TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO.: T06/078

Analyzing the Vehicles' Platooning and Evaluation of Operational Performance Measures of Two-Lane Intercity Highway in Nepal: A Case Study of the Muglin-Narayanghat Section (NH44-004)

by

Kshitiz Dhakal

078/MSTRE/006

A THESIS

SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE IN TRANSPORTATION

ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING

LALITPUR, NEPAL

April, 2025

COPYRIGHT

Head
Department of Civil Engineering
Pulchowk Campus, Institute of Engineering
Lalitpur, Kathmandu
Nepal

TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

DEPARTMENT OF CIVIL ENGINEERING

The undersigned certify that they have read and recommended to Institute of Engineering for acceptance, a thesis entitled **"Analyzing the Vehicles' Platooning and Evaluation of Operational Performance Measures of Two-Lane Intercity Highway in Nepal: A Case Study of the Muglin- Narayanghat Section (NH44-004)"** submitted by Mr. Kshitiz Dhakal in partial fulfillment of the requirement for degree of Master of Science in Transportation Engineering.

....

Supervisor: Mr. Anil Marsani
Program Coordinator
M.Sc. in Transportation Engineering
Department of Civil Engineering

....

External Examiner: Mr. Rajesh Khadka
Program Coordinator, TEAM
Nepal Engineering College

....

Program Coordinator: Mr. Anil Marsani
M.Sc. in Transportation Engineering
Department of Civil Engineering

Date: ..2082/01/09..........

ABSTRACT

The study analyzed platooning behavior and evaluated several operational performance measures on a two-lane intercity highway in Nepal. Field data were collected from a section of NH44-004, focusing on speed differential (SD) and vehicle gap characteristics to distinguish between platooning and free-flow conditions. Based on the analysis, an 8-second time gap was established as the threshold for free-flow conditions. Vehicles with a time gap of less than 8 seconds and a speed differential (SD) within ±6 km/h were classified as platooning. To identify platooning occurrences, probability density functions (PDFs) of SD under free-flow conditions were superimposed on histograms representing all traffic conditions.

The study found that 37% of vehicles were involved in platoons, typically led by heavy trucks, with platoon sizes generally between 2 to 4 vehicles. Welch's t-test revealed a significant reduction in speed for most vehicle types in platooning conditions compared to free-flow conditions, except for three-wheelers and multi-axle trucks, which showed no significant difference in mean speed. Effect size analysis further indicated that platoon formation had a large impact on the speed of cars and microbuses, and medium to small impacts on other vehicle categories.

Follower Density (FD) per lane was identified as the most effective operational performance measure, showing a strong correlation with directional traffic volume (R^2 = 0.703, MAPE = 14%). This relationship provides a valuable tool for Level of Service (LOS) evaluation, aligned with the updated criteria of the U.S. Highway Capacity Manual. The study recommends further validation of these findings on other roads in Nepal and suggests that follower density be considered a key metric for LOS analysis as Nepal's road infrastructure continues to develop.

Keywords: Two-lane roads, Platooning, Free-flow conditions, Distribution fitting, Superimposition analysis, Welch's t-test, Cohen's d test, Traffic performance evaluation

ACKNOWLEDGEMENT

I would like to express my heartfelt gratitude to Assistant Prof. Anil Marsani, Program coordinator, M.Sc. in Transportation Engineering, my dissertation supervisor, for his highly valuable and constant support, guidance, motivation and encouragement. I am deeply grateful to my External Examiners, Assistant Prof. Rajesh Khadka and Dr. Thusitha Chandani Shahi for their valuable comments during my thesis work. I want to thank my teachers Dr. Rojee Pradhananga, Dr. Pradeep Kumar Shrestha, Dr. Surya Raj Acharya and Dr. Padma Bahadur Shahi, for their insightful guidance and knowledge imparted during my master's studies. Their expertise has been invaluable in shaping my understanding and approach to this research. I extend my sincere appreciation to my friends Motiram Giri, Sanjay Luitel, Aadarsha Ram Shrestha, and Neeva Dahal for their unwavering support throughout this project. Their constant encouragement and insightful discussions have played a significant role in refining my ideas. Additionally, I am immensely thankful to my family and other friends for their continuous support and motivation.

Name: **Kshitiz Dhakal**

Roll No: **078/MSTrE/006**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

2W	Two-Wheelers
3W	Three-Wheelers
AADT	Annual Average Daily Traffic
ATS	Average Travel Time
CDF	Cumulative Distribution Function
DOR	Department Of Roads
FD	Followers' Density
FFS	Free- Flow Speed
HCM	Highway Capacity Manual
HT	Heavy Truck
Km/hr	Kilometer Per Hour
LCV	Light Commercial Vehicles
LOS	Level Of Service
LT	Light Trucks
MAT	Multi-Axle Trucks
MLR	Multiple Linear Regression
NF	Number Of Followers
NFPC	Number Of Followers Per Capacity
PCU	Passenger Car Unit
PDF	Probability Density Function
PF	Percentage Followers
SD	Speed Deferential
Std.	Standard Deviation

CHAPTER 1 : INTRODUCTION

1.1 Background

Road transportation has a major share in Nepal's national transport network. Approximately 90% of freight and passenger movement across the country is through the road (Investment Board Nepal, 2024). A significant portion of Nepal’s road network comprises undivided roads, serving various purposes, including rural connectivity and intercity transportation for passengers and goods. These undivided roads primarily include single-lane, intermediate-lane, and two-lane configurations.

Over the past decade, Nepal has experienced a continuous rise in vehicle registrations (Ministry of Finance Government of Nepal, 2024) leading to increased road traffic, and congestion. And this increase in traffic is expected to rise, with passenger transport activity estimated to grow at 1.5% per annum up to 2050, and freight transport activity estimated to grow faster at 4.8% per annum over the same period (Asian Transport Observatory, 2020). Consequently, managing traffic, planning transportation, analyzing driver behavior, and infrastructure planning have become more challenging. To address strategic transportation needs and the increasing traffic demand, Nepal has been actively expanding and upgrading its road network. The primary focus has been on upgradation of single-lane and intermediate-lane roads to at least two-lane configurations and also the upgradation of two-lane roads into divided multilane highways (National Planning Commission, 2025), (DOR, Annual Progress Report (2080/081), 2023). Given these upgrades, studying the traffic characteristics and assessing operational performance with appropriate performance measures is crucial for two-lane roads in Nepal. Such studies will provide essential guidance for future road upgrades, ensuring efficient and sustainable transport infrastructure development.

Around the world, two lane roads have played a major role in the development of modern societies, both in developed and developing countries, serving various functions, from local roads handling low volumes of local traffic to principal arteries connecting towns and small cities, and everything in between (Al-Kaisy, 2022). These undivided roads accommodate bidirectional traffic flow within a shared carriageway, resulting in frequent interactions between vehicles traveling in the same and opposing directions. The bidirectional nature, of these roads, limits overtaking opportunities, often forcing faster vehicles to slow down, which leads to following conditions and the formation of platoons, where vehicles move in groups at similar speeds. Platoon formations lead to a decline in the traffic performance of two-lane roads and a reduction in the level of service (LOS) (Samadi et al., 2023). As a result, studying platoon formation and its characteristics has become essential for analyzing traffic performance on two-lane highways. (Transportation Research Board and National Academies of Sciences, 2022) (Penmetsa et al., 2015) (Ghosh et al., 2013)

Unlike in most of the developed countries, Nepal's roads consist of a diverse mix of vehicles (including buses, trucks, light commercial vehicles, cars, motorcycles, and scooters) all sharing the same road space. This heterogeneity influences key traffic performance parameters such as speed, time headway, gap, and equivalency factors (Sharma et al., 2011) making traffic flow more complex.

1.2 Problem Statement

With the significant upgrades to and from two-lane roads expected in the coming years, evaluating their operational performance has become increasingly important. On two-lane, two-way roads, identifying follower vehicles and studying platooning characteristics are crucial for understanding traffic flow and operational performance. While numerous studies have been conducted in homogeneous traffic conditions, where vehicle types and behaviors are relatively uniform, such analysis is comparatively simpler. However, in heterogeneous traffic conditions, characterized by a diverse mix of vehicle types and driving behaviors, limited studies have been conducted. In the Nepalese context, this area remains largely unexplored, thereby creating a research gap. Although the (Indian Highway Capacity Manual, 2017) proposes a preliminary methodology for platoon identification under heterogeneous traffic conditions, particularly linked with Level of Service (LOS) analysis for undivided roads, it remains in an early developmental stage and requires further refinement.

In Nepal, the Muglin–Narayanghat highway section serves as a critical transport corridor linking the capital with several key regions. This segment experiences high traffic volumes and a wide range of vehicle types (DOR, 2022/2023). Despite its strategic importance, no comprehensive study has been conducted on platooning behavior and performance measures in this section. This highlights the need to investigate platooning events and evaluate operational performance on this key intercity highway.

1.3 Objective of Study

The main objective of this study is to analyze platooning events, their characteristics, and their application in evaluating operational performance of two-lane highway. The specific objectives are as follows:

- To identify free-flow and platooning conditions using a detailed methodology based on vehicle gap and speed differential (SD).
- To analyze the effect of platooning conditions on stream speed and on the speeds of different vehicle types.
- To evaluate key operational performance measures for the selected section of the two-lane highway.

1.4 Scope of Study

This study focuses on analyzing vehicle platooning behavior and evaluating different operational performance measures for a two-lane intercity highway of Nepal. The study is conducted on the Muglin–Narayanghat section (NH44-004), with the following scopes:

- Data Collection: Data were collected through a video-graphic survey, which provided detailed information on classified traffic volume, vehicle (time) gap, spot speed, space mean speed, and speed differential (SD) for different vehicle types.
- Traffic Condition Identification: Free-flow and platooning conditions were identified based on thresholds of gap and speed differential data. The curve fitting and superimposition techniques were used for identifying such events.
- Traffic Speed Analysis: The effect of platooning conditions on overall stream speed and the speeds of different vehicle types was analyzed where graphical and statistical methods were used.

- Evaluation of Operational Performance Measures: Key operational performance measures: Follower Density (FD), Average Travel Speed (ATS), Number of Followers (NF), Number of Followers per Capacity (NFPC), Percentage of Followers (PF) were evaluated based on multiple linear regression and correlation analysis. These measures were assessed within the selected section of the highway.

1.5 Limitation of Study

- The study was conducted under base condition, and therefore, further research is needed in other scenarios where factors such as grade, curves, variations in roadway width, pavement condition, and weather conditions may influence traffic behavior.
- While the methodology can be applied to other undivided roads, the study's focus on a single section means the findings cannot be generalized to other two-lane roads across Nepal.
- The data were collected over a span of 30 hours at a single section of the road, which may not capture the full range of traffic behaviors. Therefore, additional data collection across different times and locations is needed for a broader understanding of traffic patterns.
- Shorter data aggregation intervals should be considered to more effectively capture impact of directional volume, opposite traffic volume, and the percentage of heavy vehicles on operational performance.

1.6 Organization of the Report

The report consists of the following chapters:

Chapter 1: Introduction: This chapter presents the background, problem statement, objectives of the study, scope of the study, and limitations of the study.

Chapter 2: Literature Review: This chapter presents a comprehensive review of the methodologies outlined in the HCMs for evaluating the performance of two-lane, two-way roads. It explores existing approaches for identifying free-flow and platooning conditions and examines various traffic characteristics and operational performance measures used in these evaluations. The review covers both homogeneous and heterogeneous traffic environments, providing insights into how these conditions influence platooning behavior and performance outcomes.

Chapter 3: Methodology: This chapter discussed the methodology for identification of the free flow and platooning condition, statistical analysis and the evaluation of different operational performance measures in detail.

Chapter 4: Analysis and Design: This chapter includes the analysis and interpretation of the results.

Chapter 5: Conclusion and Recommendation: It provides summary of the study, and recommendation, with scopes for further studies.

CHAPTER 2 : LITERATURE REVIEW

2.1 Performance Measure of Two-Lane Roads Based on HCM

The HCM has been the primary reference for studying the performance measures of two-lane roads. Since the first edition of the HCM in 1950 (U.S. Bureau of Public Roads, 1950), which primarily used operational speed and practical capacity as performance measures, the methodology has evolved considerably. The second edition introduced the concept of Level of Service (LOS), incorporating the volume-to-capacity (V/C) ratio and operational speed. The HCM 1985 (Transportation Research Board, 1985) introduced Percent Time Delay (PTD) as the primary LOS measure for two-lane highways, defining "following" vehicles as those with headways of less than 5 seconds. Over time, PTD was replaced by Percent Time Spent Following (PTSF) to better capture platooning effects (Al-Kaisy & Karjala, 2008). However, due to challenges in direct measuring PTSF, HCM 2000 recommended Percentage Followers (PF) as a surrogate measure. PF is defined as the proportion of vehicles with headways below 3 seconds at a specific roadway point (Transportation Research Board, 2000). The latest 7th edition of HCM marks a major shift in methodology. Instead of using PTSF and average travel speed (ATS) to determine LOS for different classes of two-lane roads (Class I, Class II, and Class III), the new approach defines Follower Density (FD) and incorporates posted speed limits for LOS identification. In this update, the concept of PTSF has been removed, and FD has been introduced. Vehicles with a headway of less than 2.5 seconds are now considered as following (Transportation Research Board and National Academies of Sciences, 2022).

2.2 Other Studies on Performance Measure of Two-Lane Roads

Several other studies were conducted for the assessment of the performance of two-lane highways around the world. A study on the Tokai–Hokuriku Expressway in Japan (Catbagan & Nakamura, 2006) assessed different performance measures such as Average travel speed (ATS), Percentage time spent following (PTSF), Percentage followers (PF) and Follower’s density (FD), which were evaluated against the directional flow as the platooning variables. Where a positive linear relationship between directional flow and follower density was identified. Given its strong correlation with directional flow rate, FD was recommended as the primary measure for evaluating LOS on two-lane expressways. A study on two-lane rural highways in Montana, (Al-Kaisy & Karjala, 2008) analyzed six performance indicators: Average travel speed (ATS), Average travel speed of passenger cars (ATS-PC), ATS as a percent of free-flow speed (ATS/FFS), ATS-PC as a percent of free-flow speed of passenger cars (ATS-PC/FFS-PC), Percent followers (PF), and Follower density (FD), to examine their relationship with platooning variables/traffic characteristics such as directional traffic flow, opposing traffic flow, percent heavy vehicles, and speed variation. A correlation analysis revealed that traffic flow in the direction of travel had the highest correlation with performance indicators, while other platooning variables showed weak or no significant correlation. A multivariate linear regression analysis was conducted, modeling each performance indicator as a dependent variable. Among the regression models developed, only follower density and percent followers were found to be statistically significant at a 95% confidence level. FD was considered as a strongest measure for level of service (LOS) analysis given its strong correlation with traffic flow and ability to reflect congestion effects. A similar study was conducted on Egyptian intercity rural two-lane roads (Hashim, 2011), incorporating the same six performance measures as (Al-Kaisy & Karjala, 2008) along with percent impeded (PI). The analysis found that FD, PF, and PI showed positive correlations with traffic flow, while speed-related measures like ATS and ATS-PC exhibited negative and weaker correlations with traffic flow. Among the performance measures, PF had the strongest and most significant correlation with traffic flow rate, followed by FD and PI. The opposing flow rate showed weaker correlations, and the percentage of heavy vehicles had almost no significant correlation with any of the performance measures. Further regression analysis showed that the model for follower density was the most effective, with an R^2 value of 0.75 and significant results ($p < 0.05$) at the 95% confidence level. Among the traffic characteristics, directional traffic flow was the most significant. A quadratic model was developed to describe the relationship between follower density and directional traffic flow. Additionally, based on the relationship between PF and FD and referencing HCM guidelines, threshold values for different LOS levels based on follower density were proposed for the local context of the Egypt.

Very few studies have been conducted in the heterogeneous traffic, and in the context of Nepal, such research is still a due. Since the methodologies and operational parameters from the Highway Capacity Manuals (HCM) were considered not directly applicable to heterogeneous traffic scenarios (Ghosh et al., 2013), most studies have focused on assessing the applicability of various operational parameters originally introduced for homogeneous traffic. These studies aimed to adapt and validate these parameters for local heterogeneous conditions before implementation and additional efforts were also made to establish a connection between the LOS framework from HCM and its applicability in heterogeneous traffic environments.

A study was conducted based on data collected from three two-lane rural highway sites in India (Penmetsa et al., 2015), where six performance measures: ATS, ATS PC, ATS/FFS, PF (PCU/hr), FD, and a new measure, NFPC (the ratio of the number of followers to the capacity of the roadway) were analyzed. The study found that PF and FD showed better relationships with the two-way traffic volume but suggested NFPC as the preferred measure for analysis. As NFPC was identified as a good performance measure for assessing road performance under mixed traffic conditions it was related with PF, the surrogate of PTSF in HCM. Using the HCM LOS as reference, threshold values for different LOS were determined, based on the relationship ($R^2 = 0.90$) between PF and NFPC. The study also highlighted that the HCM (2000) definition of "followers" — vehicles with headways of less than 3 seconds — was misleading in mixed traffic. Instead, a probability plot of gap versus following behavior was used, with vehicles classified as followers if their speed difference was 2 km/hr or less, and the critical gap was found to be 2.6 seconds. Similar study was conducted in other heterogenous environment, (Boora et al., 2017) across five two-lane intercity highways in different regions of India, to assess Level of Service (LOS) measures. The study included the seven performance measures from (Hashim, 2011), as well as two additional measures: DOB (the ratio of the total number of followers to the total number of vehicles in a particular time interval) and the NFPC as (Penmetsa et al., 2015). A correlation analysis was performed between two-way traffic volume (PCU/h) as a platooning variable and the nine performance measures, (six speed-related and three follower-related measures). The results revealed that speed-related measures exhibited low R^2 values, indicating weak correlations, while follower-related measures showed strong correlations, except for PF, which did not demonstrate a significant correlation with traffic volume. FD, with an R^2 value of 0.82, and NF (in PCU/h), with an R^2 of 0.86, both showed strong correlations with traffic volume. NFPC was also studied which, exhibited a strong correlation ($R^2 = 0.86$) with traffic volume. A clustering analysis was then conducted to identify LOS ranges, with the help of FD and NFPC, and different ranges were proposed based on the values of NFPC. In context of Nepal studies related to operational performance evaluation has not yet been explored creating a research gap.

2.3 Studies on Vehicle Following Conditions on Two-Lane Roads

Previous studies (as discussed in Section 2.1 and 2.2) suggested that before analyzing the operational performance of two-lane roads, it is essential to identify the free-flow condition and the vehicles' platooning conditions. Where for a free-flow condition HCM recommends Free-flow speed (FFS) as the mean speed under low flow conditions (up to two-way flows of 200 pc/h) and considers platooning or following events as the event where any vehicle follows another vehicle at a headway of 2.5 s or less and percent followers is simply the percentage of all vehicles with a headway of 2.5 (Transportation Research Board and National Academies of Sciences, 2022). A vehicles' platoon is also defined as "a group of vehicles traveling together in a relatively close formation due to constraints imposed by traffic control devices, roadway geometry, or interactions with other vehicles, particularly slower-moving vehicles that limit passing opportunities" (Transportation Research Board, 2016). While the exact definition may vary, in general, a group of vehicles with a leading vehicle and at least one following vehicle, moving with similar speed is considered as a platoon. The minimum number of vehicles in a platoon group is generally considered to be two or more (Gaur & Mirchandani, 2001) (Kasi & Karuppanan, 2024).

Various studies have examined different methodologies for determining the free-flow and the vehicle platooning conditions, which were based on speed differences, headway thresholds, and gap analysis. The effectiveness of these methods in heterogeneous traffic conditions, such as those observed in developing countries, has also been evaluated.
In a study, where (GUELL & VIRKLER, 1988) examined LOS criteria for general terrain segments, the vehicle delay/platooning was identified within a range of 3.5 to 4.0 seconds. (Gattis et al.) studied platooning on three rural two-lane highways in northwest Arkansas, where the average speed was plotted against the headway value and a 5-second headway was identified as critical headway threshold for platoon formation, beyond this threshold the average speed was stable or the traffic was in free moving condition. A similar finding was observed in a study at Egypt where data was collected at 20 two-lane roads (Hashim,

2011). In the study, headway was plotted against the 85th percentile speed instead of the average speed. The study determined a 5-second threshold, beyond which the 85th percentile speed stabilized, defining it as the critical headway. A study conducted on a two-lane road between Stockholm and Uppsala, identified criteria for distinguishing queueing and non-queueing vehicles (Miller). A histogram of observed time intervals between vehicles was superimposed with a negative exponential curve for free-flowing vehicles. An 8-second threshold was set to differentiate non-queueing or the free-flowing vehicles. To further refine queue identification, relative velocities were analyzed. The analysis showed that non-queueing vehicles followed a gamma distribution, leading to approximately normal distributions for their relative velocities. A comparison of expected and observed relative velocity distributions identified a range of -4 to +8 km/h, for indicating queueing behavior.

Few studies have also been conducted in heterogeneous traffic environments for the identification of the free-flow condition and the platoons. A study conducted on nine two-lane intercity highway sites in India (Boora et al., 2018), proposed a method for identifying free-flow conditions, where it utilized SD and gap relation, establishing a 10-second gap threshold as an indicator of traffic stabilization and free-flow conditions. Additionally, the study applied the superimposition method similar to (Miller) across multiple sites by overlaying the histogram of SD values for all vehicles with the normal probability density curve of SD values in free-flow conditions, to identify the platooning condition. This approach determined a SD range of −4 to +10 km/h, refining the identification of platooning. And further cut off value between 1.9 - 4.3 sec for gap was identified, at which the probability of not following is 50%. Similarly in other heterogenous traffic environments, (Kasi & Karuppanan, 2024) formulated a three-step strategy to identify vehicle platoons in the urban road network under heterogeneous traffic conditions. With traffic data collected by infrared sensors, on a six-lane divided urban arterial road, the study identified platoons based on three key measures: lateral clearance, critical headway, and relative speed difference. The analysis indicated that a lateral clearance of 0.5 seconds, a critical headway of 5 seconds, and a relative speed difference of 10 km/hr were the thresholds for platoon identification. Furthermore, the study analyzed platoon characteristics and found a direct correlation between the percentage of platooning vehicles and traffic volume.

The use of the SD-gap plots for identifying free-flow conditions, along with the method of superimposition for detecting platooning, and the method of superimposition for platoon identification has been found to be particularly effective in the context of heterogeneous traffic. This is supported by several additional studies (Boora et al., 2017) (Boora & Ghosh, 2017). The methodology has also been incorporated into the (Indian Highway Capacity Manual, 2017) where it is recommended for undivided road configurations, including single-lane, intermediate and two-lane roads. While the method of superimposition is widely recommended, its accurate application on appropriate distribution fitting and the calculation of optimal bin width for continuous variables such as speed differential. These statistical refinements, as suggested by (Freedman & Diaconis, 1981) (Scott, 1979) are essential for improving accuracy. This is particularly important in the Nepalese context, where traffic heterogeneity adds complexity to such analyses.

2.4 Summary of Literature Review

A review of existing literature indicates that the operational measures for two-lane roads vary significantly between homogeneous and heterogeneous traffic environments. These measures are typically classified into two broad types: speed-based measures and followers based. Speed-based measures include ATS, ATS-PC, ATS/FFS, ATS-PC/FFS-PC, while the follower-based measure include FD, NF, PF, NFPC. These measures have been evaluated against various variables such as directional volume, opposite volume and percentage of heavy vehicles. A majority of the literatures suggested the use of the follower-based measures over the speed-based measures for performance evaluation. Supporting this, the latest (7^{th}) edition of the US-HCM recommends the use of FD, and the Indian-HCM endorses NFPC for LOS analysis of undivided roadways. However, in the Nepalese context, these measures have yet to be applied or evaluated, representing a significant research gap.

Before calculating operational performance measures, accurate identification of free-flow and platooning conditions (i.e., vehicle following state) is essential. While some studies suggested using critical headway values or speed-headway plots, such approaches are more suited to the homogeneous traffic environments. In contrast, for heterogeneous traffic environments, such as those in Nepalese roads, alternative methodologies have been suggested. In heterogeneous traffic environments, the SD-gap plot has been recommended for identifying free-flow conditions, and the superimposition method is suggested for detecting platooning conditions. The superimposition technique involves overlaying the speed differential distribution of free-flow vehicles onto the histogram of all vehicles to distinguish platooning events. However, further methodological refinement was thus required for its effective application in Nepal's unique traffic context, where such a study has not been conducted.

CHAPTER 3 : METHODOLOGY

3.1 Methodological Framework:

After a detail literature review, a proper site was selected to fulfil the condition of uninterrupted flow which will be discussed in details in section 3.2. The Figure 3.1 provides a methodological framework of the study.

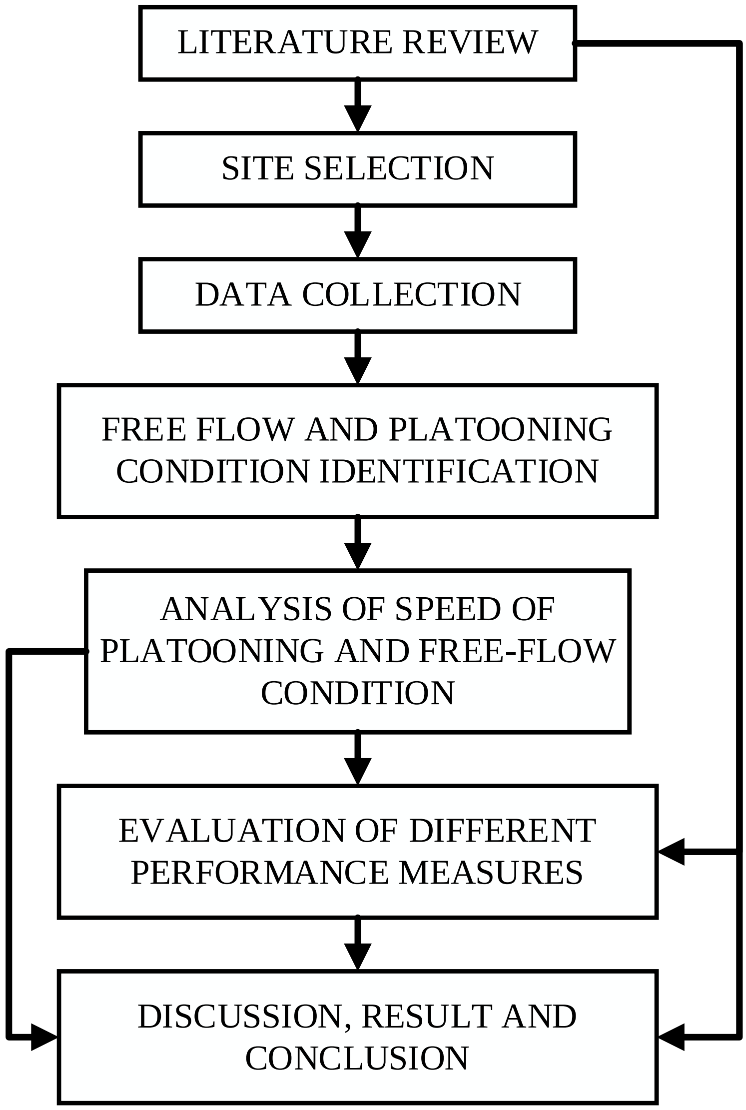


Figure 3.1: Overall Methodology

3.2 Study Area

As a study site, a location with significant traffic volume was required to ensure representative traffic flow conditions, along with a diverse traffic composition to reflect the heterogeneous traffic environments typical of Nepalese roads. Additionally, the site needed to be free from disruption events such as construction activities or temporary closures, which could interfere with the natural flow of traffic. The Muglin-Narayanghat Road (NH44-04), a key segment of Nepal's Strategic Road Network (SRN), was selected as the study area. With major highways across the country undergoing expansion and construction, this road was considered more suitable due to minimal construction activity during the study period. Functioning as a crucial corridor, it connects the Prithivi highway with the East- West highway, serving traffic to and from Nepal's capital, the western region, and parts of the east. The road experience an Annual Average Daily Traffic (AADT) of 18,864 PCU (DOR, 2022/2023). Its strategic importance, along with the presence of diverse traffic and a significant proportion of heavy vehicles, made it a more suitable location for analysis. The road is an undivided two-way, two-lane highway with a single carriageway with width varying between 9-11 m (World Bank, 2025).

