QUANTIFICATION OF LEVEL OF SERVICE OF U-TURNS IN MEDIAN OPENINGS UNDER MIXED TRAFFIC CONDITION

PROJECT REPORT

Submitted by

SUMINAMOL A

REG NO. : TKM20CETE16

to

the A P J Abdul Kalam Technological University in partial fulfilment of the requirements for the award of the Degree

of

Master of Technology

in

Transportation Engineering

DEPARTMENT OF CIVIL ENGINEERING

T.K.M. College of Engineering, Kollam

July 2022

DECLARATION

I undersigned hereby declare that the project report “Quantification of level of service of U turns in median openings under mixed traffic condition”, 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 Dr. Kavitha Madhu. 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.

KOLLAM SUMINAMOL A

07-07-2022

DEPARTMENT OF CIVIL ENGINEERING

T.K.M College of Engineering Kollam

CERTIFICATE

Certified that this report entitled '**Quantification of Level of Service of U-Turns in Median Openings under mixed traffic condition'** is the report of the project presented by **SUMINAMOL A,** Reg. No.: **TKM20CETE16** during the year **2021-2022** in partial fulfilment of the requirement for the award of Degree of Master of Technology in Transportation Engineering of the A P J Abdul Kalam Technological University.

Guide and Co-ordinator:	Head of the Department:
Dr. Kavitha Madhu	**Dr. Sajeeb R**
Associate Professor,	Professor,
Dept. of Civil Engg.	Dept. of Civil Engg.
TKMCE, Kollam	TKMCE, Kollam

ACKNOWLEDGEMENT

I take this opportunity to express my deep sense of gratitude and sincere thanks to all who helped me to complete this phase of my project successfully.

I am deeply indebted to my guide, **Dr. Kavitha Madhu.**, Associate Professor, Department of Civil Engineering for her excellent guidance, positive criticism and valuable assistance for the preparation of this work.

I am greatly thankful to the project coordinator's **Dr. Kavitha Madhu.**, Associate Professor, Department of Civil Engineering, **Prof. Meenu Tomson**., Assistant Professor, Department of Civil Engineering and **Prof. Jijin A.**, Assistant Professor, Department of Civil Engineering, for giving me the opportunity and necessary information to present this work.

I am thankful to **Dr. Sajeeb R**., Professor and Head of the Department of Civil Engineering, for his kind support.

I would also like to convey my sincere thanks to my parents and friends, without whose help this work would not have been a success.

Above all, I thank the almighty God for the successful conduct of this project.

SUMINAMOL A.

ABSTRACT

Median openings are provided to facilitate the U-turn movement of vehicles. Majority of median openings are uncontrolled and no priority is given for through vehicles. Uncontrolled median openings result in two kinds of delay. Firstly, the U-turning vehicles impart delay to the through traffic. At the same time, U-turning vehicles are also subjected to a certain amount of delay while waiting for suitable gap to merge with the through traffic stream. The delay experienced by U-turning vehicles are referred to as service delay while the delay experienced by the approaching through vehicle at the median opening is termed as median delay. The effect of both U-turning and through vehicles are incorporated into a single term referred to as area occupancy. The Level of service (LOS) of U-turn movement at a median opening will be beneficial to analyse the operational efficiency of the traffic facility. Service delay, median delay and area occupancy are used to quantify the LOS of the U-turn facility. K- Means clustering method is adopted in this study to group the parameters to define the LOS. A comparison among the different LOS classification using the various parameters are also conducted.

The delay was found to have an exponential increase with rise in vehicular volume with the two-wheelers experiencing the lowest delay. The models developed from this study can be used to determine the delay parameters from the vehicular volume obtained from field data. Clusters were developed for all three parameters that were classified from A to F. The operational efficiency of various traffic facilities can be analysed by the LOS determination. A better understanding of such facilities can help to avoid the problems of congestion and thereby improve the overall quality of service in such facilities.

Keywords— U-turns, service delay, median delay, area occupancy, level of service, K-means clustering

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AO	Area Occupancy
ANOVA	Analysis of Variance
CBD	Central Business District
CHI	Calinski-Harabasz index
DBI	Davies- Bouldin Index
DI	Dunn Index
FCM	Fuzzy C-means
GA	Genetic Algorithm
HAC	Hierarchical Agglomerative Clustering
HCM	Highway Capacity Manual
HI	Hartigan Index
KLI	Krzanowski-Lai Index
LOS	Level of Service
LCV	Light Commercial Vehicle
MAPE	Mean Absolute Percentage Error
QOS	Quality of Service
RI	R-square index
SC	Silhouette Coefficient
SPSS	Statistical Package for Social Sciences
SUV	Sports Utility Vehicle
SWI	Silhouette Width Index
WI	Weighted Inter Intra Index

CHAPTER 1

INTRODUCTION

1.1. General

In major roads, directional flow of traffic is demarcated into two streams with the help of medians thus reducing the chances of head on collisions and to increase the capacity. The provision to change the direction of travel from one traffic stream to other is facilitated by means of openings in the medians. Careful manoeuvring is required for turning direction from one stream to another. Most median openings lack any kind of traffic control mechanism to regulate traffic and ensure the safety of vehicles making U turns, particularly in developing countries. These median openings frequently result in a localised decline of Level of Service (LOS) in the roadway facilities. The primary cause for this is that the through vehicles in the merging lane are not given priority. The majority of U-turning vehicles watch for a critical gap, or appropriate space in the flow of through traffic, before merging into the lane and switching lanes. HCM (2010) defines critical gap as the minimum time interval between the front bumpers of two successive vehicles in the major traffic stream that will allow the entry of one minor street vehicle. The driver will make a forced entry if the waiting period goes beyond a certain point, which can slow down the through traffic. As a result, the through vehicle and the U-turning vehicle both encounter delays that are referred to as service and median delays, respectively.

Median opening results in traffic issues like decreased capacity and safety concerns on urban roads (Diwakar et al., 2016). According to Mohapatra et al. (2014), the median opening area forces 60 to 80 percent of oncoming mainline vehicles to slow down. Speed reduction of vehicles were also seen at unmanaged roads in India, according to Ashalatha and Chandra (2011). Ma et al. (2013) evaluated the main stream delay in a context with restricted priority at unsignalized junctions. It is crucial to look at the delays experienced by both vehicular traffic (U-turns and approaching through traffic stream) while evaluating median opening’s performance, especially when the priority of movement is shared. "Area occupancy" (AO) refers to the combined impact of through traffic and U turns while taking into account the impact of a diverse traffic situation.

For each type of facility, the HCM-2010 specifies six service levels, ranging from "A" to "F." The HCM-2010 focuses in particular on the quality of service characteristics of trip duration, speed, delay, manoeuvrability, and comfort (Mohapatra et al., 2015). These parameters, namely service delay, median delay, and area occupancy, will be used to categorise the LOS of a U-turn facility in this study. To group and classify the limits of the values for establishing the LOS of a facility, different clustering methods are used.

1.2. Problem Statement

Due to prevalence of U turn facilities in mid-block median openings on urban arterials, studies on such facilities is essential for the effective planning and control of traffic at such a facility. The results of earlier research shed light on the significance of U-turn manoeuvres, not only in terms of the repercussions that have an impact on the sustainability of the transportation system but also in terms of the causes of traffic congestion. These traffic delays (caused by U-turns) can result in inconvenience, financial losses to drivers and have widespread impacts like increased vehicle operating cost, air pollution and so on.

In order to effectively define the LOS category, the study focuses on low priority mobility metrics such as service delay, median delay, and area occupancy. The initial step in the LOS analysis process is defining LOS, although this step has not been adequately established for the varied traffic conditions present on Indian urban highways (Bhuyan and Rao, 2013). Due to the lack of a priority provision for through traffic movement, a comparison between the service delay and the median delay can be made to ascertain the parameter that best describes the state of a roadway. Assessing the functioning of the traffic facility will be made easier by identifying localised LOS degradation. Presence of median openings at closer intervals on urban arterials of India highlights the need to study and analyse the effect of U-turns on delay estimation.

1.3. Summary

In this study the level of service of U-turns under mixed traffic condition will be quantified. The study comprises of five sections in which the first section deals with the literature study conducted so far which is followed by the framing of objectives and scope. The methodology modelling and analysis part has been formulated in the next section and the final section includes the concluding remarks.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

The operation of heterogeneous traffic in emerging nations differs significantly from the operation of homogeneous traffic due to differences in the functioning and operational parameters of the various types of vehicles. Mixed traffic condition is characterized by the presence of different vehicle types and weak lane discipline. The driving behaviour and vehicle characteristics of 2 wheelers (2W) and passenger cars which constitute the major share of traffic are different from each other (Madhu et al., 2022). Additionally, vehicles of all categories utilise the road space. Smaller vehicles frequently squeeze into any opening between larger vehicles and manoeuvre haphazardly. Vehicles are found to move nearby on the road when there is no lane control and a large variation in the size of various vehicle types. Service delay, median delay, and area occupancy are among the metrics that were examined in this study to quantify LOS. In a study by Mohapatra et al. (2016), service delay was used as a metric to calculate the amount of service provided by U turns. For the purpose of quantifying service delay, Mohanty and Dey (2018) used area occupancy.

Delay is a crucial metric that is frequently utilised in traffic engineering to assess the effectiveness of a number of traffic facilities (Chaudhry and Ranjitkar, 2013). The HCM (2010) provides a special focus on parameters of service quality such as journey duration, speed, delay, manoeuvrability, and comfort (Patnaik et al., 2016). At controlled or signalised intersections, control delay is employed to quantify LOS (LOS) (HCM 2010). The delay suffered by low-priority movements serves as a performance indicator for unsignalized intersections (Ashalatha and Chandra, 2011). Mohapatra et al. (2015) conducted the initial study on the LOS of U-turning vehicle at unmanaged openings in median. They evaluated LOS using the service delay incurred by lesser priority flow.

2.2. Service Delay

Service delay is significant because it affects departure headway, which is inversely related to capacity. In order to gauge the effectiveness of unmanaged opening of a medians, Mohapatra et al. (2015) used the delay that low priory movement, or U-tuning movement, experienced. In order to assess the LOS for unmanaged median openings on multilane separated highways with mixed traffic, service delay is taken into account as a measure of effectiveness (MOE). On several weekdays throughout peak and off-peak hours, statistics on service delays were gathered at various median openings for five different groups of vehicles. The cluster analysis approach was used to find a solution to the classification problem that is the quantification of delay margins into LOS (A to F) of 6 different categories. In this regard, 5 different validation indices were utilised in identifying ideal cluster division. The classification of service delay into 6 different categories was attained by the K-means clustering technique after finalising the ideal cluster division for the data input, and service delay ranges of various LOS categories were proposed. The ideal working situation, LOS category "A," has delay ranges of less than 5 seconds, and the worst operating state, LOS category "F," has delay ranges of more than 33 seconds. Researchers and practitioners in areas where varied traffic conditions are prevalent can benefit greatly from the suggested delay ranges for the LOS categories.

2.3. Median Delay

According to Mohanty and Dey's (2019) study, the impact on median delay by U turns occurs in ascending order. Because of the adaptability to shift laterally, the vehicles in major stream typically engage in more lane switching during low traffic levels rather than slowing down. With more traffic, this speed drop becomes more pronounced. Because of this, major stream vehicles are observed to incur a median delay that is lower at low traffic quantities than it is at greater traffic volumes. Because vehicles are discovered to be decelerating in the initial portion of the median opening while accelerating the second stretch. Median delay at the second portion was found to be lower than the median delay at the first portion of opening. A 5% significant threshold t-test showed that there was a significant difference between Median delay 1 and Median delay 2. Mohanty and Dey (2018) suggested three models to determine the median delays 1 and 2 and total. In the regression study, three variables that affect the median delay were taken into consideration as independent variables: (1) the amount of U-turning traffic; (2) the zone of vehicular travel in the area of median opening; and (3) the type of vehicle taking U turn. By contrasting delay values produced from the models and those received from the field, the suggested models' correctness was evaluated. Additionally, it was discovered that the maximum MAPE values were less than 9%, demonstrating the accuracy of the suggested models.

2.4. Area Occupancy

Traffic density has been cited in numerous studies as a crucial factor in determining how well roads are maintained. According to Sakai et al. (2011), "traffic density" and "travelling speed" are suitable for assessing a road section's quality of service (QOS). A suggestion was made which is that a key aspect affecting how QOS is perceived is traffic density (Washburn et al., 2006). According to reports, traffic density, a gauge of traffic congestion, is crucial in determining how satisfied road users are, even though variations in speed and visibility influence how drivers perceive their surroundings (Choocharukul et al., 2004). Additionally, HCM (2010) quantifies LOS using traffic flow and density as parameters (Kita et al., 2000). In India, the quality of flow varies depending on the amount of traffic present on a given roadway. The diverse properties of a traffic stream are not taken into account by traffic density. According to Arasan and Dhivya (2008), traffic density will only remain stable in a traffic flow which is homogeneous, where vehicular streams move at consistent speeds and constant distances. In this investigation, Mallikarjuna and Rao (2006) reported that occupancy is substituted for density. They added that occupancy is expressed in terms of vehicular length, a statistic used to explain traffic, comprising vehicles of various lengths positioned throughout the width of road. However, lane discipline is rarely enforced under Indian conditions, and the traffic stream is mixed, made up of vehicles with a varied range of dynamic and static features.

Multiple vehicle kinds and non-lane-based movement are two characteristics of typical heterogeneous traffic. It was taken into account that the vehicles were off-centre. To quantify the performance of vehicles in diverse traffic situations, Mallikarjuna and Rao (2006) suggested a novel measure of occupancy termed "Area Occupancy," which was later refined by Arasan and Dhivya (2008). The idea of area occupancy, as opposed to occupancy, takes into account the flow of cars occupying the entire width of the road. The assumption used in measuring area occupancy is that a vehicle's entry and exit speeds inside the test segment must be constant. This presumption might not always be accurate, though. This study by Mohanty and Dey (2021) takes into account the entry and exit speed corresponding to the vehicle as it passes the study segment and thus suggests a changed methodology for assessing AO.

In order to consider vehicular traffic that doesn’t follow lane discipline, Mallikarjuna and Rao (2006) established the concept of "area occupancy." The percentage of time that a particular stretch of a road is occupied by the group of observed cars is how area occupancy is expressed. Figures 2.1 to 2.5 show the process for determining area occupancy according to Mohanty and Dey (2017). Arasan and Dhivya (2008) made the assumption that the vehicle's speed would remain constant throughout the road's length. The vehicles must cross the detecting zone at a steady speed, according to Mallikarjuna and Rao (2006). But at openings in median, neither the approaching major stream vehicle that are coming at them nor the vehicle making the U turn can keep their speeds steady. In their study of the speed profiles of approaching through vehicles, Mohanty and Dey (2017) that the speed of the vehicles gradually decreased. The median opening's centre had the greatest speed drop. Similar to U-turns, which require a 180-degree turn to be completed, it is difficult for the vehicles to maintain a consistent speed during this process. Additionally, it has been observed that during slow merging, U-turning cars wait for service before beginning to roll at a low speed and gradually complete the merging procedure. As a result, maintaining a steady speed at openings in median area becomes almost impossible for both the incoming through traffic and U-turning traffic. The idea of evaluating AO by approaching major stream vehicles and vehicles making a U-turn has been changed in light of this actual situation in the field.

