Microscopic Traffic Flow Parameters Analysis for Highways and Motorways

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School of Civil and Environmental Engineering
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Dedicated to

my beloved Brother (Tariq Rahim),

who always wished & prayed for my success

and encouraged me to upgrade

& share my knowledge/ideas.

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In the name of Allah, the Mighty, the Merciful, and the Beneficent, who created us and always planned the best for us. I am glad to Allah for his innumerable benefits and kindness showered upon me amid life's problems, and I seek His direction and pray to Him for blessings and ease in this life and the life to come. I am highly indebted to my honorable thesis supervisor Dr. Kamran Ahmed for his continuous support, valuable guidance, and supervision throughout my master's. I am grateful that he has been very kind and patient, and his enthusiastic encouragement motivated me to complete my research work. He was always guiding and encouraging me despite his tight schedule and commitments. I am thankful to him for the warmth of my heart.

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(Suleman Saani)

NOMENCLATURE

FL: Fast Lane

SL: Slow Lane

IQR: Interquartile range

LQ.: Lower quartile

UQ: Upper Quartile

Km/h: kilometer per hour

Veh/h: Vehicles per hour

K-S: Kolmogorov-Smirnov

GOF test: Goodness-of-fits test

CV: Coefficient of variance

Sk: Skewness

Kr.: Kurtosis

TMS: Time mean Speed

SMS: Space mean Speed

PDF: Probability density function

PRT.: Pneumatic Road Tube

TH: Time Headway

CDF: Cumulative distribution function

ECDF: Empirical Cumulative distribution function

NTRC: National Transportation research center

NH: National Highway

M: Motorway

NOTATIONS

μ (mu) or θ (theta) or k	Location parameter
σ (sigma) or β (beta)	Scale parameter
λ (lambda) or α (alpha)	Shape parameter
γ (gamma)	Shape-location parameter
δ (delta)	Scale-location parameter
η (eta)	Shape-scale parameter
ζ (zeta) or ε (epsilon)	Nuisance parameter
$f(t)$	Probability density function (PDF)
$F(t)$	Cumulative distribution function

LIST OF IMPORTANT CONCEPTS

Speed - The distance covered per unit time is called speed. **Time Mean Speed –** If speed is measured by keeping time as a reference is called TMS. In practice, pneumatic tubes are used to measure time mean speed. **Space Mean Speed** - If speed is measured by space reference, it is called SMS. The speed determined by the entire highway segment is the space mean speed. It is measured by fixing a video camera on a pole in practice. It is the harmonic mean of time mean Speed.

Critical Speed: The speed at which the optimum flow occurs is called the "critical speed" or "optimum flow speed." This is the speed at which the traffic volume on a roadway is at its maximum for a given set of conditions, such as the number of lanes, the presence of traffic signals or other obstacles, and the characteristics of the vehicles using the roadway.

Traffic Count/Density – It is defined as the number of vehicles per unit area of the roadway.

Headway – It measures the distance/time between vehicles in a transit system. Headway can be either time headway, time that elapses between the arrival of a leading vehicle and the following vehicle at a point, measured in seconds, or space headway, which is the difference in position between the front of a leading vehicle and the front of the following vehicle measured in meters.

Traffic Congestion – It is a condition on road networks that occurs when the number of vehicles on the road increases and is characterized by slower speeds, longer trip times. **Travel Delay** – According to HCM, "The additional travel time experienced by a driver, passenger, or pedestrian is called travel delay. It is the difference between an actual and an ideal travel time.

Homogeneous Traffic- Homogeneous traffic is one in which there are very few types of vehicles present and where there is no alternation done to them. The drivers in homogeneous traffic flow follow lane discipline and other traffic rules. This traffic includes passenger cars and heavy vehicles of some specified dimensions.

Heterogeneous Traffic- Heterogeneous traffic or mixed traffic is one in which enormous categories of vehicles have a considerable change in static and dynamic characteristics. This traffic is poor lane discipline and usually does not obey traffic rules.

Probability Distribution- The mathematical function calculates the likelihood of many probable outcomes for an experiment. It is a mathematical explanation of a random phenomenon in sample space and event probability.

Non-parametric test- A statistical distribution test that does not assume anything about the underlying distribution. It is also called a distribution-free test. When the word "non-parametric" is used in stats, it does not quite mean that you know nothing about the population. It usually means that you know the population data does not have a normal distribution.

Passenger Car Unit- It is commonly used in the transportation field to measure the volume of passenger car traffic. It is a metric that reflects the number of passenger cars that pass a certain point on a road or highway within a given time.

ABSTRACT

On a microscopic level, Time headway is the temporal distance between two consecutive vehicles, and speed is frequently employed as a qualitative service indicator. Time headway and speed are critical for traffic modeling because they provide a complete picture of the aggregate flow of vehicles and can inherently define the features of traffic flow. Previous research on this topic mainly focused on stochastic modeling of homogenous traffic following lane discipline. Few studies demonstrate weak-lane discipline heterogeneous traffic, considering the whole road section as a single lane.

This research focuses on the theoretical modeling and statistical analysis of "Time headway and Speed" for heterogeneous data on slow and fast lanes**.** For analysis, a large amount of "Time headway and speed" data was collected using metrocount@5600 on NH-5 (site-1), NH-45 (site-2), and M-1 (site-3) in Pakistan. Site-1 and site-2 are four-lane median separated highways, and site-3 is a six-lane median separated motorway.

Time headway analysis for mixed traffic and different leader-follower vehicle pairs and speed analysis for mixed traffic are examined with varying flow ranges starting from 0 to 1500 PCU/hr with an increment difference of 100 PCU/hr. Kolmogorov-Smirnov (K-S) test is used to check the statistical validity of each distribution**.** The results demonstrate that the speed and time headway follow distinct distribution patterns at various flows for each case. Similarly, speed data analysis for different sites' heterogeneous traffic and vehicle classes is also carried out on FL and SL to determine the influence of overall flow and vehicle mix on speed**.**

These results can be used to perform capacity analysis, safety analysis, delay analysis, accident analysis, gap acceptance analysis, queue analysis, LOS analysis, etc. These outcomes will also assist in understanding driver behavior and developing microsimulation mode.

Keywords: Time Headway, Speed, Distribution, Statistical parameters, Flow levels, Heterogenous traffic, Pneumatic tubes, Goodness-of-fit test, K-S test.

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CHAPTER 1: INTRODUCTION

1.1 Outline

This research investigates statistical parameters of Time Headway and Speed for heterogeneous traffic streams and Time Headway and speed distribution for highways and motorways. Additionally, it offers temporal headway analysis for various leader-follower vehicle pairings and the speed distribution characteristics of various vehicle groups. This chapter outlines the research's background, objectives, significance, and scope. It clarifies the gap for the research to be carried out. It consists of outlines of the remaining chapters at the end.

1.2 General background

Mobility is the soul of our freedom. Being mobile is the best thing that can happen in the modern world. As time moved forward and due to population increase, being mobile seemed reasonable, and it became the major component of interaction with society. So, transportation facilities are built that make it safe, easy, and efficient for people and goods to move from one place to another. There are some shortcomings in the system, e.g., accidents, delays, etc. Traffic flow modeling is vital to keep people facilitating and reducing malfunctions. Time Headway and speed distribution studies are essential for traffic engineers in the analysis and traffic flow modeling as their statistical properties provide an in-depth understanding of vehicles and drivers.

Speed is a microscopic traffic flow measure frequently employed as a qualitative service indicator. (May, 1990). It is a critical indicator of a transportation system's traffic performance. At any given time, the speed of travel is arbitrary. Rather than a single characteristic speed, a traffic mix has a range of speeds that can describe the behavior of vehicle movements on a road facility. Most simulation and analytical transportation models generate speed as an output or input for calculating trip time, delay, and LOS. (Park *et al.*, 2010). Finding an acceptable mathematical distribution for describing the measured speeds is desirable. When creating vehicles in microscopic simulations, the speed of each vehicle must be determined using a mathematical model. (Park et al., 2010).

Understanding speed distribution requires establishing a speed limit that enables traffic to travel safely and efficiently.

Headway is "the temporal or spatial distance between two consecutive vehicles" on a microscopic level. Headway is a critical flow parameter, and headway distribution can estimate capacity, study driver behavior, and conduct safety analysis (May, 1990). The distribution of headways establishes the possibility and necessity of merging, passing, and crossing. (May, 1990). Under capacity-flow situations, headway distribution also plays a significant role in determining a system's capacity. Additionally, a critical component of many microscopic simulation models is the generation of entrance vehicle headway during the simulation process. Correct vehicle arrival times on the simulated network can be generated using proper mathematical distributions to simulate headway.

Headway fluctuates according to traffic circumstances, the more traffic, the smaller the headway. The capacity of highways, motorways, and saturation flow rates of intersections are reciprocal to minimum time headway.

Headway is location-specific, as it might vary between road types or sites. Due to various vehicle sizes with differing maneuverability and dynamic characteristics, vehicle time headways may range from 0 to several seconds.

Headway and speed translate to "density and flow" on a macroscopic level. Speed and TH are random variables that can be predicted and described using probabilistic models on any highway facility. Speed and headway analyses and distributions are critical in various traffic flow research and simulation domains.

Speed and headway are critical to understanding since they are vital markers of a highway system's traffic performance. As a result, it is crucial to create robust and novel analytical tools for analyzing these variables.

1.3 Problem statement

Predicting the Speed and Time Headway distribution from the previously available research is possible if the traffic is homogeneous. However, when the traffic mix becomes heterogeneous, congestion and free flow are present, and the distribution curves depart from earlier research. Once again, different vehicle types have varying lengths, widths, maneuverability, and acceleration-deceleration capabilities. All these factors contribute to the complexity of the traffic situation. Moreover, no TH and speed distribution analysis has been performed on motorways and highways in Pakistan. No research is available on TH and Speed for FL and SL traffic distribution models. Therefore, statistical speed and headway data analysis at various flow levels are critical for rural infrastructure design and traffic management. Statistical analysis of TH and Speed is critical for traffic modeling because it provides a complete picture of the aggregate flow of vehicles and can inherently define traffic flow features. Designing probability distribution models for different flow levels of heterogeneous traffic is vital for understanding traffic behavior.

1.4 Objectives of research

The following are the study's primary objectives:

a) Time headway distributions for mixed traffic under various flow levels on fast and slow lanes.
b) Time headway distributions for various vehicle pairs (Car-Truck, Auto-Bus, etc.) under different flow levels on fast and slow lanes.
c) Speed distributions for mixed traffic under various flow levels on fast and slow lanes.
d) Speed distributions for different vehicle classes on fast and slow lanes.
e) Speed distributions for heterogenous traffic on fast and slow lanes at national highways and motorways.

1.5 Research significance

TH and speed provide information about the overall flow of vehicles to perform capacity analysis, safety analysis, delay analysis, accident analysis, gap acceptance analysis, and queue analysis of intersections, highways, and roundabouts. They have a variety of applications, including calculating the Level of Service (LOS) and regulating and controlling traffic operations. Speed distribution analysis is critical for geometric road design, determining trip time, and establishing speed limits to enable free movement. Headway analysis is a prime factor in estimating passenger car units (PCU). With the rapid advancement of information and communication technology, intelligent transportation systems (ITS) have become more critical in reducing traffic congestion and improving safety by giving better information and management to road users. (Chowdhury, Norwood and Alam, 2003).

1.6 Scope of the study

The study is carried out for Fast and Slow lanes on highways and motorways. Transportation agencies will utilize the study's findings in traffic regulation and management, signal design, and operation of highways and motorways. More precisely, a statistical model of time headways can be employed as an input parameter in microsimulation models to generate vehicles (M. and Verma, 2016). These simulation models will then solve problems for interpreted and uninterpreted facilities. Moreover, the statistical analysis and distribution findings will assist the agencies in travel time analysis and driver behavior w.r.t vehicle classification. The results will assist the agencies in designing roads for highways and motorways. Based on the study results, proper speed limits will be selected for different lane roads to facilitate people's safe and efficient movement.

1.7 Thesis organization

This thesis is structured into five separate sections.

Chapter 1 is based on the overall context, the issue being addressed, the research goals, the study's importance, and the extent of its coverage.

Chapter 2 is based on the previous literature available on the research topic. It also explains in detail the methods and terms used in this research.

Chapter 3 is based on the description of the study site, data overview and preliminary analysis of the collected data.

Chapter 4 is based on the detailed analysis of speed and TH distributions which explains traffic stream, vehicular pairs, and vehicular class behavior. It also has a detailed discussion of the acquired results.

Chapter 5 is based on the conclusions and recommendations about the analysis results. It also tells us how this research will help the existing departments.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter provides a general idea of Pneumatic tubes, Testing hypotheses, and probability density functions for TH and Speed. It briefly introduces the different statistical parameters used in this research. Specifically, it provides a detailed review of the research studies on TH and speed distributions.

2.2 Technological Background Of Traffic Data Collection Techniques

Real-time traffic data is required to develop a highly efficient Intelligent Transportation System (ITS). Traditional on-field videography techniques are necessary but insufficient for collecting traffic data due to their limited coverage capacity and high maintenance costs. In-roadway sensors must be installed on, embedded in, or beneath the road surface to capture essential data. In-roadway sensors provide precise data on vehicle size, volume, Speed, headway, lane occupancy, and flow rate.

2.2.1 Pneumatic Road Tubes (PRT)

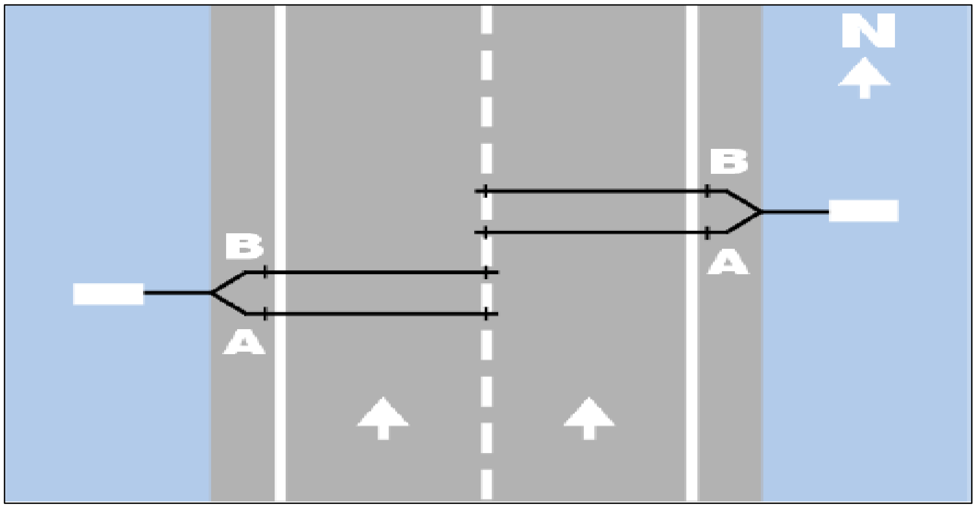
A pneumatic road tube, also known as a traffic counting tube, is a device used to collect road traffic data.

Pneumatic tubes are programmed according to the vehicles on that road, considering their axles' configuration and weight. Air pressure is sent along a rubber tube when a vehicle's tires travel over a pneumatic road tube sensor. A pressure pulse closes an air switch, generating an electrical signal sent to a counter or analysis software. The pneumatic road tube sensor is portable and powered by lead-acid, gel, or rechargeable batteries.

Vehicle classification by axle count and spacing, planning, and research benefit from the road tube's installation perpendicular to the direction of traffic flow. When the counter is coupled with a vehicle transmission sensor, some versions can gather data for calculating vehicle gaps, intersection stop delays, stop sign delays, saturation flow rates, spot speeds based on vehicle classes, and trip times.

The low power consumption and simple installation of road tube sensors make them an attractive option for long-term data archiving. It is common for road tube sensors to be inexpensive and easy to maintain. Data analysis can be made more accessible using the software provided by sensor manufacturers.

Some disadvantages are inaccurate axle counting due to increased truck and bus traffic, air switch temperature sensitivity, and severed tubes from vandalism and truck tire wear.



(Source: https://metrocount.com/towards-a-traffic-database-for-perth-and-wa/)

Figure 2-1 PRT arrangements for median separated carriageway

(Source: https://metrocount.com/?attachment_id=4246)

Figure 2-2 Metro Count installed on the roadside

2.3 Descriptive Statistic (trends and tendencies)

Descriptive statistics describe or summarize the characteristics of a sample or data set.

The essential statistics commonly used are discussed below:

2.3.1 Measures of location

It depicts the central tendency of the data.

2.3.1.1 Mean or Average

It is a generally used measure of the center of a collection of numbers. It is the addition of all observations divided by the number of observations. Numerous statistical analyses utilize the mean as the data distribution's standard measure. If the data is symmetrical, the mean is equal to the median, equal to the mode.

Formula

$$\overline{X} = \frac{\sum_{i=1}^{N} x_i}{N}$$

Eq. 2-1 Mean formula

Where:

x_i ith observation

N number of data observation

2.3.1.2 Median

When data are ranked ascending or descending, the sample median is in the middle. The mean is more sensitive than the median to outliers.

For an Even number of observations (Ungrouped data)

$$Median = \frac{N}{2} \text{ and } \frac{N+2}{2}$$

Eq. 2-2 Median formula for even observation

For an Odd number of observations (Ungrouped data)

$$Median = \frac{N+1}{2}$$

Eq. 2-3 Median formula for Odd observations

Where:

N is the number of data points

2.3.1.3 Mode

Mode refers to the data value frequently appearing in the collection. At times, data may have multiple modes.

2.3.2 Measures of dispersion

It describes data spread around a central value (mean, median, mode). It tells us about the variability of data.

2.3.2.1 Interquartile range (IQR)

The interquartile range (IQR) is the distance between the first and third quartiles. This range contains the central 50% of the data.

$$IQR = Q_3 - Q_1$$

Eq. 2-4 IQR formula

It describes the spread of the data about the median. As the spread of the data increases, the IQR becomes larger.

2.3.2.2 Standard deviation (SD)

The symbol σ (sigma) is frequently used to denote a population data set's standard deviation; s, on the other hand, reflects the standard deviation of a sample data set.

The standard deviation is frequently easier to read than the variance since it is expressed in the same units as the data.

Formula

If the column contains x 1, x 2,..., x N, with mean x, then the sample standard deviation is:

$$s = \sqrt{\frac{\sum(x_i - \overline{x})}{N - 1}}$$

Eq. 2-5 SD formula

Where:

x_i represents i^{th} observation

$\overline{\mathbf{x}}$ represents the mean of the observations

N represents observations

It represents the spread of data around the mean. The high the sigma value, the high is data spread around the mean.

2.3.2.3 Co-efficient of variation (CV)

The coefficient of variation measures relative variability calculated as a percentage. It is a standardized measure of a probability distribution or frequency distribution dispersion. It is also called relative standard deviation. The coefficient of variation is changed to make the values on a unitless scale. Because of this modification, you can compare the variation in data with different units or highly different means using the coefficient of variation rather than the standard deviation.

The greater the coefficient of variation, the greater the data spread.

Formula

$$\mathrm{CV} = \frac{\mathrm{SD}}{\mathrm{Mean}} * 100$$

Eq. 2-6 CV formula

2.3.2.4 Standard error of the mean (SE Mean)

It determines the differences between more than one sample of data. It helps you estimate how well your sample data represents the whole population by measuring the accuracy of the sample data representing a population using standard deviation.

The standard deviation divided by the square root of the sample size yields the standard error of the mean.

Formula

$$\boldsymbol{SE\ Mean} = \frac{\boldsymbol{s}}{\sqrt{\boldsymbol{n}}}$$

Eq. 2-7 represents SE Mean

Notation

s sample standard deviation

$\boldsymbol{n}$ number of non-missing observations

2.3.3 Measures of shape

It describes the distribution or pattern of the data within a data set.

2.3.3.1 Skewness (Sk)

Skewness is a measure of asymmetry or distortion that differs from the data collection's symmetrical bell curve or normal distribution. A positive value implies right-side skewness, a negative value shows left-side skewness, and a zero value represents symmetry or no skewness.

Formula

$$Sk = \frac{N}{(N-1)(N-2)} \sum [\frac{x_i}{s}]^3$$

Eq. 2-8 General Skewness formula

When the sample data exhibit a substantial mode value, we use Pearson mode skewness:

Formula:

$$Sk = \frac{(\overline{x} - M_o)}{s}$$

Eq. 2-9 Person mode skewness formula

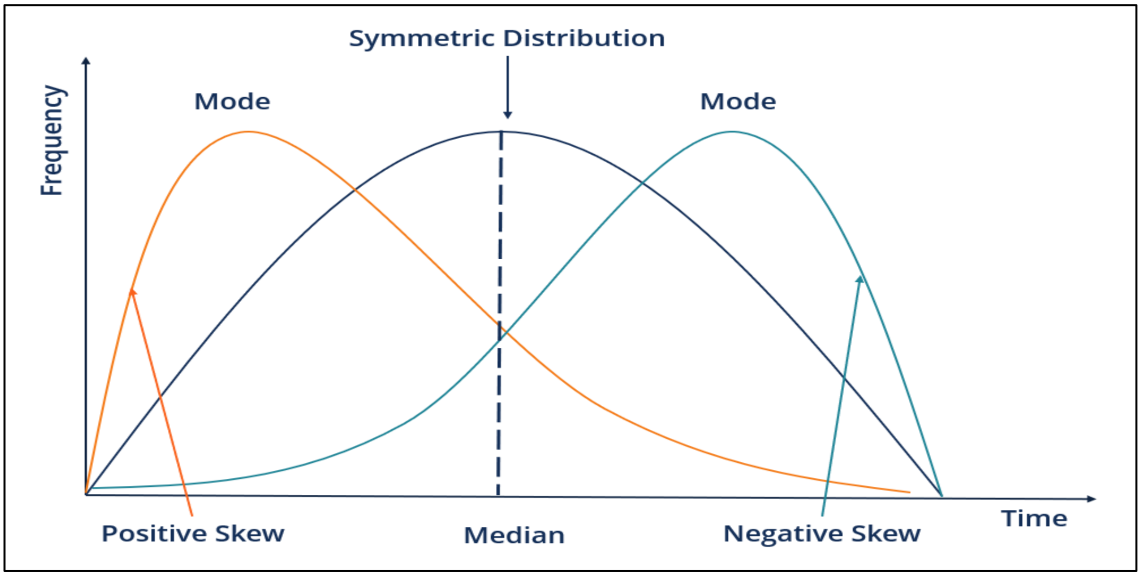
When the sample data exhibit a multiple or weak mode, we use Pearson median skewness:

$$Sk = \frac{(3\overline{x} - M_d)}{s}$$

Eq. 2-10 Person median skewness formula

Notation

Term	**Description**
x_i	i^{th} observation
$\overline{x}$	Mean of the observations
N	number of non-missing observations
s	sample standard deviation
M_o	Mode value of the data
M_d	Median value of the data



(Source: https://corporatefinanceinstitute.com/resources/data-science/skewness/)

Figure 2-3 Zero, positive and negative skewness curves

2.3.3.2 Kurtosis

Kurtosis is a statistical term that refers to the degree to which a distribution's tails deviate significantly from a normal distribution's tails. It is a generic term that refers to the features of data dispersion. In other words, kurtosis indicates whether a distribution's tails contain extreme values. Excess kurtosis is a statistic that compares a distribution's kurtosis to that of a normal distribution. A normal distribution's kurtosis equals three. Thus, the extra kurtosis is determined using the following formula:

$$Excess\ Kurtosis = Kurtosis - 3$$

Eq. 2-11 Excess kurtosis formula

We will use excess kurtosis in data analysis instead of kurtosis.

2.3.3.2.1 Types of kurtosis

Mesokurtic: Excess kurtosis is zero or close to zero for data that follows a mesokurtic distribution. A kurtosis value of 0 implies that the data is normal.

Leptokurtic: Leptokurtic denotes an excess of kurtosis in the positive direction. The leptokurtic distribution exhibits prominent tails on both sides, indicating the presence of solid outliers.

Platykurtic: A platykurtic distribution has a negative excess kurtosis. The kurtosis indicates the presence of distribution with flat tails. The flat tails denote the distribution's minor outliers.

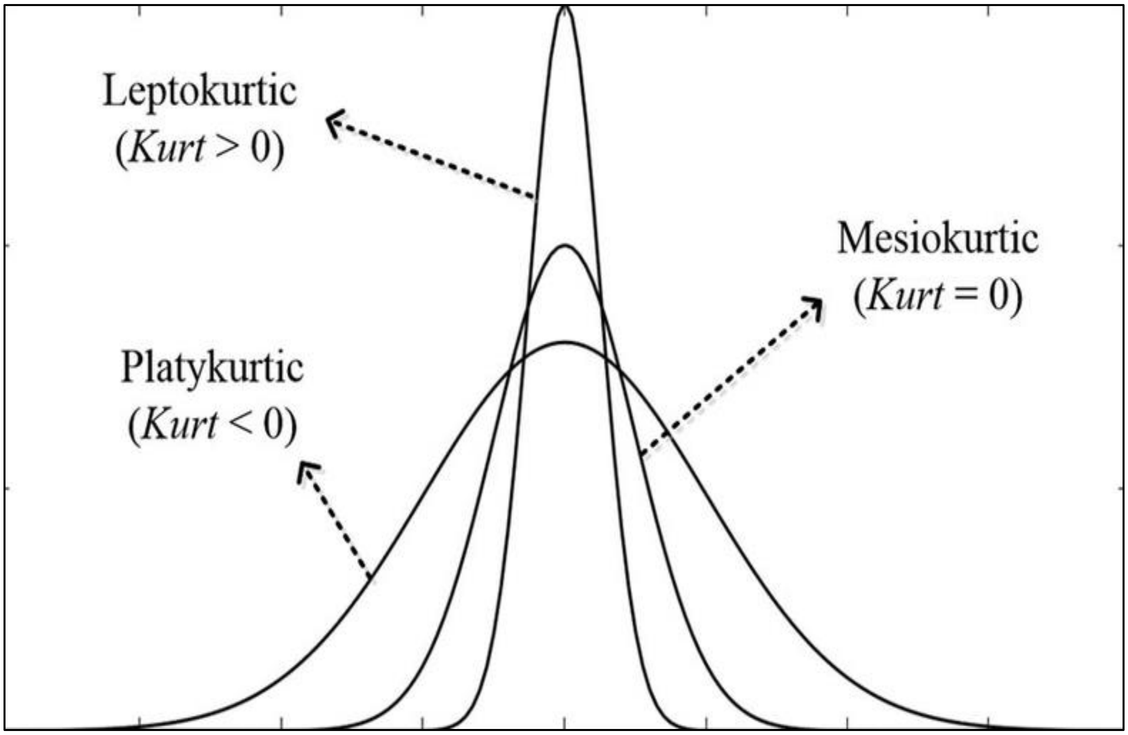


Figure 2-4 Mesokurtic, Platykurtic, and Leptokurtic curves

Formula

$$KR = \frac{N(N+1)}{(N-1)(N-2)(N-3)} \sum [\frac{x_i - \overline{x}}{s}]^4 - \frac{3(N-1)^2}{(N-2)(N-3)}$$

Eq. 2-12 Kurtosis formula

Notation

Term	Description
x_i	i^{th} observation
$\bar{x}$	Mean of the observations
N	number of non-missing observations
s	Standard deviation of the sample

The difference between skewness and kurtosis is that skewness measures the distribution's symmetry, whereas kurtosis quantifies the heaviness of the distribution's tails.

2.3.4 Measures of position (Quantiles)

It establishes the relative position of a single value inside a sample or population data collection. These cut points divide the range of a probability distribution into intervals of equal probability.

2.3.4.1 Quartiles

Quartiles are the three values–the first quartile at 25% (Q1), the second quartile at 50% (Q2 or median), and the third quartile at 75% (Q3) that divide a sample of ordered data into four equal parts. Quartiles help in detecting outliers and tell us about data spreads.

Q1: The first quartile is the 25th percentile and indicates that 25% of the data are less than or equal to this value.

Q2: The second quartile is the 50th percentile, indicating that 50% of the data are less than or equal to this value.

Q3: The third quartile is the 75th percentile, indicating that 75% of the data are less than or equal to this value.

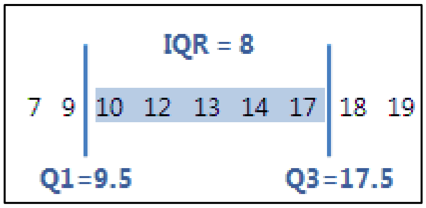


Figure 2-5 Quartiles and Interquartile range

2.3.4.2 Percentiles

The 85th and the 15th percentiles are two parameters commonly used in traffic engineering and safety.

The 15th percentile represents the speed below which 15% of vehicles are traveling at or below.

The 85th percentile indicates that 85% of the data are less than or equal to this value.

These values are helpful for traffic engineers to determine safe and efficient road design speeds and monitor traffic flow patterns. By considering the 15th and 85th percentile speeds, traffic engineers can better understand the range of speeds most drivers consider reasonable and safe and use this information to make decisions about road design and traffic control measures.

85th percentile speeds are used to set speed limits and evaluate the effectiveness of safety countermeasures, and 15th percentile speeds are used to establish typical walking speeds for traffic signal timing. (Hou, Sun and Edara, 2012)

2.4 Hypothesis testing

A statistical hypothesis test is a method of statistical inference used to decide whether the data at hand sufficiently support a particular hypothesis. It uses a null and alternative hypothesis as mutually exclusive statements about a population.

Null hypothesis

The null hypothesis states that a population parameter (such as the mean, standard deviation, etc.) equals a hypothesized value. The null hypothesis is often an initial claim based on previous analyses or specialized knowledge.

Alternative hypothesis

The alternative hypothesis states that a population parameter is minor, more significant, or different from the hypothesized value in the null hypothesis. The alternative hypothesis is what you might believe to be accurate or hope to prove true.

Level of significance (α)

Select the α value for hypothesis testing. Generally, $\alpha = 0.05$ is used for headway analysis, and $\alpha = 0.01$ is used for speed analysis.

Test statistic

Test statistic value is determined from different equations depending upon the type of hypothesis testing.

Interpretation

If the absolute value of the test statistics is greater than the critical value, you reject the null hypothesis. If it is not, you fail to reject the null hypothesis.

A probability value (P-value)

The p-value measures the evidence against the null hypothesis. A smaller p-value provides more robust evidence against the null hypothesis.

Interpretation

To determine whether the difference between the population parameters is statistically significant, compare the p-value to the significance level.

P-value ≤ α: The difference between the population parameters is statistically significant (Reject H_0)

P-value > α: The difference between the population parameters is not statistically significant (Fail to reject H_0)

Assumptions

- Normality of samples (Normality plot, Central limit theorem)

- The constant variance of samples (Residuals vs fits plots)
- Independence of samples (Residuals vs order plots)
- Continuous data samples

2.5 Selection of fitted distribution

It explains which methods select the best-fitted distributions for experimental data.

2.5.1 Goodness-of-fit test

The goodness of fit (GOF) tests measure a random sample's compatibility with a theoretical probability distribution function. In other words, these tests show how well your selected distribution fits your data. They are based on hypothesis testing having nun and alternative hypotheses. There are many goodness-of-fit tests, but the Kolmogorov-Smirnov test is essential here.

2.5.1.1 Kolmogorov-Smirnov test

This test decides if a sample comes from a hypothesized continuous distribution. It is based on the empirical cumulative distribution function (ECDF). Assume we have a random sample x_1, ..., x_n from some distribution with CDF *F(x)*. The empirical CDF is denoted by

$$F_n(X) = \frac{1}{n}.\left[Number\ of\ observation \leq x\right]$$

Eq. 2-13 Empirical cumulative distribution function

Definition

The Kolmogorov-Smirnov statistic (D) is based on the enormous vertical difference between the theoretical and the empirical cumulative distribution function:

$$D = Max_{1\leq i\leq n}\left(F(x)_n - \frac{i-1}{n}, \frac{i}{n} - F(x)_n\right)$$

Eq. 2-14 Kolmogorov-Smirnov statistic

Hypothesis Testing

The null and the alternative hypotheses are:

H_0: the data follow the specified distribution.

H_A: the data do not follow the specified distribution.

