT	68.35	

6.1.2.4 Level of service

The ATS is found to be 44.4% of the FFS. Hence the LOS of Kacherippadi – Thurakkal bypass is determined as 'C' from the relevant table.

6.2 Signalized Intersection

The research findings about the signalized intersection, namely Jaseela junction are provided in the following sections.

6.2.1 Geometric characteristics

Jaseela junction is a 4-legged intersection as shown in Figure 21.

Fig. 21. Jaseela Junction

The details of approaches are given as follows:

Approach 1 – Towards Malappuram

Approach 2 – Towards Nilambur

Approach 3 – Towards Pandikkad

Approach 4 – Towards Kozhikode

The approach width is 7.0 metres on all the approaches. The approaches are intersecting at right angles. Although there is a lane available for free left turn movement on all approaches, they are not separated and hence get occupied by through and right turn movement vehicles waiting for their phase, eliminating the possibility of a free left turn. Additionally, this lane is utilized by through and right turn vehicles too along with left turners during green phase. As a result, the full approach width of 7.0 m is considered for capacity analysis and the number of movement group is taken as one.

Buses stopping at a vicinity of 75 m from the middle of the intersection is present only on one approach. Since a separate bus bay is available for this bus stop, it causes no obstruction to the traffic flow. Therefore, bus blockage due to curbside bus stop is taken as zero. Hence, F_{bb} = 1.

Approach flare resulting in expected early discharge of vehicles is found to be absent. Therefore, the initial surge of vehicles due to approach flare and anticipation effect is taken as zero. Hence, F_{is} = 1.

Since the through and right turn vehicles operate at the same phase, blockage of through vehicles by standing right turning vehicles waiting for their turn is also taken as zero. Hence, F_{br} = 1.

6.2.2 Traffic characteristics

6.2.2.1 Traffic volume (V)

The traffic volume on individual approaches of the intersection was obtained from the field by means video recording technique. The video was then played on a computer to manually extract the categorized turning vehicle counts. These are then converted into equivalent PCU utilizing the values provided. The approach wise traffic volume details are given in table 24.

Table 24. Traffic Volume Details of Jaseela Junction

Approach	Volume (PCU/hour)
Towards Malappuram	820
Towards Nilambur	1040
Towards Pandikkad	666
Towards Kozhikode	567

6.2.3 Control characteristics

The control characteristics of the intersection for each approach are provided in Table 25.

Table 25. Control characteristics of Jaseela Junction

Approach	Total Green 'G' (seconds)	Amber 'Y' (seconds)	Red 'R' (seconds)	Lost Time/Cycle 'L' (seconds)	Effective Green Time 'g' = G+Y-L
Towards Malappuram	30	2	86	2	30
Towards Nilambur	35	2	81	2	35
Towards Pandikkad	25	2	91	2	25
Towards Kozhikode	20	2	96	2	20

6.2.4 Saturation flow

The saturation flow for each approach of the intersection is calculated using the saturation flow model. From the model explained in methodology section, the unit base saturation flow rate, USFo is found to be 720 PCU/hour/m. This saturation flow is for per metre width of the approach. The details of total existing saturation flow for each approach after adjusting for bus blockage, standing right turn vehicles and initial surge was calculated using the provided equation. The details of this saturation flow are provided in Table26.

Table 26. Saturation Flow Details of Jaseela Junction

Approach	Towards Malappuram	Towards Nilambur	Towards Pandikkad	Towards Kozhikode
Width (m)	7	7	7	7
USFo (PCU/hr/m)	720	720	720	720
F_{bb}	1	1	1	1
F_{br}	1	1	1	1
F_{is}	1	1	1	1
Adjusted SF (PCU/hr)	5040	5040	5040	5040

6.2.5 Capacity and V/C ratio

6.2.5.1 Capacity

The capacity of each approach of the intersection was calculated by substituting the values of saturation flow, effective green time and overall cycle time in the relevant equation. The obtained capacity details are given in Table 27.

Table 27. Capacity of Jaseela Junction

Approach	**Capacity (PCU/hr)**
Towards Malappuram	1281
Towards Nilambur	1495
Towards Pandikkad	1067
Towards Kozhikkode	854

6.2.5.2 Volume/Capacity ratio

Having found the volume of each approach and the capacity of each of them, we can compute the volume to capacity (v/c) ratio or degree of saturation (X) of each intersection. The V/C ratio of all approaches are provided in Table 28.

Table 28. V/C ratio of Jaseela Junction

Approach	**V/C Ratio**
Towards Malappuram	0.64
Towards Nilambur	0.696
Towards Pandikkad	0.624
Towards Kozhikode	0.664

6.2.6 Determination of delay

6.2.6.1 Control delay model

Since the existence of initial queue ‘Q_b’ (in PCU) before the beginning of period of analysis is found to be absent, the value of ‘d_3’ is taken as zero in the calculation of control delay. The analysis period ‘T’ is taken as 15 minutes, i.e., T = 0.25 hr. The value of uniform delay ‘d_1’, incremental delay ‘d_2’ and the control delay ‘d’ obtained using relevant equation for each of the approaches of the subject signalized intersection is shown in Table 29.

Table 29. Control delay details of Jaseela Junction

Approach	**d1** (s)	**d2** (s)	**d3** (s)	**d** (s)
Towards Malappuram	39.2	2.44	0	37.72
Towards Nilambur	36.78	2.68	0	35.78
Towards Pandikkad	42.23	2.73	0	40.74
Towards Kozhikode	45.85	4	0	45.26

6.2.6.2 Intersection delay

Intersection delay was computed as the weighted average delay for each approach using the provided equation. The value of intersection delay was found to be 39.26 second.

6.2.7 Level of service

Level of Service (LOS) is determined based on the control delay encountered. From the control delay and corresponding LOS table provided earlier, the LOS of the signalized intersection is determined to be ‘B’.

6.3 Unsignalized Intersection

The research findings about the unsignalized intersection, namely Kacherippadi junction are provided in the following sections.

6.3.1 Geometric and traffic data

Kacherippadi junction is a four-legged unsignalized intersection as shown in Figure 22.

Fig. 22. Kacherippadi Junction

The major street is of 2-lane undivided configuration with a width of 3.8 m for each lane. The minor street is of 5.5 m total width. They are intersecting at right angles.

Video recording was employed to obtain the classified traffic volume count for various movements happening at the intersection during the peak hour. The peak hour was observed to be from 17.00 to 18.00. The video data was played on a computer to extract the same. Table 30 shows the classified traffic volume for each turning movement during peak hour in vehicle/hour.