In order to determine the LOS ranges for the unmanaged opening of a median sections, Mohanty and Dey (2018) used the total AO at the area of the median opening that could lead to conflict (the entire width of the road segment, from the opening's centre to its tip, 3 m downstream). The methods put out by Arasan and Dhivya (2008) to estimate AO need not retain the premise of keeping the speed uniform at the entrance and departure of a test segment.

2.5. Clustering

By using the details from the data set indicating their connections, objects are grouped through the process of cluster analysis. The goal of the clustering technique is to organise the data into groups where the data points are distinct from one another while also being similar to one another. In comparison to the centres of other cluster groups, the cluster centre of one particular cluster is closer to the individual data points in that cluster than others. The clusters created by an effective clustering method will have a big inter-cluster distance and small intra-cluster distance. K-means, K-medoid, and Hierarchical Agglomerative are three popular clustering methods that can be used to define LOS criterion.

Maitra et al. (1999) advocated categorising the LOS into nine groups, "A" to "I," and used congestion as a measure of efficacy for the current diverse traffic environment in India. For the varied traffic conditions present in India, Marwah and Singh (2000) divided LOS into four classes (I–IV). Researchers have used the clustering method to try to alleviate various traffic issues. For the varied traffic conditions present in India, Bhuyan and Rao (2010) used a GPS palmtop to acquire speed data and created LOS categories using Fuzzy C-means (FCM), Hierarchical Agglomerative Clustering (HAC), K-means, and K-medoid clustering. Free flow speed and average travel speed were utilised by Mohapatra and Bhuyan (2012) to categorise urban roadways in India. Using a hybrid approach made up of a Genetic Algorithm (GA) and a Fuzzy C-mean, a model was created by Mohapatra et al. (2015) to determine the LOS classifications of urban Indian roads. Azimi and Zhang (2010) classified the state of highway traffic flow using three distinct clustering techniques. Additionally, they looked for consistency between the HCM classification and the clustering approach. Ivana et al. (2011) created an innovative hybrid algorithm for the categorization of urban highways based on traffic and road facilities observational data. In order to define the LOS ranges in an Indian setting, Bhuyan and Rao (2010) used the K-mean and K-medoid clustering method. To determine LOS of U-turns at unmanaged opening of a medians, Mohapatra et al. (2015) used various clustering algorithms. After examining the cluster validation indices, Mohapatra and Dey, 2021) concluded that the AP algorithm is the most reliable approach for clustering of service delay and that 6 clusters are the ideal number for the given data set.

K-mean clustering is among the unsupervised hard partitioning approaches for addressing the classification problem. Using a cluster's internal variation as a quantity, the K-mean technique generates homogenous clusters. The method aims to partition the data in such a way as to minimise variation within a cluster. Objects are first distributed randomly among the clusters in this stage of the clustering process. To lessen the within-cluster variation, which is essentially the distance between each observation and the associated cluster's centre, the objects are then gradually relocated to new clusters (squared). If moving an object to another cluster minimises the variation within the cluster, it is relocated to that cluster (Mohapatra and Dey, 2021).

Because the computing stages are identical, the K-medoid clustering algorithm is equal to the k-means clustering technique. These two algorithms use different centroid choices. In contrast to the medoid approach, where one of the point from the data set is chosen as the centroid, K-mean clustering does not require the same. It is necessary to calculate fictitious cluster centroids and the nearest data point to these chosen points is finalized as centroid which is a useful technique for characterising or reducing sample. The drawback is that it is similar to the well-known K-means algorithm, which aims to produce centroids by minimising the average squared distance.

Affinity propagation, a theoretical clustering technique created by Dueck in 2009, is special in that it simultaneously evaluates every data point as a potential exemplar (cluster centre). The algorithm's ability to count the clusters connected to a specific data set is a benefit. The theory of responsibility and availability are crucial theories that depict how well-suited a data point is to be a prospective cluster centre. The sum of the values of r I k) and a serves as the foundation for choosing a certain data point as the cluster centre (i, k). The similarity (s) matrix, responsibility (r), and availability (a) matrices are the three matrices this algorithm uses to operate. The only connection between fuzzy logic and fuzzy cluster analysis is the use of the membership coefficient. The clustering technique developed by Bezdek (1981) was applied in the current investigation. Due to its broad use and effective outcomes, cluster analysis was done using it. Both Mohapatra et al. (2012) and Bhuyan and Rao (2010) used the technique to determine the urban roads LOS.

Utilizing cluster validity metrics allows for the quality of clustering results to be confirmed. It has mostly been used to estimate and compare entire partitions, produced by various techniques or by the same algorithms when various parameters were employed. To establish the appropriate cluster number for a data sample and to select the best clustering method, the cluster validation measure is used (Mohaptara and Bhuyan, 2012). Different cluster validation factors were used in this investigation. The Dunn index (DI), Silhouette Width index (SWI), Calinski-Harabasz index (CHI) are utilised to select the best clustering technique out of these eight validation parameters. The ideal cluster number in the sample set is determined using R-square (RI) index and four additional validation parameters, including the Davies-Bouldin index (DBI), Weighted inter-intra index (WI), Krzanowski-Lai index (KLI) and Hartigan index (HI). Mohanty and Dey (2019) employed the K-means clustering technique in their investigation since it outperformed the hierarchical agglomerative strategy. Using the ANOVA test and a post hoc comparison test known as the Bonferroni test, the resultant cluster groupings are checked for statistical correctness. Both analyses demonstrate that the resulting cluster groups are statistically valid and that the cluster centres' means are statistically distinct from one another at the 5% level of significance. The recommended ranges for service levels A through F have finally been established. These values may be used in cities with similar shaped roads. For cities with different road geometry, the exact same process that has been provided here may also be utilised to calculate LOS ranges.

2.6. Summary

As a result, the delay caused by U-turns alone cannot be taken into account when calculating LOS. The delay to through traffic in any unmanaged opening of a median impacts the performance of opening of a median. Delay that approaching through cars in the median opening region experience is estimated by Mohanty and Dey's (2018) study. Thus, when major and minor traffic stream's net impact is taken into account, the LOS of the opening of the median is represented entirely. Median openings with characteristics other than the ones considered for study could potentially employ the adopted technique. Additionally, delays in traffic at any traffic facility result in queues, longer travel times, and higher prices. Minh et al., 2010 stated that traffic congestion delays also increase the pollution to noise and air. Therefore, it is crucial and significant to be able to measure traffic delays while planning, designing, and evaluating various traffic-flow factors (Minh et al., 2010). Factors including delay, capacity, speed, and queue lengths, among others, are used to assess the LOS at any traffic facility. The most significant of these is delay since it provides a quantitative representation of travel time loss and usage of fuel. As a result, predicted traffic facility delays can be utilised to analyse both economic and environmental factors, such as lost time and fuel consumption (Akgüngör and Bullen, 2007). By using the derived delays of major stream vehicles, it may become possible to better understand how traffic moves through median openings and, as a result, suggest more effective measures for controlling congestion there.

The research gap identified from the literature review is that a comparison between the various LOS classifications obtained from considering U turning and through vehicular movements separately have not been conducted. To overcome the research gap the following objectives are formulated.

CHAPTER 3

OBJECTIVE AND SCOPE

3.1. Introduction

The study aims to quantify the LOS of median opening facilities in mixed traffic condition by considering different parameters. It also aims to compare the classification results obtained from each of the parameters and to state the parameters that best represent the LOS of a median opening facility.

3.2. Objectives

The objectives formulated for the present study include:

- To identify the parameters that influence the behaviour of vehicle at median opening
- To develop delay models for median opening
    - Service delay models for different vehicle categories
    - Median delay models
    - Area occupancy models
- To quantify the LOS of U turn facility at a median opening using
    - Delay experienced by U turning vehicle
    - Delay experienced by through vehicle
    - Combined delay experienced by both U turning and through vehicles

3.3. Scope

The study is conducted on a road stretch which is an uncontrolled four lane divided midblock section**.** The stretch is selected in such a way that the effect of horizontal curve, intersections, bus stop, pedestrian activity, or any form of side friction is minimum.

CHAPTER 4

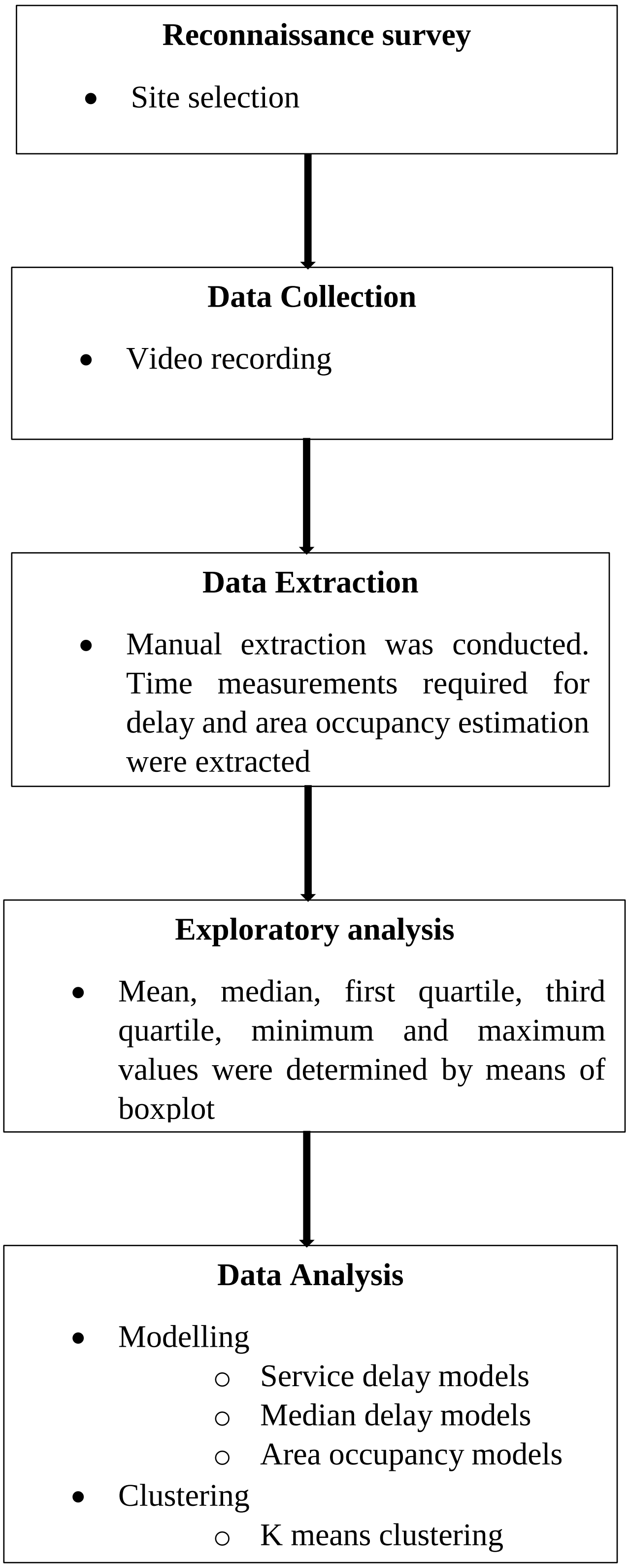
METHODOLOGY AND DATA COLLECTION

4.1. Introduction

The methodology for the study was formulated based on the investigations that have been done up to this point in the context of a U-turn facility in a heterogeneous traffic situation. The literature survey was followed by reconnaissance survey to select a section and the data collection was done by videography. Manual method of data extraction was followed. Statistical package for social sciences (SPSS) was the tool used for analysis.

4.2. Detailed Methodology

In the reconnaissance survey the criteria taken into account for categorising the LOS provided by a U-turn facility were identified. After completing a thorough examination of the major roadways in numerous sites throughout Kollam, Ernakulam, and Trivandrum, a spot suited for the study was found. The Maharaja's Road in Ernakulam City was found to contain a U-turn facility that met the study's requirements. A total of three hour data was collected from 9 am in the morning to 12 pm in afternoon. After consulting the locals in the neighbourhood about peak hour traffic and taking into account morning travel to the central business district (CBD), this time frame was chosen. During the morning rush hour, it was assumed that the lane leading to the CBD was the merging lane to which the U-turn movement was linked from the opposing lane leading away from the CBD. The variables such as through traffic volume and composition, U turning traffic volume and composition, service delay, area occupancy and median delay were extracted manually. The relation between the traffic volume and the parameters service delay, median delay and area occupancy were analysed. Relationship trend graphs and vehicle composition were determined. SPSS was adopted for clustering analysis to group the parameters studied under various LOS categories. A flowchart representing the methodology is shown in Figure 4.1.



Reconnaissance survey

- Site selection

Data Collection

- Video recording

Data Extraction

- Manual extraction was conducted. Time measurements required for delay and area occupancy estimation were extracted

Exploratory analysis

- Mean, median, first quartile, third quartile, minimum and maximum values were determined by means of boxplot

Data Analysis

- Modelling
  - Service delay models
  - Median delay models
  - Area occupancy models
- Clustering
  - K means clustering

Figure 4.1. Flowchart Representing Methodology

4.3. Data Collection

The pertinent traffic variables were gathered from the field in order to evaluate the operational effects of U-turns at unmanaged opening of a medians. In order to ensure that the traffic flow at this test site is unaffected by horizontal curvature, the presence of downstream or upstream crossings, bus stop pedestrian movements, or any type of side friction, a test stretch in the Indian city of Ernakulam was chosen. The test section's geometrical details are shown in Table 4.1 below. On a four-lane divided urban road, the current study was carried out. Field data have been gathered using video capturing techniques. In order to capture an unimpeded view of all traffic movements, video cameras were set up at key locations, and data during peak hours and off peak hours was recorded.

Table 4.1. Geometrical Details of Selected Study Stretch

Road Section	Ernakulam Maharaja’s road
Length of median opening, m	14.18
Width of road section, m	6.18
Length of section for determination of steady speed, m	19.61

4.4. Data Extraction

By playing the video, the information needed for analysis was extracted. Five categories were used to group the subject vehicles: two-wheelers (2W), three-wheelers (3W), sports utility vehicles (SUVs), cars, and light utility vehicles (LCV). Playing the video allowed for the extraction of the category and volume of each type of vehicle. Using this method, it was possible to count the number of U-turns and through vehicles.

4.4.1. Service delay

Since there were no heavy vehicles in the composition of the U turning traffic, the service delay experienced by HVs was not taken into consideration for this study. From the moment the front of the vehicle touched the reference line until the rear of the vehicle crossed the reference line, Mohapatra et al. (2015) measured the vehicle's service time. Here, the service delay that a vehicle experience was determined by timing the front bumper's arrival at the considered point (t_1) and the rear bumper's passage over the same (t_2) as shown in Figures 4.2 and 4.3 respectively.

The service delay (S.D.) to a subject vehicle was computed using the following Equation 4.1:

$$\text{Service delay} = t_2 - t_1 \qquad (4.1)$$

Where,

t_1 = time of arrival of front bumper at reference line

t_2 = time of departure of back bumper from the reference line

The relationship between the parameter service delay and traffic volume was examined. The traffic characteristic such as the vehicular volume count of the through and U turning traffic were acquired. Additionally, a comparison of the service delays for different categories of vehicles was conducted.