Based on the predefined base conditions outlined in Indian-HCM (Indian Highway Capacity Manual, 2017) for the capacity estimation of a two-lane road, a reconnaissance survey was conducted for identifying a suitable site for data collection. To ensure compliance with these conditions, the survey confirmed that the selected section met the following criteria:

- The section was straight and level.
- The section was unaffected by interruptions, such as intersections, steep gradients, curves, or adjoining roads.
- There were no physical barriers, such as speed breakers or rumble strips.
- The section was largely free from roadside friction activities.
- The section was clear of any construction or maintenance work for at least 1 km on either side.
- The site had favorable environmental conditions, including clear weather, good visibility, and a well-maintained paved road surface.
- The site had as proper place for setting up the camera for data collection.

A section (as shown in Figure 3.2) at Dashdhunga was selected as the appropriate study section meeting the above-mentioned criteria. At the study section, the carriageway width is of 11 m, both lanes having width of 3.5 meters each, and 2 meters of paved shoulder on both sides.

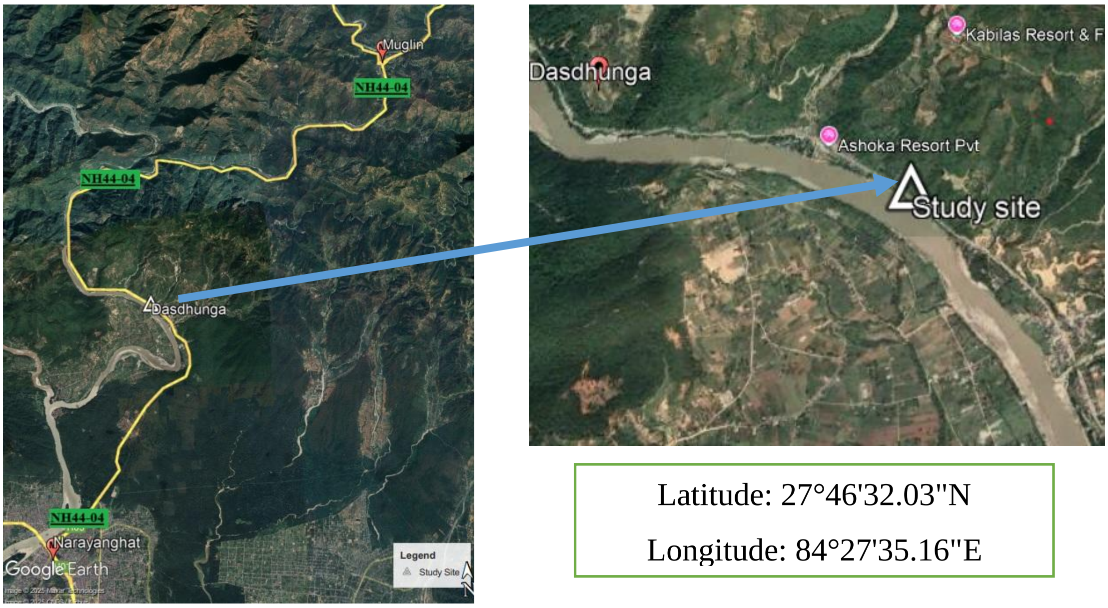


Figure 3.2: Study section

3.3 Traffic Data Collection

For traffic data collection, a camera was mounted on top of a building adjacent to the study area to capture traffic movement. While selecting the study section, a base section of 72.2 meters, which could be fully captured by the camera and exceeds the minimum recommended 60 meters in the Indian-HCM, was selected. The traffic study focused on analyzing traffic volume, composition, gap, and speed within the selected section. Data collection was conducted daily from 6 AM to 6 PM over three days: 8th, 9th, and 10th September 2024.

3.3.1 Video Data Extraction

The recorded video was displayed in Wondershare Filmora to collect the timestamps, and the data were manually entered into Excel for analysis. The timeline bar in the software displays the time from the start of the video in the format of Hours: Minutes: Seconds: Frames (00:00:00:00) (as shown in Figure 3), with an accuracy of 30 frames per second.

Based on the reference points marked in the field, a trap was drawn in the video editing software. The time at which vehicles entered and exited the trap was noted from the timeline, which is then input in the excel work sheet (as shown in Table 3.1) including the type of the vehicles (as per Table 3.2), direction of the vehicle movement, video number and the day of the data extraction. The noted time was then converted into seconds using the Equation 3.1.

Time in seconds = (minutes × 60) + seconds + (frames / 30). Equation 3.1

As the video from the camera displayed the date and time stamp, the timestamp at the start of the video (in Hours:minutes:seconds format) was added to the calculated time from Equation 3.1 to convert it into a 24-hour format.

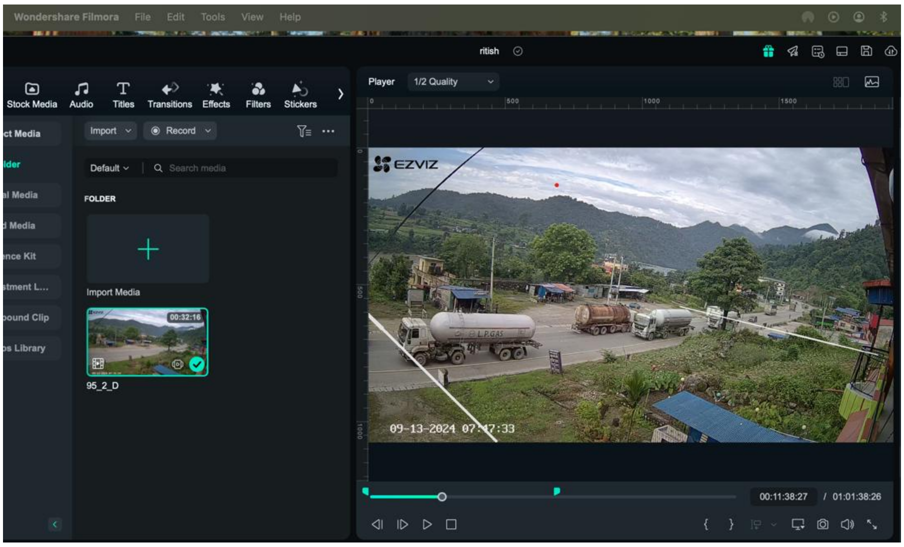


Figure 3.3 : Sample of Video in Wondershare filmora 13 for data collection

Table 3.1: Sample excel sheet for data input

Data collection sample													
S.N.	Vehicle Type	Video number	Day	Direction	In			Out			Travel Time (Second)	Length of Trap (Meter)	Gap (Second)
					Minute	Second	Millisecond	Minute	Second	Millisecond			
1	Car	29	1	M-N	1	8	25	1	14	4	5.650	72.2	1.3
2	Microbus	49	2	M-N	1	9	22	1	15	5	5.716	72.2	0.9
3	Two-wheelers	59	3	N-M	1	11	3	1	17	7	6.066	72.2	1.7

For each vehicle types, based on the time difference between the entry and exit for each vehicle types and the length of the trap, the spot speed was calculated as per the Equation 3.2. The speed difference was calculated as per Equation 3.3 and gap was calculated as per Equation 3.4 where, gap is defined as the time difference between the moment the rear bumper of the leading vehicle passes a specific point and the moment the front bumper of the following vehicle reaches the same point.

$$\text{Spot speed} = \frac{\text{Time of exit - Time of entry}}{\text{Length of Trap}} \qquad \text{Equation 3.2}$$

$$\text{Speed differential (SD)} = S_1 - S_2 \qquad \text{Equation 3.3}$$

$$\text{Gap} = T_1 - T_2 \qquad \text{Equation 3.4}$$

Where,

- S_1 is the speed of lead vehicle
- S_2 is speed of following vehicle
- T_1 is the time when the back bumper of the leading vehicle exits the trap.
- T_2 is the time when the front bumper of the following vehicle exits the trap.

3.3.2 Vehicle Types and Dimension

While extracting the data, vehicles in the traffic stream were mainly divided into 10 categories: Two wheelers, Three Wheelers, Cars, Light Commercial Vehicles, Microbus, Mini Bus, Big Bus, Light Trucks, Heavy Trucks and Multi axle trucks. A detailed description of each vehicle category is provided in Table 3.2, while their respective dimensions are presented in Table 3.3.

Table 3.2: Vehicle categorization and descriptions

S. N	Vehicle Type	Vehicle description
1	Multi-Axle Trucks (MAT)	Trucks with more than 3 axles. (>3 axles)
2	Heavy Truck (HT)	Standard / heavy trucks, trailers/articulated. (1,2/3 axles)
3	Light Truck (LT)	Mid-sized trucks with single rear-axle.
4	Big Bus	Buses with seating capacity of 35-50 seats.
5	Mini Bus	Medium size buses with seating capacity of 20-35 seats.

S. N	Vehicle Type	Vehicle description
6	Micro Bus	Small buses/vans with seating capacity of 10-15 seats.
7	Car	Passenger car, taxis and vans.
8	Light commercial Vehicle (LcV)	Commercial Pickups and other 4 wheeled Light vehicles
9	Three-Wheeler (3 W)	Electrical, gasoline/LPG fueled 3-wheeled vehicles.
10	Two wheelers (2W)	Motorized two wheelers (Scooters and motorcycles).

Table 3.3: Dimension of different vehicles (with references)

Vehicles		Length (M)	Width (M)	Projected area (M^2)	Area taken (M^2)	References
2 W		1.87	0.64	1.20	1.20	A
3W		2.64	1.3	3.43	3.61	C
		2.7	1.4	3.78		
Cars	Car	3.72	1.44	5.36	6.73	A
	Big Car	4.58	1.77	8.11		
LCV		4.2	1.7	7.14	7.14	B
Microbus		5.38	1.88	9.01	10.1	D
		5.05	2.03	10.25		E
Mini bus		6	2.43	14.58	14.58	A
Big Bus		10.1	2.43	24.54	24.54	
LT		6.1	2.1	12.81	12.81	
HT		7.5	2.35	17.63	17.63	
MAT		12.1	2.44	29.52	29.52	

Sources: A= (Indian Highway Capacity Manual, 2017), *B*= (Kasalawat, 2024),*C*= (Kumaratunga, 2018),*D*= (Toyota Nepal, n.d.) *E*= (Fotonnepal, n.d.)

During data collection, several challenges were encountered. Suitable sections with the required characteristics were limited, and in many locations, cameras could not be installed for the entire study period due to power issues, which make the study to focus on one section. While the study aimed to collect data for 12 hours over three weekdays (a total of 36 hours), only 30 hours of data (7A.M. to 5 P.M.) could be utilized, due to the visibility issues.

3.4 Identification of Free-Flow and Platooning Condition

After collection of the spot speed, gap and SD data the methodology (as per Figure 3.4) was followed for the identification of the free-flow and the platooning condition.

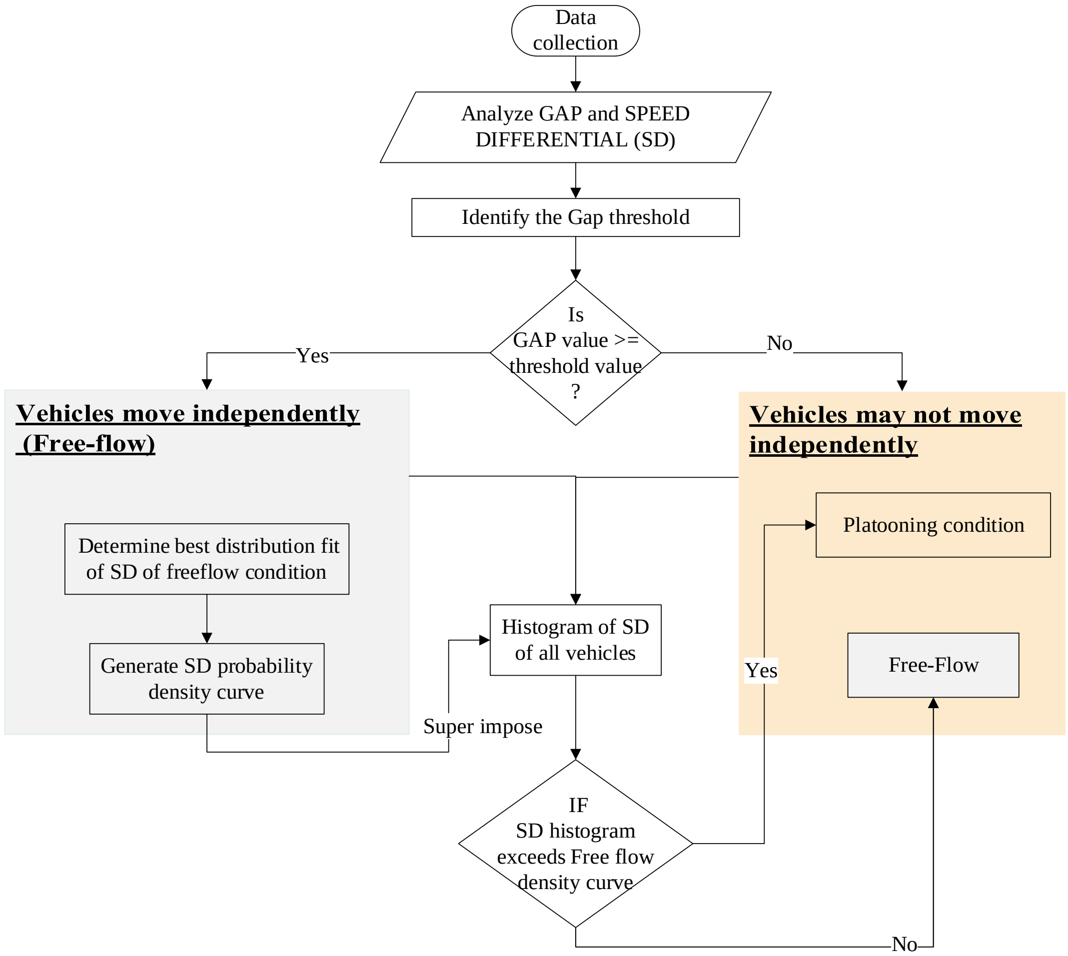


Figure 3.4: Methodology for free flow and platoon identification

3.4.1 Identification of Free-Flow Condition

Generally, the free-flow condition is identified using a headway threshold value, which is either obtained directly from a predefined value or determined based on the relationship between speed (85th percentile or average speed) and headway. However, in this study, due to the presence of heterogeneous traffic with varying vehicle lengths, the use of gap was considered more appropriate than headway. Additionally, instead of using average speed or 85th percentile speed, SD was found to be a more suitable measure. Therefore, the relationship between SD and gap values was first analyzed to identify the maximum gap value beyond which a vehicle was no longer considered to be moving in a platoon.

The gap data was organized into 1-second intervals and the average SD was calculated for each interval (Boora et al., 2018). A scatter plot and curve fitting techniques were used to analyze the relationship between the gap interval and SD. The free-flow threshold was identified as the gap value beyond which SD remained constant, even as the gap increased.

Once the free-flow condition was determined, the platooning range was identified using the superimposition method. This method involves overlaying the probability density curve of SD for the free-flow condition onto the histogram of SD for all conditions (both free-flow and platooning condition). To achieve this, various statistical distributions were fitted, and the best-fit probability density curve of the selected distribution was chosen for further analysis.

3.4.2 Best Fit Distribution for SD of Free-Flow Condition

To identify the best-fit distribution for the observed data, the "Fitter" library in Python was used. This library automates the process of fitting multiple candidate probability distributions to a given dataset, providing a more comprehensive framework for statistical model selection. In this study, a variety of distributions were tested, including the Normal, Logistic, Gamma, Log-Normal, and Weibull distributions. The evaluation of the best-fit distribution was based on SSE and the KS-test (D- statistics and P-value).

a) Kolmogorov-Smirnov (KS) Test

The KS test is a non-parametric statistical test used to compare the observed data with a specified distribution. It measures the largest difference between the cumulative distribution function (CDF) of the observed data and the CDF of the fitted distribution. The calculation of the KS test involves the D-statistic, followed by the p-value calculation. Mathematically, it is expressed as Equation 3.5 (Massey, 1951).

$$D = \max|F_n(x) - F(x)| \qquad \text{Equation 3.5}$$

Where,

- $F_n(x)$ is the empirical CDF of the observed data,
- F(x) is the CDF of the fitted distribution.

The KS-test calculates the p value with the Null hypothesis: The empirical CDF of the data and the CDF of the proposed distribution are the same.

b) Sum of Squared Errors (SSE)

SSE is a widely used metric to evaluate the goodness of fit between observed data and a fitted distribution. It is calculated as the sum of squared differences between each observed data point and the corresponding predicted value from the fitted model. The mathematical formulation is shown in Equation 3.8.

$$SSE = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$ Equation 3.6

Where, y_i=the observed data value at index i, $\hat{y}_i$= is the predicted data value at index i, and n = the total number of observations

A smaller SSE value indicates a better fit of the distribution to the data. A value close to zero suggests that the fitted distribution approximates the observed data very well.

c) Evaluation of best fit

- After calculating the KS p-value, the goodness of fit was evaluated, where for models with $p > 0.05$, the null hypothesis failed to be rejected, indicating that the empirical CDF and the proposed distribution CDF were not significantly different and that thus the distribution provided a good fit. Whereas, models with $p < 0.05$ were considered poor fits and excluded from further analysis.
- Among the good fit models (with $p > 0.05$), the Sum of Squared Errors (SSE) was used to determine the best-fit model, with the model having the lowest SSE being selected as the best-fit.

3.4.3 Identification of the Platooning Ranges

After determining the best-fit probability density function (PDF) for the SD under free-flow conditions, normalization of the SD histogram for all vehicles was required before superimposition.

a) Normalization of histogram

Normalization involves scaling the histogram so that the total area under the bars equals 1, ensuring that the histogram represents a probability density rather than raw frequencies. In this process, the normalized height of each bin (or density of a bin for normalized histogram) was computed based on Equation 3.7 (Scott, 2010).

$$\text{Density of bin} = \frac{\text{Frequency of Bin}}{\text{Total number of datapoint x Bin width}}$$ Equation 3.7

Since speed differential is a continuous variable, choosing an optimal bin width is crucial for better estimate (Scott, 1979). The optimal bin width is determined using the Freedman-Diaconis rule (as Equation 3.8) (Freedman & Diaconis, 1981):

$$\text{Bin width} = 2 \text{ x } \frac{\text{IQR}}{n^{(1/3)}} \qquad \text{Equation 3.8}$$

Where, IQR is the interquartile range and n is the total number of data points.

b) Method of Superimposition

Once the histogram is normalized, the density histogram of all vehicles is superimposed with the free-flow PDF curve. The SD ranges where the maximum deviation occurs between the histogram and the free-flow PDF indicate platooning behavior, as these deviations highlight changes in speed interactions among vehicles.The superimposition was performed in python with the use of library Pandas, NumPy, fitter and Matplotlib, where Pandas was used to load and manipulate the dataset, NumPy was used for numerical operations, Matplotlib was used for visualizing the histograms and distribution curves with providing a detailed graphical comparison of the speed differential distributions and the Fitter library is used for fitting different probability to the speed differential data and determining the best fit based on the provided dataset.

3.5 Analysis of Speed under Free-Flow and Platooning Conditions

For analyzing stream and vehicle-wise speeds, distribution analysis using the Cumulative Distribution Function (CDF) curve and statistical tests were performed. To compare changes in stream speed across both directions under free-flow and platooning conditions, distribution analysis was conducted, followed by a detailed statistical evaluation for each vehicle class. Among statistical analysis methods, both parametric and non-parametric tests are commonly used when comparing two groups of independent data. Given that the sample size exceeds 30 and the data exhibits a light-tailed distribution, normal approximation is valid, and parametric tests were appropriate (Field, 2017) (Peat & Barton, 2005). Thus, with normal approximation parametric test were used for comparison of speed of different vehicles.

When analyzing two independent datasets, the independent samples t-test (Student's t-test) and Welch's t-test are widely used parametric methods. Welch's t-test is particularly robust across various data types, including continuous and discrete distributions, and can accommodate deviations from normality. Unlike the Student's t-test, it does not assume equal variances between groups, making it a more suitable choice when this assumption is violated (Tsagris et al., 2020). Therefore, Welch's t-test was used in this study.

3.5.1 Welch's T-test

Welch's t-test is a parametric test used to compare the means of two independent groups. In this study, it is applied to compare vehicle speeds in platooning and free-flow conditions. The hypothesis of the Welch's t-test is as follows:

- Null Hypothesis (H_0): The mean speed of vehicles in platoon is greater than or equal to the mean speed of vehicles in free-flow.

$$i.e. \qquad H_0: \mu_1 \geq \mu_2$$

- Alternate Hypothesis (H_1): The mean speed of vehicles in platoon is less than the mean speed of vehicles in free-flow.

$$i.e. \qquad H_1: \mu_1 < \mu_2$$

Where, μ_1 represents the mean speed in platoon and μ_2 represents the mean speed in free flow.

a) Calculation of t-statistics, degree of freedom

The Welch's t test is based on the calculation of Welch's t-statistic (based on Equation 3.9) and its corresponding degrees of freedom (df) (based on Equation 3.10). t-statistic and df are calculated to determine the critical t-value and p-value. The t-critical value sets the threshold for rejecting the null hypothesis, while the p-value quantifies the probability of observing the given difference by chance. In general, the t-statistic and degrees of freedom (df) are calculated to determine whether an observed difference is due to random chance or represents a real effect.

$$t = \frac{|\overline{X_1} - \overline{X_2}|}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \qquad \text{Equation 3.9}$$

$$df = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{s_2^2}{n_2}\right)^2}{n_2 - 1}}$$ Equation 3.10

- $\overline{X_1}$ and $\overline{X_2}$ are the sample means of the two groups (platoon and free-flow resp.).
- $s_1$and s_2 are the variances of the two groups.
- $n_1$and n_2 are the sample sizes of the two groups.

b) Result interpretation

At 95% confidence interval,

- If the p-value <= α (0.025 one-tailed), there is enough statistical evidence to support the alternative hypothesis (H_1), rejecting the null hypothesis suggesting that the mean speed of vehicle in the platoon is significantly less than the mean speed of vehicles in free-flow.
- If the p-value > α (0.025 one-tailed), there is insufficient statistical evidence to reject the null hypothesis. Therefore, there is no significant difference, implying that the mean speed of vehicles in platoon is not significantly less than that of free-flow.

3.5.2 Effect Size Analysis

While significance testing (such as t-tests) helps determine whether there is a statistical difference between conditions (i.e., platoon vs. free-flow conditions), it does not indicate which vehicle class has the largest speed difference. This is where effect size analysis becomes important, as it provides clearer understanding of the practical significance of the results. In this study, Cohen’s d test (Cohen, 1992) was used for effect size analysis, as the significance test for speed difference being a parametric test.To assess the magnitude of the difference in mean speeds between the platoon and free-flow conditions, Cohen’s d value was calculated as per Equation 3.11 and the effect size was identified based on the ranges as shown in the Table 3.4.

$$d = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}}$$ Equation 3.11

Table 3.4: Cohen's d ranges for effect size analysis ((Cohen, 1992)

Cohen's d ranges	Effect size
0.20 to 0.50	Small difference
0.50 to 0.80	Medium difference
>0.8	Large difference

3.6 Evaluation of Different Operational Performance Measures.

There were several performance measures evaluated for two lane roads around the world, and these were evaluated against different traffic characteristics. The performance measures have been mostly divided into two groups: the speed-based measures and the follower-based measures. The speed-based measures include average travel speed (ATS), average travel speed of passenger cars (ATS-PC), ATS as a percent of free-flow speed (ATS/FFS), ATS-PC as a percent of free-flow speed of passenger cars (ATS-PC/FFS-PC) and the follower-based measures include Number of followers (NF), Percent of followers (PF), Number of followers per capacity (NFPC), Follower density (FD), Percentage impeded (PI). These performance measures being dependent variables were evaluated against several traffic characteristics such as hourly directional traffic flow, % heavy vehicles, opposing traffic flow, two-way volume etc., as the independent variables. Based on literatures (as discussed in chapter 2.2), few of the performance measure indicators were selected for evaluation, which includes ATS as the speed-based measure and NF, PF, FD, NFPC as the follower-based measures.

3.6.1 Selection of the Key Operational Performance Measures

Based on the literature review, key performance measures were selected for evaluation. The definition of several performance measures is shown as below:

a) Average travel speed (ATS)

ATS is the average speed of the stream aggregated over a certain time interval.

b) Number of following (NF

The number of followers was calculated based on the follower identification criteria as discussed in chapter 3.4.3. Unlike the homogeneous traffic the number of followers taken in terms of PCU is more appropriate in heterogenous traffic environment, so the number of followers was multiplied by PCU for each following vehicle types.

c) Percentage followers (PF)

PF is the ratio of number of followers relative to the total traffic volume for every aggregated time interval. PF was calculated at 15-min interval data aggradation.

d) Follower density (FD)

Follower density is defined as the number of followers per kilometer of traveled lane and was estimated as the product of percentage followers and density. Where density (PCU/km) was calculated as the ratio of the volume (PCU/hr) and speed (Km/hr). The calculation is as per Equation 3.12.

$$\text{Density (D)} = \frac{\text{Volume (V)}}{\text{Average speed}}$$

Equation 3.12

$$\text{Follower density (FD)} = \text{Density} * \text{PF}$$

e) Number of following per capacity (NFPC)

Number of following per capacity is defined as the ratio of the number of followers and the capacity of a particular roadway facility and calculated as Equation 3.13.

$$\text{NFPC} = \frac{\text{NF}}{\text{Capacity}}$$

Equation 3.13

Where the capacity of the road section was calculated based on the local data. For evaluation of these performance measures, different variables such as through traffic flow (PCU/hr/lane), truck percentage and opposite traffic flow (PCU/hr/lane) were taken as the platooning variable. Initially, the calculation of these variables involved determining the Passenger Car Unit (PCU) and directional capacity.

3.6.2 Calculation of PCU and Capacity

For macroscopic traffic flow analysis, the HCM (Transportation Research Board, 2016) recommends the use of 15-minute aggregation interval to ensure a stable traffic flow rate. Thus, at each 15-min interval of time, space mean speed and dynamic PCUs of different vehicle types were calculate followed by the estimation of the capacity of the road.

a) Space mean speed calculation:

Space mean speed of any vehicle type for a certain time interval is defined as the ratio of time taken, for that vehicle type, to move over a certain stretch of road in the interval of time and is calculated based on Equation 3.14.

$$V_s = \frac{\mathrm{n} * \mathrm{L}}{\sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{t_i}} \qquad \text{Equation 3.14}$$

Where, V_s = space mean speed (km/hr),

n = number of vehicles of a specific type within the time interval

L = Trap length in km,

t_i = Travel time of i^{th} vehicle over trap length (in hours.)

b) Calculation of (Dynamic) PCU

Among the various PCU estimation methods, the speed-area method (dynamic PCU method) has been widely used. Where the PCU of a vehicle is defined as "the ratio of the speed ratio of a car to the vehicle and the space ratio of a car to the vehicle." (Chandra, 2004) and was calculated based on Equation 3.15, where space mean speed was calculated as per Equation 3.14, and areas were the taken from Table 3.3.

$$\text{(Dynamic) PCU}_i = \frac{\text{Speed ratio of car to ith vehicle}}{\text{Space ratio of car to the ith vehicle}} \qquad \text{Equation 3.15}$$

$$\text{i.e. PCU}_i = \frac{\frac{\mathrm{V_C}}{\mathrm{V_i}}}{\frac{\mathrm{A_C}}{\mathrm{A_i}}}$$

Where, V_c = speed of car (km/hr)

V_i = speed of i^{th} type vehicle (km/hr)

A_c = projected rectangular area of a car (m^2)

A_i = projected rectangular area of i^{th} type of vehicle (m^2)

c) Estimation of capacity based on field data

As the NFPC includes the calculation of the capacity of the road, the conventional flow modelling technique was used to calibrate and predict the capacity. The calibration was based on data from the field and establishing the relation between the volume, speed and the density (Tiwari & Marsani, 2014) (Sharma et al., 2011) (Nokandeh et al., 2016). For the calibration of data, the space mean speed for each 15-minute interval was calculated as the weighted space mean speed, with the weights representing the proportion of each vehicle type within the interval. The vehicle volume per 15-minute interval was converted into PCU per 15-minute and then multiplied by 4 to represent the hourly volume in PCU/hr. After determining the volume and average space mean speed for each 15-minute interval, the density was calculated as per Equation 3.16. Based on the plot between the density (y) and the space mean speed (x), a best fit model was determined. The parameters from the relation were then used for projection of the capacity of the study section.

$$\text{Density (PCU/Km)} = \frac{\text{Volume (PCU/hr)}}{\text{Aggregaed space mean speed (Km/hr)}} \quad \text{Equation 3.16}$$

3.6.3 Regression-Based Evaluation of Key Performance Measures

Multiple linear regression was used to quantify the relationships between each performance measure (ATS, NF, PF, FD, and NFPC) and three traffic characteristics (through traffic flow, truck percentage, and opposite-direction flow) using the ordinary least squares method in Excel. The analysis was performed using the Ordinary Least Squares (OLS) method in Microsoft Excel, with the performance measures treated as dependent variables and the traffic characteristics as independent variables. For each performance measure, an initial model was fit including all three independent variables; any variable with a t-test p-value greater than 0.05 was then removed. An F-test p-value was used to confirm the overall significance of the models. Once the most statistically significant predictors were identified for all measures, Pearson’s correlation coefficients were computed between the significant predictors and each performance measure, based on which the measure with highest correlation value was selected as the best performance measure. Finally, a 2^{nd} degree regression model was developed using the single best performance measure and its predictor, this final relationship was validated on 20% of the data and evaluated using R^2 to explain variance and mean absolute percentage error (MAPE) to quantify average predictive error.