Table 30. Classified Traffic Volume at Kacherippadi Junction during Peak Hour.

Movement	2 - Wheeler	Auto	Std Car	Big car	LCV	All Heavy Vehicles	Total (veh/hr)
1	86	15	39	9	9	2	160
2	349	55	304	33	34	14	789
3	76	12	13	3	0	1	105
4	14	6	3	0	0	0	23
5	398	54	327	34	32	36	881
6	89	12	40	5	2	1	149
7	87	19	36	5	1	1	149
8	235	84	32	6	5	2	364
9	87	13	36	5	10	5	156
10	81	13	20	2	2	0	118
11	231	101	21	1	4	0	358
12	14	4	9	0	3	0	30

6.3.2 Traffic volume converted into PCU

The details of traffic volume happening at each turning movement at the given intersection in corresponding PCU values are provided in Table 31.

Table 31. Turning Traffic Volume at Kacherippadi Junction in PCU/hr

Movement	2 - Wheeler	Auto	Std Car	Big Car	LCV	All Heavy Vehicles	Total (PCU/h)
1	29	15	39	12	15	5	115
2	168	54	304	43	58	33	660
3	26	12	13	4	0	2.4	57
4	5	6	3	0	0	0	14
5	191	53	327	44	54	85	754
6	30	12	40	6.5	3.5	2.4	94
7	30	19	36	6.5	1.7	2.4	96
8	80	82	32	8	8.5	5	216
9	30	13	36	6.5	17	11.7	114
10	28	13	20	3	4	0	68
11	79	99	21	1	7	0	207
12	5	4	9	0	5	0	23

6.3.3 Conflicting traffic flow rates

The volume of conflicting traffic flows for each subject non priority movement is determined using the conflicting flow details provided earlier. The details of which are presented below in Table 32.

Table 32. Conflicting Flows for Each Non-Priority Movement at Kacherippadi Junction

Priority Rank	Movement	Conflicting Flow Equation	Conflicting Flow
1	Movement 2	-	-
	Movement 3	-	-
	Movement 5	-	-
	Movement 6	-	-
2	Movement 1	1.5v5 + v6 + v7	1321
	Movement 4	1.5v2 + v3+ v10	1115
3	Movement 7	v4 + v5 + v1 + v2	1543
	Movement 10	v1 + v2 + v4 + v5	1543
4	Movement 8	v4 + v5 + v1 + v2 + v3 + v10	1668
	Movement 9	-	-
	Movement 11	v1 + v2 + v4 + v5 + v6 + v7	1733
	Movement 12	-	-

6.3.4 Critical gap values for each movement

Critical gap values for every movement type calculated from base values of critical gap by modifying them to accommodate for the share of heavy vehicles in the conflicting traffic flows are presented in Table 33.

Table 33. Modified Critical Gap Values for Each Movement

Movement	Base Critical Gap (t c,base)	Adjustment Factor for Large Vehicles (f LV)	Proportion of Large Vehicles in the Conflicting Traffic Stream (PLV)	Critical Gap t c,x = t c,base + f LV × ln (PLV)
Movement 1	3.5	0.78	6.6	4.97
Movement 4	3.5	0.78	5.33	4.8
Movement 7	3.8	0.01	4.7	3.82
Movement 10	3.8	0.01	4.7	3.82
Movement 8	4.9	0.07	6.26	5.03
Movement 11	4.9	0.07	6.14	5.03

6.3.5 Capacity of turning movements

The details of capacity (Cx) in PCU/h of individual turning movements at an unsignalized intersection estimated based on the model of gap acceptance using the critical gap value for passenger cars, conflicting flow and assuming follow-up time as 60 % of critical gap are presented in Table 34.

Table 34. Capacity of Non-Priority Turning Movements at Kacherippadi Intersection

Movement	**Critical Gap (s) tcx**	**Follow-up Time tfx = 06* tcx**	**Conflicting Flow Vcx**	**Adjustment Factor "a"**	**Adjustment Factor "b"**	**Capacity**
Movement 1	4.97	2.98	1321	0.70	-0.11	216
Movement 4	4.8	2.88	1115	0.70	-0.11	289
Movement 7	3.82	2.29	1543	0.80	0.72	523
Movement 10	3.82	2.29	1543	0.80	0.72	523
Movement 8	5.03	3.02	1668	1.10	0.72	331
Movement 11	5.03	3.02	1733	1.10	0.72	312

6.3.6 Level of service

The LOS determined for individual movements based on the volume to capacity ratio of those individual non priority movements are given in Table 35.

Table 35. LOS of Various Non-Priority Movements of Kacherippadi Junction

Movement	Volume	Capacity	V/C Ratio	LOS
Movement 1	115	216	0.53	C
Movement 4	14	289	0.05	A
Movement 7	96	523	0.18	B
Movement 10	68	523	0.13	A
Movement 8	216	331	0.65	D
Movement 11	207	312	0.66	D

6.4 User Perception Survey

A total of 400 responses were collected. The vehicle class wise details of number of responses are given below in Table 36.

Table 36. Vehicle Proportion Details of Perception Survey

Type of vehicle	No. of responses
2 – Wheeler	204
Auto	40
Car	124
Bus	7
LCV	16
HV	9

The proportion of each vehicles class participated in the survey is shown in Figure 23. This proportion was kept in line with proportion of peak hour traffic.

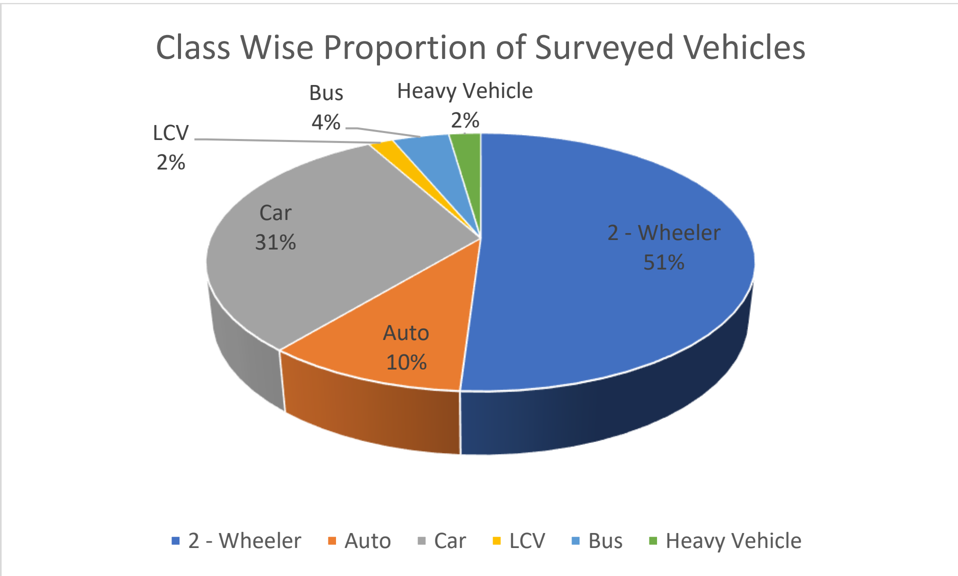

Fig. 23. Class Wise Proportion of Surveyed Vehicles

The gender proportion of participants are shown in Figure 24.