Figure 4.2. U-Turning Vehicle Approaching towards Reference Line

Figure 4.3. The Rear Bumper of the U-Turning Vehicle Departs from the Reference Line

4.4.2. Median delay

As the oncoming through traffic advances into unmanaged opening of a medians, various types of delay are recognised, including approach delay and median delay. Figure 4.4 is a graphic illustration of these delay principles. The median delay is the time it takes for approaching through traffic to pass the median opening area. It is calculated as the extra time required for slowing inside the median opening, the time spent halted (if any), and the delay for acceleration before the median opening. In order to determine the median delay, the time needed to travel from point 2 to point 3 is recorded. The median delay (D_m) is then calculated as per the Equation 4.2 as follows:

$$D_m = (t_3 - t_2) - \frac{(L2 - L3)}{Vs} \tag{4.2}$$

Where,

t_2 = the time the vehicle reaches Point 2 (start of the median opening)

t_3 = the time the vehicle reaches Point 3 (end of median opening)

$L_2 - L_3$ = length of the median opening

Vs = steady speed of the approaching through vehicle

With the aid of a significant amount of field data, the delay for each vehicle type at different flow levels was examined. The speed profile of vehicles as they approach the opening of median was investigated by Mohanty and Dey (2017). They claimed that as the car approached the potential slowdown area, it generally began to slow down. They came to the conclusion that once the vehicles were past the slow down area (which was about 50 m upstream to the opening of median), they exhibited neither speeding nor slowing. As soon as a vehicle crosses the slowing down segment, the speed of vehicles were essentially constant, with a reported speed differential of less than 2.2 km/h between two successive parts. Here, a section 140 m upstream to the opening of median was selected for determination of steady speed. Two cameras were set up, one at the median opening and the other at the trap length upstream. Four time measurements are required for the analysis. It includes the time t_1 when front bumper of the vehicle enters the median opening, the time t_2 when back bumper of the vehicle leaves the median opening, the time t_3 when the vehicle enters the trap length and the time t_4 when the vehicle leaves the trap length. The time measurements required are represented by the following Figures 4.5 to 4.8.

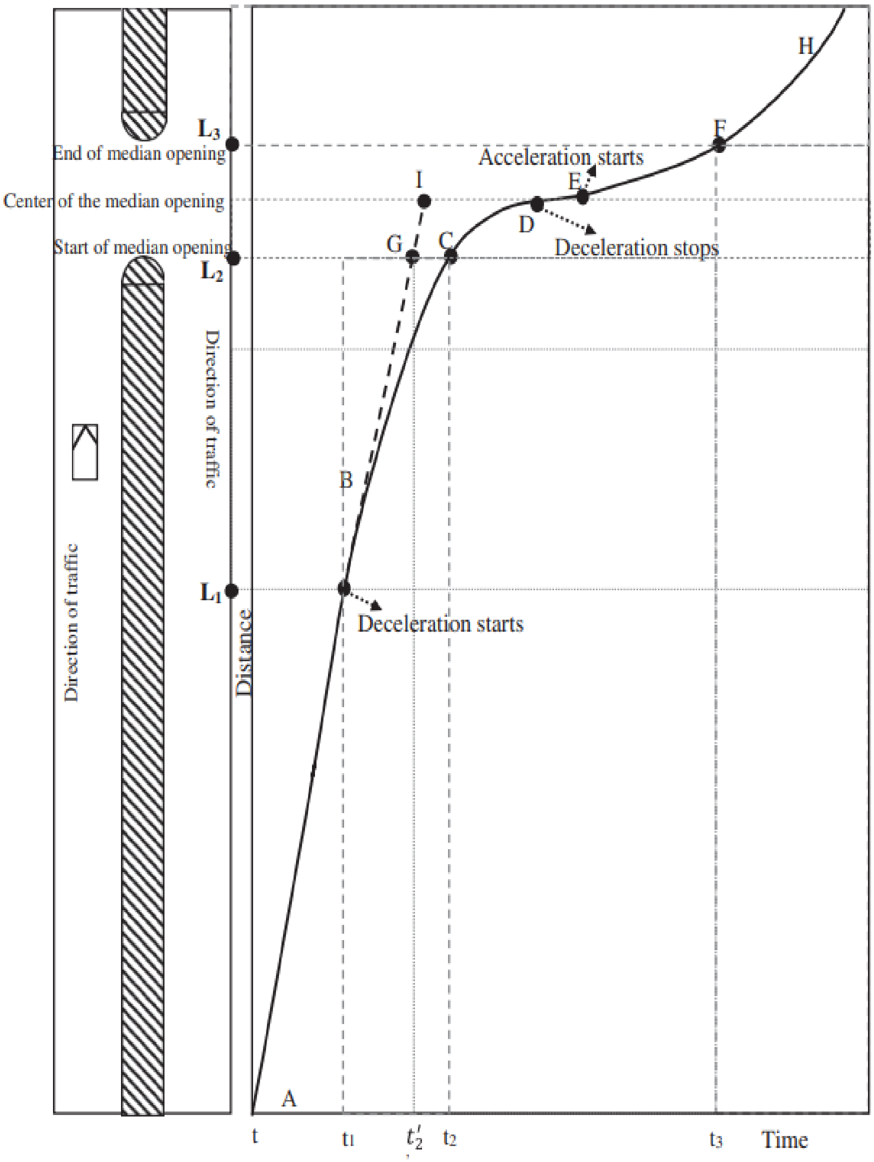


Figure 4.4. Time–Distance Diagram of Approaching Through Vehicles

Figure 4.5. Time t_1 when Front Bumper of Vehicle Enters the Median Opening

Figure 4.6. Time t_2 when Back Bumper of Vehicle Leaves the Median Opening

Figure 4.7. Time t_3 when Vehicle Enters the Trap Length

Figure 4.8. Time t_4 when Vehicle Leaves the Trap Length

4.4.3. Area occupancy

It is desirable to consider the traffic parameters of both approaching and U-turning vehicles to establish a LOS for any median opening. Due of the varied flow patterns and lack of lane discipline on Indian roadways, it is challenging to evaluate microscopic features (Mallikarjuna and Rao 2006). According to Arasan and Dhivya (2008), the quality of flow for a specific route varies with the amount of traffic using it. The varied properties of a traffic stream are not taken into account by the traffic density, though. Mallikarjuna and Rao (2006) introduced a new measure of occupancy called "area occupancy," which was later updated by Asaran and Dhivya (2008), to account for the non-lane based movement and diverse traffic nature that are common in developing nations like India. This idea of AO is thoroughly examined in the current work. Additionally, a method for calculating area occupancy for both U-turns and through vehicles is suggested. Then, at varying U-turn traffic volumes, the variation in AO across the opening of median is assessed. AO, when referring to a section of road, is defined as the percentage of time the set of observed vehicles are present along the selected segment of the road (Arasan and Dhivya 2008). So, the following Equation 4.3 is how AO is expressed:

$$AO = \frac{\sum_i tiai}{TA} \tag{4.3}$$

Where,

t_i =time during which a stretch of a roadway is occupied by vehicle i (s)
a_i =area of the road space occupied by the vehicle i during time t_i in m^2
A=area of the total road stretch in m^2
T=total observation period in s

Arasan and Dhivya (2008) stated that the vehicle's speed was steady for the whole of the stretch of road. The vehicles must cross the detecting zone at a consistent pace, according to Mallikarjuna and Rao (2006) as well. Neither the through nor the vehicles making a U turn can keep their speeds uniform at the opening in a median. A progressive decrease in vehicle speed was noticed when Mohanty and Dey (2017) analysed the through vehicles's speed profile. The centre of an opening in median had the greatest speed drop. Similar to U-turns, which require a 180-degree turn to be completed, the vehicles struggle to maintain a consistent speed during this operation. Additionally, it has been observed that during slow merging, U-turning cars wait for service before beginning to roll slowly and complete the merging procedure. As a result, maintaining a steady speed at the opening in a median area becomes almost impossible for both the through traffic and the traffic making a U turn. The idea of measuring the AO by considering both through vehicles and vehicles making a U turn has been adjusted in light of this actual condition in the field, as stated in the following sections.

The occupancy time of a through vehicle is divided into 4 separate durations when taking into account two reference lines, X_1 and X_2 (start and finish of the test section, respectively, in Figure 4.9) on a stretch of a road (t_0, t_1, t_2, and t_3). The front bumper's initial contact with the test area is referred to as time t_0 (X_1). The same vehicle's back bumper had just left X_1, which is what t_1 refers to. Similar to t_1, t_2 denotes the time at which the front bumper reaches the test section at X_2 once more, and t_3 denotes the instant at which the rear bumper departs X_2. The Figure shows that a vehicle will be present in its entire area (100%) within the test section between the times (t_1 and t_2). The road space utilised by a vehicle during this time period is always equal to the vehicle's predicted rectangular area. The vehicle gradually enters the test portion from time t_0 to t_1, and it gradually exits the test part from time t_2 to t_3. The steps for this process are detailed in Figure 4.10 and below.

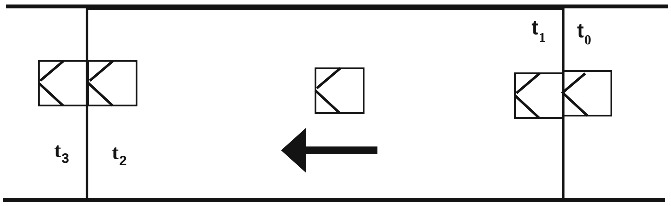


Figure 4.9. Entry and Exit of Through Vehicle

(Source: Mohanty et al., 2019)

The length of the vehicle (L) inside the test section is zero at time t_0. However, the vehicle length within the test section progressively grows from zero to L and is represented by line AB between times t_0 and t_1. The vehicle length inside the test section is constant and is depicted by line BC at any point in time between time intervals t_1 and t_2. Similar to line AB, line CD depicts the vehicle's slow exit from the test portion. It is clear that the lines AB and CD does not have the same slope. The entire area within the study length that a vehicle occupies is given in terms of $t_i a_i$ (meter^2 * second) by multiplying the vehicle width (w_i) by the area under the graph ABCD ($t_i L_i$). This $t_i a_i$ is calculated for all vehicles passing through the test section at time T. Equation 4.3 is used to determine the AO for the study stretch during the time frame considered. The aforementioned method was applied in the current investigation to evaluate the AO at the test section when cars were utilised as approaches. Computing AO of a U turning vehicle is a tiresome job , though.

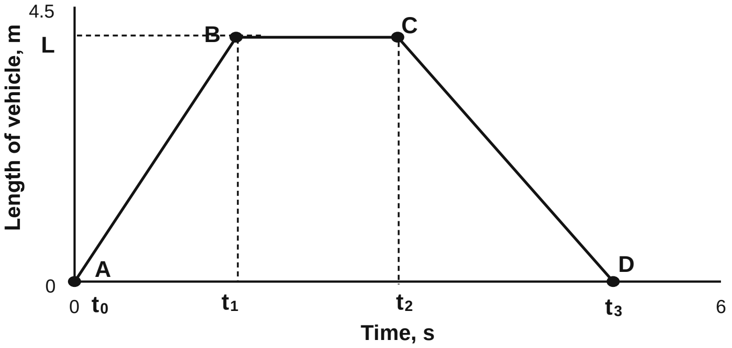


Figure 4.10. Occupancy of Approaching Through Vehicle at a Test Section

(Source: Mohanty et al., 2019)

When merging gradually, the U-turning vehicle either comes to a complete stop or moves more slowly across the median opening. Therefore, taking into account the complete length overestimates the area occupancy for vehicles that are only partially parked in the median opening area. As a result, it is important to measure the length of the vehicle, which is the component of the vehicle that enters the median opening area, more precisely. As indicated in Figure 4.11, the vehicle’s length has been divided into three sections as a result. The estimations were created based on plainly identifiable automobile wheels. As a result, the approach for determining the AO of vehicles making u turn is not the same, as described in the paragraph that follows (Figure 4.12).

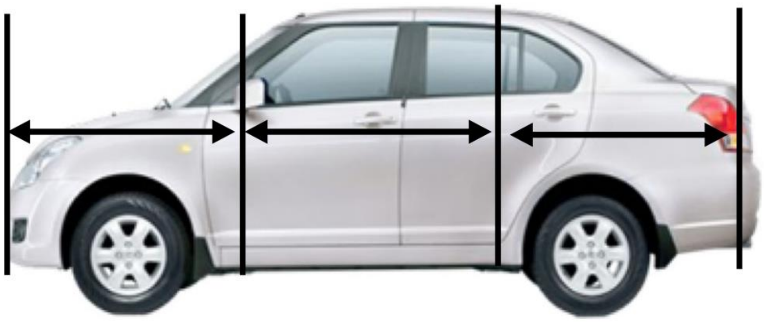


Figure 4.11. Approximate Length Considered for U-Turning Vehicle

(Source: Mohanty et al., 2019)

At t_0 the vehicle length (L) inside the test section is now zero. Only a piece of the vehicle is inside the test section as of time t_1. When merging gently, the U-turning vehicle begins moving at a slow pace before moving into the other lane to complete the merge. The car may halt for a while during this progressive merging, and this stopping time is indicated by t_1-t_2 and t_3-t_4. Only two stoppages have been demonstrated in this example. This amount of stoppages may go down or up depending on how the traffic is moving. The entire length of the vehicle is still inside the test portion from time t_5 to t_6. The car leaves the test portion between the times t_6 and t_7. It is clear that at this point, the U-turning vehicle's length inside the study stretch drops from 0 from L. The entire study section area that the vehicle occupied in units of $t_i a_i$ (meter^2 * second) can be calculated by multiplying the area under the graph ABCDEFGH by the width of the vehicle. This $t_i a_i$ is calculated for all of the vehicles that pass through the test section during a specific amount of time, T. After determining the area occupancy for both incoming through traffic and for vehicle making U turns at the study stretch for each minute, the summation of it provides the total AO per minute for both types of traffic.

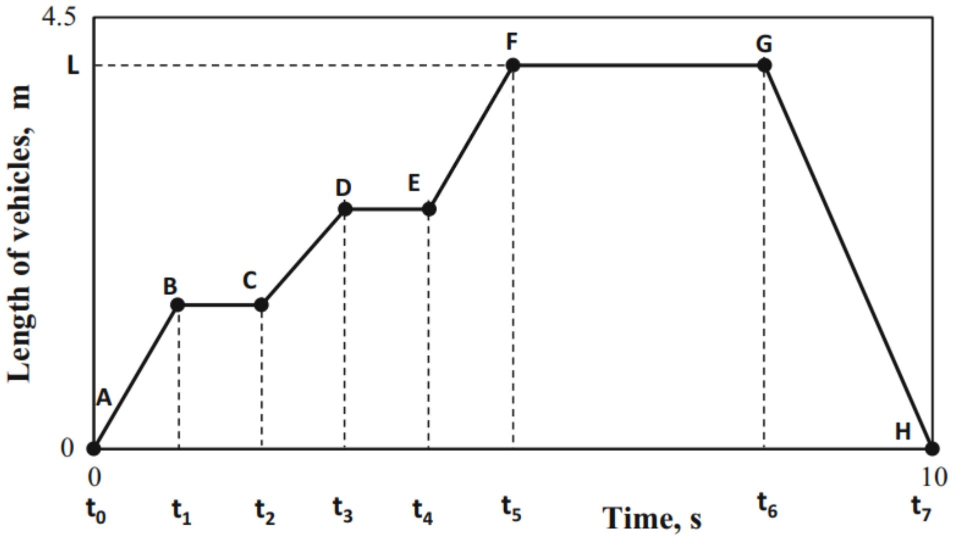


Figure 4.12. Occupancy of U-Turning Vehicle

(Source: Mohanty et al. (2019))

The Figures 4.13 to 4.16 below represent the on field data collection of through vehicle adopted to determine the area occupancy whereas the Figures 4.17 to 4.24 represent the time measurements required to be taken in the case of a U turning vehicle.

