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**HEADWAY DISTRIBUTION IN EXPRESSWAYS IN SRI
LANKA**

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Degree of Master of Engineering

Department of Civil Engineering

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Sri Lanka

April 2024

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(199577D)

Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree
Master of Engineering

Department of Civil Engineering
University of Moratuwa
Sri Lanka

April 2024

DECLARATION

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Date: 15th April 2024

R.M.C.B.Rathnayke

The undersigned hereby certify that I have read and recommended the thesis for the acceptance in partial fulfillment of the requirements for the M.Eng in Highway & Traffic Engineering.

.....

Date: 15th April 2024

Prof. H. R. Pasindu

DEDICATION

This dissertation is dedicated to my loving parents, my wife, my siblings and my friends for their endless love, support, and encouragement given during this journey.

ACKNOWLEDGEMENT

I express my sincere appreciation to Prof. H. R. Pasindu, my research supervisor, for granting me the opportunity to conduct this research. I am deeply grateful for the consistent support and guidance extended to me throughout the research process.

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ABSTRACT

The relationship between traffic flow parameters such as speed, flow and density should be understood to properly construct, plan and design traffic operation and improve them. Headway distribution can be considered as the basis of the traffic flow modelling but there has not been studied done on understanding headway distribution in expressways in Sri Lanka. It is mostly used to evaluate road capacity, line changing, vehicle conversion and traffic control strategies in intersection as studies of headways are also important for safety assessments. This study is focused on developing a time headway distribution for different flow categories and different vehicle pairs. To find the data, 12-hour video clips were recorded during peak hours from three different locations. Then Passenger Car Units (PCU) were considered for calculation by selecting eight vehicle categories Car, Van, Light good vehicle (LGV), Medium lorry (MG1), Large lorry (MG2), Medium bus (MBU), Large bus (LBU) and Truck (TRK). Since the headway distribution can be changed according to its flow category it should be tested so the headway distribution is tested by choosing 5 flow (PCU/5min/lane) categories 20-40, 40-60, 60-80, 80-100, 100-120, and considered whether they can be combined or not. The results show that flow categories have to be considered separately and 20-40 followed the “Dagum distribution” with 8.87s average time headway, 40-60 followed the “Frechet distribution” with 6.32s time headway distribution, 60-80 followed the “Generalized Extreme Value distribution” with 5.07s average time headway, 80-100 followed the “Burr distribution” with 4.12s time headway and 100-120 followed the “Pert distribution” with 3.43s time headway. The same process was done for vehicle categories, testing whether they can be combined or not as well as the distribution types of each category belongs to concerning the properties such as mean, mode, and median. All the flow and vehicle categories were tested using random and normality tests to check the parametric and non-parametric states of each category. The results show that the flow categories cannot be combined (have to consider them separately), and vehicle pair categories can be combined. In vehicle pairs Car-Bus & Bus-Car is considered as one group and it is followed the “Dagum distribution” with average time headway of 5.22s and rest of the vehicle groups can be combined as a one group and followed the “Burr distribution” with 5.52s average time headway.

Key Words: Headway distribution, road capacity, average time headway, parametric, non-parametric, Passenger car unit, randomness, normality, 5min time interval.

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LIST OF ABBREVIATIONS

Abbreviation	Description
PCU	Passenger Car Unit
PCE	Passenger Car Equivalent
LOS	Level of Service
HCM	Highway Capacity Manual
IAT	Inter Arrival Time

1 INTRODUCTION

1.1 Background

Time Headway is defined as "the distance, measured from the same common characteristic of both vehicles, in seconds, between two subsequent cars as they pass a location on the highway"(Highway Capacity Manual, 2010). It is a key aspect of microscopic traffic flow and has higher significance for the analysis, planning, construction, and operation of highway systems. That has an impact on the capacity analysis, level of service (LOS), and safety as well. For safety considerations, it is imperative to uphold a minimum time headway in the event of a sudden stop by the leading vehicle. From the perspective of LOS, it measures a motor vehicle for passing, merging, and crossing with other vehicles. Different factors affect the time headway distribution such as vehicle composition, flow, road structure and weather conditions.

The capacity of a roadway segment is defined as "The maximum number of cars that may pass through a stretch in a certain amount of time under the current traffic, road, and control circumstances" (Highway Capacity Manual,2010). Several factors affect road capacity as road factors, traffic factors, and environmental factors.

- a. Road factors: lane width, road shoulders, median, road surface condition, lateral freedom, road alignment
- b. Traffic factors: lane distribution, traffic composition, side friction
- c. Environmental factors: weather conditions, animals

Passenger Car Unit (PCU) is essentially the difference between a certain mode of transportation and the passenger automobile in terms of how it affects various traffic characteristics, such as speed, density, and headway. This definition has evolved to account for diverse traffic situations where research has shown that the impact of vehicles other than trucks and buses is considerable.

1.2 Problem statement

With the development of Sri Lanka, the expressway has become a major topic these days. Sri Lanka currently has 05 expressways,

- Southern expressway(E01)
- Outer circular expressway(E02)
- Colombo-Katunayake expressway(E03)
- Central expressway(E04)
- Magampura expressway(E09)

They help the Sri Lankan transportation system to give maximum service to people in the country.

A key area of discussion in traffic engineering is headway distribution. Because it is crucial to consider when making judgments regarding the designs of infrastructure and when using traffic engineering techniques like capacity design, level of service, and safety studies.

Because of these reasons, it is a very essential need these days to develop “Headway distribution” for expressways in Sri Lanka. It will help to give correct and timely solutions for upcoming problems in expressways and help to give correct designs for upcoming expressways in Sri Lanka.

Different traffic flow theories have evolved as a result of changes to the transportation system and road network. These ideas are influencing how automobiles behave on the road under various circumstances and in various road environment situations. Therefore, theories might be changed for different countries based on different conditions.

Traffic flow models can be divided into two main categories based on macroscopic and microscopic traffic views. In terms of speed, flow, and density, macroscopical representation is referred to as a traffic stream notion. Microscopic behavior, such as headway, clearing, etc., is regarded as individual behavior. For planning, design, traffic operations, and facility development, we must have a solid understanding of time headway. Calibration and validation of multiple macroscopic models before choosing the optimal model is the initial stage in planning and design.

There are currently no methods available in Sri Lanka to predict time headway for expressways. Due to a variety of factors, the application of models produced in other nations has limited applicability. Vehicle compositions in the traffic stream are different from country to country. They thus significantly affect the flow of traffic. Headway is affected by a variety of road factors, including design speed, access locations, road quality, and availability of shoulders. Driver conduct and lane discipline also have an impact on traffic flow and, consequently, a road's time headway. These elements must be considered in the time headway distribution because they vary by country.

The PCU is a statistic that measures a vehicle type's influence on traffic factors in a passenger car. The ability to express heterogeneous traffic as a multiple of the passenger car is made possible by knowledge of PCU factors. As a result, it is simple to do traffic analysis and estimations. Both the features of the route and the traffic have an impact on PCU variables. As a result, it has to be estimated appropriately.

1.3 Objectives

The research aims can be succinctly outlined as follows:

1. Develop best fitted Time Headway Distribution values for expressway
2. Develop best fitted Headway Distribution for different flow categories (PCU/5min/lane)
3. Develop best fitted Headway Distribution for different vehicle pairs (Car-Car, Car-Cab, Car-Bus, Car-M.Lorry, Car-L.Lorry, etc.)

1.4 Research Design

Headway distribution is a measurement that can be useful in traffic flows as time intervals. It is used worldwide to determine traffic flow parameters. This research provides a better evaluation to improve road networks and traffic flows considering 3 different expressway locations considering Sri Lanka as a case study. The methodology and the analysis of the data fulfill all the research objectives of the study. Analysis of the gathered data is done using two software and the relevant road network properties were found.

1.5 Scope and Limitations of the Study

This dissertation consists of five chapters. Chapter 1 provides an idea about headway distribution and how the study has been conducted including the importance of doing a study like this. Chapter 2 will clear all the misconceptions and provide a better idea of headway distribution in expressways including key concepts and characteristics. Moreover, the chosen criteria will be meticulously detailed to ensure that readers proceed to the next chapter with a comprehensive understanding of the study. Chapter 3 will delineate the research methodology, elucidating all study limitations. It will define the research problem statement and outline the procedure employed to address the study's challenges. The chapter will encompass details on data collection and the preparatory steps. Subsequently, Chapter 4 will present the analysis of the collected data, predominantly focusing on the evaluation of the framework. In Chapter 5, the researcher's concepts will be substantiated with the gathered data and implementations. This section will also highlight the prospective scope and limitations of the research. This study is limited to finding road networks propertied for expressways only because selecting a wide range of road networks is a wider area for the study. The research areas are limited to Sri Lankan expressways. The summary of the thesis is shown below.

- Chapter 2 – Literature review. Past studies done both locally and abroad on Time headway, PCU, and Transport models are included in the chapter.
- Chapter 3 – Summary of site selection, data collection, and methodology.
- Chapter 4 – Analysis of the results obtained from the research. Further, a discussion on PCU values results has been included.
- Chapter 5 – Summary of the research outputs and a discussion on the applicability of said results.

1.6 Chapter Summary

This chapter includes the background, problem statement, and objectives of the study within the research design and limitations. The background of the study gives a clear idea about the study and the problem statement indicates why the study is important to Sri Lankan road construction as expressways are still a new road networking method introduced in Sri Lanka. The study fulfills three objectives, which are to develop a time headway distribution, develop a headway distribution for different flow categories and vehicle pairs. The limitations of the study have been mentioned in the scope and limitation section.

2 LITERATURE REVIEW

Typically, traffic streams exhibit non-uniform patterns, fluctuating across both spatial and temporal dimensions. Consequently, articulating the phenomenon of traffic flow becomes challenging without using a standardized vocabulary terms such as headway, flow, speed, and density.

2.1 Headway

Headway can refer to either time headway, which is the number of seconds that pass between a leading and a following vehicle arriving at a particular location, or space headway, which is the distance in meters between a leading and a following vehicle's front ends. One of the crucial factors to consider while modeling and analyzing the flow of traffic on the road, particularly in studies of traffic simulation, is headway. Because headway and its distribution can have an impact on a variety of flow factors, such as capacity, quality of service, and safety, headway modeling is crucial (Arasan and Koshy, 2003). The amount of headway varies depending on the flow of the traffic; the greater the flow, the less headway will be. Therefore, it is crucial to comprehend headway to complete theoretical and simulated traffic flow modeling. Since headway might vary for two distinct road types or sections, headway is location-specific.

2.2 Headway distribution

On the distribution of headways, mostly for homogenous and lane-based traffic, several studies have been described. In his study of headway under three flow conditions (low, medium, and high), Al-Ghambi (2001) found that headway at arterial sites follows the gamma distribution and the Erlang distribution at high flow locations. In their 2009 study of headways in congested traffic, Brackstone, Waterson, and McDonald found that headways vary based on the type of vehicle that follows. A thorough investigation of the effectiveness of typical headway distribution methods on urban highways was conducted in 2007 by Zhang, Wang, Wei, and Chen. They used the Advanced Loop Event Data Analyzer (ALEDA) technology to collect time headway data from Interstate 5 in the Seattle region of Washington. The performance of multiple headway models was calibrated using these headway data. They used the gathered headway to test the quality of fit for several distribution models. The Kolmogorov-Smirnov test and visually

represented comparison curves were used to assess how well various headway models performed. The Double Displaced Negative Exponential Distribution model, particularly for HOV lanes at a range of flow levels, offered the greatest fit to the urban freeway headway data, according to the findings of their tests. The general-purpose-lane headways were similarly fitted by the shifted lognormal distribution. In their analysis of real traffic data from several urban highway sections, He, Guan, and Ma (2007) found that time-headway distributions under various velocities match well with a class of distributions. The distribution is broken down into an independent Gaussian fluctuation and an exponentially distributed variable. Li, Lu, Yu, and Sui (2011) gathered headway data from loop detectors at various locations along a Beijing urban arterial route. Both the Gamma and the Erlang distributions were tested, and the K-S test determined that the Gamma distribution provided the greatest match.

It is difficult to define and measure these factors under conditions of heavy traffic like those in India, where there is a lack of lane discipline and a diversity of vehicle types. In their 2003 research on the temporal headway distribution of urban heterogeneous traffic, Arasan and Koshy found that negative exponential distribution may be used to represent the headways of mixed traffic that are dominated by tiny vehicles like motorized two-wheelers.

2.3 Expressways

Expressways, also known as throughways, thruways, parkways, freeways, superhighways, or motorways, are major arterial divided highways with two or more traffic lanes in each direction, with opposing traffic separated by a median strip. They also have controlled entries and exits, the elimination of grade crossings, and cutting-edge designs that eliminate steep grades, tight curves, and other driving hazards and inconveniences. Expressways have frequently been built on entirely new roads, going close to but not through major population centers, and on more or less straight lines between targeted termini. High speed, increased safety, comfort, and convenience for drivers and passengers, as well as lower vehicle running costs, are some of its benefits. Particularly in the United States, many of these new express routes include tolls, but this is only a supplementary, not a necessary, aspect.

Italy started constructing toll motorways, or *autostrada*, in 1924. They were created, owned, and paid for by private businesses through tolls and advertising. German engineers created the *autobahns*, the first real expressways. The *Reichsautobahnen*, a nationwide highway system constructed by the Nazi dictatorship for both commercial and military goals, totaled 1,310 miles (2,110 km) by 1942 even though the concept and first blueprints were drafted between 1930 and 1932. The Netherlands was the only other nation in Europe to start building expressways before World War II.

The express highway movement grew after the war, initially slowly due to budgetary issues and the necessity of postwar reconstruction, then more quickly. Eight U.S. states had toll highways with a length of more than 750 miles by 1950 that satisfied express highway criteria (1,210 km). The Special Roads Act of 1949 established a network of new "motorways" in Great Britain of around 700 miles (1,130 km), which was later increased to more than 1,000 kilometers (1,600 km). With a government policy favoring rail travel, France developed several small express roads, or *autoroutes*, in the 1950s to ease egress from its main cities, but it did not start large new building projects until the 1960s and 1970s. With three four-year plans for federal roads, West Germany commenced building the *autobahns* in 1957. It had around one-fourth of all of Europe by 1970. The *Autostrada del Sole*, a nearly 800-kilometer (500-mile) route between Milan and Naples, was completed in Italy in 1964. Since then, some branches, spurs, and

extensions have been built. Expressways were also created in Japan and other European nations. Even some emerging nations in Latin America and Africa constructed brief segments close to their big cities.

2.4 Difference between Highways and Expressways

Access control is the main distinction between a highway and an expressway. Expressways have restricted access lanes where only a small number of vehicles are permitted to enter, and no additional roads are allowed to merge with or cross the expressway at any location. This also reduces the likelihood of accidents. However, several roads intersect or merge with highways often in the case of highways.

Roadways that connect significant cities, villages, and other locations are referred to as highways, and they often feature four lanes to accommodate high-speed traffic. However, an expressway is a high-speed road with limited access and a variety of features, including lane separators, access ramps, high mobility, and low accessibility in expressways, etc.

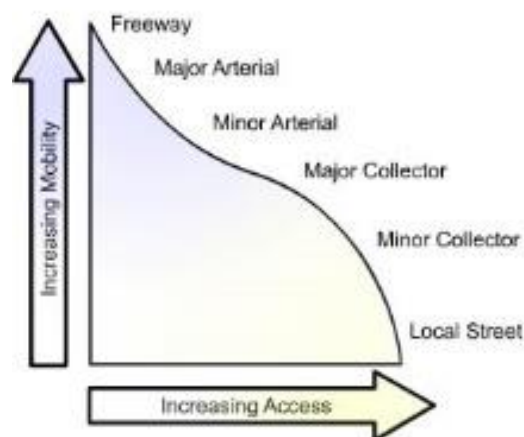


Figure 2.1 – Description of expressways

2.5 Expressways in Sri Lanka

The southern and central regions of Sri Lanka are now served by expressways totaling more than 271 kilometers (168 mi). Sri Lanka's first expressway, the E01 Expressway (Southern Expressway), was completed in stages over a 95.3-kilometer length beginning in 2011. (59.2 mi). The expressways are off-limits to tractors, bicycles, motorcycles, three-wheelers, and pedestrians.