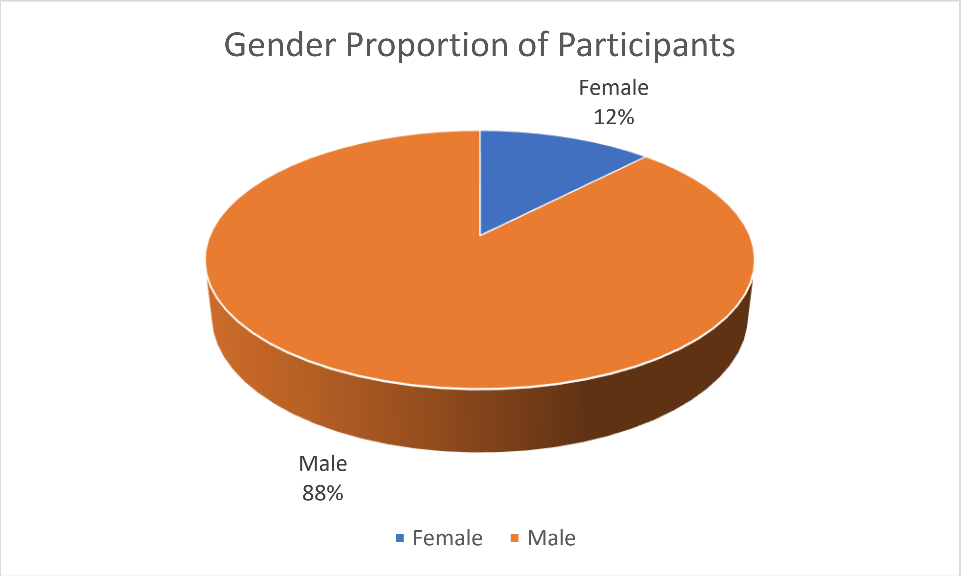

Fig. 24. Gender Proportion of Participants

The results of K-means clustering analysis and LOS determination is explained in the following sections.

6.4.1 Kacherippadi bypass

The details regarding the final cluster centers for Kacherippadi bypass are shown in Table 37.

Table 37. Final Cluster Centres for Kacherippadi bypass

Cluster	Final Cluster Centre
1	7.00
2	8.00
3	9.89
4	11.48
5	13.66
6	15.99

The final cluster centers represent the average LOS score of each corresponding clusters. From the table, Cluster 1 corresponds to LOS F, cluster 2 corresponds to LOS E, cluster 3 corresponds to LOS D, cluster 4 corresponds to LOS C, cluster 5 corresponds to LOS B and cluster 6 corresponds to LOS A. The average LOS score of first cluster is 7, second cluster is 8, third cluster is 9.89 and so on. This is shown in Figure 25.

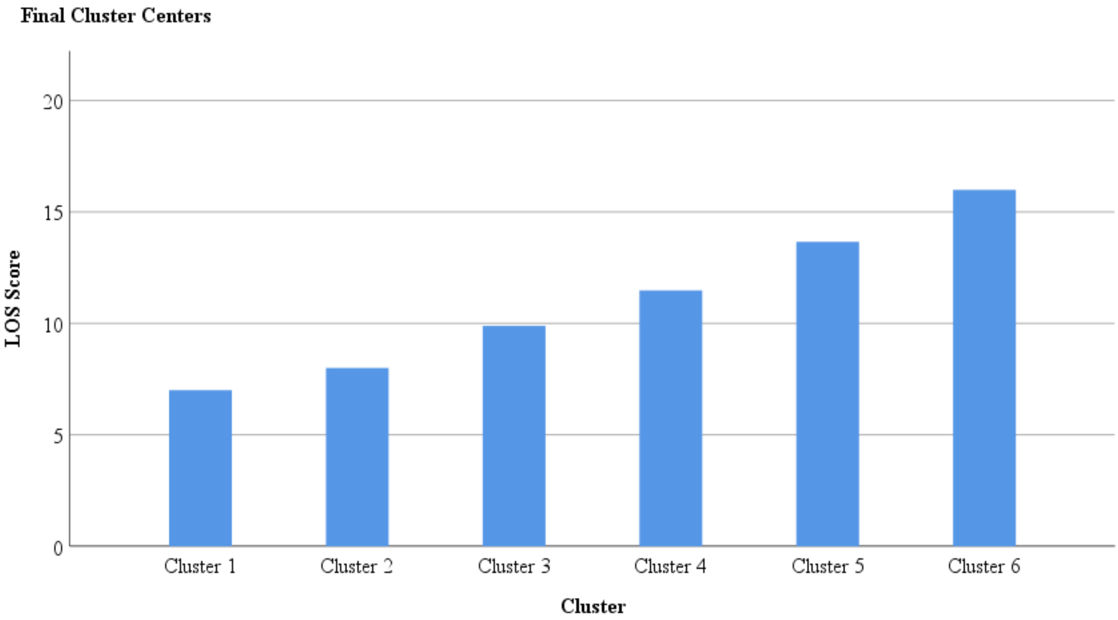

Fig. 25. Graph Showing Final Cluster Centres for Kacherippadi Bypass

The details of distances between final cluster centers are provided in Table 38.

Table 38. Distances Between Final Cluster Centres for Kacherippadi Bypass

Cluster	1	2	3	4	5	6
1		1.00	2.889	4.477	6.662	8.995
2	1.00		1.889	3.477	5.662	7.995
3	2.889	1.889		1.588	3.773	6.106
4	4.477	3.477	1.588		2.185	4.518
5	6.662	5.662	3.773	2.185		2.333
6	8.995	7.995	6.106	4.518	2.333	

The number of cases in each cluster is shown in Table 39.