The hypothesis regarding the distributional form is rejected at the chosen significance level (**α**) if:

- The test statistic, D, is greater than the critical value obtained from a table.
- P-value ≤ α

The K-S test's advantage over the Chi-Square test is that the K-S test can use data with a continuous distribution, and there is no minimum frequency per test interval (Binned data) (Massey, 1951). The K-S test's advantage over the Anderson-Darling test is that the K-S test is not limited to specific distributions. The k-S test gives less weightage to tails. In addition, because the K-S test is non-parametric and distribution-free, it cannot assume the data distribution. K-S test location, scale, and shape parameters are estimated from the data. This research uses the K-S test to identify the best-fitted models because of these advantages, realizing research data does not closely follow the normal distribution.

2.5.2 Graphical Representation

It consists of different graphs which tell us whether the theoretical distribution follows the field data.

2.5.2.1 P-P Plot

The probability-probability (P-P) plot graphs the "empirical CDF values plotted against the theoretical CDF values." It determines how well a specific distribution fits the observed data. This plot will be approximately linear if the specified theoretical distribution is the correct model.

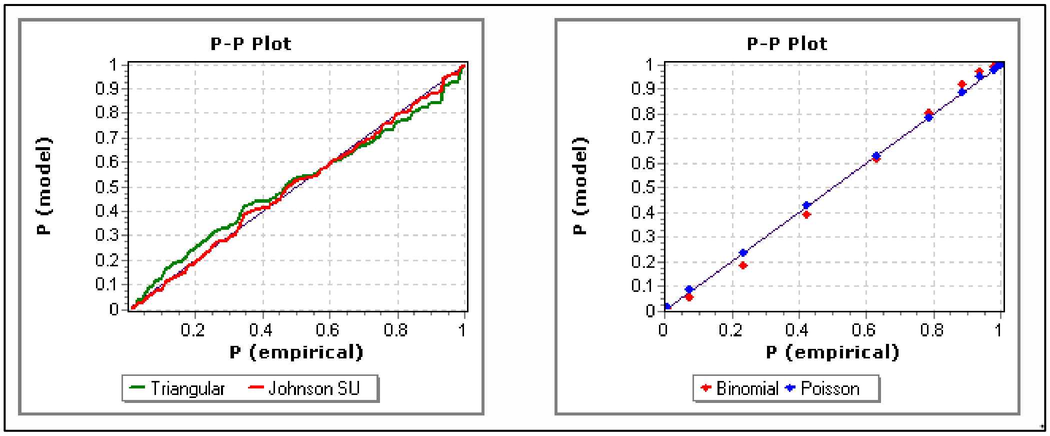


Figure 2-6 P-P plot for continuous and discreet data

2.5.2.2 Q-Q Plot

The quantile-quantile (Q-Q) plot is a graph of the "input (observed) data values plotted against the theoretical (fitted) distribution quantiles." Both axes of this graph are in units of the input data set.

The quantile-quantile graphs are produced by plotting the observed data values x_i (i = 1, ..., n) against the X-axis and the following values against the Y-axis:

$$F^{-1}(F_n(x_i) - \frac{0.5}{n})$$

Eq. 2-15 Q-Q plot formula

Where:

$F^{-1}(x)$ — inverse cumulative distribution function (ICDF);

$F_n(x)$ — empirical CDF;

n — sample size.

The Q-Q plot will be approximately linear if the specified theoretical distribution is the correct model.

2.5.2.3 Probability Difference

The probability difference graph is a plot of the difference between the empirical CDF and the theoretical CDF:

$$Diff_{(x)} = F_n(x) - F(x)$$

Eq. 2-16 Probability difference formula

This graph can determine how well the theoretical distribution fits the observed data and compare the goodness of fit of several fitted distributions. It is displayed as a continuous curve or a scatterplot for continuous distributions and a collection of vertical lines (at each integer x) for discrete distributions:

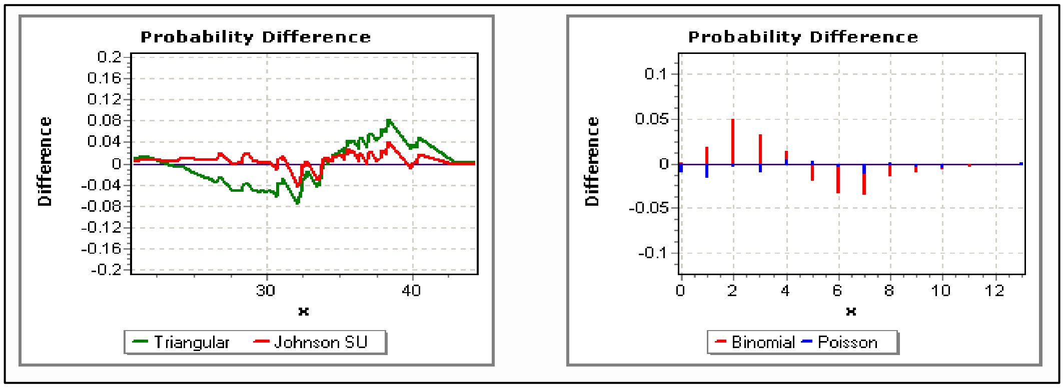


Figure 2-7 Probability difference plot

2.6 Probability density function (PDF)

A probability density function, or density of a continuous random variable, is a function whose value at any given sample (or point) in the sample space can be interpreted as providing a relative likelihood that the value of the random variable would be close to that sample ('Grinstead and Snell's Introduction to Probability, 2006). For continuous distributions, the PDF is expressed in terms of integration between two points:

$$\int_a^b f(x)dx = P(a \leq x \leq b)$$

Eq. 2-17 PDF for continuous data

The empirical PDF is displayed as a histogram consisting of equal-width vertical bars (bins), each representing the number of sample data values (falling into the corresponding interval) divided by the total number of data points. The theoretical PDF is displayed as a continuous curve appropriately scaled depending on the number of intervals. The scaling means multiplying the PDF values by the interval width.

2.6.1 Types of Parameters in Probability Distribution

There are several types of parameters in probability distributions, including:

1. **Location parameter (μ or θ):** It determines the location of the distribution along the x-axis. An increase in this parameter shifts the distribution to the right. A decrease in this parameter shifts the distribution to the left. This parameter is most likely the mean of the distribution. A positive increase in the mean shifts the distribution to the right, resulting in a positive skew. A negative decrease in the mean shifts the distribution to the left, resulting in a negative skew.
2. **Scale parameter (σ or β):** It determines the spread or variability of the distribution. An increase in this parameter spreads out the distribution. A decrease in this parameter makes the distribution more compact.
3. **Shape parameter (λ or α or** k): It determines the distribution's shape. An increase in this parameter makes the distribution more peaked. A decrease in this parameter makes the distribution flatter.
4. **Shape-location parameter (γ):** It combines the effects of the location and shape parameters into one. An increase in this parameter shifts the distribution to the right, making it more peaked. A decrease in this parameter shifts the distribution to the left, making it flatter.
5. **Scale-location parameter (δ):** It combines the effects of the location and scale parameters into one. An increase in this parameter shifts the distribution to the right and spreads it out. A decrease in this parameter shifts the distribution to the left, making it more compact.
6. **Shape-scale parameter (η):** It combines the effects of the shape and scale parameters into one. An increase in this parameter makes the distribution more peaked and spreads. A decrease in this parameter makes the distribution flatter and more compact.
7. **Nuisance parameter (ζ or ε):** It is a parameter that is not of direct interest but is needed to specify the distribution fully. These parameters typically do not directly affect the distribution's location, scale, or shape.

2.7 Previous research

Due to the presence of different types of vehicles and their complex movement patterns on the same road space, there is a wide variation in the extent of vehicular interactions with the variation in the traffic mix. Due to significant variations in the traffic mix, it does not always follow conventional distributions.

2.7.1 Speed distribution

Much research explains speed distribution patterns in homogeneous traffic conditions, but only a few demonstrate the distribution pattern under heterogeneous traffic. (Zhang et al.,1998) used normal distribution in the simulation study and lognormal distribution in applying the matching-Furness method to estimate the real data trip matrix with platoon dispersion. (Dixon *et al.*, 1999) examined speed data in 12 sites on rural multilane highways and concluded that the distribution of free-flow speed was normally distributed. (Park et al.,2010) explored the distribution of 24-hour speed data with a g-component normal mixture model. (June et al.,2010) suggested that the Gaussian mixture model using the EM algorithm on specific roadway systems could properly characterize the severity and variability in speed distribution due to congestion under mixed traffic conditions on the interstate freeway. (Hashim et al. 2011) conducted a study on a two-lane rural highway in Egypt. He found that the speed data were normally distributed by conducting the Kolmogorov-Smirnov one-sample test. (Praticò and Giunta, 2011) Studied low-volume roads in Italy and observed that speeds are normally distributed. (Zou and Zhang, 2011) said that a single normal distribution could not accurately accommodate the excess kurtosis present in the speed distribution. They proposed skew-normal and skew-t distribution to fit speed data. They suggested that these two distributions can be applied effectively for homogeneous and heterogeneous traffic. (Sacchi et al., 2012) developed a new operating speed model to predict urban arterial and collector street speeds. He found that speed data in all sites are normally distributed. (Wang *et al.*, 2012) introduced truncated normal and lognormal distribution for modeling speeds and travel time. (Chandra et al., 2013) conducted a study on the multilane divided urban road under mixed traffic conditions. They concluded that speed distribution would follow a normal distribution if SSR (Speed Spread ratio) is between 0.86-1.11. (Hustim et al., 2013) have studied speed distribution in two and four lanes one-way roads on heterogeneous traffic in Makassar, Indonesia. They found that the majority of the road sites failed the normality tests. (Maurya, Dey, and Das, 2015) divide the traffic into different flow levels and conclude that Lognormal distribution is best fitted for the speed of the entire traffic flow. (Singh and Santhakumar, 2021) conducted speed study on multi-class commercial vehicles utilizing IR sensors. They concluded that commercial vehicles uniquely affect highway characteristics under mixed traffic.

2.7.2 Time Headway distribution

Vehicles' time headways in heterogeneous traffic are different from homogeneous traffic. Many TH models have been created to represent vehicle headway distribution. The actual headways distribution is between negative exponential and normal. Starting from (Adams, 1936), who formulated the idea of arrival as a Poisson process, he concluded that the negative exponential distribution would best fit the time headway distribution. (Dawson and Chimni, 1968) proposed the Hyperlang model as a linear combination of translated exponential and Erlang functions. (Tolle, 1971) concluded that the lognormal distribution provided a good fit for platoons' traffic. (Cowan, 1975) proposed four headway models, M1, M2, M3, and M4, yielding the Poisson process, shifted exponential distribution, mixed and exponential distribution, and generalized M3 distribution. (Griffiths and Hunt, 1991) considered double displayed negative exponential distribution appropriate for modeling the vehicular headways in urban areas. (Hoogendoorn and Botma, 1997) & (Hoogendoorn and Bovy, 1998) proposed a new parameter estimation technique based on Fourier-series analysis for time headway models. They used time headway data from a two-lane rural highway and the estimated parameters for vehicle-type-specific headway distributions with a Pearson-III-based Generalized Queuing Model (GQM). (Hossain and Iqbal, 1999) reported that the headways followed exponential and lognormal distribution for the vehicles in Dhaka. Under homogeneous conditions, Al-(Ghamdi, 2001) suggested that negative exponential distribution fitted well for flow rates less than 400 veh/h, shifted exponential and gamma distribution for medium flows, i.e., 400-1200 veh/h and Erlang distribution for high flows above 1200 veh/h. (Chandra and Kumar, 2001) reported Hyperlang distribution as the best distribution to describe headways on urban roads under mixed traffic. (Zhang, 2007) said Doubly Displaced negative exponential distribution (DDNED) fitted well for flow levels 400 veh/h and

1,400 veh/h. (Riccardo and Massimiliano, 2012) found that Inverse Weibull distribution fitted well for most flow rate ranges and Log Logistic, Person 5 fitted well for high flow rates on two-lane two-way roads in the Province of Venice. (Dubey et al., 2013) reported Weibull + Lognormal (WLN) and Weibull + Extreme value (WEV) models as the best mixture models to model time gaps at flows of 2300 veh/h and 1900 veh/h, respectively, under mixed traffic conditions in Chennai. (Rossi, Gastaldi and Pascucci, 2014) conducted a study on two-lane bidirectional rural roads in Italy and found that the Skew-T single model turned out to be the one that best fitted the observed phenomena. (Maurya, Dey and Das, 2015) conducted a study on four two-lane bidirectional roads in Assam under mixed traffic conditions. The traffic was divided into six different flow levels. They concluded that Log-Pearson Type 3 distribution is best fitted for all flow levels ranging from 0-600 PCU/h, the Gamma distribution is best suited for 600-800 PCU/h, Inverse Gaussian distribution is best served for 800-1000 and 1000- 1200 PCU/h. (Badhrudeen, Ramesh and Vanajakshi, 2016) Carried out a study on the whole traffic stream and mode-wise characteristics and concluded that Weibull distribution is the most subtle approach. (Das and Maurya, 2017) Intends to study the variations in time headway distributions for four flow levels (0‑600, 600‑1200, 1200‑1800, and 1800‑ 2400 PCU/h) for different two-lane and four-lane roads in Assam. They concluded that Log-Pearson 3 and lognormal distributions are suitable for modeling mixed vehicle-type headways on all two-lane highways with a traffic flow of fewer than 600 PCU/h and on four-lane roads; both the Log-Pearson 3 and Weibull distributions are appropriate. Log-logistic and lognormal distributions match the headway distribution patterns for all two-lane roads with traffic volumes greater than 600 PCU/h. The lognormal distribution is suitable for describing time headway data for all two-lane roadways, regardless of traffic volume. For four-lane roads, Burr and Log-Pearson distributions are appropriate for traffic flows between 600 and 1200 PCU/h, whereas Lognormal and log-logistic distributions are suitable for traffic rates above 1200 PCU/h. (Roy and Saha, 2018) studied the two-lane road under heterogeneous conditions and found that log-logistic and Pearson 5 distributions are best to approach for moderate and congested flow, respectively.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter illuminates the data information and analysis methodologies used in the research. The idea of selecting the most valuable data for the analysis will also be discussed. Proper data selection is crucial to ensure accurate analysis and reliable results. The chapter outlines the study site characteristics, data overview, and PCU estimation. It describes traffic data characteristics and preliminary research to represent data behavior and statistics.

3.1.1 Schematic representation of research

Figure 3-1 represents the number and type of activities carried out in research work. It also demonstrates the logical sequence of the activities.

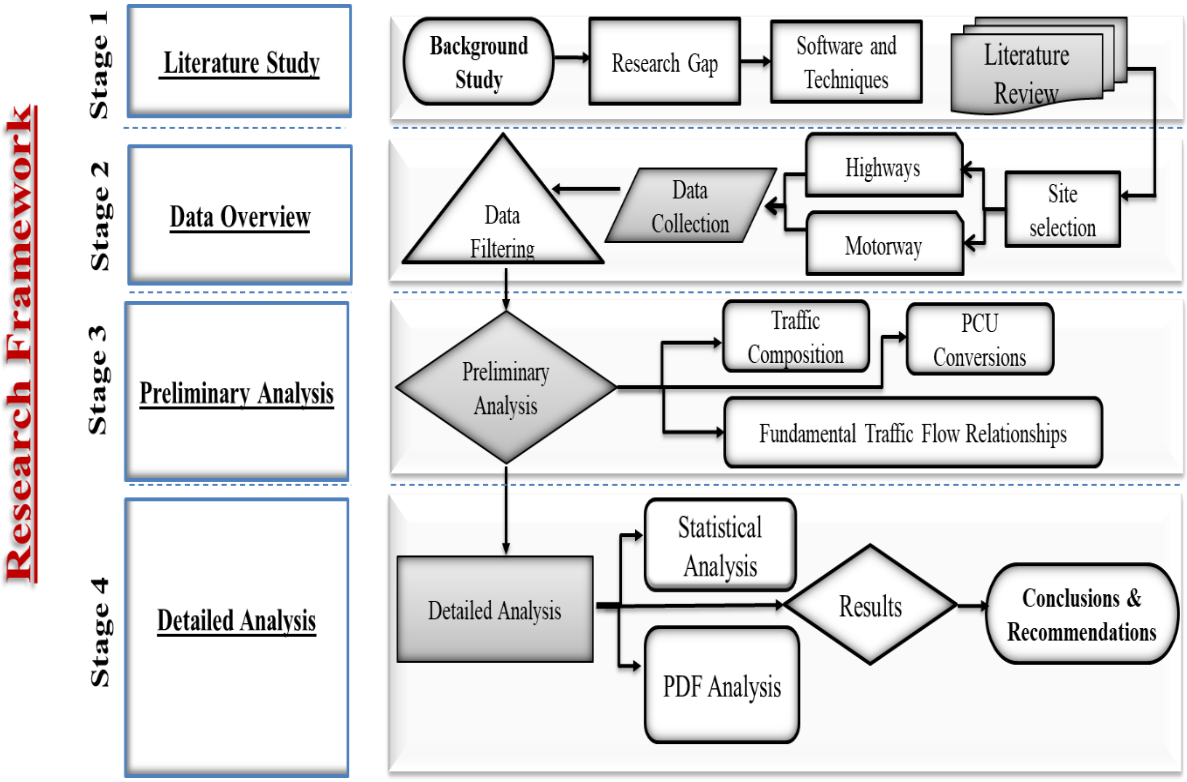


Figure 3-1 Schematic diagram of research work

3.2 Characteristics of traffic data

Traffic flow observations at a certain point (cross-section) of a road segment help describe the traffic flow characteristics of the entire segment only if we accept the hypothesis that the segment is homogeneous (in geometric and functional terms). And, on the segment and for a specific time interval, steady traffic conditions exist (constant traffic volume, regardless of the section position along the road segment, and time-independent traffic density)(Riccardo and Massimiliano, 2012). The field studies examine the time headways and speed in free-flowing traffic on desired road sites.

3.3 Geometric details of sites

The highway sites are uninterrupted facilities with uniform traffic operating conditions, leveled portions without vertical gradient, and straight parts without horizontal curvature. Also, the sites are free from access points in the vicinity of data collection zones to ensure minimal or no influence of side friction on the traffic flow other than the influence of multi-class CVs. The chosen sites are free from any side hindrance, such as parking lots, gradients, bus stops, intersections, etc. The selected pavements' conditions are excellent and free from ribbon development. We also assume that steady traffic conditions prevailed concerning a time sub-interval of 15 minutes.

Table 3-1 Geometric details of data collection sites

Road Type	Total no of lanes	Lane width(m)	Shoulder type	Shoulder width Int/Ext(m)	Median Separated	PRT Installation location
NH-5	4	3.65	Tripple surface bitumen Concrete	0.6/2	Yes /5.5m	N-5 near Mullan Mansoor
NH-45	4	3.65	Earthen	0.5 to 1.5/0.3	Yes/0.6m	N-45 near Raskai Interchange of M-1
M-1	6	3.65	Tripple surface bitumen Concrete	0.6/3	Yes/11m	M-1 near AWT-Sangjani Interchange

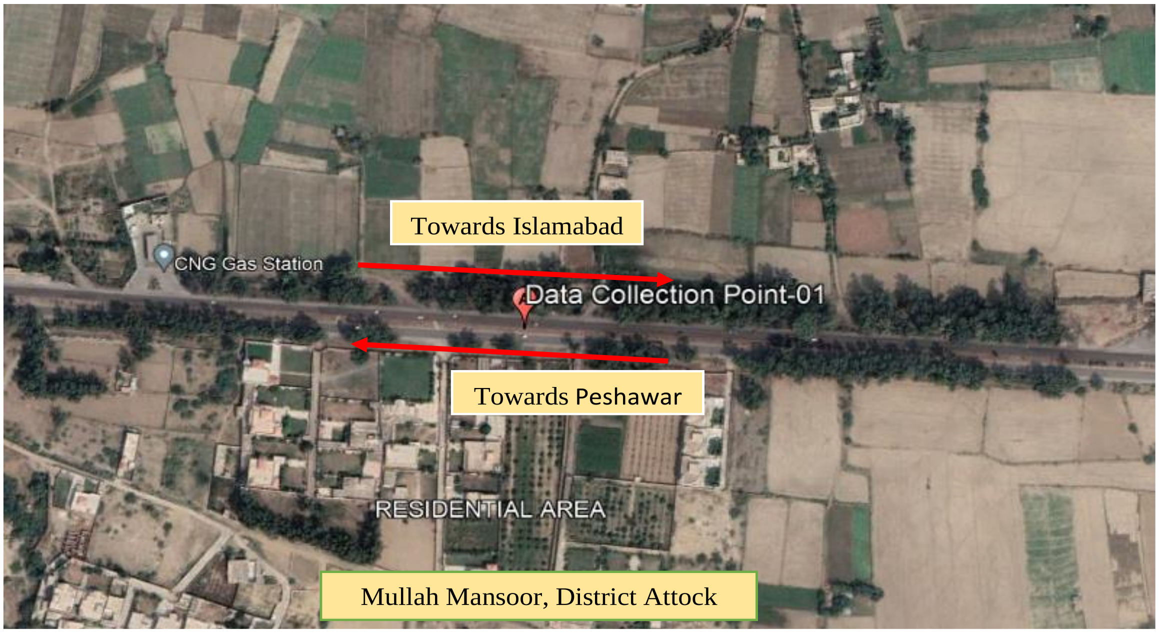


Figure 3-2 Data Collection Point-01 on N-5

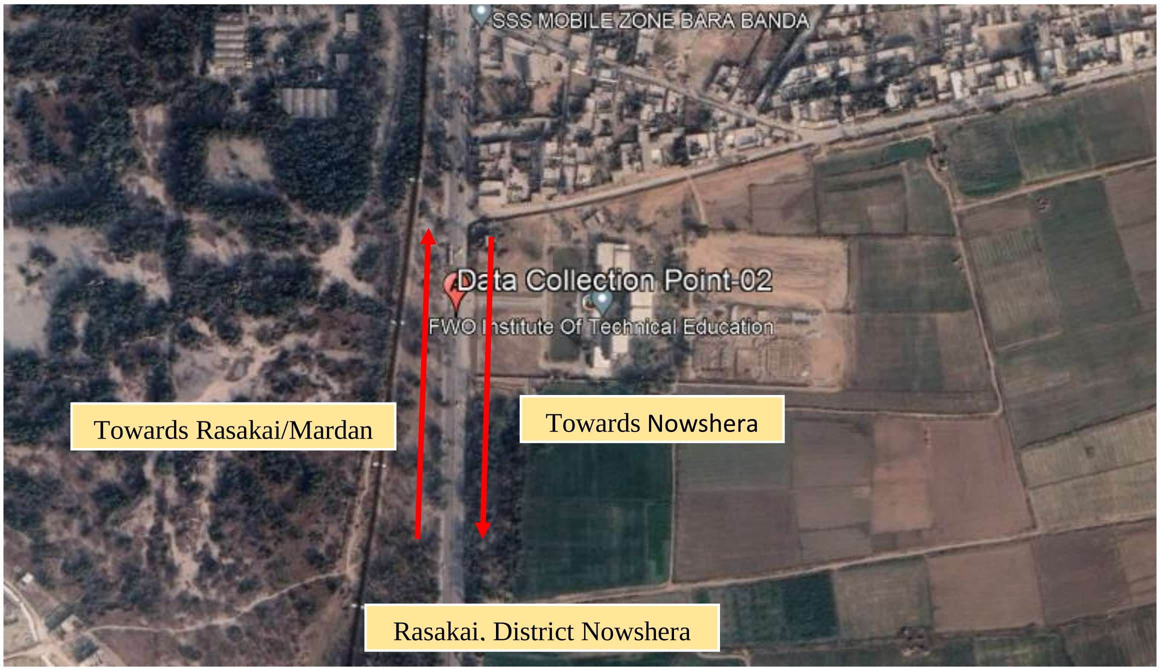


Figure 3-3 Data Collection Point-02 on N-45

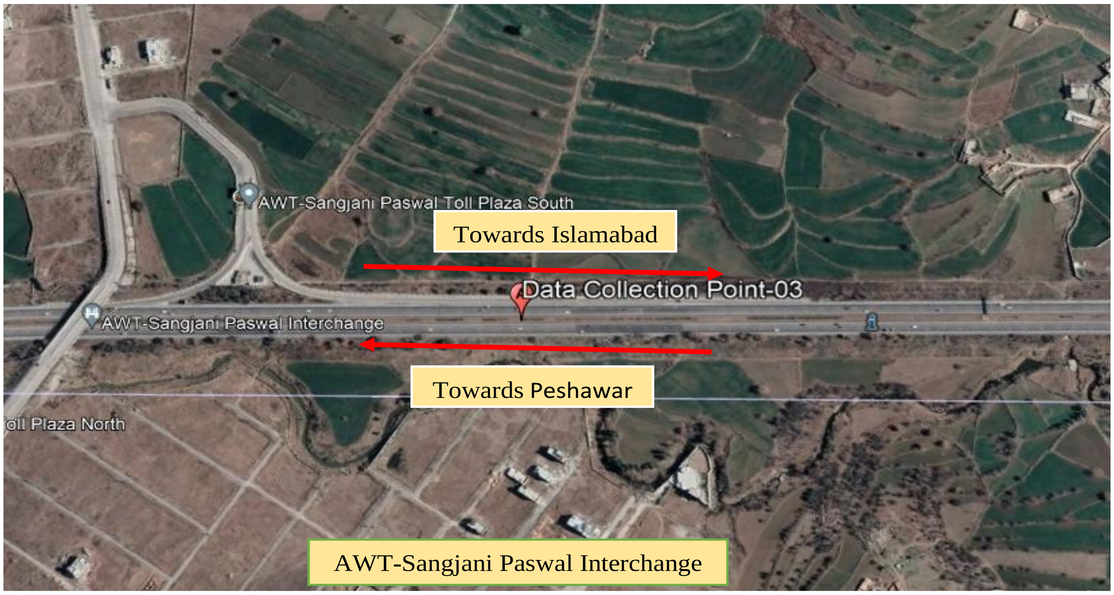


Figure 3-4 Data Collection Point-03 on M-1

3.4 Data Overview

It explains the general background of data. It consists of data requirements, data collection, and data filtering.

3.4.1 Data requirements

For a comprehensive analysis, we require eight days of continuous data collection covering weekdays and weekends, including peak and off-peak hours for northbound and southbound directions. To ensure accuracy, the data collection area should be clear of any obstructions or blockages. Outliers in the data will be carefully managed, and we will eliminate any instances of zero headways. This data is collected for individual lanes; two vehicles can't pass simultaneously in the same lane.

3.4.2 Data collection

The conventional videography methods for collecting and extracting massive traffic data are time-consuming and strenuous. This difficulty can be overcome using the PRT, which records each vehicle's arrival times, instantaneous speed, headway, gap, and wheelbase.

3.4.2.1 Traffic data collection using the Pneumatic tubes

The field data in our analysis came from the NTRC (National Transport Research Center). NTRC collected the data through a continuous survey using PRT installed on free-flow and homogeneous (in geometric and functional terms) road segments with the least count of 1 sec. Each PRT monitors directional traffic volumes on a single lane.

The data details the following individual vehicle information:

- Time of passage
- Date (Day/Month/Year)
- Speed
- Vehicle Class

3.4.2.2 Accuracy of the traffic data collected using Pneumatic tubes

The proper working of PRTs is manually checked with time to remove the chances of error. Speed, TH, and vehicle category are visually observed using a speed gun and stopwatch.

3.4.3 Data filtering

Eight days' data were filtered for N-45, N-5, and M1 from data provided by NTRC. This period includes four weekdays, two weekends, and two half-days to ensure a comprehensive analysis. We have eliminated any instances of zero-time headway values, except for M-1 SL, as it was observed that these values resulted from PRT overcounting since two vehicles cannot pass through a lane simultaneously on FL or SL.

3.5 Estimation of Passenger Car Units (PCU)

In general terms, traffic composition affects traffic operations significantly for the same traffic volume. For this reason, the effect of impedance caused by heavy vehicles cannot be omitted from the analysis. Hence, heterogeneous traffic must be converted to homogeneous traffic (equivalent passenger-car flow) by the passenger-car equivalent or unit (PCE or PCU). Since PCU is used as a volume count adjustment factor for different vehicle types on different lanes; therefore, it is considered a complex parameter in measuring traffic flow.

In this study, PCUs are estimated from NTRC:

Table 3-2 Vehicle class in terms of PCU

Vehicle Class	**PCU Factor**
Motorcycle	0.25
Rickshaw	0.5
Car/Jeep/Van/Taxi	1
Minibus/Coaster/Hiace	1.5
Large Buses	2.5
2-Axle Truck	1.5
3-Axle Truck	2.5
4-Axle Truck	3.5
>5-Axle Truck	4

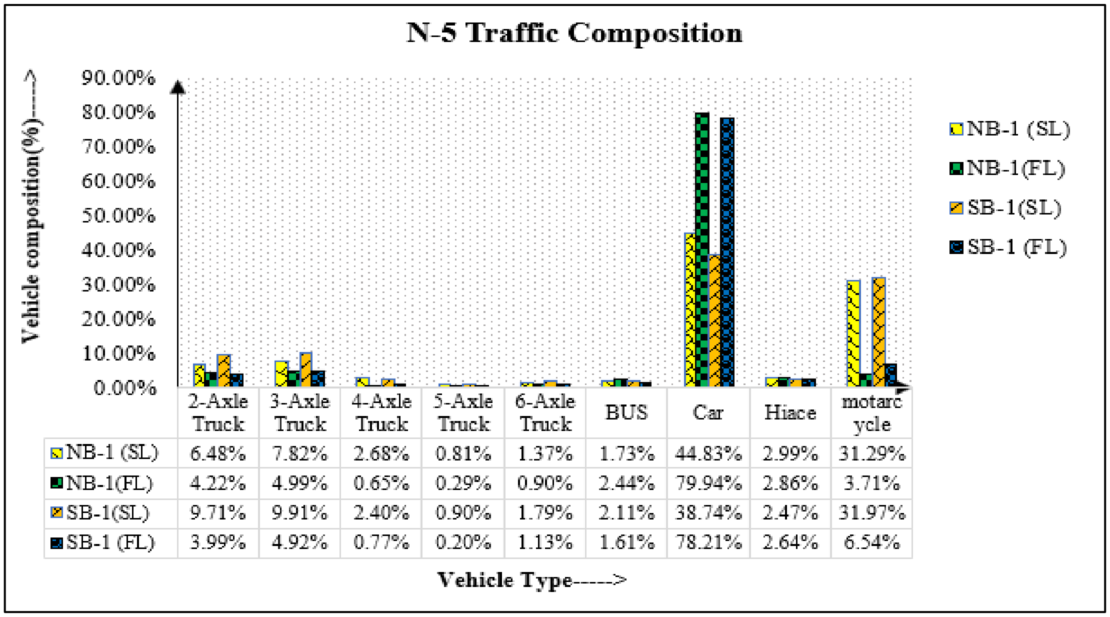
3.6 Preliminary analysis

Stream characteristics (speed, flow, and density) were averaged over 15-minute intervals for each road section. Fifteen minutes aggregation is a reliable representation of an hourly flow, yet they provide a sizeable sample of individual vehicles for further analysis. Headways are examined independently for each lane. The corresponding traffic volumes were converted into Passenger Car Units (PCU) according to NTRC (Table 2).