CHAPTER 4 : TRAFFIC DATA COLLECTION AND ANALYSIS

4.1 Summary of Traffic Count

Over the study period of 30 hrs, a total of 13,179 vehicles were counted. Where 6,715 vehicles were travelling from (Muglin to Narayanghat direction (M-N direction) and 6,464 vehicles from Narayanghat to Muglin direction (N-M direction). The summary of the traffic count over the study period is shown in Table 4.1.

Table 4.1: Traffic count summary

Vehicles types		Direction of travel					
		Muglin to Narayanghat (M-N)		Narayanghat to Muglin (N-M)		Both directions combined	
		Volume	Proportion	Volume	Proportion	Volume	Proportion
2 W		2023	30%	1971	30%	3994	30%
3W		126	2%	132	2%	258	2%
Car		823	12%	958	15%	1781	14%
LCV		770	11%	732	11%	1502	11%
Buses	Big Bus	223	3%	268	4%	491	4%
	Mini bus	352	5%	357	6%	709	5%
	Microbus	430	6%	383	6%	813	6%
Trucks	LT	368	5%	274	4%	642	5%
	HT	1394	21%	1213	19%	2607	20%
	MAT	206	3%	176	3%	382	3%
Total count		6715		6464		13179	

Where, 2 W = Two-wheelers, 3W= Three-wheelers, LCV=Light commercial vehicles, LT= Light trucks, HT= heavy truck, MAT= multi-axle trucks (description is shown in Table 3.2)

The traffic composition on the road included a diverse mix of vehicle types. Motorcycles and scooters (2-W) accounted for 30% of the total traffic, making them one of the dominant modes. Trucks, including light trucks (LT), heavy trucks (HT), and multi-axle trucks (MAT), comprised 28%, indicating a significant presence of freight vehicles. Long-route public transport, consisting of big buses, mini buses, and microbuses, made up 15% of the traffic. Passenger cars contributed 14%, while light commercial vehicles (LCVs) such as vans and pickup trucks represented 11%. The remaining 3% consisted of three-wheelers (3-Ws), which primarily operate as on-demand public transportation providers.

4.2 Analysis of Speed Data

The speed analysis was conducted using descriptive statistics to extract key insights from the speed data. Additionally, box plot analysis was done for a directional-wise comparison, allowing for the evaluation of speed variations among different vehicle types traveling in both directions. This approach provided a clearer understanding of speed distribution and directional differences across vehicle categories.

4.2.1 Descriptive Statistics of Speed Data:

The descriptive statistics of the directional-wise speed data is shown in Table 4.2, where the sample size, the percentile speeds (15th, 50th and 85th percentile speeds), mean and the standard deviations were calculated for all the vehicle types moving in both the directions.

Table 4.2: Descriptive statistics of direction-wise speed for different vehicles

M-N direction						
Vehicle Type	Sample Size	V_{15}	V_{50}	V_{85}	Mean	Std.
2 W	2023	42.84	55.3	68.4	55.9	12.56
3W	126	32.9	40.09	46.97	40.06	6.36
Big Bus	223	46.41	54.53	62.23	54.3	7.66
Car	823	45.87	59.52	72.2	59.69	12.42
HT	1394	39.38	45.07	51.3	45.34	5.98
LCV /4 W	770	43.81	54.53	64.98	54.53	10.21
LT	368	42.15	50.31	57.76	50.24	7.53
MAT	206	34.2	41.48	48.58	41.94	6.94
Microbus	430	50.1	62.38	70.25	61.35	10.04
Mini bus	352	43.48	54.53	62.38	53.43	8.69
Stream	6715	41.28	51.98	65.53	53.15	11.65
N-M direction						
Vehicle Type	Sample Size	V_{15}	V_{50}	V_{85}	Mean	Std.
2 W	1971	41.48	54.91	67.81	54.91	12.42
3W	132	32.76	39.58	48.13	40.21	6.71
Big Bus	268	46.43	57.76	65.53	56.69	9.42
Car	958	45.33	59.07	70.89	58.93	12.18
HT	1213	35.44	41.04	47.55	41.68	6.25
LCV /4 W	732	42.3	53.04	63.91	53.05	10.43
LT	274	37.84	45.47	52.7	45.62	7.78
MAT	176	32.02	36.1	43.08	37.19	5.36
Microbus	383	49.67	61.89	70.25	60.64	10.31
Mini bus	357	39.99	54.91	64.44	53.32	10.69
Stream	6464	38.41	50.96	65.53	51.96	12.45

** Here Std. refers to the standard deviation.*

a) Mean and percentile Speeds

Based on descriptive data as per Table 4.2 it can be seen that, Microbuses and Cars consistently had the highest mean speeds across both directions, with Microbuses having a mean speed of 61.35 km/hr in the M-N direction and 60.64 km/hr in the N-M direction, similarly car also showed similar mean speed with a speed of 59.69 km/hr in the M-N direction and 58.93 km/hr in the N-M direction. On the other hand, Multi-Axle Trucks (MAT), Three-Wheelers (3W), and Heavy Trucks (HT) had the lowest mean speeds in both the direction. While comparing the percentile speed, Cars had 85th percentile speed (V85) values of 72.20 km/hr (M-N direction) and 70.89 km/h (N-M direction), while Microbuses maintain 70.25 km/hr in both directions. The lowest 15th percentile speed (V15) was recorded for MAT with 32.02 km/hr (N-M direction) and 34.20 km/hr in (M-N direction).

b) Speed Variability

The analysis shows that 2W, Cars, LCVs, Microbuses, and Minibuses had higher standard deviations in speed, indicating greater variability in their speed compared to other vehicle types. In contrast, 3Ws, Trucks (LTs, HTs, and MATs), and Big Buses comparatively maintained more consistent speeds, as reflected by their significantly lower standard deviations. Among all vehicle categories, 2W and Cars had the highest speed variability in both directions, likely due to their greater maneuverability, allowing them to weave through traffic more freely.

4.2.2 Direction-Wise Analysis of Speed Data

A box plot analysis was conducted to compare the speed differences of various vehicle types across the two directions. The box plots (Figure 4.1) visually represent key statistical measures, including the median (50th percentile) and the interquartile range (IQR, 25th to 75th percentile), which capture the middle 50% of the speed data within the box, reflecting variability. The lines in the plot extend up to 1.5 times the IQR, showing the spread of the data, while outliers appear as individual points beyond the lines, indicating extreme speed variations.

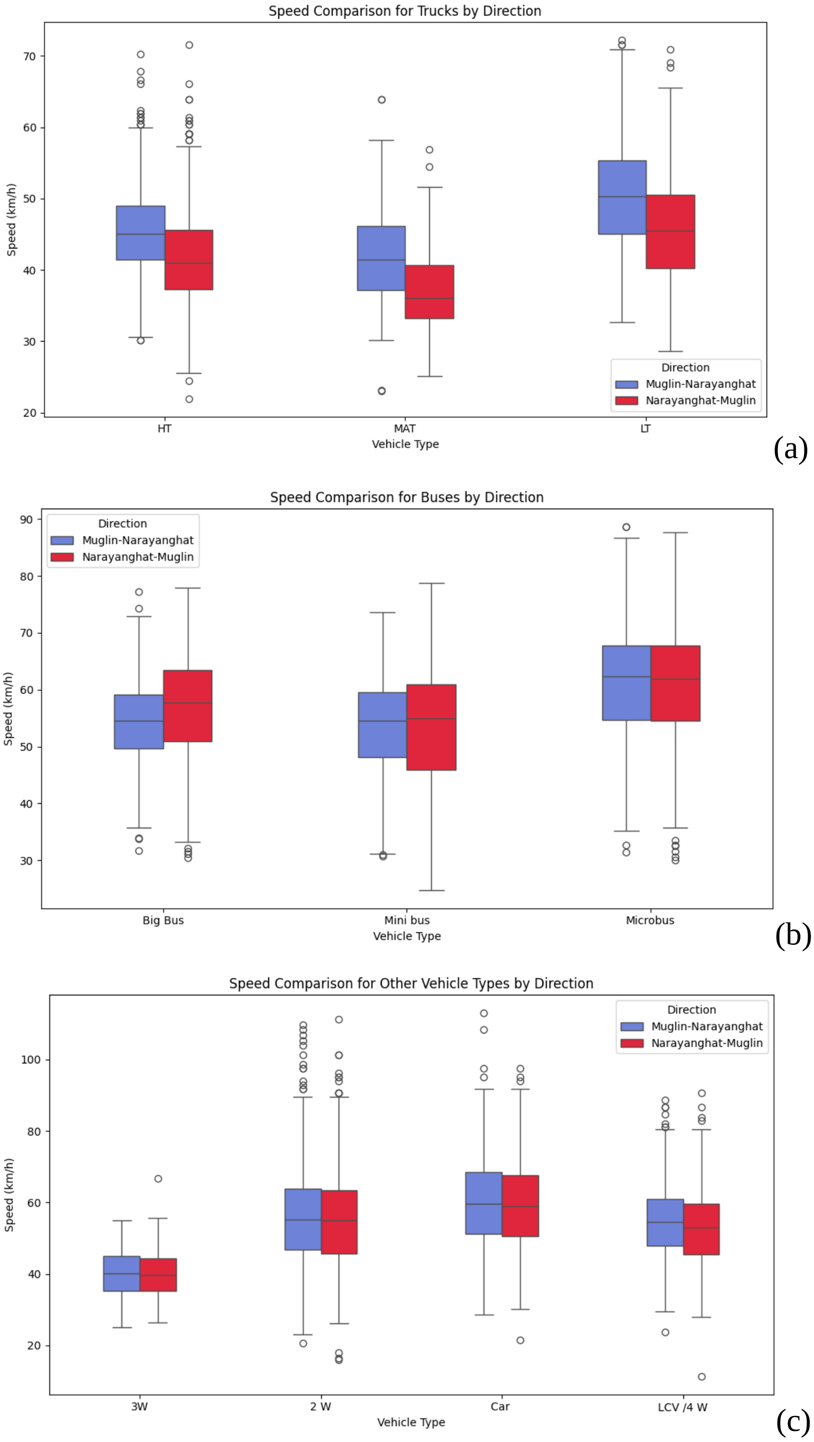


Figure 4.1: Box plot for the direction-wise speed comparison of (a) trucks, (b) buses and (c) other vehicles

When comparing the two directions, the mean speed of the traffic stream was slightly higher in the M-N direction (53.15 km/hr) than in the N-M direction (51.96 km/hr), while the 85th percentile speed remained similarly in both the directions at 65.53 km/hr. For the trucks group, the speed was comparably lower in the N-M direction than in M-N direction.

Where, heavy trucks (HT) had a mean speed of 45.34 km/hr in the M-N direction but this dropped to 41.68 km/hr in N-M direction. Light trucks (LT) showed a similar trend, with the mean speed of 50.24 km/hr in the M-N direction, decreasing to 45.62 km/hr in the N-M direction. Multi-axle truck (MAT) showed the most reduction in the N-M direction, with a mean speed of 37.19 km/hr, compared to 41.94 km/hr in the M-N direction. The N-M direction, leading to Kathmandu, mostly contained many loaded trucks transporting goods, particularly from the Indian border. The additional load likely contributed to the lower speeds observed in this direction compared to the M-N direction, where trucks were relatively lighter or empty, allowing for higher speeds. For other vehicles, the speed remained quite similar across both directions. Cars, for instance, showed very little difference, with a mean speed of 59.69 km/hr in the M-N direction and 58.93 km/hr in the N-M direction. Microbuses and mini buses also maintained similar speeds across directions, with microbuses traveling at 61.35 km/hr in the M-N direction and 60.64 km/hr in the N-M direction, and mini buses showing a mean of 53.43 km/hr in M-N and 53.32 km/hr in N-M.

4.3 Identification of Free-Flow and Platooning Condition

As, platoon identification involves two main steps: identifying the free-flow condition and then determining the platooning ranges. First, the free-flow condition was identified for both directions by plotting the relationship between SD and gap. Once the free-flow condition was established, a best-fit distribution for SD was determined based on the free-flow data. Next, the probability density function (PDF) curve of this best-fit distribution was overlaid with the normalized histogram of SD from total data. This overlay allowed for the identification of platooning ranges by analyzing variations in SD, thus distinguishing between free-flow and platooning conditions.

4.3.1 Identification of Free-Flow Condition

For free-flow condition was identified based on relation between the gap and the speed differential data. The gap values were organized into 1-second intervals, and the average SD within these intervals was calculated as shown in Appendix B. The relationship between the gap and the average SD across the intervals was then studied, as shown in Figure 4.2.

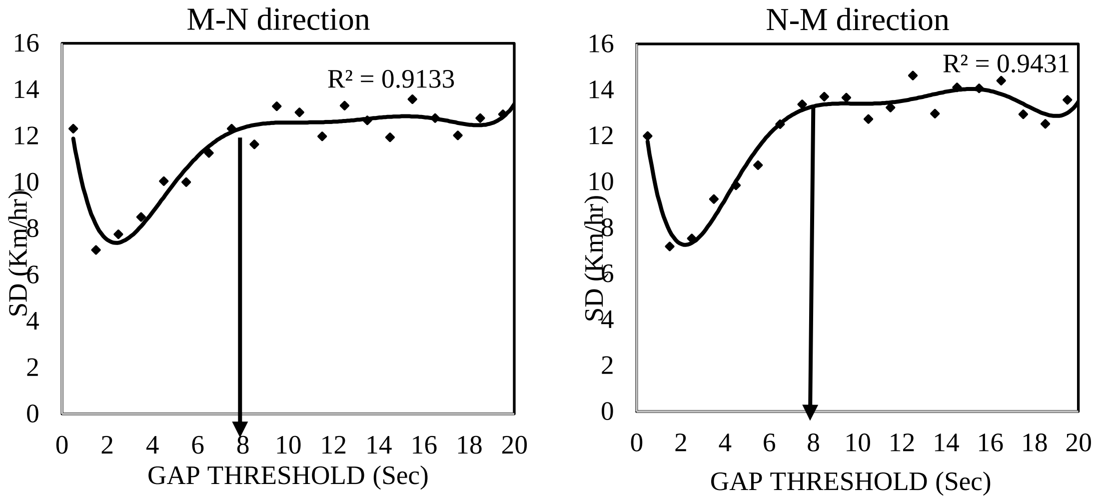


Figure 4.2 : Relation Between Speed Differential (SD) & Gap (Sec)

From the Figure 4.2, it can be seen that up to 8 sec gap threshold value there is a notable relation between the vehicles as their relative speed is varied with the gap value whereas beyond 8 sec, the relative speed tends to be more stable compare to any threshold value. A similar result was found in the past studies, with 8 second gap (Miller) and 10 second gap (Boora et al., 2018). Other notable trend is high relative speed in the lowest gap threshold range (gap between approximately 0-1 sec) with sudden drop. In this lower gap range, the higher SD might be an indication of the gap range for the overtaking in this two-lane road.

a) Determination of the best fit distribution free-flow Condition

Before identifying the range of relative speed for platooning vehicles based on method of superposition, the best fit distribution of the SD of free-flow condition was determined for both the direction of traffic. Various distributions: logistic, normal, gamma, Weibull, and log-normal, were tested using the SSE and KS test. The Table 4.3 presents the results of the KS test and SSE values for different distribution of SD in both the direction.

Table 4.3: Curve fitting (for free-flow speed differential) summary

For M-N direction				
Distribution	Sum square Error	KS D-Statistic	KS p-value	Fit
Logistic	0.000147	0.012638	0.668	Best fit
Normal	0.000184	0.020989	0.111	Can Fit
Gamma	0.000191	0.023966	0.046	Poor fit
Weibull Min	0.000272	0.030438	0.005	Poor fit
Log-Normal	0.034672	0.757064	0.000	Poor fit
For N-M direction				

Distribution	Sum square Error	KS D- Statistic	KS p-value	Fit
Normal	0.000201	0.01140	0.77205	Best fit
Gamma	0.000213	0.01132	0.77963	Can fit
Log-Normal	0.000213	0.01129	0.78256	Can fit
Weibull Min	0.000227	0.01728	0.26700	Can fit
Logistic	0.000281	0.02076	0.11010	Can fit

For the M-N direction, the KS test show that the Logistic and Normal distributions, with KS-p value 0.668 and 0.111 respectively, were found to be good fit for the SD data, the KS p-value being greater than 0.05 for both of the cases. While the gamma, Weibull, and log-normal distributions demonstrated poor fits, with lower KS-p values all being less than α, at 5% significance, indicating significant deviation. Among the good fit distribution, Logistic distribution was found to be best fit with SSE being lower than that of the Normal distribution. Similarly for the N-M direction, while all the distributions were found to be good fit with KS p-value being greater than 0.05, the normal distribution was identified as the best fit with SSE being the lowest of all. Thus, for the M-N direction, the logistic distribution was identified as the best fit for the SD under free-flow conditions, while for the N-M direction, the normal distribution was the best fit.

b) Probability density function and its parameters

For Muglin to Narayanghat direction, as logistic probability distribution function best fitted the SD of this direction, where Equation 4.1 shows the equation of logistic distribution. And for Narayanghat to Muglin direction, normal probability function best fitted the SD of this direction, where Equation 4.2 shows the equation of the normal distribution The parameters of both fitted distributions are shown in Table 4.4

$$f(\mathrm{x}) = \frac{1}{\sigma} \cdot \mathrm{e}^{-\frac{\mathrm{x}-\mu}{\sigma}} \cdot \left(1 + \mathrm{e}^{-\frac{\mathrm{x}-\mu}{\sigma}}\right)^{-2} \quad \text{Equation 4.1}$$

$$.f(x) = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad \text{Equation 4.2}$$

Table 4.4: Parameters for PDF of SD for both directions

Distribution	Parameters			
	Mean (μ)	Standard Deviation (σ)	Min	Max
Logistic (M-N)	1.01012	9.365028	-73.22	66.82
Normal (N-M)	1.32339	17.69144	-71.61	62.42

4.3.2 Identification of Platooning Condition

Before superimposition, the histogram of the SD of both conditions (free-flow and platooning) was normalized based on the Equation 3.7.

a) Normalization of the histogram

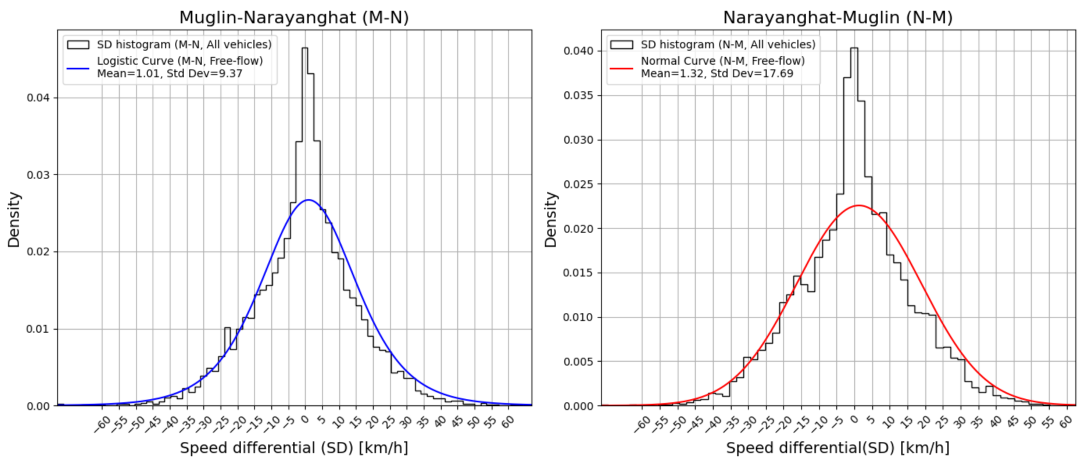
For normalization the optimal bin width was calculated based on the Freedman-Diaconis's equation (Equation 3.8), where the parameters are shown in Table 4.5.

Table 4.5: Parameters for normalization of histogram of SD (Both direction)

Direction	Distribution	Q1	Q3	IQR	n	Optimized bin width
M-N	Logistic	-8.3	8.3	16.6	6714.0	1.8
N-M	Normal	-9.5	9.2	18.8	6463.0	2.0

b) Identification of platooning ranges based on superimposition

The normalized histogram and the PDF curves, calculated were then overlayed using python (as shown in Figure 4.3). The interval for estimation of the f(x) value for each PDF curves of free flow was taken as 0.05. With reference to the interval and midpoint of calculated bin intervals of the normalized histogram, the difference in estimated density value from the curve and the height value of the normalized histogram was calculated. And the SD ranges from where the deviation or the difference in the values from the curve and the histogram increase was taken as the platooning ranges.



(a) (b)

Figure 4.3: Superimposition of PDF of free-flow with the histogram of both platoon and free-flow condition (a) M-N direction, (b) N-M direction

From the superimposition analysis, it was observed that, for M-N direction, the theoretical curve (logistic curve of the Speed differential (SD) under free-flow conditions) deviates from the empirical data (histogram of SD for all vehicles) within the range of -4.32 km/h to +5.13 km/h. This range indicates the ranges for identification of the platooning conditions. Similarly, for the N-M direction, the identified range was -5.61 km/h to +5.84 km/h. The range was similar to the case of Indian two-lane highways, where the range was in between -4 km/hr to 10km/hr for platooning events identification (Boora et al., 2018). Thus, for vehicles with gap value less than 8 sec with SD within the wider range of -6 km/h to +6 km/h can be considered as the vehicles in the platoons.

4.3.3 Characteristics of Platooned Vehicles

This section discusses the characteristics of the platooned vehicles, including determining which vehicles led and followed the platoons for most of the time, and analyzing the size of the platoons (i.e., the number of vehicles involved in a single platoon) along with their frequency (as shown in Table 4.6 and Figure 4.4). Additionally, the average speed of the platoons was calculated based on the type of the leading vehicle as shown in Figure 4.5.

Table 4.6: Summary of the vehicles in platoon and non-platoons

Vehicle Types	Platoons			Non-platoons	Grand total
	Leaders	Followers	Total		
2 W	405	877	1282	2712	3994
3W	35	31	66	192	258
Car	154	487	641	1140	1781
LT	117	141	258	384	642
HT	609	498	1107	1500	2607
Microbus	100	203	303	510	813
MAT	119	48	167	215	382
Big Bus	113	117	230	261	491
Mini bus	122	159	281	428	709
LCV	203	380	583	919	1502
Grand total	1977	2941	4918	8261	13179

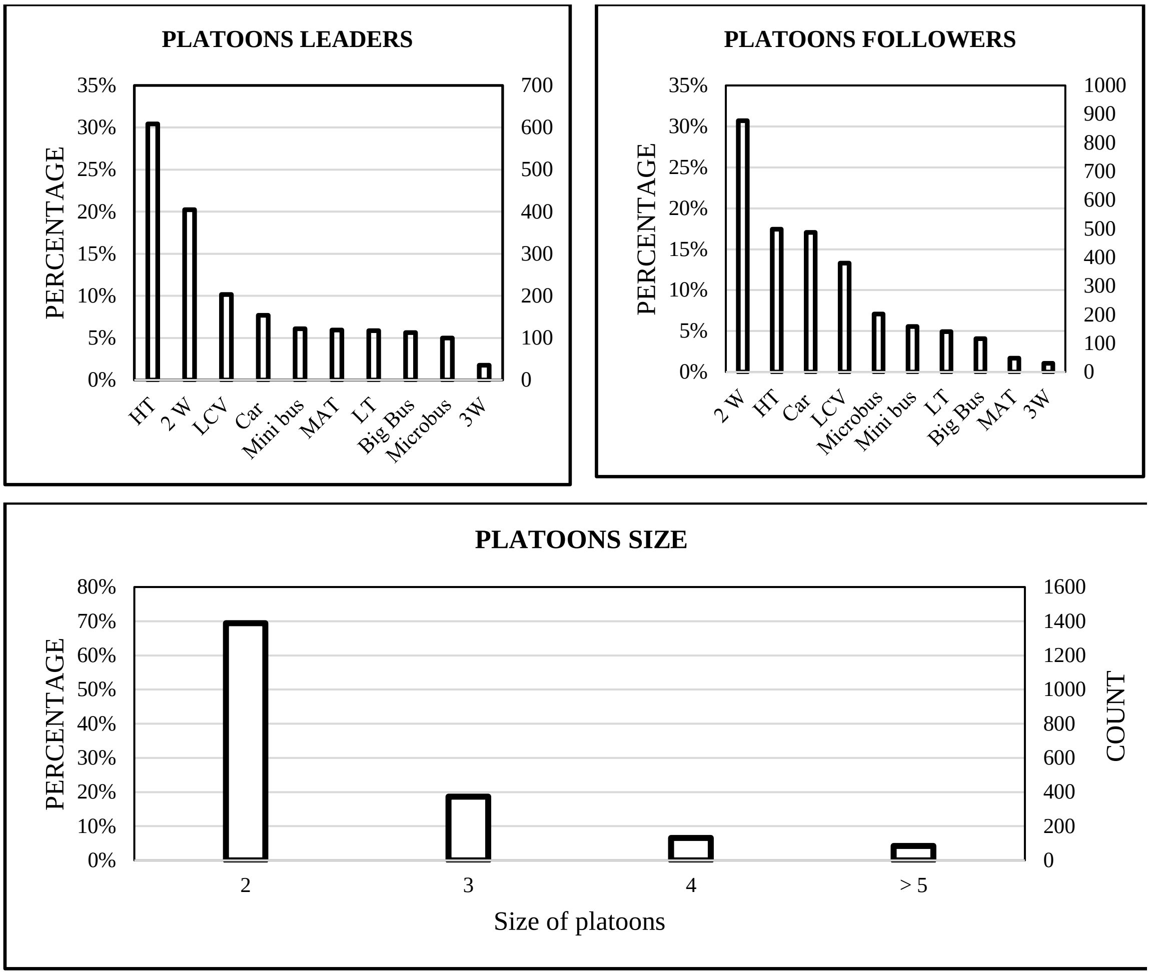


Figure 4.4: Figures showing platoon leaders, followers and size of the platoons

After the identification of the platooning conditions, it was found that about 37% of the total volume was involved in platooning events, with 1,977 leaders and 2,941 followers. Among the leading vehicles, HTs were identified as most frequent leaders being 31% of the total leading vehicles, compared to other vehicle types and two-wheelers were identified as the most frequent followers, comprising nearly 30% of the following vehicles. Three-wheelers were found to be least involved in these platoons. The majority of platoons were small, with 68% consisting of just two vehicles. Platoons of three vehicles accounted for 20%, while those with four vehicles made up 7%. Larger platoons (five or more vehicles) were relatively rare, comprising only 5% of the total platoon formed. For each platoon based on the leader type, the average speed of the platoon was calculated, as shown in Figure 4.5, to further understand the traffic characteristic of the platoons.