Table 39. Number of cases in Each Cluster for Kacherippadi Bypass

		No. of cases
Cluster	1	1.000
	2	6.000
	3	9.000
	4	65.000
	5	133.000
	6	186.000
Valid		400.000
Missing		.000

We can determine the number of responses corresponding to each LOS category from the table above. 1 response corresponded to LOS F, 6 responses corresponded to LOS E, 9 responses corresponded to LOS D, 65 responses corresponded to LOS C, 133 responses corresponded to LOS B and 186 responses corresponded to LOS A.

The cluster intervals for Kacherippadi bypass were calculated from the details of cluster centers provided. The cluster intervals and corresponding LOS are given in Table 40.

Table 40. Cluster Intervals and Corresponding LOS of Kacherippadi Bypass

Cluster Interval	LOS
> 14.825	A
12.57 – 14.825	B
10.685 – 12.57	C
8.945 – 10.685	D
7.5 – 8.945	E
< 7.5	F

The average LOS score of Kacherippadi bypass was found to be 14.205. Therefore, the perceived LOS is ‘B’.

6.4.2 Melakkam bypass

The details regarding the final cluster centers for Melakkam bypass are shown in Table 41.

Table 41. Final Cluster Centres for Melakkam bypass

Cluster	Final Cluster Centre
1	6.00
2	8.18
3	10.42
4	7.00
5	13.12
6	16.03

The final cluster centers represent the average LOS score of each corresponding clusters. From the table, Cluster 1 corresponds to LOS F, cluster 2 corresponds to LOS D, cluster 3 corresponds to LOS C, cluster 4 corresponds to LOS E, cluster 5 corresponds to LOS B and cluster 6 corresponds to LOS A. The average LOS score of first cluster is 6, second cluster is 8.18, third cluster is 10.42 and so on. This is shown in Figure 26.

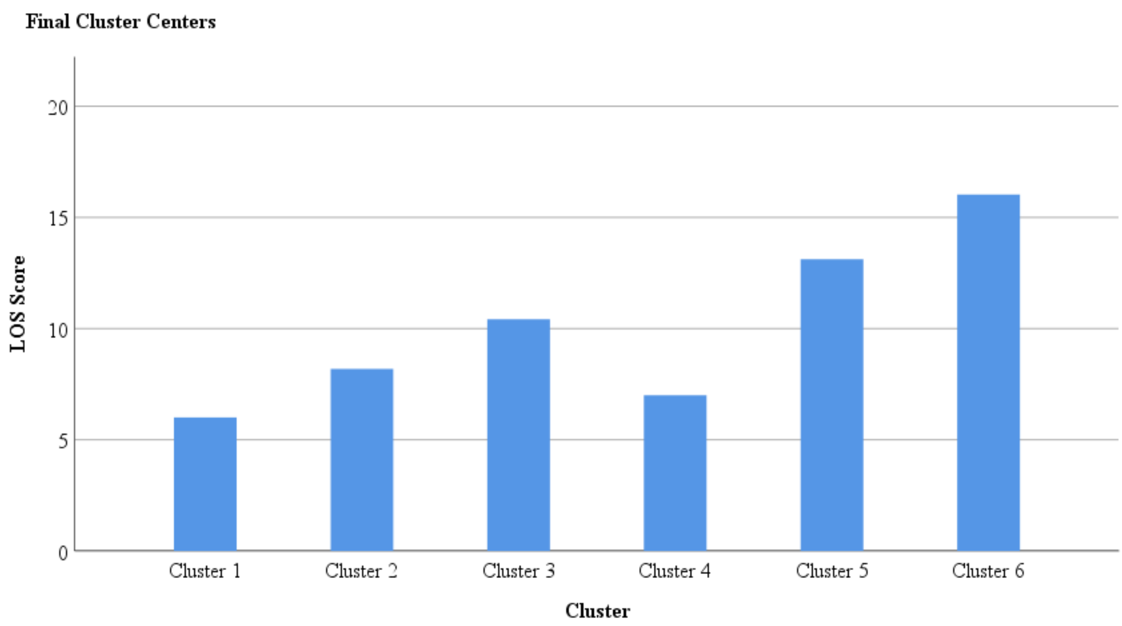

Fig. 26. Graph Showing Final Cluster Centres for Melakkam Bypass

The details of distances between final cluster centers are provided in Table 42.

Table 42. Distances Between Final Cluster Centres for Melakkam Bypass

Cluster	1	2	3	4	5	6
1		2.182	4.423	1.000	7.116	10.029
2	2.182		2.241	1.182	4.934	7.847
3	4.423	2.241		3.423	2.693	5.606
4	1.000	1.182	3.423		6.116	9.029
5	7.116	4.934	2.693	6.116		2.913
6	10.029	7.847	5.606	9.029	2.913	

The number of cases in each cluster is shown in Table 43.

Table 43. Number of cases in Each Cluster for Melakkam Bypass

		No. of cases
Cluster	1	3.000
	2	11.000
	3	52.000
	4	7.000
	5	258.000
	6	69.000
Valid		400.000
Missing		.000

We can determine the number of responses corresponding to each LOS category from the table above. 3 responses corresponded to LOS F, 11 responses corresponded to LOS D, 52 responses corresponded to LOS C, 7 responses corresponded to LOS E, 258 responses corresponded to LOS B and 69 responses corresponded to LOS A.

The cluster intervals for Melakkam bypass were calculated from the details of cluster centers provided. The cluster intervals and corresponding LOS are given in Table 44.

Table 44. Cluster Intervals and Corresponding LOS of Melakkam Bypass

Cluster Interval	LOS
> 14.575	A
11.77 – 14.575	B
9.3 – 11.77	C
7.59 – 9.3	D
6.5 – 7.59	E
< 6.5	F

The average LOS score of Melakkam bypass was found to be 12.9725. Therefore, the perceived LOS is ‘B’.

6.4.3 Kacherippadi junction

The details regarding the final cluster centers for Kacherippadi Junction are shown in Table 45.

Table 45. Final Cluster Centers for Kacherippadi Junction

Cluster	Final Cluster Centre
1	5.00
2	8.00
3	9.00
4	7.00
5	10.96
6	13.43

The final cluster centers represent the average LOS score of each corresponding clusters. From the table, Cluster 1 corresponds to LOS F, cluster 2 corresponds to LOS D, cluster 3 corresponds to LOS C, cluster 4 corresponds to LOS E, cluster 5 corresponds to LOS B and cluster 6 corresponds to LOS A. The average LOS score of first cluster is 5, second cluster is 8, third cluster is 9 and so on. This is shown in Figure 27.