3.6.1 Directional Traffic composition

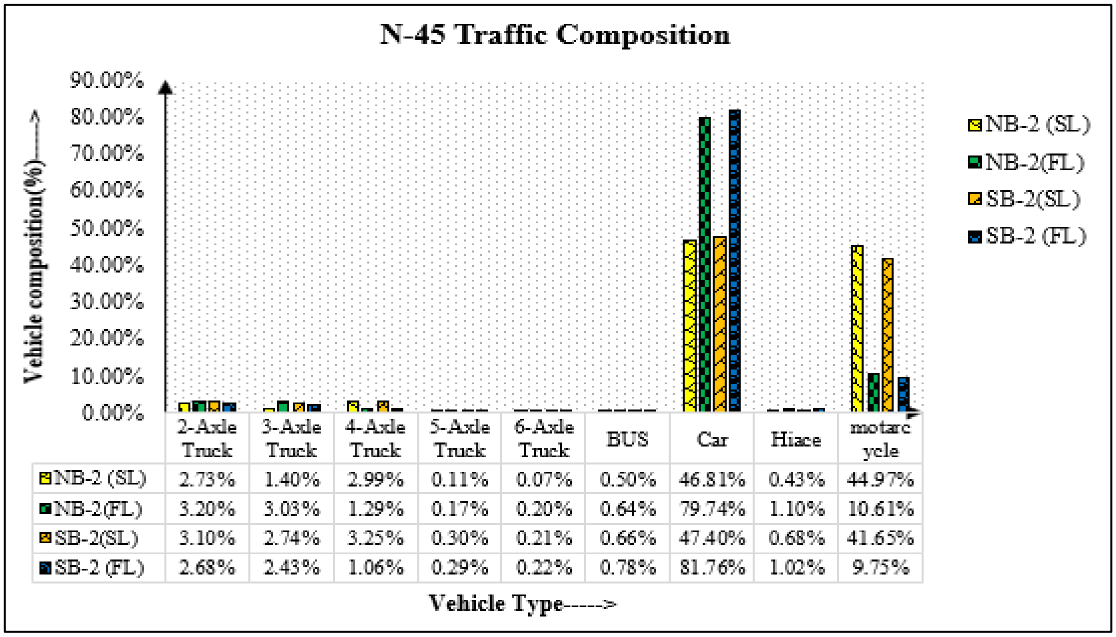
In this study, time headways and speeds were analyzed for both directions of traffic together. Significant differences were not observed in traffic composition and flow values between each direction of traffic at all sites, as shown in Figures 3-2, 3-3, and 3-4. Moreover, 2 sample t-tests and 2 sample F-tests were performed to compare the NB and SB directional flow of N-5, N-45, and M-1. Still, no significant differences in NB and SB data's mean and standard deviation concerning FL and SL were observed. Therefore, SB_FL data was synchronized with NB_FL data, and SB_SL data was synchronized with NB_SL data. The data was synchronized w.r.t date.

A complex interplay of factors, including flow rates and traffic composition, determines traffic flow's dynamic nature. Analysis of two four-lane roads, N-45 and N-5, revealed significant variations in these factors. Specifically, we observed that N-45 had a lower concentration of heavy vehicles and a high percentage of motorcycles than N-5, as depicted in Figures 3-5 and 3-6. This disparity can be attributed to the higher prevalence of motorcycles on N-45, which tend to intersperse themselves among larger vehicles due to their high maneuverability, impacting their mobility, as depicted in Figures 3-7 and 3-8.



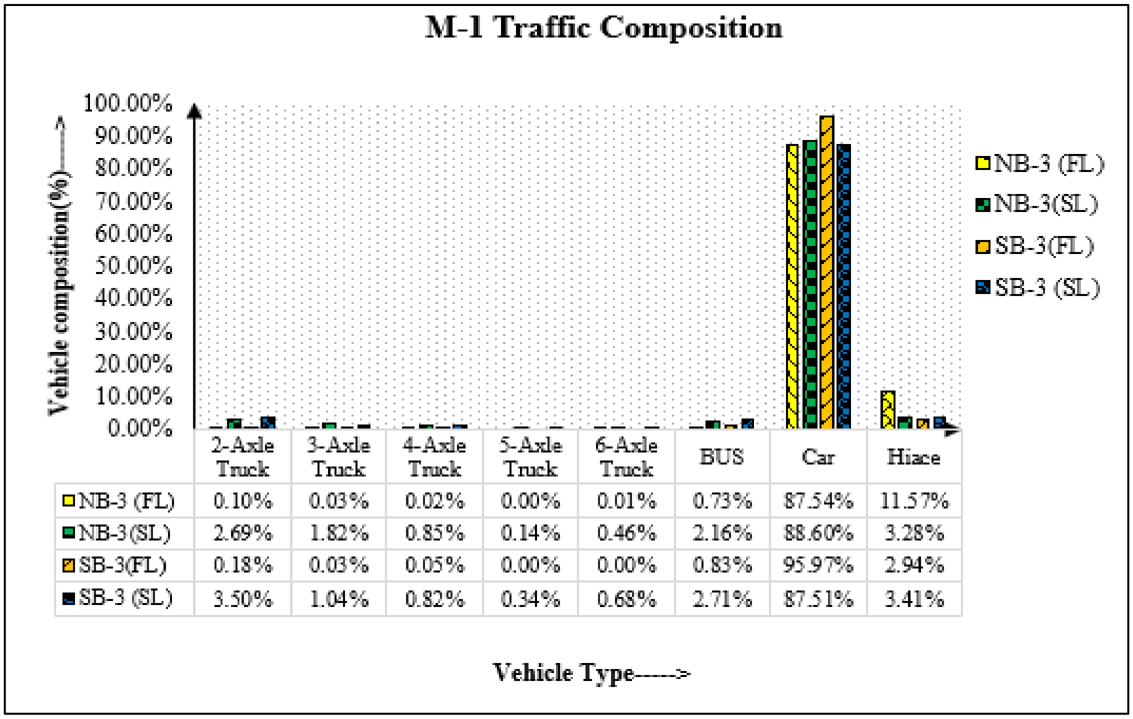
	2-Axle Truck	3-Axle Truck	4-Axle Truck	5-Axle Truck	6-Axle Truck	BUS	Car	Hiace	motarcycle
NB-1 (SL)	6.48%	7.82%	2.68%	0.81%	1.37%	1.73%	44.83%	2.99%	31.29%
NB-1(FL)	4.22%	4.99%	0.65%	0.29%	0.90%	2.44%	79.94%	2.86%	3.71%
SB-1(SL)	9.71%	9.91%	2.40%	0.90%	1.79%	2.11%	38.74%	2.47%	31.97%
SB-1 (FL)	3.99%	4.92%	0.77%	0.20%	1.13%	1.61%	78.21%	2.64%	6.54%

Figure 3-5 N-5 Directional Traffic Composition



	2-Axle Truck	3-Axle Truck	4-Axle Truck	5-Axle Truck	6-Axle Truck	BUS	Car	Hiace	motarcycle
NB-2 (SL)	2.73%	1.40%	2.99%	0.11%	0.07%	0.50%	46.81%	0.43%	44.97%
NB-2(FL)	3.20%	3.03%	1.29%	0.17%	0.20%	0.64%	79.74%	1.10%	10.61%
SB-2(SL)	3.10%	2.74%	3.25%	0.30%	0.21%	0.66%	47.40%	0.68%	41.65%
SB-2 (FL)	2.68%	2.43%	1.06%	0.29%	0.22%	0.78%	81.76%	1.02%	9.75%

Figure 3-6 N-45 Directional Traffic Composition



	2-Axle Truck	3-Axle Truck	4-Axle Truck	5-Axle Truck	6-Axle Truck	BUS	Car	Hiace
NB-3 (FL)	0.10%	0.03%	0.02%	0.00%	0.01%	0.73%	87.54%	11.57%
NB-3(SL)	2.69%	1.82%	0.85%	0.14%	0.46%	2.16%	88.60%	3.28%
SB-3(FL)	0.18%	0.03%	0.05%	0.00%	0.00%	0.83%	95.97%	2.94%
SB-3 (SL)	3.50%	1.04%	0.82%	0.34%	0.68%	2.71%	87.51%	3.41%

Figure 3-7 M-1 Directional Traffic Composition

Analysis of the traffic flow on a specific road section revealed a distinct disparity in the composition of vehicles between the fast and slow lanes. Specifically, the fast lane is characterized by a higher concentration of high-speed light vehicles, such as cars. In contrast, a more significant proportion of slow-moving vehicles, such as trucks, dominate the slow lane. This variation in vehicle types significantly impacts the overall traffic flow and highlights the intricate balancing act between maintaining a safe and efficient traffic flow on this road section.

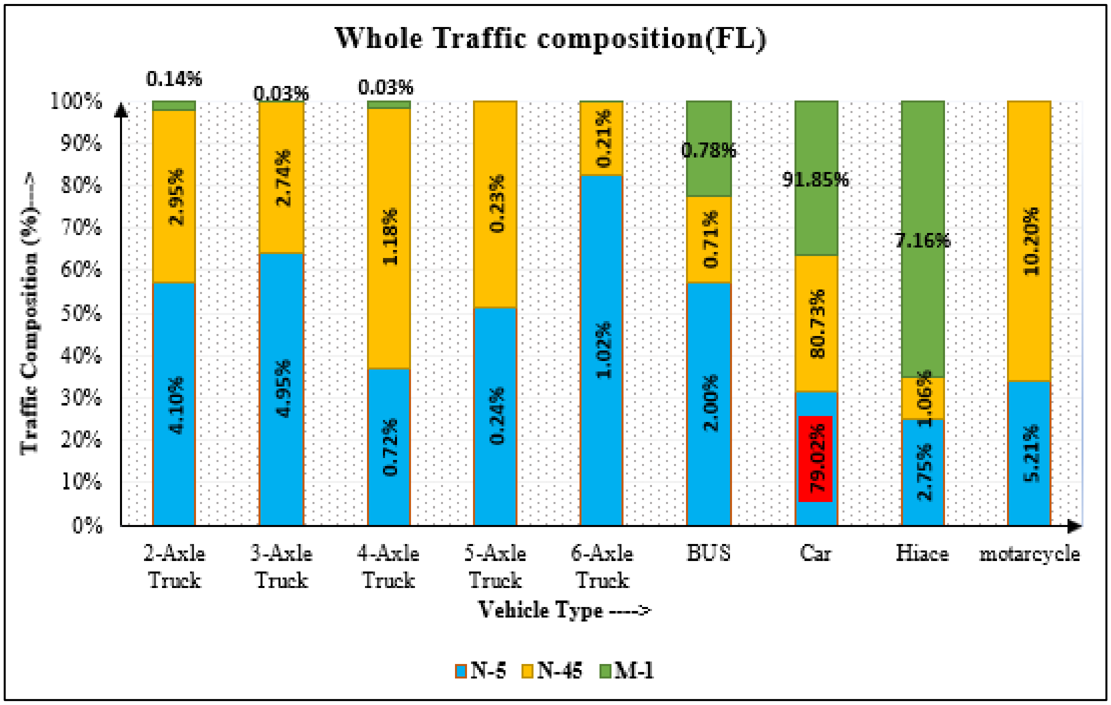


Figure 3-8 Fast Lane traffic composition

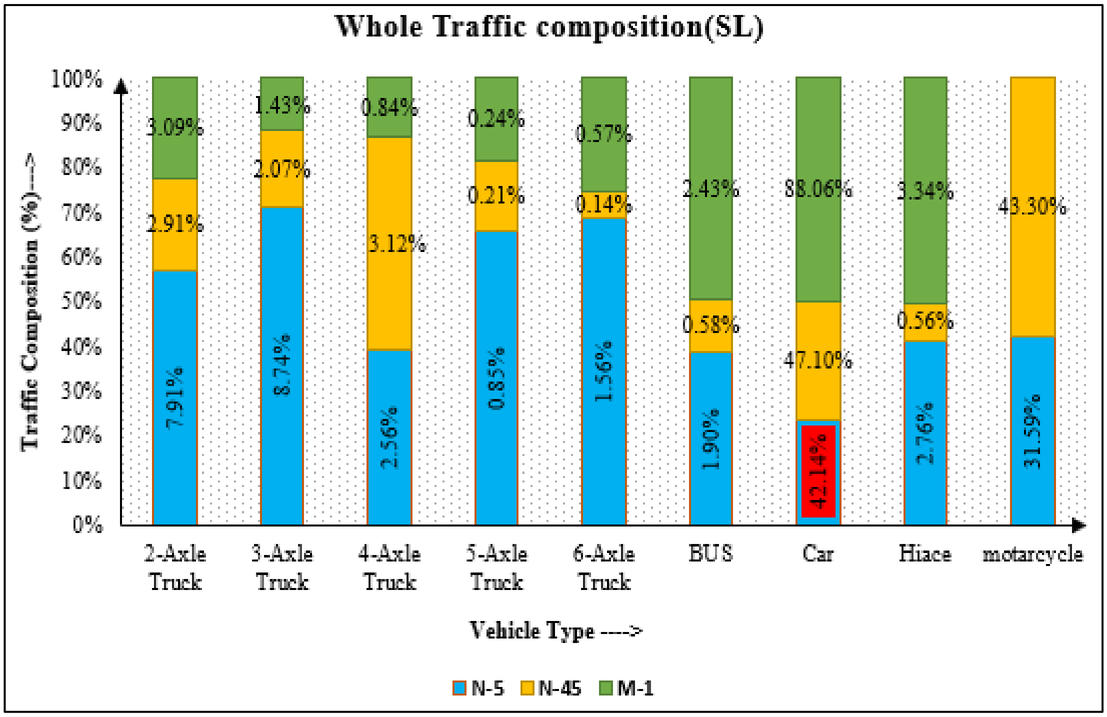


Figure 3-9 Slow Lane traffic composition

3.6.2 Fundamental traffic flow relationships

The flow-density, TH-flow, and speed-flow diagrams illustrate the traffic patterns observed on the FL and SL lanes at the M1 and NH sites, providing valuable insights into the traffic conditions during the analyzed periods.

3.6.2.1 N-5

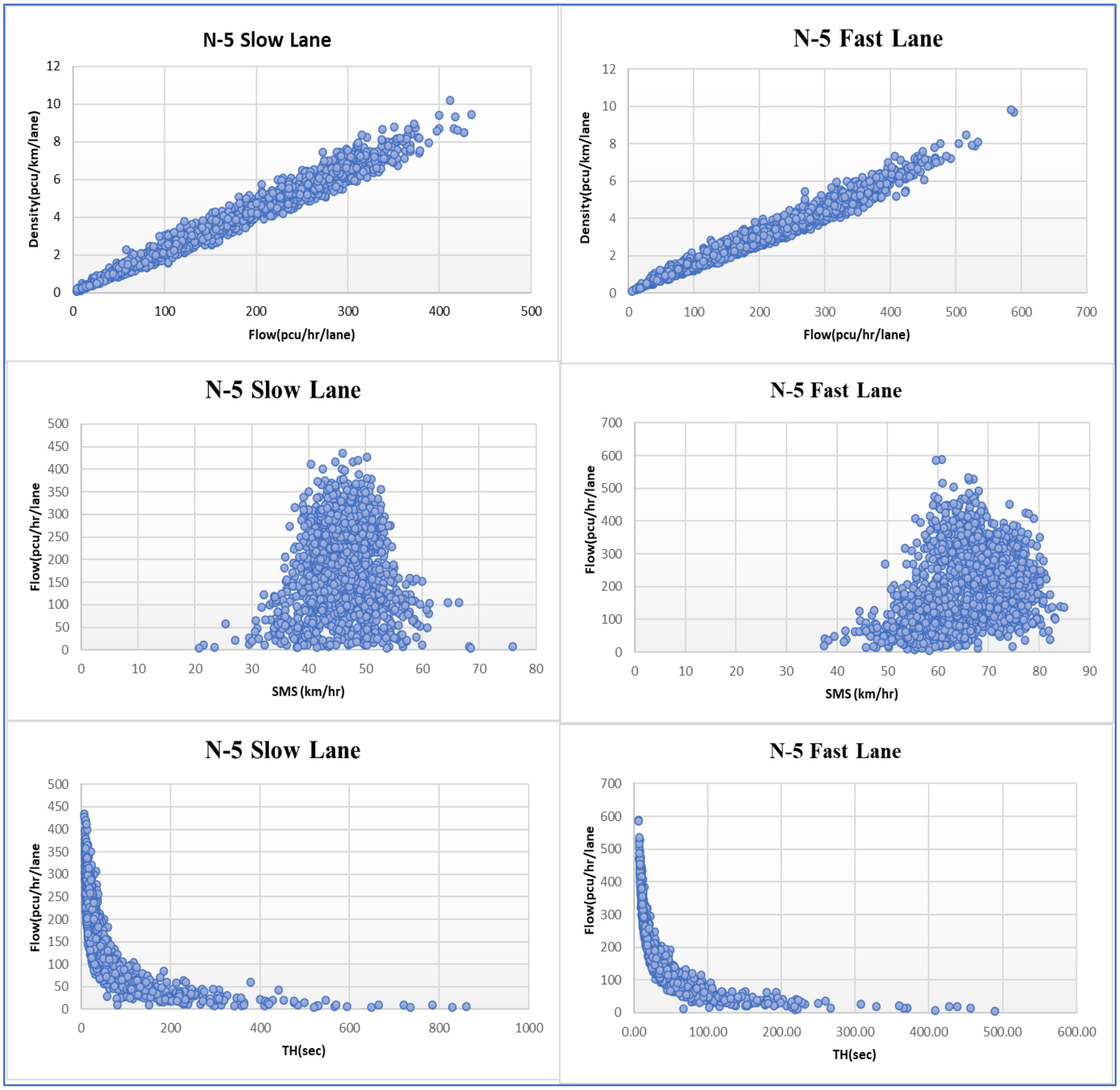


Figure 3-10 N-5 Density-Flow, TH-Flow, and Speed–Flow Diagrams

3.6.2.2 N-45

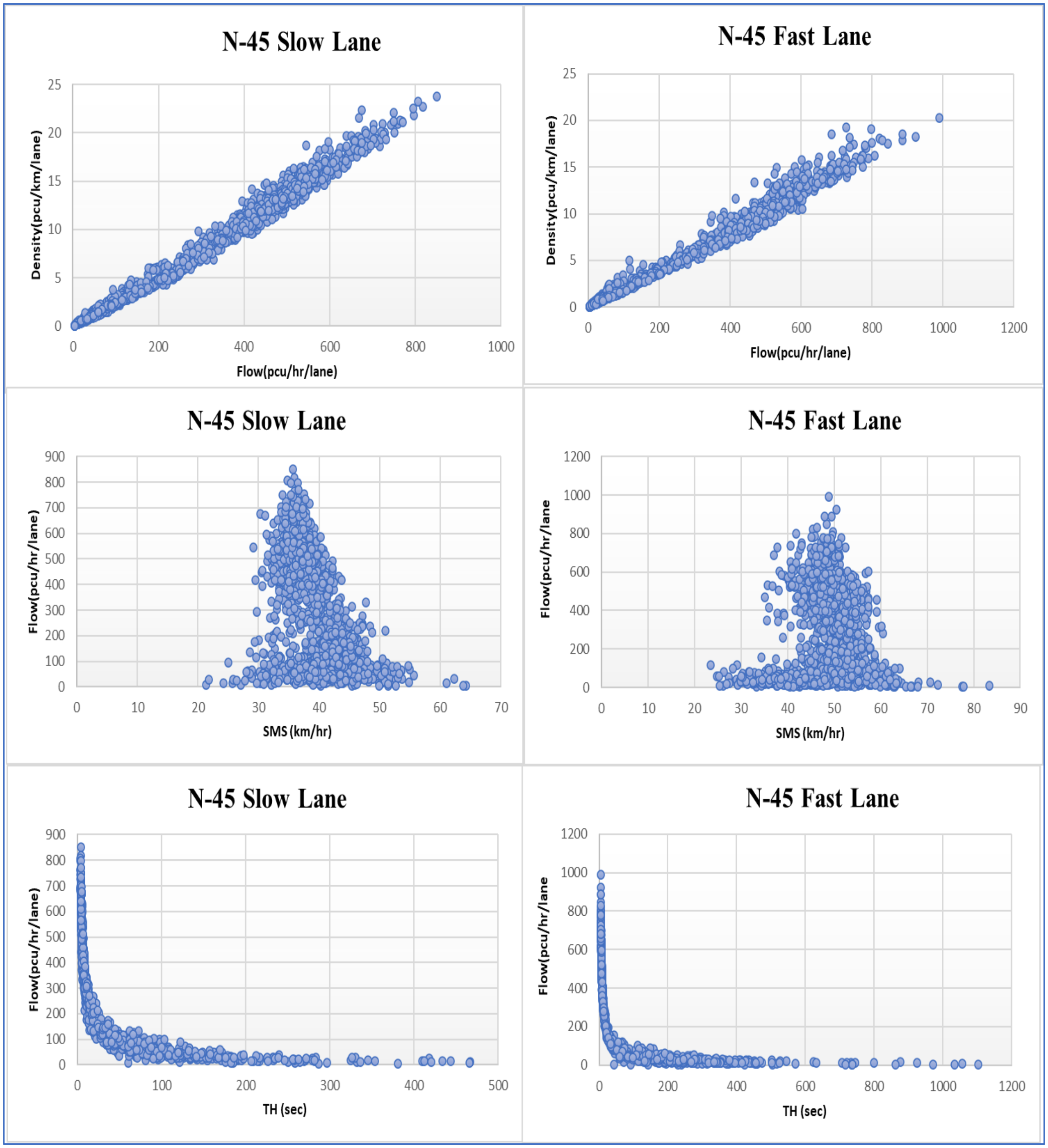


Figure 3-11 N-45 Density-Flow, TH-Flow, and Speed–Flow Diagrams

3.6.2.3 M-1

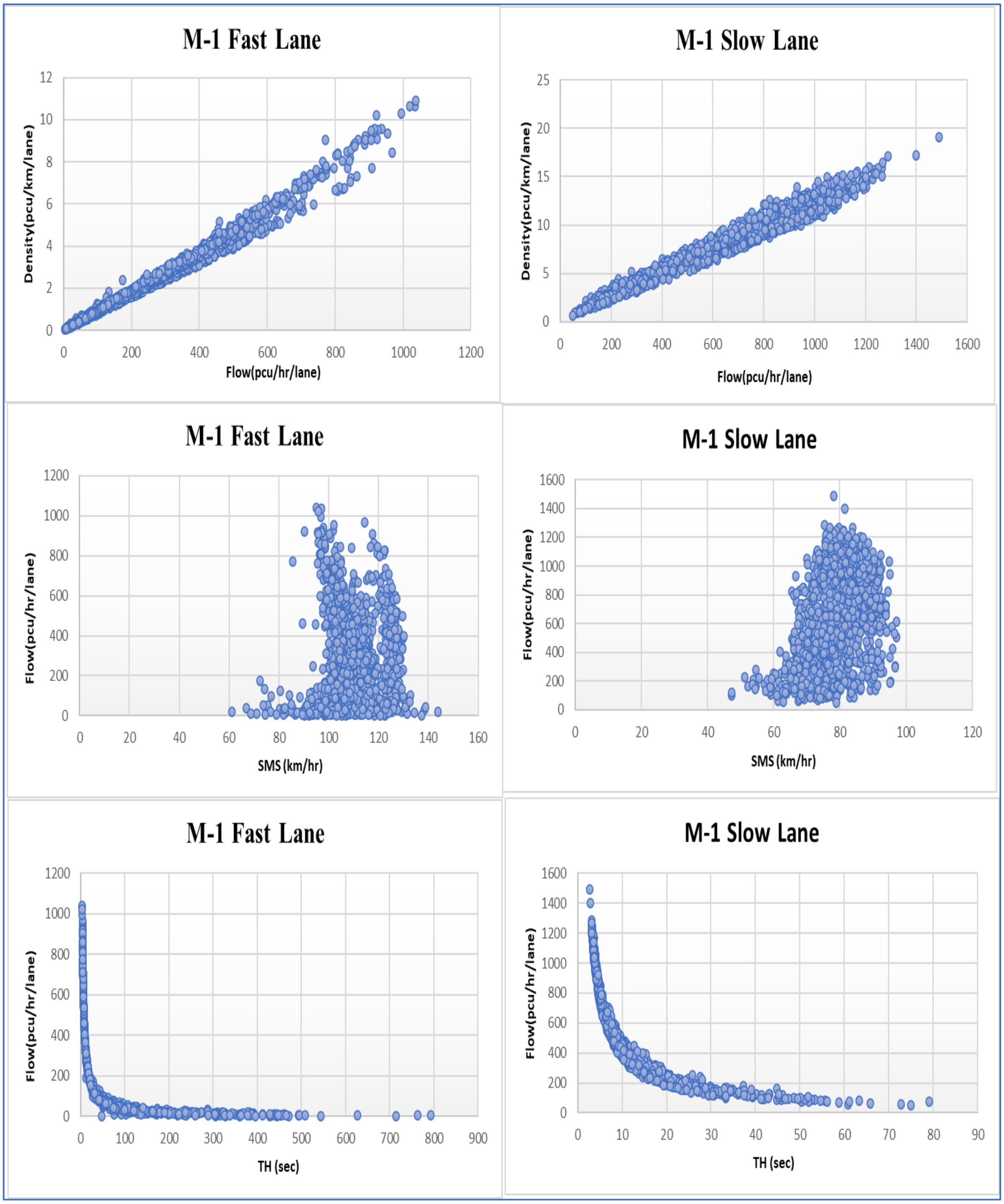


Figure 3-12 M-1 Density-Flow, TH-flow, and Speed–Flow Diagrams

Conclusion

These above figures depict that all the road sites exhibit varying traffic flow rates ranging from 0 PCU/h to 1500 PCU/h (M-1). The maximum traffic flows observed at different sites are 600 PCU/hr at (N-5),1000 PCU/hr at (N-45), and 1500 PCU/hr at (M-1). Flow rate is one of the endogenous traffic parameters affecting vehicle time headway distribution. Thus, to comprehend the variations in the statistical properties of headways and their type of distributions concerning different flow rate levels, an increment of 100 PCU/h was chosen for the study. Accordingly, 15 flow rate ranges (PCU/h) are considered, **[(0-100), (100-200), (200-300), (300-400), (400-500), (500-600), (600-700), (700-800), (800-900), (900-1000), (1000-1100), (1100-1200), (1200-1300), (1300-1400) and (1400-1500)].**

Figures 3-10 and 3-11 show that the critical speed for the N-5 SL and N-45 SL lanes is lower than 50 km/h. This results from the high presence of slow-moving vehicles on these lanes, such as trucks and buses. The speed on SLs is less than FLs due to the proportionate presence of heavy vehicles and the scarcity of light vehicles on SLs. Furthermore, the N5 lane exhibits a higher speed than N45; this can be attributed to the considerable percentage of motorcycles on the N45 that tend to intersperse among larger vehicles due to their high maneuverability, consequently impacting their mobility.

Figures 3-10 to 3-12 illustrate a clear trend of increasing flow with increasing speed up to optimum flow capacity. Beyond this point, as speed continues to grow, flow begins to decrease until the state of free flow is reached, at which point flow is at zero. Additionally, the results demonstrate an inverse hyperbolic relationship between flow and TH.

3.7 Analysis of Speed and TH distribution

The following assumptions of the probability distribution are validated:

- The sample is independent (Autocorrelation test)
- The sample is random (Run test)

Several probability density functions are tried to identify a best-fitted model for each flow rate range based on the following:

- Graphs i-e Histogram, P-P Plot, Q-Q Plot, and Probability difference.

- Goodness-of-fit test.

The goodness-of-fit of each distribution is determined using the Kolmogorov-Smirnov (K-S) testing technique. The significance level for time headway is set at 5% and for speed at 1%. The K-S test statistic calculates the maximum difference between the empirical and cumulative distribution functions for various observation periods. This value is then compared to the expected test statistics, considering the sample size and desired significance level. If the calculated K-S value exceeds the critical K-S value, the null hypothesis, which assumes the data follows a specific density function, is rejected. Easy-fit software fits a set of probability density functions to the observed data. It ranks the best-fitted distributions based on the K-S test statistic values.

CHAPTER 4: ANALYSIS AND RESULTS

4.1 Introduction

This chapter provides a detailed analysis of time headway and speed data collected on 2 four lane median-separated national highways and 1 six lanes median-separated motorways. It consists of descriptive statistical analysis and fitted probability density functions to accomplish each objective. It outlines time headway analysis of mixed traffic and vehicle pairs for various flow levels. It also explains the speed analysis of mixed traffic, vehicle classes, and sites.

4.2 Time Headway statistical parameters and distribution

Time headway statistical properties and distribution analysis is carried out for mixed traffic and different vehicle pairs under various flow levels, as discussed below.

4.2.1 Time Headway statistical properties for mixed traffic

Tables 3, 4, and 5 present a comparative analysis of the variation in the statistical properties of the time headways across different flow ranges for Site-1, Site-2, and Site-3, respectively. The information in these tables provides a comprehensive view of the dynamic behavior of the time headways under varying flow conditions.

Table 4-1 Statistical analysis of time headway data at site-1

Section-1 SL													
Flow range (pcu/hr)	**Sample size**	**No. of 15 min counts**	**%FR**	**Mean (sec)**	**Median (sec)**	**Std Dev (sec)**	**CV(%)**	**IQR**	**SE of mean**	**Sk**	**Kr**	**Q1 (sec)**	**Q3 (sec)**
0-100	3252	348	22.7%	95.77	50	133.92	139.8%	95	2.35	3.47	16.97	20	115
100-200	16462	517	33.7%	28.35	18	33.79	119.2%	28	0.26	3.51	21.71	8	36
200-300	30333	512	33.3%	15.20	11	15.14	99.6%	15	0.09	2.84	15.14	5	20
300-400	11837	151	9.8%	11.49	8	10.90	94.9%	11	0.10	3.32	29.99	4	15
400-500	741	8	0.5%	9.72	7	8.15	83.8%	9	0.30	1.55	2.87	4	13
Section-1 FL													
Flow range (pcu/hr)	**Sample size**	**No. of 15 min counts**	**%FR**	**Mean (sec)**	**Median (sec)**	**Std Dev (sec)**	**CV(%)**	**IQR**	**SE of mean**	**Sk**	**Kr**	**Q1 (sec)**	**Q3 (sec)**
0-100	3642	367	23.9%	80.30	50	95.21	118.6%	85	1.58	3.05	14.80	20	105
100-200	12668	441	28.7%	32.35	21	35.24	108.9%	35	0.31	2.57	10.98	8	43
200-300	24658	420	27.3%	15.79	11	16.52	104.6%	18	0.11	2.74	18.27	4	22
300-400	20339	245	16.0%	11.43	8	11.57	101.2%	13	0.08	2.08	6.41	3	16
400-500	5813	56	3.6%	8.96	6	8.91	99.5%	9	0.12	1.96	5.23	3	12
500-600	892	7	0.5%	7	5	7.11	100.5%	7	0.24	2.12	6.05	2	9

Tables 3,4 and 5 show a consistent decrease in time headways mean, median values, and standard deviation as flow rate ranges increase. The trend implies that with higher flow rate ranges, fewer vehicles can maintain free-flow conditions, resulting in decreased mean time headways. However, it is worth noting that across all cases, the median values are less than the mean time headways, indicating that over 50% of drivers opt for time headways shorter than the mean value.