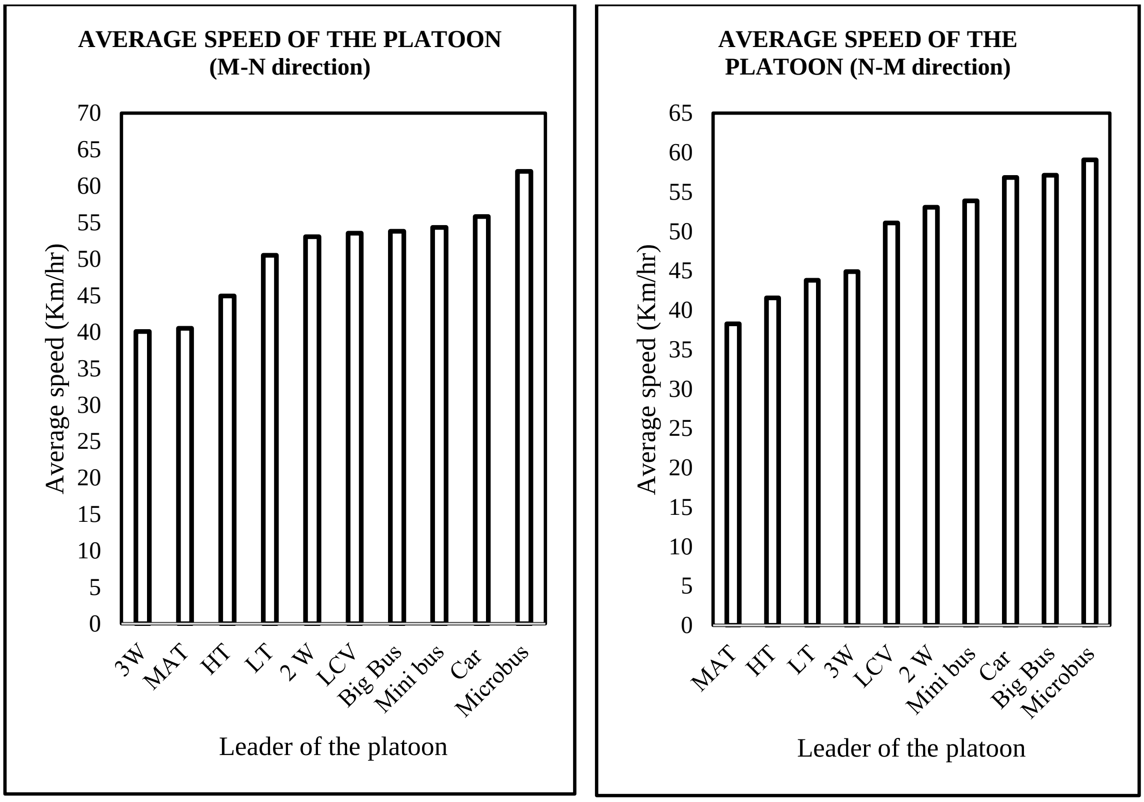


Figure 4.5: Average speed of the platoons mased on different leaders

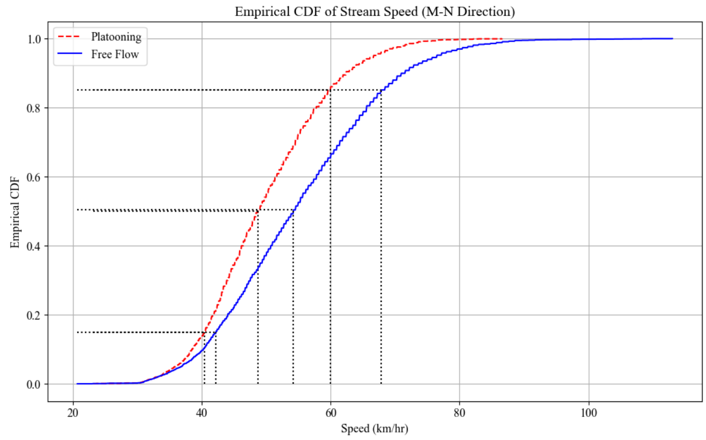
Based on Figure 4.5, the average speed of platoons based on their leader type, it can be found that when the platoon leaders were 3W, MAT, HT, LT the average platoon speed was significantly lower compared to when other vehicle types led the platoon. This effect was seen more in the N-M direction, where MAT and HT as platoon leaders had the lowest average speeds, with MAT at 38.27 km/hr and HT at 41.57 km/hr. The calculation is shown in Appendix C.

4.4 Analysis of Speed of Free-Flow and Platooning Conditions

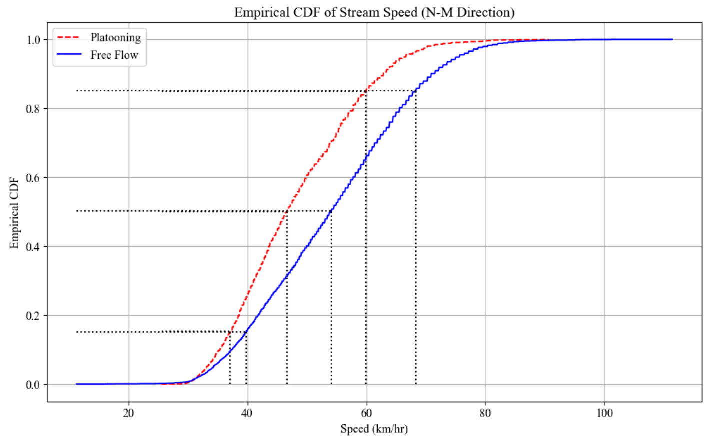
For analyzing the stream and vehicle-wise speeds, distribution analysis using the CDF curve and statistical analysis were performed.

4.4.1 Distribution Analysis of the Stream Speed

The cumulative probability distribution graph of speed of the overall stream was plotted between these two conditions of platooning and the free-flowing condition. The direction-wise plots are shown in Figure 4.6.



(a)



(b)

Figure 4.6: CDF comparisons between platoon and free-flow (a) M-N direction (b) N-M direction

The comparison of the cumulative distribution of speed in free-flow and platooning conditions reveals (as from Figure 4.6.a and b) a noticeable shift in the curve to the left after the platooning event, indicating a reduction in the overall speed of the traffic stream. This shift can be observed in both the directions, where platooning conditions have slower speeds across all percentiles. The speed calculated at different percentile for platooned and free-flow conditions for both the directions is shown in Table 4.7.

Table 4.7: Comparison of the percentile speed in free-flow and platoon

Direction	Traffic Condition	15th Percentile (km/hr)	50th Percentile (km/hr)	85th Percentile (km/hr)
M-N	Free flow	42.15	54.15	67.81
	Platooning	40.4	48.73	59.98
	Difference	1.75	5.42	7.83
N-M	Free flow	39.78	54.15	68.4
	Platooning	37.13	46.69	59.98
	Difference	2.65	7.46	8.42

When examining the 15th, 50th (median), and 85th percentiles, it is seen (from Table 4.7) that free-flow speeds are consistently higher than platooning speeds in both directions. The median speed in the M-N direction reduced by 5.42 km/h due to Platooning, and in the N-M direction, it dropped by 7.46 km/h, suggesting that the platooning event had comparatively more effect on speeds in the N-M direction. Additionally, the data shows that the difference between free-flow and platooning speeds increased as moving up to higher percentiles. For example, the 85th percentile showed a more substantial speed difference compared to the 15th percentile, indicating that the slower-moving vehicles in the platooning condition are more likely to affect higher-speed vehicles, leading to a larger reduction in overall stream speed at higher percentiles.

4.4.2 Statistical Analysis of Speed of Different Vehicles

To identify the vehicle class with the most significant speed difference between the platooned and free-flow conditions, a Welch's t-test was conducted, followed by an effect size analysis. This analysis involved identifying the vehicles with the maximum speed difference in both conditions. The descriptive statistics for the speed of different vehicles in both the platooned and free-flow conditions are shown in Table 4.8.

Table 4.8:Descriptive statistics of the speed of platooning and the free-flow condition for different vehicles

Descriptive Statistics of speed at Platooned condition					
Vehicle Type	Count (n_1)	Mean (μ_1)	Std. Dev. (s_1)	Skewness	Kurtosis
3W	66	40.5	5.5	0.4	0.1
HT	1107	43	6.1	-0.2	-0.2
MAT	167	39.6	6.4	-0.2	-0.2
2W	1282	51.1	10.5	0.4	0.1
Car	641	52.6	10.5	-0.2	-0.2
LT	258	46	7.4	-0.2	-0.2
LCV	583	50.6	9.1	-0.2	-0.2
Big Bus	230	52.6	8.7	-0.2	-0.2
Mini Bus	281	51.1	9.3	-0.1	-0.7
Microbus	303	56.3	10.1	-0.2	-0.2
Descriptive Statistics of speed at free-flow condition					
Vehicle Type	Count (n_2)	Mean (μ_2)	Std. Dev. (s_2)	Skewness	Kurtosis
3W	192	40	6.8	0.2	0.2
HT	1499	44.1	6.5	-0.2	0.4
MAT	215	39.9	6.9	-0.2	0.4
2W	2712	57.4	12.8	0.2	0.2
Car	1140	63	11.6	-0.2	0.4

LT	384	49.8	8	-0.2	0.4
LCV	918	55.8	10.6	-0.2	0.4
Big Bus	261	58.3	7.9	-0.2	0.4
Mini Bus	428	54.9	9.7	-0.5	0
Microbus	510	63.8	9.1	-0.2	0.4

The sample sizes for all vehicle types exceeded 30, the Central Limit Theorem supports the assumption of normality. Additionally, the kurtosis values within the range (-1,1), as seen in the Table 4.8, further validate the approximate normal distribution of speed data for each vehicle type (Field, 2017), (Peat & Barton, 2005). Given the robustness of Welch's t-test, which remains effective regardless of whether variances are equal or not, it was chosen over the independent t-test to compare speed variations between free-flow and platooning conditions for each vehicle type. The test was conducted using the following hypotheses:

- Null Hypothesis (H_0): The mean speed of vehicles in platoon is greater than or equal to the mean speed of vehicles in free-flow.

$$i.e. \qquad H_0: \mu_1 \geq \mu_2$$

- Alternate Hypothesis (H_1): The mean speed of vehicles in platoon is less than the mean speed of vehicles in free-flow.

$$i.e. \qquad H_1: \mu_1 < \mu_2$$

The output of the Welch's t-test, including the calculated t-statistic, df, P-value (one-tailed), and the acceptance or rejection of the hypothesis based on the significance test, is shown in Table 4.9.

Table 4.9 Output of the Welch's T-test

Vehicle Type	T-Statistic	Degrees of Freedom	One-tailed p-value	Significance test	Null hypothesis at 95%
3W	0.555	139	0.710	> 0.025	fail to reject
HT	-4.595	2464	0.000	< 0.025	reject
MAT	-0.496	370	0.310	> 0.025	fail to reject
2 W	-16.517	3017	0.000	< 0.025	reject
Car	-19.396	1440	0.000	< 0.025	reject
LT	-6.217	577	0.000	< 0.025	reject
LCV	-10.217	1372	0.000	< 0.025	reject
Big Bus	-7.568	467	0.000	< 0.025	reject
Mini bus	-5.158	616	0.000	< 0.025	reject
Microbus	-10.542	583	0.000	< 0.025	reject

Based on the one-tailed test (left tailed) conducted at a 95% confidence interval (or 0.025 significance level for a one-tailed test), it can be observed that the p-values for all vehicle types were less than α (0.025), except for 3W and MAT. The result suggests that for 3W and MAT, the null hypothesis could not be rejected, indicating that the mean speed during platooning is significantly equal to the mean speed during free-flow conditions. In contrast, for all other vehicle classes, the alternative hypothesis was accepted, rejecting the null hypothesis, which indicates that the mean speed during platooning conditions is significantly lower than the mean speed during free-flow conditions. This, result indicates that 3-W and MAT being slowest vehicles (as shown in Table 4.2), were unaffected by platoon formation, whereas other vehicles were affected. For identification of the extent of the effect of the platooning on different vehicles, effect size analysis was done based on Cohen's d test. The output of the Cohen's d test is shown in Table 4.10.

Table 4.10: Output of Cohen's d test

Vehicles	Effect Size (d-value)	Effect Category
Car	-0.93	Large
Microbus	-0.81	Large
Big Bus	-0.69	Medium
2 W	-0.52	Medium
LCV	-0.52	Medium
LT	-0.49	Small
Mini bus	-0.39	Small
HT	-0.2	Small
MAT	-0.05	Insignificant
3W	0.07	Insignificant

Based on the Cohen's effect size category, there has been a large effect in the speed of Car and Microbus, due to the platoon formation. For 2 W, LCV and Big Bus, the effect was medium and there was small impact in the speed of Minibus, Light truck and Heavy truck. Whereas, for the 3-W and MAT the impact was not significant. The negative sign indicates the reduction in speed being less in platooning event.

4.5 Evaluation of Different Operational Performance Measures

For evaluating different performance measures, the heterogenous traffic was to be converted into its homogenous car equivalent traffic, for which the passenger car unit was calculated.

4.5.1 Calculated (Dynamic) Passenger Car Units (PCU)

The Table 4.11 shows the PCU calculated from the field data, its average and range of variation, calculated based on the speed-area method (Chandra, 2004) for both the directions. The PCU was calculated based on space mean speed aggregated at 15-min interval, which considered more stable for data aggregation (Transportation Research Board, 2016). The size of the vehicles was taken from different references as shown in Table 3.3. (The calculated values for the space mean speed and PCU values at different interval are shown in Appendix D).

Table 4.11: Field estimated PCU

Vehicles	M-N direction		N-M direction	
Categories	Average	Ranges	Average	Ranges
2 W	0.19	0.13 - 0.3	0.19	0.15 - 0.3
3W	0.82	0.52 - 1.2	0.78	0.47 - 1.18
Car	1	-	1	-
LCV /4 W	1.2	0.84 - 2.11	1.19	0.87 - 1.81
Microbus	1.44	1.07 - 2.04	1.47	1.04 - 2.57
Mini bus	2.42	1.58 - 3.91	2.4	1.52 - 3.95
LT	2.27	1.62 - 3.57	2.42	1.65 - 3.56
HT	3.48	2.56 - 6.09	3.66	2.89 - 5.09
Big Bus	3.92	2.62 - 5.08	3.77	2.48 - 8.5
MAT	6.36	3.87 - 11.61	6.92	3.95 - 10

It can be seen that the variations in PCU values for different vehicles exists in both the direction. It can be seen that for MAT, the PCU varied the range of 3.87 to 11.61 in M- N direction. Similar variation can be seen in other direction. The variations might be because of the large difference in the speed of the car and MAT within certain 15-minute interval of time. The average values of the PCU are then used for converting the heterogenous flow of the traffic into a homogenous or passenger car equivalent traffic.

4.5.2 Traffic Flow Modeling for Capacity Estimation

The traffic modelling was based on conventional models the field calculated data, here the volume was converted into passenger car equivalent for better representation of the heterogenous traffic flow. The relation between the calculated (weighted) space mean speed and the density was analyzed as shown in Figure 4.7 and based on this relationship, a speed vs volume relationship was analyzed as Figure 4.8. The calculated values are shown in Appendix E.

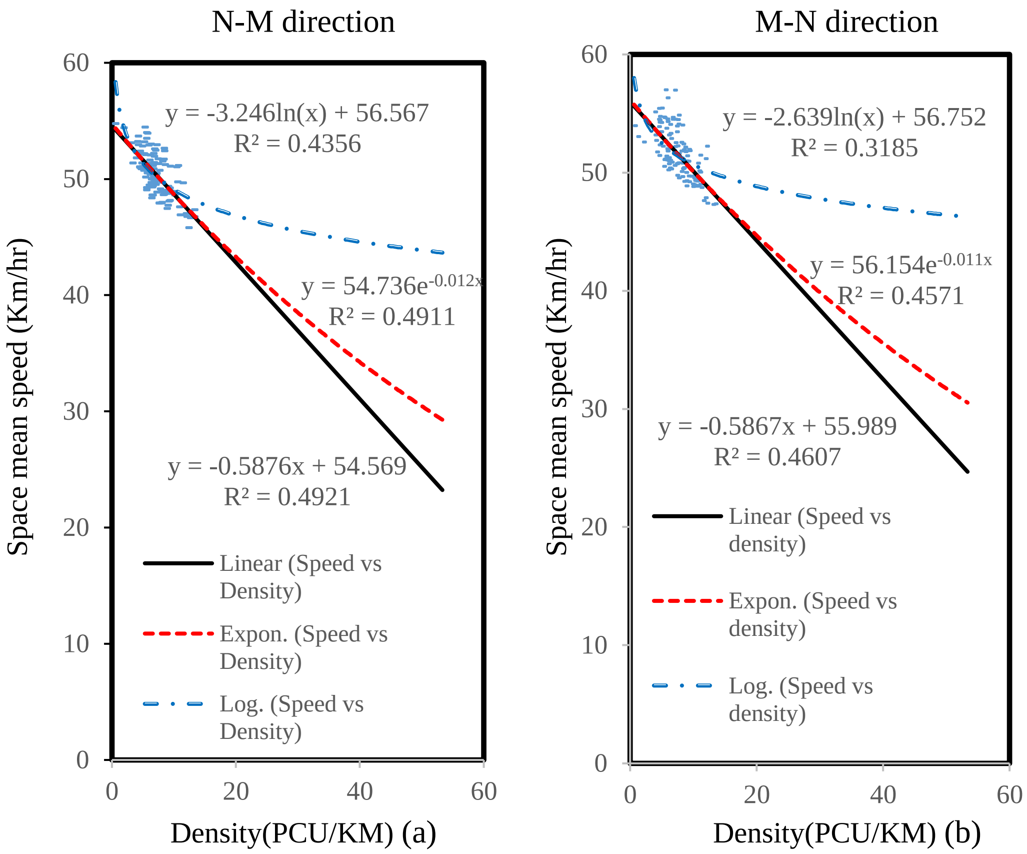
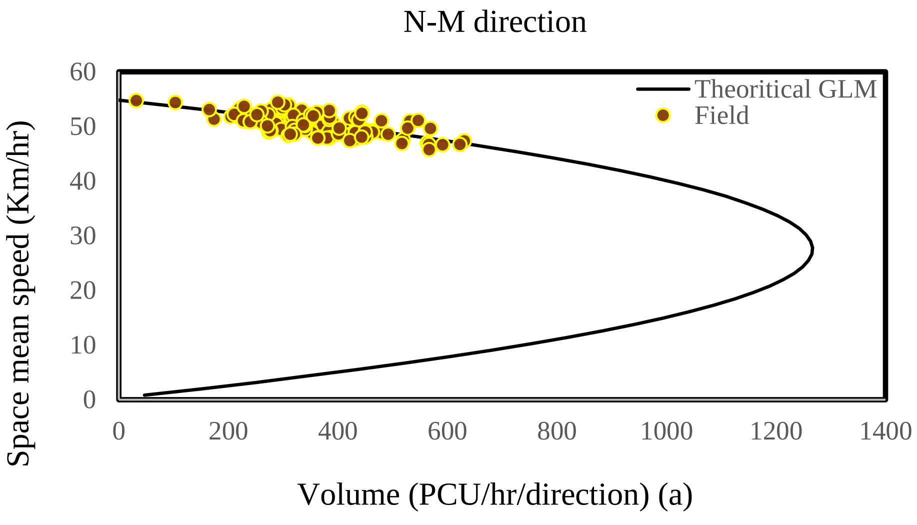


Figure 4.7: Traffic flow modelling (Speed vs density) (a) N-M direction and (b) M-N direction



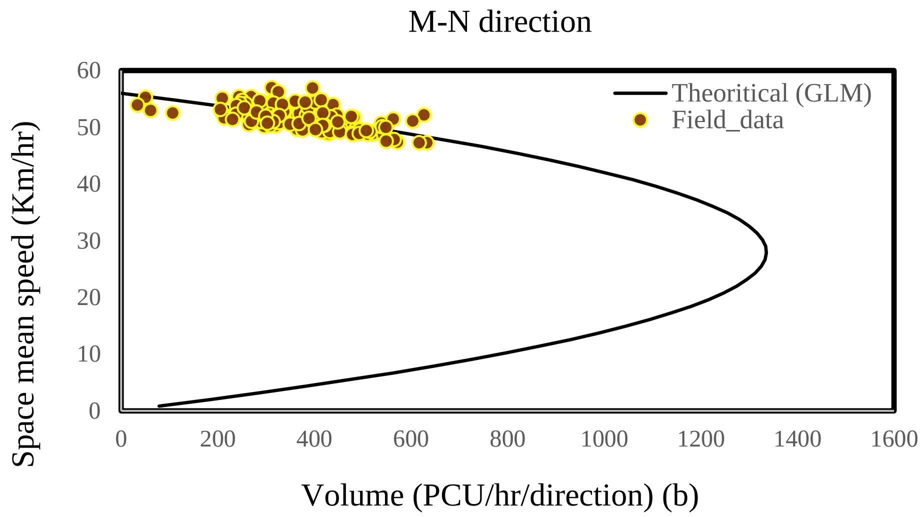


Figure 4.8: Traffic flow modelling (Speed vs Volume (PCU/hr/direction) (a) N-M direction and (b) M-N direction

Three models (Linear, exponential and Logarithmic) were fitted but, GLM showed better fit with highest R^2 when compared with other models (as shown in Figure 4.7 a and b), thus for the capacity estimation, Greenshields's model was used. The result also aligned with different Indian context (Indian Highway Capacity Manual, 2017), where based on multiple studies GLM was suggested for capacity estimation for the two lane heterogenous traffic in Indian context. The capacity calculation was based on the Greenshields formula as shown in Equation 4.3 where the directional capacity (Qc) was calculated (projected)for each direction, these values were summed to obtain the total capacity (Qc*) of the road at the section and the calculated values are shown in Table 4.12.

Table 4.12 :Capacity estimation based on Greenshields linear model

GLM Calculation	Units	Direction	
		M-N	N-M
Greenshields's Free Flow speed (Vf)	Km/hr	55.989	54.569
Jam density (Kj)	PCU/KM	95.4304	92.868
Directional Capacity (Qc)	PCU/hr/lane	1336	1267
Total capacity (Qc*)	PCU/hr	2603	

$$Q_c = \frac{K_j \cdot V_f}{4}$$

$$Q_c^* = Q_{c\,(M\text{-}N)} + Q_{c\,(N\text{-}M)}$$

Equation 4.3

Based on the Greenshield's formula the total capacity of the road was estimated to be approx. 2600 PCU/hr. The capacity calculated for the M-N (1336 PCU/hr/lane) section was slightly higher than the N-M direction (1267 PCU/hr/lane). The lower speed values, across all the vehicles (specially for loaded truck) as discussed in the chapter 4.2.2 might be the reason for lower capacity estimation in the M-N direction. The performance measures as discussed in chapter 3.6 were then used for establishing the relation with the platooning variable.

4.5.3 Regression-Based Evaluation of Performance Measures

For the evaluation of performance measures, an initial analysis was conducted using multiple linear regression. Based on the literature review, through traffic flow, truck percentage, and opposite traffic flow were selected as independent variables and: ATS, NF, PF, FD and NFPC (as discussed in chapter 4.5.3) as the dependent variables/ performance measures. The MLR models and its result is shown in the Table 4.13.

Table 4.13: Regression analysis between the performance measures and traffic characteristics

Independent Variables	Dependent variables					
		ATS	NF	PF	FD	NFPC
Constant	Coefficient	57.72	-28.46	0.11	-0.69	-0.02
	t (p-value)	128.48 (0.000*	-3.53 (0.000*	4.96 (0.000)*	-4.34 (0.000*	-3.53 (0.000)*
Through Flow (PCU/hr/lane)	Coefficient	-0.007	0.2845	2.40E-04	0.00573	2.20E-04
	t (p-value)	-6.93 (0.000*	15.66 (0.000)*	4.96 (0.000)*	15.86 (0.000*	15.66 (0.000)*
Truck Percentage	Coefficient	-5.87	-7.27	-0.0291	0.0065	-0.0056
	t (p-value)	-7.62 (0.000*	-0.53 (0.599)	-0.79 (0.432)	0.02 (0.981)	-0.53 (0.599)
Opposite Flow (PCU/hr/lane)	Coefficient	-0.0022	0.0065	0.000035	0.00015	0.000005
	t (p-value)	-2.23 (0.027)*	0.36 (0.719)	0.72 (0.470)	0.43 (0.665)	0.36 (0.719)
Model Fit	Adjusted R^2	0.3881	0.5383	0.1039	0.5482	0.5383
	F-Value	53.65	97.76	10.62	101.71	97.76
	p-Value	0.000*	0.000*	0.000*	0.000*	0.000*

*Note: P-values with * indicates the significant models at 5% significance level*

The results shows that the truck percentage and opposite volume were insignificant for all the regression models at the 5% significance level, except for ATS, suggesting that the proportion of trucks and opposite volume does not have a meaningful impact on these performance measures. Among the independent variables, the through traffic flow was the most significant. Given the lower p values of truck proportion and the opposite flow based on t-test in the MLR models, through traffic flow (PCU/hr/lane) alone was used as the traffic characteristics for the prediction of the performance measures. Similar result was seen in several studies (Catbagan & Nakamura, 2006) (Hashim & Abdel-Wahed, 2011).

Thus, being a single independent variable, Pearson's correlation analysis was done between the directional traffic flow (PCU/hr/lane) and other dependent variables such as ATS, NF, PF, FD, NFPC and to identify best performance measure. The Table 4.14 shows the Pearson's correlation values and p values at the 5 % significance level for different performance measure and the directional volume.

Table 4.14: Correlation results between different performance measures and the directional hourly volume

Correlation Results (directional volume vs. performance measures)					
Performance measures	Correlation (R)	Std. Error	t-Statistic	p-Value	N
ATS	-0.49*	0.0031	-8.8574	0.0000	250
NF	0.73*	0.0018	17.1685	0.0000	250
PF	0.33*	0.0036	5.5531	0.0000	250
FD	**0.76***	0.0018	17.5271	0.0000	250
NFPC	0.73*	0.0018	17.1685	0.0000	250

*Note: Correlations in * are significant at the 5% level (2-tailed).*

The correlations are significant at the 5% level. All the correlation are positive except for the ATS, the average speed tends to decrease with the increase in the two-way volume. Among the performance measures, it can be seen that follower density (FD) as the most appropriate due to its highest correlation with the directional flow (r = 0.76), FD (per direction/lane) was found as the best for the performance measure of the NH44-004. And further it can be easily related to the HCM LOS values as given in the 7th edition of HCM. (Transportation Research Board and National Academies of Sciences, 2022). Though, many study suggested NPFC as the better option than FD in the heterogenous environment (Boora et al., 2017) (Penmetsa et al., 2015), it was not such as per the results of this study, the reason might be the comparatively lower volume in the study section than that of the Indian intercity, resulting in lower ratios of the number of followers to capacity ratio (NPFC).

4.5.4 Relation Between FD Per Lane and Directional Hourly Volume

Since FD per lane was identified as the best performance measure and directional hourly volume as the predictor variable for FD, their relationship was further analyzed. A second-degree polynomial equation was found to be the best fit for modeling the relationship between follower density per lane and directional hourly flow (PCU/hr/lane). With 200 data set (80%) for model development and 50 datasets (20%) for validation, regression analysis was performed where the results are shown in Table 4.15.

Table 4.15: Regression result between directional flow and FD per lane(a) ANNOVA result and (b) regression result.

(a)

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	100.7774	100.7774	396.5417	3.68E-49
Residual	198	50.31986	0.254141		
Total	199	151.0973			

(b)

	Coefficients	Standard Error	t-Stat	P-value	N
Intercept	0.342	0.0728	4.700	4.86E-07	200
(Directional flow)2	8.42E-06	4.23E-07	19.913	3.68E-49	

The ANOVA results as seen in Table 4.15 (a) confirm the model's statistical significance. The computed F-value (396.542) is significantly higher than the critical F-value (2.7) at α = 0.05, leading to the rejection of the null hypothesis in favor of the alternative hypothesis indicating a strong relationship between the variables. The relation as per Equation 4.4 was developed which was validated using the 20% dataset.

$$\text{Follower density per lane} = 8.42*10^{-6} * \left(\text{Directional flow (Pcu/hr/lane)}\right)^2 + 0.342$$

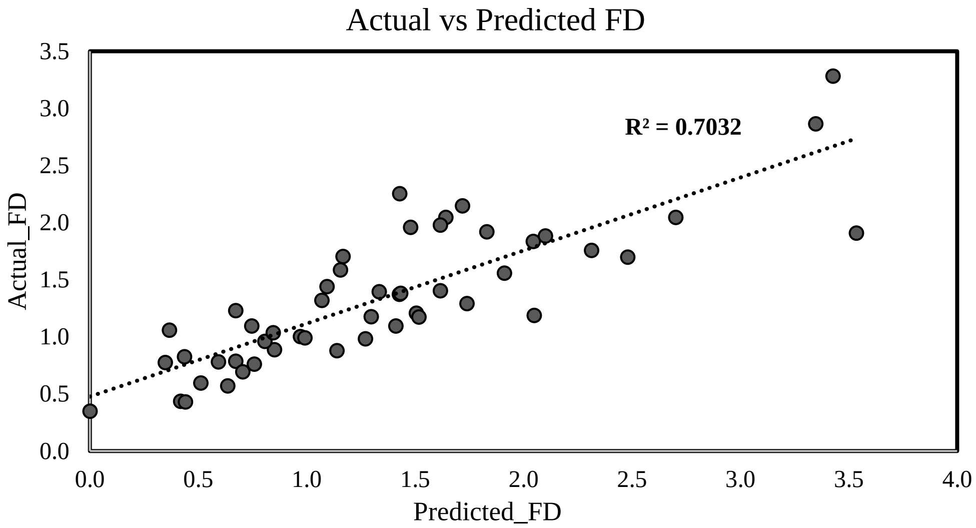
Equation 4.4

The developed regression model was evaluated using several metrics, and the results indicate that the model performs reasonably well in predicting the dependent variable (FD). The R^2 value of 0.703 suggests that 70.3% of the variance in FD is explained by the model, indicating a decent fit. The Adjusted R^2 of 0.697 confirms that the model is not overfitting, and the inclusion of predictors is justified. Additionally, the Mean Absolute Percentage Error (MAPE) of 14% shows that, on average, the model's predictions deviate by 14% from the actual FD values, reflecting moderate accuracy.