Figure 4.13. Time t_0 when the Front Bumper of a Vehicle Crosses Reference Line

Figure 4.14. Time t_1 when the Front Bumper of a Vehicle Crosses Reference Line

Figure 4.15. Time t_2 when the Front Bumper of a Vehicle Crosses Reference Line

Figure 4.16. Time t_3 when the Back Bumper of a Vehicle Crosses Reference Line

Figure 4.17. Time t_0 when the Front Bumper of a Vehicle Crosses Reference Line

Figure 4.18. Time t_1 when Initial Portion of Vehicle Crosses Reference Line

Figure 4.19. Time t_2 when Initial Portion of Vehicle Crosses Reference Line after Stoppage

Figure 4.20. Time t_3 when the Initial Two Portions of a Vehicle Crosses Line

Figure 4.21. Time t_4 when the Initial Two Portions of Vehicle Crosses Reference Line after Stoppage

Figure 4.22. Time t_5 when the Back Bumper of a Vehicle Crosses Reference Line

Figure 4.23. Time t_6 when the Front Bumper of a Vehicle Crosses Reference Line

Figure 4.24. Time t_7 when the Back Bumper of a Vehicle Crosses Reference Line

4.5. Data Analysis

K means clustering is adopted in this study for LOS determination. It is a non-hierarchical method of clustering because of the fact that cluster memberships might vary during the clustering process i.e., an object may move to a different cluster during the study. The steps involved in the k-means clustering procedure are explained in the upcoming section:

- The number of clusters that the k-means algorithm should keep from the data must be specified by the researcher. The algorithm chooses a centre for each cluster based on this input.

- Euclidean distances between each object and the cluster centres are calculated. The cluster centre closest to each object is then given that position. The distance between two points (or the straight line distance) can be calculated using the Euclidean distance formula. Assume that there are two points in a two-dimensional plane at (x_1, y_1) and (x_2, y_2). The Euclidean distance is shown below in Equation 4.4:

  $$d = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2} \qquad (4.4)$$

  where,

  X_1,Y_1 = Coordinates of the first point
  X_2,Y_2 = Coordinates of the second point
  d = Euclidean distance

- The geometric centre, or centroid, of each cluster is calculated using the original partition from step 2 as a starting point. This is accomplished by calculating the mean values of the cluster's objects in terms of each of the variables. Now, the cluster centres change locations.
- Each object's distance to the newly found cluster centres is calculated, and the objects are once more assigned to a specific cluster based on their minimum distance from other cluster centres.
- Now, the k-means technique is repeated until convergence or a preset number of iterations are attained.

The cluster number is determined by means of utilising the silhouette coefficient. The silhouette value gauges an object's cohesion with its own cluster in comparison to other clusters (separation).The formula for its determination is depicted in Equations 4.5 and 4.6 respectively:

$$S(i) = \frac{b(i) - a(x)}{\max\{a(x), b(x)\}} \qquad (4.5)$$

Where,

Cohesion, a(x) = Average distance of i to all other vectors in the same cluster
Separation b(x) = Average distance of i to the vectors in other clusters

Silhouette coefficient (SC)

$$SC = \frac{1}{N} \sum_{i=1}^{N} S(i) \qquad (4.6)$$

Where,

N – Number of data points

S (i) – Silhouette value

The value of silhouette is averaged out for every clustering partition to obtain the silhouette coefficient and the cluster partition with the highest silhouette coefficient is used as the input (number of clusters) for k means clustering.

Multilinear regression was carried out to develop median delay models with the aid of artificial or dummy variables. These indicate the presence or absence of a variable. These were validated by using mean absolute percentage error.

4.6. Summary

The methodology has been framed in detail in this section. The method of collection of data and the method of data extraction has been explained. The procedure for the determination of parameters such as service delay, median delay and area occupancy with pictorial representation are also provided.

CHAPTER 5

MODELLING, ANALYSIS AND FINDINGS

5.1. Introduction

The vehicular composition of the through traffic and U-turning traffic was plotted by means of pie charts. Exploratory analysis was conducted on service delay, median delay and area occupancy to determine the trends of these parameters. It was followed by development of service delay, median delay and area occupancy models. Sensitivity analysis was conducted on these models developed. A comparison was also done between the aggregate and disaggregate models for median delay. Finally the clustering of variables was conducted.

5.2. Exploratory Analysis

The vehicular composition was analysed by means of plotting pie charts separately for U-turning and through traffic volumes. With the aid of box plots the range of values determined for service delay, median delay and area occupancy are represented in this section.

5.2.1. Vehicular composition

The vehicular composition of the through and the U turning traffic are represented in the Figures 5.1 and 5.2. There is a high percentage of two-wheelers whereas the number of HCV, LCV and bus are negligible. More than 40% of the U turning and through vehicular volume comprises of two-wheelers. The analysis was done separately for five categories of vehicles: 2-W, 3-W, SUV and car at different median openings.

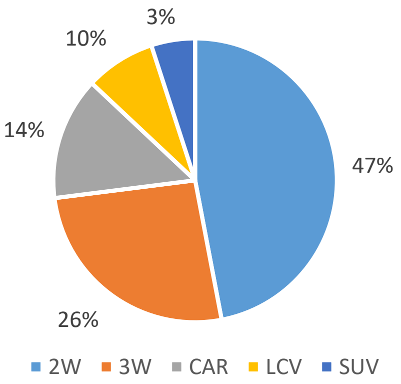


Figure 5.1. Vehicular Composition of U-Turning Traffic

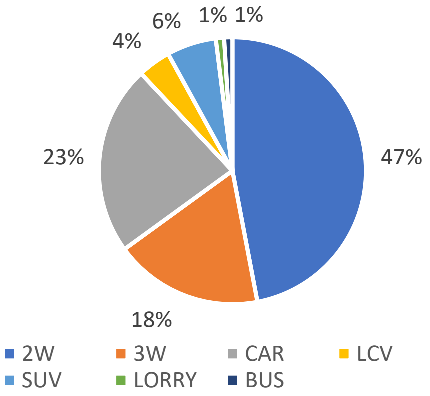


Figure 5.2. Vehicular Composition of Through Traffic

The traffic volume per minute was calculated. The approaching through traffic volume was observed to vary from less than 500 vph to 4500 vph whereas the U turning volume varied from 400 vph to 1600 vph. The variation in traffic volume gives an overall picture of how much variation the parameters analysed have within the vehicular volume ranges.

5.2.2. Service delay

The service delay value was determined by extracting about 1 hour of data. The average service delay that each group of vehicles encountered prior to merging was investigated, and the service delay Figures are shown in Table 5.1 and graphically represented by boxplot as in Figure 5.3. Driver behaviour (including age, sex, experience, and other factors) may also be to blame for the variance in service delays. The least average service wait is experienced by 2W, which is followed in order by 3W, Car, LCV and SUV. 2W had the smallest delay as every gap in the road space is explored to move into the stream which is a unique driver behaviour at heterogeneous traffic condition (Kanagaraj et al., 2010).

Table 5.1. Service Delay Statistics for Different Category of Vehicle

	2W	3W	Car	SUV	LCV
Sample size (N)	336	152	96	70	8
Mean (s)	2.12	4.45	4.94	5.58	5.18
Minimum (s)	1.25	0.44	1.97	3.14	1.89
First Quartile (s)	1.57	0.86	2.34	3.94	2.79
Third Quartile (s)	2.41	4.52	7.75	7.01	8.88
Maximum (s)	14.81	29.28	13.37	8.74	10.54

The average service delay experienced by two-wheelers is 2.12 s. The value obtained for service delay is not in the range with earlier studies. This might be due to data inefficiency as the earlier studies conducted survey in about six sections and for longer durations. Hence there is a need to use collect data from multiple sections for longer duration including peak and off peak hour to have a large data set and arrive at a generalised value for the parameter of service delay. Due to the frontal shape and distinctive driving style of 2-W, which involves searching for every opening in the available road stretch in order to merge into the opposite lane, the average service delay to 2-W is smaller than other vehicles. Because of the conical frontal shape of the auto rickshaw and the aggressive driving style of auto drivers, the average delay suffered by 3-W is less than that of SUVs and cars.

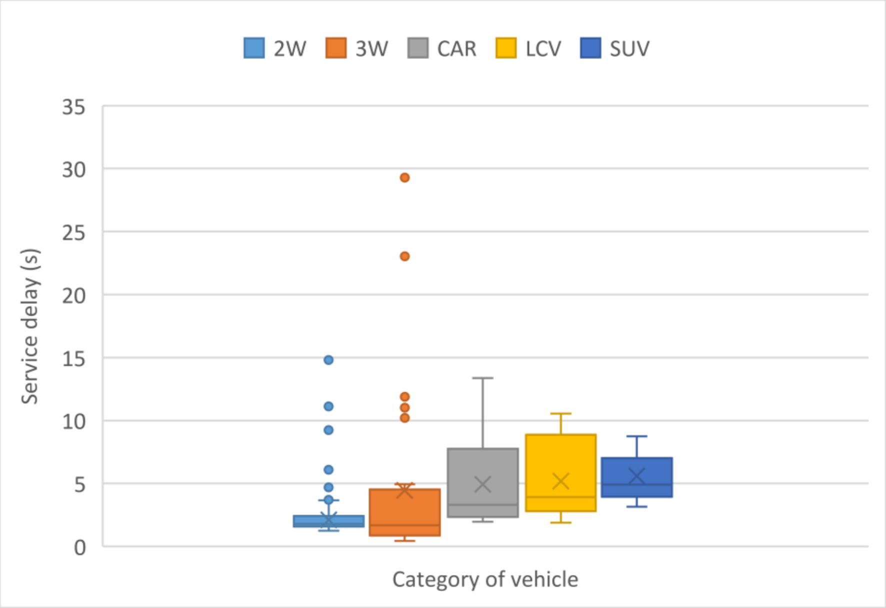


Figure 5.3. Box Plot Depicting Service Delay

5.2.3. Median delay

In order to compute median delay about 30 minutes of data was extracted. Table 5.2's descriptive statistics illustrate the variability in median delay for various vehicle categories which is also depicted by means of box plots as in Figure 5.4. A boxplot is drawn to represent the sample data into quartiles. The lowest value, lower quartile, median, upper quartile, and highest value are displayed in the boxplot. The Y axis displays the range of data. The bottom and top of the box, respectively, reflect the 25th and 75th percentiles of the median delay (Day, et al., 2012). There are 2 sections for the box with the line separating the two section standing for the 50th percentile of median delay. The vast range in vehicle characteristics, engine power to weight ratio, and driver behaviour are the main causes of the delay variations between various categories of vehicles (Sil et al., 2017). The least amount of median delay is to 2W, then comes 3W, Car, SUV, and LCV.

Table 5.2. Overview of Median Delay Values

	2W	3W	Car	SUV	LCV
Sample size (N)	326	129	165	38	11
Mean (s)	0.590	0.692	1.121	1.163	1.192
Minimum (s)	0.026	0.220	0.112	0.558	0.660
First Quartile (s)	0.200	0.564	0.595	0.768	0.940
Second Quartile (s)	0.546	0.614	0.916	1.018	0.990
Third Quartile (s)	0.870	0.774	1.180	1.620	1.470
Maximum (s)	1.631	1.500	1.980	2.816	1.760

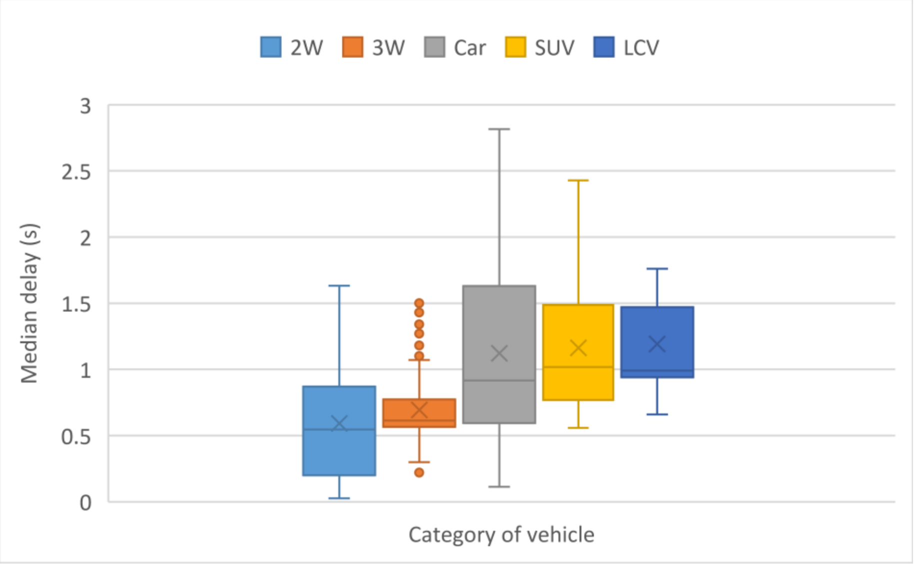


Figure 5.4. Box Plot Depicting Median Delay Values of Different Vehicle Categories

5.2.4 Area Occupancy

The area occupancy was determined by considering an interval of 1 minute. The data was extracted for 60 minutes and for each 1 min the area occupancy values were determined. As a result a total of 60 data points were obtained. The range of values of AO is represented by means of Table 5.3 and Figure 5.5.

Table 5.3. Overview of Area Occupancy Values

Sample size (N)	60
Mean (%)	19.20
Minimum (%)	6.74
First Quartile (%)	12.87
Third Quartile (%)	24.85
Maximum (%)	35.84

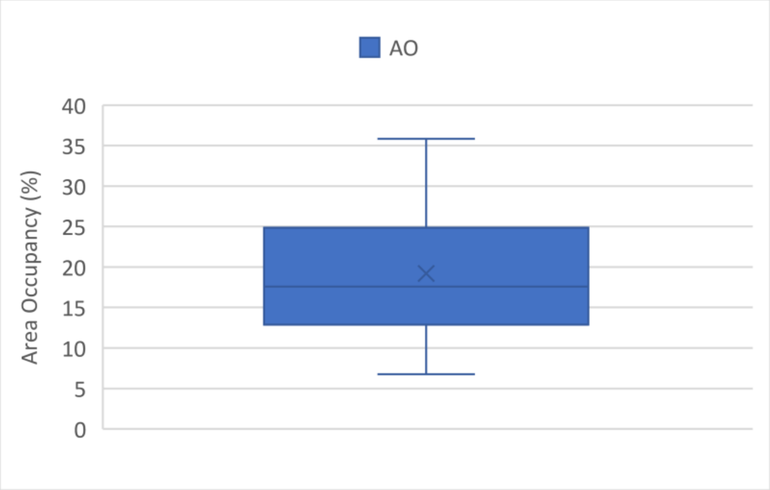


Figure 5.5. Box Plot Depicting Area Occupancy

5.3. Modelling

Models depicting the relationship of the parameters studied with the traffic volumes such as total traffic volume, through vehicular volume and U-turning volume were obtained in this section.

5.3.1 Model1 - Service delay models

The service delay models developed can be used to determine the delay faced by each category of vehicle. The models were prepared by relating the through traffic volume with the service delay faced by each category of vehicle. The delay faced by a U-turning vehicle is mostly influenced by the traffic volume present in the major stream. An exponential relation was derived which increases with the rise in through vehicular volume. The graphs plotted are represented in Figures 5.6 to 5.9.