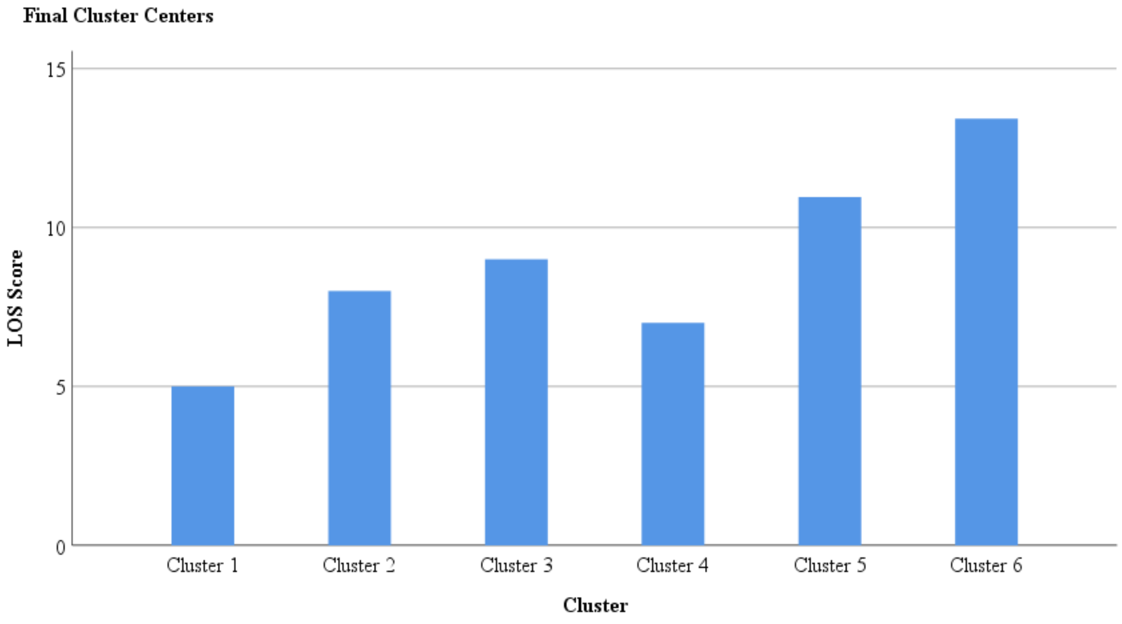

Fig. 27. Graph Showing Final Cluster Centres for Kacherippadi Junction

The details of distances between final cluster centers are provided in Table 46.

Table 46. Distances Between Final Cluster Centres for Kacherippadi Junction

Cluster	1	2	3	4	5	6
1		3.000	4.000	2.000	5.959	8.425
2	3.000		1.000	1.000	2.959	5.425
3	4.000	1.000		2.000	1.959	4.425
4	2.000	1.000	2.000		3.959	6.425
5	5.959	2.959	1.959	3.959		2.466
6	8.425	5.425	4.425	6.425	2.466	

The number of cases in each cluster is shown in Table 47.

Table 47. Number of cases in Each Cluster for Kacherippadi Junction

		No. of cases
Cluster	1	3.000
	2	20.000
	3	61.000
	4	6.000
	5	270.000
	6	40.000
Valid		400.000
Missing		.000

We can determine the number of responses corresponding to each LOS category from the table above. 3 responses corresponded to LOS F, 20 responses corresponded to LOS D, 61 responses corresponded to LOS C, 6 responses corresponded to LOS E, 270 responses corresponded to LOS B and 40 responses corresponded to LOS A.

The cluster intervals for Kacherippadi Junction were calculated from the details of cluster centers provided. The cluster intervals and corresponding LOS are given in Table 48.

Table 48. Cluster Intervals and Corresponding LOS of Kacherippadi Junction

Cluster Interval	LOS
> 12.195	A
9.98 – 12.195	B
8.5 – 9.98	C
7.5 – 8.5	D
6.0 – 7.5	E
< 6.0	F

The average LOS score of Kacherippadi junction was found to be 10.655. Therefore, the perceived LOS is ‘B’.

6.4.4 Jaseela junction

The details regarding the final cluster centers for Jaseela junction are shown in Table 49.

Table 49. Final Cluster Centres for Jaseela Junction

Cluster	Final Cluster Centre
1	3.00
2	4.00
3	5.00
4	6.50
5	8.67
6	12.02

The final cluster centers represent the average LOS score of each corresponding clusters. From the table, Cluster 1 corresponds to LOS F, cluster 2 corresponds to LOS E, cluster 3 corresponds to LOS D, cluster 4 corresponds to LOS C, cluster 5 corresponds to LOS B and cluster 6 corresponds to LOS A. The average LOS score of first cluster is 3, second cluster is 4, third cluster is 5 and so on. This is shown in Figure 28.