Table 4.16:Regression model validation

Metrics	MAPE	R^2	Adj.R^2
Values	14%	0.703	0.697

Figure 4.9: Actual vs Predicted output



CHAPTER 5 : CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As the study was conducted with the objectives of identifying the conditions for Free-flowing and platooning events, analyzing the stream speed and speed of different vehicles between these conditions, and identification of the best performance measures for two-lane roads of Nepal especially the roads with similar characteristics as the study site (NH44-004), the following conclusion could be derived:

- An 8-second time gap was identified as the threshold beyond which interaction between vehicles ceases. When the gap exceeds this value, vehicles are considered to be in a free-flow condition, moving independently without influencing each other.
- For identifying platooning conditions, the speed differential (SD) was considered alongside the time gap. In the M–N direction, the SD range was observed to be between -4.32 km/h and +5.13 km/h, while in the N–M direction, the range was slightly broader, from -5.61 km/h to +5.84 km/h. In general, a broader SD range of approximately ±6 km/h can be used to identify followers, with a gap of 8 seconds or less indicating platooning behavior.
- During the study period, 37% of the total vehicles were involved in platoons, with heavy trucks (HT) typically serving as the platoon leaders and two-wheelers as the followers in most cases. The size of the platoon was generally between 2 to 4 vehicles for nearly 95% of the time, while platoons consisting of 5 or more vehicles were rare, occurring only 5% of the time.
- When comparing the speeds between platooning and free-flow conditions, it was observed that the stream speed was lower in the platooning condition, consistent across both directions. For specific vehicle types, there was no significant decrease in the mean speed for 3-W and MAT. However, for other vehicle types, a significant reduction in speed was found when vehicles were platooning compared to when they were in free-flow conditions. The effect size analysis further indicated that the impact of platoon formation on speed was large for Cars and Microbuses, while it was medium to small for the other vehicle categories.

- This study identified *Follower Density per lane (FD/lane)* as the most effective operational performance indicator for evaluating traffic conditions on two-lane two-way roads. The established second-degree relationship between follower density and directional traffic volume, with a reasonably strong R^2 of 0.703 and a MAPE of 14%, demonstrates its potential for practical application. Given that directional volume is easily measurable in field conditions, the model offers a feasible method for estimating follower density. This can serve as a valuable input for Level of Service (LOS) evaluation, aligning with the updated threshold criteria presented in the 7th Edition of the U.S. Highway Capacity Manual.

5.2 Recommendation

The following recommendations are suggested based on the findings of this study:

- This study presents a detailed methodology for identifying platooning and free-flow conditions using a case study approach. It is recommended that this methodology be tested and validated on other undivided two-lane roads across Nepal to assess its general applicability under varying traffic conditions.
- Given the identified speed reduction under platooning, particularly for Cars and Microbuses, interventions such as overtaking lanes may be explored in future road upgrades to reduce delays caused by platoons. To support this, simulation-based evaluations may be carried out to examine the potential impact and feasibility of implementing passing lanes on Nepal's two-lane highways.
- This study identified Followers' Density (FD) per lane as the most effective measure for evaluating the operational performance. As the U.S-HCM provides updated Level of Service (LOS) thresholds based on FD per lane for various highway conditions, it is recommended that these established thresholds be adopted for Nepalese undivided roads, at least until a capacity manual designed for local road and traffic conditions is developed.
- Future studies should extend the data collection period and incorporate diverse terrain, weather conditions, and road gradients. Additionally, exploring various data aggregation intervals may offer deeper insights into traffic performance under varying conditions.

REFERENCES

Al-Kaisy, A. (2022). Two-Lane Highways: Indispensable Rural Mobility. *Encyclopedia, 2*, 625--631. https://doi.org/10.3390/encyclopedia2010042

Al-Kaisy, A., & Karjala, S. (2008). Indicators of performance on two-lane rural highways: Empirical Investigation. *Transportation Research Record, 2071*, 87-97. https://doi.org/https://doi.org/10.3141/2071-11

Asian Transport Observatory. (2020). *E-mobility Assessment for Nepal.*

Boora, A., & Ghosh, I. (2017). Performance Indicator for Two-Lane Intercity Highways under Heterogeneous Traffic Condition. *Transportation Research Procedia, 22*, 459-468.

Boora, A., Ghosh, I., & Chandra, S. (2017). Assessment of level of service measures for two-lane intercity highways under heterogeneous traffic conditions. *Canadian Journal of Civil Engineering, 44*(2), 69-79.

Boora, A., Ghosh, I., & Chandra, S. (2018, 2). What Characterizes a Vehicle as Follower on Two-Lane Intercity Highways under Heterogeneous Traffic Conditions. *Journal of Transportation Engineering, Part A: Systems, 144*(2).

Catbagan, J., & Nakamura, H. (2006). Evaluation of Performance Measures for Two-Lane Expressways in Japan. *Transportation Research Record: Journal of the Transportation Research Board, 1988*, 111-118. https://doi.org/10.1177/0361198106198800114

Chandra, S. (2004). Capacity Estimation Procedure for Two-Lane Roads Under Mixed Traffic Conditions. *Journal of Indian Road Congress, 165*, 139-170.

Cohen, J. (1992). Quantitative Methods in Psychology: A Power Primer. *Psychological Bulletin*. https://doi.org/DOI: 10.1037//0033-2909.112.1.155

DOR, M. G. (2022/2023). Retrieved from http://ssrn.aviyaan.com/traffic_controller/get_summary

DOR, M. G. (2023). *Annual Progress Report (2080/081).* DOR.

Field, A. (2017). *Discovering Statistics Using IBM SPSS Statistics* (5th ed.). (J. Seaman, Ed.) London, England: SAGE Publications Ltd.

Fotonnepal. (n.d.). *Fotonnepal*. Retrieved from https://fotonnepal.com/vehicle/products/view-c2

Freedman, D., & Diaconis, P. (1981, 12). On the histogram as a density estimator:L 2 theory. *Zeitschrift f r Wahrscheinlichkeitstheorie und Verwandte Gebiete, 57*(4), 453-476.

Gattis, J., Alguire, M., Townsend, K., Rao, S., & -Blackwell, M. (n.d.). *Rural Two-Lane Passing Headways and Platooning.*

Gaur, A., & Mirchandani, P. (2001, 01). Method for Real-Time Recognition of Vehicle Platoons. *Transportation Research Record, 1748*, 8-17. https://doi.org/10.3141/1748-02

Ghosh, I., Chandra, S., & Boora, A. (2013, 12). *Operational Performance Measures for Two-lane Roads: An Assessment of Methodological Alternatives* (Vol. 104). Elsevier BV.

GUELL, D., & VIRKLER, M. (1988). Capacity Analysis of Two-Lane Highways. *Transportation Research Record*(1194), 199.

Hashim, I. (2011). Analysis of speed characteristics for rural two-lane roads: A field study from Minoufiya Governorate, Egypt. *Ain Shams Engineering Journal, 2*(1), 43-52.

Hashim, I., & Abdel-Wahed, T. (2011). Evaluation of performance measures for rural two-lane roads in Egypt. *Alexandria Engineering Journal, 50*(3), 245-255.

(2017). *Indian Highway Capacity Manual.* New Delhi, India: Council of Scientific and Industrial Research (CSIR) - Central Road Research Institute (CRRI).

Investment Board Nepal. (2024, 4). Transport Sector Profile.

Kasalawat, N. &. (2024). Determination of Motorcycle Equivalent Unit and Road Capacity: A Case Study of Selected Road Sections of Kathmandu Valley. *International Journal on Engineering Technology, 1*, 59-73. https://doi.org/10.3126/injet.v1i2.66705

Kasi, K., & Karuppanan, G. (2024, 1). Framework to Identify Vehicle Platoons under Heterogeneous Traffic Conditions on Urban Roads. *Sustainability (Switzerland), 16*(2).

Kumaratunga, P. C. (2018, May). Evaluation of PCU Factors for Two Lane. Sri Lanka: University of Moratuwa.

Massey, F. (1951, 3). The Kolmogorov-Smirnov Test for Goodness of Fit. *Journal of the American Statistical Association, 46*(253), 68-78.

Miller, A. (n.d.). A Queueing Model for Road Traffic Flow.

Ministry of Finance Government of Nepal. (2024). *Economic Survey 2023-24.*

National Planning Commission. (2025). *The 16th Plan (2021).*

Nokandeh, M. M., Ghosh, I., & Chandra, S. (2016). Estimation of Capacity of Two-lane Inter-Urban Roads in India from Free Speed data. *International Conference on Transportation and Traffic Engineering (ICTE), 15.* Tehran, Iran.

Peat, J., & Barton, B. (2005, 1). *Medical Statistics.* Wiley.

Penmetsa, P., Ghosh, I., & Chandra, S. (2015). Evaluation of Performance Measures for Two-Lane Intercity Highways under Mixed Traffic Conditions. *Journal of Transportation Engineering, 141*, 04015021. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000787

Samadi, H., Aghayan, I., Nasiri, I. S., Rahmani, O., & Hasanvand, M. (2023). Platoon-Based Assessment of Two-Way Two-Lane Roads Performance Measure: A Classification Method. *Journal of Advanced Transportation, 2023*, 1--13. https://doi.org/10.1155/2023/5054427

Scott, D. (1979, 12). On Optimal and Data-Based Histograms. *Biometrika, 66*(3), 605.

Scott, D. (2010, 1). Histogram. *WIREs Computational Statistics, 2*(1), 44-48.

Sharma, N., Arkatkar, S., & Sarkar, A. (2011, 6). Study on Heterogeneous Traffic Flow Characteristics of a Two-Lane Road. *TRANSPORT, 26*, 185-196.

Tiwari, H., & Marsani, A. (2014). Calibration of Conventional Macroscopic Traffic Flow Models for Nepalese Roads (A Case Study of Jadibuti - Suryabinayak Section). *International Conference on Technology and Innovation Management & IOE Graduate Conference, 2014. 2.* Proceedings of IOE Graduate Conference.

Toyota Nepal. (n.d.). *Toyota*. Retrieved from https://www.toyota.com.np/en/models/ace/hiace.html#specifications

Transportation Research Board. (1985). *Highway Capacity Manual.* Washington, D.C.: National Research Council.

Transportation Research Board. (2000). *Highway Capacity Manual 2000.* Washington, D.C.: National Research Council, Transportation Research Board.

Transportation Research Board. (2016). *Highway Capacity Manual 6th Edition: A Guide for Multimodal Mobility Analysis.* (L. A. Elefteriadou, Ed.) Washington, DC: The National Academies Press. https://doi.org/10.17226/24798

Transportation Research Board and National Academies of Sciences, E. a. (2022). *Highway Capacity Manual 7th Edition: A Guide for Multimodal Mobility Analysis.* Washington, D.C.: The National Academies Press. https://doi.org/10.17226/26432

Tsagris, M., Alenazi, A., Verrou, K.-M., & Pandis, N. (2020, 1). Hypothesis testing for two population means: parametric or non-parametric test? *Journal of Statistical Computation and Simulation, 90*(2), 252-270. https://doi.org/https://doi.org/10.48550/arXiv.1812.11361

U.S. Bureau of Public Roads. (1950). *Highway Capacity Manual.* Washington, D.C.: U.S. Government Printing Office.

World Bank. (2025). *Protecting Slopes to Build Resilient Roads in Nepal.* Retrieved February 10, 2025

APPENDIX A: TRAFFIC DATA COLLECTION SAMPLE SHEET

APPENDIX A: TRAFFIC DATA COLLECTION SAMPLE SHEET

Sample Table for data collection in excel

Vehicle type	Direction	Video N.o.	Day	In time entry			Out time entry			Time converted in sec			Length_ (M)	Speed_ (Km/Hr)	Time in 12hr format			Speed difference	Time_interval (15-min)	Time interval _class	GAP
				Min	Sec	Frame	Min	Sec	Frame	in	out	Travel_time			In	Out	Difference				
HT	N-M	31	1	17	29	23	17	37	9	1049.77	1057.30	7.5	72.2	34.50	7:07:39 AM	7:07:46 AM	0:00:08	-11.1	7:15:00 AM	1- 7	17.04
HT	N-M	31	1	17	34	25	17	42	1	1054.83	1062.03	7.2	72.2	36.10	7:07:44 AM	7:07:51 AM	0:00:07	1.6	7:15:00 AM	1- 7	4.28
HT	N-M	31	1	17	39	6	17	46	3	1059.20	1066.10	6.9	72.2	37.67	7:07:48 AM	7:07:55 AM	0:00:07	1.6	7:15:00 AM	1- 7	3.62
HT	N-M	31	1	17	42	25	17	50	8	1062.83	1070.27	7.4	72.2	34.97	7:07:52 AM	7:07:59 AM	0:00:07	-2.7	7:15:00 AM	1- 7	2.92
HT	N-M	31	1	17	44	24	17	52	15	1064.80	1072.50	7.7	72.2	33.76	7:07:54 AM	7:08:01 AM	0:00:08	-1.2	7:15:00 AM	1- 7	1.19
HT	N-M	31	1	17	46	27	17	54	23	1066.90	1074.77	7.9	72.2	33.04	7:07:56 AM	7:08:04 AM	0:00:08	-0.7	7:15:00 AM	1- 7	1.30
Microbus	N-M	31	1	18	14	10	18	18	21	1094.33	1098.70	4.4	72.2	59.52	7:08:23 AM	7:08:28 AM	0:00:04	26.5	7:15:00 AM	1- 7	26.62
LCV /4 W	N-M	31	1	18	23	27	18	29	3	1103.90	1109.10	5.2	72.2	49.98	7:08:33 AM	7:08:38 AM	0:00:05	-9.5	7:15:00 AM	1- 7	9.23
LT	N-M	31	1	18	54	13	19	0	5	1134.43	1140.17	5.7	72.2	45.33	7:09:03 AM	7:09:09 AM	0:00:06	-4.6	7:15:00 AM	1- 7	30.23
2 W	N-M	31	1	19	34	17	19	39	16	1174.57	1179.53	5.0	72.2	52.33	7:09:44 AM	7:09:49 AM	0:00:05	7.0	7:15:00 AM	1- 7	39.65
2 W	N-M	31	1	19	45	11	19	50	22	1185.37	1190.73	5.4	72.2	48.43	7:09:54 AM	7:10:00 AM	0:00:05	-3.9	7:15:00 AM	1- 7	10.67
Microbus	N-M	31	1	20	34	18	20	38	13	1234.60	1238.43	3.8	72.2	67.81	7:10:44 AM	7:10:47 AM	0:00:04	19.4	7:15:00 AM	1- 7	49.09
Mini bus	N-M	31	1	20	47	27	20	54	10	1247.90	1254.33	6.4	72.2	40.40	7:10:57 AM	7:11:03 AM	0:00:06	-27.4	7:15:00 AM	1- 7	13.00
HT	N-M	31	1	21	13	9	21	19	23	1273.30	1279.77	6.5	72.2	40.19	7:11:22 AM	7:11:29 AM	0:00:06	-0.2	7:15:00 AM	1- 7	24.87
Big Bus	N-M	31	1	21	14	16	21	21	4	1274.53	1281.13	6.6	72.2	39.38	7:11:24 AM	7:11:30 AM	0:00:07	-0.8	7:15:00 AM	1- 7	0.56
2 W	N-M	31	1	21	16	21	21	24	0	1276.70	1284.00	7.3	72.2	35.61	7:11:26 AM	7:11:33 AM	0:00:07	-3.8	7:15:00 AM	1- 7	1.24
2 W	N-M	82	2	12	12	28	12	17	7	732.93	737.23	4.30	72.2	60.45	3:40:30 PM	3:40:34 PM	0:00:04	22.2	3:45:00 PM	2- 41	9.32
2 W	N-M	82	2	13	31	10	13	35	4	811.33	815.13	3.80	72.2	68.40	3:41:48 PM	3:41:52 PM	0:00:04	8.0	3:45:00 PM	2- 41	78.29
Car	N-M	82	2	13	31	10	13	35	2	811.33	815.07	3.73	72.2	69.62	3:41:48 PM	3:41:52 PM	0:00:04	1.2	3:45:00 PM	2- 41	-0.10
LT	N-M	82	2	13	35	21	13	42	12	815.70	822.40	6.70	72.2	38.79	3:41:53 PM	3:41:59 PM	0:00:07	-30.8	3:45:00 PM	2- 41	4.15
LT	N-M	82	2	14	13	25	14	18	25	853.83	858.83	5.00	72.2	51.98	3:42:31 PM	3:42:36 PM	0:00:05	13.2	3:45:00 PM	2- 41	37.57
HT	N-M	82	2	15	6	23	15	14	3	906.77	914.10	7.33	72.2	35.44	3:43:24 PM	3:43:31 PM	0:00:07	-16.5	3:45:00 PM	2- 41	52.51
Car	N-M	82	2	15	23	16	15	26	21	923.53	926.70	3.17	72.2	82.08	3:43:41 PM	3:43:44 PM	0:00:03	46.6	3:45:00 PM	2- 41	16.00
2 W	N-M	82	2	15	51	29	15	55	4	951.97	955.13	3.17	72.2	82.08	3:44:09 PM	3:44:12 PM	0:00:03	0.0	3:45:00 PM	2- 41	28.25
Car	N-M	82	2	17	30	17	17	33	26	1050.57	1053.87	3.30	72.2	78.76	3:45:48 PM	3:45:51 PM	0:00:03	20.6	3:45:00 PM	2- 41	19.38
HT	N-M	82	2	18	44	9	18	49	24	1124.30	1129.80	5.50	72.2	47.26	3:47:01 PM	3:47:07 PM	0:00:05	-31.5	3:45:00 PM	2- 41	73.54
LCV /4 W	N-M	82	2	18	54	14	18	58	28	1134.47	1138.93	4.47	72.2	58.19	3:47:11 PM	3:47:16 PM	0:00:04	10.9	3:45:00 PM	2- 41	9.60
2 W	N-M	82	2	18	54	23	19	2	8	1134.77	1142.27	7.50	72.2	34.66	3:47:12 PM	3:47:19 PM	0:00:08	-23.5	3:45:00 PM	2- 41	0.04
2 W	N-M	82	2	18	56	23	19	2	23	1136.77	1142.77	6.00	72.2	43.32	3:47:14 PM	3:47:20 PM	0:00:06	8.7	3:45:00 PM	2- 41	1.81
Car	N-M	82	2	19	19	0	19	22	3	1159.00	1162.10	3.10	72.2	83.85	3:47:36 PM	3:47:39 PM	0:00:03	40.5	3:45:00 PM	2- 41	22.08
MAT	N-M	82	2	19	39	18	19	46	11	1179.60	1186.37	6.77	72.2	38.41	3:47:57 PM	3:48:03 PM	0:00:07	-45.4	3:45:00 PM	2- 41	20.42
2 W	N-M	82	2	19	57	1	20	0	21	1197.03	1200.70	3.67	72.2	70.89	3:48:14 PM	3:48:18 PM	0:00:04	32.5	3:45:00 PM	2- 41	16.30
HT	M-N	31	1	19	23	15	19	29	16	1163.50	1169.53	6.0	72.2	43.08	7:09:33 AM	7:09:39 AM	0:00:06	-5.7	7:15:00 AM	1- 7	3.0231
MAT	M-N	31	1	20	15	20	20	23	15	1215.67	1223.50	7.8	72.2	33.18	7:10:25 AM	7:10:32 AM	0:00:08	-9.9	7:15:00 AM	1- 7	51.54
Car	M-N	31	1	20	46	1	20	49	12	1246.03	1249.40	3.4	72.2	77.20	7:10:55 AM	7:10:58 AM	0:00:03	44.0	7:15:00 AM	1- 7	29.054
3W	M-N	31	1	21	23	29	21	31	0	1283.97	1291.00	7.0	72.2	36.96	7:11:33 AM	7:11:40 AM	0:00:07	-40.2	7:15:00 AM	1- 7	37.74
HT	M-N	31	1	21	52	23	21	57	26	1312.77	1317.87	5.1	72.2	50.96	7:12:02 AM	7:12:07 AM	0:00:05	14.0	7:15:00 AM	1- 7	28.54
LT	M-N	31	1	22	21	29	22	26	12	1341.97	1346.40	4.4	72.2	58.63	7:12:31 AM	7:12:35 AM	0:00:04	7.7	7:15:00 AM	1- 7	28.67

APPENDIX B: GAP AND SPEED DIFFERENTIAL DATA

Gap and Speed differentials (SD)						
M-N direction				N-M direction		
Gap Range	**Midpoint (Sec)**	**Average SD (Km/hr)**		**Gap Range**	**Midpoint (Sec)**	**Average SD (Km/hr)**
0-1	0.5	12.3		0-1	0.5	12.0
1-2	1.5	7.1		1-2	1.5	7.2
2-3	2.5	7.8		2-3	2.5	7.5
3-4	3.5	8.5		3-4	3.5	9.2
4-5	4.5	10.0		4-5	4.5	9.8
5-6	5.5	10.0		5-6	5.5	10.7
6-7	6.5	11.3		6-7	6.5	12.5
7-8	7.5	12.3		7-8	7.5	13.4
8-9	8.5	11.6		8-9	8.5	13.7
9-10	9.5	13.3		9-10	9.5	13.7
10-11	10.5	13.0		10-11	10.5	12.7
11-12	11.5	12.0		11-12	11.5	13.2
12-13	12.5	13.3		12-13	12.5	14.6
13-14	13.5	12.7		13-14	13.5	13.0
14-15	14.5	11.9		14-15	14.5	14.1
15-16	15.5	13.6		15-16	15.5	14.1
16-17	16.5	12.8		16-17	16.5	14.4
17-18	17.5	12.0		17-18	17.5	12.9
18-19	18.5	12.8		18-19	18.5	12.5
19-20	19.5	12.9		19-20	19.5	13.6
>20	-	14.2		>20	-	14.3

APPENDIX C: AVERAGE SPEED OF PLATOONS BY LEADERS' TYPES

AVERAGE SPEED OF PLATOONS BY LEADERS' TYPES		
MUGLIN TO NARAYANGHAT		
Platoon leaders	Number of vehicles in platoon	Average Speed of platoon (Km/hr)
2 W	420	53.06
3W	42	40.06
Car	175	55.83
LT	150	50.51
HT	832	44.93
MAT	202	40.49
LCV /4 W	260	53.52
Microbus	128	62.02
Mini bus	149	54.33
Big Bus	149	53.82
Grand Total	2507	49.80
NARAYANGHAT TO MUGLIN		
Platoon leaders	Number of vehicles in platoon	Average Speed of platoon (Km/hr)
2 W	503	53.04
3W	37	44.89
Car	190	56.84
LT	149	43.80
HT	798	41.57
Microbus	93	59.08
MAT	161	38.27
Big Bus	121	57.11
Mini bus	138	53.87
LCV /4 W	222	51.07
Grand Total	2412	48.17

APPENDIX D: CALCULATION OF SPACE MEAN SPEED AND DYNAMIC PCU AT 15 MIN INTERVAL

APPENDIX D: CALCULATION OF SPACE MEAN SPEED AND DYNAMIC PCU AT 15 MIN INTERVAL (N-M DIRECTION)