Table 4-2 Statistical analysis of time headway data at site-2

Section-2 SL													
Flow range (pcu/hr)	**Sample size**	**No. of 15 min counts**	**%FR**	**Mean (sec)**	**Median (sec)**	**Std Dev (sec)**	**CV(%)**	**IQR**	**SE of mean**	**Sk**	**Kr**	**Q1 (sec)**	**Q3 (sec)**
0-100	4422	445	29.0%	90.27	53	113.60	125.8%	95	1.71	3.97	35.22	21	116
100-200	6409	190	12.4%	26.71	17	31.11	116.5%	26	0.39	3.80	26.95	8	34
200-300	9071	130	8.5%	12.93	9	12.26	94.8%	12	0.13	2.30	8.42	5	17
300-400	13748	120	7.8%	7.85	6	7.07	90.1%	7	0.06	2.05	5.87	3	10
400-500	41953	284	18.5%	6.09	5	5.20	85.3%	6	0.03	2.10	7.24	2	8
500-600	41945	243	15.8%	5.21	4	4.37	83.8%	5	0.02	2.64	24.33	2	7
600-700	19161	96	6.3%	4.51	3	3.66	81.2%	4	0.03	2.00	6.03	2	6
700-800	5302	24	1.6%	4.06	3	3.24	79.8%	3	0.04	1.97	5.51	2	5
800-900	921	4	0.3%	3.92	3	3.08	78.7%	3	0.10	1.98	5.99	2	5
Section-2 FL													
Flow range (pcu/hr)	**Sample size**	**No. of 15 min counts**	**%FR**	**Mean (sec)**	**Median (sec)**	**Std Dev (sec)**	**CV(%)**	**IQR**	**SE of mean**	**Sk**	**Kr**	**Q1 (sec)**	**Q3 (sec)**
0-100	4214	569	37.0%	120.70	66	161.67	133.9%	125	2.49	3.50	21.59	23	148
100-200	4990	158	10.3%	28.68	17	33.27	116.0%	31	0.47	3.36	24.67	7	38
200-300	6001	99	6.4%	14.89	9	16.09	108.0%	16	0.21	2.29	7.63	4	20
300-400	12079	135	8.8%	10.04	6	10.83	107.9%	10	0.10	3.17	26.73	3	13
400-500	27135	245	16.0%	8.13	5	8.58	105.5%	9	0.05	2.61	12.81	2	11
500-600	27033	200	13.0%	6.66	4	6.78	101.8%	7	0.04	2.32	7.63	2	9
600-700	12904	82	5.3%	5.72	4	6.02	105.4%	5	0.05	3.11	21.64	2	7
700-800	7201	39	2.5%	4.88	3	5.01	102.5%	4	0.06	2.91	14.82	2	6
800-900	1428	7	0.5%	4.40	3	4.57	103.9%	4	0.12	3.18	17.44	2	6
900-1000	463	2	0.1%	3.90	3	3.21	82.1%	3	0.15	1.94	5.52	2	5

Where %FR represents the percentage occurrence of flow rate in measured time

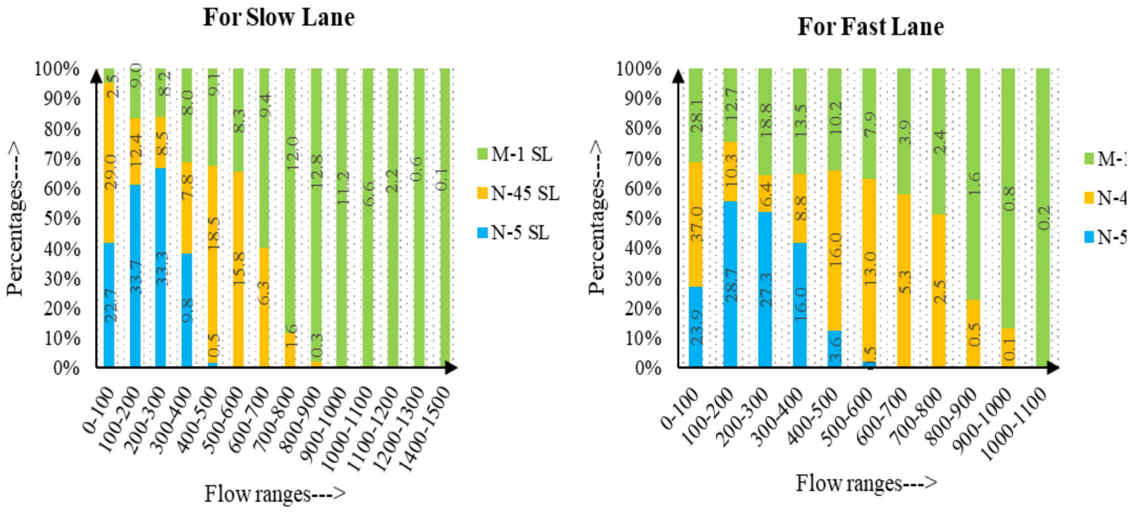


Figure 4-1 Dynamic flow rate frequency observed over a specified period

Table 4-3 Statistical analysis of time headway data at site-3

Section-3 SL													
Flow range (pcu/hr)	**Sample size**	**No. of 15 min counts**	**%FR**	**Mean (sec)**	**Median (sec)**	**Std Dev (sec)**	**CV(%)**	**IQR**	**SE of mean**	**Sk**	**Kr**	**Q1 (sec)**	**Q3 (sec)**
0-100	489	38	2.5%	52.54	38	54.22	103.2%	64	2.45	1.80	4.20	12	76
100-200	4020	139	9.0%	28.28	18	30.65	108.4%	32	0.48	2.28	7.50	7	39
200-300	6622	126	8.2%	17.81	12	18.63	104.6%	19	0.23	2.75	16.82	5	24
300-400	8499	123	8.0%	12.81	9	12.51	97.6%	13	0.14	2.08	5.98	4	17
400-500	13183	140	9.1%	9.69	7	9.33	96.3%	10	0.08	3.01	29.31	3	13
500-600	15490	128	8.3%	7.43	6	6.65	89.6%	7	0.05	2.08	7.05	3	10
600-700	21605	144	9.4%	6.09	5	5.24	86.2%	6	0.04	1.96	6.61	2	8
700-800	29961	184	12.0%	5.22	4	4.37	83.7%	5	0.03	1.73	4.43	2	7
800-900	23575	196	12.8%	4.70	4	3.87	82.4%	4	0.03	1.74	4.74	2	6
900-1000	29032	172	11.2%	4.19	3	3.42	81.7%	4	0.02	1.74	4.83	2	6
1000-1100	3785	101	6.6%	3.80	3	3.09	81.2%	3	0.05	1.95	6.82	2	5
1100-1200	4354	34	2.2%	3.52	3	2.86	81.2%	4	0.04	1.66	3.94	1	5
1200-1300	4481	9	0.6%	3.21	3	2.59	80.6%	3	0.04	1.74	4.87	1	4
1400-1500	642	2	0.1%	2.81	2	3.01	107.2%	3	0.12	3.09	16.07	1	4
Section-3 FL													
Flow range (pcu/hr)	**Sample size**	**No. of 15 min counts**	**%FR**	**Mean (sec)**	**Median (sec)**	**Std Dev (sec)**	**CV(%)**	**IQR**	**SE of mean**	**Sk**	**Kr**	**Q1 (sec)**	**Q3 (sec)**
0-100	4150	432	28.1%	93.42	50	131.74	141.0%	101	2.05	3.64	19.93	16	117
100-200	6865	195	12.7%	25.64	15	31.04	121.1%	29	0.37	4.11	48.55	6	35
200-300	18105	288	18.8%	14.31	9	15.84	110.7%	15	0.12	2.36	8.35	4	19
300-400	17526	207	13.5%	10.62	7	11.47	107.9%	11	0.09	2.34	8.00	3	14
400-500	17167	156	10.2%	8.18	5	8.82	107.7%	9	0.07	2.67	14.05	2	11
500-600	16466	121	7.9%	6.62	4	6.90	104.3%	7	0.05	2.55	9.97	2	9
600-700	9608	60	3.9%	5.63	4	5.66	100.7%	5	0.06	2.35	8.26	2	7
700-800	6728	37	2.4%	4.95	3	5.24	105.9%	4	0.06	3.45	29.09	2	6
800-900	4997	24	1.6%	4.32	3	4.22	97.5%	4	0.06	2.60	10.60	2	6
900-1000	2991	13	0.8%	3.91	3	3.77	96.3%	4	0.07	2.50	9.75	1	5
1000-1100	769	3	0.2%	3.52	2	3.50	99.5%	3	0.13	3.26	17.13	1	4

Where %FR represents the percentage occurrence of flow rate in measured time

The following points are concluded from the Tables:

- The highest 15-minute traffic counts were recorded for flow rates of 0-100 PCU/h, 100-200 PCU/h, and 0-100 at site-2 (FL & SL), Site-1 (FL & SL), and Site-3 FL, respectively, indicating a lower traffic volume during most hours.
- Site-1 experienced peak traffic volume for flow rates of 200-300 PCU/h. Site-2 observed the highest traffic volume for flow rates of 400-500 PCU/h and 500-600 PCU/h. At site-3 FL, the highest traffic was recorded at 200-300 PCU/h, while Site-3 SL experienced its peak traffic at 700-800 PCU/h.
- The average headways in the fast lane (FL) are consistently more significant than in the slow lane (SL) along all segments. However, exceptions are observed at Site-1 within the PCU/h flow rate of 0-100 and 300-400, where the SL headways are slightly higher than FL. This deviation is attributed to the increased traffic volume in FL compared to SL in these flow rate ranges, indicating a lack of lane discipline by both high and low-flow drivers who attempt to utilize the faster lane.
- At site-3, the sample size is higher on the fast lane than on the slow lane in the low flow range. It decreases on FL and increases on SL as flow increases. It means all vehicle class drivers follow the fast lane when the flow is less, and as flow increases, they accommodate their selves accordingly.
- The median value closes to the mean value as flow increases, indicating extreme values reduction.
- Site-2 has lower statistical parameters than Site-1 due to more motorcycles and narrower shoulder width.
- As the flow rate increases, standard deviation, coefficient of variation, and interquartile range decrease for both sites, reducing data spread around mean and median. The reduction in mean as flow increases causes a peak on lower values with a long right tail.
- High positive kurtosis values exist for all sites, meaning each flow rate indicates a more peaked distribution than a normal distribution.

- Positive skewness values for all sites indicate that each flow range distribution has a longer tail on the positive side. It means the values tend to be higher on the right side of the distribution.

4.2.2 Time Headway distributions for mixed traffic

To accurately model the time headway data using various probability distribution functions, we exclude the 5% longest time headways and evaluate the statistical results for different flow levels based on the remaining 95% of the time headway values. The K-S testing technique is employed to conduct a goodness-of-fit assessment for each probability density function at a significance level of 5%. The fitted time headway distributions for the flow rate ranges at site two are presented in the figure below.

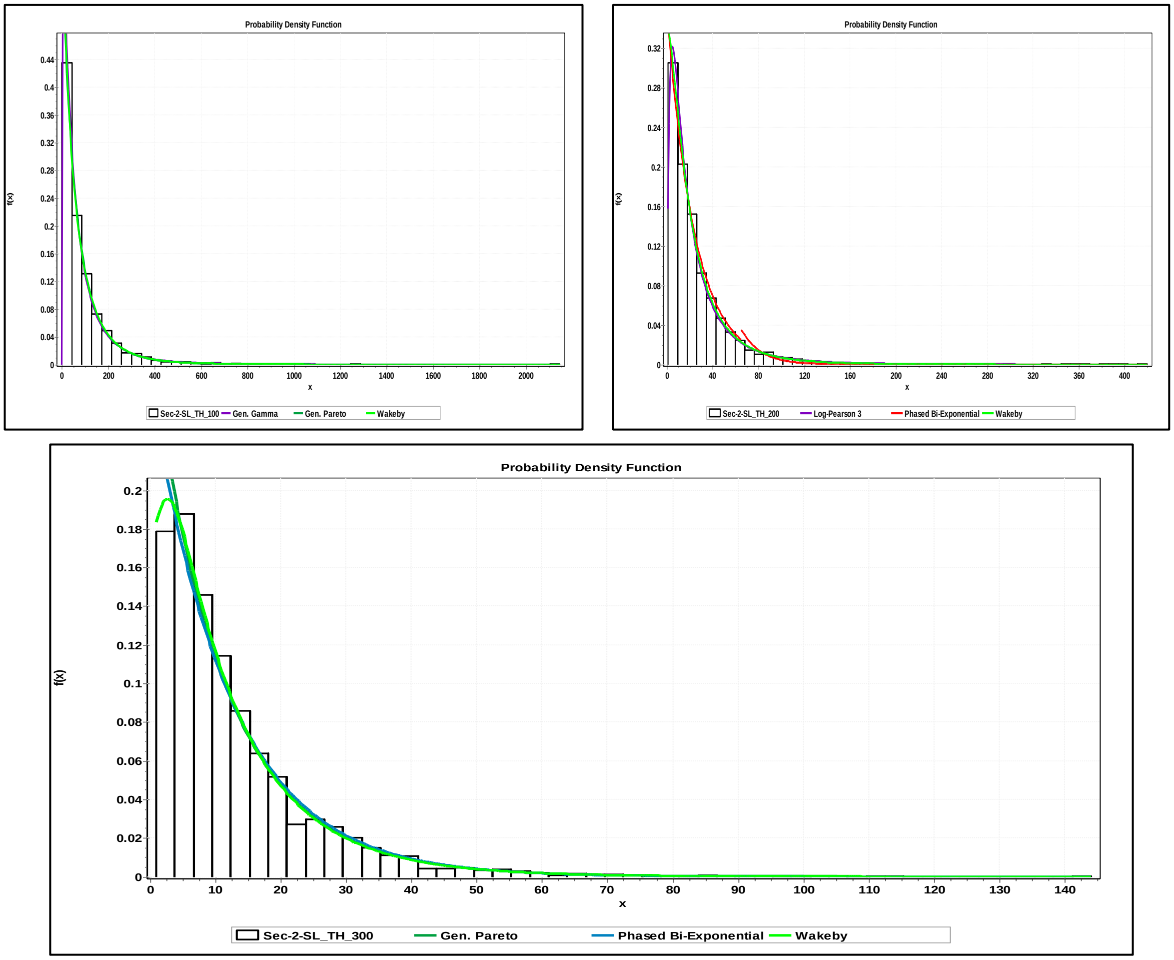


Figure 4-2 Time headway PDF for flow levels 0-300 PCU/h at Site-2 Slow Lane.

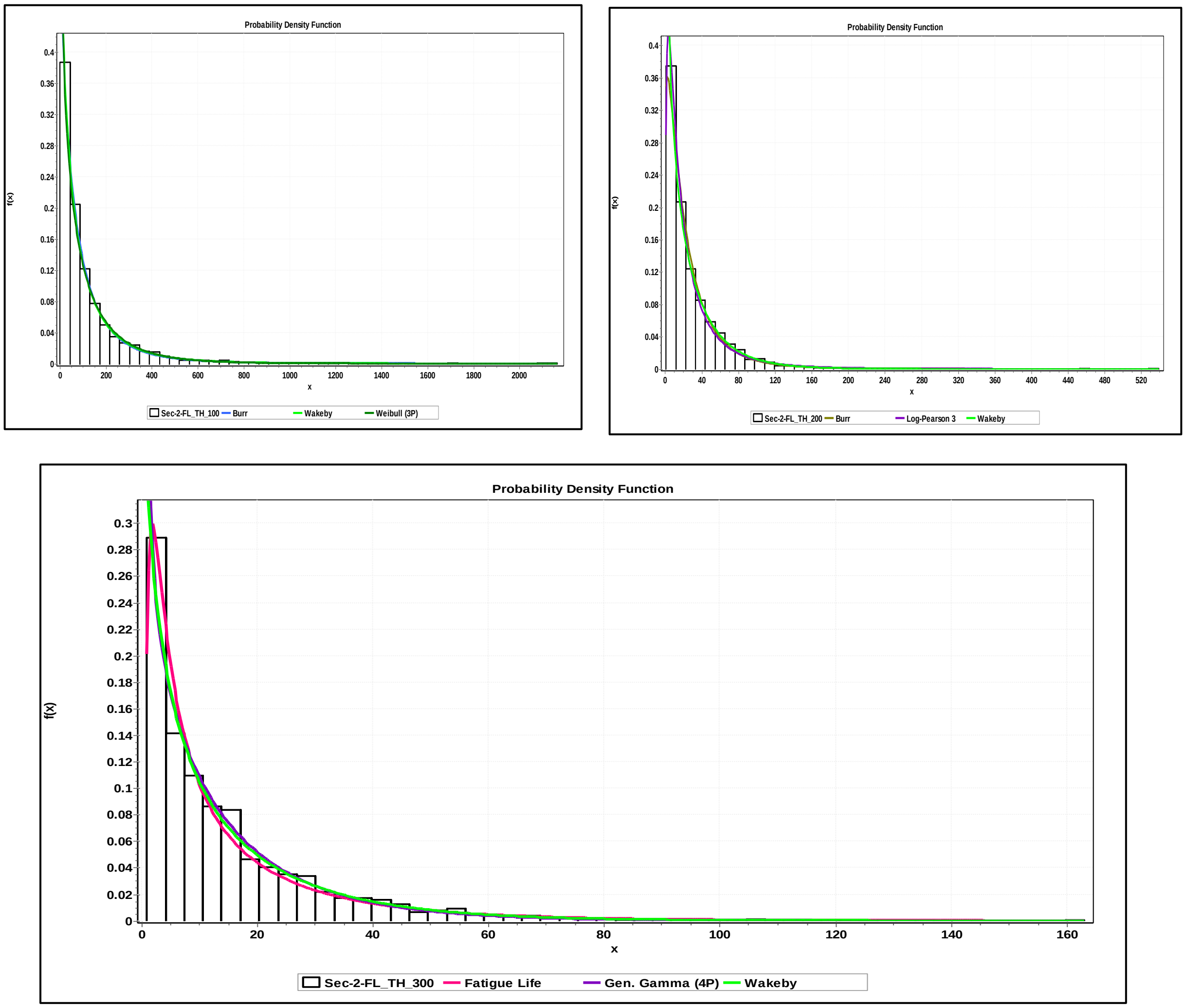


Figure 4-3 Time headway PDF for flow levels 0-300 PCU/h at Site-2 Fast Lane

From Figures 4-2 & 4-3, the histogram for the 0-100 PCU/h flow rate range displays significant fluctuations in time headways, indicating a flexible movement of vehicles that can maintain any time headway in this flow range. However, as the flow rate level increases, the mean time headways decrease with a heightened peak. High flow rate ranges result in light-tailed histograms due to a concentration of smaller, clustered time headways.

Tables 6 & 7 illustrate a comprehensive overview of the best-fitted time headway distributions. It includes the results of the K-S (Kolmogorov-Smirnov) test statistic values, which measure the difference between the observed and expected time headway distributions. The tables also display the estimated parameters of the time headway distributions, which provide insight into the underlying pattern of the data. Finally, the tables include p-values, indicating the fitted distributions' statistical significance. Tables 6,7,8,9 & 10 are crucial for evaluating the quality of the time headway models and making informed decisions about the traffic flow characteristics at sites 1,2, and 3.

Table 4-4 Best-fitted TH distributions for Various Flow Levels at Site 2_SL

SL_Flow (PCU/hr)	Sample Size	Best Fitted Distributions	K-S Value	Parameters	P-Value
0-100	4422	Wakeby	0.0121	$\alpha=-18.101,\beta=2.7422,\gamma=77.674,\delta=0.16859,\xi=1.6813$	0.9534
		Gen. Pareto	0.0214	$\kappa=0.19757,\sigma=72.305,\mu=0.16129$	0.9432
		Gen. Gamma	0.0220	$\kappa=0.40378,\alpha=4.3988,\beta=1.6078$	0.9244
100-200	6409	Wakeby	0.0224	$\alpha=4.1982,\beta=3.9246,\gamma=20.375,\delta=0.17879,\xi=1.0415$	0.9123
		Log-Pearson 3	0.0286	$\alpha=57.295,\beta=-0.14255,\gamma=10.929$	0.8943
		Phased Bi-Exponential	0.0289	$\lambda_1=0.04111,\gamma_1=1,\lambda_2=0.05828,\gamma_2=65$	0.8764
200-300	9071	Wakeby	0.0357	$\alpha=4.9295,\beta=7.3136,\gamma=10.864,\delta=0.05598,\xi=0.82843$	0.9821
		Gen. Pareto	0.0414	$\kappa=0.03343,\sigma=11.373,\mu=1.1627$	0.9382
		Phased Bi-Exponential	0.0431	$\lambda_1=0.08279,\gamma_1=1,\lambda_2=0.01057,\gamma_2=104$	0.9251
300-400	13748	Johnson SB	0.0620	$\gamma=2.7314,\delta=1.0554,\lambda=84.812,\xi=-0.23114$	0.9445
		Wakeby	0.0638	$\alpha=144.43,\beta=147.88,\gamma=6.6688,\delta=0.03031,\xi=0$	0.9349
		Fatigue Life	0.0650	$\alpha=0.94859,\beta=5.4$	0.9212
400-500	41953	Wakeby	0.0762	$\alpha=2.2575,\beta=7.0133,\gamma=4.9695,\delta=0.01769,\xi=0.75301$	0.5540
		Fatigue Life	0.0763	$\alpha=0.87991,\beta=4.3876$	0.5435
		Johnson SB	0.0773	$\gamma=4.0406,\delta=1.3337,\lambda=119.72,\xi=-0.84047$	0.5320
500-600	41945	Fatigue Life	0.0860	$\alpha=0.83878,\beta=3.8547$	0.4532
		Wakeby	0.0896	$\alpha=1.7384,\beta=5.1972,\gamma=4.0584,\delta=0.02659,\xi=0.76237$	0.4324
		Lognormal	0.0968	$\sigma=0.78808,\mu=1.3503$	0.3912
600-700	19161	Johnson SB	0.1004	$\gamma=3.2283,\delta=1.2033,\lambda=56.188,\xi=-0.12187$	0.8502
		Fatigue Life	0.1021	$\alpha=0.80574,\beta=3.4075$	0.8421
		Wakeby	0.1056	$\alpha=1.5613,\beta=7.5953,\gamma=3.5155,\delta=0.01756,\xi=0.75138$	0.8127
700-800	5302	Fatigue Life	0.1139	$\alpha=0.77695,\beta=3.1237$	0.9760
		Johnson SB	0.1143	$\gamma=2.8507,\delta=1.1175,\lambda=41.042,\xi=0.1427$	0.9643
		Log-Pearson 3	0.1158	$\alpha=412.39,\beta=0.03628,\gamma=-13.831$	0.9543
800-900	921	Dagum	0.1244	$\kappa=2.0142,\alpha=1.9146,\beta=1.7976$	0.9533
		Frechet (3P)	0.1254	$\alpha=2.3124,\beta=3.4704,\gamma=-1.208$	0.9514
		Johnson SB	0.1273	$\gamma=3.3533,\delta=1.2405,\lambda=50.027,\xi=-0.08033$	0.9313

Tables 6 and 7 consist of different distributions with the following parameters: Location parameter (μ , θ) represents a distribution's central or average value. An increase in this parameter shifts the distribution to the right. A decrease in this parameter shifts the distribution to the left. The Scale parameter (σ , β) represents the spread or variability of a distribution. An increase in this parameter spreads out the distribution. A decrease in this parameter makes the distribution more compact. The shape parameter, represented by symbols λ, α, or k, signifies the form of the distribution. This parameter determines the peakedness of the distribution. An increase in the shape parameter results in a more pronounced peak, while a decrease causes the distribution to become flatter. The shape-location parameter, symbolized by γ, indicates the interdependence between the shape and location of the distribution.

Table 4-5 Best fitted TH distributions for Various Flow Levels at Site 2_FL

FL_Flow (PCU/hr)	Sample Size	Best Fitted Distributions	K-S Value	Parameters	P-Value
0-100	**4214**	Wakeby	0.0165	$\alpha=-62.838,\beta=0.72914,\gamma=136.6,\delta=0.13018,\xi=0$	0.9321
		Weibull (3P)	0.0185	$\alpha=0.79324,\beta=102.69,\gamma=1.0$	0.9231
		Burr	0.0218	$\kappa=4.4412,\alpha=0.94559,\beta=433.9$	0.8843
100-200	**4990**	Wakeby	0.0246	$\alpha=-11.692,\beta=2.5955,\gamma=28.676,\delta=0.07268,\xi=1.0123$	0.8776
		Log-Pearson 3	0.0375	$\alpha=42.344,\beta=-0.18116,\gamma=10.433$	0.8631
		Burr	0.0399	$\kappa=3.7514,\alpha=1.1137,\beta=75.919$	0.8321
200-300	**6001**	Wakeby	0.0488	$\alpha=-8.5456,\beta=1.3729,\gamma=17.801,\delta=-0.00659,\xi=0.80634$	0.9223
		Gen. Gamma (4P)	0.0492	$\kappa=1.0391,\alpha=0.74577,\beta=17.941,\gamma=1.0$	0.9123
		Fatigue Life	0.0566	$\alpha=1.2345,\beta=8.3778$	0.9079
300-400	**12079**	Gen. Pareto	0.0690	$\kappa=0.12717,\sigma=8.279,\mu=0.55172$	0.8767
		Fatigue Life (3P)	0.0698	$\alpha=1.2392,\beta=5.4559,\gamma=0.30055$	0.8675
		Fatigue Life	0.0702	$\alpha=1.1199,\beta=6.1604$	0.8572
400-500	**27135**	Gen. Pareto	0.0778	$\kappa=0.14071,\sigma=6.4871,\mu=0.58352$	0.7132
		Wakeby	0.0816	$\alpha=-5.2874,\beta=0.96862,\gamma=10.121,\delta=-0.01274,\xi=0.82526$	0.6943
		Inv. Gaussian (3P)	0.0822	$\lambda=5.0589,\mu=8.0425,\gamma=0.09043$	0.6432
500-600	**27033**	Gen. Pareto	0.0880	$\kappa=0.1392,\sigma=5.1835,\mu=0.63854$	0.6832
		Wakeby	0.0880	$\alpha=0,\beta=0,\gamma=5.1835,\delta=0.1392,\xi=0.63854$	0.6648
		Johnson SB	0.0944	$\gamma=2.7586,\delta=0.97992,\lambda=84.761,\xi=-0.30703$	0.6539
600-700	**12904**	Wakeby	0.1011	$\alpha=0,\beta=0,\gamma=4.1425,\delta=0.17939,\xi=0.66738$	0.8731
		Gen. Pareto	0.1011	$\kappa=0.17939,\sigma=4.1425,\mu=0.66738$	0.8612
		Log-Pearson 3	0.1142	$\alpha=72.722,\beta=0.10599,\gamma=-6.3812$	0.8501
700-800	**7201**	Gen. Pareto	0.1162	$\kappa=0.18726,\sigma=3.3806,\mu=0.72456$	0.9366
		Wakeby	0.1162	$\alpha=0,\beta=0,\gamma=3.3806,\delta=0.18726,\xi=0.72456$	0.9264
		Inv. Gaussian	0.1221	$\lambda=4.6452,\mu=4.884$	0.9216
800-900	**1428**	Inv. Gaussian	0.1226	$\lambda=4.077,\mu=4.3999$	0.9564
		Johnson SB	0.1265	$\gamma=4.0314,\delta=1.0617,\lambda=135.63,\xi=3.7409\text{E}-4$	0.9545
		Gen. Pareto	0.1302	$\kappa=0.20422,\sigma=2.9385,\mu=0.70724$	0.9453
900-1000	**463**	Gamma	0.1451	$\alpha=1.4832,\beta=2.6328$	0.9924
		Pearson 6	0.1455	$\alpha_1=33.661,\alpha_2=2.2472,\beta=0.15729$	0.9813
		Gen. Pareto	0.1481	$\kappa=0.06023,\sigma=2.9029,\mu=0.81601$	0.9771

An increase in this parameter shifts the distribution to the right, making it more peaked. A decrease in this parameter shifts the distribution to the left, making it flatter. Scale-location parameter (δ) represents the relationship between the scale and location of a distribution. An increase in this parameter shifts the distribution to the right and spreads it out. A decrease in this parameter shifts the distribution to the left, making it more compact. Shape-scale parameter (η) represents the relationship between shape and scale of distribution. An increase in this parameter causes the distribution to peak and spread. A decrease in this parameter makes the distribution flatter and more compact. The nuisance parameter (ζ , ε) represents a parameter in a statistical model that is not of primary interest but is necessary for the model to be correctly specified. It is a parameter not of direct interest but needs to specify the distribution fully. These parameters typically do not directly affect the distribution's location, scale, or shape.

Table 4-6 Best-fitted TH distributions for Various Flow Levels at Site 1_SL

Flow (PCU/hr)	Best Fitted Distributions	P-Value
0-100	Gen. Gamma	0.9728
	Burr	0.9564
	Pearson 6	0.9451
100-200	Log-Pearson 3	0.9637
	Burr	0.9561
	Gen. Pareto	0.9431
200-300	Wakeby	0.8453
	Gen. Pareto	0.8312
	Exponential (2P)	0.8063
300-400	Wakeby	0.8971
	Gen. Pareto	0.8873
	Log-Pearson 3	0.8563
400-500	Wakeby	0.9281
	Johnson SB	0.9213
	Gamma	0.9013

Table 4-7 Best fitted TH distributions for Various Flow Levels at Site 1_FL

Flow (PCU/hr)	Best Fitted Distributions	K-S Value	P-Value
0-100	Wakeby	0.0165	0.9273
	Gen. Pareto	0.0165	0.9134
	Pareto 2	0.0189	0.8931
100-200	Gamma (3P)	0.0247	0.9321
	Gen. Pareto	0.0293	0.9012
	Wakeby	0.0293	0.8831
200-300	Gen. Pareto	0.0358	0.8061
	Wakeby	0.0358	0.7831
	Burr	0.0461	0.7134
300-400	Weibull (3P)	0.0587	0.9123
	Gen. Pareto	0.0587	0.8931
	Beta	0.0591	0.8731
400-500	Gen. Pareto	0.0747	0.9431
	Wakeby	0.0801	0.9312
	Fatigue Life	0.0819	0.9120
500-600	Wakeby	0.0880	0.9321
	Gen. Pareto	0.0880	0.9213
	Johnson SB	0.0964	0.9131

Table 4-8 Best-fitted TH distributions for Various Flow Levels at Site 3_SL

Flow (PCU/hr)	Best Fitted Distributions	P-Value
0-100	Wakeby	0.9139
	Phased Bi-Weibull	0.9021
	Kumaraswamy	0.8913
100-200	Wakeby	0.9543
	Phased Bi-Weibull	0.9431
	Weibull	0.9321
200-300	Gen. Pareto	0.9761
	Wakeby	0.9631
	Weibull	0.9413
300-400	Wakeby	0.9873
	Johnson SB	0.9765
	Gen. Pareto	0.9123
400-500	Wakeby	0.8937
	Gen. Pareto	0.8873
	Weibull	0.87113
500-600	Wakeby	0.8837
	Johnson SB	0.8651
	Gen. Pareto	0.85313
600-700	Wakeby	0.8736
	Johnson SB	0.8631
	Gen. Pareto	0.84213
700-800	Wakeby	0.9013
	Johnson SB	0.8971
	Gamma	0.8901
800-900	Wakeby	0.9313
	Gamma	0.9213
	Gen. Pareto	0.9123
900-1000	Wakeby	0.8731
	Gamma	0.8631
	Johnson SB	0.85431
1000-1100	Wakeby	0.8031
	Johnson SB	0.7987
	Gamma	0.7831
1100-1200	Johnson SB	0.7931
	Wakeby	0.7865
	Gamma	0.77631
1200-1300	Johnson SB	0.8419
	Wakeby	0.8321
	Gamma	0.8231
1300-1400	Inv. Gaussian	0.9513
	Wakeby	0.9431
	Johnson SB	0.9321

Table 4-9 Best-fitted TH distributions for Various Flow Levels at Site 3_FL

Flow (PCU/hr)	Best Fitted Distributions	P-Value
0-100	Wakeby	0.9506
	Weibull (3P)	0.9431
	Burr	0.9321
100-200	Pareto 2	0.9543
	Pearson 6 (4P)	0.9321
	Weibull (3P)	0.9132
200-300	Wakeby	0.9313
	Fatigue Life	0.9213
	Burr	0.9012
300-400	Gen. Pareto	0.9131
	Wakeby	0.8972
	Burr	0.8871
400-500	Gen. Pareto	0.9021
	Fatigue Life	0.8876
	Log-Pearson 3	0.8731
500-600	Gen. Pareto	0.8931
	Fatigue Life	0.8873
	Log-Pearson 3	0.8614
600-700	Gen. Pareto	0.8731
	Burr	0.8635
	Lognormal	0.8541
700-800	Gen. Pareto	0.8317
	Burr	0.8221
	Lognormal	0.8131
800-900	Johnson SB	0.9131
	Gamma (3P)	0.9013
	Wakeby	0.8976
900-1000	Johnson SB	0.9371
	Gen. Logistic	0.9213
	Gen. Pareto	0.9123
1000-1100	Inv. Gaussian	0.9131
	Log-Logistic	0.9082
	Gen. Logistic	0.8976

The goodness of fit test assesses the compatibility of the observed data with the chosen distribution. The results showed a high p-value, indicating that the observed data strongly agrees with the expected values from the selected distribution. The corresponding graph illustrates this close match between the observed data and the predicted distribution. These findings suggest that the chosen distribution fits the observed data well. The best-fitted distributions for each flow range and their respective p-values are presented in tables 6,7 and 8.

It is observed from the above tables that Wakeby and Burr distributions are the best-fitted distribution in low flow ranges at site 2 and site 1 SL, respectively. The analysis determined that the Wakeby, Phased Bi Weibull distributions and the Wakeby, Weibull distributions are the most suitable models for low flow ranges in the fast and slow lanes at site 3, respectively. For mid to high flow ranges, the Fatigue Life, General Pareto, Johnson SB, and Wakeby distributions have been determined to be the most appropriate models for site 2 through analysis. Wakeby and General Pareto distributions are the most suitable models for all flow ranges in the fast lane at site 1. Analysis has established that the Wakeby, General Pareto, and Weibull distributions are the most appropriate models for the middle flow ranges in the slow lane at site 3. Meanwhile, the General Pareto and Fatigue Life distributions are the most suitable for intermediate flow levels in the fast lane. The Johnson SB distribution is observed to be the most appropriate for high flow levels in both the fast and slow lanes at site 3.

4.2.3 Time Headway statistical Properties for Different Vehicle-pairs

Examining vehicle-type specific time headway distributions provides deeper insight into the interactions between different combinations of leading and following vehicles and their driving behavior in mixed traffic conditions. This analysis considers the differences in driving behavior between the same vehicle pair, the impact of leading vehicles on the driving behavior of following vehicles, and how the vehicle-pair time headway distribution changes with flow levels. However, this study did not consider the interactions of two-wheelers with other vehicles due to their better maneuverability and complex behavior.