Table 2.1 - Completed Expressways in Sri Lanka

No.	Name	Length (km)	Northern end	Southern end
E01	Southern Expressway	200.45	Kadawatha, Colombo	Mattala
E02	Outer Circular Expressway	29.2	Kerawalapitiya	Kottawa, Colombo
E03	Colombo-Katunayake Expressway	25.8	Bandaranaike International Airport	New Kelani Bridge, Colombo
E04	Central Expressway (Section II)	40.0	Kurunegala	Mirigama
E06	Magampura Expressway	16.5	Andarawewa	Hambantota

Table 2.2 - Expressways under Construction in Sri Lanka

No.	Name	Length(km)	Northern end	Southern end
E4	Central Expressway (Section I, III & IV)	137.1	Dambulla	Kadawatha
	Ruwanpura Expressway	73.9	Kahathuduwa	Pelmadulla
E9	Port Access Elevated Highway	5.3	New Kelani Bridge, Colombo	Port city

2.6 Traffic variables:

- Flow (vehicle/hour) - number of vehicles crossing a particular section within a stated period
- Average Speed (km/hour) – average spot speed of several vehicles passing a specific location

$$\text{Time mean speed}(U_t) = \sum_{i=1}^n U_i/n$$

$$\text{Space mean speed}(U_s) = \frac{n}{\sum_{i=1}^n 1/U_i}$$

For the modeling calculations, space mean speed was considered.

- Density (vehicles/km) – number of vehicles occupying a particular section of the road

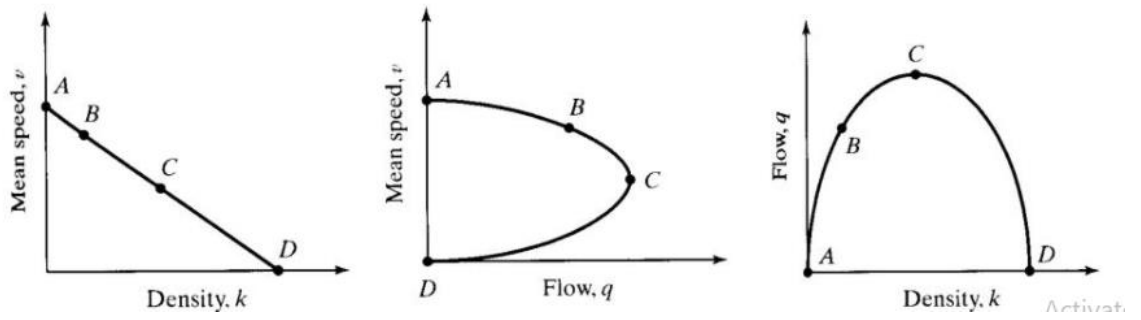
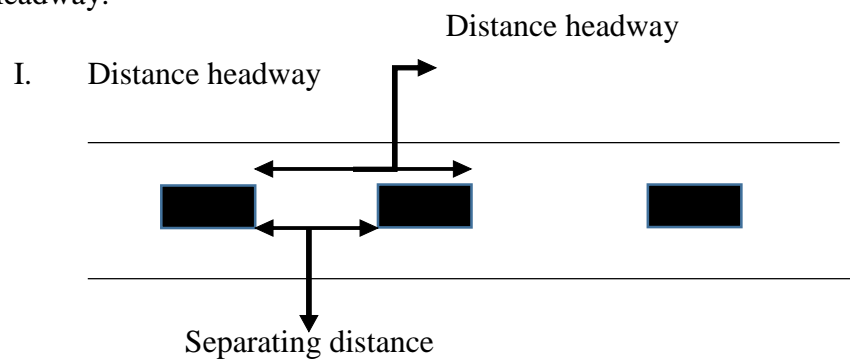


Figure 2.2 - Speed, Flow, Density Relationship

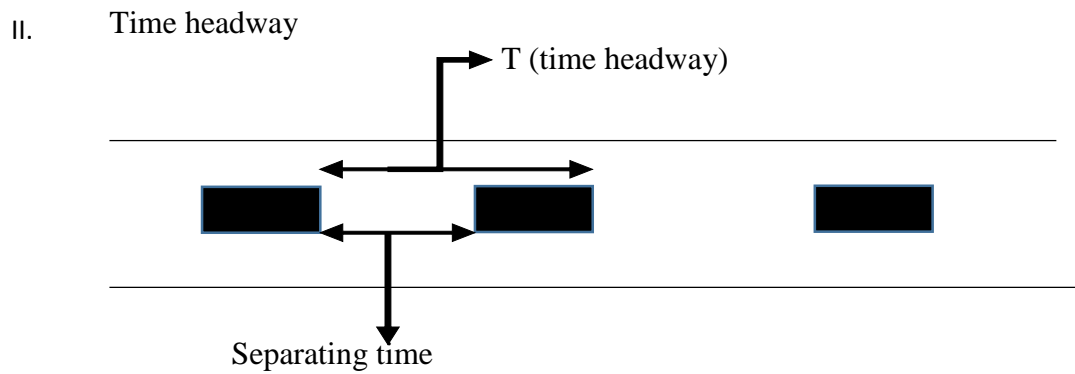
2.7 Traffic variations:

- Time, space, mode

Headway:



$$\text{Density} = 1 / \text{average space headway}$$



Flow = 1/ average time headway

2.8 Speed flow relationship

Table 2.3 - Summary of Models

Model	Description	Equation
Greenshield's	<ul style="list-style-type: none"> • Assume that speed and density have a linear relationship when there is unbroken flow. • An easy modeling technique. • Unsuitable for heavily traveled and very low-density roads. 	$U = U_f \times \{ 1 - K/K_j \}$
Greenberg	<ul style="list-style-type: none"> • Assume that a one-dimensional fluid may be used to describe how traffic moves along a road. • Beneficial in a packed situation. • At a low-density regime, the boundary condition is not satisfied (fails to predict free-flow speed). 	$U = U_c \times \ln(K_j/K)$
Underwood's Exponential	<ul style="list-style-type: none"> • Does not handle crowded conditions, but provides a better match for the uncongested traffic scenario than the previous two models. <p>Does not meet the boundary requirement in the regime of high density.</p>	$U = U_f \times e^{-(K/K_0)}$

Pipes-Munjial	<ul style="list-style-type: none"> The more generalized modeling approach 	$U = U_f \{ 1 - (K/K_j)^n \}$
Polynomial		$U = U_f + b \times K + c \times K^2$

2.9 PCU estimating methods

Various studies have developed a variety of methods to calculate PCU factors over time. It is necessary to determine which techniques are best suited for the diverse traffic conditions present in Sri Lanka. Therefore, the best PCU calculation techniques may be identified by categorizing them as ones that fit homogeneous traffic situations and ones that suit heterogeneous traffic conditions.

PCU estimation techniques can be grouped according to the traits they are built on.

2.9.1 Based on Flow rates and Density

Based on the volume-to-capacity ratio of trucks, mixed vehicle flow, and percentage of grade, John & Glauz (1976) suggested the equation that is listed below.

$$PCE = \frac{q_B - q_M(1 - P_T)}{q_M \times P_T}$$

q_B – Equivalent passenger car flow rate for a given v/c ratio

q_M – Mixed flow rate

P_T – Truck proportion in the mixed traffic flow

Huber (1982) devised a model that relates the ratio of the volumes of two streams at a given common level of impedance to the PCU under free-flow circumstances.

$$CE = \frac{1}{P_T} \left(\frac{q_B}{q_M} - 1 \right) + 1$$

2.9.2 Based on Speed

Chandra et al., (1995) proposed a method to calculate PCU for mixed traffic conditions. The PCU is derived as a function of the speed and projected area of the vehicle.

$$PCU_i = \frac{V_{car}/V_i}{A_{car}/A_i}$$

PCU_i – Passenger car unit value of i^{th} vehicle type

V_{car} – Speed of car (km/h)

V_i – Speed of i^{th} vehicle type (km/h)

A_{car} - Static (a projected rectangular) area of the passenger car (m^2)

A_i - Static (a projected rectangular) area of the i^{th} vehicle type (m^2)

Table 2.4 - Comparison of PCU methods (Muhammad,2014)

Vehicle Type	PCU factors estimation Approaches		
	Headway	Speed	Regression
Small cars	1	1	1
Large cars	1.142	1.182	1.757
Three wheelers	1.387	0.909	1.35
Motorcycles	0.595	0.453	1.068
Mini Buses	1.675	3.024	3.718
Pickups	1.56	1.543	1.204
Heavy vehicles	2.035	3.288	1.951
Non-motorized	2.271	3.138	2.408

Taking into account the results, it was discovered that the regression approach produced inconsistent values, particularly for motorbikes. This investigation determined that the headway and speed approaches were adequate in light of the data's consistency and believability. It was discovered that there is less contrast between groups like minibus, HCL, and pickups when using the headway approach when compared to the speed method. This study discovered that the speed-based strategy is more suited for diverse traffic situations since it integrates both dynamic and static features (projected area) whereas the headway method just considers dynamic characteristics.

Furthermore, Shalini & Kumar (2014) found that Chandra's technique (speed-based methods) is the best suitable for heterogeneous traffic situations, even though the headway method is the most often used. & Kumar, 2014)

2.10 Chapter Summary

This chapter selected the most suitable literature that can be useful to the study and organized it according to the correct order. First, it describes what headways are and how it's connected to the headway distribution. Since the study is focused on expressways, knowledge of expressways should be gathered. Expressways as well as the difference between highways and expressways, expressways in Sri Lanka are discussed in this chapter.

The next part of the study is mainly related to the methodology and the analysis of the study. Traffic variables and variations are discussed then the relationship between speed and flow is discussed. In the speed flow section, various model types are addressed including the equations that can be used. Next, the Passenger Car Unit estimating methods are discussed to select the most suitable method for the study. Given the information compiled from the literature review, the methodology chosen for estimating Passenger Car Units (PCU) in this research is Chandra's method (Chandra, et al., 1995).

3 METHODOLOGY

3.1 Site Selection

It is not easy to consider a one-kilometer distance. Opting for a shorter distance might not align with reality, while contemplating a greater distance could introduce parallax errors. Taking both factors into account, the optimal distance was selected. The locations were spread out on the Southern Expressway (E01) and Colombo-Katunayake Expressway (E03). More than 24m long, straight road and level terrain sections were considered. Locations were spread out in E01, and E03 (Ch.14+275, Ch.22+700).



Figure 3.1 - E01 Kottawa Interchange

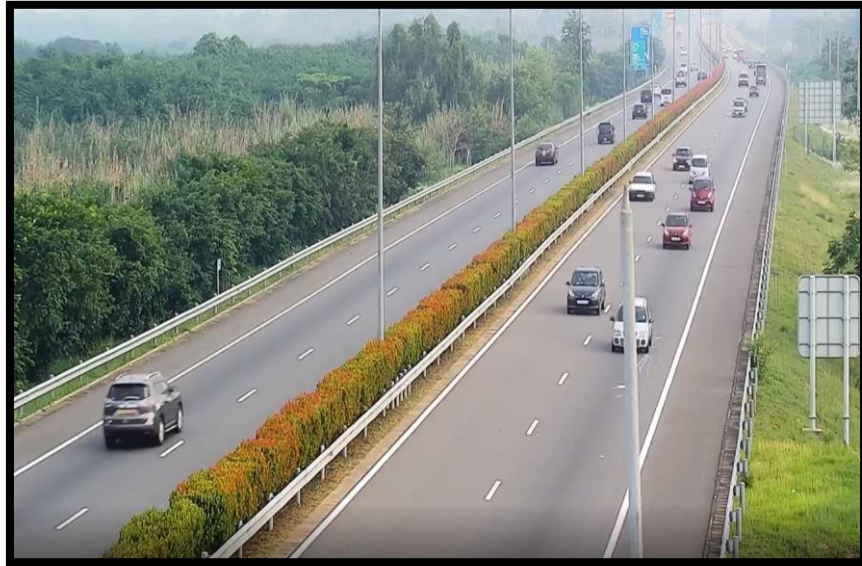


Figure 3.2 - E03 Ch. 14+275



Figure 3.3 - E03 Ch. 22+700

3.2 Data Collection

Data was gathered using the technique of video capturing. To collect the traffic statistics, 12-hour video clips were taken between the hours of 0600 and 1800 at three different sites. The dates 27.02.2020, 05.04.2021, 10.04.2021, and 10.06.2022 were taken into consideration. The video camera was positioned to capture the longest possible segment

of the road without impeding vehicle movement. Over 16000 automobiles in all were examined.

3.3 Creating the traffic database

A thorough examination of the video clips was conducted, leading to the establishment of a database containing counts (in 5-minute intervals) as well as time headway and vehicle speeds for each location. ABRUTECH software was used to calculate the time headway and speed. The only left lane is considered for counting because the right lane is used for overtaking vehicles. Counts were done based on covering the congested and uncongested vehicle flow at each location. For the calculations three hours from the morning (0600- 0900), one hour from the afternoon (1200-1300), and two hours from the evening (1600-1800) time were selected.

The vehicles were classified into 08 categories. Namely, Car, Van, Light goods vehicle (LGV), Medium lorry (MG1), Large lorry (MG2), Medium bus (MBU), Large bus (LBU), and Truck (TRK).

3.4 Categorization of vehicles

The vehicles have been categorized according to the ABRUTECH software categorization. Figure 4.1 shows the interface of the software and in the right corner, the vehicle groups are mentioned. MCL, TWL, and BCL categories are not considered as they referred to motorcycles, three-wheelers, and bicycles. These are not included in expressways.

The vehicles were categorized as follows,

- Car (Cars and Jeeps are included in this group)
- Van
- Light good vehicle (Cabs, Crew cabs, and small lorries are included - LGV)
- Medium Bus (MBU)
- Large Bus (LBU)
- Medium lorry (Medium lorry and Canter are included - MG1)

- Large lorry (MG2)
- Truck (TRK)

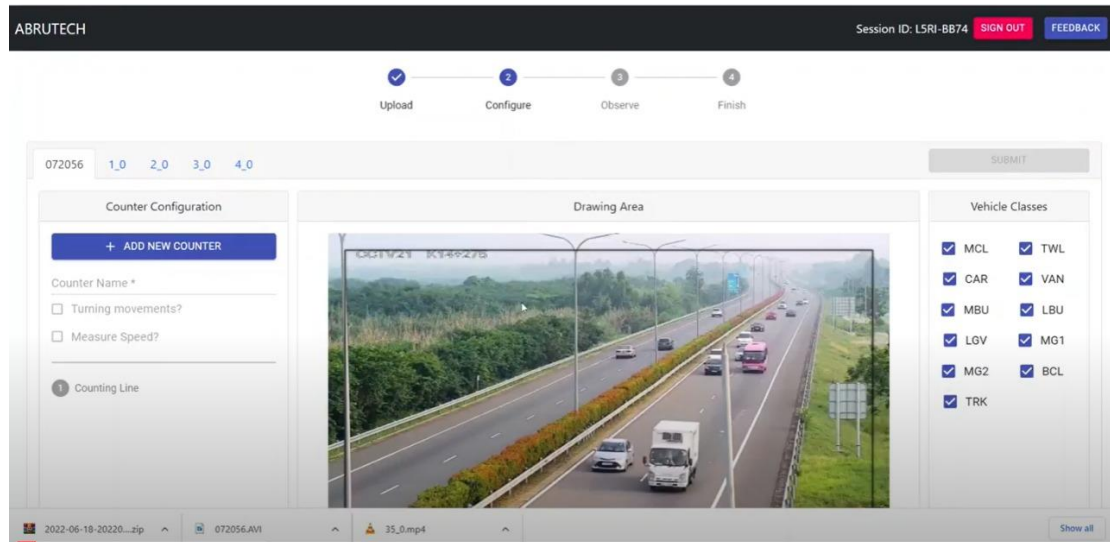


Figure 3.4 - Interface of the ABRUTECH software

3.5 Calculation of the projected area of vehicles

By choosing one or more nominal cars for each category, the estimated areas of the vehicles were determined. For calculations, the most popular car types in 2020 were considered. The car specifications were gathered from each company's website. The predicted area is depicted in Table 3.1.