Time interval	Space mean speed (KM/hr)										Dynamic PCU Calculation									
	2 W	3W	Big Bus	Car	HT	LCV	LT	MAT	Microbus	Mini bus	2 W	3W	Big Bus	Car	HT	LCV	LT	MAT	Microbus	Mini bus
1- 1	54.66	0.00	53.41	68.40	44.87	58.63	36.61	0.00	63.91	0.00	0.22	0.00	4.67	1.00	3.99	1.24	3.56	0.00	1.61	0.00
1- 10	48.19	38.54	0.00	57.29	40.76	57.48	52.16	36.27	54.72	53.92	0.21	0.80	0.00	1.00	3.68	1.06	2.09	6.93	1.58	2.30
1- 11	46.55	33.32	47.40	51.68	40.83	52.21	0.00	37.03	64.44	52.37	0.20	0.83	3.98	1.00	3.32	1.05	0.00	6.12	1.21	2.14
1- 12	48.20	38.41	45.11	48.78	38.92	50.47	0.00	35.36	70.57	56.34	0.18	0.68	3.94	1.00	3.28	1.03	0.00	6.05	1.04	1.88
1- 13	51.47	32.83	58.19	54.40	46.07	56.03	0.00	36.87	55.40	51.90	0.19	0.89	3.41	1.00	3.09	1.03	0.00	6.47	1.48	2.27
1- 14	49.67	40.19	51.36	57.76	38.58	49.72	50.63	37.58	62.88	44.09	0.21	0.77	4.10	1.00	3.92	1.23	2.17	6.74	1.38	2.84
1- 15	52.15	0.00	50.28	54.24	41.04	50.12	42.61	33.61	53.78	55.80	0.18	0.00	3.93	1.00	3.46	1.15	2.42	7.08	1.52	2.11
1- 16	56.98	36.52	60.45	53.78	37.85	45.46	42.07	32.67	56.40	43.08	0.17	0.79	3.24	1.00	3.72	1.26	2.43	7.22	1.44	2.70
1- 17	56.80	37.31	0.00	56.10	38.22	0.00	49.98	35.44	50.31	48.21	0.18	0.80	0.00	1.00	3.84	0.00	2.14	6.94	1.68	2.52
1- 18	47.87	46.83	57.48	56.98	39.77	51.05	47.84	36.78	75.70	48.63	0.21	0.65	3.62	1.00	3.75	1.18	2.27	6.80	1.13	2.54
1- 19	49.80	37.55	0.00	67.30	45.33	57.23	46.14	31.83	63.40	54.24	0.24	0.96	0.00	1.00	3.89	1.25	2.78	9.28	1.60	2.69
1- 2	45.94	0.00	55.50	64.98	42.23	58.52	0.00	36.96	61.08	0.00	0.25	0.00	4.27	1.00	4.03	1.18	0.00	7.71	1.60	0.00
1- 20	49.25	0.00	61.40	57.02	41.15	45.47	31.83	35.88	59.89	63.91	0.21	0.00	3.39	1.00	3.63	1.33	3.41	6.97	1.43	1.93
1- 21	51.96	38.22	62.38	56.59	41.81	46.76	36.93	0.00	57.34	52.33	0.19	0.79	3.31	1.00	3.54	1.28	2.92	0.00	1.49	2.34
1- 22	53.15	34.66	57.55	63.91	37.55	56.50	41.35	30.46	0.00	44.81	0.21	0.99	4.05	1.00	4.46	1.20	2.94	9.21	0.00	3.09
1- 23	51.25	49.67	54.53	51.27	38.67	46.76	41.37	33.61	62.05	52.33	0.18	0.55	3.43	1.00	3.47	1.16	2.36	6.69	1.24	2.12
1- 24	57.55	47.35	56.50	57.13	42.67	46.14	41.26	0.00	62.38	45.73	0.18	0.65	3.69	1.00	3.51	1.31	2.64	0.00	1.38	2.71
1- 25	54.15	49.67	49.14	53.27	38.00	54.53	36.78	32.90	57.42	40.40	0.17	0.57	3.95	1.00	3.67	1.04	2.76	7.10	1.40	2.86
1- 26	54.96	0.00	56.30	53.13	47.04	49.56	44.88	0.00	56.81	62.88	0.17	0.00	3.44	1.00	2.96	1.14	2.25	0.00	1.41	1.83
1- 27	51.92	0.00	57.34	56.45	42.45	44.20	52.33	39.18	63.50	46.92	0.19	0.00	3.59	1.00	3.48	1.35	2.05	6.32	1.34	2.61
1- 28	56.23	36.61	57.06	53.53	40.11	51.98	38.04	33.25	57.20	39.99	0.17	0.78	3.42	1.00	3.50	1.09	2.68	7.06	1.41	2.90
1- 29	53.55	0.00	54.20	55.72	39.48	52.69	45.73	25.15	67.81	61.40	0.19	0.00	3.75	1.00	3.70	1.12	2.32	9.72	1.24	1.97
1- 3	54.45	0.00	55.66	61.89	39.62	45.13	52.10	33.18	62.63	64.98	0.20	0.00	4.05	1.00	4.09	1.45	2.26	8.18	1.49	2.06
1- 30	51.06	40.19	59.37	51.79	41.29	40.47	39.02	0.00	62.78	58.85	0.18	0.69	3.18	1.00	3.28	1.36	2.53	0.00	1.24	1.91
1- 31	55.65	31.44	50.20	58.58	37.31	47.99	40.83	0.00	47.62	48.96	0.19	1.00	4.26	1.00	4.11	1.30	2.73	0.00	1.85	2.59
1- 32	52.75	55.70	57.55	63.11	42.84	49.04	42.57	0.00	56.10	58.19	0.21	0.61	4.00	1.00	3.86	1.37	2.82	0.00	1.69	2.35
1- 33	47.64	0.00	57.13	60.38	40.90	53.23	40.51	0.00	61.64	60.92	0.23	0.00	3.85	1.00	3.87	1.20	2.84	0.00	1.48	2.15
1- 34	52.28	0.00	67.22	60.45	38.77	48.28	34.55	38.22	63.71	46.14	0.21	0.00	3.28	1.00	4.08	1.33	3.33	6.94	1.43	2.84
1- 35	52.33	0.00	54.28	56.19	39.90	51.81	38.25	30.16	51.64	46.92	0.19	0.00	3.78	1.00	3.69	1.15	2.80	8.17	1.64	2.59
1- 36	50.42	0.00	0.00	58.72	38.76	41.92	50.63	0.00	60.92	62.88	0.21	0.00	0.00	1.00	3.97	1.49	2.21	0.00	1.45	2.02
1- 37	53.86	34.35	0.00	57.15	41.08	45.47	47.94	0.00	51.47	57.34	0.19	0.89	0.00	1.00	3.64	1.33	2.27	0.00	1.67	2.16
1- 38	53.50	37.07	57.34	56.14	39.60	46.32	39.82	33.18	60.45	51.73	0.19	0.81	3.57	1.00	3.71	1.29	2.68	7.42	1.40	2.35
1- 39	49.71	0.00	53.78	56.73	42.74	52.42	42.96	0.00	66.93	53.23	0.20	0.00	3.85	1.00	3.48	1.15	2.51	0.00	1.28	2.31
1- 4	50.39	37.67	0.00	65.09	39.58	48.96	37.40	0.00	63.00	62.88	0.23	0.92	0.00	1.00	4.31	1.41	3.31	0.00	1.56	2.24
1- 40	48.89	42.38	47.19	54.12	37.56	38.44	42.80	38.04	60.60	58.63	0.20	0.68	4.18	1.00	3.77	1.49	2.41	6.24	1.35	2.00
1- 41	51.41	0.00	48.74	55.90	42.15	51.87	44.49	0.00	72.20	53.59	0.19	0.00	4.18	1.00	3.47	1.14	2.39	0.00	1.17	2.26
1- 42	51.93	31.57	44.05	58.35	43.54	52.87	46.62	0.00	56.10	60.68	0.20	0.99	4.83	1.00	3.51	1.17	2.38	0.00	1.57	2.08
1- 43	54.76	34.81	46.41	52.85	39.40	48.63	55.30	0.00	59.98	61.24	0.17	0.81	4.15	1.00	3.51	1.15	1.82	0.00	1.33	1.87
1- 44	51.19	43.20	58.96	55.66	44.05	54.96	43.00	0.00	52.22	0.00	0.19	0.69	3.44	1.00	3.31	1.07	2.46	0.00	1.61	0.00
1- 45	58.00	43.32	0.00	63.52	40.40	45.98	46.14	34.97	58.28	57.76	0.19	0.78	0.00	1.00	4.12	1.47	2.62	7.97	1.64	2.38
1- 46	49.82	0.00	47.99	55.40	42.23	59.37	48.43	38.04	59.75	49.14	0.20	0.00	4.21	1.00	3.44	0.99	2.18	6.39	1.40	2.44
1- 47	49.98	0.00	0.00	61.52	39.86	57.39	49.35	0.00	65.25	69.62	0.22	0.00	0.00	1.00	4.04	1.14	2.37	0.00	1.42	1.91
1- 48	51.48	0.00	31.57	52.42	43.75	51.47	38.60	0.00	68.10	45.87	0.18	0.00	6.06	1.00	3.14	1.08	2.58	0.00	1.16	2.48
1- 49	52.59	44.56	0.00	58.13	40.59	48.96	0.00	0.00	63.91	64.18	0.20	0.70	0.00	1.00	3.75	1.26	0.00	0.00	1.37	1.96

APPENDIX D: CALCULATION OF SPACE MEAN SPEED AND DYNAMIC PCU AT 15 MIN INTERVAL (N-M DIRECTION)

Time interval	Space mean speed (KM/hr)										Dynamic PCU Calculation									
	2 W	3W	Big Bus	Car	HT	LCV	LT	MAT	Microbus	Mini bus	2 W	3W	Big Bus	Car	HT	LCV	LT	MAT	Microbus	Mini bus
1- 5	52.78	41.04	53.63	58.19	40.93	45.87	0.00	35.20	61.40	56.92	0.20	0.76	3.96	1.00	3.72	1.35	0.00	7.25	1.43	2.21
1- 50	55.17	49.04	58.19	55.07	41.96	48.77	45.33	36.78	59.43	57.34	0.18	0.60	3.45	1.00	3.44	1.20	2.31	6.57	1.40	2.08
1- 51	58.12	38.04	57.76	53.34	42.61	46.18	45.92	0.00	0.00	43.32	0.16	0.75	3.37	1.00	3.28	1.23	2.21	0.00	0.00	2.67
1- 52	60.54	35.44	0.00	57.41	40.76	49.82	38.04	47.26	46.60	54.15	0.17	0.87	0.00	1.00	3.69	1.22	2.87	5.33	1.86	2.30
1- 6	54.02	38.13	65.53	55.62	44.34	59.75	38.60	0.00	56.78	59.07	0.18	0.78	3.10	1.00	3.28	0.99	2.74	0.00	1.48	2.04
1- 7	48.98	41.70	52.87	55.70	37.59	55.36	45.33	0.00	67.08	53.04	0.20	0.71	3.84	1.00	3.88	1.07	2.34	0.00	1.25	2.27
1- 8	49.44	44.56	51.08	49.04	37.28	59.64	35.05	39.74	63.14	53.78	0.18	0.59	3.50	1.00	3.45	0.87	2.66	5.41	1.17	1.98
1- 9	50.63	42.84	64.62	48.77	42.75	51.24	45.53	43.81	60.17	55.22	0.17	0.61	2.75	1.00	2.99	1.01	2.04	4.88	1.22	1.91
2- 30	52.42	50.63	57.44	57.34	50.85	39.99	49.67	45.33	47.12	46.83	0.19	0.61	3.64	1.00	2.95	1.52	2.20	5.55	1.83	2.65
2- 31	54.72	0.00	54.53	58.03	40.27	55.17	53.90	36.96	66.27	64.44	0.19	0.00	3.88	1.00	3.77	1.12	2.05	6.89	1.32	1.95
2- 32	49.90	0.00	60.21	57.16	39.18	55.11	47.55	36.02	62.26	49.54	0.20	0.00	3.46	1.00	3.82	1.10	2.29	6.96	1.38	2.50
2- 33	56.22	0.00	59.18	52.04	38.38	43.26	56.92	35.93	63.29	48.86	0.16	0.00	3.21	1.00	3.55	1.28	1.74	6.35	1.24	2.31
2- 34	55.91	0.00	46.97	54.53	36.71	56.02	45.47	33.95	51.30	62.88	0.17	0.00	4.23	1.00	3.89	1.03	2.28	7.05	1.60	1.88
2- 35	61.04	0.00	0.00	53.19	41.63	55.01	47.91	34.86	61.11	56.50	0.15	0.00	0.00	1.00	3.35	1.03	2.11	6.69	1.31	2.04
2- 36	52.39	0.00	0.00	55.81	40.72	49.81	44.05	36.27	68.40	55.01	0.19	0.00	0.00	1.00	3.59	1.19	2.41	6.75	1.23	2.20
2- 37	52.33	49.67	0.00	64.31	40.32	61.06	56.10	0.00	61.72	59.30	0.22	0.69	0.00	1.00	4.18	1.12	2.18	0.00	1.57	2.35
2- 38	52.67	32.22	56.20	58.89	36.27	44.85	48.96	36.52	67.41	44.97	0.20	0.98	3.82	1.00	4.25	1.39	2.29	7.07	1.32	2.84
2- 39	57.99	0.00	56.92	55.45	40.54	54.15	48.94	0.00	59.22	45.94	0.17	0.00	3.55	1.00	3.58	1.09	2.16	0.00	1.41	2.62
2- 40	53.09	0.00	0.00	61.02	41.38	55.04	46.97	0.00	49.04	45.51	0.20	0.00	0.00	1.00	3.86	1.18	2.47	0.00	1.87	2.90
2- 41	54.18	39.92	0.00	59.94	41.02	45.56	42.32	37.22	0.00	43.89	0.20	0.80	0.00	1.00	3.83	1.40	2.70	7.06	0.00	2.96
2- 42	54.97	38.22	56.71	58.91	42.00	45.56	42.32	0.00	55.50	36.44	0.19	0.82	3.79	1.00	3.67	1.37	2.65	0.00	1.60	3.50
2- 43	47.94	41.92	49.04	54.91	40.32	51.44	43.56	33.83	56.02	58.37	0.20	0.70	4.08	1.00	3.57	1.13	2.40	7.12	1.48	2.04
2- 44	53.60	0.00	61.40	59.62	42.02	59.78	41.04	36.44	55.70	44.81	0.20	0.00	3.54	1.00	3.72	1.06	2.77	7.18	1.61	2.88
2- 45	51.69	39.78	45.87	59.98	41.26	52.84	38.67	31.70	39.18	47.55	0.21	0.81	4.77	1.00	3.81	1.20	2.95	8.30	2.31	2.73
2- 46	50.91	32.49	60.68	71.54	38.95	41.95	48.73	34.66	50.15	51.98	0.25	1.18	4.30	1.00	4.81	1.81	2.79	9.06	2.15	2.98
2- 47	51.86	0.00	0.00	55.99	41.10	53.59	46.88	32.76	68.40	59.52	0.19	0.00	0.00	1.00	3.57	1.11	2.27	7.50	1.23	2.04
2- 48	52.43	35.05	0.00	55.59	41.82	53.87	45.33	38.60	53.19	43.32	0.19	0.85	0.00	1.00	3.48	1.09	2.33	6.32	1.57	2.78
2- 49	57.26	35.39	49.67	59.98	40.84	50.63	43.68	35.12	48.73	46.55	0.19	0.91	4.40	1.00	3.85	1.26	2.61	7.49	1.85	2.79
2- 50	55.82	40.09	63.40	50.78	39.11	43.81	45.47	37.96	55.56	34.97	0.16	0.68	2.92	1.00	3.40	1.23	2.13	5.87	1.38	3.15
2- 51	50.18	38.41	61.16	52.58	39.37	47.62	0.00	49.35	60.21	48.43	0.19	0.73	3.14	1.00	3.50	1.17	0.00	4.67	1.32	2.35
2- 52	56.79	41.81	51.64	58.01	39.51	43.93	0.00	33.47	48.89	0.00	0.18	0.74	4.10	1.00	3.85	1.40	0.00	7.60	1.79	0.00
2- 53	64.27	36.78	0.00	77.20	48.13	0.00	0.00	39.04	0.00	60.45	0.21	1.12	0.00	1.00	4.20	0.00	0.00	8.68	0.00	2.77
3- 10	51.79	0.00	55.86	63.98	42.86	46.28	49.25	0.00	60.17	61.01	0.22	0.00	4.18	1.00	3.91	1.47	2.47	0.00	1.60	2.27
3- 11	50.29	0.00	57.34	63.17	45.79	57.44	44.30	39.09	69.01	55.18	0.22	0.00	4.02	1.00	3.61	1.17	2.71	7.09	1.38	2.48
3- 12	45.96	38.04	33.47	77.98	40.10	63.03	0.00	34.20	66.42	63.91	0.30	1.10	8.50	1.00	5.09	1.31	0.00	10.00	1.77	2.64
3- 13	58.46	41.48	50.09	62.80	44.69	44.18	47.55	39.25	54.34	51.47	0.19	0.81	4.57	1.00	3.68	1.51	2.51	7.02	1.74	2.64
3- 14	56.45	0.00	56.81	0.00	43.78	44.94	53.41	0.00	63.40	48.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3- 15	56.10	0.00	46.69	57.13	41.65	50.09	43.97	41.26	59.07	46.97	0.18	0.00	4.46	1.00	3.59	1.21	2.47	6.07	1.46	2.63
3- 16	53.09	0.00	77.20	55.30	36.36	55.90	56.92	33.32	64.71	55.80	0.19	0.00	2.61	1.00	3.98	1.05	1.85	7.28	1.29	2.15
3- 17	49.28	50.96	70.25	47.84	39.82	51.85	45.47	35.81	55.40	53.11	0.17	0.50	2.48	1.00	3.15	0.98	2.00	5.86	1.30	1.95
3- 18	52.75	42.15	0.00	66.76	38.70	50.82	41.48	0.00	67.51	56.74	0.23	0.85	0.00	1.00	4.52	1.39	3.06	0.00	1.49	2.55
3- 19	49.62	32.90	58.19	63.60	42.31	53.96	49.04	0.00	72.20	70.25	0.23	1.03	3.99	1.00	3.94	1.25	2.47	0.00	1.33	1.96
3- 2	61.11	0.00	70.89	57.17	41.85	60.74	46.88	36.67	59.52	53.41	0.17	0.00	2.94	1.00	3.58	1.00	2.32	6.84	1.45	2.32
3- 20	50.82	0.00	0.00	55.36	45.05	54.91	49.67	0.00	66.65	59.41	0.19	0.00	0.00	1.00	3.22	1.07	2.12	0.00	1.25	2.02

APPENDIX D: CALCULATION OF SPACE MEAN SPEED AND DYNAMIC PCU AT 15 MIN INTERVAL (N-M DIRECTION)

Time interval	Space mean speed (KM/hr)										Dynamic PCU Calculation									
	2 W	**3W**	**Big Bus**	**Car**	**HT**	**LCV**	**LT**	**MAT**	**Microbus**	**Mini bus**	**2 W**	**3W**	**Big Bus**	**Car**	**HT**	**LCV**	**LT**	**MAT**	**Microbus**	**Mini bus**
3- 21	49.90	48.13	57.62	54.34	45.37	52.10	51.13	0.00	51.98	54.15	0.19	0.60	3.44	1.00	3.14	1.11	2.02	0.00	1.57	2.17
3- 22	52.42	0.00	60.76	57.08	38.57	48.60	38.04	0.00	49.04	60.92	0.19	0.00	3.43	1.00	3.88	1.25	2.86	0.00	1.75	2.03
3- 23	49.78	0.00	54.91	54.15	42.15	58.02	62.38	30.58	61.04	54.53	0.19	0.00	3.60	1.00	3.36	0.99	1.65	7.77	1.34	2.15
3- 25	0.00	0.00	0.00	67.81	0.00	0.00	0.00	41.70	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	7.13	0.00	0.00
3- 26	52.43	43.08	68.70	61.08	42.82	53.90	49.98	0.00	50.15	59.75	0.21	0.76	3.24	1.00	3.74	1.20	2.33	0.00	1.83	2.21
3- 27	52.92	39.99	62.38	48.27	40.91	51.80	53.59	0.00	53.41	47.26	0.16	0.65	2.82	1.00	3.09	0.99	1.71	0.00	1.36	2.21
3- 28	48.93	66.65	0.00	59.04	42.55	49.32	41.37	37.94	59.07	65.53	0.21	0.47	0.00	1.00	3.63	1.27	2.72	6.83	1.51	1.95
3- 29	56.07	0.00	58.02	53.57	43.39	39.43	54.15	0.00	49.35	39.66	0.17	0.00	3.37	1.00	3.23	1.44	1.88	0.00	1.63	2.93
3- 3	58.78	0.00	64.71	52.22	41.62	57.62	49.98	43.97	60.82	74.26	0.16	0.00	2.94	1.00	3.29	0.96	1.99	5.21	1.29	1.52
3- 30	52.38	39.94	60.92	55.76	36.02	51.16	47.12	32.49	60.68	47.55	0.19	0.75	3.34	1.00	4.05	1.16	2.25	7.53	1.38	2.54
3- 31	55.13	0.00	65.53	58.88	43.51	53.78	51.53	31.57	55.30	54.15	0.19	0.00	3.28	1.00	3.54	1.16	2.18	8.18	1.60	2.36
3- 32	50.70	0.00	57.62	49.90	38.79	55.60	49.04	32.36	61.40	52.45	0.18	0.00	3.16	1.00	3.37	0.95	1.94	6.77	1.22	2.06
3- 33	48.81	42.61	52.51	56.64	35.66	57.38	41.04	39.78	64.71	58.41	0.21	0.71	3.93	1.00	4.16	1.05	2.63	6.25	1.32	2.10
3- 34	49.60	44.05	51.47	52.98	38.64	50.76	40.75	0.00	45.80	47.72	0.19	0.64	3.75	1.00	3.59	1.11	2.47	0.00	1.74	2.41
3- 35	55.88	0.00	56.00	59.71	42.80	47.67	40.54	0.00	57.34	35.28	0.19	0.00	3.89	1.00	3.65	1.33	2.80	0.00	1.57	3.67
3- 36	50.94	26.43	0.00	54.62	48.74	53.84	45.07	0.00	74.03	54.00	0.19	1.11	0.00	1.00	2.94	1.08	2.31	0.00	1.11	2.19
3- 37	58.13	0.00	56.92	52.78	38.11	56.92	34.35	29.20	52.12	41.04	0.16	0.00	3.38	1.00	3.63	0.98	2.92	7.93	1.52	2.79
3- 38	53.60	0.00	56.50	60.33	39.77	53.78	40.26	0.00	64.44	38.22	0.20	0.00	3.89	1.00	3.97	1.19	2.85	0.00	1.41	3.42
3- 39	50.18	41.04	62.05	62.15	40.01	53.67	0.00	0.00	60.45	60.76	0.22	0.81	3.65	1.00	4.07	1.23	0.00	0.00	1.55	2.22
3- 4	52.87	40.40	0.00	59.16	39.89	49.54	0.00	0.00	66.79	0.00	0.20	0.78	0.00	1.00	3.88	1.27	0.00	0.00	1.33	0.00
3- 42	56.00	0.00	0.00	49.04	39.45	59.98	43.93	54.53	69.01	32.27	0.16	0.00	0.00	1.00	3.26	0.87	2.12	3.95	1.07	3.29
3- 43	42.35	0.00	57.87	56.03	41.77	54.84	48.23	0.00	70.25	48.13	0.24	0.00	3.53	1.00	3.51	1.08	2.21	0.00	1.20	2.52
3- 44	52.02	0.00	45.87	58.76	38.65	45.23	37.37	37.43	45.60	53.96	0.20	0.00	4.67	1.00	3.98	1.38	2.99	6.89	1.94	2.36
3- 45	52.38	31.70	0.00	54.91	40.24	45.60	48.73	0.00	59.37	47.04	0.19	0.93	0.00	1.00	3.57	1.28	2.14	0.00	1.39	2.53
3- 46	50.27	43.08	0.00	54.32	39.07	54.23	0.00	36.27	45.60	38.10	0.19	0.67	0.00	1.00	3.64	1.06	0.00	6.57	1.79	3.09
3- 47	46.78	33.25	36.96	59.71	41.29	52.08	45.69	34.81	69.01	72.87	0.23	0.96	5.89	1.00	3.79	1.22	2.49	7.52	1.30	1.77
3- 48	50.60	44.47	66.08	51.00	41.70	57.41	56.71	30.82	60.92	42.15	0.18	0.61	2.81	1.00	3.20	0.94	1.71	7.26	1.26	2.62
3- 49	50.85	38.79	71.54	57.76	41.38	58.10	43.64	0.00	63.91	67.22	0.20	0.80	2.94	1.00	3.66	1.05	2.52	0.00	1.36	1.86
3- 5	45.73	0.00	65.25	59.61	45.52	58.34	54.91	51.64	62.24	61.40	0.23	0.00	3.33	1.00	3.43	1.08	2.07	5.06	1.44	2.10
3- 50	51.10	36.44	0.00	62.03	41.76	48.85	50.15	0.00	61.40	34.05	0.22	0.91	0.00	1.00	3.89	1.35	2.35	0.00	1.52	3.95
3- 51	55.22	40.61	0.00	53.78	40.03	57.06	50.15	0.00	31.57	38.22	0.17	0.71	0.00	1.00	3.52	1.00	2.04	0.00	2.57	3.05
3- 52	50.43	40.06	48.13	61.04	41.36	50.04	55.30	0.00	62.38	0.00	0.22	0.82	4.62	1.00	3.87	1.29	2.10	0.00	1.47	0.00
3- 53	49.89	0.00	53.04	56.18	43.72	50.71	48.13	35.77	58.63	0.00	0.20	0.00	3.86	1.00	3.36	1.18	2.22	6.89	1.44	0.00
3- 6	55.83	0.00	67.81	47.99	43.51	54.23	53.04	40.26	60.92	64.44	0.15	0.00	2.58	1.00	2.89	0.94	1.72	5.23	1.19	1.61
3- 7	52.65	39.51	59.90	59.89	40.98	46.87	52.92	42.15	56.37	52.51	0.20	0.81	3.65	1.00	3.83	1.36	2.15	6.23	1.60	2.47
3- 8	50.31	0.00	0.00	56.42	40.28	60.10	37.67	0.00	64.09	57.97	0.20	0.00	0.00	1.00	3.67	1.00	2.85	0.00	1.33	2.11
3- 9	51.26	35.88	59.98	49.35	43.01	50.80	40.72	39.23	53.70	44.45	0.17	0.74	3.00	1.00	3.00	1.03	2.31	5.52	1.38	2.41

APPENDIX D: CALCULATION OF SPACE MEAN SPEED AND DYNAMIC PCU AT 15 MIN INTERVAL (M-N DIRECTION)

Time	Space mean speed (KM/hr)										Dynamic PCU Calculation									
intervl	2 W	3W	Big Bus	Car	HT	LCV	LT	MAT	Microbus	Mini bus	2 W	3W	Big Bus	Car	HT	LCV	LT	MAT	Microbus	Mini bus
1- 1	0.00	44.05	0.00	0.00	44.94	46.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1- 10	60.45	43.44	0.00	59.87	44.66	48.43	48.36	40.06	0.00	58.63	0.18	0.74	0.00	1.00	3.51	1.31	2.36	6.56	0.00	2.21
1- 11	59.86	39.43	0.00	53.96	44.45	42.38	50.96	44.56	0.00	47.64	0.16	0.73	0.00	1.00	3.18	1.35	2.02	5.31	0.00	2.45
1- 12	52.25	0.00	0.00	48.25	42.95	47.52	52.89	39.46	0.00	60.76	0.16	0.00	0.00	1.00	2.94	1.08	1.74	5.36	0.00	1.72
1- 13	54.89	42.84	52.69	57.62	45.31	52.26	53.96	0.00	54.53	47.12	0.19	0.72	3.99	1.00	3.33	1.17	2.03	0.00	1.59	2.65
1- 14	54.83	0.00	0.00	53.85	42.98	61.72	0.00	0.00	66.84	43.44	0.17	0.00	0.00	1.00	3.28	0.93	0.00	0.00	1.21	2.69
1- 15	55.47	37.85	0.00	58.44	43.56	52.69	43.02	0.00	62.38	44.71	0.19	0.83	0.00	1.00	3.51	1.18	2.59	0.00	1.41	2.83
1- 16	54.53	0.00	61.40	55.11	42.96	41.31	46.41	34.86	48.89	61.64	0.18	0.00	3.27	1.00	3.36	1.42	2.26	6.93	1.70	1.94
1- 17	54.62	34.81	0.00	56.76	42.78	47.10	36.44	47.26	46.14	54.06	0.18	0.87	0.00	1.00	3.47	1.28	2.97	5.27	1.85	2.27
1- 18	53.68	35.65	51.64	58.14	40.70	52.05	46.92	0.00	63.05	53.12	0.19	0.87	4.11	1.00	3.74	1.18	2.36	0.00	1.39	2.37
1- 19	50.96	40.83	49.35	59.56	44.42	54.83	53.93	45.07	61.28	41.48	0.21	0.78	4.40	1.00	3.51	1.15	2.10	5.80	1.46	3.11
1- 2	79.57	0.00	0.00	65.53	45.02	56.10	52.40	38.74	0.00	0.00	0.15	0.00	0.00	1.00	3.81	1.24	2.38	7.42	0.00	0.00
1- 20	53.15	42.69	0.00	56.71	43.15	53.41	45.69	43.56	52.43	46.41	0.19	0.71	0.00	1.00	3.44	1.13	2.36	5.71	1.63	2.65
1- 21	55.25	31.07	54.91	57.88	44.43	52.57	43.56	45.60	64.98	51.64	0.19	1.00	3.84	1.00	3.41	1.17	2.53	5.57	1.34	2.43
1- 22	55.81	0.00	68.40	58.85	45.39	51.13	46.88	50.80	61.52	52.33	0.19	0.00	3.14	1.00	3.40	1.22	2.39	5.08	1.44	2.44
1- 23	50.56	40.90	49.51	53.23	42.91	51.06	47.26	0.00	62.13	53.17	0.19	0.70	3.92	1.00	3.25	1.11	2.14	0.00	1.29	2.17
1- 24	53.31	42.38	61.16	67.81	43.59	57.76	55.30	35.77	64.71	62.38	0.23	0.86	4.04	1.00	4.07	1.25	2.33	8.32	1.58	2.35
1- 25	56.43	31.83	50.31	53.53	44.71	56.86	49.92	39.83	60.45	50.96	0.17	0.90	3.88	1.00	3.14	1.00	2.04	5.90	1.33	2.28
1- 26	55.39	42.84	51.37	52.25	45.02	58.08	60.45	40.40	63.83	58.74	0.17	0.65	3.71	1.00	3.04	0.95	1.65	5.67	1.23	1.93
1- 27	56.70	37.67	53.47	64.84	42.15	55.65	45.07	0.00	54.53	54.06	0.20	0.92	4.42	1.00	4.03	1.24	2.74	0.00	1.79	2.60
1- 28	51.92	42.84	51.30	52.85	44.88	53.23	43.56	30.46	60.68	61.64	0.18	0.66	3.76	1.00	3.08	1.05	2.31	7.61	1.31	1.86
1- 29	56.10	33.83	56.10	49.84	46.06	53.09	42.90	42.26	66.65	54.91	0.16	0.79	3.24	1.00	2.83	1.00	2.21	5.17	1.13	1.97
1- 3	64.66	35.12	60.45	74.98	44.62	37.67	52.57	37.37	0.00	0.00	0.21	1.14	4.52	1.00	4.40	2.11	2.71	8.80	0.00	0.00
1- 30	59.13	46.55	54.40	56.23	43.71	50.45	43.99	37.31	58.63	52.60	0.17	0.65	3.77	1.00	3.37	1.18	2.43	6.61	1.44	2.32
1- 31	52.94	0.00	54.53	61.80	48.46	49.74	47.55	34.09	65.94	54.47	0.21	0.00	4.13	1.00	3.34	1.32	2.47	7.95	1.41	2.46
1- 32	52.89	32.56	55.80	53.36	43.44	41.48	51.47	30.82	69.93	53.25	0.18	0.88	3.49	1.00	3.22	1.36	1.97	7.60	1.15	2.17
1- 33	54.11	34.66	54.34	60.19	43.28	55.54	61.40	0.00	56.13	0.00	0.20	0.93	4.04	1.00	3.64	1.15	1.87	0.00	1.61	0.00
1- 34	51.12	0.00	51.05	51.09	44.10	56.61	57.97	41.92	58.54	51.98	0.18	0.00	3.65	1.00	3.03	0.96	1.68	5.35	1.31	2.13
1- 35	51.18	0.00	50.96	54.15	42.71	54.15	49.67	0.00	58.72	46.48	0.19	0.00	3.87	1.00	3.32	1.06	2.08	0.00	1.39	2.52
1- 36	56.71	39.09	49.04	59.78	44.43	51.89	0.00	0.00	66.36	58.41	0.19	0.82	4.45	1.00	3.52	1.22	0.00	0.00	1.36	2.22
1- 37	44.65	0.00	47.16	65.68	44.35	55.76	47.84	0.00	62.33	53.68	0.26	0.00	5.08	1.00	3.88	1.25	2.61	0.00	1.59	2.65
1- 38	53.39	0.00	49.32	49.21	43.28	45.33	42.24	0.00	55.80	45.07	0.16	0.00	3.64	1.00	2.98	1.15	2.22	0.00	1.33	2.37
1- 39	54.15	0.00	52.69	59.98	46.46	50.85	46.07	0.00	58.38	61.08	0.20	0.00	4.15	1.00	3.38	1.25	2.48	0.00	1.55	2.13
1- 4	58.12	37.31	0.00	67.66	44.07	57.34	45.87	38.71	0.00	0.00	0.21	0.97	0.00	1.00	4.02	1.25	2.81	7.67	0.00	0.00
1- 40	52.65	0.00	53.41	52.28	49.26	47.26	49.43	0.00	59.68	47.94	0.18	0.00	3.57	1.00	2.78	1.17	2.01	0.00	1.32	2.36
1- 41	52.09	0.00	51.13	59.07	46.85	53.04	46.97	0.00	59.37	35.28	0.20	0.00	4.21	1.00	3.30	1.18	2.39	0.00	1.50	3.63
1- 42	48.01	41.48	41.92	57.73	48.27	51.60	49.49	0.00	53.59	48.08	0.21	0.74	5.02	1.00	3.13	1.19	2.22	0.00	1.62	2.60
1- 43	45.14	0.00	61.30	54.53	44.18	54.26	38.04	45.47	66.16	48.86	0.21	0.00	3.24	1.00	3.23	1.07	2.73	5.26	1.24	2.42
1- 44	54.51	0.00	0.00	56.32	45.98	54.68	54.53	46.55	51.98	40.93	0.18	0.00	0.00	1.00	3.21	1.09	1.97	5.31	1.63	2.98
1- 45	50.65	30.70	60.45	55.11	44.97	53.14	53.96	0.00	56.42	50.96	0.19	0.96	3.32	1.00	3.21	1.10	1.94	0.00	1.47	2.34
1- 46	48.14	38.04	51.55	69.01	41.02	56.60	44.30	43.08	79.57	52.87	0.25	0.97	4.88	1.00	4.41	1.29	2.96	7.03	1.31	2.83
1- 47	55.03	0.00	55.11	58.19	45.25	53.04	49.90	44.56	58.63	58.81	0.19	0.00	3.85	1.00	3.37	1.16	2.22	5.73	1.49	2.14
1- 48	55.42	40.83	54.91	48.55	40.23	50.28	56.92	29.42	66.36	48.13	0.16	0.64	3.22	1.00	3.16	1.02	1.62	7.24	1.10	2.19
1- 49	55.09	47.84	0.00	63.01	46.32	45.47	53.41	44.30	63.91	58.19	0.20	0.70	0.00	1.00	3.56	1.47	2.25	6.24	1.48	2.35