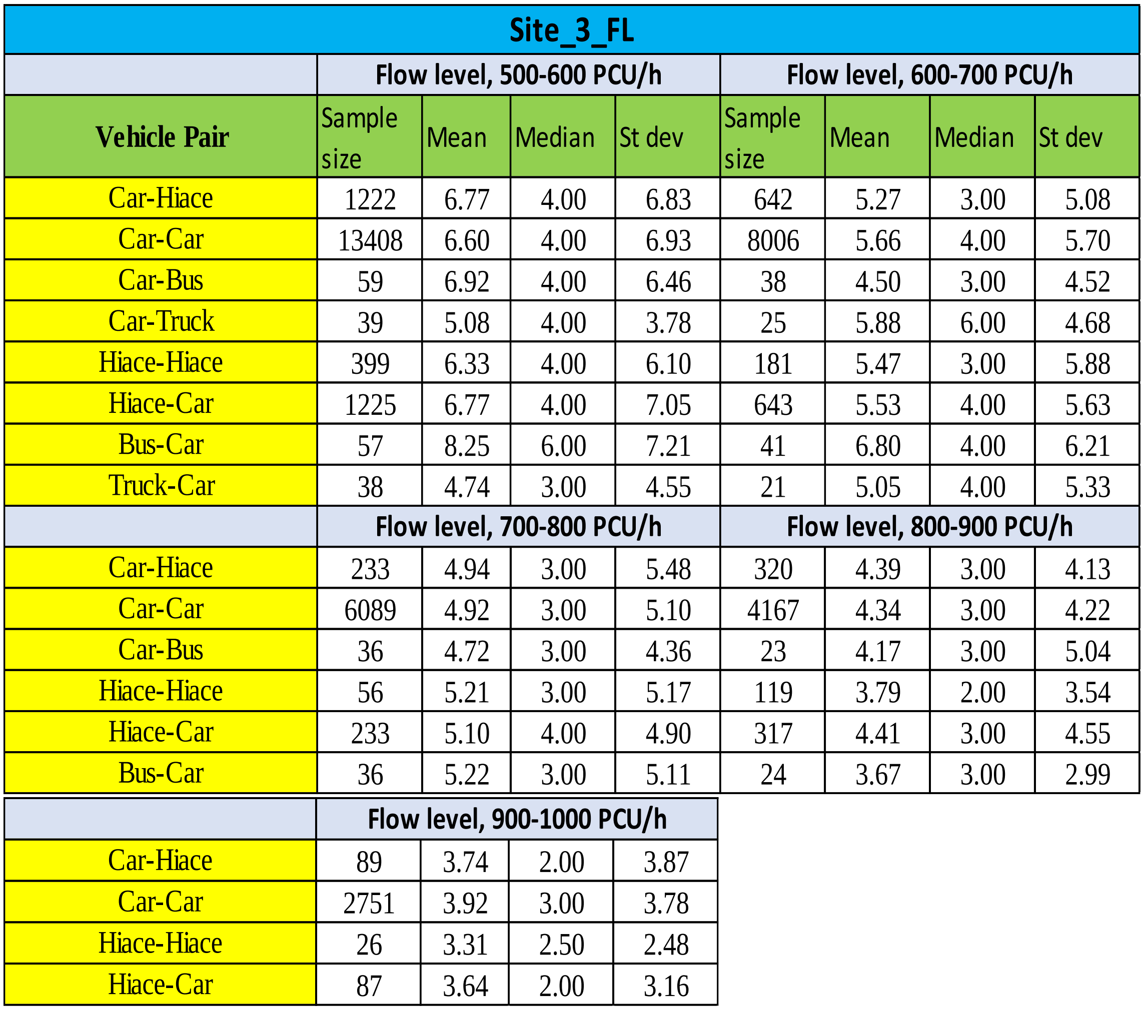
This research considers separate lanes (FL and SL), which results in high mean headways in low flow ranges. High mean headways indicate a large gap between leading and following vehicles. The high standard deviation for low flow ranges reflects the scattered nature of the data due to the low number of vehicles per hour. Consequently, the characteristics of leading and following vehicles do not affect each other in the low flow ranges. Therefore, in the vehicle pair analysis, high flow ranges will be analyzed where the vehicles significantly impact each other. Thus, flow levels exceeding 500 PCU/h are analysed for both the fast lane (FL) and slow lane (SL) at Site-2 and Site-3. Table 12 represents the basic statistical properties of time headway for eight pairs of vehicles consisting of a car as a leading vehicle and a following vehicle at various flow levels at site-2. Table 13,14 depict the basic statistical properties of the time headways for 16 vehicle pairs, composed of a car, Hiace, bus, and truck, both as leading and following vehicles, at different flow levels at Site-3 fast lane and slow lane, respectively. The vehicle pair is in the following order leading vehicle -following vehicle.

Table 4-10 Statistical properties of vehicle pairs TH for various flows at Site_2

	Site_2_FL				**Site_2_SL**			
Flow level, 500-600 PCU/h								
Vehicle Pair	Sample size	Mean	Median	St dev	Sample size	Mean	Median	St dev
Car-Hiace	195	5.93	4.00	5.71	77	5.83	4.00	6.12
Car-Car	9978	6.10	2.00	5.90	8809	5.33	4.00	4.41
Car-Bus	133	8.77	6.00	8.10	66	4.98	4.00	3.69
Car-Truck	1303	8.65	6.00	7.89	1376	5.77	5.00	4.50
Hiace-Car	208	6.52	4.00	5.90	73	5.51	4.00	4.18
Bus-Car	146	5.93	4.00	5.67	76	6.74	6.00	4.66
Truck-Car	1358	6.05	4.00	6.31	1419	6.01	5.00	4.35
Truck-Truck					261	6.79	5.00	5.05
Flow level, 600-700 PCU/h								
Car-Hiace	84	4.76	3.00	5.13	21	4.19	4.00	2.64
Car-Car	8633	5.50	3.00	5.77	3889	4.53	3.00	3.69
Car-Bus	76	8.21	5.00	8.11	57	4.07	3.00	2.95
Car-Truck	592	7.85	6.00	6.84	654	4.88	4.00	4.00
Hiace-Car	82	5.16	3.00	5.91	22	5.27	3.50	5.07
Bus-Car	76	5.12	3.00	6.09	58	6.64	6.00	4.25
Truck-Car	646	5.32	3.00	5.31	643	5.07	4.00	3.53
Truck-Truck	72	5.72	4.00	4.87	149	5.28	4.00	3.54
Flow level, 700-800 PCU/h								
Car-Hiace	50	4.36	3.00	3.40				
Car-Car	4858	4.69	3.00	4.74	1124	4.06	3.00	3.24
Car-Bus	32	5.66	4.50	4.34				
Car-Truck	297	6.19	4.00	5.86	199	4.12	3.00	3.68
Hiace-Car	49	4.39	3.00	3.48				
Bus-Car	33	4.39	3.00	5.39				
Truck-Car	321	4.64	3.00	5.20	190	4.53	4.00	3.03
Truck-Truck	31	6.90	4.00	7.96	34	5.06	4.00	3.28
Flow level, 800-900 PCU/h								
Car-Car	954	4.27	3.00	4.57	152	3.76	3.00	2.64
Car-Truck	56	6.05	4.00	6.83	51	4.57	3.00	3.95
Truck-Car	70	4.21	2.00	3.71	43	4.40	3.00	3.87
Flow level, 900-1000 PCU/h								
Car-Car	291	3.70	3.00	2.85				
Car-Truck	20	4.30	3.00	3.44				

Tables 12,13, and 14 show a change in headway distributions and statistical parameters for the same vehicle pair when the leading vehicle changes. This suggests that the leading vehicle impacts the driving behavior of the following vehicle.

Table 4-11 Statistical properties of vehicle pairs TH at Site-3 Fast Lane



Site_3_FL								
	Flow level, 500-600 PCU/h				**Flow level, 600-700 PCU/h**			
Vehicle Pair	Sample size	Mean	Median	St dev	Sample size	Mean	Median	St dev
Car-Hiace	1222	6.77	4.00	6.83	642	5.27	3.00	5.08
Car-Car	13408	6.60	4.00	6.93	8006	5.66	4.00	5.70
Car-Bus	59	6.92	4.00	6.46	38	4.50	3.00	4.52
Car-Truck	39	5.08	4.00	3.78	25	5.88	6.00	4.68
Hiace-Hiace	399	6.33	4.00	6.10	181	5.47	3.00	5.88
Hiace-Car	1225	6.77	4.00	7.05	643	5.53	4.00	5.63
Bus-Car	57	8.25	6.00	7.21	41	6.80	4.00	6.21
Truck-Car	38	4.74	3.00	4.55	21	5.05	4.00	5.33
	Flow level, 700-800 PCU/h				**Flow level, 800-900 PCU/h**			
Car-Hiace	233	4.94	3.00	5.48	320	4.39	3.00	4.13
Car-Car	6089	4.92	3.00	5.10	4167	4.34	3.00	4.22
Car-Bus	36	4.72	3.00	4.36	23	4.17	3.00	5.04
Hiace-Hiace	56	5.21	3.00	5.17	119	3.79	2.00	3.54
Hiace-Car	233	5.10	4.00	4.90	317	4.41	3.00	4.55
Bus-Car	36	5.22	3.00	5.11	24	3.67	3.00	2.99
	Flow level, 900-1000 PCU/h							
Car-Hiace	89	3.74	2.00	3.87				
Car-Car	2751	3.92	3.00	3.78				
Hiace-Hiace	26	3.31	2.50	2.48				
Hiace-Car	87	3.64	2.00	3.16				

The time headway between two vehicles traveling on the road is affected by the size and weight of the vehicles. More extensive, heavier vehicles require a longer stopping distance, meaning they need to maintain a more significant following distance and have a longer time headway.

Table 4-12 Statistical properties of vehicle pairs TH at Site-3 Slow Lane

Site_3_SL								
	Flow level, 500-600 PCU/h				Flow level, 600-700 PCU/h			
Vehicle Pair	Sample size	Mean	Median	St dev	Sample size	Mean	Median	St dev
Car-Hiace	514	6.57	5.00	5.77	643	5.68	4.00	4.92
Car-Car	11373	7.40	6.00	6.53	17223	6.06	5.00	5.19
Car-Bus	311	7.40	5.00	7.62	321	5.49	4.00	5.16
Car-Truck	1016	7.48	5.00	6.98	1043	6.39	5.00	5.75
Hiace-Hiace	35	6.69	4.00	6.27	43	5.37	4.00	4.29
Hiace-Car	514	7.32	6.00	6.33	637	6.09	4.00	5.58
Hiace-Truck	59	7.51	6.00	5.63	54	6.11	4.50	5.42
Bus-Car	311	8.25	5.00	7.90	310	6.13	5.00	5.55
Bus-Truck	33	7.06	6.00	5.49	34	6.53	4.00	5.76
Truck-Hiace	57	8.89	6.00	9.80	51	5.35	4.00	4.02
Truck-Car	1017	7.75	6.00	6.90	1059	6.57	5.00	5.31
Truck-Bus	35	8.63	6.00	8.68	21	7.33	5.00	7.25
Truck-Truck	168	7.78	5.00	7.09	129	6.32	5.00	5.65
	Flow level, 700-800 PCU/h							
Car-Hiace	763	4.93	4.00	4.27				
Car-Car	26310	5.23	4.00	4.36				
Car-Bus	425	4.46	3.00	3.86				
Car-Truck	1357	4.94	4.00	4.28				
Hiace-Hiace	33	4.18	3.00	3.12				
Hiace-Car	767	4.97	4.00	4.68				
Hiace-Truck	57	5.67	4.00	5.41				
Bus-Car	427	5.38	4.00	4.44				
Bus-Truck	32	3.38	2.50	2.37				
Truck-Hiace	65	5.12	4.00	4.36				
Truck-Car	1351	5.53	4.00	4.43				
Truck-Bus	30	5.43	4.00	4.83				
Truck-Truck	110	5.70	4.00	4.37				
	Flow level, 800-900 PCU/h				Flow level, 900-1000 PCU/h			
Car-Hiace	962	4.42	3.00	4.24	938	3.78	3.00	3.25
Car-Car	30535	4.69	4.00	3.85	30439	4.19	3.00	3.40
Car-Bus	665	4.11	3.00	3.88	655	3.60	3.00	3.04
Car-Truck	1615	4.37	3.00	3.67	1519	4.08	3.00	3.33
Hiace-Hiace	53	5.02	3.00	4.79	51	4.18	3.00	4.06
Hiace-Car	969	4.66	4.00	3.95	930	4.15	3.00	3.82
Hiace-Bus	22	4.18	3.00	3.45	31	3.90	3.00	3.31
Hiace-Truck	61	4.10	3.00	3.42	50	4.02	3.00	3.02
Bus-Hiace	27	4.70	4.00	3.41	22	3.41	3.00	2.13
Bus-Car	657	4.70	4.00	3.80	653	4.30	3.00	3.70
Bus-Bus	22	4.00	3.50	2.18	28	3.29	2.50	2.84
Bus-Truck	40	4.93	3.00	4.49	40	4.15	3.00	4.05
Truck-Hiace	63	4.60	4.00	3.29	51	3.94	3.00	3.33
Truck-Car	1615	4.84	4.00	3.78	1529	4.51	4.00	3.49
Truck-Bus	37	3.76	2.00	4.05	29	3.97	3.00	3.20
Truck-Truck	95	4.89	4.00	3.79	119	4.47	3.00	3.35

Table 4-13 Statistical properties of vehicle pair TH at Site-3 Slow Lane (Continued)

Site_3_SL								
	Flow level, 1000-1100 PCU/h				Flow level, 1100-1200 PCU/h			
Vehicle Pair	Sample size	Mean	Median	St dev	Sample size	Mean	Median	St dev
Car-Hiace	592	3.51	3.00	3.16	263	3.00	2.00	2.58
Car-Car	19346	3.80	3.00	3.10	9879	3.50	3.00	2.83
Car-Bus	440	3.23	2.00	3.00	185	2.97	2.00	2.44
Car-Truck	988	3.61	3.00	3.00	522	3.24	2.00	2.84
Hiace-Hiace	29	3.59	3.00	3.16				
Hiace-Car	601	3.52	3.00	3.03	262	3.32	3.00	2.81
Hiace-Truck	29	3.97	2.00	3.90				
Bus-Car	441	3.84	3.00	2.79	188	3.70	3.00	2.63
Bus-Truck	29	3.66	2.00	2.96				
Truck-Hiace	38	4.32	3.50	3.09				
Truck-Car	978	3.87	3.00	2.95	520	3.58	3.00	2.78
Truck-Bus	30	2.90	2.00	2.55				
Truck-Truck	73	3.82	3.00	2.32	41	4.66	3.00	3.69
	Flow level, 1200-1300 PCU/h				Flow level, 1300-1400 PCU/h			
Car-Hiace	101	2.60	2.00	2.57	19	2.79	2.00	3.95
Car-Car	3678	3.21	3.00	2.59	503	2.71	2.00	2.93
Car-Bus	71	2.46	2.00	2.22				
Car-Truck	208	3.14	3.00	2.46	33	3.21	2.00	3.00
Hiace-Car	112	3.76	3.00	2.99	20	2.85	2.50	2.30
Bus-Car	70	3.44	3.00	3.05				
Truck-Car	198	3.34	3.00	2.30	31	3.35	2.00	3.63

The following points are concluded from tables 12,13,14 and 15:

For the same vehicle pair mean time headway for FL is more significant than the mean time headway for the slow lane, and the reverse is for standard deviation. Additionally, statistical parameters of TH decrease as flow increases because of the large number of vehicles in the same section. For all sites, irrespective of FL and SL, the mean and standard deviation of TH for car-hiace are less than hiace-car, and the gap decreases as flow increases.

At site-2, when the passenger car was the leading vehicle, the mean TH of car-hiace was found to be the lowest among the different vehicle combinations, followed by car-car on FL, while the mean TH of car-bus was the smallest on SL. With the Car as a following vehicle, mean TH increases in the following order: car-car < hiace-car < bus-car on SL and bus-car < hiace-car < car-car except for flow level 500-600 where car-car <hiace-car on FL.

The average time headway is distributed in the following order for the specific vehicle pairs with the same leading and following vehicle: Hiace-Hiace < Car-Car < Truck-Truck. However, for flow levels of 700-800 PCU/h in the fast lane (FL) and 800-900 PCU/h in the slow lane (SL) of site-3, the Hiace-Hiace mean time headway is more significant than the Car-Car mean time headway due to a higher degree of variability in the Hiace-Hiace data. On the other hand, the Bus-Bus pairs observed in the SL at site-3 for flow ranges of 800-900 and 900-1000 PCU/h maintain a lower mean and degree of variability in the time headway than the Hiace-Hiace pairs.

At site-2, FL car-bus Th is greater than bus-car, and the reverse is for SL. At site-3, car-bus Th is lesser than bus-car because of the high speed of motorway busses. At sites 2 and 3, FL car-truck Th is greater than truck-car, and the reverse is for SL except for flow 800-900 PCU/h at site-2 SL. Drivers of cars take into account safety when following heavy vehicles on SL and retain a larger time headway. Due to the less agile maneuvering capabilities of heavy vehicles, it is difficult for heavy vehicles to catch a car in the fast lane, which results in longer headway. This difference in pace highlights the unique challenges faced by truck drivers on the roadways and highlights the importance of optimizing traffic flow for all types of vehicles

At site-3 SL, the mean TH of hiace-bus< bus-hiace for the flow of 800-900 PCU/h and reverse is for 900-1000 PCU/h.The standard deviation of hiace-bus > bus-hiace, and the value is more for flow 900-1000 PCU/h.

At site-3, for flow less than 800 PCU/h, the mean and spread of TH for bus-truck < truck-bus and the reverse are for flows more significant than 800 PCU/h on SL. Below flow 800 PCU/h, truck-bus data is more spread than bus-truck, resulting in a high mean for bus-truck. As flow increase gap between the standard deviation of both pairs decreases.

At SL site-3, the combination of truck and hiace vehicles showed no consistent pattern in terms of mean and standard deviation measurements when one vehicle was leading and the other was following. For flow levels of 500-600 PCU/h, 800-900 PCU/h, and 1000-

1100 PCU/h, the mean TH of hiace-truck was less than truck-Hiace. Conversely, for flow levels of 600-700 PCU/h, 700-800 PCU/h, and 900-1000 PCU/h, the mean TH of truck-hiace was less than Hiace-truck.

4.2.4 Time Headway distributions for Different Vehicle-pairs

Further analysis of headway data for different vehicle pairs was performed to identify the type of distribution that each leader-follower vehicle pair follows. This involved fitting various probability distribution functions to the headway data of different vehicle pairs and conducting a goodness-of-fit test for each probability density function using the K-S testing technique at a 5% significance level. To ensure the reliability of our results, we only consider time headway data with sample sizes greater than 50 for fitting the time headway distributions. Tables 16,17,18 and 19 represent various vehicle pairs' best-fitted distributions along with parameters and p-value for different flow levels at site-2 and site-3.

Table 4-14 Various vehicle pairs TH distributions and parameters for Site-2_SL

Leading veh-Following veh	Best Fitted Distributions	K-S Value	Parameters	P-Value	Sample
Flow level, 500-600 PCU/h					
Bus-Car	Weibull	0.0727	$\alpha=1.7551,\beta=7.2515$	0.9789	76
car-Bus	Beta	0.0873	$\alpha_1=0.59078,\alpha_2=1.6331,\alpha=1.0,\beta=17.6$	0.9664	66
Car-Car	Johnson SB	0.0881	$\gamma=2.8558,\delta=1.1326,\lambda=55.74,\xi=-0.08913$	0.9836	8809
car-Hiace	Pearson 5	0.1108	$\alpha=1.8034,\beta=5.4536$	0.9280	77
Car-Truck	Wakeby	0.0736	$\alpha=3.7668,\beta=5.2155,\gamma=4.3888,\delta=0.00261,\xi=0.75968$	0.9619	1376
Hiace-Car	Burr (4P)	0.1119	$\kappa=4.9267,\alpha=1.2907,\beta=14.641,\gamma=0.92736$	0.9298	73
Truck-Car	Wakeby	0.0820	$\alpha=2.925,\beta=1.5029,\gamma=3.2135,\delta=0.13039,\xi=1.2388$	0.8992	1420
Truck-Truck	Log-Pearson 3	0.0725	$\alpha=631.83,\beta=-0.02872,\gamma=19.812$	0.9224	261
Flow level, 600-700 PCU/h					
Bus-Car	Johnson SB	0.0721	$\gamma=1.0842,\delta=0.99838,\lambda=23.764,\xi=-0.21207$	0.9924	58
car-Bus	Lognormal	0.1084	$\sigma=0.6914,\mu=1.1694$	0.9482	57
Car-Car	Johnson SB	0.1016	$\gamma=2.9473,\delta=1.1393,\lambda=49.197,\xi=0.01396$	0.9432	3889
Car-Truck	Lognormal (3P)	0.1049	$\sigma=0.93891,\mu=1.0955,\gamma=0.44718$	0.9396	654
Truck-Car	Fatigue Life (3P)	0.1039	$\alpha=0.71963,\beta=3.9993,\gamma=0.02858$	0.9317	643
Truck-Truck	Gamma	0.0772	$\alpha=2.2146,\beta=2.382$	0.9321	149
Flow level, 700-800 PCU/h					
Car-Car	Frechet (3P)	0.1177	$\alpha=2.3241,\beta=3.6002,\gamma=-1.2624$	0.9499	1124
Car-Truck	Inv. Gaussian	0.1240	$\lambda=5.1572,\mu=4.1156$	0.9399	199
Truck-Car	Inv. Gaussian (3P)	0.1059	$\lambda=10.217,\mu=4.6286,\gamma=-0.09698$	0.9262	190
Flow level, 800-900 PCU/h					
Car-Car	Pearson 5 (3P)	0.1374	$\alpha=3.079,\beta=9.0478,\gamma=-0.42876$	0.9579	152
Car-Truck	Pearson 5 (3P)	0.1287	$\alpha=2.0288,\beta=5.3873,\gamma=-0.10802$	0.9338	51

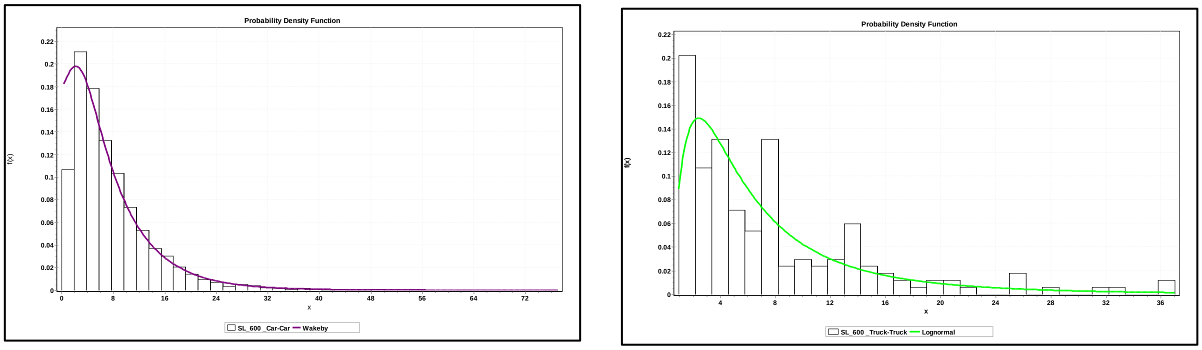


Figure 4-4 Time headway distributions for (i) car-car (ii) truck-truck at site-2_SL

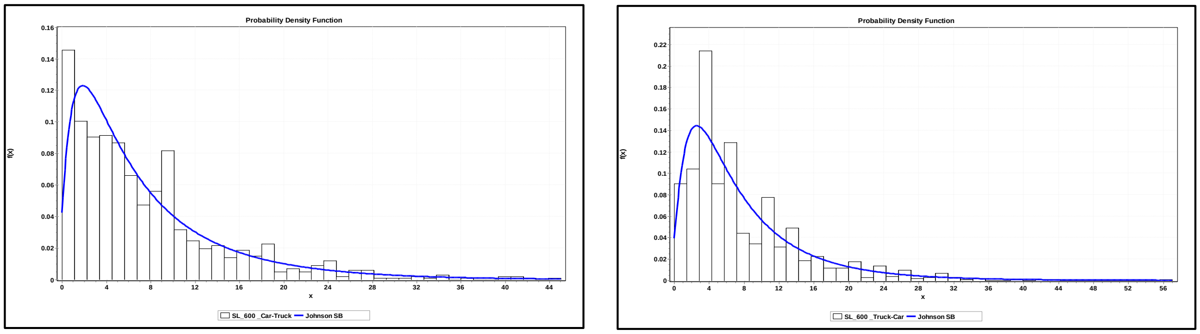


Figure 4-5 Time headway distributions for (iii) car-truck (iv) truck-car at site-2_SL

Table 4-15 Time headway distributions for different vehicle pairs at site-3 FL

Leading veh-Following veh	**Flow levels in PCU/h at Site 3 FL**					
	500-600	**600-700**	**700-800**	**800-900**	**900-1000**	**1000-1100**
Bus-Car	Fatigue Life (3P)					
Car-Car	Gen. Pareto	Gen. Pareto	Gen. Pareto	Gen. Pareto	Johnson SB	Inv. Gaussian
car-Hiace	Gen. Pareto	Johnson SB	Inv. Gaussian	Gen. Extreme Value	Weibull (3P)	
Car-Truck	Log-Pearson 3					
Hiace-Car	Gen. Pareto	Johnson SB	Beta	Gen. Logistic	Kumaraswamy	
Hiace-Hiace	Gen. Pareto	Pearson 6	Gen. Extreme Value	Kumaraswamy		

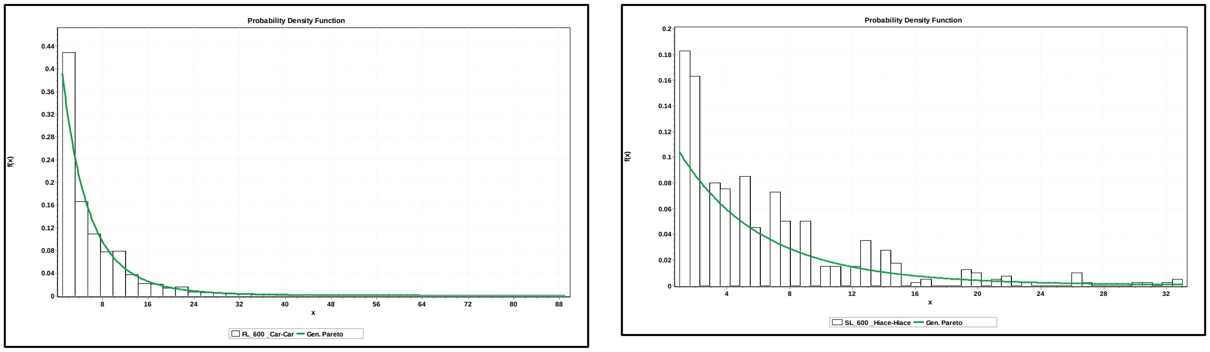


Figure 4-6 Time headway distributions for (v) car-car (vi) hiace-hiace at site-3_FL

Table 4-16 Time headway distributions for different vehicle pairs at site-2 FL

Leading veh-Following veh	**Flow levels in PCU/h at Site 2 FL**				
	500-600	**600-700**	**700-800**	**800-900**	**900-1000**
Bus-Car	Frechet	Log-Pearson 3			
car-Bus	Johnson SB	Inv. Gaussian (3P)			
Car-Car	Gen. Pareto	Wakeby	Gen. Pareto	Log-Pearson 3	Pearson 6
car-Hiace	Log-Pearson 3	Gen. Pareto	Gamma		
Car-Truck	Fatigue Life (3P)	Johnson SB	Lognormal (3P)	Gen. Extreme Value	
Hiace-Car	Beta	Log-Pearson 3	Chi-Squared		
Truck-Car	Pearson 5	Log-Pearson 3	Log-Pearson 3		
Truck-Truck	Pearson 6	Inv. Gaussian (3P)			

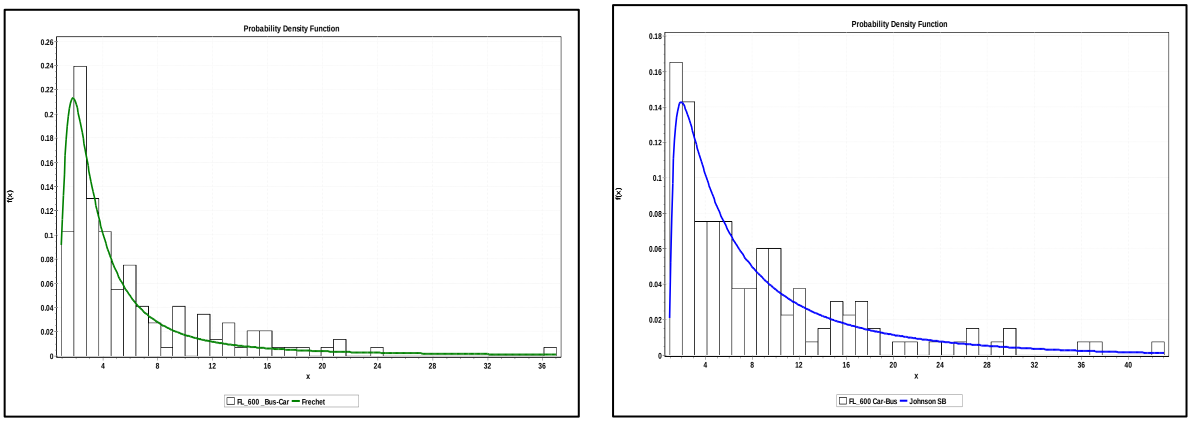


Figure 4-7 Time headway distributions for (vii) car-bus (viii) bus-car at site-2_FL

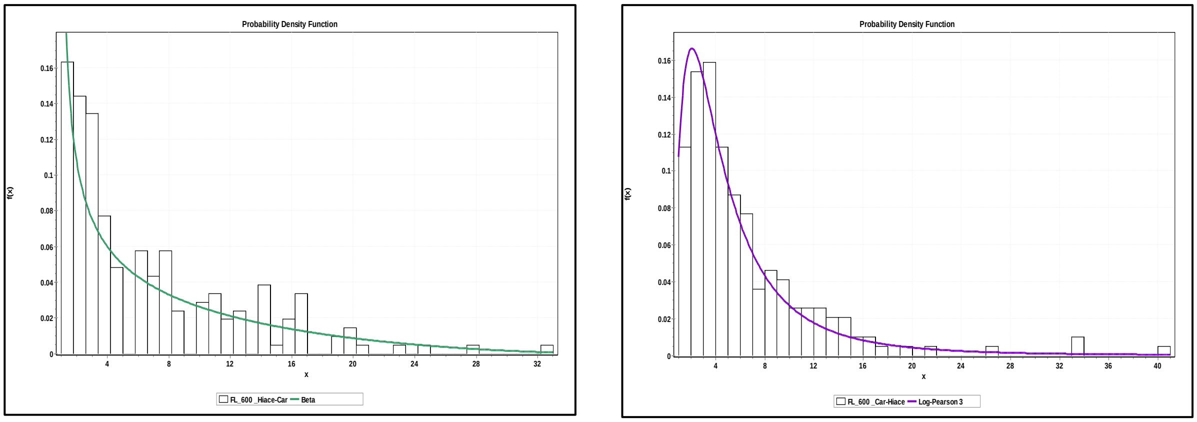


Figure 4-8 Time headway distributions for (ix) car-hiace (x) hiace-car at site-2_FL