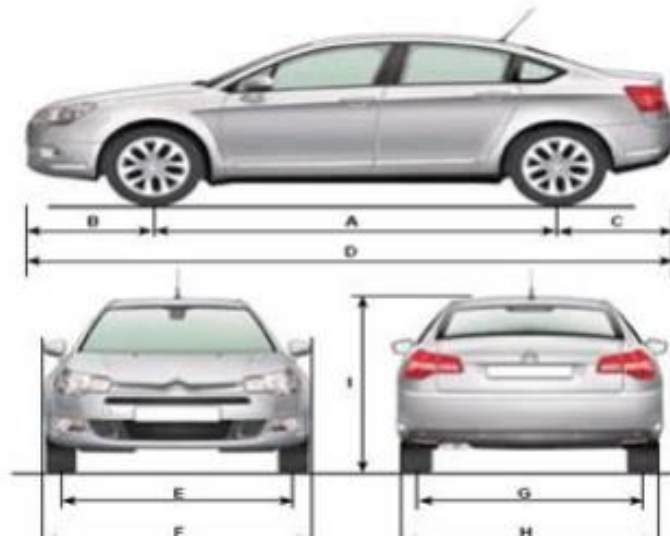


Figure 3.5 - Vehicle dimensions

Table 3.1 - Projected areas of each vehicle category

Vehicle Category	Average Projected Area
Car	6.77
Van	7.96
LGV	7.79
MBU	13.85
LBU	29.84
MG1	13.85
MG2	18.79
Truck	33.46

3.6 Calculation of PCU (Passenger Car Unit)

The PCU value serves to standardize the non-uniformity (heterogeneity) across all vehicle modes into a common unit. Calculations for PCU values were performed utilizing

Chandra's method (Chandra, et al., 1995), employing the following equation for the computation:

$$PCU_i = \frac{V_{car}/V_i}{A_{car}/A_i}$$

3.7 Summary of PCU values

Table 3.2 - PCU Values

Vehicle Category	PCU Values
Car	1
Van	1.14
LGV	1.34
MBU	2.20
LBU	4.34
MG1	2.39
MG2	3.41
Truck	5.64

3.8 Chapter Summary

This chapter shows how the relevant data has been gathered for the study by selecting suitable locations. According to the methodology, three areas have been selected from the Southern Expressway and Colombo-Katunayake Expressway. Then the data collection is done using video recording and the gathered data was used to create a database suitable for the study.

4 DATA ANALYSIS

The analysis is done based on the three main objectives. The significance interval was selected as 0.05. “SPSS”, “Easy-Fit” and “Microsoft Excel” software were used for analyzing and graph plotting.

Table 4.1 - Statistical tests

Test	Output
K-S Test	Goodness of Fit
Runs Test	Randomness
Normality Test	Normality
One way Anova	Check the similarity between Parametric data sets
Kruskal-Wallis test	Check the similarity between Non Parametric data sets

4.1 Headway Distribution

- In their research titled "Modeling of Time Headway Distribution on Suburban Arterial" (2011), Jinhwan Jang, Changsoo Park, Byunghwa Kim, and Namkuk Choi considered Johnson SB, Johnson SU, Log-Logistic, and Log-normal distributions.
- In their study titled "An empirical analysis of vehicle time headways on rural two-lane two-way roads" (2012), Rossi Riccardo and Gastaldi Massimiliano explored Inverse Gaussian, Inverse Weibull, Log-Logistic, Pearson 5, and Pearson 6 distributions.

Different researchers have used various distributions for their study. To find the appropriate model for time headway distribution, Easy-Fit software was used. The reason to select this software is it has 61 distribution types, and we can select the most appropriate model. Some of the distribution types are mentioned below,

- Weibull

- Burr
- Rice
- Dagum
- Gamma
- Inverse Gaussian
- Lognormal
- Pearson
- Exponential
- Beta General etc.

The software has three tests to rank the distribution types as

- Kolmogrov Smirnov (K-S test)
- Anderson Darling
- Chi-Squared

To select the most appropriate distribution type K-S test was used.

Table 4.2 - Results of the K-S test

Burr					
Kolmogorov- Smirnov					
Sample size	280				
Statistic	0.04518				
P-Value	0.060091				
Rank	1				
A	0.2	0.1	0.05	0.03	0.01
Critical Value	0.06412	0.07309	0.08116	0.09072	0.09735
Reject?	No	No	No	No	No

The selected distribution type is “Burr”. The symbol α is the significant value that we mentioned earlier as 0.05. According to 0.05, the relevant critical value is 0.08116. The statistics value mentioned(0.04518) is lower than the critical value(0.08116). That’s the reason why the reject criteria have indicated ‘No’

The screenshot displays a software interface with two main panels: 'Properties' and 'Functions'. The 'Properties' panel lists various statistical measures for a Burr distribution, including Domain, Min, Max, Mode, Mean, Variance, St. Dev., Coef. of Var., Skewness, and Kurtosis. The 'Functions' panel includes input fields for 'x' and 'P', and output fields for Density, Cum. Density, Survival, Hazard, and Cum. Hazard. The 'Inverse CDF' section shows 'P' set to 0.5 and 'x(P)' set to 5.1039.

Property	Value
Domain	Continuous
Min	0
Max	+INF
Mode	4.8039
Mean	5.3838
Variance	2.6776
St. Dev.	1.6363
Coef. of Var.	0.30394
Skewness	2.5338
Kurtosis	22.978

Function	Value
x	0
Density	0
Cum. Density	0
Survival	1
Hazard	0
Cum. Hazard	0

Inverse CDF	Value
P	0.5
x(P)	5.1039

Figure 4.1 - Properties of distribution

Figure 4.4 describes the property distribution gathered from the software. The mean value is 5.38s and the mode is 4.8s. 50% percentile value(median) is 5.10s and 90% percentile value is 7.23s.

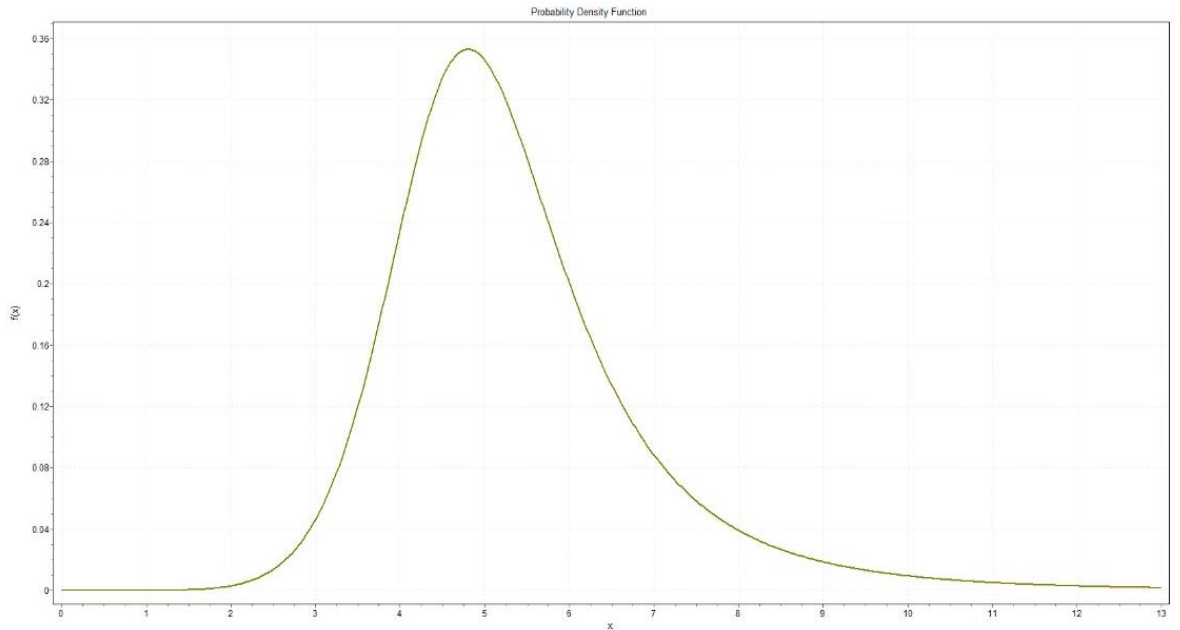


Figure 4.2 - Probability density function Curve

Figure 4.3 shows the probability density function curve. The estimated parameters that were used to create the curve are shown below,

$C - 7.8171$

$\lambda - 0.70034$

$k - 4.7724$

The probability density function can be identified using this curve and also from the equation stated down below.

The probability density function for Burr distribution is as follows,

$$f(x; c, k) = ck \frac{x^{c-1}}{(1 + x^c)^{k+1}}$$

$$f(x; c, k, \lambda) = \frac{ck}{\lambda} \left(\frac{x}{\lambda}\right)^{c-1} \left[1 + \left(\frac{x}{\lambda}\right)^c\right]^{-k-1}$$

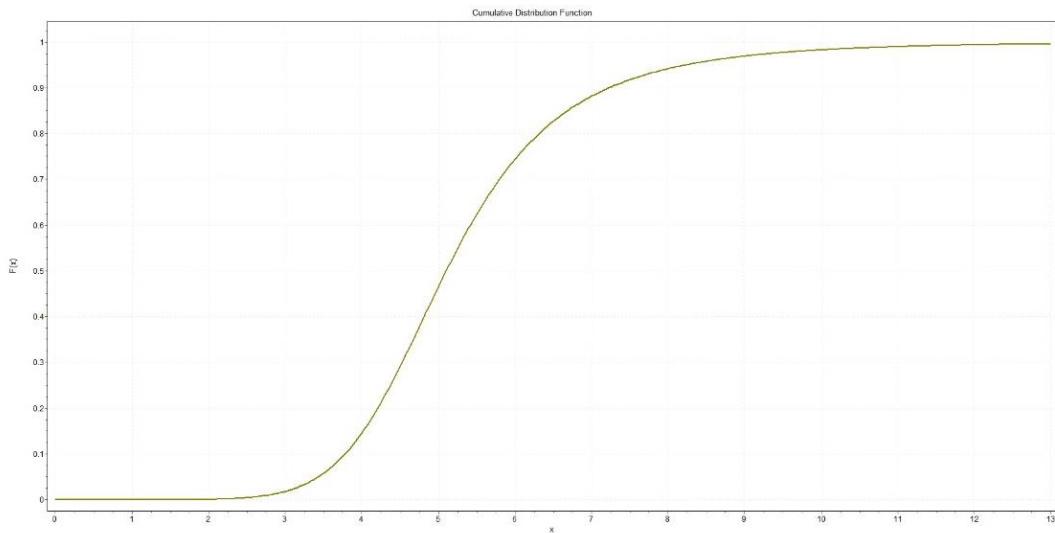


Figure 4.3 - Cumulative Density Function Curve

Figure 4.3 shows the cumulative density function curve. The estimated parameters that were used to create the curve are shown below,

C – 7.8171

λ – 0.70034

k – 4.7724

The cumulative density function can be identified using this curve and also from the equation stated down below.

The cumulative density function for Burr distribution is as follows,

$$f(x; c, k) = 1 - (1 + x^c)^{-k}$$

$$f(x; c, k, \lambda) = 1 - \left[1 + \left(\frac{x}{\lambda}\right)^c\right]^{-k}$$

4.2 Calculation of Flow

All eight (08) vehicle classifications per lane were taken into consideration while calculating the vehicle flow every five minutes. The resulting PCU values for each site

were used to generate hourly flow values. The computation was performed using the equation below.

$$Flow = 12 \sum Count\ of\ i^{th}\ vehicle\ category \times PCUi$$

4.3 Headway distribution for different flow categories

Previous studies have shown that the time headway distribution varies with the flow. To categorize traffic flows effectively, maximum and minimum flow thresholds were established. These thresholds were derived from the maximum and minimum flow conditions. Flow categories were defined based on the analyzed maximum and minimum flow values. This categorization allowed for the classification of traffic flow into distinct groups representing varying levels of congestion. The selection of flow categories involved an iterative process as each category included significant data points for analysis. Therefore, the total flow was divided into five (05) categories such as (PCU/5min/ln),

- 20 – 40
- 40 – 60
- 60 – 80
- 80 – 100
- 100 – 120

Although it was divided into 5 categories, it is better to check whether are considerable similarities within different categories if there is considerable similarity, then it can be combined and considered as the same flow category. For example, if 20-40 category and 40-60 categories have a similar type of distribution then that category can be considered as one from 20 – 60. To check the similarity, there are various test methods. Some of them are parametric tests and some are non-parametric tests. Hence first is required to identify whether the data set is parametric or non-parametric. Parametric and non-parametric tests differ based on 2 assumptions as follows,

- Randomness
- Normality

If both these assumptions are fulfilled, then a Parametric test is chosen to analyze and if one of these assumptions is not fulfilled then a non-parametric test is chosen to analyze.

Table 4.1 - Parametric and Non-parametric test

Nonparametric Tests	Parametric Tests
Mann- Whitney U Test	Independent Samples T-test
Wilcoxon Signed Rank Test	Paired Samples Test
Kruskal-Wallis Test	One-way ANOVA
Chi-squared Test	

Randomness was tested using the “Runs test” and Normality was tested using the “Normality test”. Both tests were done using SPSS software. The significance level was considered as 0.05.

4.3.1 Randomness Test

Runs test was used to check the randomness of the data set.

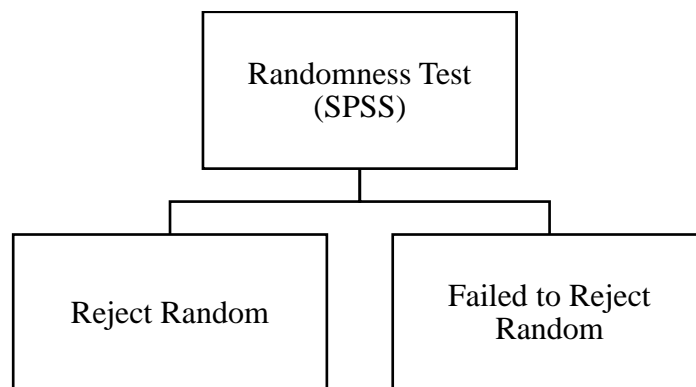


Figure 4.4 - Options available in the Randomness test

The hypothesis is taken as,

Ho – The variable follows randomness

H1 – The variable doesn't follow randomness

Then the comparison of the P value with the significance value is done as follows,

P value < 0.05 – Reject Ho(The variable doesn't follow randomness)

P value > 0.05 – Failed to reject Ho

4.3.2 Normality Test

The normality test was used to check the normality of the data set.

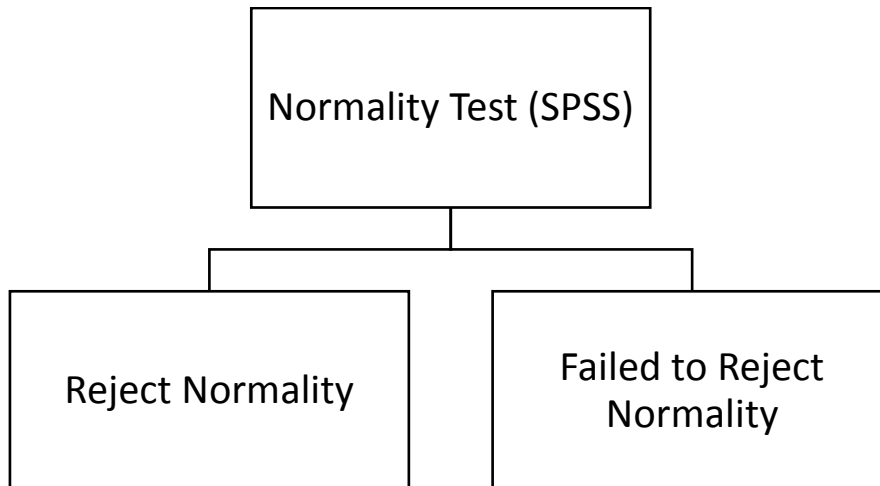


Figure 4.5 - Options available in the Normality test

The hypothesis is taken as,

Ho – The variable follows randomness

H1 – The variable doesn't follow randomness

Then the comparison of the P value with the significance value is done as follows,

P value > 0.05 – Failed to reject Ho

P value < 0.05 – Reject Ho

Table 4.2 - Properties of different flow categories

Characteristics	100_120	20_40	40_60	60_80	80_100
Mean	3.43429	8.84043	6.33968	5.07228	4.11702
95% confidence interval for the mean,					
- Lower bound	3.20140	8.03943	6.13028	4.96172	3.94531
- Upper bound	3.66717	9.64144	6.54908	5.18284	4.28873
5% trimmed mean	3.43095	8.91589	6.29029	5.05192	4.08875
Median	3.42000	9.24000	6.03000	5.01000	3.99000
Variance	0.262	3.431	0.680	0.396	0.342
Std. Deviation	0.511621	1.852334	0.824563	0.629596	0.584833
Minimum	2.420	4.970	5.040	3.700	3.080
Maximum	4.520	11.320	9.290	7.690	5.650
Range	2.100	6.350	4.250	3.990	2.570
Interquartile range	0.735	3.100	1.090	0.810	0.740
Skewness	0.023	-0.611	1.124	0.668	0.883
Kurtosis	0.076	-0.702	1.384	1.406	0.507
Std. error for					
-Mean	0.11645	0.386238	0.104720	0.055868	0.085307
-Skewness	0.501	0.481	0.304	0.215	0.347
-Kurtosis	0.972	0.935	0.599	0.427	0.681

The table shows the properties of different flow categories.