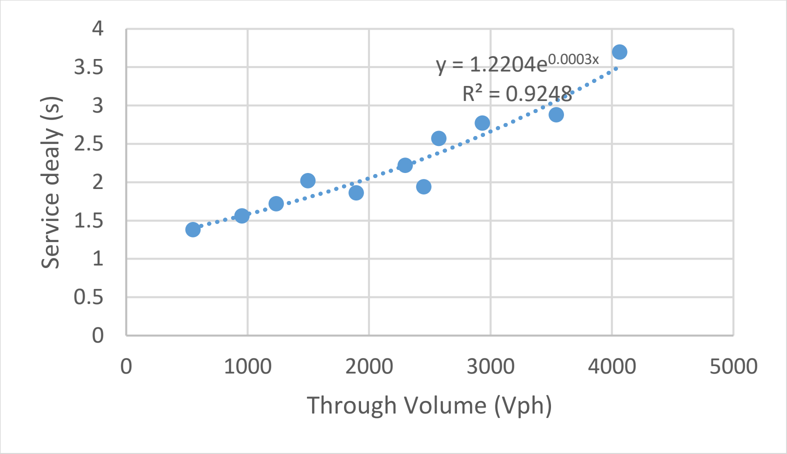


Figure 5.6. Relation between Through Traffic Volume and Service Delay for 2W

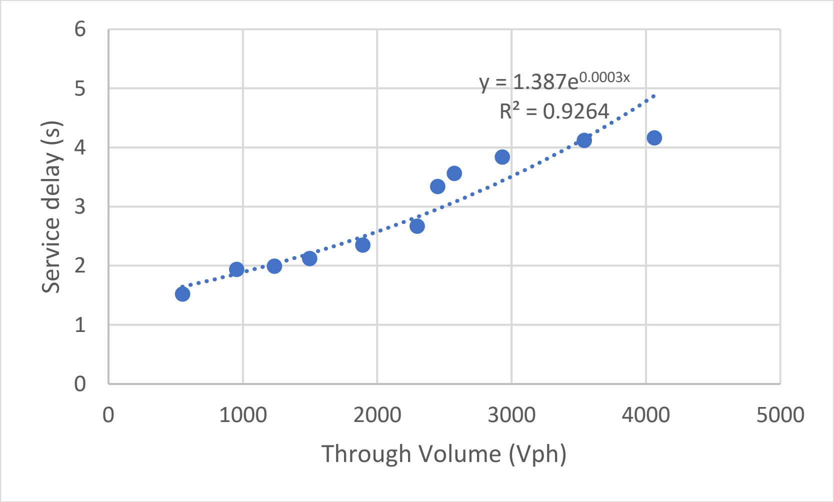


Figure 5.7. Relation between Through Traffic Volume and Service Delay for 3W

The subject vehicle rejects the tiny gap sizes (less than the critical gap) in heavy traffic and waits for a gap larger than it. It follows that it is evident that a high amount of major flow would cause more minor gaps to be rejected, which would then lengthen the service delay. The suggested mathematical relationship could be used to calculate the low priority traffic movement's typical service delay at any traffic volume. The proposed mathematical models for different vehicle categories are tabulated in Table 5.4. All the models developed has an r square value of more than 0.9 which indicates that they are reliable.

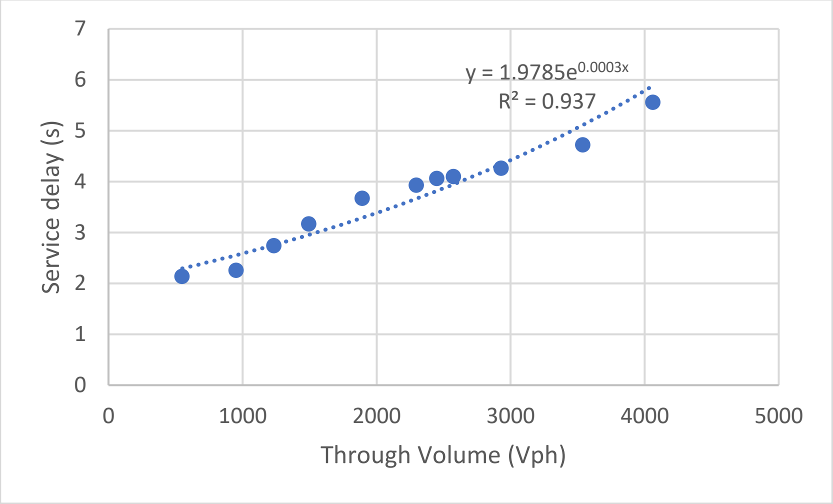


Figure 5.8. Relation between Approaching Traffic Volume and Service Delay for Car

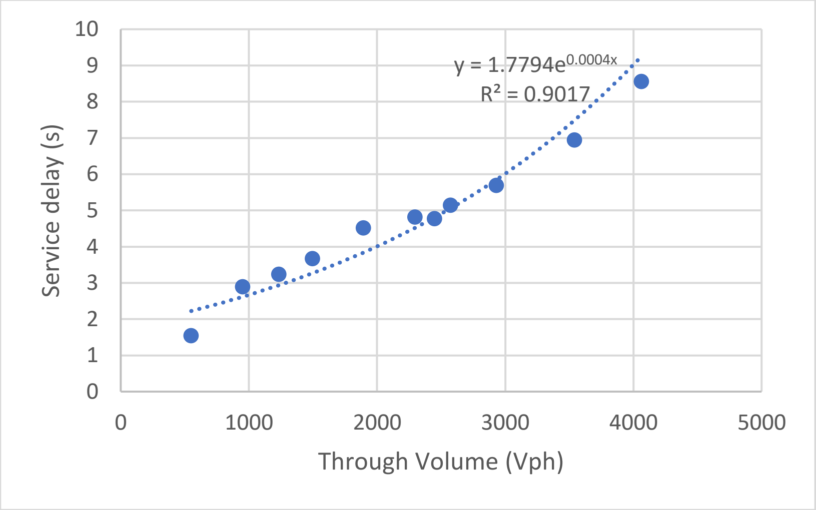


Figure 5.9. Relation between Approaching Traffic Volume and Service Delay for SUV

Table 5.4. Service Delay Models

Category of vehicle	Model	R square
2W	$y = 1.2204e^{0.0003x}$	0.925
3W	$y = 1.387e^{0.0003x}$	0.926
Car	$y = 1.9785e^{0.0003x}$	0.937
SUV	$y = 1.7794e^{0.0004x}$	0.902

Sensitivity analysis have been conducted on the models obtained and it is represented in Figure 5.10. Sensitivity analysis is the study of how the uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model input. It is visible from the graph that below a vehicular volume of 2000 vph, with unit change in vehicular volume the corresponding change in service delay for 2 wheelers is the least and is about 0.05%. In the case of delay experienced by 3 wheelers there is an increase of 1.14 times as compared to 2 wheelers. Similarly for car and SUV's a respective increase of 1.63 times and 2.18 times are observed. Beyond 2000 vph a steep increase in service delay is observed for unit change in vehicular volume. Therefore, the trend beyond 2000 vph will be different to that compared to a volume less than 2000 vph. With a unit increase in the through vehicular volume in the second portion of curve the service delay had an increase of 0.11%. In comparison with 2 wheelers for the other categories such as 3 wheelers, car and SUV the service delay increased by 1.12, 1.59 and 2.78 times respectively.

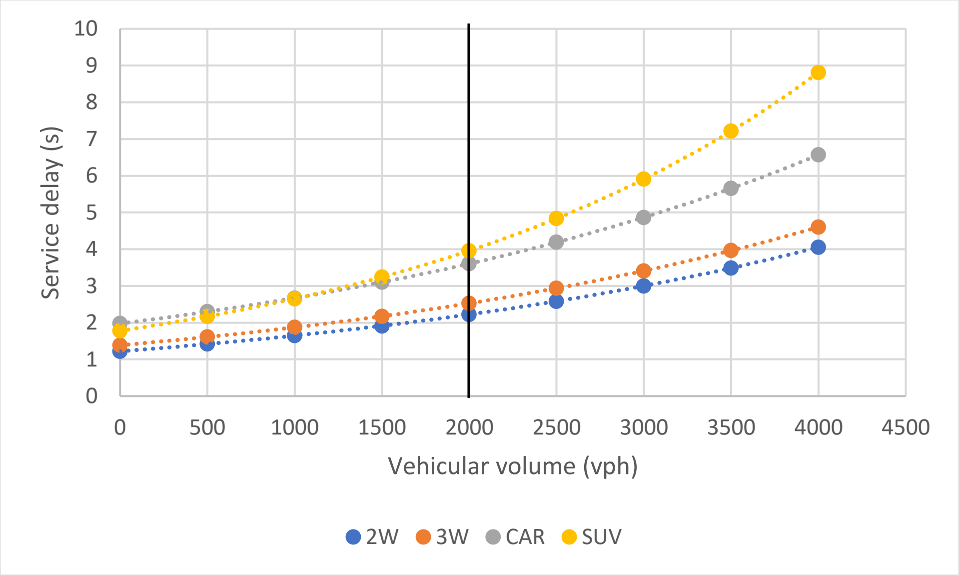


Figure 5.10. Sensitivity Analysis on Service Delay

5.3.2. Model 2 - Median delay models

While approaching through vehicles are decelerating in the initial portion of the opening in median, they accelerate throughout the outer half. Studying impact of traffic flow on median delays, Figures 5.11 to 5.13 illustrates the relationship between various traffic volumes and the median delay values. The regular entry of vehicles making a U turn adds to the delay faced by the through vehicles. It goes without saying that as U-turns occur more frequently, there is a greater chance that they will collide with oncoming traffic. When there is little traffic, approaching through cars can move laterally towards the curb to prevent a collision. Compared to high traffic volumes, low traffic volumes are observed to have a lower median delay for approaching through vehicles. This can be represented by means of the graphs plotted below portraying the relationship obtained between total traffic, through traffic and traffic volume making U turn with median delay.

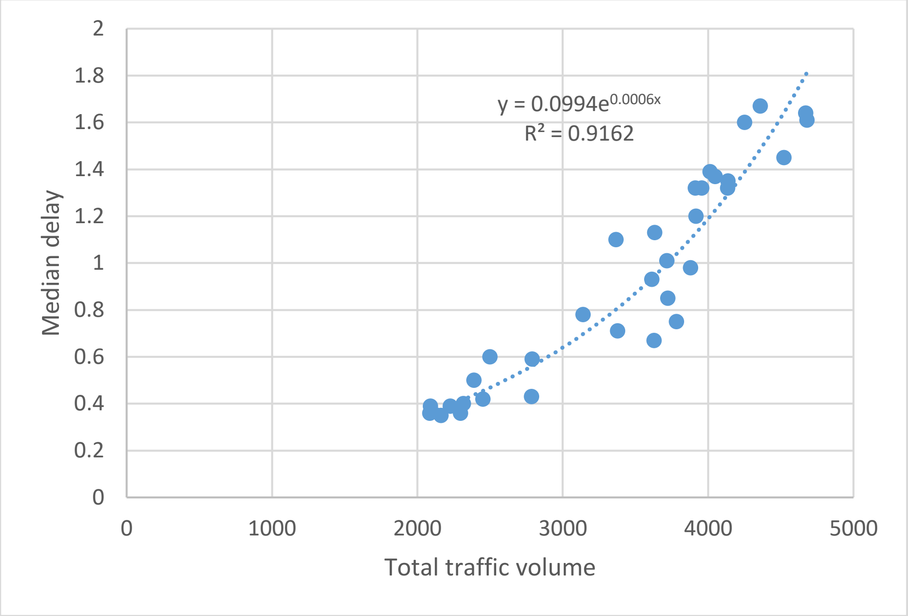


Figure 5.11. Relation between Total Traffic Volume and Median Delay

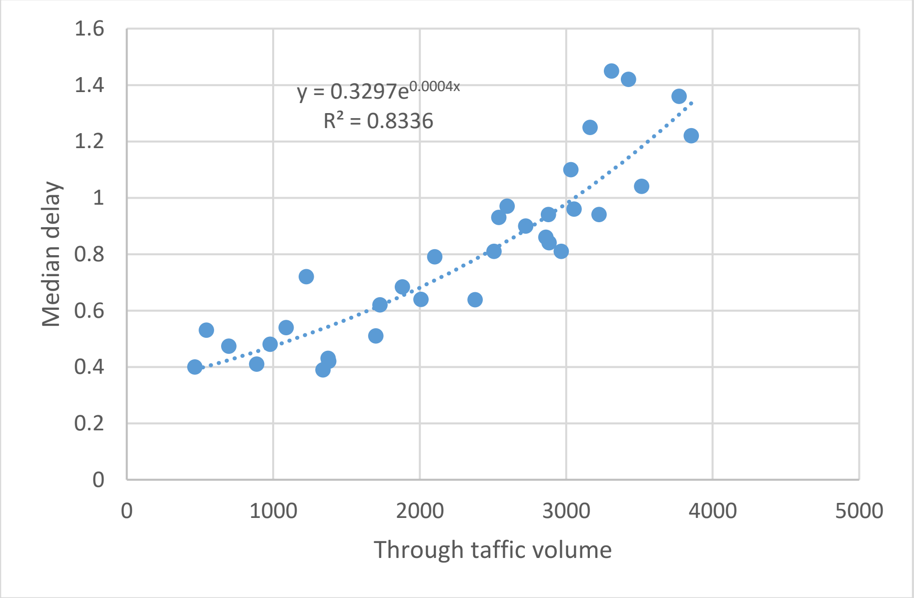


Figure 5.12. Relation between Through Traffic Volume and Median Delay

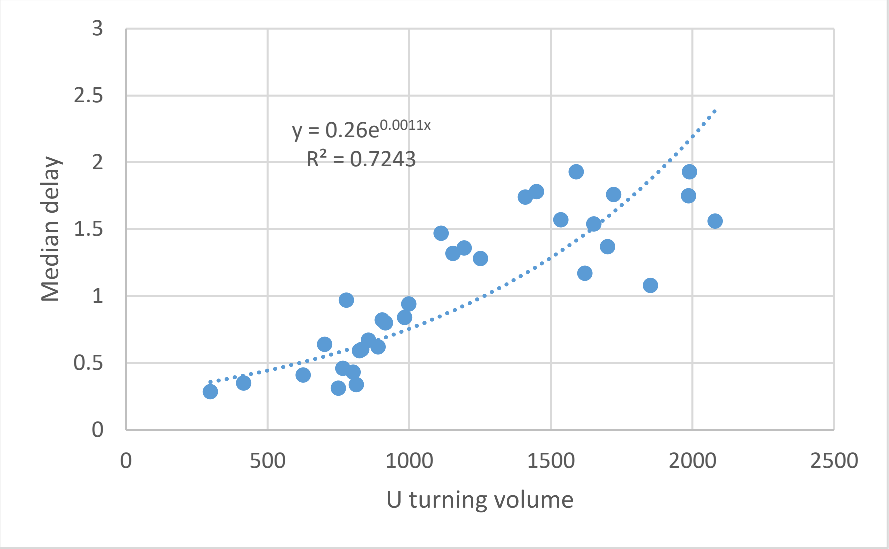


Figure 5.13. Relation between U Turning Traffic Volume and Median Delay

The sensitivity analysis result conducted on median delay values is presented in Figure 5.14. From the plot the U turning vehicle was found to have a higher influence on median delay values.