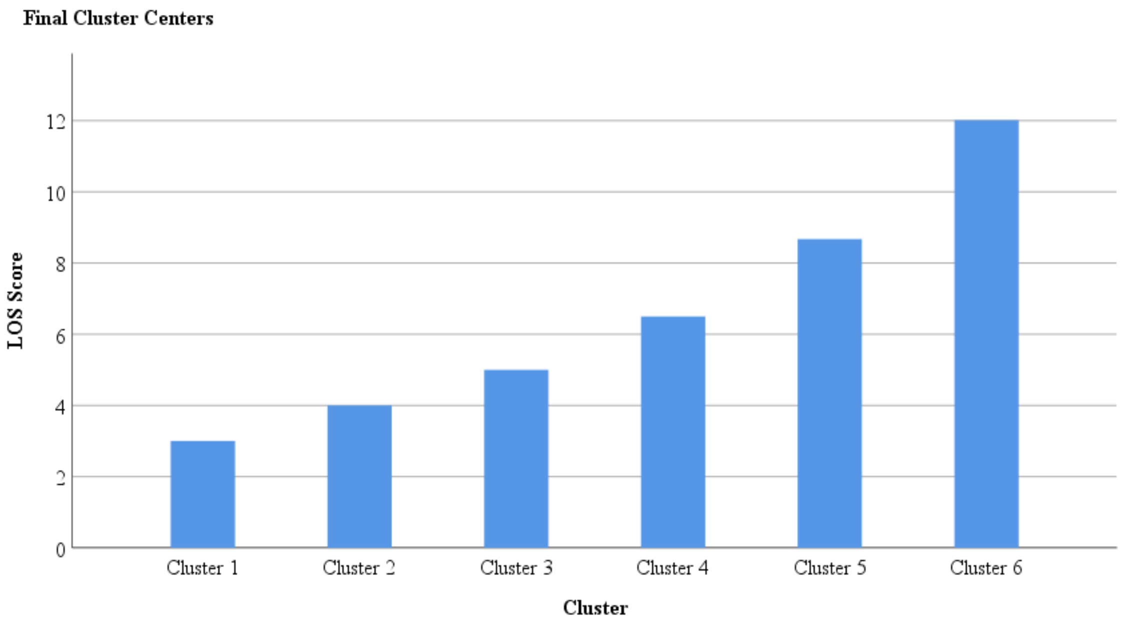

Fig. 28. Graph Showing Final Cluster Centres for Jaseela Junction

The details of distances between final cluster centers are provided in Table 50.

Table 50. Distances Between Final Cluster Centres for Melakkam Junction

Cluster	1	2	3	4	5	6
1		1.000	2.000	3.496	5.673	9.016
2	1.000		1.000	2.496	4.673	8.016
3	2.000	1.000		1.496	3.673	7.016
4	3.496	2.496	1.496		2.177	5.520
5	5.673	4.673	3.673	2.177		3.343
6	9.016	8.016	7.016	5.520	3.343	

The number of cases in each cluster is shown in Table 51.

Table 51. Number of cases in Each Cluster for Melakkam Junction

		No. of cases
Cluster	1	6.000
	2	15.000
	3	26.000
	4	129.000
	5	162.000
	6	62.000
Valid		400.000
Missing		.000

We can determine the number of responses corresponding to each LOS category from the table above. 6 responses corresponded to LOS F, 15 responses corresponded to LOS E, 26 responses corresponded to LOS D, 129 responses corresponded to LOS C, 162 responses corresponded to LOS B and 62 responses corresponded to LOS A.

The cluster intervals for Jaseela junction were calculated from the details of cluster centers provided. The cluster intervals and corresponding LOS are given in Table 52.

Table 52. Cluster Intervals and Corresponding LOS of Jaseela Junction

Cluster Interval	LOS
> 10.345	A
7.585 – 10.345	B
5.75 – 7.585	C
4.5 – 5.75	D
3.5 – 4.5	E
< 3.5	F

The average LOS score of Jaseela junction was found to be 7.99. Therefore, the perceived LOS is 'B'.

6.4.5 General questions

6.4.5.1 Midblock sections

The response to general question regarding the most important factor affecting the LOS of a midblock section is shown in the Figure 29.

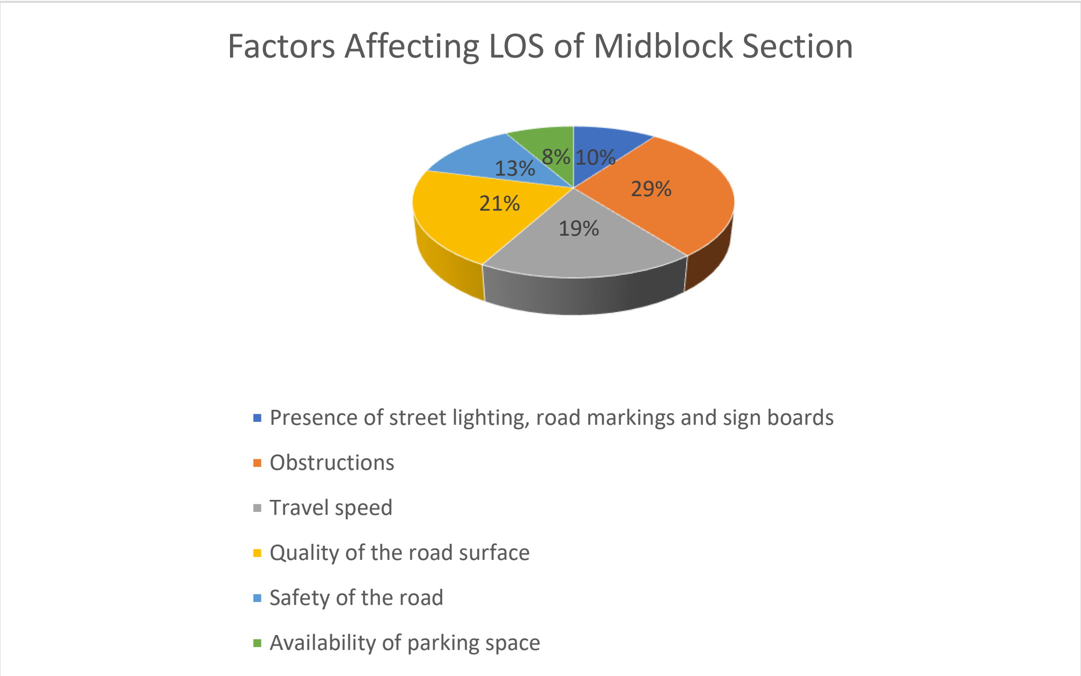

Fig. 29. Factors Affecting LOS of a Midblock Section

From the figure, it is observed that obstructions to traffic flow (29%) is the most important factor affecting the service of a road followed by quality of road surface (21%) and travel speed (19%).

6.4.5.2 Intersections

The response to general question regarding the most important factor affecting the LOS of an intersection is shown in the Figure 30.