4.3.3 Randomness test results from SPSS software

The median is used as the cut point when adding different flow categories.

Table 4.3 - Randomness test results obtained for different flow categories

Flow category	20_40	40_60	60_80	80_100	100_120
Test value	9.240	6.030	5.010	3.990	3.420
Cases<Test Value	11	31	63	22	10
Cases=> Test Value	12	31	64	25	11
Total Cases	23	62	127	47	21
No of runs	12	28	46	17	7
Z	0.000	-1.024	-3.296	-2.045	-1.785

Asymp.Sig(2-tailed)	1.000	0.306	0.001	0.041	0.074
---------------------	-------	-------	-------	-------	-------

If Asymp.Sig values are lesser than 0.05 then the randomness is rejected and if asymp.sig values are higher than 0.05 then the randomness is failed to reject. According to the gained results, HW60_80 and HW80_100 are smaller than 0.05. Hence, this is considered rejected. The rest of the values are considered as failed to reject.

4.3.4 Normality test results from SPSS Software

Table 4.4 - Normality test results obtained for different flow categories

Flow category	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
100_120	0.095	21	0.200	0.991	21	0.999
20_40	0.163	23	0.115	0.918	23	0.062
40_60	0.167	62	0.000	0.909	62	0.000
60_80	0.060	127	0.200	0.973	127	0.011
80_100	0.131	47	0.042	0.936	47	0.012

The test of normality can be checked by two tests Kolmogorov-Smirnov and Shapiro-Wilk. The chosen test for the study is Kolmogorov-Smirnov(as mentioned earlier). If Sig. values are lesser than 0.05 then the normality is rejected and if Sig. values are higher than 0.05 then the normality is failed to reject. According to the gained results HW40_60 and HW80_100 are smaller than 0.05. Hence, this is considered rejected. The rest of the values are considered as failed to reject.

The below Figures also help to interpret the values shown in the table.

4.3.5 Flow category 20 – 40

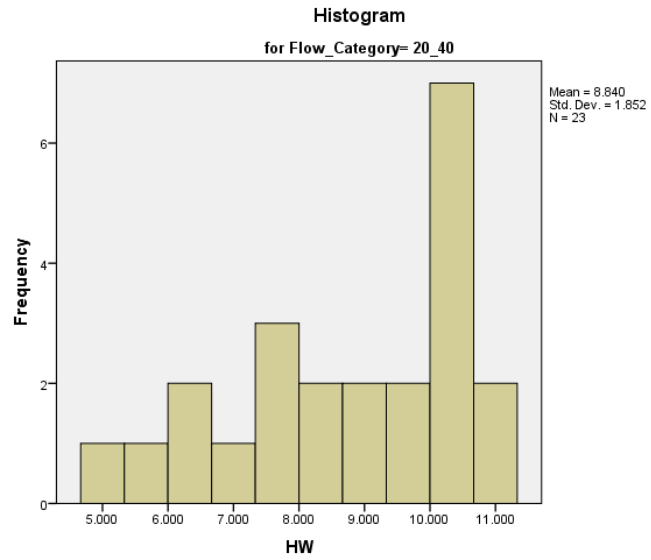


Figure 4.6 - Histogram of Flow category 20 - 40

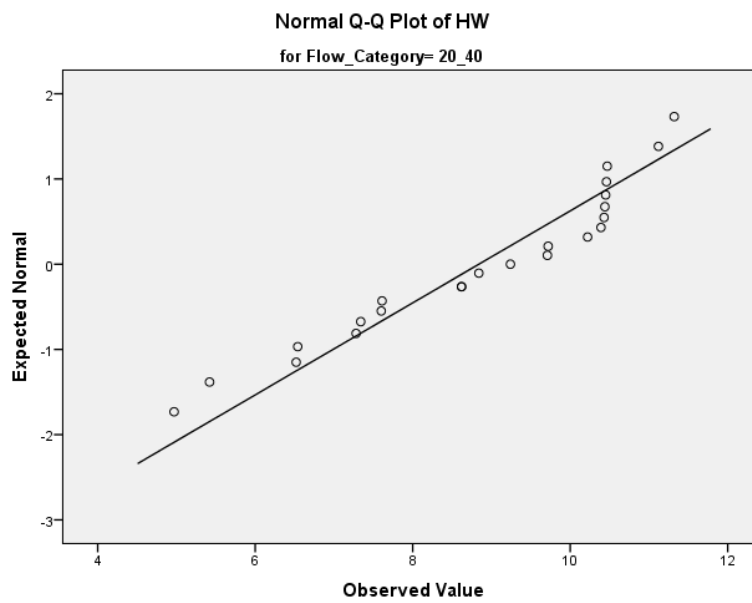


Figure 4.7 - Normal Q-Q plot of flow category 20- 40

4.3.6 Flow category 40 – 60

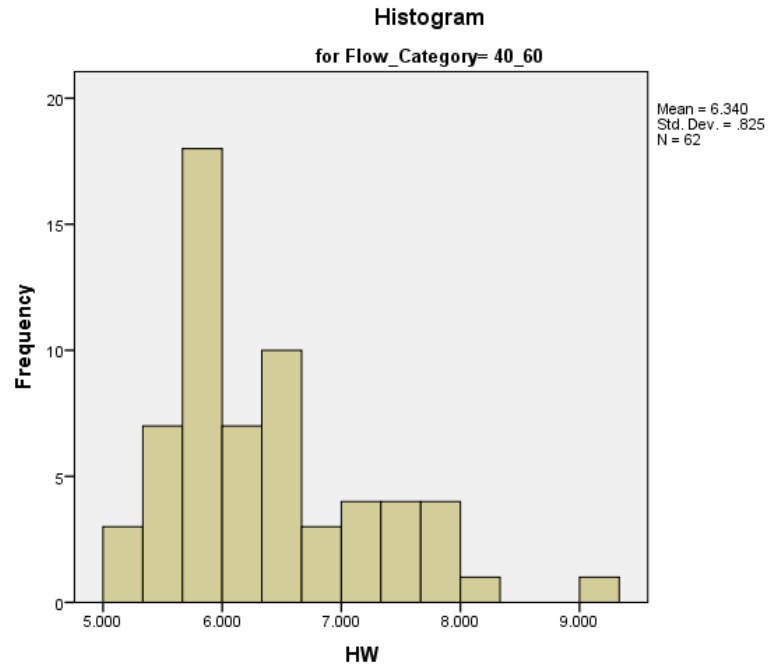


Figure 4.8 - Histogram of Flow category 40 - 60

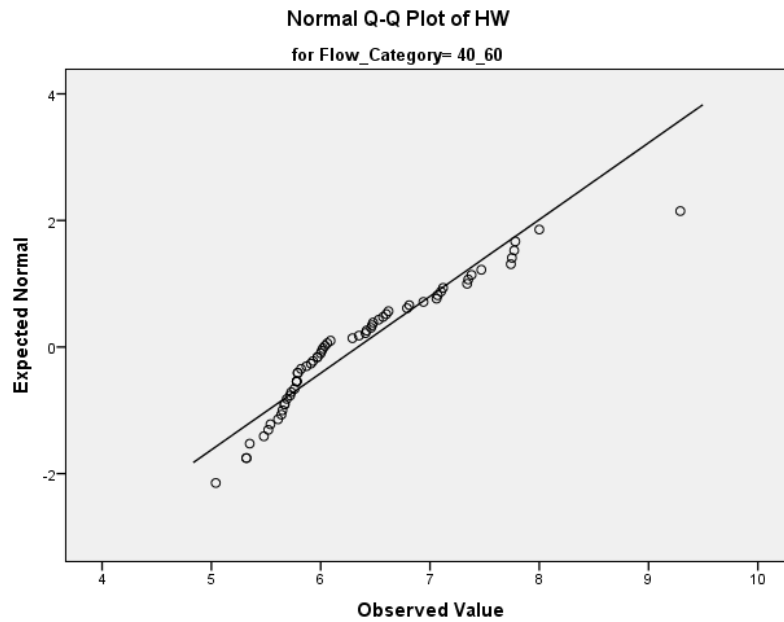


Figure 4.9 - Normal Q-Q plot of flow category 40- 60

4.3.7 Flow category 60 – 80

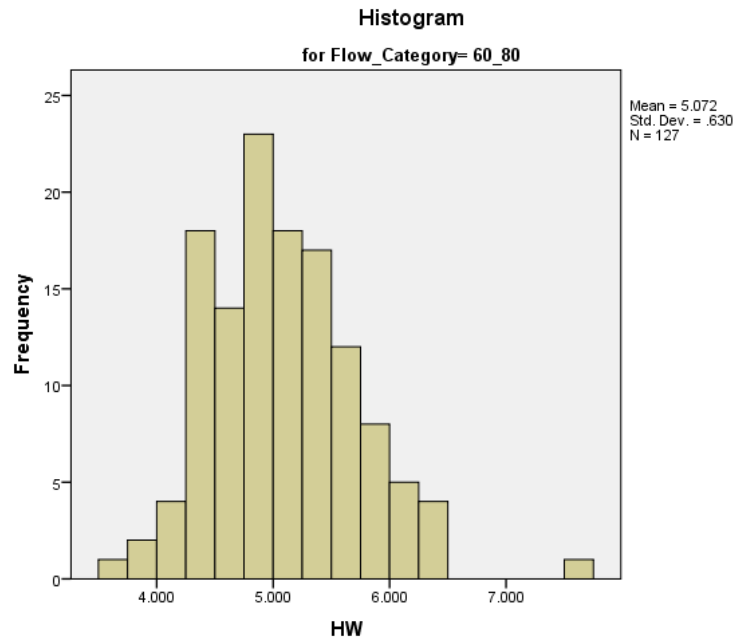


Figure 4.10 - Histogram of Flow category 60 - 80

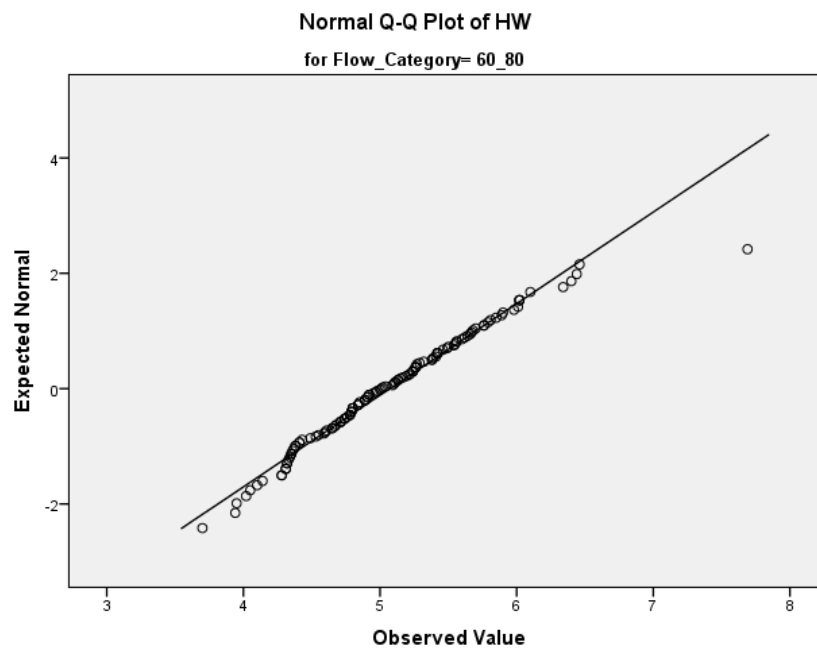


Figure 4.11 - Normal Q-Q plot of flow category 60- 80

4.3.8 Flow category 80 – 100

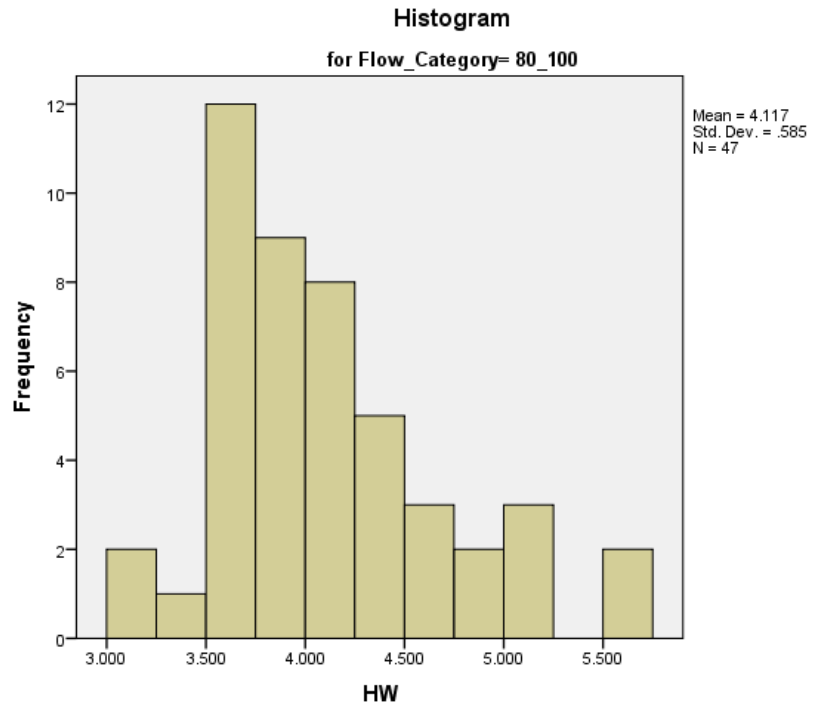


Figure 4.12 - Histogram of Flow category 80 - 100

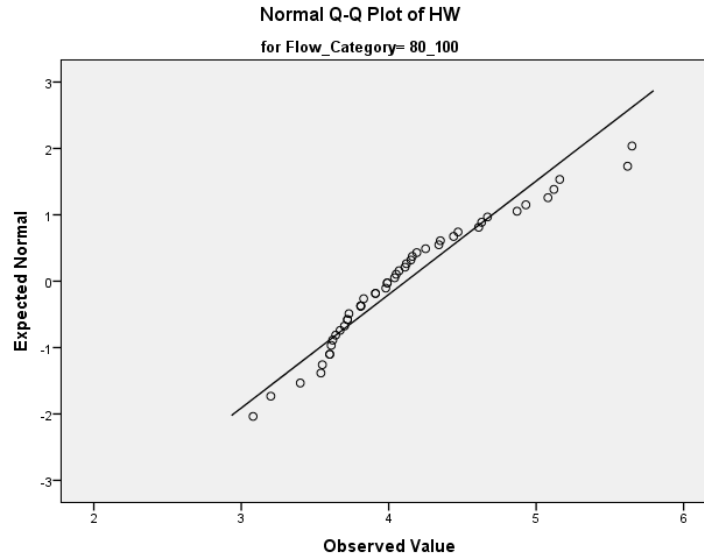


Figure 4.13 - Normal Q-Q plot of flow category 80- 100

4.3.9 Flow category 100 – 120

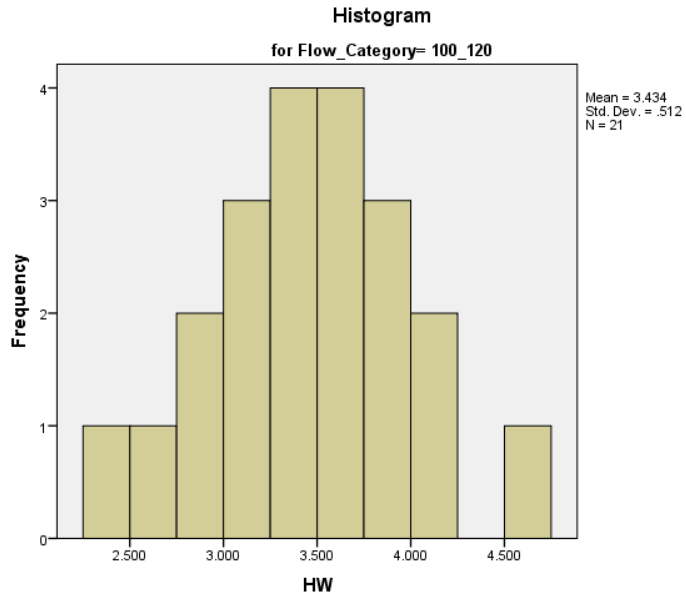


Figure 4.14 - Histogram of Flow category 100 - 120

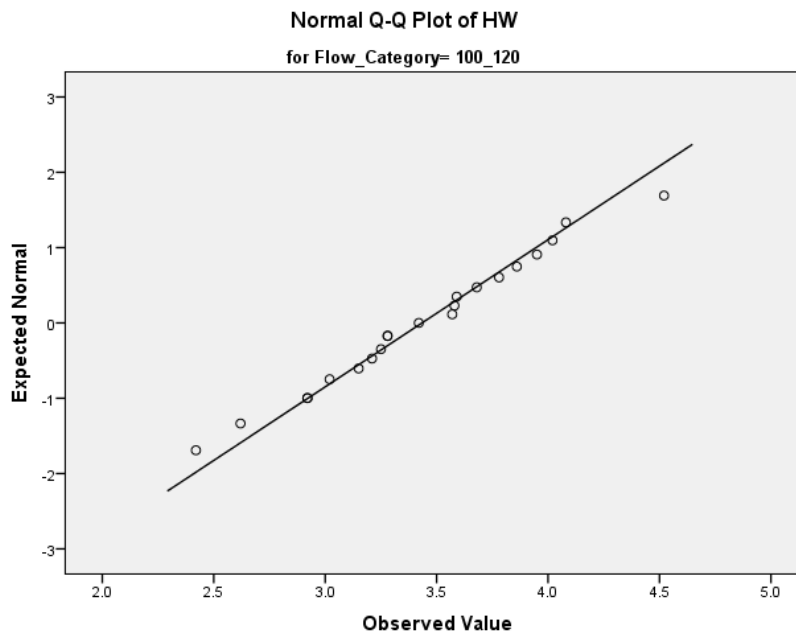


Figure 4.15 - Histogram of Flow category 100 – 120's

Then check the similarities between different flow categories. As mentioned earlier parametric and non-parametric tests were used.