Table 4-17 Vehicle pair TH distributions and parameters at Site-3_SL

Leading veh-Following veh	Best Fitted Distributions	K-S Value	Parameters	P-Value	Sample size
Flow level, 500-600 PCU/h					
Bus-Car	Wakeby	0.0637	$\alpha=0,\beta=0,\gamma=7.5992,\delta=0.0237,\xi=0.46387$	0.9540	311
car-Bus	Wakeby	0.0816	$\alpha=0,\beta=0,\gamma=6.8225,\delta=0.05949,\xi=0.14795$	0.9299	311
Car-Car	Wakeby	0.0570	$\alpha=4.521,\beta=4.3735,\gamma=6.0527,\delta=0.02395,\xi=0.35534$	0.9543	11373
car-Hiace	Wakeby	0.0613	$\alpha=4.6669,\beta=1.6079,\gamma=4.5627,\delta=0.04825,\xi=-0.00959$	0.9405	514
Car-Truck	Johnson SB	0.0638	$\gamma=2.2951,\delta=0.9924,\lambda=65.446,\xi=-0.55472$	0.8876	1016
Hiace-Car	Wakeby	0.0571	$\alpha=5.9081,\beta=0.6932,\gamma=2.6925,\delta=0.21176,\xi=0.41392$	0.9673	514
Hiace-Truck	Wakeby	0.0666	$\alpha=10.007,\beta=0.82699,\gamma=0.61379,\delta=0.56925,\xi=0.6064$	0.9405	59
Truck-Car	Johnson SB	0.0628	$\gamma=2.9171,\delta=1.1507,\lambda=90.035,\xi=-0.84125$	0.9628	1017
Truck-Hiace	Burr	0.0963	$\kappa=0.60426,\alpha=2.5944,\beta=4.1386$	0.8631	57
Truck-Truck	Lognormal	0.0709	$\sigma=0.88472,\mu=1.6809$	0.9351	168
Flow level, 600-700 PCU/h					
Bus-Car	Wakeby	0.0734	$\alpha=2.2919,\beta=4.4414,\gamma=5.3714,\delta=0.01116,\xi=0.27906$	0.9673	310
car-Bus	Wakeby	0.0893	$\alpha=15.379,\beta=29.238,\gamma=4.707,\delta=0.05551,\xi=0$	0.9112	321
Car-Car	Wakeby	0.0647	$\alpha=4.8162,\beta=5.7516,\gamma=5.0995,\delta=-0.0037,\xi=0.26933$	0.8757	17223
car-Hiace	Wakeby	0.0693	$\alpha=4.0376,\beta=2.9833,\gamma=4.6283,\delta=0.00277,\xi=0.02642$	0.8740	643
Car-Truck	Wakeby	0.0704	$\alpha=2.3783,\beta=8.4471,\gamma=5.8674,\delta=-0.01193,\xi=0.33551$	0.7616	1043
Hiace-Car	Wakeby	0.0661	$\alpha=2.8092,\beta=3.7472,\gamma=5.0302,\delta=0.0368,\xi=0.28007$	0.9729	637
Hiace-Truck	Fatigue Life	0.0776	$\alpha=0.89454,\beta=4.3625$	0.9759	54
Truck-Car	Wakeby	0.0687	$\alpha=10.517,\beta=18.479,\gamma=6.2235,\delta=-0.09945,\xi=0.37085$	0.8512	1059
Truck-Hiace	Johnson SB	0.0804	$\gamma=2.364,\delta=1.2585,\lambda=39.316,\xi=-0.83406$	0.8698	51
Truck-Truck	Log-Logistic	0.0973	$\alpha=1.9032,\beta=4.2798$	0.9163	129
Flow level, 700-800 PCU/h					
Bus-Car	Wakeby	0.0895	$\alpha=21.048,\beta=24.173,\gamma=4.6181,\delta=-0.017,\xi=0$	0.8265	427
car-Bus	Gamma	0.0886	$\alpha=1.3332,\beta=3.3463$	0.8724	425
Car-Car	Wakeby	0.0750	$\alpha=5.9677,\beta=8.3948,\gamma=4.6303,\delta=-0.04103,\xi=0.1519$	0.7975	26310
car-Hiace	Wakeby	0.0764	$\alpha=3.7352,\beta=3.0416,\gamma=3.8439,\delta=0.02281,\xi=0.0675$	0.8256	763
Car-Truck	Wakeby	0.0830	$\alpha=10.333,\beta=15.676,\gamma=4.3478,\delta=-0.01373,\xi=0.02665$	0.7914	1357
Hiace-Car	Wakeby	0.0864	$\alpha=3.5108,\beta=8.1022,\gamma=4.4435,\delta=0.02468,\xi=0.02832$	0.8197	767
Hiace-Truck	Gamma	0.0902	$\alpha=1.0987,\beta=5.1576$	0.7709	57
Truck-Car	Wakeby	0.0706	$\alpha=5.2907,\beta=5.0013,\gamma=4.1615,\delta=0.0124,\xi=0.43681$	0.7266	1351
Truck-Hiace	Gen. Extreme Value	0.1083	$\kappa=0.31819,\sigma=2.065,\mu=2.9956$	0.9403	65
Truck-Truck	Gen. Extreme Value	0.0886	$\kappa=0.21499,\sigma=2.5528,\mu=3.5448$	0.9334	110
Flow level, 800-900 PCU/h					
Bus-Car	Wakeby	0.0935	$\alpha=5.2564,\beta=7.4286,\gamma=3.7827,\delta=-0.02163,\xi=0.36931$	0.9186	657
car-Bus	Wakeby	0.1020	$\alpha=6.1023,\beta=13.049,\gamma=3.4462,\delta=0.06237,\xi=0$	0.9178	665
Car-Car	Wakeby	0.0837	$\alpha=5.1189,\beta=7.0742,\gamma=3.9973,\delta=-0.0322,\xi=0.18039$	0.8436	30535
car-Hiace	Gen. Pareto	0.1001	$\kappa=-0.0043,\sigma=4.1114,\mu=0.32203$	0.8755	962
Car-Truck	Wakeby	0.0913	$\alpha=2.9825,\beta=6.6438,\gamma=4.034,\delta=-0.05725,\xi=0.16332$	0.8368	1615
Hiace-Car	Wakeby	0.0849	$\alpha=2.35,\beta=5.3199,\gamma=4.6335,\delta=-0.09786,\xi=0.06503$	0.9156	969
Hiace-Hiace	Johnson SB	0.1147	$\gamma=1.6009,\delta=0.77476,\lambda=29.781,\xi=0.0296$	0.9455	53
Hiace-Truck	Wakeby	0.1099	$\alpha=6.7871,\beta=58.814,\gamma=4.6596,\delta=-0.16932,\xi=0$	0.9542	61
Truck-Car	Wakeby	0.0923	$\alpha=3.8377,\beta=5.3054,\gamma=3.6122,\delta=0.03704,\xi=0.54429$	0.9620	1616
Truck-Hiace	Pearson 6	0.0987	$\alpha_1=3.4644,\alpha_2=7.2834,\beta=8.3602$	0.9538	63
Truck-Truck	Dagum	0.0957	$\kappa=0.86697,\alpha=2.6094,\beta=4.2081$	0.9733	95
Flow level, 900-1000 PCU/h					
Bus-Car	Johnson SB	0.1027	$\alpha=5.2564,\beta=7.4286,\gamma=3.7827,\delta=-0.02163,\xi=0.36931$	0.9187	653
car-Bus	Wakeby	0.1164	$\alpha=6.1023,\beta=13.049,\gamma=3.4462,\delta=0.06237,\xi=0$	0.8346	655
Car-Car	Wakeby	0.0889	$\alpha=5.1189,\beta=7.0742,\gamma=3.9973,\delta=-0.0322,\xi=0.18039$	0.8321	30439
car-Hiace	Wakeby	0.1000	$\kappa=-0.0043,\sigma=4.1114,\mu=0.32203$	0.7628	938
Car-Truck	Gamma	0.0954	$\alpha=2.9825,\beta=6.6438,\gamma=4.034,\delta=-0.05725,\xi=0.16332$	0.7745	1519
Hiace-Car	Wakeby	0.0994	$\alpha=2.35,\beta=5.3199,\gamma=4.6335,\delta=-0.09786,\xi=0.06503$	0.8185	930
Hiace-Hiace	Log-Logistic	0.1259	$\gamma=1.6009,\delta=0.77476,\lambda=29.781,\xi=0.0296$	0.9631	51
Hiace-Truck	Gamma	0.1251	$\alpha=6.7871,\beta=58.814,\gamma=4.6596,\delta=-0.16932,\xi=0$	0.9383	50
Truck-Car	Johnson SB	0.0969	$\alpha=3.8377,\beta=5.3054,\gamma=3.6122,\delta=0.03704,\xi=0.54429$	0.9594	1529
Truck-Hiace	Gen. Extreme Value	0.1244	$\alpha_1=3.4644,\alpha_2=7.2834,\beta=8.3602$	0.9378	51
Truck-Truck	Gamma	0.1138	$\kappa=0.86697,\alpha=2.6094,\beta=4.2081$	0.8475	119
Flow level, 1000-1100 PCU/h					
Bus-Car	Wakeby	0.0985	$\alpha=1.9686,\beta=2.2081,\gamma=2.9639,\delta=-0.07437,\xi=0.46888$	0.0004	441
car-Bus	Chi-Squared	0.1467	$\nu=3$	0.7993	440
Car-Car	Wakeby	0.0985	$\alpha=4.3983,\beta=6.8615,\gamma=3.1673,\delta=-0.02894,\xi=0.16062$	0.8765	19346
car-Hiace	Wakeby	0.1075	$\alpha=3.2887,\beta=4.2625,\gamma=2.7673,\delta=0.04075,\xi=-0.00132$	0.7820	592
Car-Truck	Johnson SB	0.1075	$\gamma=3.168,\delta=1.3337,\lambda=42.686,\xi=-0.79547$	0.8209	988
Hiace-Car	Wakeby	0.1185	$\alpha=2.3784,\beta=4.2186,\gamma=2.7643,\delta=0.03167,\xi=0.21027$	0.8830	601
Truck-Car	Erlang	0.1143	$\mu=2,\beta=1.8468$	0.9385	978
Truck-Truck	Gen. Extreme Value	0.1147	$\kappa=0.10456,\sigma=1.6343,\mu=2.6913$	0.9271	73
Flow level, 1100-1200 PCU/h					
Bus-Car	Gamma	0.1127	$\alpha=1.9756,\beta=1.8739$	0.9215	188
car-Bus	Gen. Pareto	0.1496	$\kappa=-0.24112,\sigma=3.6548,\mu=0.02277$	0.9744	185
Car-Car	Wakeby	0.1087	$\alpha=16.133,\beta=32.296,\gamma=3.464,\delta=0.05179,\xi=0$	0.8653	10529
car-Hiace	Chi-Squared	0.1379	$\nu=3$	0.9794	263
Car-Truck	Wakeby	0.1144	$\alpha=5.4606,\beta=7.1574,\gamma=2.6872,\delta=0.0146,\xi=-0.15318$	0.9210	522
Hiace-Car	Wakeby	0.1209	$\alpha=2.9727,\beta=1.981,\gamma=1.8098,\delta=0.15546,\xi=0.18045$	0.9857	262
Truck-Car	Gen. Extreme Value	0.1297	$\kappa=0.20198,\sigma=1.6105,\mu=2.2477$	0.9429	520
Flow level, 1200-1300 PCU/h					
Bus-Car	Gen. Extreme Value	0.1264	$\kappa=0.26954,\sigma=1.5873,\mu=1.9571\kappa=0.26954,\sigma=1.5873,\mu=1.9571$	0.8958	70
car-Bus	Gamma	0.1631	$\alpha=1.2374,\beta=1.9918$	0.9141	71
Car-Car	Log-Logistic	0.1146	$\alpha=1.627,\beta=2.8987$	0.9431	4328
car-Hiace	Wakeby	0.1279	$\alpha=2.9692,\beta=3.6862,\gamma=2.0661,\delta=0.06373,\xi=-0.23633$	0.9672	101
Car-Truck	Wakeby	0.1201	$\alpha=3.1588,\beta=1.7522,\gamma=1.3872,\delta=0.17675,\xi=0.30669$	0.8454	208
Hiace-Car	Johnson SB	0.1002	$\gamma=2.0574,\delta=1.2146,\lambda=25.507,\xi=-0.90495$	0.9709	112
Truck-Car	Weibull	0.1187	$\alpha=1.4359,\beta=3.6561$	0.9689	198
Flow level, 1300-1400 PCU/h					
Car-Car	Phased Bi-Exponential	0.1448	$\lambda_1=0.07664,\gamma_1=0,\lambda_2=0.67562,\gamma_2=12$	0.9732	1153

The graph in Figure 4-5 highlights that when cars trail behind trucks, there is a more pronounced peak in the histogram, with a light-tailed distribution. It suggests that many cars keep a closer headway, amplifying the peak. Furthermore, comparing the histograms between these two pairs of vehicles reveals a broader range of headways when trucks trail cars, as opposed to when cars trail trucks, where the variation is notably reduced.

It is observed that the distribution of headways between different vehicle pairs on slow and fast lanes varies as the site and flow conditions change. The alteration in the parameters of headway distributions depends upon the data's location, spread, and position.

In conclusion, it can be established that among the various vehicle pairs, the Wakeby distribution is the most observed on slow lanes (SL) at Site-3, while the General Pareto distribution is the most observed on fast lanes (FL) at the same site. On the other hand, at Site-2, the Log-Pearson 3 distribution is the most frequently seen on fast lanes, and the Johnson SB and Pearson 5 distributions are the most prevalent on slow lanes.

4.3 Speed statistical parameters and distribution

Speed statistical properties and distribution analysis is conducted for mixed traffic and vehicle classes. Heterogeneous traffic analysis under various flow levels is also performed, as discussed below.

4.3.1 Speed statistical properties for the mixed traffic

Table 20 presents a comparative analysis of the variation in the statistical properties of the time headways across different flow ranges at Site-2. The information in the table provides a comprehensive view of the dynamic behavior of the speed under varying flow conditions.

Table 4-18 Statistical analysis of time headway data for site-2 SL and FL

Site-2 SL														
Flow range (pcu/hr)	**Sample size**	**No. of 15 min counts**	**Mean (km/hr)**	**Median (km/hr)**	**Mode (km/hr)**	**Std Dev (km/hr)**	**CV(%)**	**IQR**	**SE of mean**	**Sk**	**Kr**	**15 %ile**	**85 %ile**	**SSR(0.86-1.11)**
0-100	4422	445.00	45.03	43.19	43.96	14.06	31.2%	18.59	0.21	0.58	0.59	31.20	59.64	1.37
100-200	6409	190.00	45.07	43.86	45.31	13.93	30.9%	18.50	0.17	0.42	0.40	31.29	59.52	1.25
200-300	9071	130.00	44.31	43.69	45.12	12.69	28.6%	16.89	0.13	0.24	0.12	31.59	57.57	1.15
300-400	13748	120.00	41.36	40.80	38.80	11.17	27.0%	13.97	0.10	0.26	0.30	30.33	52.83	1.15
400-500	41953	284.00	39.83	39.45	40.25	10.64	26.7%	12.90	0.05	0.33	0.57	29.28	50.36	1.07
500-600	41945	243.00	39.55	39.27	41.69	10.40	26.3%	12.68	0.05	0.38	1.53	29.25	49.76	1.05
600-700	19161	96.00	39.03	38.73	39.53	10.21	26.2%	12.60	0.07	0.56	3.22	29.03	48.87	1.05
700-800	5302	24.00	38.68	38.17	36.03	9.64	24.9%	11.91	0.13	0.37	0.61	29.16	48.08	1.10
800-900	921	4.00	39.08	38.57	37.21	9.71	24.9%	11.83	0.32	0.31	0.51	29.71	48.34	1.10
Site-2 FL														
Flow range (pcu/hr)	**Sample size**	**No. of 15 min counts**	**Mean (km/hr)**	**Median (km/hr)**	**Mode (km/hr)**	**Std Dev (km/hr)**	**CV(%)**	**IQR**	**SE of mean**	**Sk**	**Kr**	**15 %ile**	**85 %ile**	**SSR(0.86-1.11)**
0-100	4214	569.00	51.66	52.33	51.36	14.97	29.0%	21.87	0.23	0.15	-0.22	34.92	66.81	0.83
100-200	4990	158.00	54.35	54.85	49.06	12.48	23.0%	15.69	0.18	-0.16	0.30	41.32	66.84	0.89
200-300	6001	99.00	53.79	54.02	50.09	11.06	20.6%	14.12	0.14	-0.11	0.24	42.64	64.86	0.95
300-400	12079	135.00	52.44	52.79	59.88	11.00	21.0%	14.39	0.10	-0.11	0.33	41.17	63.30	0.90
400-500	27135	245.00	51.73	51.78	49.49	10.62	20.5%	13.45	0.06	-0.01	0.47	41.10	62.18	0.97
500-600	27033	200.00	50.69	50.97	53.67	10.45	20.6%	13.12	0.06	-0.11	0.51	40.28	61.03	0.94
600-700	12904	82.00	49.53	49.69	51.91	10.19	20.6%	12.88	0.09	-0.09	0.57	39.51	59.61	0.97
700-800	7201	39.00	49.51	49.69	49.92	10.08	20.4%	12.73	0.12	-0.07	0.36	39.59	59.56	0.98
800-900	1428	7.00	49.16	49.14	49.85	8.40	17.1%	10.88	0.22	-0.08	0.47	40.53	57.48	0.97
900-1000	463	2.00	51.04	51.72	50.08	8.07	15.8%	10.51	0.38	-0.23	0.13	42.74	58.93	0.80

Table 20 presents a trend of decreasing average speed, midpoint, and variation as the flow rate increases, except for the flow levels 0-100 PCU/h and the extreme flow for both lanes. The average headways in the fast lane (FL) are consistently more significant than in the slow lane (SL) along all segments. The alterations in the central tendency and spread of the data are minimal as the flow level increases. Once the maximum sample size is reached for flow level 400-500 PCU/h, the differences in the values of the statistical measures decrease as the flow continues to rise. However, the statistical measures start to increase at the optimal flow with fewer vehicles, suggesting that sample size also affects speed.

As flow increases, the dispersion of data around the midpoint, as indicated by the interquartile range (IQR), decreases. The lower standard error values suggest the data provides a more accurate population representation. The skewness values of the fast lane show a slight right skew in speed for each flow level, except for 0-100 PCU/h. The skewness values of the slow lane indicate a slight left skew in the speed for each flow range. The positive value of kurtosis indicates that the speed of each flow level has a higher peak than that of a normal distribution. The slow lane's flow level of 600-700 PCU/h has the highest peak among all other flow levels.

The SSR values indicate that the speed conforms to a normal distribution for each flow level, with only slight deviations in the lower flow ranges on the slow lane. The skewness, kurtosis, and SSR values all suggest that the speed of each flow level approximates a normal distribution.

The percentile values are helpful for traffic engineers to determine safe and efficient road design speeds and monitor traffic flow patterns. By considering the 15th and 85th percentile speeds, traffic engineers can better understand the range of speeds most drivers consider reasonable and safe and use this information to make decisions about road design and traffic control measures.

4.3.2 Speed distributions for mixed traffic

Table 20 illustrates the optimal Speed distributions, associated K-S test statistics, estimated parameters, and p-values, which have been obtained by fitting the distributions to the collected data. These estimated parameters provide insight into the speed characteristics at each flow level and can be used to inform traffic management strategies and decision-making.

Table 4-19 Best-fitted Speed distributions for various Flow Levels at Site 2_SL

SL_Flow (PCU/hr)	Sample Size	Best Fitted Distributions	K-S Value	Parameters	P-Value
0-100	4422	Wakeby	0.0152	$\alpha=134.91,\beta=10.035,\gamma=19.738,\delta=-0.27427,\xi=17.311$	0.9258
		Gen. Extreme Value	0.0152	$\kappa=-0.10711,\sigma=12.351,\mu=39.09$	0.9121
		Pearson 6	0.0162	$\alpha_1=10.517,\alpha_2=253.61,\beta=1082.9$	0.8971
100-200	6409	Gen. Extreme Value	0.0105	$\kappa=-0.16759,\sigma=12.854,\mu=39.499$	0.9471
		Gamma (3P)	0.0108	$\alpha=26.437,\beta=2.7074,\gamma=-26.51$	0.9243
		Fatigue Life (3P)	0.0108	$\alpha=0.13204,\beta=104.31,\gamma=-60.158$	0.9123
200-300	9071	Pearson 5 (3P)	0.0083	$\alpha=155.81,\beta=24353.0,\gamma=-113.03$	0.9557
		Johnson SU	0.0089	$\gamma=-10.041,\delta=9.7489,\lambda=77.814,\xi=-51.279$	0.9321
		Lognormal (3P)	0.0091	$\sigma=0.07904,\mu=5.0739,\gamma=-115.98$	0.9128
300-400	13748	Wakeby	0.0128	$\alpha=140.45,\beta=8.9219,\gamma=13.998,\delta=-0.25473,\xi=16.047$	0.8623
		Log-Logistic (3P)	0.0130	$\alpha=19.966,\beta=125.11,\gamma=-84.237$	0.8435
		Burr	0.0145	$\kappa=2.8236,\alpha=4.9584,\beta=53.022$	0.8421
400-500	41953	Log-Logistic (3P)	0.0076	$\alpha=19.09,\beta=112.97,\gamma=-73.619$	0.7932
		Gen. Logistic	0.0078	$\kappa=0.04601,\sigma=5.8964,\mu=39.382$	0.7862
		Burr (4P)	0.0081	$\kappa=0.77833,\alpha=193.14,\beta=1036.6,\gamma=-999.17$	0.7432
500-600	41945	Gen. Logistic	0.0075	$\kappa=0.03908,\sigma=5.7512,\mu=39.176$	0.8098
		Log-Logistic (3P)	0.0078	$\alpha=22.056,\beta=127.27,\gamma=-88.119$	0.7613
		Dagum	0.0100	$\kappa=0.51913,\alpha=8.8222,\beta=44.136$	0.7342
600-700	19161	Dagum	0.0063	$\kappa=0.5229,\alpha=8.9044,\beta=43.466$	0.8451
		Log-Logistic (3P)	0.0090	$\alpha=20.282,\beta=114.25,\gamma=-75.627$	0.8342
		Gen. Logistic	0.0093	$\kappa=0.04023,\sigma=5.6126,\mu=38.659$	0.8231
700-800	5302	Log-Logistic (3P)	0.0107	$\alpha=15.439,\beta=82.853,\gamma=-44.716$	0.9729
		Dagum	0.0108	$\kappa=0.61596,\alpha=8.5392,\beta=41.656$	0.9654
		Burr	0.0112	$\kappa=2.0012,\alpha=5.7907,\beta=44.495$	0.9435
800-900	921	Burr (4P)	0.0152	$\kappa=1.3827,\alpha=9.2384,\beta=58.088,\gamma=-16.814$	0.9812
		Dagum	0.0170	$\kappa=0.59245,\alpha=8.7417,\beta=42.372$	0.9765
		Dagum (4P)	0.0175	$\kappa=1.5311,\alpha=459.73,\beta=2806.6,\gamma=-2771.4$	0.9632

Based on Table 21, at site-2, slow lane, the most used distributions in low flow ranges are Wakeby, Generalized Extreme Value, and Pearson. The most widely used distributions in high flow ranges are Log-logistic, Generalized Logistic, Burr, and Dagum. Table 22 presents the commonly used distributions at site-2 fast lane, with Wakeby being the most frequently adopted in low flow ranges. The Burr and Johnson SB distributions are largely prevalent in middle and high flow levels.

Table 4-20 Best-fitted Speed distributions for Various Flow Levels at Site 2_FL

FL_Flow (PCU/hr)	Sample Size	Best Fitted Distributions	K-S Value	Parameters	
0-100	**4214**	Wakeby	0.0164	α=79.193,β=3.6161,γ=14.881,δ=–0.22725,ξ=22.378	0.9202
		Error	0.0255	κ=2.2587,σ=14.971,μ=51.66	0.9038
		Gen. Extreme Value	0.0255	κ=–0.26365,σ=14.846,μ=46.237	0.8971
100-200	**4990**	Wakeby	0.0129	α=161.71,β=7.1804,γ=14.498,δ=–0.30334,ξ=23.455	0.9374
		Dagum (4P)	0.0163	κ=0.58825,α=26.771,β=155.89,γ=–96.216	0.9231
		Gen. Logistic	0.0187	κ=–0.04135,σ=6.9633,μ=54.822	0.9132
200-300	**6001**	Burr (4P)	0.0083	κ=3.2253,α=7.6966,β=76.865,γ=–9.7924	0.9805
		Burr	0.0097	κ=4.2064,α=6.2663,β=71.073	0.9654
		Johnson SU	0.0106	γ=0.67375,δ=4.3642,λ=46.453,ξ=61.177	0.9543
300-400	**12079**	Burr	0.0066	κ=4.2942,α=6.1299,β=69.958	0.9667
		Burr (4P)	0.0069	κ=3.4394,α=7.1192,β=73.331,γ=–6.7659	0.9543
		Johnson SU	0.0077	γ=0.47045,δ=3.7493,λ=39.458,ξ=57.582	0.9512
400-500	**27135**	Burr (4P)	0.0039	κ=2.0222,α=10.334,β=82.066,γ=–23.464	0.8140
		Error	0.0043	κ=1.644,σ=10.621,μ=51.727	0.7981
		Johnson SU	0.0070	γ=0.03098,δ=3.1482,λ=31.764,ξ=52.055	0.7843
500-600	**27033**	Burr (4P)	0.0054	κ=2.3059,α=10.771,β=87.241,γ=–28.215	0.8412
		Johnson SU	0.0076	γ=0.3043,δ=3.0826,λ=30.392,ξ=53.856	0.8342
		Dagum	0.0080	κ=0.43263,α=12.445,β=57.056	0.8183
600-700	**12904**	Burr (4P)	0.0061	κ=2.0997,α=11.724,β=89.114,γ=–32.516	0.9714
		Log-Logistic (3P)	0.0080	α=1.7142E+8,β=9.7817E+8,γ=–9.7817E+8	0.9643
		Johnson SU	0.0093	γ=0.21991,δ=2.9308,λ=28.065,ξ=51.764	0.9534
700-800	**7201**	Johnson SU	0.0091	γ=0.27622,δ=3.5678,λ=34.463,ξ=52.287	0.9593
		Burr	0.0098	κ=3.5328,α=6.4739,β=62.875	0.9454
		Gen. Logistic	0.0101	κ=–0.01424,σ=5.6341,μ=49.642	0.9345
800-900	**1428**	Burr	0.0126	κ=2.7659,α=8.0304,β=57.64	0.9747
		Johnson SU	0.0145	γ=0.23716,δ=3.1669,λ=25.2,ξ=51.146	0.9675
		Burr (4P)	0.0147	κ=2.2678,α=10.233,β=66.824,γ=–11.123	0.9536
900-1000	**463**	Dagum (4P)	0.0216	κ=0.29964,α=12.479,β=38.399,γ=19.467	0.9793
		Wakeby	0.0255	α=90.965,β=6.1993,γ=8.8332,δ=–0.28917,ξ=31.55	0.9785
		Burr	0.0269	κ=4.3406,α=8.2214,β=63.653	0.9653

Depending on the flow level, these distributions are characterized by varying parameters, K-S statistics, and P-values. These parameters and statistics serve as a means of comparing the observed data with the modeled distribution and determining the accuracy of the selected distribution in representing the data.

Figures 4-10 through 4-15 demonstrate the fitting of speed distributions and histograms for various flow levels at the site-2 slow lane. The histograms visually represent the speed data's location, position, and scale and depict the best-fitted distributions for each flow level. The below histograms for various flow levels show that the mean speed and spread of data around the mean decreases as the flow level increases. Figures 4-12 and 4-13 display the Probability-Probability (PP) plot of flow levels 400-500 PCU/h and 500-600 PCU/h, respectively. These flow levels have a high sample size, but the K-S test results are not necessarily a precise reflection of goodness-of-fit. The linear nature of the PP plot for both flow levels 400-500 PCU/h and 500-600 PCU/h suggests that the selected theoretical distributions are appropriate models for these flow levels.

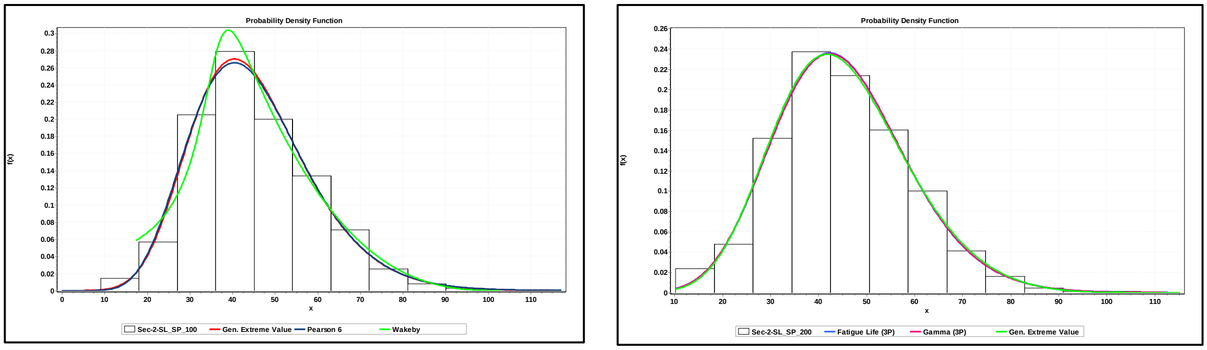


Figure 4-9 Speed PDF for (i) 0-100 PCU/h (ii) 100-200 PCU/h at Site-2 SL

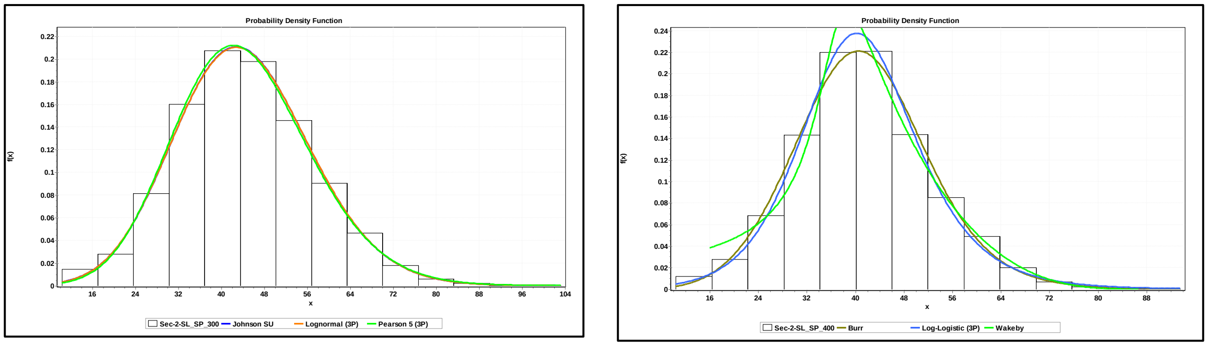


Figure 4-10 Speed PDF for (i) 200-300 PCU/h (ii) 300-400 PCU/h at Site-2 SL

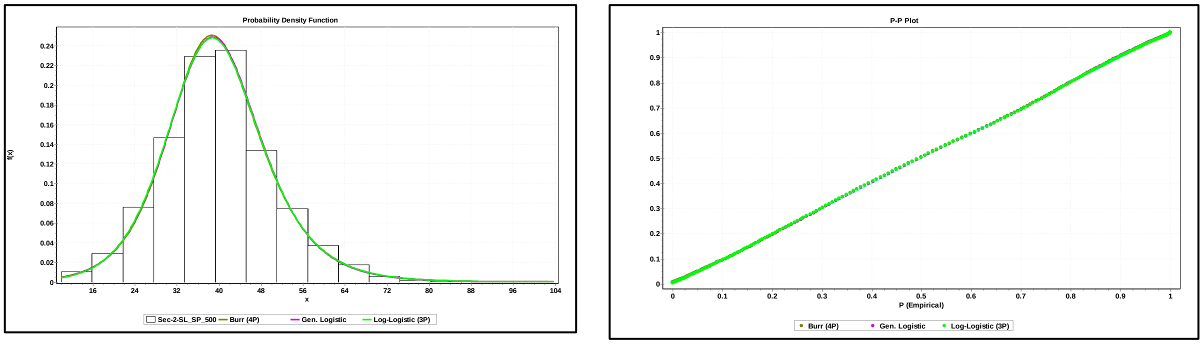


Figure 4-11 Speed PDF and P-P plot for flow level 400-500 PCU/h at Site-2 SL

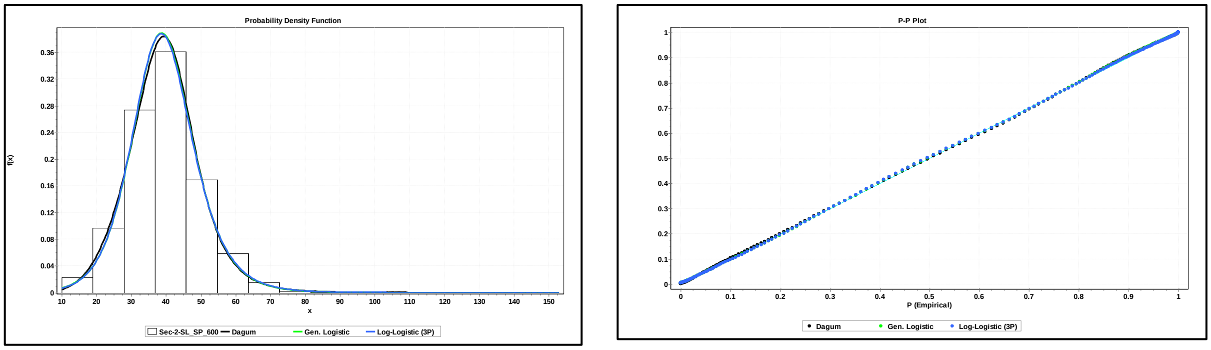


Figure 4-12 Speed PDF and P-P plot for flow level 500-600 PCU/h at Site-2 SL

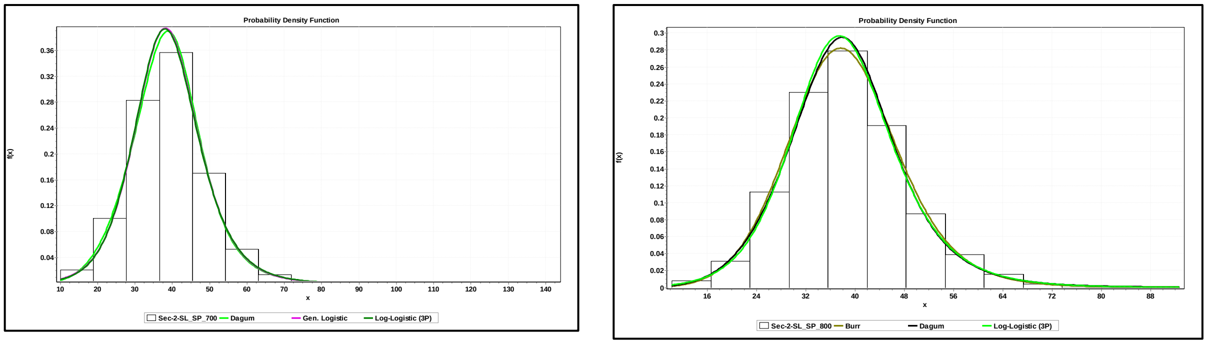


Figure 4-13 Speed PDF for (i) 600-700 PCU/h (ii) 700-800 PCU/h at Site-2 SL

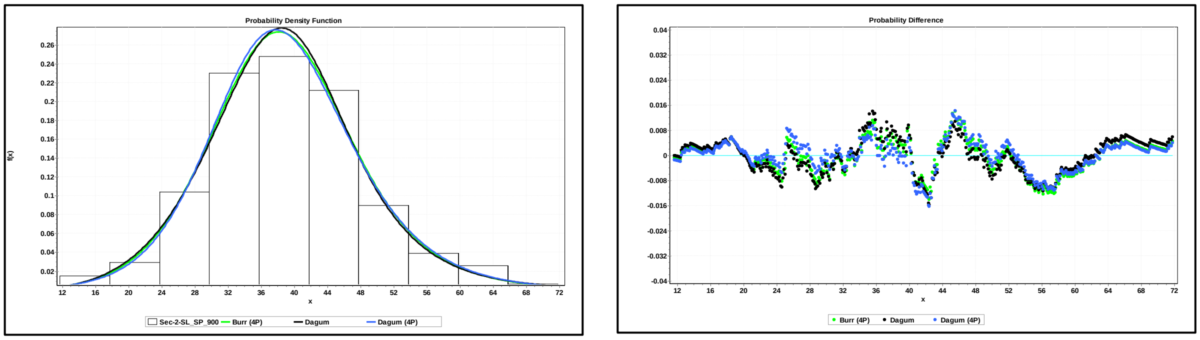


Figure 4-14 Speed PDF and PD plot for flow level 800-900 PCU/h at Site-2 SL

Figure 4-15 presents a Probability Difference Plot, which reflects the difference between the empirical cumulative distribution function (CDF) and the theoretical CDF. This plot provides insight into how well the theoretical distribution aligns with the observed data. The PDF chart shows that the specified distributions for flow level 900-1000 PCU/h at site-2 slow lane offer the best fit.