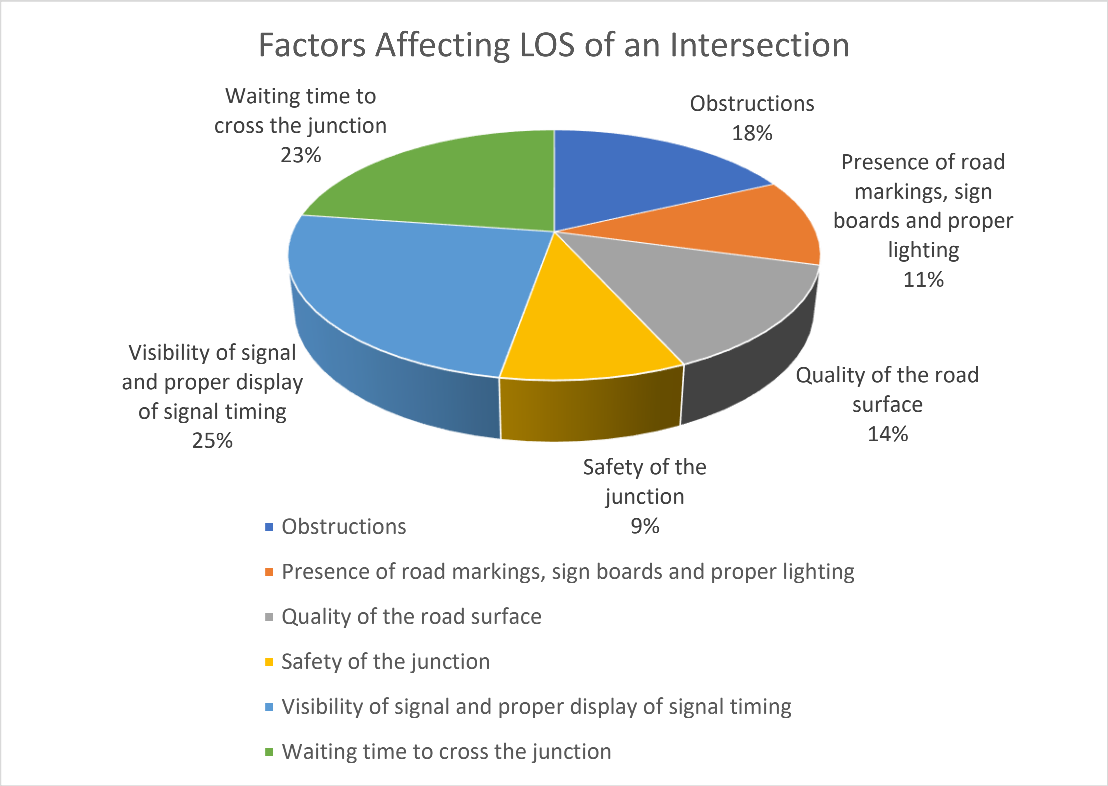

Fig. 30. Factors Affecting LOS of an Intersection

From the figure, it is observed that visibility of the signal and proper display of signal timing (25%) is the most important factor affecting the service of a junction followed by the waiting time at the junction (23%) and obstructions to traffic movement (18%).

6.4.6 User perceived average travel speed

6.4.6.1 Kacherippadi bypass

The user perceived average travel speed details of Kacherippadi bypass is given in Figure 31.

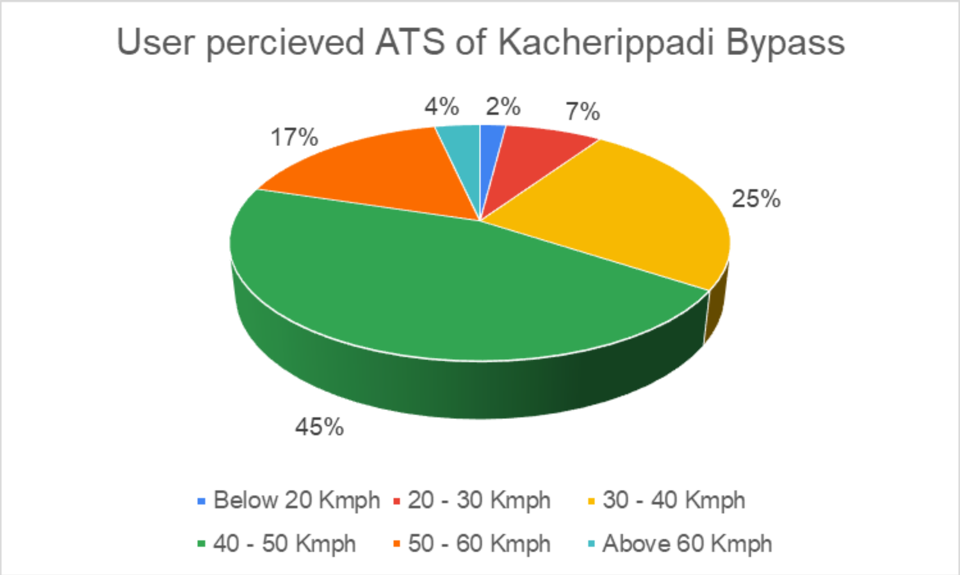

Fig. 31. User Perceived ATS of Kacherippadi Bypass

From the figure, it is found that the user perceived (45% of the participants) ATS of Kacherippadi bypass is 40 – 50 Kmph.

6.4.6.2 Melakkam bypass

The user perceived average travel speed details of Melakkam bypass is given in Figure 32.

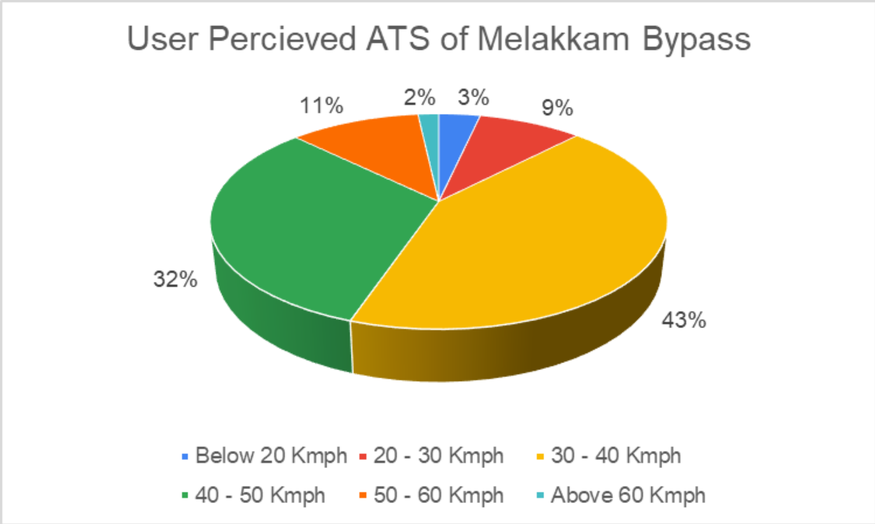

Fig. 32. User Perceived ATS of Melakkam Bypass

From the figure, it is found that the user perceived (43% of the participants) ATS of Kacherippadi bypass is 30 - 40 Kmph.