Table 4.5 – Parametric state of the flow category with randomness and normality significance values

Flow category	Randomness test results	Normality test results	Parametric/Non-parametric
20 – 40	1.0	0.115	Parametric
40 – 60	0.306	0.00	Non-parametric
60 – 80	0.001	0.2	Non-parametric
80 - 100	0.041	0.042	Non-parametric
100 - 120	0.074	0.2	Parametric

To check the similarity of the Parametric flow category the used test was one-way ANOVA and for Non-parametric, the Kruskal-Wallis test is used.

4.4 Test results of the One-way ANOVA test

Table 4.6 - Test results of One-way ANOVA test

	Sum of squares	df	Mean square	F	Sig.
Between groups	320.827	1	320.827	166.931	0.000
Within groups	80.720	42	1.922		
Total	401.547	43			

If the Sig. value is lesser than 0.05 then both groups cannot be combined, and if the Sig. value is higher than 0.05 then both groups can be combined. In the table the Sig. value is 0.00, it is less than 0.05. Hence the groups that are considered(20_40 & 100_120) cannot be combined.

4.5 Test results of the Kruskal – Wallis test

Pairwise Comparisons of Flow_Catogory2

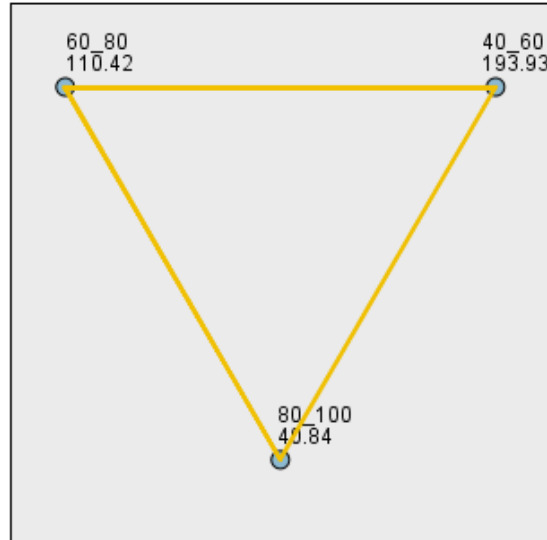


Figure 4.16 - Test results of Kruskal Wallis

Table 4.7 - Test results of Kruskal Wallis

Sample1-Sample2	Test statistic	Standard error	Standard test statistic	Significance	Adj. Significance
80_100-60_80	69.577	11.656	5.969	0.000	0.000
80_100-40_60	153.087	13.204	11.954	0.000	0.000
60_80-40_60	83.510	10.577	7.895	0.000	0.000

If the Adj. Sig. value is lesser than 0.05 then the considering two groups cannot be combined, and if the Adj. Sig. value is higher than 0.05 then the considering two groups can be combined. In the table the Adj.Sig. value is 0.00, it is less than 0.05. Hence the groups that are considered(40_60, 60_80 & 80_100) cannot be combined.

According to the test results of the one-way ANOVA test and Kruskal Wallis tests all the Sig and Adj. Sig values are less than 0.05(All are 0.00). Hence the groups can not be combined. So, the groups should be considered separately.

- 20 - 40
- 40 - 60
- 60 - 80
- 80 - 100
- 100 - 120

Using Easy-fit software, based on K-S test the distributions are ranked to each flow category separately.

4.5.1 20 – 40 Flow category

Table 4.8 - Results of K-S test for 20 – 40 flow category

Dagum					
Kolmogorov- Smirnov					
Sample size	23				
Statistic	0.12333				
P-Value	0.83377				
Rank	1				
α	0.2	0.1	0.05	0.03	0.01
Critical Value	0.21645	0.24746	0.2749	0.30728	0.32954
Reject?	No	No	No	No	No

According to Table 4.28, the selected distribution type is “Dagum”. The symbol α is the significant value mentioned earlier as 0.05. According to 0.05, the relevant critical value is 0.2749. The statistic value mentioned(0.12333) is lesser than the critical value(0.2749). That’s the reason why the reject criteria have indicated ‘No’.

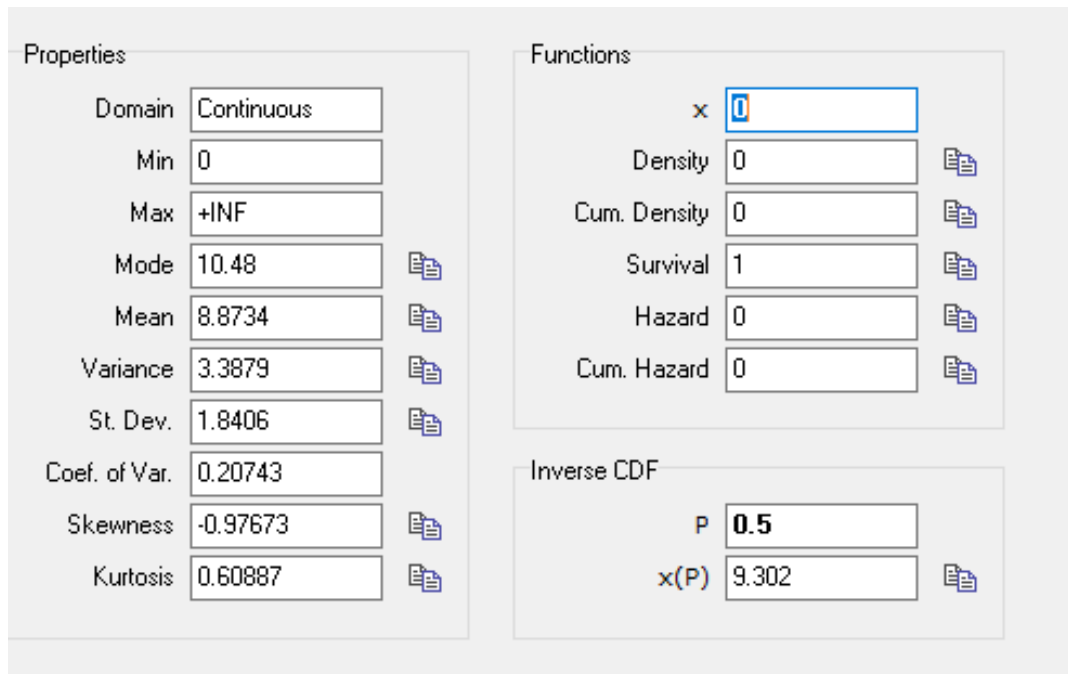


Figure 4.17 - Properties of distribution of 20 – 40 flow category

Figure 4.29 describes the property distribution gathered from the software. The mean value for the 20 – 40 flow category is 8.87s and the mode is 10.48s. 50% percentile value(median) is 9.30s.

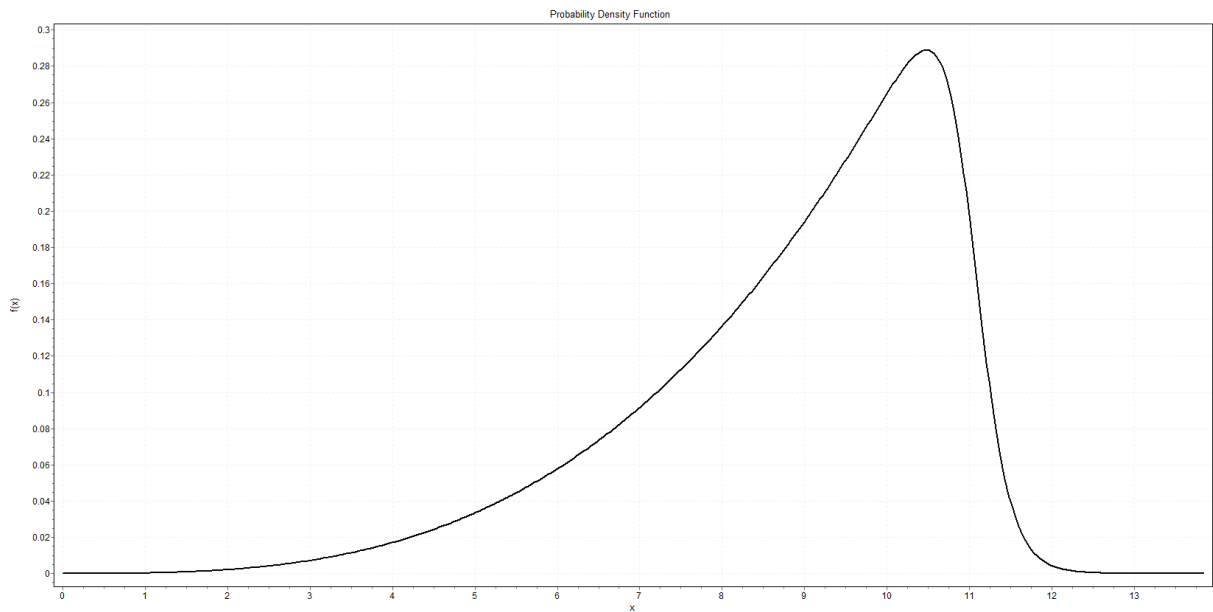


Figure 4.18 - Probability density function Curve for 20 – 40 flow category

Figure 4.3 shows the probability density function curve. The estimated parameters that were used to create the curve are shown below,

$$p = 0.07518$$

$$a = 53.053$$

$$b = 11.063$$

The probability density function can be identified using this curve and also from the equation stated down below.

Probability density function equation for Dagum distribution

$$f(x; a, b, p) = \frac{ap}{x} \left(\frac{\left(\frac{x}{b}\right)^{ap}}{\left(\left(\frac{x}{b}\right)^a + 1\right)^{p+1}} \right)$$

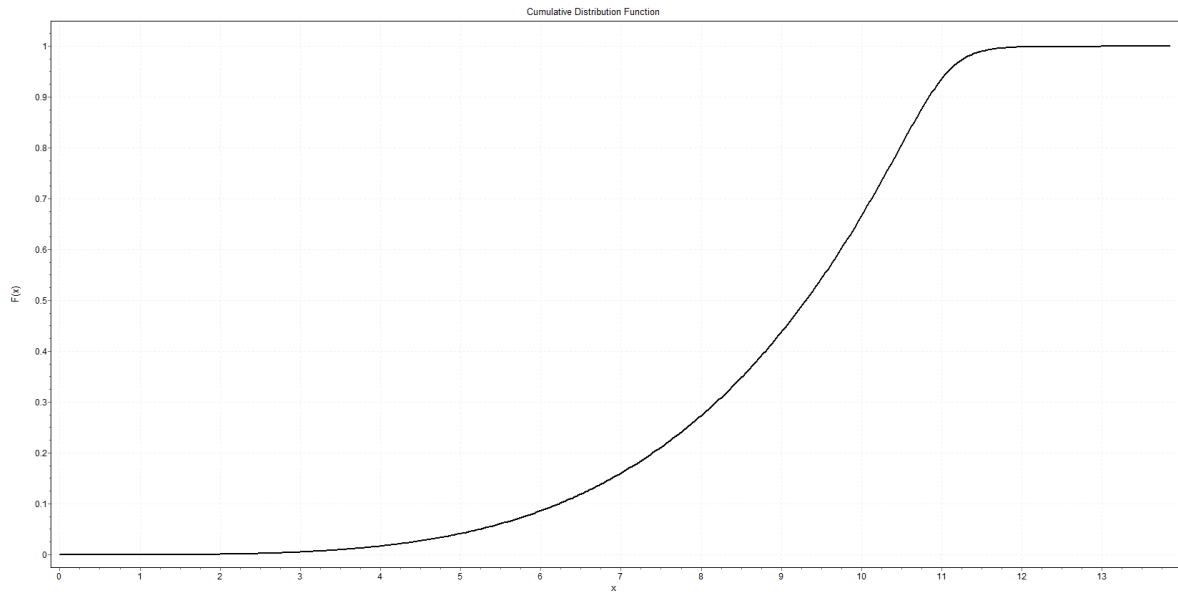


Figure 4.19 - Cumulative Density Function Curve for 20 – 40 flow category

Figure 4.3 shows the cumulative density function curve. The estimated parameters that were used to create the curve are shown below,

$$p = 0.07518$$

$$a = 53.053$$

$$b = 11.063$$

Cumulative density function can be clearly identified using this curve and also from the equation stated down below.

Cumulative density function for Dagum distribution

$$f(x; a, b, p) = \left(1 + \left(\frac{x}{b}\right)^{-a}\right)^{-p}$$

4.5.2 40 – 60 Flow category

Table 4.9 - Results of K-S test for 40 – 60 flow category

Frechet					
Kolmogorov- Smirnov					
Sample size	62				
Statistic	0.07838				
P-Value	0.81209				
Rank	1				
α	0.2	0.1	0.05	0.03	0.01
Critical Value	0.13357	0.15263	0.16956	0.1896	0.20343
Reject?	No	No	No	No	No

According to Figure 4.32, the selected distribution type is “Frechet”. The symbol α is the significant value mentioned earlier as 0.05. According to 0.05, the relevant critical value is 0.16956. The statistic value mentioned(0.07838) is lesser than the critical value(0.16956). That’s the reason why the reject criteria have indicated ‘No’.

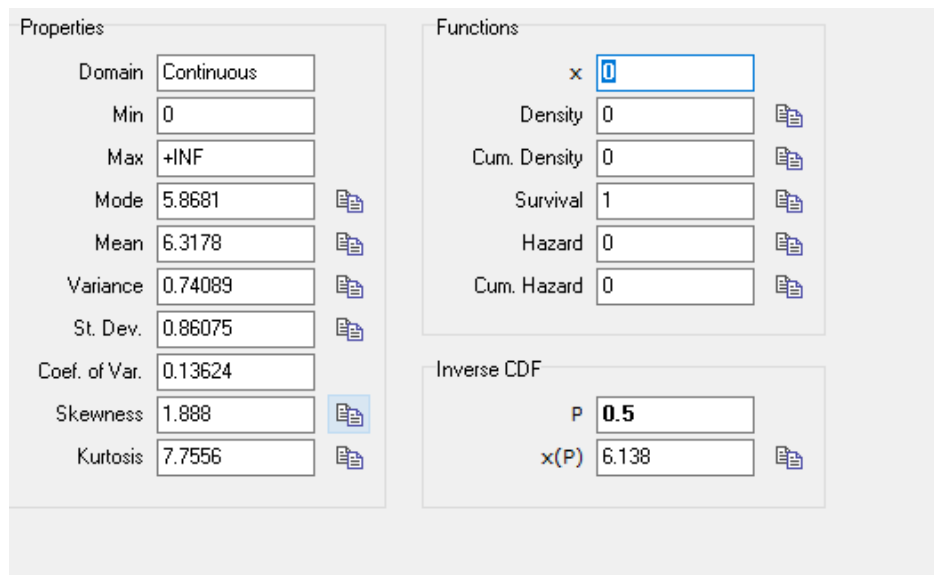


Figure 4.20 - Properties of distribution of 40 – 60 flow category

Figure 4.33 describes the property distribution gathered from the software. The mean value for the 40 – 60 flow category is 6.32s and the mode is 5.87s. 50% percentile value(median) is 6.14s.