4.3.3 Speed statistical Properties for Different sites

The statistical parameters, including mean, median, standard deviation, skewness, percentiles etc., obtained from the combined analysis across all three sites are presented in Tables 23 and 24. Figures 4-16 and 4-17 depict the trend line of mean, median, 15th percentile speed, and 85th percentile speed on slow and fast lanes, respectively.

Table 4-21 Sample size and statistical parameters of overall speed data for SL

Section _Lane	Sample size	Mean	Median	SD	CV (%)	IQR	SE	Sk	Kr	Q1	Q3	15 %tile	85 %tile	SSR (.86-1.11)
1_SL	34951	52.88	50.84	15.03	28.43%	19.72	0.08	0.56	0.46	42.38	62.10	38.48	68.81	1.45
2_SL	71226	39.92	39.44	10.72	26.86%	12.87	0.04	0.33	0.74	33.15	46.02	29.45	50.64	1.12
3_SL	110026	84.45	85.88	15.99	18.94%	20.10	0.05	-0.34	0.37	75.02	95.12	67.93	99.97	0.78

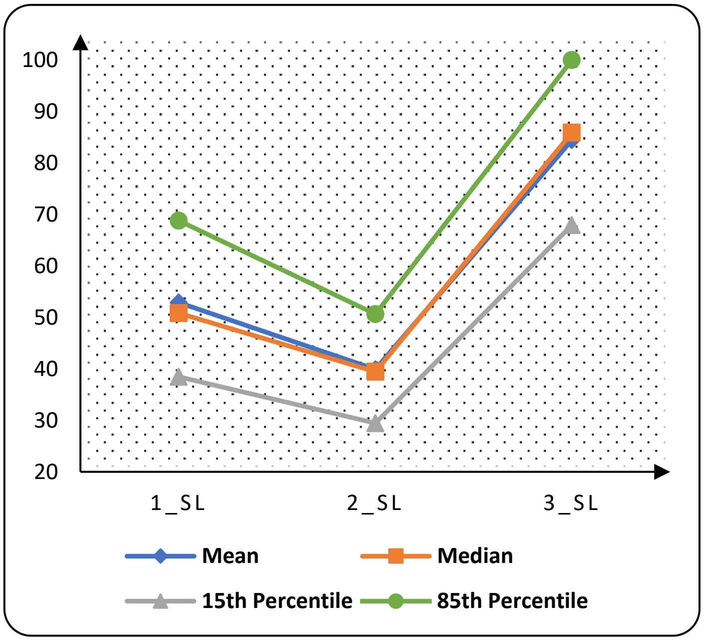


Figure 4-15 Mean, Median, 15th percentile and 85th percentile speed on SL

Table 4-22 Sample size and statistical parameters of overall speed data for FL

Section_Lane	Sample size	Mean	Median	SD	CV (%)	IQR	SE	Sk	Kr	Q1	Q3	15 %tile	85 %tile	SSR (.86-1.11)
1_FL	31927	75.13	75.84	15.15	20.17%	20.54	0.08	0.01	-0.03	64.85	85.38	58.46	90.36	0.84
2_FL	53190	51.05	51.24	9.54	18.69%	12.24	0.04	-0.04	0.54	44.93	57.17	41.46	60.49	0.95
3_FL	51547	113.96	112.27	15.13	13.28%	20.55	0.07	0.30	-0.03	103.52	124.07	99.02	130.71	1.39

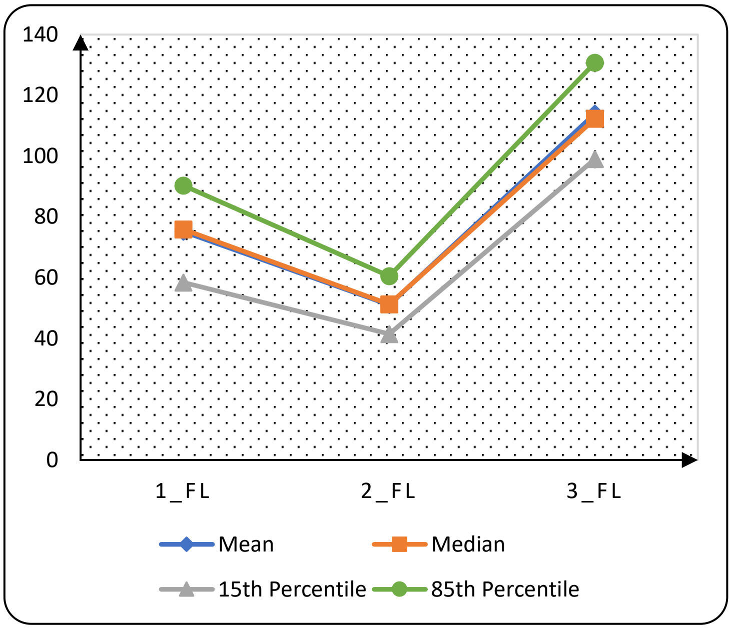


Figure 4-16 Mean, Median, 15th percentile and 85th percentile speed on FL

The 85th percentile speed is at or below which 85 per cent of the drivers travel on a road segment. Motorists traveling above the 85th percentile speed exceed the safe and reasonable speed for road and traffic conditions.

The counts of vehicles at all sites increase in the order site-1< site-2< site-3. The mean and percentile speed of site-2 is less than site-1. It is because of the high number of motorcycles at site-2, which impedes the free movement of vehicles.

Site-3 has a high mean and percentile speed across all sites because site-3 has no two-wheeler. Moreover, site-3 consists of a large number of cars and less number of heavy vehicles. Due to the bigger size and poor maneuverability, heavy vehicles decrease the overall stream speed. The speed dispersion parameters of site-1 and site-3 are almost equal and high than site-2 dispersion parameters. It means speed data is less spread at site-2 than at sites 1 and 3. The measure of fast lanes' location is higher than the slow lanes' central tendency at all sites. The measure of the dispersion of slow and fast lanes at all sites is almost equal, meaning that data spread around the measure of location are almost equal.

The slow lane speed data at site-1 and 2 are slightly positively skewed, and site-3 is slightly negatively skewed. The fast lane skewness values across all sites are less than slow lane skewness values, respectively, and are almost symmetrical. The kurtosis values of slow lanes are greater than fast lanes, which means that slow lanes' speed data has high peek and flatter tails than fast lanes.

The results suggest that the speeds are nearly symmetrically distributed, as the mean is only slightly more significant than the median, the difference between them is minimal, and the skewness values are not excessively high.

4.3.4 Speed distributions for Different Sites

The speed data observed frequencies were modeled using various probability density functions. Based on the K-S values, the most optimal fits at a 1% significance level are presented in this document. Tables 25 and 26 show the optimal distribution of vehicle speeds and accompanying statistical test results. The frequency distribution plots for each site's slow lane and fast lane are shown in figures 4-18 and 4-19.

Table 4-23 Slow Lane fitted speed distributions and their parameters at all sites

Sec_Lane	Sample Size	Type of distribution	Parameters	K-s Value
N5_SL	62625	Wakeby	$\alpha=192.12\ \ \beta=12.718\ \ \gamma=21.743,\delta=-0.28445\ \ \xi=21.943$	0.0129
		Inv. Gaussian	$\lambda=654.29\ \ \mu=52.876$	0.0132
		Gen. Extreme Value	$k=-0.0984\ \ \sigma=13.109\ \ \mu=46.481$	0.0151
		Johnson SB	$\gamma=5.905\ \ \delta=3.5463,\lambda=392.25\ \ \xi=-10.927$	0.0195
		Gamma	$\alpha=12.374\ \ \beta=4.2731$	0.0195
N45_SL	142932	Log-Logistic (3P)	$\alpha=19.603\ \ \beta=116.64\ \ \gamma=-77.199$	0.0109
		Gen. Logistic	$k=0.0463\ \ \sigma=5.9332\ \ \mu=39.464$	0.0112
		Wakeby	$\alpha=138.95\ \ \beta=8.6524\ \ \gamma=12.044,\delta=-0.1931\ \ \xi=15.428$	0.0123
		Dagum	$k=0.5363\ \ \alpha=8.4644\ \ \beta=44.341$	0.0140
		Johnson SU	$\gamma=-0.81204\ \ \delta=2.8604,\lambda=27.63\ \ \xi=31.467$	0.0174
M1_SL	216930	Dagum	$k=0.33096\ \ \alpha=16.218\ \ \beta=97.041$	0.0057
		Burr (4P)	$k=3.5481\ \ \alpha=12.354,\beta=166.4\ \ \gamma=-61.478$	0.0120
		Wakeby	$\alpha=217.77\ \ \beta=6.9453\ \ \gamma=18.078,\delta=-0.32673\ \ \xi=43.415$	0.0137
		Gen. Logistic	$k=-0.07247\ \ \sigma=8.8435\ \ \mu=85.511$	0.0161
		Johnson SU	$\gamma=2.4635\ \ \delta=4.5197,\lambda=61.021\ \ \xi=120.25$	0.0183

Table 4-24 Fast Lane fitted speed distributions and their parameters at all sites

Sec_Lane	**Sample Size**	**Type of distribution**	**Parameters**	**K-s Value**
N5_FL	68012	Weibull (3P)	α=4.4787 β=71.863 γ=7.5754	0.0148
		Wakeby	α=149.44 β=5.5603 γ=19.366,δ=-0.33074 ξ=35.868	0.0148
		Burr (4P)	k=6.4388 α=5.8484,β=113.22 γ=-4.3005	0.0156
		Gen. Extreme Value	k=-0.35299 σ=16.9 μ=67.974	0.0171
		Kumaraswamy	α_1=4.3381 α_2=42.464,a=8.7543 b=177.27	0.0172
N45_FL	103448	Burr (4P)	k=2.8498 α=7.6887,β=63.696 γ=-2.6656	0.0045
		Johnson SU	γ=0.10169 δ=2.9845,λ=26.877 ξ=52.02	0.0068
		Dagum	k=0.48683 α=12.897 β=56.095	0.0099
		Log-Logistic (3P)	α=2.6423E+8 β=1.4167E+9 γ=-1.4167E+9	0.0111
		Error	k=1.6082 σ=9.5412 μ=51.051	0.0125
M1_FL	105372	Wakeby	α=256.32 β=14.685 γ=24.846,δ=-0.38371 ξ=79.663	0.0095
		Pearson 5	α=56.315 β=6305.1	0.0151
		Gen. Extreme Value	k=-0.15829 σ=13.938 μ=107.83	0.0175
		Log-Gamma	α=1261.6 β=0.00375	0.0179
		Fatigue Life	α=0.13341 β=112.96	0.0215

The GOF tests do not give accurate probability values for a high sample size. In general, as the sample size increases, the accuracy of the GOF test tends to decrease. It occurs because the central limit theorem states that the distribution of the sample means approaches a normal distribution as the sample size increases. It leads to an increase in the variance of the GOF test statistic, which reduces the accuracy of the test. Additionally, with larger sample sizes, the probability of observing rare events increases, making it more difficult to accurately model the observed data using a theoretical distribution. Therefore, when dealing with large sample sizes, the results of a GOF test should be interpreted with caution. Thus, a graphical method checks whether the specified distributions fit the empirical data. Histograms for given speed data, the particular distribution, and the PP plots between observed CDF values against the theoretical CDF values are plotted on SL and FL across all sites. Figures 4-18 and 4-19 histograms show that the particular distributions, as specified in tables 25 and 26, closely follow the observed data for all sites' slow and fast lanes. And the PP plots are approximately linear for all cases, which means that the specified theoretical distributions for the particular lane and site are the correct models. Figures 4-18 and 4-19 show that site-2 speed data has high peak and flatter tails relative to sites 1 and 3 on both the slow and fast lanes.

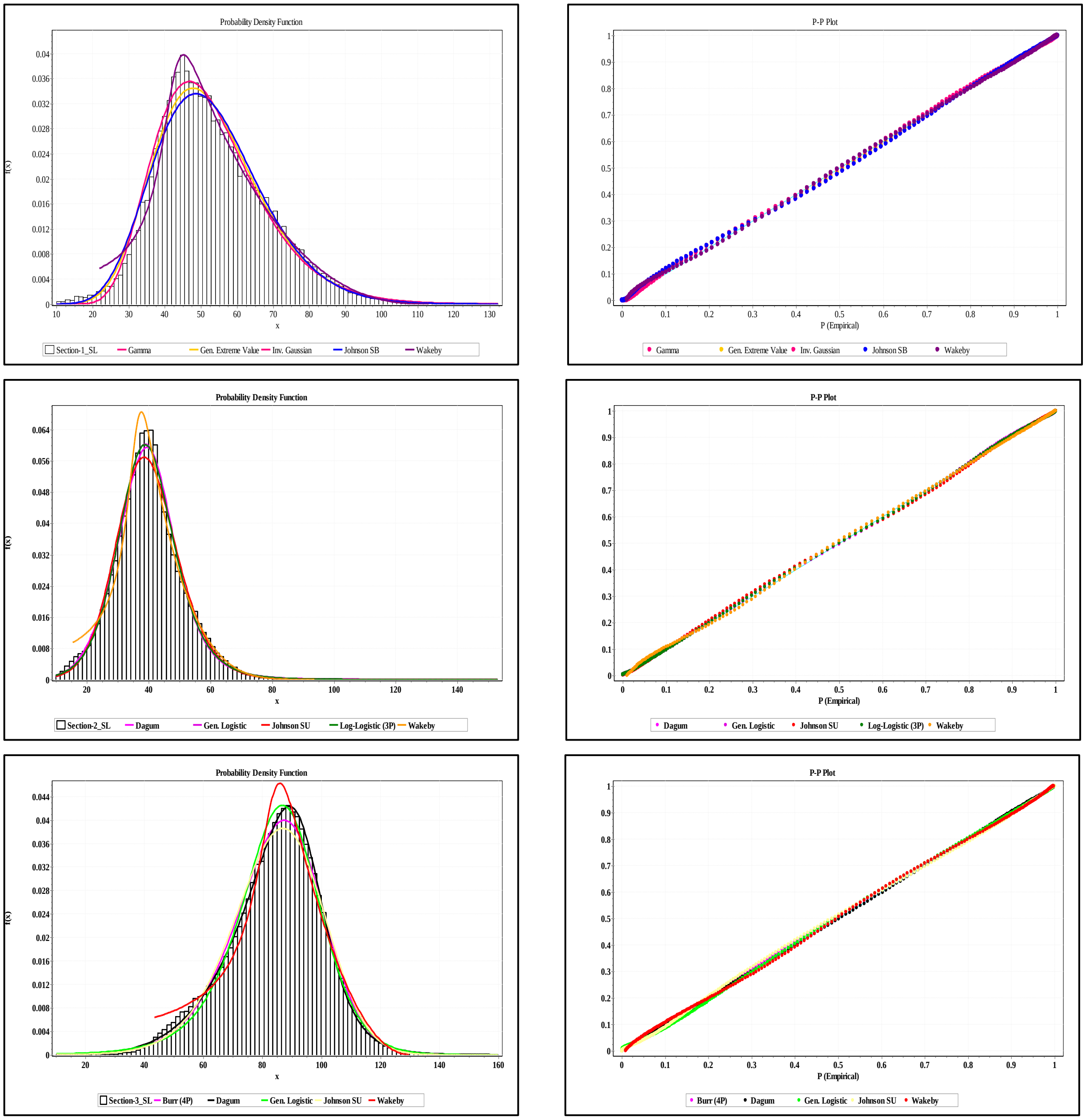


Figure 4-17 PDF and PP plot for Slow Lane at site-1, Site-2, and Site-3

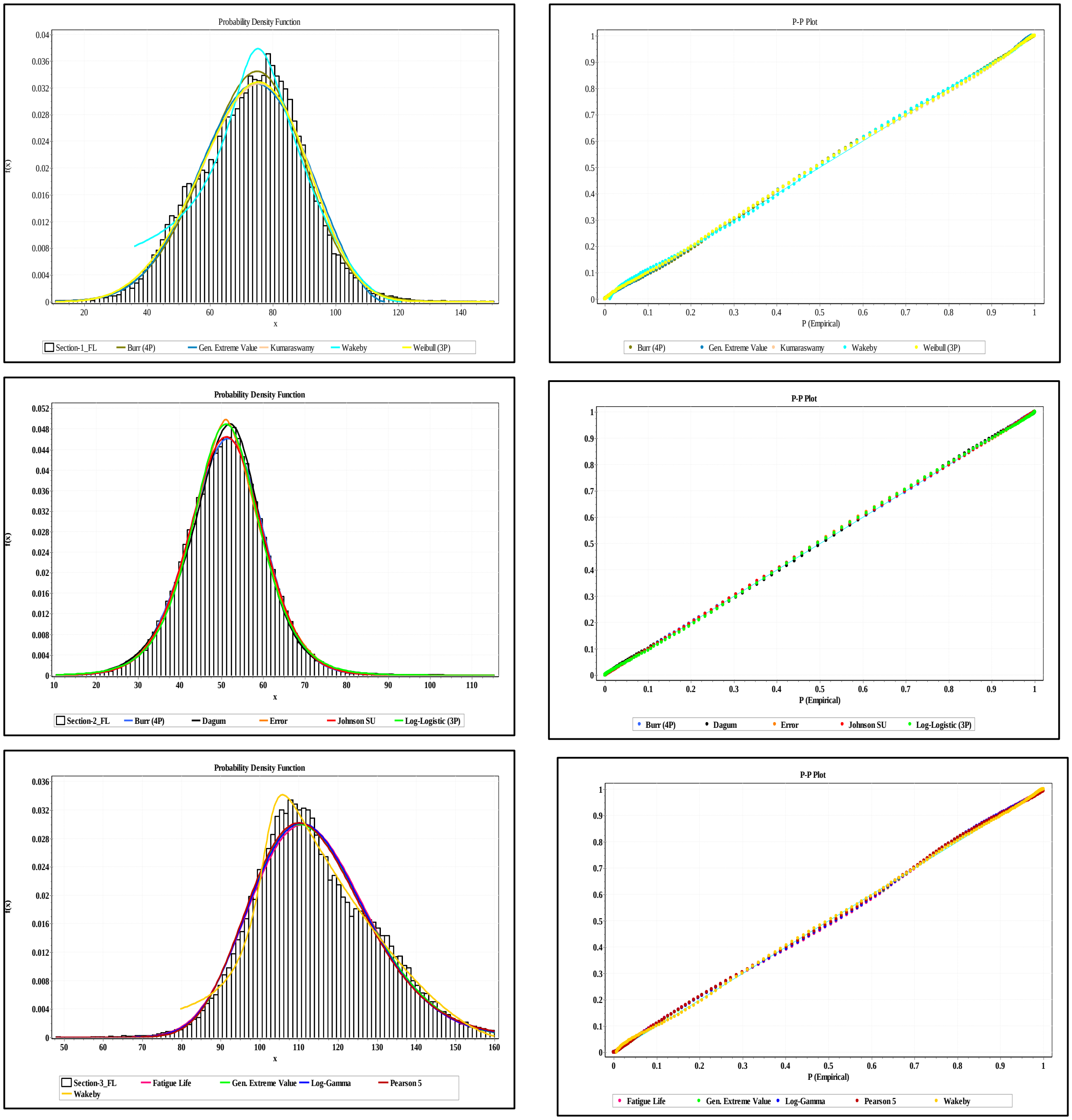


Figure 4-18 PDF and PP plot for Fast Lane at site-1, Site-2, and Site-3

4.3.5 Speed statistical Properties for Different Vehicular classes

It is crucial to thoroughly analyse the speed characteristics of individual vehicle classes in mixed traffic conditions and evaluate the overall speed distribution pattern. It is essential for effectively managing traffic speed behavior. The behavior of different vehicles can vary significantly depending on the number and types of vehicles present in the traffic stream due to their diverse static and dynamic characteristics. Tables 27 and 28 show the descriptive statistical analysis of speed for six types of vehicles, including 5 categories of trucks and trucks as general, buses, motorcycles, hiaces, and cars on the slow and fast lanes across all sites.

Table 4-25 Statistical parameters of vehicle class-wise speed data on SL

Vehicle type	Site_Lane	Sample size	Mean	Median	SD	CV (%)	IQR	SE	Sk	Kr	Q1	Q3	15 %tile	85 %tile	SSR(.86-1.11)
2-Axle Truck	Sec-1_SL	2264	46.45	45.28	9.60	20.7%	12.17	0.20	0.70	1.02	39.69	51.86	37.24	55.79	1.31
	Sec-2_SL	1941	36.69	36.95	8.49	23.1%	10.34	0.19	1.36	18.55	31.54	41.88	28.56	44.31	0.88
	Sec-3_SL	2957	58.61	56.34	12.91	22.0%	15.34	0.24	0.94	0.99	49.53	64.87	46.23	71.59	1.51
3-Axle Truck	Sec-1_SL	2733	46.51	45.66	9.81	21.1%	11.13	0.19	0.83	2.42	40.37	51.50	37.60	55.13	1.17
	Sec-2_SL	998	35.13	35.12	9.07	25.8%	12.59	0.29	0.00	-0.11	29.09	41.68	25.73	44.61	1.01
	Sec-3_SL	2000	63.84	58.75	16.94	26.5%	24.12	0.38	0.76	-0.32	51.31	75.42	48.07	86.08	2.56
4-Axle Truck	Sec-1_SL	937	43.71	43.09	9.60	22.0%	11.78	0.31	0.49	1.44	37.49	49.27	34.77	52.38	1.12
	Sec-2_SL	2128	36.01	35.88	8.08	22.4%	9.87	0.18	0.38	1.15	30.78	40.65	28.35	43.78	1.05
	Sec-3_SL	935	64.17	64.68	17.97	28.0%	28.91	0.59	0.00	-0.61	49.04	77.95	44.48	84.48	0.98
5-Axle Truck	Sec-1_SL	284	43.82	43.87	7.96	18.2%	10.37	0.47	0.36	0.74	38.00	48.37	35.42	51.51	0.90
	Sec-2_SL	76	31.30	30.58	7.75	24.7%	10.03	0.89	0.11	-0.22	26.58	36.60	23.79	38.78	1.21
	Sec-3_SL	157	56.53	51.46	16.79	29.7%	17.69	1.34	1.16	0.75	45.05	62.74	42.09	78.86	2.92
6-Axle Truck	Sec-1_SL	478	47.25	46.95	9.43	20.0%	13.58	0.43	0.02	-0.43	40.60	54.18	36.58	57.28	1.00
	Sec-2_SL	51	33.53	33.30	8.67	25.9%	12.57	1.21	0.07	-0.29	28.15	40.72	23.77	41.67	0.88
	Sec-3_SL	506	56.19	55.46	10.61	18.9%	14.48	0.47	0.44	-0.01	48.24	62.73	45.82	67.66	1.27
All Trucks	Sec-1_SL	6696	46.04	45.26	9.67	21.0%	11.89	0.12	0.67	1.60	39.59	51.48	36.84	55.06	1.16
	Sec-2_SL	5194	36.00	36.02	8.47	23.5%	10.71	0.12	0.64	7.52	30.58	41.29	27.80	44.17	0.99
	Sec-3_SL	6555	60.76	57.42	15.26	25.1%	19.33	0.19	0.78	0.28	49.74	69.07	46.37	78.27	1.89
Bus	Sec-1_SL	606	57.56	57.43	14.46	25.1%	21.37	0.59	0.28	-0.22	46.18	67.55	42.23	72.43	0.99
	Sec-2_SL	358	39.28	38.59	11.97	30.5%	13.21	0.63	0.57	2.15	32.34	45.55	27.55	50.14	1.05
	Sec-3_SL	2379	90.21	94.05	16.18	17.9%	14.09	0.33	-1.45	2.40	86.01	100.10	77.00	103.38	0.55
Hiace	Sec-1_SL	1044	50.93	49.75	11.29	22.2%	13.54	0.35	0.64	0.95	43.62	57.16	40.34	61.82	1.28
	Sec-2_SL	305	43.70	42.26	12.56	28.7%	14.41	0.72	0.47	0.61	35.97	50.38	32.39	55.79	1.37
	Sec-3_SL	3605	67.97	65.13	17.10	25.2%	26.08	0.28	0.66	0.40	54.26	80.34	50.93	86.27	1.49
Car	Sec-1_SL	15670	58.10	56.89	16.18	27.8%	23.13	0.13	0.36	-0.01	45.79	68.92	41.64	75.55	1.22
	Sec-2_SL	33338	42.43	41.28	10.27	24.2%	11.87	0.06	0.47	0.89	36.27	48.14	33.10	53.03	1.44
	Sec-3_SL	97487	86.51	87.00	14.25	16.5%	18.27	0.05	-0.15	0.62	77.55	95.82	72.00	100.56	0.90
Motorcycle	Sec-1_SL	10935	49.51	48.80	13.62	27.5%	18.24	0.13	0.18	0.16	40.26	58.50	35.95	63.83	1.17
	Sec-2_SL	32031	37.90	37.54	10.86	28.6%	13.97	0.06	0.22	0.13	30.73	44.70	27.09	48.96	1.09

On the slow lane, mean speed, as well as operating speed, are decreasing in the following order; car > bus > hiace at site-1, hiace > car > motorcycle at site-2, bus >car > hiace at site-3. On the fast lane, mean speed, as well as operating speed, are decreasing in the following order; car > bus > hiace at site-1, car > hiace > motorcycle at site-2, hiace >car > bus at site-3. The lowest mean speed on both fast and slow lanes at all places are trucks of different axles. There has been a significant decrease in the speed of vehicles traveling from Site-1 to Site-2, attributed to the presence of two-wheelers, shoulder conditions, and median factors.

The speed of the car at site-1, hiace at site-2, and 4-axle at site-3 on slow lanes are more dispersed around mean and median than other vehicle classes. On the fast lane, the spread of speed around the mean and the median is more for hiace at site-1, bus at site-2, and 2 -Axle at site-3.