APPENDIX D: CALCULATION OF SPACE MEAN SPEED AND DYNAMIC PCU AT 15 MIN INTERVAL (M-N DIRECTION)

Time	Space mean speed (KM/hr)										Dynamic PCU Calculation									
intervl	2 W	3W	Big Bus	Car	HT	LCV	LT	MAT	Microbus	Mini bus	2 W	3W	Big Bus	Car	HT	LCV	LT	MAT	Microbus	Mini bus
1- 5	65.45	0.00	0.00	74.03	41.75	0.00	44.81	36.44	0.00	0.00	0.20	0.00	0.00	1.00	4.64	0.00	3.14	8.91	0.00	0.00
1- 50	53.94	37.13	59.68	56.03	44.21	49.49	46.69	30.82	47.26	52.69	0.18	0.81	3.42	1.00	3.32	1.20	2.28	7.98	1.79	2.30
1- 51	50.93	0.00	50.80	50.96	45.82	46.75	46.97	42.84	56.69	52.33	0.18	0.00	3.66	1.00	2.91	1.16	2.07	5.22	1.35	2.11
1- 52	54.15	42.38	49.67	66.93	42.73	44.30	42.84	47.26	59.07	0.00	0.22	0.84	4.91	1.00	4.10	1.60	2.97	6.21	1.71	0.00
1- 6	74.98	35.12	0.00	74.74	45.07	48.13	52.57	43.81	0.00	0.00	0.18	1.14	0.00	1.00	4.34	1.65	2.71	7.48	0.00	0.00
1- 7	63.29	36.96	0.00	63.91	45.20	50.52	58.63	33.18	0.00	0.00	0.18	0.93	0.00	1.00	3.70	1.34	2.08	8.45	0.00	0.00
1- 8	58.69	38.22	0.00	69.62	45.26	53.67	43.81	38.99	0.00	49.98	0.21	0.97	0.00	1.00	4.03	1.38	3.03	7.83	0.00	3.02
1- 9	58.63	37.13	0.00	73.05	40.42	40.47	51.57	41.33	0.00	47.55	0.22	1.05	0.00	1.00	4.73	1.91	2.70	7.75	0.00	3.33
2- 30	53.51	44.30	60.10	58.92	50.03	52.69	0.00	0.00	71.98	0.00	0.20	0.71	3.58	1.00	3.08	1.19	0.00	0.00	1.23	0.00
2- 31	47.91	0.00	60.45	52.83	45.68	49.90	51.30	48.43	59.71	52.69	0.20	0.00	3.19	1.00	3.03	1.12	1.96	4.79	1.33	2.17
2- 32	59.29	41.48	49.25	57.24	46.74	47.84	50.20	0.00	58.74	61.40	0.17	0.74	4.24	1.00	3.21	1.27	2.17	0.00	1.47	2.02
2- 33	55.54	47.55	72.42	66.16	47.34	51.64	62.13	47.99	66.65	53.59	0.21	0.74	3.33	1.00	3.66	1.36	2.03	6.05	1.50	2.67
2- 34	58.88	0.00	0.00	69.87	48.47	56.02	59.98	40.93	67.41	61.21	0.21	0.00	0.00	1.00	3.77	1.32	2.22	7.49	1.56	2.47
2- 35	55.11	0.00	0.00	55.30	48.92	55.30	56.71	32.76	67.41	51.30	0.18	0.00	0.00	1.00	2.96	1.06	1.86	7.40	1.24	2.34
2- 36	52.39	0.00	49.98	58.45	45.87	53.30	54.72	0.00	63.57	52.62	0.20	0.00	4.26	1.00	3.34	1.16	2.03	0.00	1.38	2.41
2- 37	53.18	37.13	46.28	59.98	48.49	59.16	0.00	43.32	75.95	50.37	0.20	0.86	4.73	1.00	3.24	1.08	0.00	6.07	1.19	2.58
2- 38	56.53	0.00	46.41	49.76	40.73	55.01	47.45	35.88	70.00	51.13	0.16	0.00	3.91	1.00	3.20	0.96	2.00	6.08	1.07	2.11
2- 39	52.75	0.00	51.64	57.13	45.73	53.53	48.89	40.61	63.22	53.59	0.19	0.00	4.03	1.00	3.27	1.13	2.22	6.17	1.36	2.31
2- 40	51.45	54.53	57.13	77.20	46.24	60.56	54.91	47.84	57.02	56.50	0.27	0.76	4.93	1.00	4.37	1.35	2.68	7.08	2.04	2.96
2- 41	58.06	0.00	50.96	54.91	43.94	49.82	46.62	46.69	64.98	51.47	0.17	0.00	3.93	1.00	3.27	1.17	2.24	5.16	1.27	2.31
2- 42	49.32	42.23	47.94	58.34	44.02	50.69	46.21	53.78	57.20	52.69	0.21	0.74	4.44	1.00	3.47	1.22	2.40	4.76	1.54	2.40
2- 43	51.88	39.78	56.78	49.04	41.80	53.65	48.20	41.55	53.12	52.25	0.17	0.66	3.15	1.00	3.07	0.97	1.94	5.18	1.39	2.03
2- 44	52.37	0.00	52.69	71.54	47.84	51.98	0.00	0.00	56.92	57.97	0.24	0.00	4.95	1.00	3.92	1.46	0.00	0.00	1.89	2.67
2- 45	52.35	25.73	51.81	53.96	45.78	59.69	45.94	0.00	58.54	58.63	0.18	1.12	3.80	1.00	3.09	0.96	2.24	0.00	1.39	1.99
2- 46	53.79	44.30	55.80	57.00	42.97	55.01	49.76	39.72	61.85	46.97	0.19	0.69	3.73	1.00	3.47	1.10	2.18	6.30	1.39	2.63
2- 47	49.51	0.00	45.60	60.79	43.49	57.87	46.69	36.69	58.92	61.64	0.22	0.00	4.86	1.00	3.66	1.11	2.48	7.27	1.55	2.14
2- 48	50.68	44.69	54.34	57.38	42.92	50.02	42.42	36.65	55.04	38.60	0.20	0.69	3.85	1.00	3.50	1.22	2.57	6.87	1.57	3.22
2- 49	52.08	49.20	47.16	48.18	43.65	61.05	44.69	43.56	62.51	47.26	0.16	0.52	3.73	1.00	2.89	0.84	2.05	4.85	1.16	2.21
2- 50	49.63	37.85	46.60	58.63	43.24	48.13	51.98	38.41	67.61	47.64	0.21	0.83	4.59	1.00	3.55	1.29	2.15	6.70	1.31	2.67
2- 51	49.89	39.68	58.19	62.08	44.46	50.04	45.94	49.98	60.60	58.19	0.22	0.84	3.89	1.00	3.66	1.32	2.57	5.45	1.54	2.31
2- 52	51.04	30.94	49.35	51.42	41.77	47.48	57.76	36.61	49.75	49.98	0.18	0.89	3.80	1.00	3.22	1.15	1.69	6.16	1.56	2.23
2- 53	55.12	0.00	0.00	66.08	40.40	35.61	0.00	33.90	0.00	0.00	0.21	0.00	0.00	1.00	4.28	1.97	0.00	8.55	0.00	0.00
3- 10	47.29	0.00	0.00	59.45	46.06	52.60	47.62	51.75	0.00	0.00	0.22	0.00	0.00	1.00	3.38	1.20	2.38	5.04	0.00	0.00
3- 11	57.86	0.00	0.00	57.28	44.87	45.87	49.59	42.04	0.00	45.16	0.18	0.00	0.00	1.00	3.34	1.32	2.20	5.98	0.00	2.75
3- 12	54.56	0.00	42.15	56.33	44.81	64.18	55.30	48.96	0.00	43.81	0.18	0.00	4.87	1.00	3.29	0.93	1.94	5.05	0.00	2.79
3- 13	59.57	36.04	0.00	51.30	41.09	54.30	48.53	58.19	70.25	44.73	0.15	0.76	0.00	1.00	3.27	1.00	2.01	3.87	1.10	2.48
3- 14	55.56	0.00	0.00	56.92	38.04	52.69	53.78	0.00	70.25	0.00	0.18	0.00	0.00	1.00	3.92	1.15	2.01	0.00	1.22	0.00
3- 15	56.24	0.00	0.00	58.41	47.35	45.76	48.79	0.00	53.78	60.92	0.18	0.00	0.00	1.00	3.23	1.35	2.28	0.00	1.64	2.08
3- 16	52.44	47.55	56.10	49.93	43.95	47.04	52.83	51.98	70.25	44.56	0.17	0.56	3.25	1.00	2.98	1.13	1.80	4.21	1.07	2.43
3- 17	50.48	0.00	52.51	52.69	43.92	49.60	50.52	42.96	73.56	59.07	0.19	0.00	3.66	1.00	3.14	1.13	1.98	5.38	1.08	1.93
3- 18	56.58	0.00	60.92	70.52	44.14	57.00	54.53	40.28	64.98	51.81	0.22	0.00	4.22	1.00	4.18	1.31	2.46	7.68	1.63	2.95
3- 19	55.56	43.56	0.00	70.89	47.08	54.47	0.00	0.00	69.62	54.53	0.23	0.87	0.00	1.00	3.94	1.38	0.00	0.00	1.53	2.82
3- 2	97.47	35.44	0.00	73.56	46.34	0.00	56.23	35.34	0.00	0.00	0.13	1.11	0.00	1.00	4.16	0.00	2.49	9.13	0.00	0.00
3- 20	53.09	37.85	0.00	56.15	45.10	60.68	44.94	46.00	59.16	50.96	0.19	0.79	0.00	1.00	3.26	0.98	2.38	5.35	1.43	2.39

APPENDIX D: CALCULATION OF SPACE MEAN SPEED AND DYNAMIC PCU AT 15 MIN INTERVAL (M-N DIRECTION)

Time	Space mean speed (KM/hr)										Dynamic PCU Calculation									
intervl	2 W	3W	Big Bus	Car	HT	LCV	LT	MAT	Microbus	Mini bus	2 W	3W	Big Bus	Car	HT	LCV	LT	MAT	Microbus	Mini bus
3- 21	53.75	0.00	56.30	58.78	43.89	50.58	46.55	51.98	59.39	50.18	0.19	0.00	3.81	1.00	3.51	1.23	2.40	4.96	1.49	2.54
3- 22	52.21	44.94	41.70	56.14	44.42	57.63	53.34	41.70	48.49	47.69	0.19	0.67	4.91	1.00	3.31	1.03	2.00	5.91	1.74	2.55
3- 23	59.11	0.00	48.28	53.59	43.81	55.64	46.69	0.00	51.81	53.41	0.16	0.00	4.05	1.00	3.20	1.02	2.18	0.00	1.56	2.17
3- 25	55.90	46.69	0.00	0.00	46.14	0.00	50.63	0.00	68.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3- 26	56.13	36.48	54.34	59.43	47.04	50.78	54.91	31.44	65.39	60.10	0.19	0.87	3.99	1.00	3.31	1.24	2.06	8.29	1.37	2.14
3- 27	56.43	36.44	50.42	59.41	44.05	57.97	44.69	0.00	64.18	46.41	0.19	0.87	4.30	1.00	3.53	1.09	2.53	0.00	1.39	2.77
3- 28	53.62	0.00	63.05	59.07	45.62	59.37	49.14	40.61	63.14	32.76	0.20	0.00	3.42	1.00	3.39	1.06	2.29	6.38	1.41	3.91
3- 29	52.16	37.25	53.11	62.38	42.00	54.00	49.98	51.13	52.04	51.30	0.21	0.90	4.28	1.00	3.89	1.23	2.38	5.35	1.81	2.63
3- 3	64.18	0.00	0.00	108.30	46.57	0.00	57.76	40.93	0.00	0.00	0.30	0.00	0.00	1.00	6.09	0.00	3.57	11.61	0.00	0.00
3- 30	55.07	0.00	54.15	56.19	45.03	54.19	51.90	0.00	59.15	57.62	0.18	0.00	3.78	1.00	3.27	1.10	2.06	0.00	1.43	2.11
3- 31	53.76	44.30	59.90	59.94	48.13	49.98	56.50	0.00	62.58	55.30	0.20	0.72	3.65	1.00	3.26	1.27	2.02	0.00	1.44	2.35
3- 32	50.66	0.00	51.81	60.29	45.49	56.17	54.72	0.00	51.57	55.30	0.21	0.00	4.24	1.00	3.47	1.14	2.10	0.00	1.76	2.36
3- 33	48.49	30.40	49.67	61.60	43.12	59.80	49.04	0.00	53.78	55.70	0.23	1.08	4.52	1.00	3.74	1.09	2.39	0.00	1.73	2.40
3- 34	49.46	0.00	0.00	68.55	42.30	54.36	50.72	42.61	54.24	50.31	0.25	0.00	0.00	1.00	4.24	1.34	2.57	7.06	1.90	2.95
3- 35	50.60	47.40	70.89	50.96	45.91	54.15	45.87	41.48	64.44	54.34	0.18	0.58	2.62	1.00	2.91	1.00	2.11	5.39	1.19	2.03
3- 36	54.09	43.56	0.00	59.98	45.39	63.40	49.35	31.25	50.96	54.91	0.20	0.74	0.00	1.00	3.46	1.00	2.31	8.42	1.77	2.37
3- 37	48.19	45.87	0.00	63.20	43.02	57.06	51.23	37.67	72.39	53.71	0.23	0.74	0.00	1.00	3.85	1.18	2.35	7.36	1.31	2.55
3- 38	51.80	45.60	0.00	52.76	45.73	53.48	55.70	0.00	65.25	49.67	0.18	0.62	0.00	1.00	3.02	1.05	1.80	0.00	1.22	2.30
3- 39	51.98	40.40	0.00	60.83	47.35	54.96	51.13	48.28	62.43	50.40	0.21	0.81	0.00	1.00	3.36	1.17	2.26	5.53	1.47	2.61
3- 4	59.52	52.69	0.00	69.31	46.14	44.56	0.00	0.00	0.00	0.00	0.21	0.70	0.00	1.00	3.93	1.65	0.00	0.00	0.00	0.00
3- 42	52.12	0.00	0.00	60.45	44.05	61.64	57.62	41.26	68.70	57.42	0.21	0.00	0.00	1.00	3.59	1.04	2.00	6.43	1.33	2.28
3- 43	48.60	31.44	0.00	62.00	45.39	55.82	45.87	0.00	67.22	51.64	0.23	1.05	0.00	1.00	3.58	1.18	2.57	0.00	1.39	2.60
3- 44	54.51	35.77	51.64	44.21	45.29	51.64	52.10	44.22	58.81	50.15	0.14	0.66	3.12	1.00	2.56	0.91	1.62	4.39	1.13	1.91
3- 45	52.57	0.00	0.00	47.12	47.36	48.94	49.04	46.14	56.37	64.71	0.16	0.00	0.00	1.00	2.61	1.02	1.83	4.48	1.26	1.58
3- 46	47.92	34.81	46.00	52.39	45.65	46.27	43.68	41.26	55.11	44.72	0.19	0.81	4.15	1.00	3.01	1.20	2.28	5.57	1.43	2.54
3- 47	50.76	32.22	0.00	63.74	46.00	59.30	44.05	0.00	0.00	54.72	0.22	1.06	0.00	1.00	3.63	1.14	2.75	0.00	0.00	2.52
3- 48	48.82	0.00	63.40	54.91	43.02	53.84	0.00	0.00	64.51	0.00	0.20	0.00	3.16	1.00	3.34	1.08	0.00	0.00	1.28	0.00
3- 49	53.03	35.71	58.74	55.73	43.81	43.48	46.64	35.61	56.78	57.97	0.19	0.83	3.46	1.00	3.33	1.36	2.27	6.87	1.48	2.08
3- 5	70.25	54.91	0.00	61.40	46.01	44.05	50.43	44.24	0.00	55.30	0.16	0.60	0.00	1.00	3.49	1.48	2.32	6.09	0.00	2.41
3- 50	51.74	0.00	44.56	53.38	42.44	51.57	49.04	43.81	57.59	48.13	0.18	0.00	4.37	1.00	3.29	1.10	2.07	5.35	1.40	2.40
3- 51	54.05	37.31	63.91	51.64	44.34	58.87	50.15	46.60	55.70	54.91	0.17	0.74	2.95	1.00	3.05	0.93	1.96	4.86	1.40	2.04
3- 52	52.82	0.00	57.34	48.10	44.05	49.01	55.50	42.21	54.34	53.41	0.16	0.00	3.06	1.00	2.86	1.04	1.65	5.00	1.33	1.95
3- 53	58.92	32.90	49.98	51.38	42.00	42.73	0.00	30.11	64.66	35.93	0.16	0.84	3.75	1.00	3.20	1.28	0.00	7.49	1.20	3.10
3- 6	62.74	42.38	0.00	68.60	44.22	48.89	46.97	0.00	0.00	0.00	0.19	0.87	0.00	1.00	4.06	1.49	2.78	0.00	0.00	0.00
3- 7	55.40	0.00	0.00	0.00	47.42	57.34	59.37	49.56	0.00	55.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3- 8	49.70	31.07	0.00	69.62	45.29	60.29	52.42	49.46	62.88	0.00	0.25	1.20	0.00	1.00	4.03	1.23	2.53	6.18	1.67	0.00
3- 9	52.23	0.00	66.08	50.39	48.84	55.43	43.81	38.44	0.00	52.92	0.17	0.00	2.78	1.00	2.70	0.96	2.19	5.75	0.00	2.06

APPENDIX E: CALCULATED SPACE MEAN SPEED AND DENSITY

APPENDIX E: CALCULATED SPACEMEAN SPEED AND DENSITY

M-N direction		
Time	PCU/hr/km	Space mean speed
1- 1	135.97	52.44
1- 10	449.86	49.36
1- 11	631.01	47.35
1- 12	590.83	46.65
1- 13	271.13	51.15
1- 14	622.44	46.73
1- 15	568.62	49.67
1- 16	519.32	47.59
1- 17	327.71	49.39
1- 18	480.26	48.91
1- 19	250.12	51.06
1- 2	314.15	52.91
1- 20	341.83	49.71
1- 21	308.98	50.40
1- 22	342.87	50.20
1- 23	562.78	47.00
1- 24	283.38	52.08
1- 25	335.86	49.95
1- 26	223.38	52.94
1- 27	421.03	51.53
1- 28	291.57	51.07
1- 29	334.09	53.00
1- 3	531.52	51.03
1- 30	359.37	50.30
1- 31	284.90	50.77
1- 32	278.74	53.18
1- 33	204.61	51.81
1- 34	361.13	50.09
1- 35	455.60	48.76
1- 36	246.18	51.36
1- 37	228.80	50.98
1- 38	407.82	48.88
1- 39	302.09	50.57
1- 4	364.88	49.83
1- 40	566.22	46.76
1- 41	349.95	50.04
1- 42	365.71	50.48
1- 43	289.97	50.73
1- 44	348.04	51.40
1- 45	219.68	53.20
1- 46	334.86	50.27
1- 47	292.19	50.57
1- 48	320.63	50.01
1- 49	349.65	49.52
1- 5	461.40	49.23
1- 50	440.84	49.03
1- 51	353.49	48.85
1- 52	312.11	49.49
1- 6	210.83	52.25
1- 7	392.32	49.00
1- 8	463.09	48.94
1- 9	527.52	49.74
2- 30	237.24	52.38
2- 31	298.97	53.49
2- 32	314.16	50.87
2- 33	546.76	51.14
2- 34	390.92	50.72
2- 35	324.55	51.35
2- 36	383.79	49.13
2- 37	228.60	53.67
2- 38	427.91	48.89
2- 39	432.97	51.69
2- 40	287.21	50.51
2- 41	450.84	48.15
2- 42	331.61	49.71
2- 43	313.52	49.68
2- 44	438.06	51.23
2- 45	409.99	48.65
2- 46	431.32	47.74

M-N direction		
Time	PCU/hr/km	Space mean speed
2- 47	431.59	48.87
2- 48	449.64	49.02
2- 49	385.61	47.97
2- 50	566.51	45.79
2- 51	516.69	46.91
2- 52	380.01	47.92
2- 53	173.78	51.37
3- 10	443.76	52.62
3- 11	443.78	52.42
3- 12	315.91	51.61
3- 13	368.67	52.48
3- 14	227.25	51.03
3- 15	296.30	49.48
3- 16	272.34	52.16
3- 17	401.38	48.65
3- 18	259.58	52.82
3- 19	384.33	51.30
3- 2	310.20	53.93
3- 20	318.82	52.05
3- 21	260.77	50.73
3- 22	239.56	50.86
3- 23	384.88	51.72
3- 25	31.70	54.75
3- 26	351.09	51.41
3- 27	317.01	49.99
3- 28	347.12	51.30
3- 29	340.36	49.55
3- 3	384.23	52.95
3- 30	321.14	49.30
3- 31	302.15	53.98
3- 32	336.62	50.42
3- 33	338.93	50.17
3- 34	363.33	47.93
3- 35	361.56	52.59
3- 36	164.75	53.10
3- 37	340.87	50.87
3- 38	337.05	51.14
3- 39	350.52	52.20
3- 4	102.89	54.40
3- 42	252.31	52.16
3- 43	491.90	48.61
3- 44	421.82	47.44
3- 45	309.12	48.37
3- 46	362.87	47.93
3- 47	273.63	49.04
3- 48	337.08	50.30
3- 49	402.07	49.71
3- 5	290.29	54.46
3- 50	277.60	49.23
3- 51	320.59	48.62
3- 52	312.97	48.62
3- 53	275.78	49.25
3- 6	355.21	51.94
3- 7	479.63	51.08
3- 8	271.45	50.14
3- 9	443.35	48.09

APPENDIX E: CALCULATED SPACEMEAN SPEED AND DENSITY

N-M direction		
Time	**PCU/hr/km**	**Space mean speed**
1- 1	35.88	45.09
1- 10	413.18	50.31
1- 11	420.55	50.39
1- 12	564.81	47.86
1- 13	289.73	51.04
1- 14	304.27	51.09
1- 15	402.39	50.07
1- 16	478.64	49.02
1- 17	452.04	49.21
1- 18	349.54	50.60
1- 19	481.18	51.84
1- 2	616.35	47.29
1- 20	306.26	50.98
1- 21	383.38	52.24
1- 22	257.34	54.21
1- 23	431.76	49.30
1- 24	250.10	54.74
1- 25	433.64	51.90
1- 26	333.78	54.07
1- 27	243.76	55.42
1- 28	307.47	52.31
1- 29	413.09	51.80
1- 3	375.46	49.54
1- 30	336.19	52.85
1- 31	446.32	52.14
1- 32	285.84	51.36
1- 33	333.73	53.30
1- 34	446.61	51.76
1- 35	371.54	50.76
1- 36	315.24	54.29
1- 37	301.02	53.73
1- 38	494.55	49.70
1- 39	360.35	54.66
1- 4	571.89	47.40
1- 40	327.04	50.86
1- 41	307.64	51.23
1- 42	540.13	50.11
1- 43	386.66	51.31
1- 44	319.12	53.17
1- 45	412.52	50.77
1- 46	436.37	49.99
1- 47	358.08	54.48
1- 48	369.12	52.50
1- 49	438.72	54.01
1- 5	308.26	50.37
1- 50	514.43	49.27
1- 51	454.12	49.70
1- 52	264.31	50.50
1- 6	295.91	50.20
1- 7	319.90	50.28
1- 8	415.05	49.23
1- 9	363.18	49.74
2- 30	209.25	55.12
2- 31	411.10	51.21
2- 32	324.79	56.30
2- 33	310.93	56.98
2- 34	395.97	56.96
2- 35	240.77	54.48
2- 36	289.81	54.62
2- 37	245.31	54.42
2- 38	455.63	51.39
2- 39	461.39	50.94
2- 40	312.10	54.53
2- 41	276.14	51.13
2- 42	499.42	49.32
2- 43	473.02	49.65