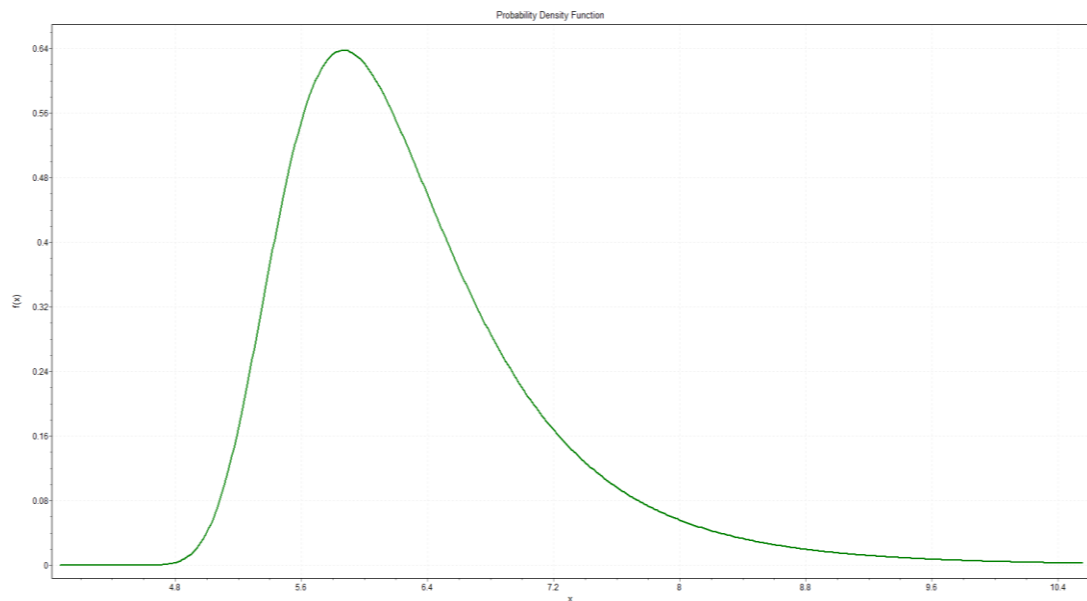


Figure 4.21 - Probability density function Curve for 40 – 60 flow category

The estimated parameters that were used to create the curve are shown below,

$$\alpha = 10.226$$

$$s = 5.9219$$

$$m = 0$$

The probability density function can be identified using this curve and also from the equation stated down below.

Probability density function equation for Frechet distribution

$$\frac{\alpha}{s} \left(\frac{x - m}{s} \right)^{-1-\alpha} e^{-\left(\frac{x-m}{s} \right)^{-\alpha}}$$

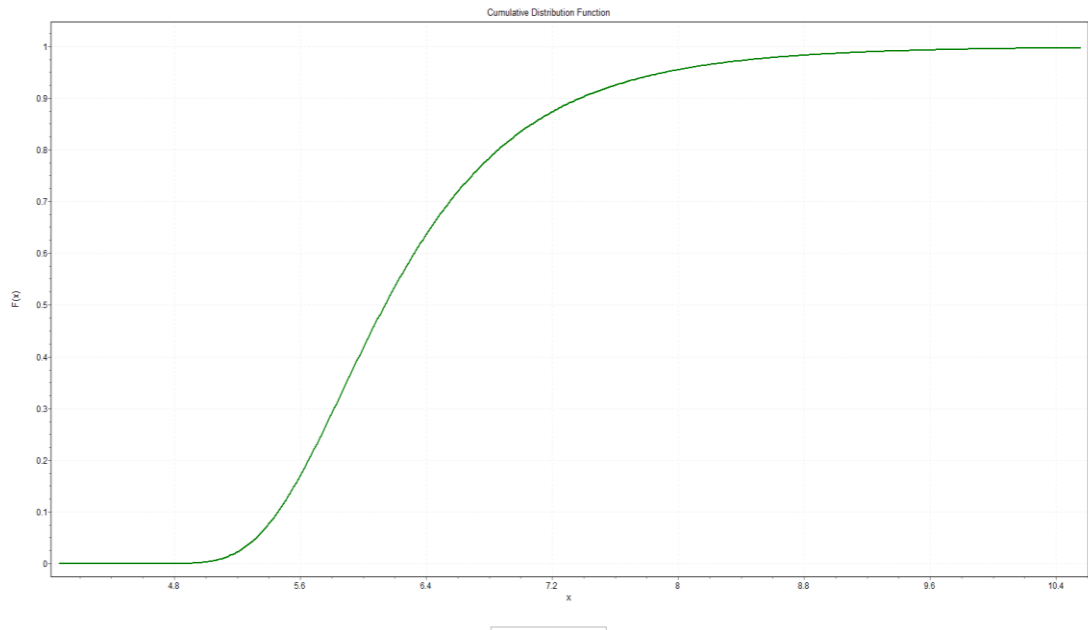


Figure 4.22 - Cumulative Density Function Curve for 40 – 60 flow category

The estimated parameters that were used to create the curve are shown below,

$$\alpha = 10.226$$

$$s = 5.9219$$

$$m = 0$$

The cumulative density function can be identified using this curve and also from the equation stated down below.

The cumulative density function for Frechet distribution

$$e^{-\left(\frac{x-m}{s}\right)^{-\alpha}}$$

4.5.3 60 – 80 Flow category

Table 4.10 - Results of K-S test for 60 – 80 flow category

Gen.Extreme Value					
Kolmogorov- Smirnov					
Sample size	127				
Statistic	0.04244				
P-Value	0.96883				
Rank	1				
α	0.2	0.1	0.05	0.03	0.01
Critical Value	0.09521	0.10852	0.1205	0.1347	0.14455
Reject?	No	No	No	No	No

According to Figure 4.36, the selected distribution type is “Generalized Extreme Value”. The symbol α is the significant value mentioned earlier as 0.05. According to 0.05, the relevant critical value is 0.1205. The statistic value mentioned(0.04244) is lesser than the critical value(0.1205). That’s the reason why the reject criteria have indicated ‘No’.

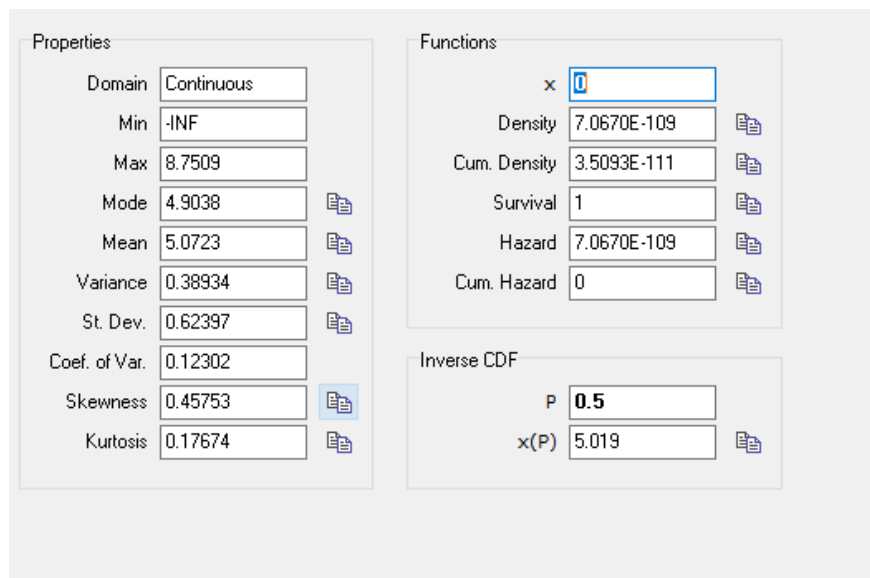


Figure 4.23 - Properties of distribution of 60 – 80 flow category

Figure 4.37 describes the property distribution gathered from the software. The mean value for the 60 – 80 flow category is 5.07s and the mode is 4.90s. 50% percentile value (median) is 5.02s.

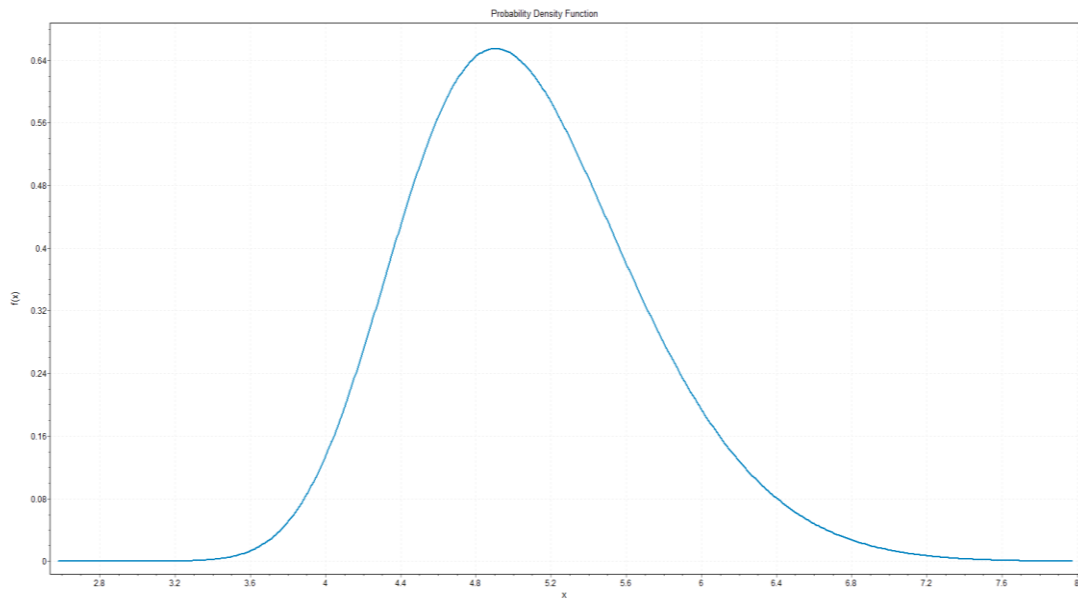


Figure 4.24 - Probability density function Curve for 60 – 80 flow category

The estimated parameters that were used to create the curve are shown below,

$$\zeta = -0.14432$$

$$\sigma = 0.56785$$

$$\mu = 4.8163$$

The probability density function can be identified using this curve and also from the equation stated down below.

Probability density function equation for Generalized Extreme Value distribution

$$\frac{1}{o} t(x)^{\xi+1} e^{-t(x)}$$

Where,

$$t(x) = \left\{ 1 + \xi \left(\frac{x - \mu}{o} \right) \right\}^{-1/\xi}$$

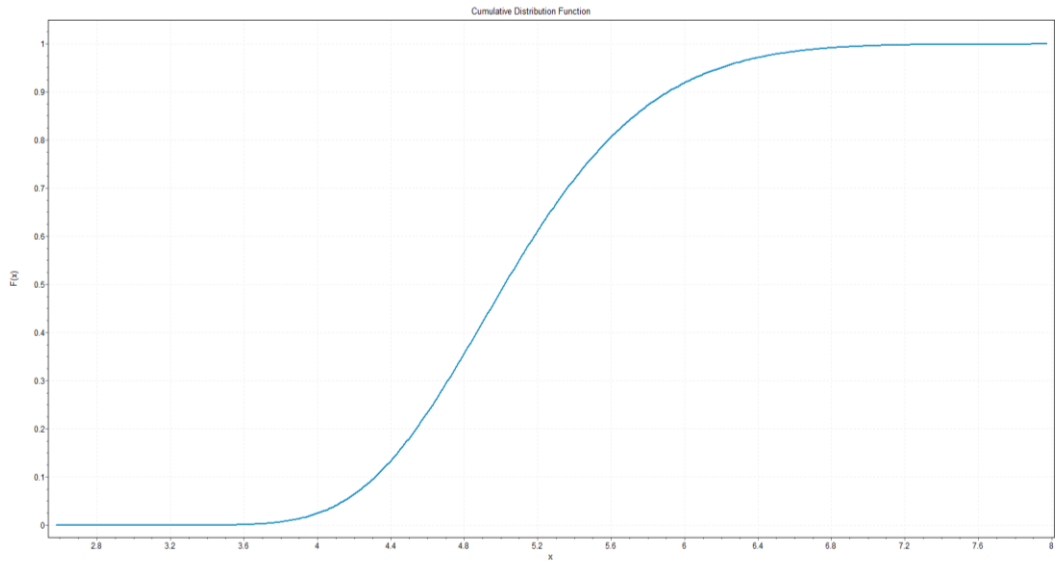


Figure 4.25 - Cumulative Density Function Curve for 60 – 80 flow category

The estimated parameters that were used to create the curve are shown below,

$$\zeta = -0.14432$$

$$\sigma = 0.56785$$

$$\mu = 4.8163$$

The cumulative density function can be identified using this curve and also from the equation stated down below.

The cumulative density function for Generalized Extreme Value distribution

$$e^{-t(x)}$$

4.5.4 80 – 100 Flow category

Table 4.11 - Results of K-S test for 80 – 100 flow category

Burr					
Kolmogorov- Smirnov					
Sample size	47				
Statistic	0.05844				
P-Value	0.99422				
Rank	1				
α	0.2	0.1	0.05	0.03	0.01
Critical Value	0.15295	0.17481	0.1942	0.21715	0.23298
Reject?	No	No	No	No	No

According to Figure 4.40, the selected distribution type is “Burr”. The symbol α is the significant value mentioned earlier as 0.05. According to 0.05, the relevant critical value is 0.1942. The statistic value mentioned(0.05844) is lesser than the critical value(0.1942). That’s the reason why the reject criteria have indicated ‘No’.

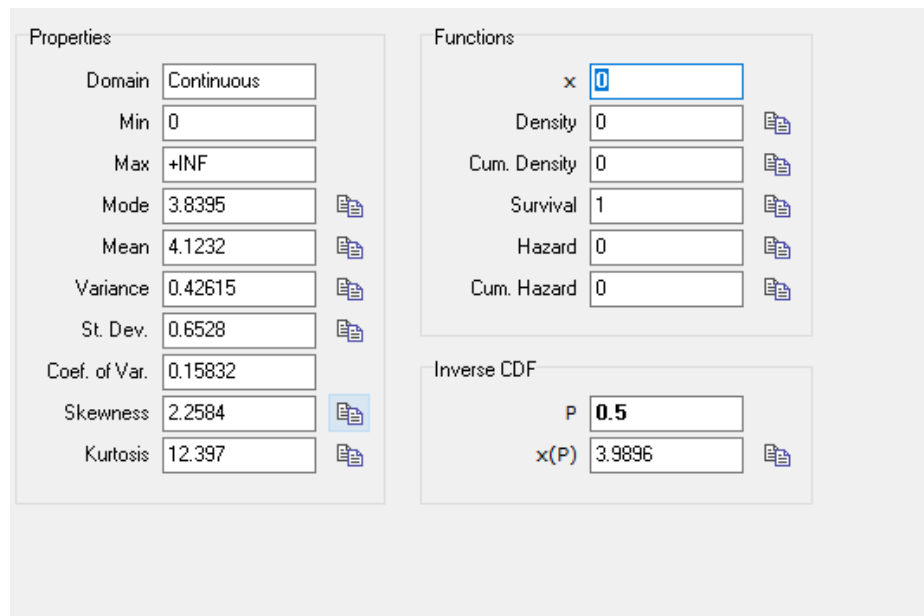


Figure 4.26 - Properties of distribution of 80 – 100 flow category

Figure 4.41 describes the property distribution gathered from the software. The mean value is 4.12s and the mode is 3.84s. 50% percentile value(median) is 3.99s.