Table 4-26 Statistical parameters of vehicle class-wise speed data on FL

Vehicle type	Site_Lane	Sample size	Mean	Median	SD	CV (%)	IQR	SE	Sk	Kr	Q1	Q3	15 %tile	85 %tile	SSR(.86-1.11)
2-Axle Truck	Sec-1_FL	1348	56.13	54.81	10.74	19.1%	12.84	0.29	0.71	0.90	49.02	61.85	45.81	66.38	1.29
	Sec-2_FL	1703	40.86	40.86	7.66	18.7%	9.47	0.19	0.06	0.39	35.87	45.34	33.46	48.31	1.01
	Sec-3_FL	54	101.59	100.02	17.48	17.2%	22.31	2.38	0.13	0.02	90.80	113.11	85.50	118.60	1.28
3-Axle Truck	Sec-1_FL	1593	52.32	51.73	8.03	15.3%	9.76	0.20	0.65	1.58	47.19	56.95	44.45	60.10	1.15
	Sec-2_FL	1614	41.03	41.32	8.22	20.0%	11.29	0.20	-0.15	0.01	35.39	46.68	32.59	49.48	0.93
	Sec-3_FL	33	96.42	97.81	13.93	14.5%	16.58	2.43	-0.11	-0.05	90.25	106.83	82.43	111.09	0.86
4-Axle Truck	Sec-1_FL	208	56.64	54.90	11.90	21.0%	13.37	0.83	0.75	0.54	48.57	61.93	44.08	69.12	1.31
	Sec-2_FL	686	45.52	45.34	8.64	19.0%	11.08	0.33	0.19	0.58	39.96	51.04	36.97	53.64	0.99
	Sec-3_FL	36	95.22	94.10	11.46	12.0%	15.03	1.91	-0.01	-0.36	88.39	103.41	84.44	105.51	1.18
5-Axle Truck	Sec-1_FL	93	51.59	50.65	9.25	17.9%	9.85	0.96	1.02	2.75	45.87	55.72	43.21	59.59	1.20
	Sec-2_FL	93	39.12	38.53	7.20	18.4%	9.63	0.75	0.26	-0.60	34.50	44.13	31.77	47.49	1.32
	Sec-3_FL														
6-Axle Truck	Sec-1_FL	288	57.06	56.54	9.01	15.8%	12.55	0.53	-0.02	-0.08	51.27	63.83	48.01	66.84	1.21
	Sec-2_FL	109	37.81	38.70	7.52	19.9%	11.18	0.72	-0.24	-0.56	31.86	43.04	28.99	45.82	0.73
	Sec-3_FL														
All Trucks	Sec-1_FL	3530	54.40	53.29	9.72	17.9%	11.53	0.16	0.78	1.35	47.99	59.52	45.14	63.48	1.25
	Sec-2_FL	4205	41.57	41.52	8.23	19.8%	10.71	0.13	0.06	0.35	36.10	46.81	33.32	50.06	1.04
	Sec-3_FL	126	97.87	96.02	15.61	15.9%	19.61	1.39	0.09	0.60	88.79	108.40	83.75	112.46	1.34
Bus	Sec-1_FL	778	69.35	69.42	12.58	18.1%	15.40	0.45	0.19	0.19	61.36	76.76	56.20	81.75	0.93
	Sec-2_FL	340	47.12	46.71	8.93	19.0%	11.33	0.48	0.09	-0.09	41.21	52.54	37.87	56.25	1.08
	Sec-3_FL	374	105.79	103.73	15.15	14.3%	17.37	0.78	0.35	0.30	96.19	113.56	92.30	123.06	1.69
Hiace	Sec-1_FL	914	68.63	68.06	15.77	23.0%	23.13	0.52	0.39	-0.29	56.16	79.29	51.57	85.01	1.03
	Sec-2_FL	584	51.67	51.12	10.78	20.9%	15.08	0.45	0.30	0.06	43.94	59.02	40.98	62.96	1.17
	Sec-3_FL	5960	131.68	132.03	12.74	9.7%	15.80	0.17	-0.47	0.98	124.20	139.99	119.61	144.51	1.01
Car	Sec-1_FL	25521	78.72	78.72	13.26	16.8%	17.52	0.08	0.18	0.35	69.68	87.20	64.94	91.89	0.96
	Sec-2_FL	42416	51.96	52.07	9.10	17.5%	11.44	0.04	-0.02	0.77	46.25	57.69	42.92	60.88	0.96
	Sec-3_FL	45087	111.73	110.55	13.78	12.3%	17.57	0.06	0.30	0.25	102.55	120.12	98.23	126.52	1.30
Motorcycle	Sec-1_FL	1184	68.53	68.51	12.99	19.0%	16.45	0.38	0.04	0.12	60.18	76.62	55.17	81.40	0.97
	Sec-2_FL	5645	51.46	51.12	9.70	18.8%	12.59	0.13	0.05	0.34	45.18	57.77	41.77	61.54	1.11

The speed of 2-Axle trucks at site-2 SL, 5-Axle trucks at site-3 SL, and 5-Axle trucks at site-1 FL are positively skewed. The bus at site-3 SL is negatively skewed. For other vehicles, skewness is not much, so data are symmetrically distributed. The speed of the 2-Axle truck at site-2 SL, 3-Axle truck at site-1 SL and FL, 4-Axle truck at site-1 SL, Bus at site-2 and 3 SL, and all trucks at site-1 and site-2 SL have high excess kurtosis values which mean high peak and flatter tails than the normal distribution. The speed of a 2-axle truck at site-2 SL has a very high kurtosis value of 18.55, indicating that data is not so well distributed and has a sharp and distinct peak.

The trend observed in the overall flow speed is also reflected in the speed of individual vehicle classes. Specifically, the speed of various vehicle classes is lower and less spread at site-2 compared to other sections. It is due to the high presence of motorcycles at site-

2. Given their maneuverability, these two-wheelers tend to navigate through inter-vehicular gaps, reducing the speed of other vehicles and the overall traffic flow.

4.3.6 Speed distributions for Different Vehicular classes

Table 29 displays the best-fitted probability density functions with parameters, their calculated K-S values, and p-values for each type of vehicle across all sites. The P-values show that the calculated K-S values are significantly higher than the critical K-S values at a 1% significance level. Tables 29 and 30 present the most appropriate distributions and their parameters for six types of vehicles, including 5 categories of trucks, all truck types as trucks, buses, motorcycles, hiaces, and cars.

Tables 29 and 30 show that the same vehicle type can produce different best-fitting distributions and varying statistical parameters when considering different lane types or sites. It highlights that the composition and percentage of other vehicles present can have a significant impact.

It is observed that the Wakeby distribution is the most followed distribution by vehicle classes. It is the best-fitted distribution for 4-Axle trucks at site-1 FL, 6-Axle truck at site-1 FL, all types of trucks as trucks at site-3 FL, buses at sites-1 and 3 FL, hiaces at site-1 FL, cars at site-3 FL, 3-Axle trucks at site-3 SL, 5-Axle trucks at site-2 SL, Buses at site-1,2, and 3 SL, Hiaces at site-2 and 3 SL, and cars at site-2 SL.

Burr distribution is the best-fitted distribution for 4-Axle trucks at site-2 FL, motorcycles at site-1 FL, motorcycles at site-2 SL, cars at site-3 SL, and all types of trucks as trucks at site-2 SL. Burr(4p) distribution is the best-fitted distribution for 3-Axle trucks at site-1 FL, cars at site-1 and site-2 FL, 3-Axle trucks at site-1 and site-3 SL, and 5-Axle trucks at site-3 SL.

Dagum distribution is best fitted for all types of trucks as trucks at site-1 FL, 2-Axle trucks at sites-2 and 3 SL, and 4-Axle trucks at site-1 SL. Dagum (4p) distribution is the best-fitted distribution for all types of trucks as trucks at site-1 SL.

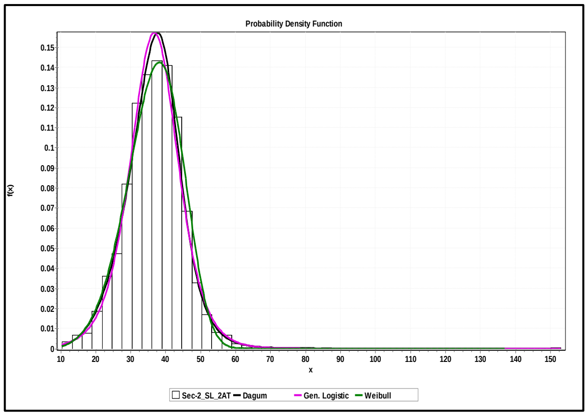
Table 4-27 Best-fitted speed distributions for all vehicle classes on FL

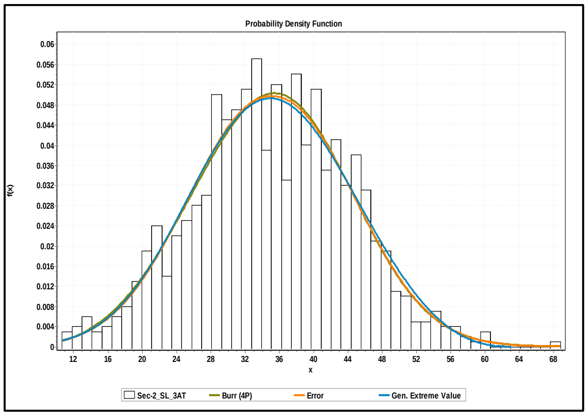
Veh Type	Section	Best Fitted Distribution	K-S Value	P-Value	Parameters
2-Axle Truck	1 (FL)	Dagum	0.0105	0.9981	$\kappa=1.1754,\alpha=9.0167,\beta=53.61$
	2 (FL)	Log-Logistic (3P)	0.0121	0.9609	$\alpha=58.844,\beta=252.16,\gamma=-211.42$
3-Axle Truck	1 (FL)	Burr (4P)	0.0112	0.9877	$\kappa=1.4607,\alpha=6.6663,\beta=35.632,\gamma=18.69$
	2 (FL)	Phased Bi-Weibull	0.0097	0.9979	$\alpha_1=0.92381,\beta_1=729.3,\gamma_1=11,\alpha_2=4.148,\beta_2=33.013,\gamma_2=13.6$
4-Axle Truck	1 (FL)	Wakeby	0.0356	0.9460	$\alpha=98.753,\beta=8.3894,\gamma=13.211,\delta=-0.12086,\xi=34.335$
	2 (FL)	Burr	0.0164	0.9916	$\kappa=2.0891,\alpha=7.6162,\beta=51.324$
5-Axle Truck	1 (FL)	Log-Logistic	0.0448	0.9881	$\alpha=10.386,\beta=50.504$
	2 (FL)	Triangular	0.0445	0.9890	$\mu=35.46,\alpha=24.219,\beta=57.61$
6-Axle Truck	1 (FL)	Wakeby	0.0239	0.9954	$\alpha=163.62,\beta=13.401,\gamma=16.345,\delta=-0.49937,\xi=34.796$
	2 (FL)	Triangular	0.0424	0.9848	$\mu=40.84,\alpha=18.361,\beta=54.2$
All Trucks	1 (FL)	Dagum	0.0077	0.9837	$\kappa=1.2088,\alpha=9.6559,\beta=51.942$
	2 (FL)	Johnson SU	0.0068	0.9888	$\gamma=-0.24986,\delta=3.6185,\lambda=28.589,\xi=39.516$
	3 (FL)	Wakeby	0.0365	0.9939	$\alpha=349.03,\beta=12.816,\gamma=20.705,\delta=-0.29207,\xi=56.584$
Bus	1 (FL)	Wakeby	0.0162	0.9850	$\alpha=127.92,\beta=6.4142,\gamma=12.469,\delta=-0.15749,\xi=41.329$
	2 (FL)	Pearson 5 (3P)	0.0244	0.9845	$\alpha=225.8,\beta=30471.0,\gamma=-88.412$
	3 (FL)	Wakeby	0.0390	0.8605	$\alpha=812.29,\beta=26.215,\gamma=20.817,\delta=-0.25735,\xi=59.389$
Hiace	1 (FL)	Wakeby	0.0308	0.8343	$\alpha=48.267,\beta=3.4082,\gamma=21.181,\delta=-0.31879,\xi=41.618$
	2 (FL)	Gamma	0.0192	0.9793	$\alpha=22.972,\beta=2.2491$
	3 (FL)	Gen. Logistic	0.0131	0.8253	$\kappa=-0.04647,\sigma=7.041,\mu=132.22$
Car	1 (FL)	Burr (4P)	0.0098	0.9143	$\kappa=2.9897,\alpha=5.514,\beta=69.42,\gamma=24.075$
	2 (FL)	Burr (4P)	0.0031	0.9819	$\kappa=1.6799,\alpha=14.823,\beta=92.11,\gamma=-35.976$
	3 (FL)	Wakeby	0.0115	0.9300	$\alpha=204.0,\beta=11.625,\gamma=19.528,\delta=-0.30145,\xi=80.568$
Motorcycle	1 (FL)	Burr	0.0148	0.9544	$\kappa=2.609,\alpha=7.2351,\beta=80.804$
	2 (FL)	Lognormal (3P)	0.0109	0.9406	$\sigma=0.0409,\mu=5.47,\gamma=-186.11$

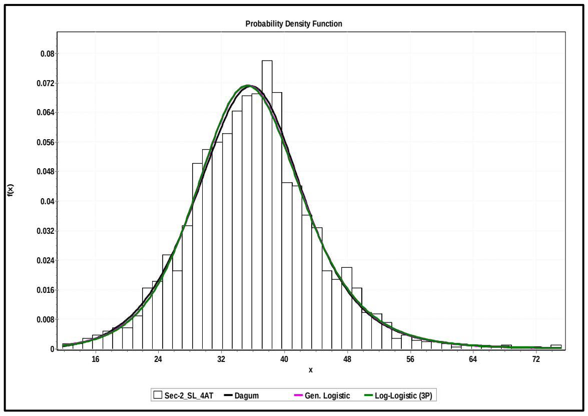
Table 4-28 Best fitted speed distributions for all vehicle classes on SL

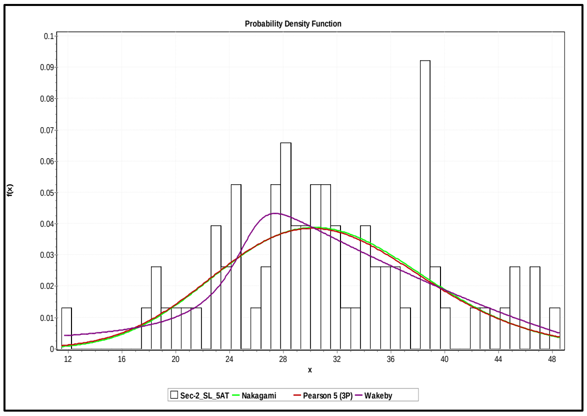
Veh Type	Section	Best Fitted Distribution	K-S Value	P-Value	Parameters
2-Axle Truck	1 (SL)	Gen. Extreme Value	0.0138	0.9442	$\kappa=-0.08283,\sigma=8.1977,\mu=42.342$
	2 (SL)	Dagum	0.0161	0.9106	$\kappa=0.42191,\alpha=11.865,\beta=41.651$
	3 (SL)	Dagum	0.0151	0.8674	$\kappa=1.9693,\alpha=7.0553,\beta=49.875$
3-Axle Truck	1 (SL)	Burr (4P)	0.0106	0.9170	$\kappa=0.70406,\alpha=28.47,\beta=125.18,\gamma=-81.831$
	2 (SL)	Burr (4P)	0.0149	0.9768	$\kappa=13.613,\alpha=4.0211,\beta=65.525,\gamma=3.7289$
	3 (SL)	Wakeby	0.0453	0.3534	$\alpha=34433.0,\beta=812.6,\gamma=28.197,\delta=-0.31043,\xi=0$
4-Axle Truck	1 (SL)	Dagum	0.0176	0.9294	$\kappa=0.66303,\alpha=9.6249,\beta=46.098$
	2 (SL)	Gen. Logistic	0.0126	0.8867	$\kappa=0.03925,\sigma=4.4502,\mu=35.721$
	3 (SL)	Gen. Pareto	0.0330	0.5378	$\kappa=-0.9482,\sigma=59.032,\mu=33.87$
5-Axle Truck	1 (SL)	Gamma	0.0303	0.9494	$\alpha=30.337,\beta=1.4444$
	2 (SL)	Wakeby	0.0504	0.9852	$\alpha=168.08,\beta=15.281,\gamma=13.237,\delta=-0.43052,\xi=11.718$
	3 (SL)	Burr (4P)	0.0585	0.8144	$\kappa=0.1224,\alpha=6.1434E+7,\beta=1.3116E+8,\gamma=-1.3116E+8$
6-Axle Truck	1 (SL)	Error	0.0242	0.9354	$\kappa=2.6172,\sigma=9.4315,\mu=47.246$
	2 (SL)	Inv. Gaussian (3P)	0.0614	0.9843	$\lambda=2.4047E+5,\mu=260.72,\gamma=-227.19$
	3 (SL)	Gen. Extreme Value	0.0220	0.9626	$\kappa=-0.12425,\sigma=9.5378,\mu=51.743$
All Trucks	1 (SL)	Dagum (4P)	0.0073	0.8903	$\kappa=1.6612,\alpha=30.95,\beta=183.12,\gamma=-141.85$
	2 (SL)	Burr	0.0113	0.8665	$\kappa=2.7567,\alpha=5.9009,\beta=44.365$
	3 (SL)	Gen. Extreme Value	0.0283	0.8137	$\kappa=0.01663,\sigma=11.926,\mu=53.679$
Bus	1 (SL)	Wakeby	0.0387	0.8732	$\alpha=56.829,\beta=3.3834,\gamma=16.759,\delta=-0.27366,\xi=31.437$
	2 (SL)	Wakeby	0.0180	0.9997	$\alpha=162.37,\beta=8.3747,\gamma=11.235,\delta=-0.09826,\xi=11.731$
	3 (SL)	Wakeby	0.0202	0.8283	$\alpha=494.76,\beta=9.0338,\gamma=11.534,\delta=-0.30746,\xi=32.081$
Hiace	1 (SL)	Log-Logistic	0.0164	0.9361	$\alpha=8.0955,\beta=49.676$
	2 (SL)	Wakeby	0.0298	0.9419	$\alpha=236.54,\beta=12.962,\gamma=15.48,\delta=-0.2053,\xi=13.919$
	3 (SL)	Wakeby	0.0285	0.8500	$\alpha=37.403,\beta=5.8344,\gamma=29.96,\delta=-0.4047,\xi=41.171$
Car	1 (SL)	Gen. Gamma	0.0159	0.8908	$\kappa=0.99265,\alpha=12.655,\beta=4.5034$
	2 (SL)	Wakeby	0.0120	0.8531	$\alpha=214.34,\beta=13.581,\gamma=12.303,\delta=-0.19229,\xi=17.416$
	3 (SL)	Burr	0.0049	0.8220	$\kappa=3.0816,\alpha=8.2305,\beta=102.72$
Motorcycle	1 (SL)	Gamma (3P)	0.0099	0.9238	$\alpha=99.183,\beta=1.371,\gamma=-86.43$
	2 (SL)	Burr	0.0091	0.9010	$\kappa=3.78,\alpha=4.4574,\beta=53.875$

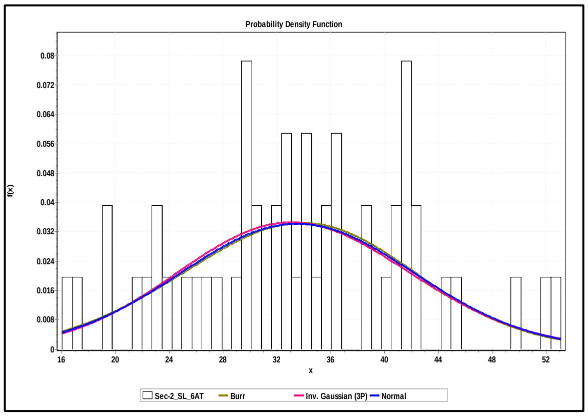
Gen.Extreme Value distribution is the best-fitted distribution for all types of trucks as trucks at site-3 SL, 6-Axle trucks at sites-3 SL, and 2-Axle trucks at site-1 SL.

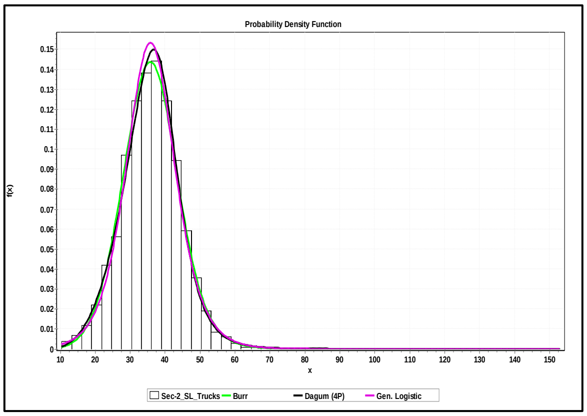












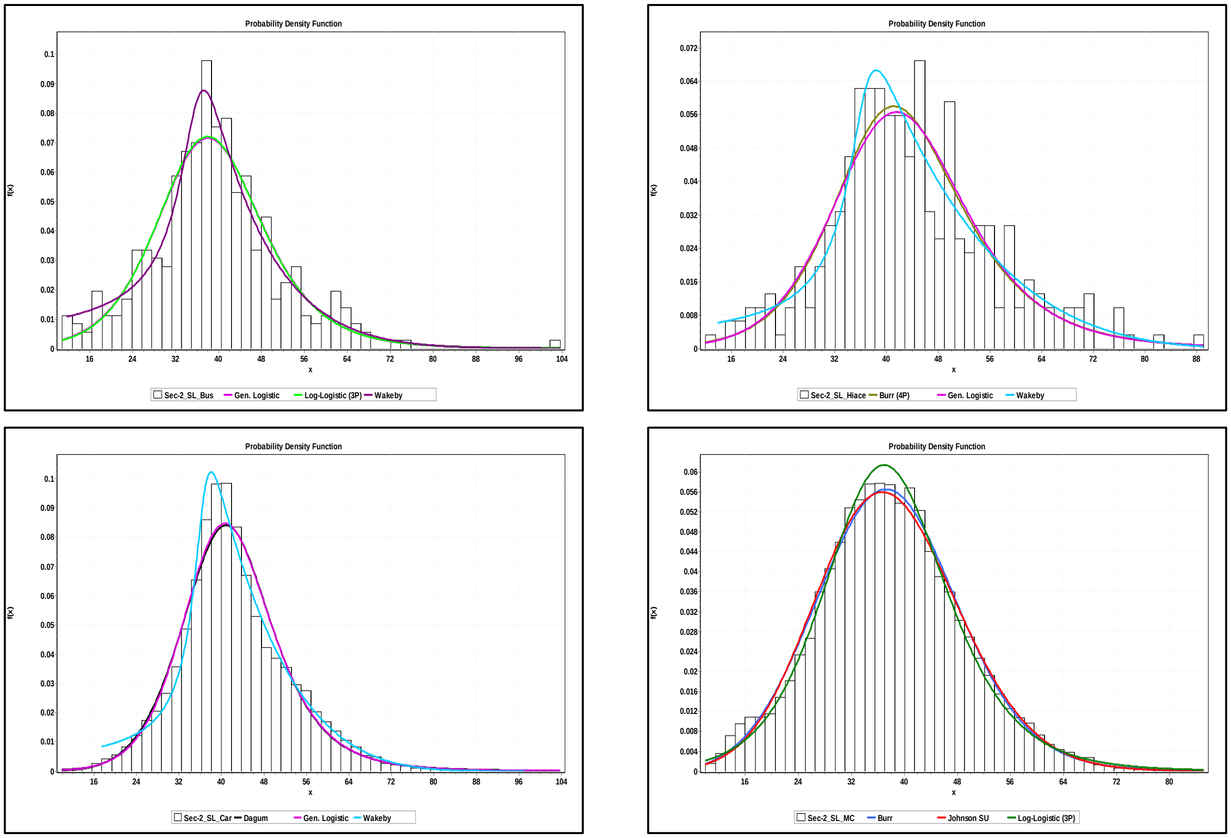


Figure 4-19 PDF of vehicle classes speed at Site-2 Slow Lane

The PDF of 5-Axle and 6-Axle at site-2 SL do not match normal distribution visually due to less sample size. All the points discussed in heading 4.2.6 can be visually observed in figure 4-20.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Traffic is a stochastic quantity that varies from place to place depending on local factors and driver's behavior. Therefore, traffic studies are essential for acquiring knowledge about the nature of vehicular flows. The information acquired assists in building better, safer, and more efficient road facilities. Roads are a part of the infrastructure, and traffic that flows through them determines the aesthetic and economic value of the country. Hence, traffic engineering ensures that vehicles travelling on the road can reach their intended destinations comfortably and efficiently without compromising safety issues. TH and speed distribution studies are essential for traffic engineers in the analysis and traffic flow modeling as their statistical properties provide an in-depth understanding of vehicles and drivers. An analysis was conducted on time headway and speed data collected from two four-lane median-separated national highways and one six-lane median-separated motorway in Pakistan. The time headways for mixed vehicular flow and various vehicle pairs were studied at multiple flow levels. The collected speed data was also analyzed to determine the speed distribution patterns for mixed traffic at different flow levels and several vehicle classes.

5.2 Conclusions

The following conclusions are drawn from the study:

5.2.1 Preliminary analysis

- There is no significant difference between directional traffic composition.
- The percentage of heavy vehicles at site 1 is larger than at site 2, and the reverse is for motorcycles.

5.2.2 Time headway analysis for various flow levels

- The location and dispersion parameters of time headway decrease as flow increases.
- The mean and standard deviation of the fast lane is higher than the slow lane, which means that data is more spread on fast lanes.

- Depending on the lane, site and traffic composition, different distributions are fitted to different flow levels.

5.2.3 Time headway analysis for different vehicle pairs

- For the same vehicle pair mean and spread of time headway for FL is more significant than the mean time headway for the slow lane.
- Vehicle-type specific analysis for different time headway groups concludes that in interacting vehicle pairs involving a truck, the mean time headway for the truck-truck pair is greater than the truck-car pair for all the flow levels.
- On national highways, car-bus time headway is more significant than bus-car on FL, and the reverse is for SL. On the motorway, car-bus time headway is lesser than bus-car because of the high speed of busses observed on the Motorway.
- When truck-car and car-truck headways are considered, cars maintain less time headway in a truck-car case than the time headway maintained by trucks in the case of a car-truck pair on the fast lane, and the reverse is for the slow lane.
- The mean time headway for specific vehicle pairs with the same leading and following vehicles is distributed as follows: Hiace-Hiace < Car-Car < Truck-Truck. However, for flow levels between 700-800 PCU/h in the fast lane and 800-900 PCU/h in the slow lane of site 3, the Hiace-Hiace mean time headway was found to be more significant due to increased variability in the Hiace-Hiace data, compared to the Car-Car mean time headway.
- Analysis of vehicle pair distributions concluded that various time headway probability density functions fitted to the exact vehicle pair depending upon the site and lane type.

Table 5-1 Best fitted Time Headway distributions for different vehicle pairs at site 3

Leading veh-Following veh	Flow levels in PCU/h at Site 3 SL							
	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200	1200-1300
Bus-Car	Wakeby	Wakeby	Wakeby	Wakeby	Johnson SB	Wakeby	Gamma	Gen. Extreme Value
car-Bus	Wakeby	Wakeby	Gamma	Wakeby	Wakeby	Chi-Squared	Gen. Pareto	Gamma
Car-Car	Wakeby	Wakeby	Wakeby	Wakeby	Wakeby	Wakeby	Wakeby	Log-Logistic
car-Hiace	Wakeby	Wakeby	Wakeby	Gen. Pareto	Wakeby	Wakeby	Chi-Squared	Wakeby
Car-Truck	Johnson SB	Wakeby	Wakeby	Wakeby	Gamma	Johnson SB	Wakeby	Wakeby
Hiace-Car	Wakeby	Wakeby	Wakeby	Wakeby	Wakeby	Wakeby	Wakeby	Johnson SB
Hiace-Truck	Wakeby	Fatigue Life	Gamma	Johnson SB	Log-Logistic			
Hiace-Hiace				Wakeby	Gamma			
Truck-Car	Johnson SB	Wakeby	Wakeby	Wakeby	Johnson SB	Erlang	Gen. Extreme Value	Weibull
Truck-Hiace	Burr	Johnson SB	Gen. Extreme Value	Pearson 6	Gen. Extreme Value			
Truck-Truck	Lognormal	Log-Logistic	Gen. Extreme Value	Dagum	Gamma	Gen. Extreme Value		

Leading veh-Following veh	Flow levels in PCU/h at Site 3 FL					
	500-600	600-700	700-800	800-900	900-1000	1000-1100
Bus-Car	Fatigue Life (3P)					
Car-Car	Gen. Pareto	Gen. Pareto	Gen. Pareto	Gen. Pareto	Johnson SB	Inv. Gaussian
car-Hiace	Gen. Pareto	Johnson SB	Inv. Gaussian	Gen. Extreme Value	Weibull (3P)	
Car-Truck	Log-Pearson 3					
Hiace-Car	Gen. Pareto	Johnson SB	Beta	Gen. Logistic	Kumaraswamy	
Hiace-Hiace	Gen. Pareto	Pearson 6	Gen. Extreme Value	Kumaraswamy		

Table 5-2 Best fitted Time headway distributions for different vehicle pairs at site 2

Leading veh-Following veh	Flow levels in PCU/h at site 2 SL			
	500-600	600-700	700-800	800-900
car-Bus	Beta	Lognormal		
Car-Car	Johnson SB	Johnson SB	Frechet (3P)	Pearson 5 (3P)
car-Hiace	Pearson 5			
Car-Truck	Wakeby	Lognormal (3P)	Inv. Gaussian	Pearson 5 (3P)
Hiace-Car	Burr (4P)			
Truck-Car	Wakeby	Fatigue Life (3P)	Inv. Gaussian (3P)	
Truck-Truck	Log-Pearson 3	Gamma		

Leading veh-Following veh	Flow levels in PCU/h at Site 2 FL				
	500-600	600-700	700-800	800-900	900-1000
Bus-Car	Frechet	Log-Pearson 3			
car-Bus	Johnson SB	Inv. Gaussian (3P)			
Car-Car	Gen. Pareto	Wakeby	Gen. Pareto	Log-Pearson 3	Pearson 6
car-Hiace	Log-Pearson 3	Gen. Pareto	Gamma		
Car-Truck	Fatigue Life (3P)	Johnson SB	Lognormal (3P)	Gen. Extreme Value	
Hiace-Car	Beta	Log-Pearson 3	Chi-Squared		
Truck-Car	Pearson 5	Log-Pearson 3	Log-Pearson 3		
Truck-Truck	Pearson 6	Inv. Gaussian (3P)			

5.2.4 Speed analysis for various flow levels under mixed traffic conditions

- There is not much variation in speed as flow increases. The statistical values of the fast lane and slow lane are almost equal. The speed on the fast lane is slightly higher than the speed on the slow lane for the same flow range.
- The skewness values of the fast lane show a slight right skew in speed for each flow level, except for 0-100 PCU/h. The skewness values of the slow lane indicate a slight left skew in the speed for each flow range.
- The speed of each flow range is almost symmetrical.
- Different flow levels follow different speed distributions depending on the site and lane type. Wakeby, Burr, Johnson SU, and Gen. logistic are the most suitable speed distributions for various flow ranges.
- The likelihood of different speed and TH values vary with differing flow rates. Hence utilizing a uniform probability density function for both Speed and TH will likely result in inaccurate outcomes.

5.2.5 Speed analysis for different study sites

- In all sections, speed data were found to be almost symmetrically distributed.
- The speed at site 3 is greater than at site 2 is greater than site1 for both slow and fast lanes.
- Weibull, Dagum, Gen.logistic, Log. Logistic, Johnson SU, and Wakeby distributions are the typically fitted distribution for speed data of various sites.

5.2.6 Speed analysis for different vehicle classes

- Notably, the best fitting distributions for the same vehicle class can vary between different sections due to changes in traffic composition and geometry of roads. Burr, Gen. logistic, Gen.Pareto, Dagum, Pearson, Johnson, and Log-normal distributions are the most followed by various vehicle classes.
- The speed of a Car, which is supposed to be the highest due to its excellent acceleration capability, depends on the presence of a Two-wheeler and lane type in the traffic stream.
- The flow of the entire stream and each specific type of vehicle is strongly correlated with the stream speed and the speed of the vehicle class.

5.2.7 MetroCount@5600

The data for the classified vehicle count was collected using the MetroCount@5600 automatic traffic tally device. This device was deemed more reliable than other video recording and decoding techniques. However, it was found that the areas with many overtaking maneuvers are not ideal for using MetroCount@5600. It is because overtaking maneuvers can reduce the accuracy of the classified counts. The reason is that there may be overtaking maneuvers where the system is set up, causing the system to detect a different class of vehicle during the maneuver.

Therefore, after careful consideration, an automatic pneumatic-tube-based traffic count device was selected as the preferred technique for collecting classified traffic count data, especially for extended periods of traffic monitoring exercises. This technique was chosen because it provides more accurate results for traffic monitoring purposes.

5.3 Recommendations

The following recommendations are made based on the research:

- ✓ Conduct regular time headway and speed analysis studies in different traffic conditions, including low and high flow levels, to understand the behavior and characteristics of vehicles in diverse circumstances.

- ✓ Consider different vehicle classes and sections when conducting speed and time headway analysis to understand the differences between various vehicle types and their effect on traffic flow and safety.
- ✓ Use the results of the statistical analysis and probability distributions to identify patterns and trends in the traffic flow, such as regular intervals between vehicles, average speeds, and differences between various vehicle types and sites.
- ✓ Use the findings of the studies to inform the development of traffic management and control strategies aimed at improving traffic efficiency and safety. It may include tactics for managing congestion, reducing bottlenecks, and reducing the risk of collisions.
- ✓ Use the analysis to understand the relationship between time headways, speeds, and flow to understand the behavior of vehicles in traffic and the factors contributing to congestion, bottlenecks, and the potential for collisions.
- ✓ The flow of vehicles is analyzed by considering the time between their arrival, known as headway, and their speed. This information helps conduct assessments of capacity, safety, delay, accidents, gap acceptance, and queues at intersections, highways, and roundabouts. The information has various purposes, such as determining the level of service and managing traffic operations.

In general, using the statistical and PDF approach, the study of headways can be reused for different types of roads to expand the scope of the study. A direct benefit of this research could be the implementation of probability density distributions in microsimulation software or driving simulators concerning vehicle generation, as well as a bench test. As vehicle pairwise time headway analysis reveals that faster vehicles, such as cars, maintain a shorter headway than slower ones. This information is useful in determining the need for and frequency of overtaking zones on two-way, two-lane highways, considering the flow and composition of heavy vehicles using the road.

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