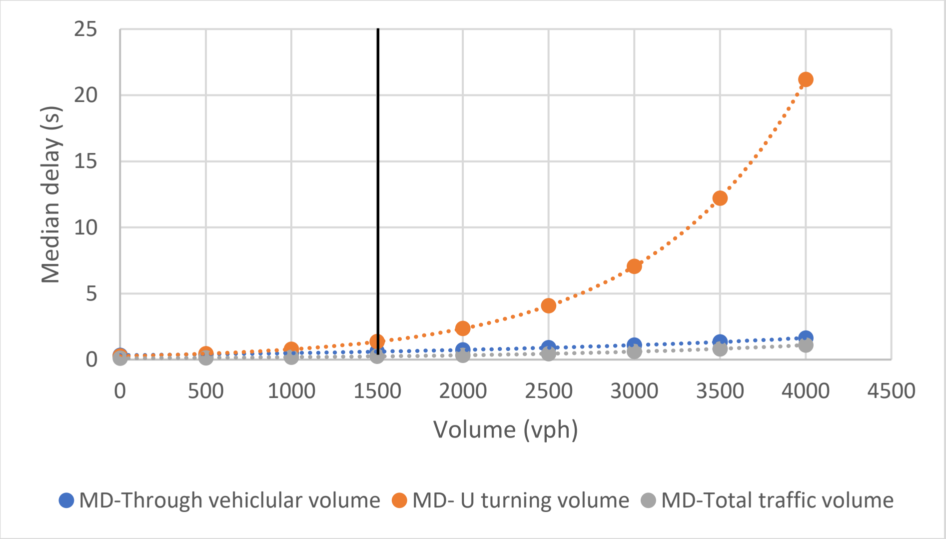


Figure 5.14. Sensitivity Analysis Result on Median Delay

At vehicular volumes below 1500 vph, a unit change in total vehicular volume produces 0.01% increase in median delay. Considering the case of through vehicular volume and U turning vehicular volume the increase is about 0.018% and 0.073% respectively. For vehicular volumes higher than 1500 vph, an increase of about 0.03% in median delay is brought about by unit increase in total vehicular volume. In the same way an increase of about 0.04% and 0.79% increase in median delay is resulted due to unit increase in through and U turning volume respectively. The impact of U turning vehicle is hence obtained to be higher than total and through vehicular volume.

5.3.3. Model 3 - Area occupancy models

Every 60 seconds, the AO for through and u turning vehicles is evaluated, and the overall AO of the study stretch for 1 minute is computed by summing these results. AO and traffic volume do not have a linear relationship. The trend is determined via curve estimate utilising various nonlinear relations, such as logarithmic and power. Figure 5.15 to 5.17 depicts an exponential relationship as a result. A good R-square value for each scenario implies that the relationships between AO and traffic volumes are well-fitted. The U-turning and through traffic volume levels produced similar findings. The relationship also complies with the basic traffic flow diagram (flow-density curve).

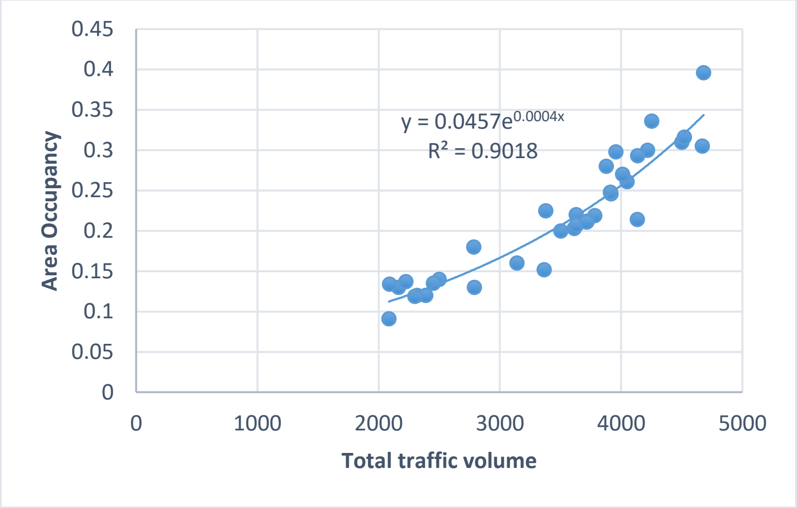


Figure 5.15. Relation between Total Traffic Volume and AO

Even if only the median opening's total traffic flow is known, it is still possible to accurately establish the AO of the conflict area there using the following Equation 5.1:

$$y = 0.0457e^{0.0004x} \tag{5.1}$$

Where,

y = Median delay in seconds

x = Total traffic volume in vehicles per hour

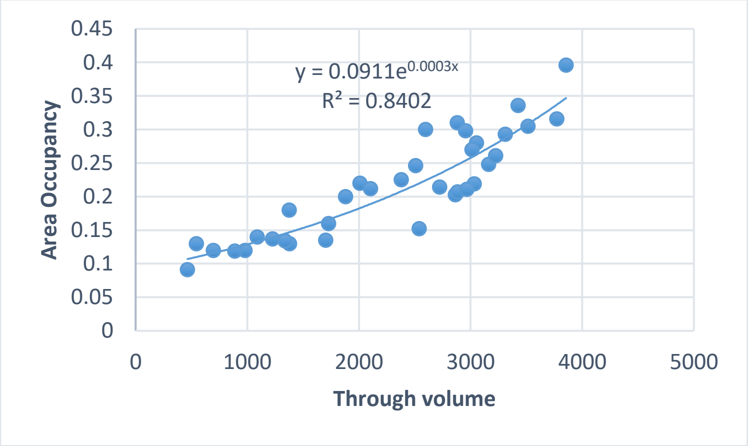


Figure 5.16. Relation between Through Traffic Volume and AO

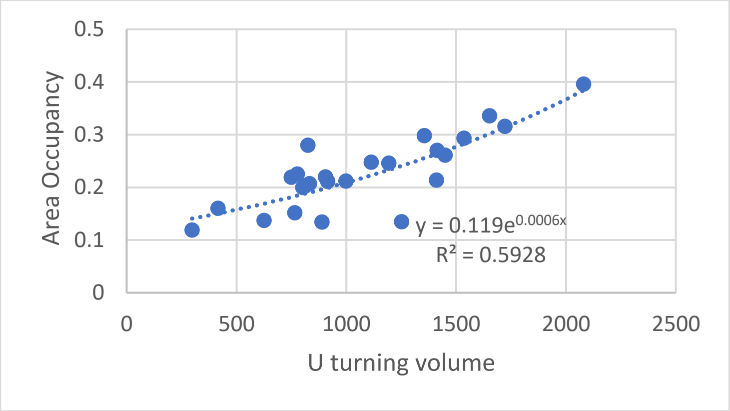


Figure 5.17. Relation between U-Turning Traffic Volume and AO

With an increase in traffic flow, AO does not significantly rise for low to moderate traffic levels. Due to the ease in lateral movement at low traffic volumes, it is observed that approaching through automobiles will shift laterally to avoid a collision with the U-turning vehicle. As a result, the vehicles are delayed less. Also it has been observed that U-turning vehicles spend less time in the test area since there are more quick merges than slow merges. A larger traffic volume results in a significant increase in the AO. The contact between the study vehicle and through traffic is relatively substantial at greater traffic volumes. The target vehicle waits for assistance at the median opening before beginning to move very slowly into the opposite traffic flow. The vehicle temporarily pauses or reduces speed in the conflicting zone during the progressive joining. In both scenarios, there will inevitably be some significant merging operation delays for vehicle. The idea of AO takes the amount of time a vehicle spends in the study section into account. The ratio of test section’s length to the vehicle's maximum sustained speed should, in theory, determine how long each vehicle spends in the test section. It is clear that when there is very little traffic, the vehicles typically don't spend any more time in the test part. However, when the number of traffic increases, the interaction between the vehicles also grows, which slows down the movement of the vehicles. As a result, it is discovered that the vehicles spend more time in the portion, causing a delay. As traffic congestion rises, this additional time increases.

The AO models computed were also subjected to sensitivity analysis to determine the trend prevalent in the models. The sensitivity analysis result is depicted in Figure 5.18. Being an exponential relation the curve can be considered to give two different trends at the threshold point of 500 vph.

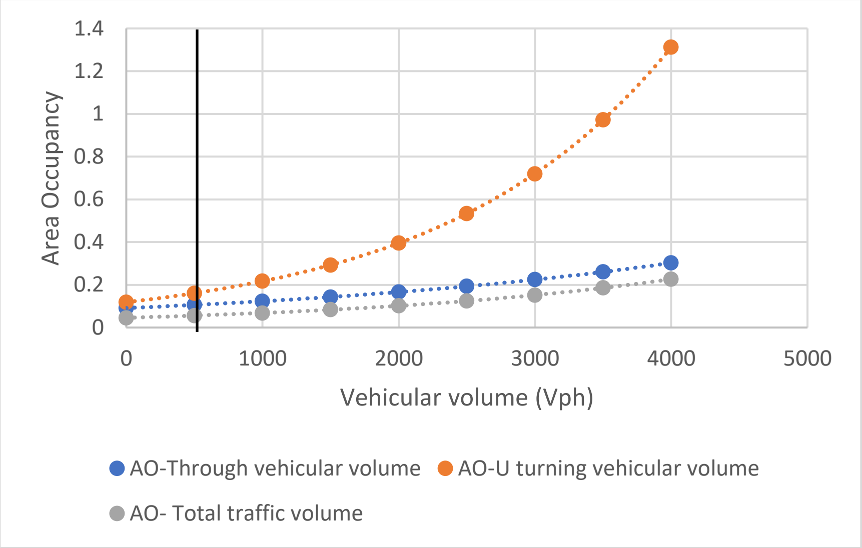


Figure 5.18. Sensitivity Analysis Result on Area Occupancy

At vehicular volumes below 500 vph, a unit change in total vehicular volume produces 0.002% increase in area occupancy. Considering the case of through vehicular volume and U turning vehicular volume the increase is about 0.003% and 0.008% respectively. For vehicular volumes higher than 500 vph, an increase of about 0.005% in area occupancy is brought about by unit increase in total vehicular volume. In the same way an increase of about 0.006% and 0.032% increase in area occupancy is resulted due to unit increase in through and U turning volume respectively. The impact of U turning vehicle is hence obtained to be higher than total and through vehicular volume.

5.3.4. Model 4 – To study the effect of vehicle type on median delay

Median delays mentioned above represent the mean delay that a vehicle can experience. It doesn’t give a vehicle specific determination of median delay. An aggregate and disaggregate median delay model have been compared in this section. The aggregate model considered here is represented by the following Equation 5.2. The aggregate mode mentioned above gives an r square value of 0.7. The development of a disaggregate model is mentioned in the following section.

$$MD = -\ 0.0555 + 0.0009 * U \qquad (5.2)$$

Where,

MD – Median delay
U – U turning volume

Median delay is primarily influenced by vehicles making U turn and the type of the vehicle facing the delay. This microscopic study aims to create models for calculating the median delay experienced by any category of approaching through vehicles. A multiple linear regression was performed for this purpose. The regression study has treated the two mentioned variables that affect the median delay as independent variables. An indicator variable is the type of vehicle. These variables often indicate whether a quality is present or absent (Gujarati, 2003). Such characteristics are typically quantified by constructing artificial variables that can have a value of 0 or 1, indicating whether the characteristic is present or absent, accordingly. Dummy variables are those variables that take values of 0 and 1. (Gujarati, 2003). The number of dummy variables that must be added must be one fewer than the categories of that variable (Gujarati, 2003).

Four dummy variables have therefore been utilised in the current research to represent the median delay that five categories of approaching through vehicle have encountered. The 2W, 3W, SUV, and LCV dummy variables were taken into account in the current analysis. If the model is to estimate the median delay brought on by 3W, 3W is given the value of 1, while the remaining dummy variables are given the value of 0. Likewise, it is possible to assess the delay inflicted on 2W, SUVs, and LCVs. It is clear that the model will output the delay experienced by the fourth category of vehicle, which is the car, if all four dummy variables have a value of 0. The following Equation 5.3 yields the median delay:

$$MD_i = -0.123 - 0.591*2W - 0.438*3W - 0.245*LCV + 0.048*SUV + 0.001*U$$

$$(0.000) \quad (0.000) \quad (0.000) \qquad (0.000) \quad (0.000) \quad (5.3)$$

Where,

MD = Median delay of ith approaching vehicle in seconds
U = U-turning traffic volume in vehicles per hour

The value of the adjusted R2 is in the range of 0.89. Each independent variable's p-value was less than 0.05, indicating significance at the 5% level. There is a substantial difference between the independent variables, as shown by the fact that the p-value from the ANOVA was also less than 0.05. The outcome of the dependent variable is significantly influenced by each independent variable (i.e., median delay). Thus, it can be said that the disaggregate models are statistically more sound than aggregate models and the regression is well-fitted.

In order to verify the suggested delay models, the median delays computed by the suggested models were contrasted with those found from the field data provided in Table 5.5. The median delay was not examined using the same data that were utilised for the validation. When assessing models for traffic studies, the mean absolute percentage error (MAPE) method is a reliable way to forecast accuracy (Liu et al. 2008). A MAPE value of up to 10% is typically regarded as favourable.

The following Equation 5.4 can be used to calculate MAPE:

$$\mathrm{M} = \frac{1}{n} * \sum_{1}^{n} \left| \frac{A-F}{A} \right| \tag{5.4}$$

Where,

n = Sample size

A = Actual value from field

F = Value obtained from model

Table 5.5 compares the anticipated average delay for each vehicle category based on the proposed model with the actual delay as determined by field data. It shows that there is good agreement between the values generated from the suggested model and the values found in the field. It is noticeable that two wheelers have the lowest mistake, or 2.4%. The 3W value showed the largest value variation, or around 9.8%. As a result, it can be said that the suggested model can accurately forecast the median delay.

Table 5.5. Validation of model

U turning vehicle type	MAPE (%)
2W	2.4%
3W	9.8%
CAR	7.5%
SUV	9.2%
LCV	8.1%

5.4. Clustering

Basically, categorising the traffic data into different groups is how LOS is generated. Through cluster analysis, three different LOS ranges have been determined using the parameters service delay, median delay and AO derived from field observations. To establish the appropriate number of clusters for a collection of data the cluster validation measure is used (Mohaptara and Bhuyan, 2012). The ideal number of clusters in the cluster analysis is initially determined using the silhouette value. A high number suggests that the object is well matched to its own cluster and poorly matched to surrounding clusters. The silhouette varies from 1 to +1. The cluster division with the highest mean silhouette value is adopted in each case. The silhouette values obtained for all the three parameters are represented in the Table 5.6. The formula for determination of silhouette coefficient is provided in the next section.

Table 5.6. Average Silhouette Value for Different Cluster Numbers

Cluster Number	Service delay	Median delay	AO
2	0.774	0.744	0.733
3	0.771	0.737	0.687
4	0.742	0.775	0.718
5	0.765	0.758	0.697
6	0.791	0.812	0.724

In the case of AO the highest silhouette value obtained is 0.733. But it is for 2 cluster division. Rather than 2 cluster classification the categorization with the second highest silhouette value which is 0.724, representing 6 cluster division is adopted. Analogous to HCM which classifies LOS into 6 ranges (LOS A to LOS F), we adopt the 6 cluster division. While the 6 cluster categorization offers the maximum silhouette value for service delay and median delay hence these parameters are also classified into 6 clusters. A silhouette value of about 0.812 and 0.791 were obtained for median delay and service delay respectively.