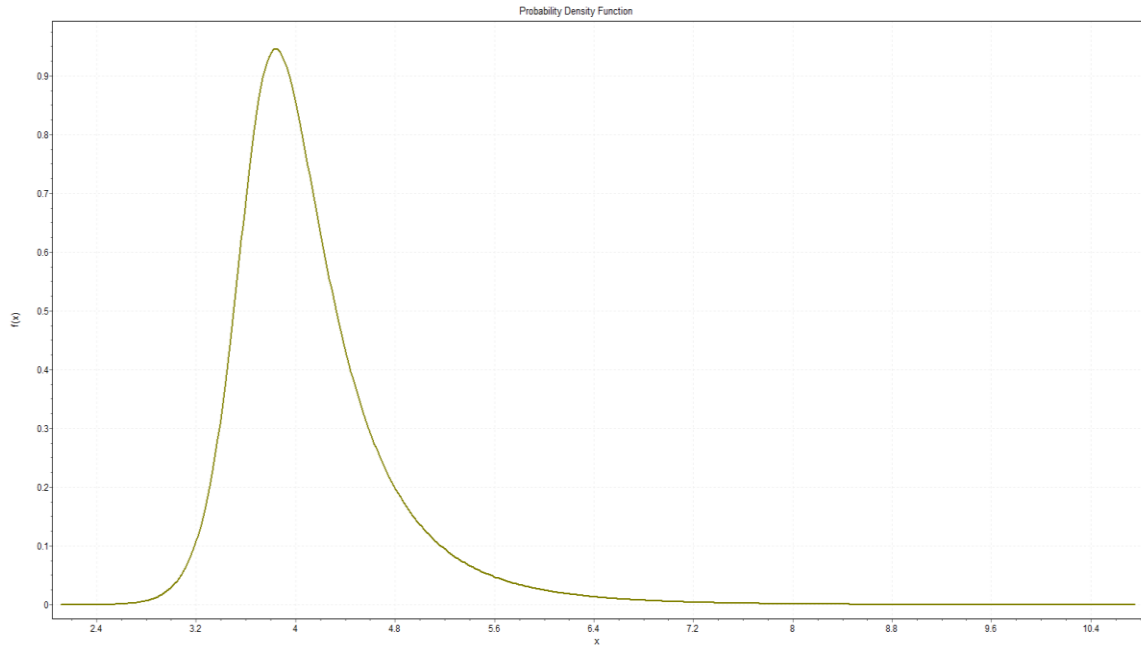


Figure 4.27 - Probability density function Curve for 80 – 100 flow category

The estimated parameters that were used to create the curve are shown below,

$$\lambda = 0.3868$$

$$c = 21.417$$

$$k = 3.7008$$

The probability density function can be identified using this curve and also from the equation stated for the Burr distribution.

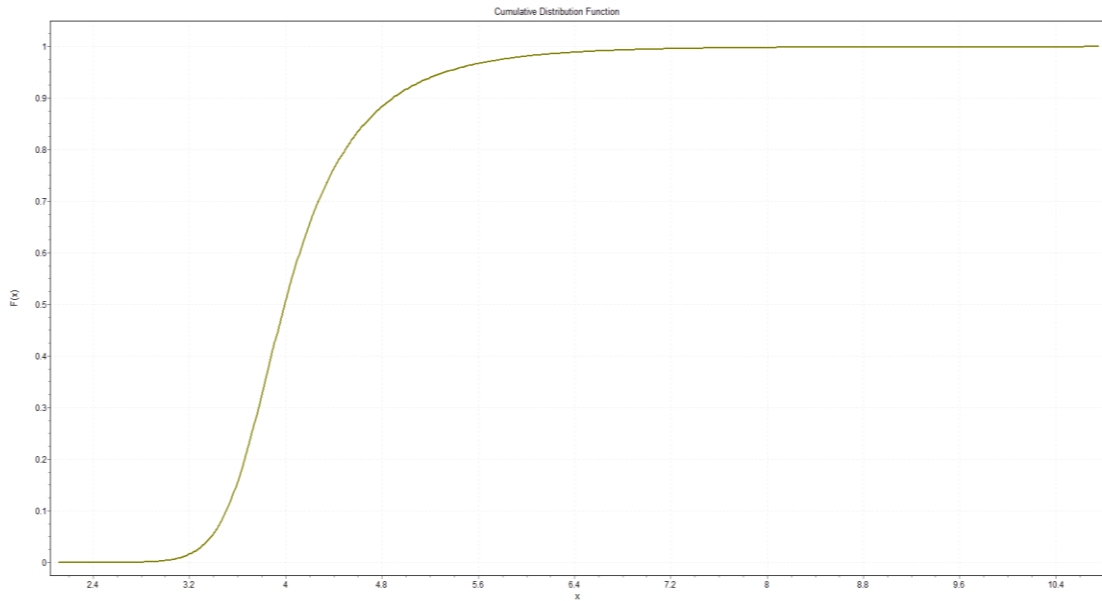


Figure 4.28 - Cumulative Density Function Curve for 80 – 100 flow category

The estimated parameters that were used to create the curve are shown below,

$$\lambda = 0.3868$$

$$c = 21.417$$

$$k = 3.7008$$

The cumulative density function can be identified using this curve and also from the equation stated for the Burr distribution.

4.5.5 100 – 120 Flow category

Table 4.12 - Results of K-S test for 100 – 120 flow category

Pert					
Kolmogorov- Smirnov					
Sample size	21				
Statistic	0.8006				
P-Value	0.99761				
Rank	1				
α	0.2	0.1	0.05	0.03	0.01

Critical Value	0.22617	0.25858	0.28724	0.32104	0.34427
Reject?	No	No	No	No	No

According to Figure 4.44, the selected distribution type is “Pert”. The symbol α is the significant value mentioned earlier as 0.05. According to 0.05, the relevant critical value is 0.28724. The statistic value mentioned(0.08006) is lesser than the critical value(0.28724). That’s the reason why the reject criteria have indicated ‘No’.

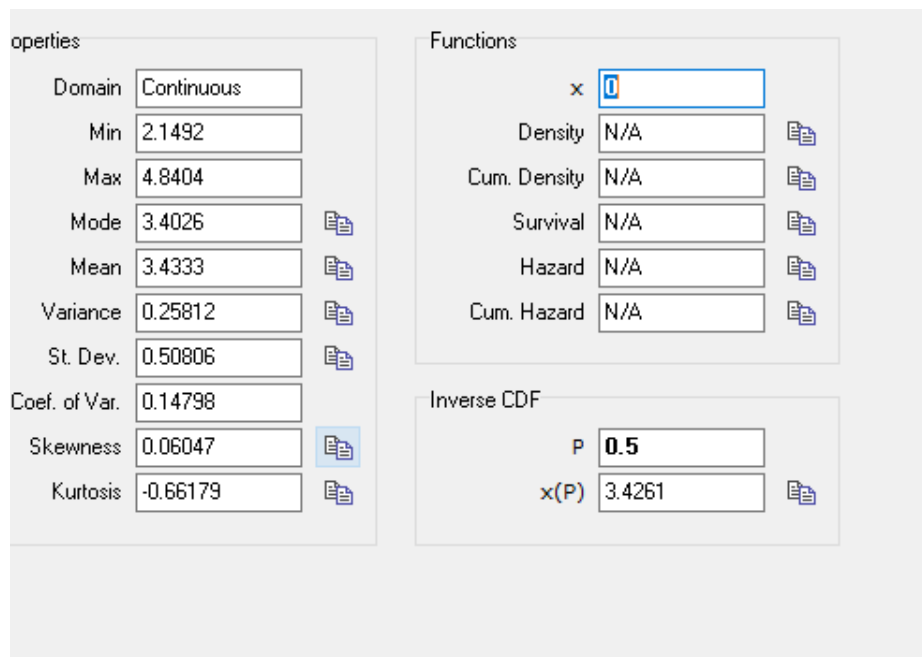


Figure 4.29 - Properties of distribution of 100 – 120 flow category

Figure 4.45 describes the property distribution gathered from the software. The mean is 3.43s and the mode is 3.40s. 50% percentile value(median) is 3.43s.

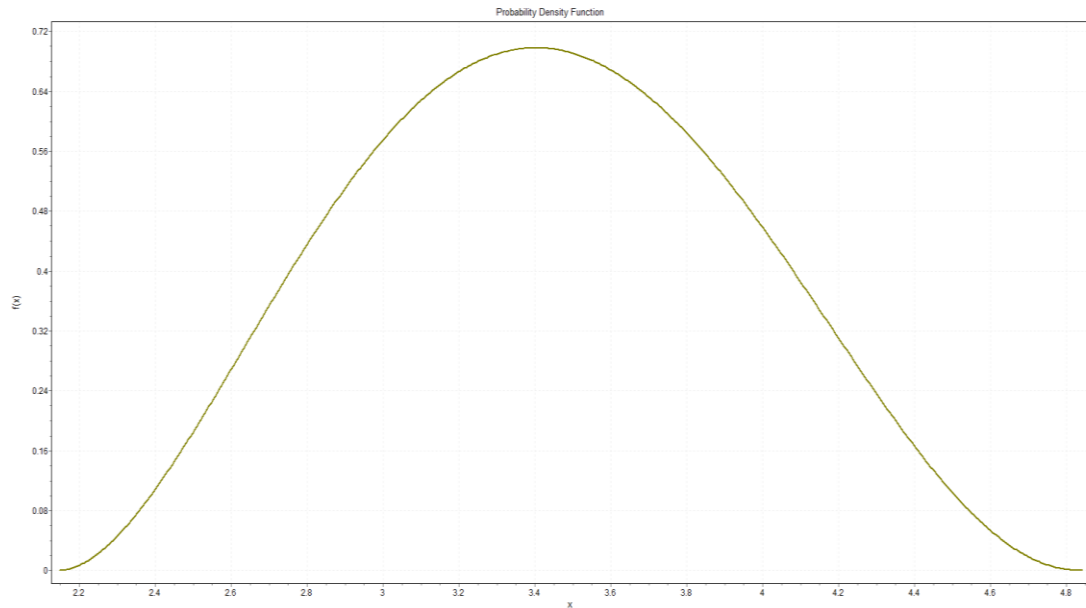


Figure 4.30 - Probability density function Curve for 100 – 120 flow category

The estimated parameters that were used to create the curve are shown below,

$$a = 2.1492$$

$$b = 4.8404$$

$$c = 3.4026$$

The probability density function can be identified using this curve and also from the equation stated down below.

Probability density function equation for Pert distribution

$$\frac{(x - a)^{\alpha-1}(c - x)^{\beta-1}}{B(\alpha, \beta)(c - a)^{\alpha+\beta-1}} \text{ where}$$

$$\alpha = \frac{4b + c - 5a}{c - a} = 1 + 4 \frac{b - a}{c - a}$$

$$\beta = \frac{5c - a - 4b}{c - a} = 1 + 4 \frac{c - b}{c - a}$$

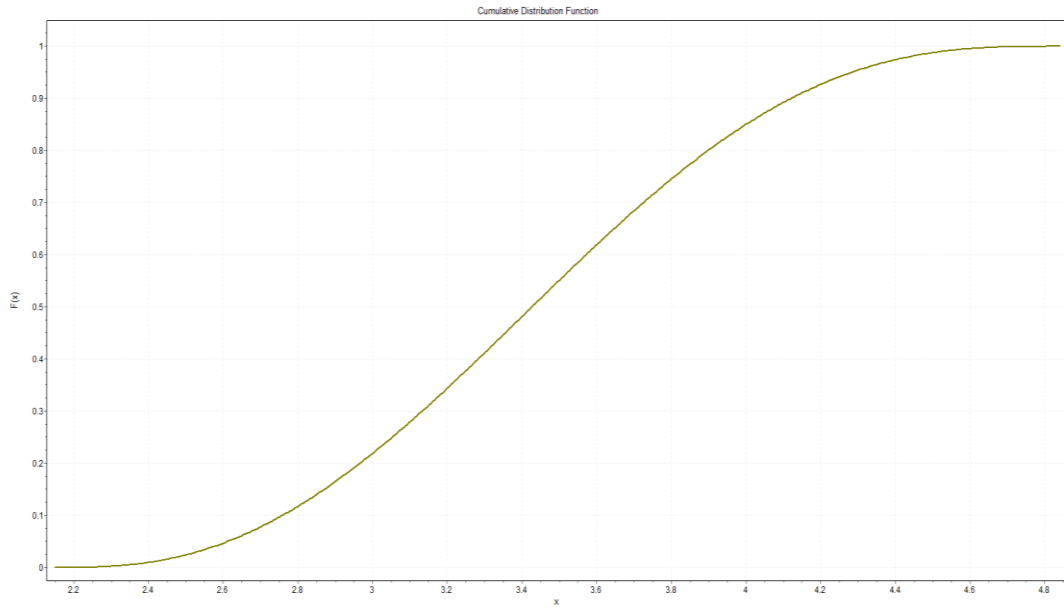


Figure 4.31 - Cumulative Density Function Curve for 100 – 120 flow category

The estimated parameters that were used to create the curve are shown below,

$$a = 2.1492$$

$$b = 4.8404$$

$$c = 3.4026$$

The cumulative density function can be identified using this curve and also from the equation stated down below.

The cumulative density function for Pert distribution

$$z = \frac{x - a}{c - a}$$

Therefore, the results are summarized below.

Table 4.13 – Properties of flow categories

Flow Category	Most suitable distribution	Mean	Mode	Median
20 – 40	Dagum	8.87 s	10.48 s	9.30 s
40 – 60	Frechet	6.32 s	5.87 s	6.14 s
60 – 80	Generalized Extreme Value	5.07 s	4.93 s	5.02 s
80 – 100	Burr	4.12 s	3.04 s	3.99 s
100 - 120	Pert	3.43 s	3.40 s	3.43 s

4.6 Headway distribution for different vehicle pairs

Previous studies are shown that the time headway distribution varies with the different vehicle pairs. Therefore, it is better to study this concept for Sri Lankan conditions as well. As mentioned earlier, there are 8 vehicle categories. Therefore, a total 64 of vehicle pair combinations are available. But all type of combinations was not considerably available in the database. Hence, vehicle categories were combined, and 8 categories were minimized to 5 types as below.

- Car - Car, Van
- Cab – Cab and Small Lorry
- Bus – Medium Bus & Large Bus
- Medium Lorry
- Large Lorry

Total combinations were minimized from 64 to 25. Although it was divided into 5 categories, it is better to check whether there are considerable similarities within different categories. If there is considerable similarity, then it can be combined and considered as the same vehicle pair category. To check the similarity, there are various test methods. Some of them are parametric tests and some are non-parametric tests. Hence firstly it is required to identify whether the data set is parametric or non-parametric as mentioned earlier. The significance level was considered as 0.05.

Table 4.14 - No. of data points for vehicle pairs

Vehicle Pair	No. of data points
CAR-CAR	249
CAR-BUS	27
CAR-CAB	234
CAR-M.Lorry	40
CAR-L.Lorry	147
CAB-CAB	94
CAB-CAR	234
CAB-BUS	5
CAB-M.Lorry	6
CAB-L.Lorry	42
BUS-BUS	1
BUS-CAR	30
BUS-CAB	4
BUS-M.Lorry	0
BUS-L.Lorry	1
M.Lorry-M.Lorry	0
M.Lorry-CAR	28
M.Lorry-CAB	5
M.Lorry-BUS	1
M.Lorry-L.Lorry	1
L.Lorry-L.Lorry	21
L.Lorry-CAR	140
L.Lorry-M.Lorry	2
L.Lorry-BUS	1
L.Lorry-CAB	31

Although 25 combinations were considered at the previous stage there were not a considerable amount of data points for all types of categories. Therefore, if there were more than 20 data points, only those were considered for analysis. Hence only

- Car-Car
- Car-Bus
- Car-Cab
- Car-M.Lorry
- Car-L.Lorry
- Cab-Cab
- Cab-Car
- Cab-L.Lorry
- Bus-Car
- M.Lorry-Car
- L.Lorry-L.Lorry
- L.Lorry-Car
- L.Lorry-Cab

vehicles pairs were considered for the analysis.

Randomness was tested using the “Runs test” and Normality was tested using the “Normality test”. Both tests were done using SPSS software. The significance level was considered as 0.05.

4.6.1 Randomness Test

Runs test was used to check the randomness of the data set.

Table 4.15 - Runs test results for different vehicle pairings

Vehicle category	Test Value	Cases test value	Cases test value	Total cases	No of runs	Z	Asymp.Sig
Car_Car	5.09	124	125	249	74	-6.540	0.000
Car-Bus	4.28	13	14	27	16	0.400	0.689
Car-Cab	5.21	117	117	234	109	-1.179	0.238
Car_M.lorry	4.40	18	22	40	19	-0.421	0.674

Car_L.lorry	4.64	72	75	147	68	-1.071	0.284
Cab_Cab	5.02	47	47	94	44	-0.830	0.407
Cab_Car	4.96	116	118	234	103	-1.964	0.049
Cab_L.lorry	4.42	21	21	42	22	0.000	1.000
Bus_Car	4.29	15	15	30	11	-1.672	0.094
M.lorry_Car	4.20	14	14	28	17	0.578	
L.lorry_L.lorry	4.04	10	11	21	13	0.460	
L.lorry_Car	4.64	70	70	140	65	-1.018	
L.lorry_Cab	6.28	15	16	31	13	-1.091	

If Asymp.Sig values are lesser than 0.05 then the randomness is rejected and if asymp.sig values are higher than 0.05 then the randomness is failed to reject. According to the gained results Car-Car and Cab-Car are smaller than 0.05. Hence, this is considered rejected. The rest of the values are considered as failed to reject.