CHAPTER 7

CONCLUSIONS

7.1 LOS Measured from the Field

LOS of the different subject facilities were found out. For Melakkam bypass, the ATS was found to be 39.7% of the FFS and the corresponding LOS as per Indo HCM was determined to be ‘C’. The LOS for the facility as per Standard HCM is turned out to be ‘E’. This difference shows the effect of heterogenous nature of traffic on LOS. This showed that an 'unstable flow' as per homogenous traffic flow is still considered as 'stable' in heterogenous traffic flow conditions. This flexibility in LOS range is to accommodate the heterogenous nature of Indian traffic conditions. For Kacherippad bypass, the ATS was found to be 44.4% of the FFS and the corresponding LOS as per Indo HCM was determined to be ‘C’. The LOS for the same facility as per Standard HCM is turned out to be ‘D’. This again is a measure of the effect of heterogenous nature of traffic has on ranges of LOS.

Although the LOS as per std HCM changed due to change in % of ATS, the LOS as per Indo HCM remain unchanged. This is due to the large interval length provided to accommodate the heterogenous nature.

The LOS of Jaseela junction was determined as ‘C’. The LOS was also determined for different non-priority movements of Kacherippadi junction, which is an unsignalized intersection. Movements 8 and 11 had LOS as ‘D’, movement 7 had LOS as ‘B’, movement 1 had LOS as ‘C’ and movements 4 and 10 had LOS as ‘A’.

7.2 LOS Obtained from Perception Survey

The LOS perceived by the users of the same subject facilities were determined from user survey. The user perceived LOS of all the facilities, namely Kacherippad bypass, Melakkam bypass, Kacherippadi junction and Jaseela junction were turned out to be ‘B’. This shows that the LOS perceived is higher than actual measured LOS in all the cases. This justifies the higher ATS perceived by the users of both the midblock sections than the actual ATS.

Obstructions to traffic flow is the most important factor affecting the service of a road (perceived by 29% of the participants) followed by quality of road surface and travel speed. Visibility of the signal and proper display of signal timing is the most important factor affecting the service of a junction (perceived by 25% of the participants) followed by the waiting time at the junction and obstruction to traffic movement.

7.3 Scope for Future Work

Researches could be conducted to systematically integrate the factors of Obstruction, safety, surface quality, etc. in the analysis of LOS a road facility. Methods need to be found out to quantitatively measure these factors based on field conditions and to develop LOS intervals based on it. More studies need to be carried out in LOS determination of a traffic facility based on user perception, so that this area can evolve and provide a highly dependable and structured format for user perception analysis.

CHAPTER 8
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APPENDIX

Questionnaire used for the survey:

ESTIMATION OF USER PERCEIVED LEVEL OF SERVICE OF URBAN ROADS AND INTERSECTIONS IN MANJERI

I'm an M.tech Transportation Engineering student at TKM College of Engineering. I kindly request you to honestly take part in this survey conducted as part of my project. The data collected will be used only for academic purposes. I shall be thankful to you for spending a little of your precious time in filling this questionnaire.
- SHUHAIB M C

This survey is concerned about two bypass roads surrounding Manjeri town, and two intersections connecting these bypasses to the main roads. The details of which are listed below. This survey should only be attended by people residing in Manjeri or nearby places, and/or those who travel through Manjeri frequently or occasionally.

Bypass roads:
1. Kacherippadi - Thurakkal Bypass
2. Melakkam - Thurakkal bypass (Jaseela junction to Thurakkal)

Junctions:
1. Kacherippadi Junction
2. Jaseela junction (Melakkam signal junction)

BASIC DETAILS

1. Gender:
a) Male
b) Female

2. Age:

a) 18 -30

b) 31 - 45

c) 46 - 60

d) Above 60

3. Driving experience in years:

a) 0 – 5

b) 6 – 15

c) 16- 30

d) Above 30

4. Type of vehicle:

a) 2-wheeler

b) 3-wheeler

c) Car/Jeep/Van

d) Goods auto/Small pickup/Other small commercial carriers

e) Bus

f) 2/3 axle truck

g) Above 3 axle truck

QUESTIONS ABOUT MIDBLOCK SECTIONS

1. The average speed with which you are usually able to travel on this road?

   a) above 60 Kmph   b) 50 - 60 Kmph   c) 40 - 50 Kmph

   d) 30 - 40 Kmph   e) 20 - 30 Kmph   f) below 20 Kmph

2. Quality of the road surface?

   a) Excellent

   b) Good

   c) Average

   d) Bad

   e) Worse

3. How much obstruction you feel due to vehicles entering/crossing the bypass from side roads, parked vehicles and bus stops?
    a) No obstructions
    b) Minor obstructions
    c) Medium obstructions
    d) Major obstructions
    e) Always obstructed

4. The level of safety experienced while travelling through the bypass?
    a) highly safe
    b) Mostly safe
    c) Average safety
    d) Less safe
    e) Unsafe

QUESTIONS ABOUT KACHERIPPADI JUNCTION

1. The delay experienced while travelling through the junction?
    a) Less than 1 minute
    b) 1 - 2 minutes
    c) 2 - 3 minutes
    d) 3 - 4 minutes
    e) More than 4 minutes

2. How much obstruction you feel due to heavy vehicles, right turning vehicles and crossing pedestrians?
    a) No obstructions
    b) Minor obstructions
    c) Medium obstructions
    d) Major obstructions
    e) Always obstructed

3. Rate the arrangement of road markings, sign boards and proper lighting in the junction? (on a scale of 1 – 5), where

1 - Not at all present

5 - Arranged in an excellent manner

QUESTIONS ABOUT MELAKKAM JUNCTION

1. The delay experienced while travelling through the junction?

a) Less than 1 minute
b) 1 - 2 minutes
c) 2 - 3 minutes
d) 3 - 4 minutes
e) More than 4 minutes

2. How much obstruction you feel due to heavy vehicles, right turning vehicles and crossing pedestrians?

a) No obstructions
b) Minor obstructions
c) Medium obstructions
d) Major obstructions
e) Always obstructed

3. The level of visibility of the signal from the queue? (on a scale of 1-5), where

1 - Not at all visible

5 - Clearly visible always

GENERAL QUESTIONS

1. Which is the most important factor affecting a road as far as service is concerned?

a) Travel speed
b) Quality of the road surface
c) Obstructions (due to crossing vehicles, bus stops and parked vehicles)
d) Safety of the road
e) Presence of street lighting, road markings and sign boards
f) Availability of parking space

2. Which is the most important factor affecting a junction as far as service is concerned?

a) Waiting time to cross the junction
b) Visibility of signal and proper display of signal timing
c) Quality of the road surface
d) Presence of road markings, sign boards and proper lighting
e) Obstructions
f) Safety of the junction