M-N direction		
Time	**PCU/hr/km**	**Space mean speed**
2- 44	207.78	52.69
2- 45	364.47	52.19
2- 46	626.71	52.21
2- 47	434.24	52.41
2- 48	542.93	48.72
2- 49	538.59	50.77
2- 50	429.32	48.86
2- 51	423.62	50.80
2- 52	632.50	47.33
2- 53	60.64	53.03
3- 10	510.27	48.82
3- 11	381.21	50.81
3- 12	360.50	51.55
3- 13	352.33	51.85
3- 14	50.15	55.30
3- 15	262.85	52.22
3- 16	519.76	48.87
3- 17	535.30	48.97
3- 18	390.49	53.91
3- 19	268.80	55.44
3- 2	212.90	51.71
3- 20	321.32	52.01
3- 21	562.84	51.46
3- 22	448.44	50.97
3- 23	253.49	53.43
3- 25	33.55	53.94
3- 26	405.94	54.08
3- 27	246.43	54.25
3- 28	386.79	53.43
3- 29	603.24	51.15
3- 3	269.30	51.07
3- 30	401.88	54.47
3- 31	413.95	54.84
3- 32	417.40	52.54
3- 33	327.18	52.10
3- 34	368.34	50.71
3- 35	298.41	51.79
3- 36	238.49	53.86
3- 37	286.87	54.68
3- 38	237.44	52.32
3- 39	380.61	54.48
3- 4	106.59	52.56
3- 42	254.68	53.44
3- 43	280.20	52.71
3- 44	493.74	49.54
3- 45	314.60	51.01
3- 46	548.62	47.61
3- 47	204.88	53.16
3- 48	298.91	51.99
3- 49	417.45	50.35
3- 5	478.59	48.79
3- 50	547.42	50.02
3- 51	476.35	51.95
3- 52	492.63	48.92
3- 53	230.11	51.42
3- 6	302.87	50.73
3- 7	388.82	51.58
3- 8	401.97	49.63
3- 9	506.98	49.44

APPENDIX F: CALCULATED PERFORMANCE MEASURE AND TRAFFIC CHARACTERISTICS

APPENDIX F: CALCULATED PERFORMANCE MEASURE AND TRAFFIC CHARACTERISTICS

M-N DIRECTION								
Time interval	**Performance measures**					**Traffic characteristics**		
	ATS (sec)	**NF (Pcu/hr/lane)**	**PF (%)**	**FD (PCU/km/lane)**	**NFPC**	**Directional flow (PCU/hr/lane)**	**Trucks Proportion**	**Opposite flow (PCU/hr/Lane**
1- 1	45	0.0	0.000	0.0	0.000	36	50%	136
1- 10	51	123.2	0.311	2.5	0.095	413	56%	450
1- 11	52	105.1	0.204	1.6	0.081	421	39%	631
1- 12	50	105.2	0.338	3.8	0.081	565	46%	591
1- 13	52	46.4	0.143	0.8	0.036	290	36%	271
1- 14	52	20.4	0.070	0.4	0.016	304	37%	622
1- 15	52	55.8	0.161	1.2	0.043	402	36%	569
1- 16	52	148.2	0.349	3.2	0.114	479	41%	519
1- 17	51	139.0	0.306	2.7	0.107	452	34%	328
1- 18	52	73.1	0.217	1.5	0.056	350	25%	480
1- 19	54	59.9	0.214	1.9	0.046	481	29%	250
1- 2	48	138.4	0.250	3.2	0.106	616	89%	314
1- 20	53	97.2	0.357	2.1	0.075	306	20%	342
1- 21	53	69.4	0.236	1.7	0.053	383	27%	309
1- 22	56	24.5	0.105	0.5	0.019	257	26%	343
1- 23	51	89.7	0.206	1.8	0.069	432	32%	563
1- 24	56	30.2	0.081	0.4	0.023	250	27%	283
1- 25	53	45.4	0.143	1.2	0.035	434	35%	336
1- 26	56	55.4	0.182	1.1	0.043	334	13%	223
1- 27	57	49.3	0.222	1.0	0.038	244	4%	421
1- 28	55	46.6	0.200	1.1	0.036	307	15%	292
1- 29	54	49.4	0.183	1.4	0.038	413	22%	334
1- 3	51	57.1	0.212	1.6	0.044	375	70%	532
1- 30	55	92.0	0.269	1.7	0.071	336	21%	359
1- 31	54	60.7	0.208	1.7	0.047	446	30%	285
1- 32	53	41.2	0.176	0.9	0.032	286	10%	279
1- 33	55	85.6	0.241	1.5	0.066	334	21%	205
1- 34	54	106.7	0.300	2.5	0.082	447	17%	361
1- 35	53	96.1	0.220	1.6	0.074	372	15%	456
1- 36	56	46.2	0.127	0.7	0.036	315	10%	246
1- 37	55	81.1	0.229	1.3	0.062	301	15%	229
1- 38	51	172.4	0.303	2.9	0.133	495	22%	408
1- 39	55	122.7	0.377	2.5	0.094	360	16%	302
1- 4	48	174.3	0.298	3.5	0.134	572	74%	365
1- 40	52	67.7	0.170	1.1	0.052	327	30%	566
1- 41	53	83.1	0.226	1.3	0.064	308	28%	350
1- 42	51	159.1	0.258	2.7	0.122	540	25%	366
1- 43	53	70.6	0.203	1.5	0.054	387	15%	290
1- 44	57	20.0	0.094	0.5	0.015	319	19%	348
1- 45	53	49.7	0.121	0.9	0.038	413	32%	220
1- 46	52	25.8	0.118	1.0	0.020	436	25%	335
1- 47	55	55.7	0.200	1.3	0.043	358	17%	292
1- 48	55	46.8	0.188	1.3	0.036	369	13%	321
1- 49	55	75.6	0.177	1.4	0.058	439	34%	350
1- 5	52	92.4	0.290	1.7	0.071	308	68%	461
1- 50	50	81.9	0.215	2.2	0.063	514	35%	441
1- 51	51	119.9	0.235	2.1	0.092	454	22%	353
1- 52	52	44.7	0.206	1.0	0.034	264	35%	312
1- 6	51	46.5	0.154	0.9	0.036	296	77%	211
1- 7	51	22.7	0.094	0.6	0.017	320	59%	392
1- 8	50	65.3	0.140	1.1	0.050	415	58%	463
1- 9	53	169.6	0.488	3.4	0.130	363	51%	528
2- 30	56	32.5	0.214	0.8	0.025	209	25%	237
2- 31	53	76.1	0.250	1.9	0.059	411	23%	299
2- 32	57	52.7	0.203	1.2	0.041	325	15%	314
2- 33	58	52.6	0.200	1.1	0.040	311	20%	547
2- 34	58	64.9	0.220	1.5	0.050	396	31%	391
2- 35	56	62.8	0.171	0.7	0.048	241	20%	325
2- 36	56	35.5	0.176	0.9	0.027	290	16%	384
2- 37	56	63.2	0.256	1.1	0.049	245	15%	229
2- 38	53	108.1	0.200	1.7	0.083	456	28%	428
2- 39	52	69.9	0.179	1.6	0.054	461	38%	433
2- 40	55	79.2	0.262	1.5	0.061	312	29%	287
2- 41	52	47.8	0.189	1.0	0.037	276	38%	451
2- 42	50	121.4	0.268	2.7	0.093	499	31%	332
2- 43	51	152.9	0.278	2.6	0.118	473	29%	314
2- 44	55	32.4	0.184	0.7	0.025	208	24%	438

APPENDIX F: CALCULATED PERFORMANCE MEASURE AND TRAFFIC CHARACTERISTICS

M-N DIRECTION								
Time interval	Performance measures					Traffic characteristics		
	ATS (sec)	NF (Pcu/hr/lane)	PF (%)	FD (PCU/km/lane)	NFPC	Directional flow (PCU/hr/lane)	Trucks Proportion	Opposite flow (PCU/hr/Lane
2- 45	53	113.4	0.308	2.1	0.087	364	26%	410
2- 46	53	112.4	0.232	2.7	0.086	627	32%	431
2- 47	54	136.5	0.239	1.9	0.105	434	24%	432
2- 48	50	192.7	0.286	3.1	0.148	543	32%	450
2- 49	52	161.6	0.268	2.8	0.124	539	30%	386
2- 50	50	97.4	0.311	2.7	0.075	429	31%	567
2- 51	52	65.9	0.184	1.5	0.051	424	41%	517
2- 52	49	214.1	0.418	5.4	0.165	633	32%	380
2- 53	54	6.3	0.188	0.2	0.005	61	13%	174
3- 10	50	86.6	0.157	1.6	0.067	510	63%	444
3- 11	53	62.4	0.229	1.7	0.048	381	44%	444
3- 12	53	76.6	0.233	1.6	0.059	360	42%	316
3- 13	54	92.9	0.217	1.4	0.071	352	27%	369
3- 14	56	0.0	0.000	0.0	0.000	50	15%	227
3- 15	54	107.7	0.333	1.6	0.083	263	38%	296
3- 16	51	124.4	0.279	2.9	0.096	520	41%	272
3- 17	51	100.1	0.235	2.5	0.077	535	46%	401
3- 18	55	40.9	0.091	0.6	0.031	390	39%	260
3- 19	57	41.9	0.211	1.0	0.032	269	19%	384
3- 2	52	39.3	0.118	0.5	0.030	213	76%	310
3- 20	53	98.6	0.300	1.8	0.076	321	26%	319
3- 21	53	123.9	0.216	2.3	0.095	563	35%	261
3- 22	53	111.5	0.246	2.1	0.086	448	32%	240
3- 23	56	59.3	0.209	1.0	0.046	253	16%	385
3- 25	54	9.8	0.333	0.2	0.008	34	33%	32
3- 26	55	83.0	0.235	1.7	0.064	406	15%	351
3- 27	57	60.1	0.176	0.8	0.046	246	12%	317
3- 28	55	58.2	0.153	1.1	0.045	387	31%	347
3- 29	52	120.4	0.256	2.9	0.093	603	19%	340
3- 3	53	28.6	0.158	0.8	0.022	269	84%	384
3- 30	56	111.8	0.258	1.8	0.086	402	16%	321
3- 31	56	51.5	0.174	1.3	0.040	414	10%	302
3- 32	55	55.8	0.157	1.2	0.043	417	23%	337
3- 33	56	80.7	0.181	1.1	0.062	327	14%	339
3- 34	53	71.8	0.192	1.3	0.055	368	33%	363
3- 35	53	56.4	0.226	1.3	0.043	298	15%	362
3- 36	55	34.0	0.132	0.6	0.026	238	21%	165
3- 37	57	39.7	0.118	0.6	0.031	287	20%	341
3- 38	54	38.3	0.224	1.0	0.029	237	12%	337
3- 39	56	84.9	0.250	1.7	0.065	381	15%	351
3- 4	55	32.6	0.214	0.4	0.025	107	43%	103
3- 42	55	76.6	0.184	0.9	0.059	255	29%	252
3- 43	55	74.8	0.191	1.0	0.058	280	21%	492
3- 44	51	117.9	0.306	3.0	0.091	494	26%	422
3- 45	53	46.0	0.218	1.3	0.035	315	29%	309
3- 46	50	234.2	0.402	4.5	0.180	549	18%	363
3- 47	55	25.8	0.143	0.5	0.020	205	14%	274
3- 48	54	82.7	0.255	1.4	0.064	299	22%	337
3- 49	52	84.0	0.210	1.7	0.065	417	27%	402
3- 5	49	103.7	0.225	2.2	0.080	479	78%	290
3- 50	51	157.4	0.313	3.3	0.121	547	25%	278
3- 51	54	85.8	0.162	1.4	0.066	476	28%	321
3- 52	51	165.0	0.375	3.6	0.127	493	36%	313
3- 53	53	32.4	0.156	0.7	0.025	230	22%	276
3- 6	52	24.5	0.118	0.7	0.019	303	62%	355
3- 7	53	27.8	0.081	0.6	0.021	389	65%	480
3- 8	51	56.4	0.119	0.9	0.043	402	60%	271
3- 9	52	143.1	0.235	2.3	0.110	507	51%	443

APPENDIX F: CALCULATED PERFORMANCE MEASURE AND TRAFFIC CHARACTERISTICS

N-M direction								
Time interval	Performance measures					Traffic characteristics		
	ATS (sec)	NF (Pcu/hr/lane)	PF (%)	FD (PCU/km/lane)	NFPC	Directional flow (PCU/hr/lane)	Trucks Proportion	Opposite flow (PCU/hr/Lane
1- 1	53	45.3	0.267	0.7	0.035	136	40%	36
1- 10	51	69.9	0.187	1.6	0.054	450	23%	413
1- 11	49	105.3	0.203	2.6	0.081	631	22%	421
1- 12	49	167.4	0.284	3.4	0.129	591	23%	565
1- 13	53	17.7	0.158	0.8	0.014	271	16%	290
1- 14	49	189.3	0.257	3.3	0.146	622	28%	304
1- 15	51	147.2	0.246	2.8	0.113	569	20%	402
1- 16	49	161.4	0.254	2.7	0.124	519	27%	479
1- 17	51	63.8	0.208	1.3	0.049	328	31%	452
1- 18	50	111.4	0.211	2.0	0.086	480	30%	350
1- 19	53	11.1	0.102	0.5	0.009	250	16%	481
1- 2	54	31.2	0.139	0.8	0.024	314	33%	616
1- 20	51	41.8	0.205	1.4	0.032	342	27%	306
1- 21	52	59.9	0.250	1.5	0.046	309	23%	383
1- 22	52	56.1	0.218	1.4	0.043	343	25%	257
1- 23	49	84.9	0.197	2.3	0.065	563	34%	432
1- 24	55	58.8	0.175	0.9	0.045	283	18%	250
1- 25	53	79.6	0.273	1.7	0.061	336	18%	434
1- 26	55	18.5	0.186	0.8	0.014	223	19%	334
1- 27	54	97.2	0.260	2.0	0.075	421	18%	244
1- 28	53	8.8	0.067	0.4	0.007	292	22%	307
1- 29	54	50.1	0.230	1.4	0.039	334	11%	413
1- 3	52	46.6	0.115	1.2	0.036	532	37%	375
1- 30	53	69.1	0.167	1.1	0.053	359	20%	336
1- 31	54	80.9	0.280	1.5	0.062	285	14%	446
1- 32	55	79.6	0.294	1.5	0.061	279	18%	286
1- 33	53	19.8	0.184	0.7	0.015	205	13%	334
1- 34	52	57.1	0.158	1.1	0.044	361	25%	447
1- 35	50	112.4	0.311	2.8	0.086	456	28%	372
1- 36	53	23.1	0.116	0.5	0.018	246	23%	315
1- 37	53	39.1	0.217	0.9	0.030	229	20%	301
1- 38	51	97.5	0.234	1.9	0.075	408	27%	495
1- 39	51	57.2	0.179	1.1	0.044	302	33%	360
1- 4	51	101.5	0.259	1.9	0.078	365	29%	572
1- 40	49	153.0	0.274	3.2	0.118	566	27%	327
1- 41	52	69.5	0.212	1.4	0.053	350	31%	308
1- 42	52	56.2	0.169	1.2	0.043	366	29%	540
1- 43	53	45.3	0.245	1.4	0.035	290	19%	387
1- 44	53	86.1	0.261	1.7	0.066	348	16%	319
1- 45	56	31.7	0.125	0.5	0.024	220	20%	413
1- 46	52	42.4	0.156	1.0	0.033	335	27%	436
1- 47	52	53.5	0.154	0.9	0.041	292	38%	358
1- 48	53	81.4	0.250	1.5	0.063	321	29%	369
1- 49	51	76.7	0.214	1.5	0.059	350	29%	439
1- 5	50	68.2	0.179	1.6	0.052	461	30%	308
1- 50	50	87.2	0.184	1.6	0.067	441	41%	514
1- 51	51	63.0	0.191	1.3	0.048	353	40%	454
1- 52	51	65.7	0.171	1.0	0.051	312	37%	264
1- 6	53	24.8	0.108	0.4	0.019	211	22%	296
1- 7	50	135.9	0.315	2.5	0.105	392	28%	320
1- 8	50	61.0	0.186	1.7	0.047	463	22%	415
1- 9	51	84.6	0.240	2.5	0.065	528	27%	363
2- 30	54	36.4	0.111	0.5	0.028	237	19%	209
2- 31	55	20.2	0.136	0.7	0.016	299	27%	411
2- 32	53	36.1	0.255	1.5	0.028	314	19%	325
2- 33	53	113.0	0.329	3.4	0.087	547	22%	311
2- 34	52	98.7	0.220	1.7	0.076	391	30%	396
2- 35	52	15.4	0.108	0.7	0.012	325	38%	241
2- 36	52	71.2	0.160	1.2	0.055	384	32%	290
2- 37	55	11.9	0.143	0.6	0.009	229	21%	245
2- 38	51	87.0	0.250	2.1	0.067	428	25%	456
2- 39	53	88.7	0.226	1.8	0.068	433	29%	461
2- 40	52	28.3	0.154	0.8	0.022	287	36%	312
2- 41	51	131.7	0.298	2.6	0.101	451	35%	276
2- 42	51	47.1	0.176	1.1	0.036	332	25%	499
2- 43	51	49.6	0.214	1.3	0.038	314	21%	473
2- 44	53	59.9	0.177	1.5	0.046	438	34%	208

APPENDIX F: CALCULATED PERFORMANCE MEASURE AND TRAFFIC CHARACTERISTICS

N-M direction								
Time interval	Performance measures					Traffic characteristics		
	ATS (sec)	NF (Pcu/hr/lane)	PF (%)	FD (PCU/km/lane)	NFPC	Directional flow (PCU/hr/lane)	Trucks Proportion	Opposite flow (PCU/hr/Lane
2- 45	50	110.8	0.283	2.3	0.085	410	30%	364
2- 46	50	176.9	0.411	3.5	0.136	431	29%	627
2- 47	51	121.3	0.283	2.4	0.093	432	43%	434
2- 48	50	136.0	0.302	2.7	0.105	450	32%	543
2- 49	50	111.7	0.273	2.1	0.086	386	41%	539
2- 50	48	214.8	0.377	4.5	0.165	567	44%	429
2- 51	49	51.1	0.145	1.5	0.039	517	42%	424
2- 52	51	108.0	0.255	1.9	0.083	380	38%	633
2- 53	52	15.4	0.154	0.5	0.012	174	54%	61
3- 10	53	128.2	0.271	2.2	0.099	444	27%	510
3- 11	54	94.2	0.226	1.9	0.072	444	26%	381
3- 12	54	70.9	0.233	1.4	0.055	316	28%	360
3- 13	54	111.6	0.294	2.0	0.086	369	24%	352
3- 14	52	29.7	0.080	0.3	0.023	227	36%	50
3- 15	51	81.1	0.243	1.4	0.062	296	35%	263
3- 16	54	44.0	0.265	1.3	0.034	272	18%	520
3- 17	51	145.1	0.316	2.5	0.112	401	23%	535
3- 18	54	13.4	0.151	0.7	0.010	260	13%	390
3- 19	53	43.0	0.159	1.2	0.033	384	27%	269
3- 2	55	32.2	0.167	0.9	0.025	310	33%	213
3- 20	53	70.8	0.277	1.7	0.054	319	30%	321
3- 21	52	78.2	0.229	1.1	0.060	261	29%	563
3- 22	52	39.2	0.095	0.4	0.030	240	17%	448
3- 23	55	57.3	0.143	1.0	0.044	385	17%	253
3- 25	55	0.0	0.000	0.0	0.000	32	50%	34
3- 26	54	62.7	0.219	1.4	0.048	351	22%	406
3- 27	52	112.8	0.333	2.0	0.087	317	21%	246
3- 28	53	57.3	0.233	1.5	0.044	347	20%	387
3- 29	54	64.3	0.151	1.0	0.049	340	17%	603
3- 3	54	71.4	0.216	1.5	0.055	384	41%	269
3- 30	50	30.2	0.180	1.1	0.023	321	20%	402
3- 31	55	46.4	0.214	1.2	0.036	302	16%	414
3- 32	52	54.8	0.125	0.8	0.042	337	20%	417
3- 33	53	48.7	0.219	1.4	0.037	339	14%	327
3- 34	50	123.6	0.349	2.5	0.095	363	19%	368
3- 35	54	75.3	0.210	1.4	0.058	362	21%	298
3- 36	55	38.7	0.211	0.6	0.030	165	8%	238
3- 37	53	39.4	0.167	1.1	0.030	341	20%	287
3- 38	52	68.5	0.271	1.7	0.053	337	27%	237
3- 39	54	98.0	0.286	1.8	0.075	351	17%	381
3- 4	56	19.4	0.238	0.4	0.015	103	10%	107
3- 42	54	48.2	0.244	1.1	0.037	252	20%	255
3- 43	52	153.9	0.295	2.8	0.118	492	24%	280
3- 44	49	61.9	0.220	1.9	0.048	422	34%	494
3- 45	50	72.1	0.213	1.3	0.055	309	23%	315
3- 46	50	54.6	0.292	2.1	0.042	363	18%	549
3- 47	51	11.0	0.130	0.7	0.008	274	24%	205
3- 48	53	59.9	0.200	1.3	0.046	337	22%	299
3- 49	51	55.0	0.148	1.2	0.042	402	39%	417
3- 5	55	34.9	0.211	1.1	0.027	290	26%	479
3- 50	51	24.6	0.182	1.0	0.019	278	30%	547
3- 51	51	100.4	0.319	2.0	0.077	321	38%	476
3- 52	51	65.8	0.174	1.1	0.051	313	26%	493
3- 53	51	42.5	0.235	1.3	0.033	276	29%	230
3- 6	54	75.7	0.244	1.6	0.058	355	33%	303
3- 7	52	89.7	0.194	1.8	0.069	480	24%	389
3- 8	52	64.3	0.175	0.9	0.049	271	33%	402
3- 9	50	81.0	0.276	2.4	0.062	443	22%	507

APPENDIX G: PYTHON CODES

FOR BEST FIT IDENTIFICATION

```
import numpy as np

import pandas as pd

from fitter import Fitter

import matplotlib.pyplot as plt

# Load data

file_path = r"D:\For_thesis \file_to_work.xlsx"

df1 = pd.read_excel(file_path, sheet_name='1')

# Clean and convert data

df = df.dropna(subset=["SD", "GAP"])

df["SD"] = df["SD"].astype(float)

# Filter free-flow vehicles (GAP >= 8 sec)

free_flow_df = df[df["GAP"] >= 8]

free_flow_sd = free_flow_df["SD"].values

# Fit distributions

f = Fitter(free_flow_sd1, distributions=['logistic', 'norm', 'lognorm', 'gamma', 'weibull_min'])

f.fit()

f.summary()

# Get the best distribution and its parameters

best_dist_name, best_params = list(f1.get_best().items())[0]  # Get first (best) result

print(f"Best distribution: {best_dist_name}")

print(f"Parameters: {best_params}")
```

FOR SUPERIMPOSITION

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
from fitter import Fitter
def optimal_bin_width (data, method='freedman'):
    n = len(data)
    if n == 0:
        return 1 # Prevent division by zero error
    if method == 'freedman':
        iqr = np.percentile(data, 75) - np.percentile(data, 25)
        bin_width = (2 * iqr) / (n ** (1/3))
    elif method == 'scott':
        bin_width = (3.5 * np.std(data)) / (n ** (1/3))
    else:
        raise ValueError("Invalid method.")
    return max(bin_width, 1)
# Load data
file_path = r"D:\........ xlsx"
df = pd.read_excel(file_path, sheet_name='1')
df = df.dropna(subset=["Speed", "SD", "GAP"])
df[["SD", "GAP"]] = df[["SD", "GAP"]].astype(float)
# Filter free-flow vehicles (GAP >= 8 sec)
free_flow_df = df[df["GAP"] >= 8]
# Free-flow SD values
free_flow_sd = free_flow_df["SD"].values
# All vehicles SD values
all_vehicles_sd = df["SD"].values
# Determine bin width dynamically
bin_width = optimal_bin_width(df["SD"], method='freedman')
# Fit logistic (M-N) and normal (N-M) to free-flow vehicles
f = Fitter(free_flow_sd, distributions=['logistic'])
f.fit()
# Generate x values for curves at intervals of 0.05
x_interval = np.arange(min(free_flow_sd), max(free_flow_sd), 0.05)
# Compute PDFs for the curves at each interval
```

logistic_curve_interval = (np.exp(-(x_interva - mean_sd) / std_sd)) / (std_sd * (1 + np.exp(-(x_interval - mean_sd) / std_sd))**2)

 # Calculate histogram values for all vehicles

hist_all, bin_edges_all = np.histogram(all_vehicles_sd, bins=np.arange(min(all_vehicles_sd), max(all_vehicles_sd) + bin_width, bin_width), density=True)

 # Find the bin centers for all vehicles

bin_centers_all = (bin_edges_all[:-1] + bin_edges_all[1:]) / 2

 # Compute the y-values for the histogram of all vehicles at the specified interval of 0.05

logistic_curve_at_interval_all = (np.exp(-(x_interval - mean_sd) / std_sd)) / (std_sd * (1 + np.exp(-(x_interval - mean_sd) / std_sd))**2)

 # Calculate the deviations (residuals) at each interval

deviation_all_interval = np.abs(np.interp(x_interval, bin_centers_all, hist_all) - logistic_curve_at_interval_all)

 # Plotting using matplotlib

fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(14, 6))

ax.hist(all_vehicles_sd, bins=np.arange(min(all_vehicles_sd), max(all_vehicles_sd) + bin_width, bin_width), histtype='step', color='black', label='SD histogram (M-N, All vehicles)', density=True)

ax.plot(x_interval, logistic_curve_interval, color='blue', label=f'Logistic Curve (M-N, Free-flow)\nMean={mean_sd:.2f}, Std Dev={std_sd:.2f}')

ax.set_title('Muglin-Narayanghat (M-N)', fontsize=16)

ax.set_xlabel('SD [km/h]', fontsize=14)

ax.set_ylabel('Density', fontsize=14)

ax.grid(True)

ax.legend()

ax.set_xlim([min(free_flow_sd), max(free_flow_sd)])

FOR STATISTICAL ANALYSIS

```
import pandas as pd
import numpy as np
import scipy.stats as stats
from numpy import mean, std
```

 # Load dataset

```
file_path = r"D:\For_thesis\Python\Group_data\Re\New folder\MAin_file (Repaired).xlsx"
df1 = pd.read_excel(file_path, sheet_name='1')  # Muglin-Narayanghat (M-N)
df2 = pd.read_excel(file_path, sheet_name='2')  # Narayanghat-Muglin (N-M)
df1["Platooning"] = df1["Platooning"].astype(int)
df2["Platooning"] = df2["Platooning"].astype(int)
df1["Speed"] = df1["Speed"].astype(float)
df2["Speed"] = df2["Speed"].astype(float)
df_combined = pd.concat([df1, df2], ignore_index=True)
vehicle_types = df_combined["Vehicle_type"].unique()
results = {}
```

 # Function to calculate Cohen's d for Welch's t-test

```
def cohens_d(x1, x2):
    n1, n2 = len(x1), len(x2)
    s1, s2 = std(x1, ddof=1), std(x2, ddof=1)
    s_pooled = np.sqrt((s1**2 + s2**2) / 2)
    return (mean(x1) - mean(x2)) / s_pooled
```

 # Function to calculate degrees of freedom for Welch's t-test

```
def welch_df(x1, x2):
    n1, n2 = len(x1), len(x2)
    s1, s2 = std(x1, ddof=1), std(x2, ddof=1)
    numerator = (s1**2 / n1 + s2**2 / n2)**2
    denominator = ((s1**2 / n1)**2 / (n1 - 1)) + ((s2**2 / n2)**2 / (n2 - 1))
    return numerator / denominator if denominator!= 0 else np.nan  # Avoid division by zero
```

Functions calls for different vehicles types

```
for vehicle in vehicle_types:
    vehicle_data = df_combined[df_combined["Vehicle_type"] == vehicle]
    free_flow = vehicle_data[vehicle_data["Platooning"] == 0]["Speed"]
    platoon = vehicle_data[vehicle_data["Platooning"] == 1]["Speed"]
```

```
    n_p, n_ff = len(platoon), len(free_flow)
    mean_p, mean_ff = mean(platoon), mean(free_flow)
    sd_p, sd_ff = std(platoon, ddof=1), std(free_flow, ddof=1)
    levene_stat, levene_p = stats.levene(platoon, free_flow)
    stat, p_value = stats.ttest_ind(platoon, free_flow, equal_var=False)
    df = welch_df(platoon, free_flow)
    one_tailed_p_value = p_value / 2 if stat < 0 else 1 - (p_value / 2)
    effect_size = cohens_d(platoon, free_flow)
    results[vehicle] = {
        "Platoon_n": n_p,
        "Freeflow_n": n_ff,
        "Mean Platoon": mean_p,
        "Mean Freeflow": mean_ff,
        "SD Platoon": sd_p,
        "SD Freeflow": sd_ff,
        "Levene's p-value": levene_p,
        "Test Statistic": stat,
        "One-tailed p-value": one_tailed_p_value,
        "Degrees of Freedom": df,
        "Effect Size": effect_size,
        "Significant?": "Yes" if one_tailed_p_value < 0.025 else "No"
    }
results_df = pd.DataFrame.from_dict(results, orient='index')
```