With the use of SPSS software, the K-means clustering approach is employed to conduct the cluster analysis. Six clusters in total, which have also undergone statistical validation, have been examined. For service delay, cluster convergence was attained at 8 iterations whereas it took 6 and 7 iterations, respectively, for median delay and AO. The change in values for all of the cluster centres at the end of the respective iteration is zero, signalling the completion of the iteration process. It is possible to say that convergence of cluster centres have been attained. Thus, the final cluster centres are ultimately acquired. Statistical verification is required to confirm that the final cluster centres are accurate. As a result, a one-way ANOVA in SPSS was used to perform a mean comparison test. The SPSS Bonferroni post hoc multiple comparison tool was also used to perform numerous comparisons between the groupings. Tables 5.7 to 5.12 present the findings of the two tests for the three parameters.

Table 5.7. ANOVA Test for the Clusters Obtained for Service Delay

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	47710.702	5	9542.140	5941.822	.000
Within Groups	1390.734	866	1.606		
Total	49101.436	871			

Table 5.8. ANOVA Test for the Clusters Obtained for Median Delay

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	390.708	5	78.142	5488.023	.000
Within Groups	19.478	1368	.014		
Total	410.187	1373			

Table 5.9. ANOVA Test for the Clusters Obtained for AO

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3540.059	5	708.012	403.938	.000
Within Groups	92.897	53	1.753		
Total	3632.956	58			

Additionally, Tables 5.10 to 5.12's comparison among clusters demonstrate that the clusters are distinct from one another and that their means are statistically distinct from one another at the 5% significant level.

Table 5.10. Post Hoc Multiple Comparison in One Way ANOVA for Service Delay

Bonferroni

(I) Cluster Number of Case	(J) Cluster Number of Case	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-5.256062*	.109250	.000	-5.57762	-4.93450
	3	-11.111633*	.130392	.000	-11.49543	-10.72784
	4	-22.438820*	.207641	.000	-23.04998	-21.82766
	5	-16.899948*	.157486	.000	-17.36349	-16.43641
	6	-26.329976*	.271604	.000	-27.12941	-25.53055
2	1	5.256062*	.109250	.000	4.93450	5.57762
	3	-5.855572*	.145072	.000	-6.28257	-5.42857
	4	-17.182759*	.217160	.000	-17.82194	-16.54358
	5	-11.643887*	.169841	.000	-12.14379	-11.14398
	6	-21.073915*	.278949	.000	-21.89496	-20.25286
3	1	11.111633*	.130392	.000	10.72784	11.49543
	2	5.855572*	.145072	.000	5.42857	6.28257
	4	-11.327187*	.228529	.000	-11.99983	-10.65454
	5	-5.788315*	.184154	.000	-6.33035	-5.24628
	6	-15.218343*	.287888	.000	-16.06570	-14.37098
4	1	22.438820*	.207641	.000	21.82766	23.04998
	2	17.182759*	.217160	.000	16.54358	17.82194
	3	11.327187*	.228529	.000	10.65454	11.99983
	5	5.538872*	.245000	.000	4.81775	6.26000
	6	-3.891156*	.330139	.000	-4.86288	-2.91943
5	1	16.899948*	.157486	.000	16.43641	17.36349
	2	11.643887*	.169841	.000	11.14398	12.14379
	3	5.788315*	.184154	.000	5.24628	6.33035
	4	-5.538872*	.245000	.000	-6.26000	-4.81775
	6	-9.430028*	.301130	.000	-10.31636	-8.54369
6	1	26.329976*	.271604	.000	25.53055	27.12941
	2	21.073915*	.278949	.000	20.25286	21.89496
	3	15.218343*	.287888	.000	14.37098	16.06570
	4	3.891156*	.330139	.000	2.91943	4.86288
	5	9.430028*	.301130	.000	8.54369	10.31636

*. The mean difference is significant at the 0.05 level.

Table 5.11. Post Hoc Multiple Comparison in One Way ANOVA for AO

Bonferroni

(I) Cluster Number of Case	(J) Cluster Number of Case	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-12.80700*	.59208	.000	-14.6271	-10.9869
	3	-4.43600*	.59208	.000	-6.2561	-2.6159
	4	-17.50729*	.65244	.000	-19.5129	-15.5016
	5	-8.44685*	.55687	.000	-10.1587	-6.7350
	6	-23.90856*	.60830	.000	-25.7785	-22.0386
2	1	12.80700*	.59208	.000	10.9869	14.6271
	3	8.37100*	.59208	.000	6.5509	10.1911
	4	-4.70029*	.65244	.000	-6.7059	-2.6946
	5	4.36015*	.55687	.000	2.6483	6.0720
	6	-11.10156*	.60830	.000	-12.9715	-9.2316
3	1	4.43600*	.59208	.000	2.6159	6.2561
	2	-8.37100*	.59208	.000	-10.1911	-6.5509
	4	-13.07129*	.65244	.000	-15.0769	-11.0656
	5	-4.01085*	.55687	.000	-5.7227	-2.2990
	6	-19.47256*	.60830	.000	-21.3425	-17.6026
4	1	17.50729*	.65244	.000	15.5016	19.5129
	2	4.70029*	.65244	.000	2.6946	6.7059
	3	13.07129*	.65244	.000	11.0656	15.0769
	5	9.06044*	.62066	.000	7.1525	10.9684
	6	-6.40127*	.66719	.000	-8.4523	-4.3503
5	1	8.44685*	.55687	.000	6.7350	10.1587
	2	-4.36015*	.55687	.000	-6.0720	-2.6483
	3	4.01085*	.55687	.000	2.2990	5.7227
	4	-9.06044*	.62066	.000	-10.9684	-7.1525
	6	-15.46171*	.57409	.000	-17.2265	-13.6969
6	1	23.90856*	.60830	.000	22.0386	25.7785
	2	11.10156*	.60830	.000	9.2316	12.9715
	3	19.47256*	.60830	.000	17.6026	21.3425
	4	6.40127*	.66719	.000	4.3503	8.4523
	5	15.46171*	.57409	.000	13.6969	17.2265

*. The mean difference is significant at the 0.05 level.

Table 5.12. Post Hoc Multiple Comparison in One Way ANOVA for Median Delay

Bonferroni						
(I) Cluster Number of Case	(J) Cluster Number of Case	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-.34541*	.00917	.000	-.3724	-.3185
	3	-1.91571*	.01579	.000	-1.9621	-1.8693
	4	-2.32089*	.02903	.000	-2.4062	-2.2355
	5	-.68896*	.00955	.000	-.7170	-.6609
	6	-1.22592*	.01093	.000	-1.2580	-1.1938
2	1	.34541*	.00917	.000	.3185	.3724
	3	-1.57029*	.01517	.000	-1.6149	-1.5257
	4	-1.97548*	.02870	.000	-2.0599	-1.8911
	5	-.34354*	.00849	.000	-.3685	-.3186
	6	-.88050*	.01002	.000	-.9100	-.8511
3	1	1.91571*	.01579	.000	1.8693	1.9621
	2	1.57029*	.01517	.000	1.5257	1.6149
	4	-.40518*	.03145	.000	-.4976	-.3127
	5	1.22675*	.01540	.000	1.1815	1.2720
	6	.68979*	.01630	.000	.6419	.7377
4	1	2.32089*	.02903	.000	2.2355	2.4062
	2	1.97548*	.02870	.000	1.8911	2.0599
	3	.40518*	.03145	.000	.3127	.4976
	5	1.63193*	.02882	.000	1.5472	1.7167
	6	1.09497*	.02931	.000	1.0088	1.1811
5	1	.68896*	.00955	.000	.6609	.7170
	2	.34354*	.00849	.000	.3186	.3685
	3	-1.22675*	.01540	.000	-1.2720	-1.1815
	4	-1.63193*	.02882	.000	-1.7167	-1.5472
	6	-.53696*	.01036	.000	-.5674	-.5065
6	1	1.22592*	.01093	.000	1.1938	1.2580
	2	.88050*	.01002	.000	.8511	.9100
	3	-.68979*	.01630	.000	-.7377	-.6419
	4	-1.09497*	.02931	.000	-1.1811	-1.0088
	5	.53696*	.01036	.000	.5065	.5674
*. The mean difference is significant at the 0.05 level.						

It can be said that the clusters obtained are mathematically accurate because the centres converged and have statistically diverse means. The increasing order cluster membership Table obtained from SPSS programme is used to establish the range for each cluster. Six cluster centres have been obtained using K-means clustering for the parameters under study. The cluster centres availed for each of the parameters are depicted in Table 5.13.

Table 5.13. Cluster Centres from K Means Clustering

Cluster	Service delay(s)	Median delay(s)	AO (%)
1	1.917	0.385	8.83
2	7.173	0.730	21.63
3	13.028	2.300	13.26
4	24.355	2.705	26.33
5	18.816	1.073	17.27
6	28.247	1.610	32.74

It is simple to determine the lowest and greatest values for a given cluster. The values, however, are not continuous. The closest cluster centre is located and checked for continuous values. With the aid of an example, this is thoroughly explained here. Considering AO the centre of cluster 1 is 8.83 and that of cluster 3 is 13.26. It was clear from the acquired AO values for clusters 1 and 3 that cluster 1 has a range of 0 to 10.45 and cluster 3 has a range of 11.09 to 14.75. However, no AO values were found in the study for the values between 10.45 and 11.09, hence cluster analysis was unable to group them with any other values. The K-means clustering, on the other hand, operates according to the notion of the cluster centre and value’s least Euclidean distance. Any number between 10.45 and 11.09 was tested at the closest cluster centre. For instance, the distance between 10.50 and 8.83 (the centre of cluster 1) is 1.67 units. However, it is 2.76 units from cluster 3's 13.26-centered centre. 10.50 therefore belongs in cluster 1. In the same way, 12.24 is 3.41 units away from 8.83 and 1.02 units away from 13.26. 12.24 is categorised within cluster 3 since it is closer to 13.26 than 8.83. The continuous range of clusters was obtained using this approach. Similar procedure was conducted for both service delay and median delay. Finally, Table 5.14 to 5.16 displays the range LOS values for each parameter. The cluster ranges are sorted in ascending order to achieve this. A visual representation of the clustering of each parameters is depicted by means of scatter plot in Figures 5.19 to 5.21.

The Highway Capacity Manual (HCM), categorises the LOS of various traffic facilities and roadways into 6 groups. Any traffic facility's six LOS categories indicate the LOS a road user can expect to receive while using that specific facility. From "A," which stands for the finest experience, up to “F”, depicting the poorest quality perception by a road user. Six numbers of clusters have generated in this investigation in line with the HCM.

Table 5.14. LOS Classification for Service Delay

LOS Range	Service delay (s)
A	0-4.54
B	4.54-10.10
C	10.10-15.92
D	15.92-21.58
E	21.58-26.30
F	>26.30

Table 5.15. LOS Classification for Median Delay

LOS Range	Median delay (s)
A	0-0.56
B	0.56-0.90
C	0.90-1.34
D	1.34-1.95
E	1.95-2.50
F	>2.50

Table 5.16. LOS Classification for Area Occupancy

LOS Range	AO (%)
A	0-11.04
B	11.04-15.26
C	15.26-19.45
D	19.45-23.98
E	23.98-29.53
F	>29.53

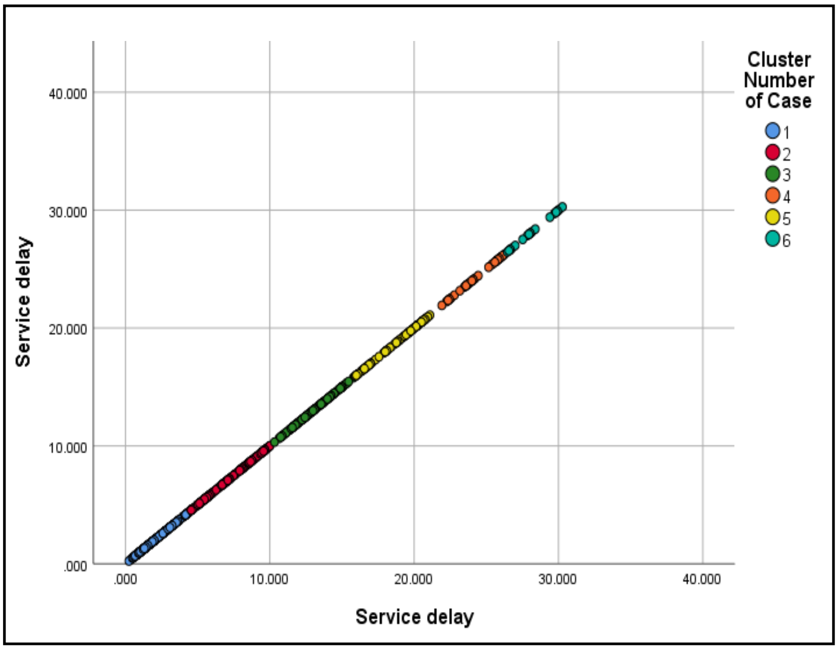


Figure 5.19. Scatter Plot of Service Delay

Furthermore, the analysis revealed that six clusters is the ideal number. These organisations reflect the LOS that a driver might receive while using a median opening area. The optimal experience for road users is when the AO in the opening of the median falls under 11.04. Similar to this, road users who are travelling in the road section at the opening of the median have worst service quality when AO exceeds 29.53. Considering the case of service delay if the vehicles undergo a delay value below 4.5s it is having a LOS A. For service delay values above 26.3s it is the worst case scenario i.e., LOS F.

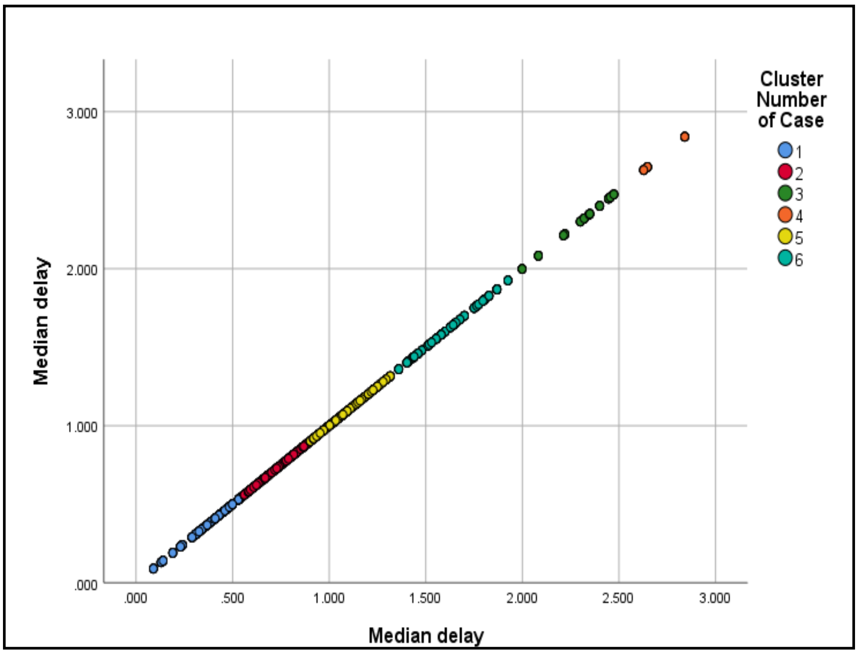


Figure 5.20. Scatter Plot of Median Delay

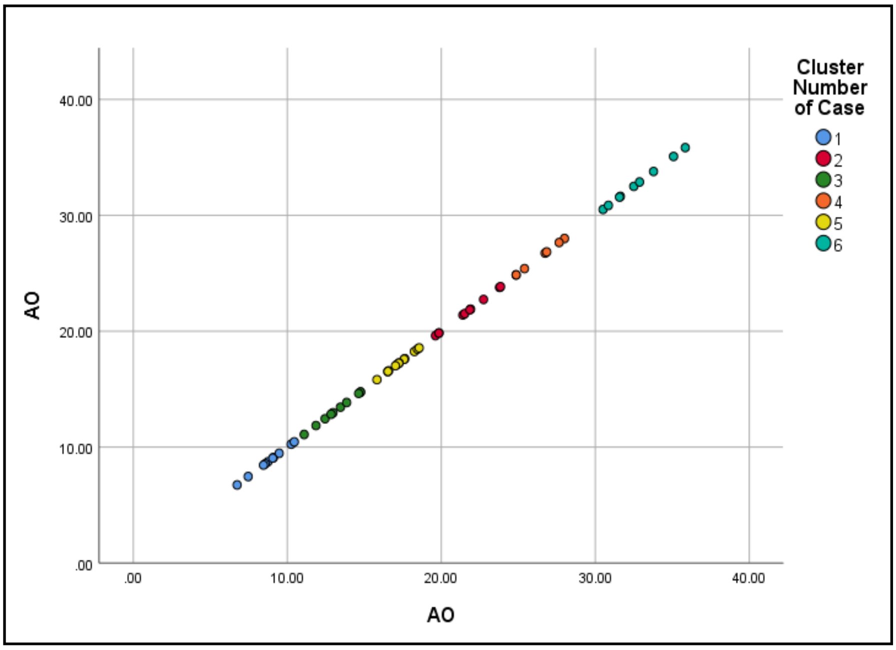


Figure 5.21. Scatter Plot of Area Occupancy

Similarly, for median delay the value indicating LOS A and LOS F ranges from lower than 0.56s and greater than 2.5s respectively. A part of the data extracted from the same median opening which was not used for the clustering procedure was used to classify the median opening considered for the study into an LOS category. The respective values obtained for each of the parameters and the corresponding LOS are described in the Table 5.17 given below.

Table 5.17. LOS Categorisation for the Selected Median

Parameter	Value obtained	LOS Category
Service delay	6.78 s	B
Median delay	1.18 s	C
AO	17.4%	C

The service delay obtained was about 6.78s which falls under the category of LOS B while the median delay and AO had values in the range of 1.18 s and 17.4% respectively. Both classifying the median opening under LOS C. We can conclude from this findings that in this particular median opening where the priority rule is not followed the vehicle taking U turn mostly enforces a forced entry which makes the through vehicle to face delay to an extent that the LOS in the context of median delay falls in the range of LOS C. AO is a term which in addition to the time that a vehicle spends in a median opening takes into the account the heterogeneous traffic condition prevalent in the median opening which makes the parameter quite dependable compared to the other two parameters. As the median delay and AO are giving the same LOS classification we can conclude that in such median openings rather than using the U turn movement to quantify the LOS (which is the general norm) it will be more accurate to adopt the median delay to classify the LOS.

5.5. Summary

The exploratory analysis was conducted to determine the trend of the parameters service delay, median delay and area occupancy. Service delay, median delay and area occupancy models were generated and sensitivity analysis was conducted on these models. A comparison between disaggregate and aggregate model for median delay was conducted. Finally, K means clustering was adopted to classify the LOS of a median opening using the parameters service delay, median delay and area occupancy.

CHAPTER 6

CONCLUSION

LOS is a term which describes the quality with which a specific type of facility is operating. Three measures have been used in this study to classify the LOS of an unmanaged opening of a median. Delay faced by low priority movements, such as U-turning vehicles helps to explain the operational state of a median opening. Due to this, the service delay faced by vehicles taking U turn was taken into account to calculate the LOS of unmanaged opening of a medians. In developing nations like India, violations in priority rule are particularly prevalent. Vehicles having more priority (major stream flow) are therefore observed to incur delays. Median delay experienced by through vehicle is another parameter employed to measure LOS. In instances where there is a continual flow of traffic, the HCM's primary indicator of LOS is traffic density. Field density is challenging to quantify, and traffic density ignores varied and non-lane-based traffic movement that characterises traffic in developing nations. As a superior alternative to traffic density, Mallikarjuna and Rao established the idea of "AO" to consider the non-lane-based vehicle movement. As a result, AO has been employed as another parameter in this study area to evaluate the LOS. The traffic stream quality at unmanaged opening of a medians can be assessed using the results of this study.

The conclusions derived from this study is as follows:

- The type of vehicle has a major influence in determining the delay that it experiences. The two wheelers have the lowest value of delay pertaining to its smaller size and ability to fit into smaller gaps considering the case of service delay.
- In the context of median delay also two wheelers merge at a faster rate than car or SUV confirming to the lower value obtained for median delay categorisation.
- The service delay, median delay and AO are found to have an exponential rise with rise in vehicular volume. The models developed relating the vehicular volume and each of these parameters can be used to obtain the value of service delay, median delay and AO pertaining to the corresponding vehicular volume.
- A relationship is also developed to determine the vehicle specific median delay using the parameters of vehicular volume making a u turn and the type of vehicle under study. By analysing the delay values produced from the models and those received from the field, the suggested model's correctness is evaluated.

- A MAPE value of less than 10% is obtained for the developed model indicating its reliability.
- K means clustering classified the parameters into LOS categories. The cluster numbers are fixed by comparing the silhouette width values obtained for different number of cluster groups. All of them gave a higher silhouette value for 6 number of clusters.
- The ANOVA test and the post hoc Bonferroni test are used to assess the statistical accuracy of the cluster groups produced. Both analyses demonstrate that the statistical validity of the cluster groups generated and that the cluster centre’s means are statistically distinct from one another at 5% level of significance.
- In comparison with HCM’s control delay to define the quality of service in a roadway facility the values obtained for service delay and median delay are lower.
- In relation to service delay, the best condition at a facility (LOS A) is depicted by a value of less than 4.54 s whereas the worst condition i.e., LOS F is defined by a value of higher than 23.6s.
- For median delay, LOS A is represented by a value of less than 0.56 s, while its worst state, LOS F, is indicated by a value of more than 2.5 s.
- Sensitivity analysis conducted for service delay provided results which indicate that for unit change in vehicular volume (for volume less than 2000 vph) the rise in service delay for 2W is 0.05% and for that of 3W, car and SUV is 1.14, 1.63 and 2.18 times that of 2 wheelers. For volumes higher than 2000 vph the service delay rise was 0.11% for 2W and for 3W, car and SUV it was about 1.12, 1.59 and 2.78 times of 2W respectively
- At vehicular volume less than 1500 vph for unit increase in total vehicular volume, the increase in median delay is about 0.01%. For through vehicular volume and U turning vehicular volume the increase in median delay is about 0.018% and 0.073% respectively. Beyond 1500 vph an increase of about 0.03% in median delay is brought about by unit increase in total vehicular volume. While for through and U turning vehicular volume the increase in median delay is about 0.04% and 0.79% respectively.
- The sensitivity analysis conducted on area occupancy showed different trends at the boundary of 500 vph. At vehicular volume less than 500 vph for unit increase in total vehicular volume, the increase in area occupancy is about 0.002%. For

through vehicular volume and U turning vehicular volume the increase in area occupancy is about 0.003% and 0.008% respectively. Beyond 500 vph an increase of about 0.005% in area occupancy is brought about by unit increase in total vehicular volume. While for through and U turning vehicular volume the increase in area occupancy is about 0.006% and 0.032% respectively.

The results from this study data can be applied to other urban areas with comparable road geometry comparable road geometry. For cities with varying road geometry the same methodology that has been adopted here may be used and LOS ranges can be generated. As a result, the recommended models may be useful for estimating major stream delay within the vicinity of the opening of the median. It would help improve understanding of the traffic operations at median openings and subsequently allow for the offering of improved strategies to control traffic congestion in openings of median.

REFERENCES

1. Akgüngör, A. P., and A. G. R. Bullen. (2007). "A new delay parameter for variable traffic flows at signalized intersections." *Turkish J. Eng. Environ. Sci*. 31 (1): 61–70.
2. Arasan, V.T.; Dhivya, G. (2008). "Measuring heterogeneous traffic density. In: Proceedings of International Conference on Sustainable Urban Transport and Environment", *World Academy of Science, Engineering and technology, Bangkok,* vol. 36, pp. 342–346.
3. Ashalatha, R., and Chandra, S. (2011). "Critical Gap through Clearing Behaviour of Drivers at Unsignalized Intersections". *KSCE Journal of Civil Engineering* 15 (8): 1427–1434.
4. Azimi, M., and Zhang, Y. (2010) "Categorizing freeway flow conditions by using clustering methods" *Transportation Research Record: Journal of the Transportation Research Board*, 2173, pp. 105-114.
5. Bezdek J. C. (1981). "Pattern Recognition with Fuzzy Objective Function Algorithm" Plenum, New York.
6. Bhuyan, P. K., Rao, K. V. K. (2010). "FCM clustering using GPS data for defining LOS criteria of urban streets in Indian context", Transport Problems, 5(4), pp. 105-113.
7. Chaudhry, M. S., and P. Ranjitkar. (2013). "Delay Estimation at Signalized Intersections with Variable Queue Discharge Rate". *Journal of the Eastern Asia Society for Transportation Studies* 10: 1764–1775.
8. Choocharukul, K.; Sinha, K.C.; Mannering, F.L. (2004)." User perceptions and engineering definitions of highway LOS: an explanatory statistical comparison". *Transp. Res. Part A* 38, 677–689.
9. Day, C. M., Wasson, J. S., Brennan Jr, T. M., and Bullock, D. M. (2012). "Application of Travel Time Information for Traffic Management".
10. Dueck, D. (2009). "Affinity propagation: clustering data by passing messages", Ph.D. thesis, University of Toronto.
11. Gujarati, D. N. (2003). Basic Econometrics. 4th Edition. New York: McGraw-Hill.
12. Ivana, C., Zvonko, K., and Marjana, P. (2011) "Hybrid approach for urban roads classification based on GPS tracks and road sub segments data", *Promet-Traffic & Transportation*, 23(4), pp. 289-296.

13. Kanagaraj, V., Srinivasan, K. K., and Sivanadan, R. (2010) "Modeling vehicular merging behaviour under heterogeneous traffic conditions", *Transportation Research Record: Journal of the Transportation Research Board,* 2188, pp. 140–147.
14. Kita, H. (2000). "Level-of-service measure of road traffic based on the driver's perception". *In: 4th International Symposium on Highway Capacity. Transportation Research Circular EC*, vol. 18, pp. 53–62.
15. Liu, P., Lu, J., Hu, F., and Sokolow, G. (2008). "Capacity of U-turn movement at median openings on multilane highways." Journal of Transportation Engineering, ASCE, Vol. 134, No. 4, pp. 147-154.
16. Ma, D.F.; Ma, X.L.; Jin, S.; Sun, F.; Wang, D.H. (2013). "Estimation of major stream delays with a limited priority merge*". Canad. J. Civil Eng.* 40(12), 1227–1233.
17. Madhu, K., Srinivasan, K. and Sivanandan, R. (2022) "Acceleration models for two-wheelers and cars in mixed traffic: effect of unique vehicle-following interactions and driving regimes". *Current Science*, Vol 122, No 12.
18. Maitra, B., Sikdar, P.K. and Dhingra, S.L. (1999) "Modeling congestion on urban roads and assessing LOS", *Journal of Transportation Engineering,* 125 (6), pp. 508-514.

19. Mallikarjuna, C., Rao, K.R. (2006). "AO characteristics of heterogeneous traffic". *Transportmetrica* 2(3), 223–236.
20. Marwah, B.R., Singh, B. (2000). "LOS classification for urban heterogeneous traffic: A case study of Kanpur metropolis". *In Proc., Fourth International Symposium on Highway Capacity, Hawaii, June-July,* 2000, pp. 271-286.
21. Minh, C. C., T. H. Binh, T. T. Mai, and K. Sano. (2010). "The delay estimation under heterogeneous traffic conditions." *J. East. Asia Soc. Transp. Stud*. 8: 1583–1595.

22. Mohapatra, S. S., and Bhuyan, P. K. (2012). "Self-organizing map of artificial neural network for defining LOS criteria of urban streets", *International Journal for Traffic & Transport Engineering*, 2(3).
23. Mohanty, M., and Dey, P.P. (2021). "Operational effects of U-turns at median opening", *Transportation Letters*, 1-13.
24. Mohanty, M., Dey, P.P. (2019). "Quantification of LOS at Unmanaged opening of a medians Using AO Through Cluster Analysis". *Arabian Journal for Science and Engineering* **44,** 4667–4679.

25. Mohanty, M., and Dey, P.P. (2018). “Major stream delay under limited priority conditions”, *Journal of Transportation Engineering Part A: System's,* volume *145, issue 3.*
26. Mohanty, M., and Dey, P.P. (2017). “Modelling the major stream delay due to U-turns”, *Transportation Letters.*
27. Mohanty, M., and Dey, P.P. (2018). “Modelling the area occupancy of major stream traffic”. *European Transport*, Issue 66, Vol 1, pp. 1825-3997
28. Mohapatra, S., and Dey, P.P. (2021). “Application of Cluster Analysis to Define LOS Criteria of U-turns at Median Openings”, *European Transport*, Issue 81.
29. Mohapatra, S. S., Dey, P.P., Chandra, S. (2016a). “Conflicting Volume for U-turns at Unmanaged opening of a medians.” *Proceedings of the Institution of Civil Engineers-Transport* 169 (4), 195–204.
30. Mohapatra, S. S., Dey, P.P., S. Chandra. (2016b). “Modeling the Critical Position of U-turning Vehicles at Unmanaged opening of a medians.” *KSCE Journal of Civil Engineering* 20 (1), 411–420.
31. Mohapatra, S. S. and Dey, P.P. (2015). “Lateral Placement of U-turns at Median Openings on Six-lane Divided Urban Roads.” *Transportation Letters* 7 (5), 252–263.
32. Mohapatra, S., Sil, G., Dey, P.P. (2015). “Quantification of LOS at median openings through cluster analysis”. *Indian Highways*, Indian Road Congress, 43, 25-31.
33. Patnaik, A.K.; Bhuyan, P.K.; Rao, K.K. (2016). “Divisive analysis (DIANA) of hierarchical clustering and GPS data for LOS criteria of urban streets”. *Alex. Eng. J.* 55(1), 407–418.
34. Sakai, T.; Yamada-Kawai, K.; Matsumoto, H.; Uchida, T. (2011). “New measure of the LOS for basic expressway segments incorporating customer satisfaction”. *Proc. Soc. Behav. Sci.* 16, 57– 68.
35. Sil, G., Mohapatra, S. S., Dey, P. P., and Chandra, S. (2017). “Assessment of Service Delay and Merging Time at Unmanaged opening of a medians” (No. 17-00925).
36. Sujay Diwakar, B., Ranjith Kumar, V., Kameswara Rao, M. (2016). “Development of delay model at median openings of along NH-44”, *International Journal for Technological Research in Engineering, Volume* 4, Issue 3, 2347-4718.
37. Transportation Research Board TRB. (2000). Highway capacity manual, National Council, Washington, D.C.

38. Washburn, S.S.; Kirschner, D.S. (2006). “Rural freeway LOS based upon traveler perception”. *In: The 85th Annual Meeting of the Transportation Research Board*, pp. 1–21.