4.6.2 Normality Test

Table 4.16 - Normality test results obtained for different vehicle pairs

Vehicle category	Kolmogorov - Smirnov			Shapiro - Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Bus_Car	0.143	30	0.118	0.925	30	0.036
Cab_Cab	0.156	94	0.000	0.881	94	0.000
Cab_Car	0.159	234	0.000	0.766	234	0.000
Cab_L.lo	0.214	42	0.000	0.790	42	0.000
Car_Bus	0.134	27	0.200	0.875	27	0.004
Car_Cab	0.092	234	0.000	0.911	234	0.000
Car_Car	0.143	249	0.000	0.769	249	0.000
Car_L.lo	0.136	147	0.000	0.798	147	0.000
Car_M.Lo	0.154	40	0.17	0.904	40	0.002
L.lorry_	0.118	192	0.000	0.891	192	0.000
M.Lorry	0.202	28	0.005	0.788	28	0.000

The test of normality can be checked by two tests Kolmogorov-Smirnov and Shapiro-Wilk. The chosen test for the study is Kolmogorov-Smirnov(as mentioned earlier). If Sig. values are lesser than 0.05 then the normality is rejected and if Sig. values are higher than 0.05 then the normality is failed to reject. According to the gained results Cab-Cab, Cab-

Car, Cab-Large Lorry, Car-Cab, Car-Car, Car-Large Lorry and Large Lorry are smaller than 0.05. Hence, this is considered rejected. The rest of the values are considered as failed to reject.

4.6.3 Vehicle Category Cab-Large Lorry

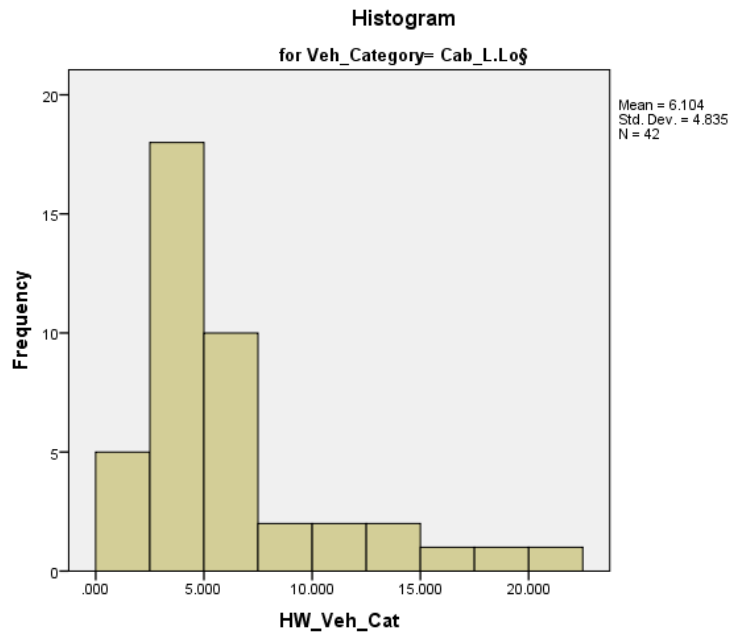


Figure 4.32 - Histogram of vehicle category Cab-Large lorry

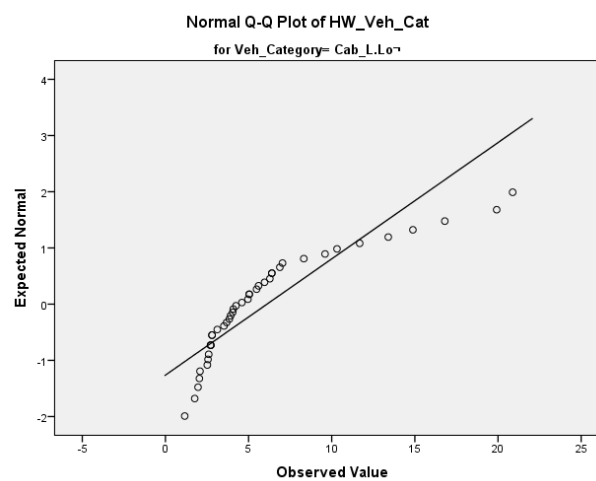


Figure 4.33 - Normal Q-Q plot of Vehicle category Cab-Large Lorry

4.6.4 Vehicle Category Cab-Car

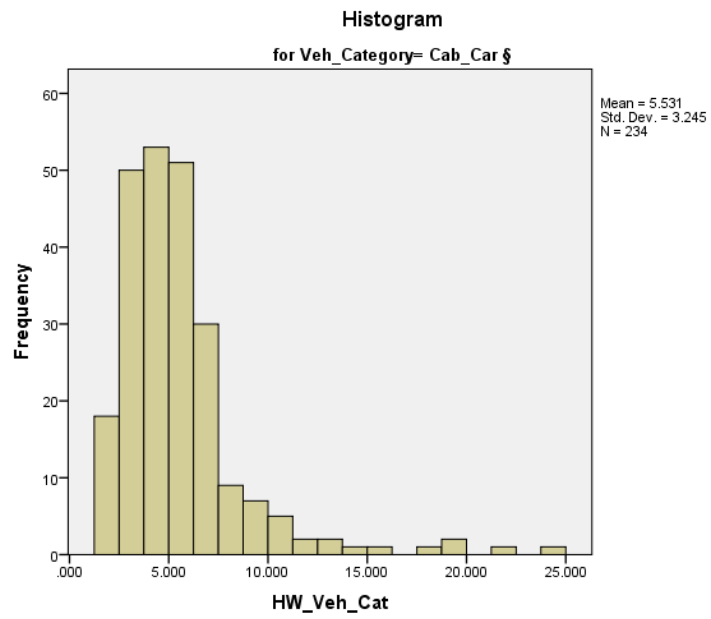


Figure 4.34 - Histogram of vehicle category Cab-Car

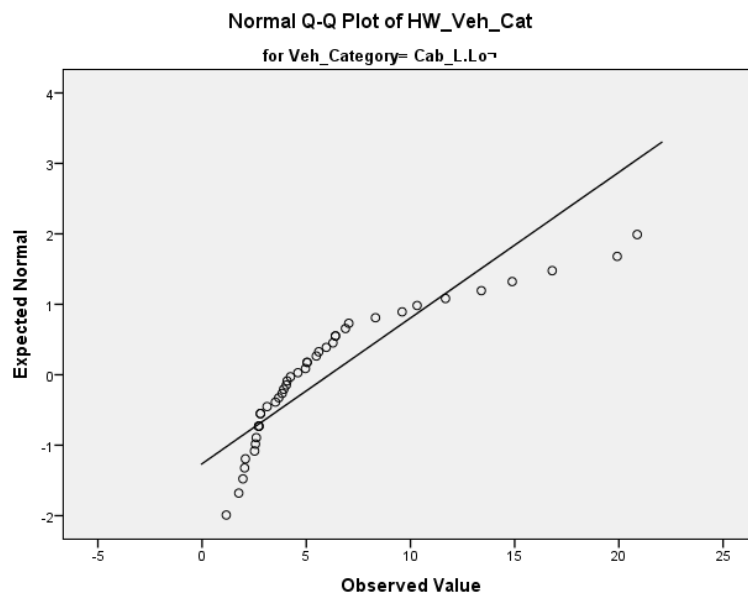


Figure 4.35 - Normal Q-Q plot of Vehicle category Cab-Car

4.6.5 Vehicle Category Cab-Cab

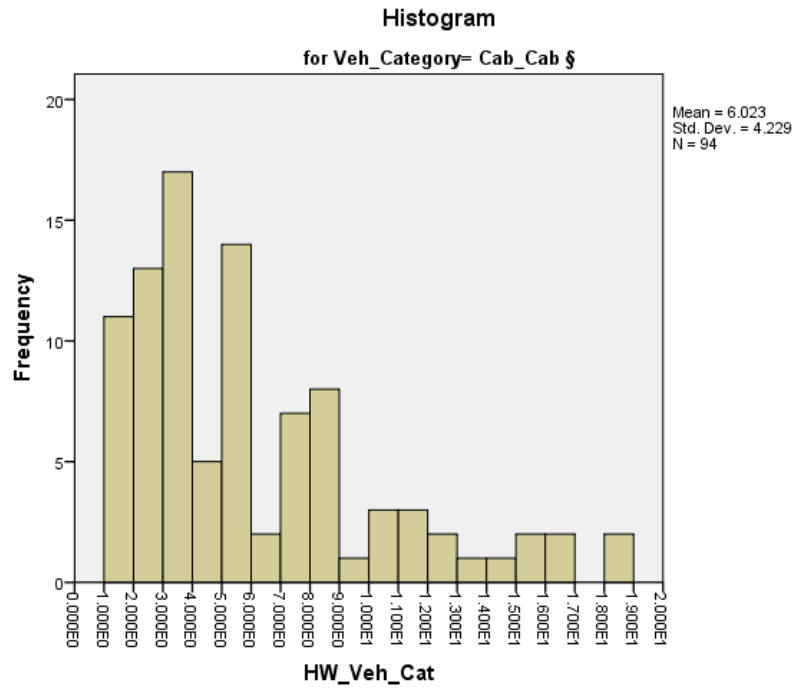


Figure 4.36 - Histogram of vehicle category Cab-Cab

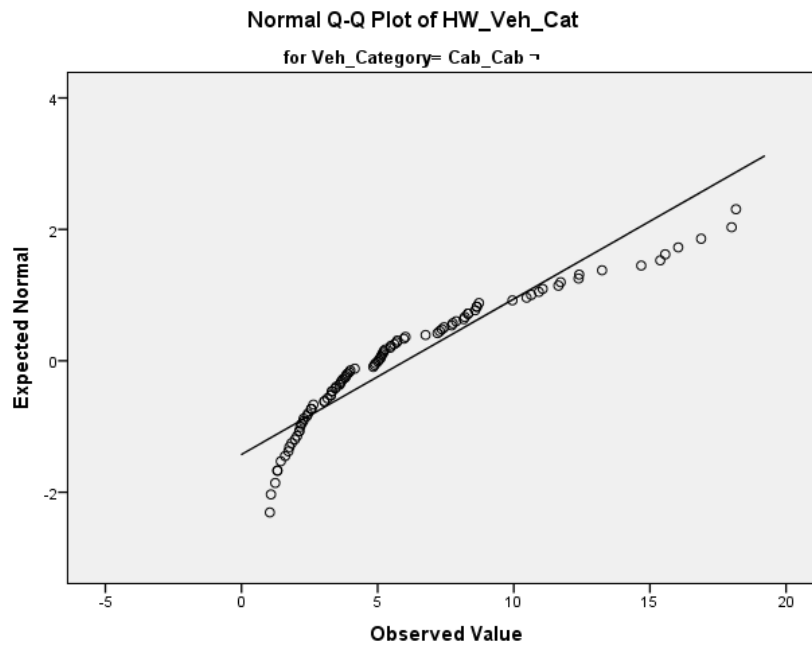


Figure 4.37 - Normal Q-Q plot of Vehicle category Cab-Cab

4.6.6 Vehicle Category Bus-Car

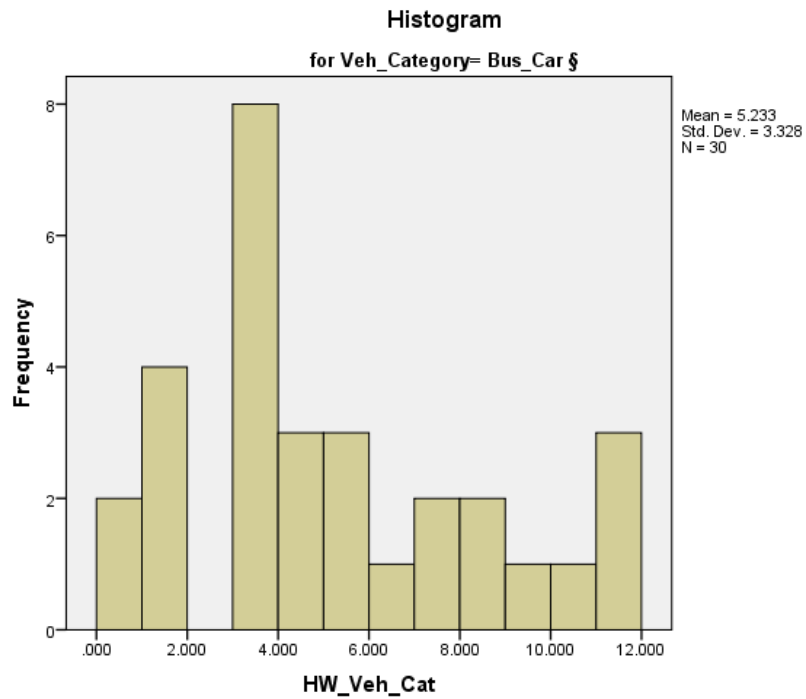


Figure 4.38 - Histogram of vehicle category Bus-Car

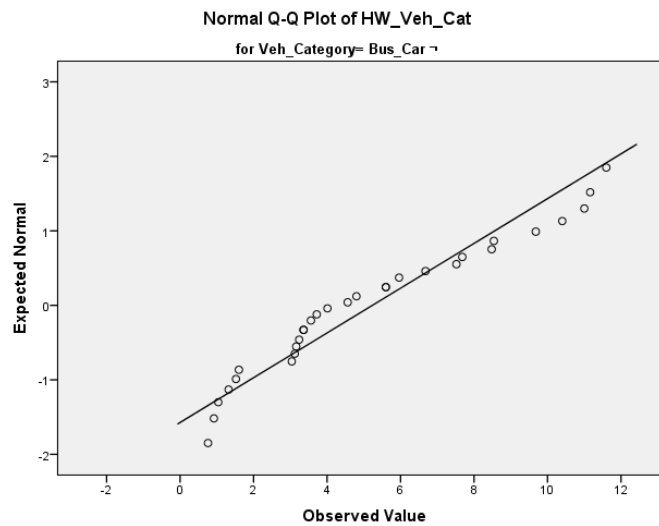


Figure 4.39 - Normal Q-Q plot of Vehicle category Bus-Car

4.6.7 Vehicle Category Car-Bus

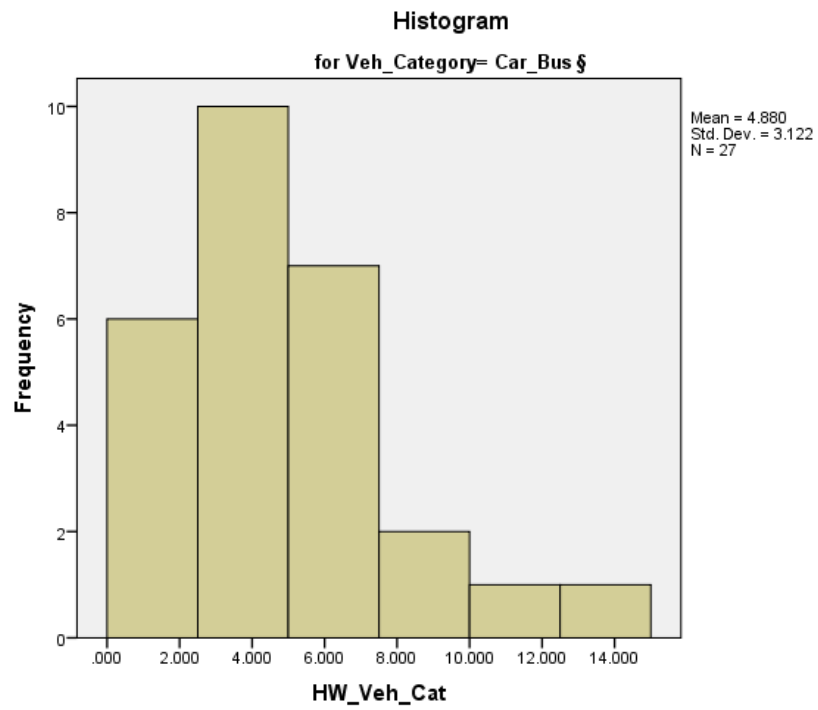


Figure 4.40 - Histogram of vehicle category Car-Bus

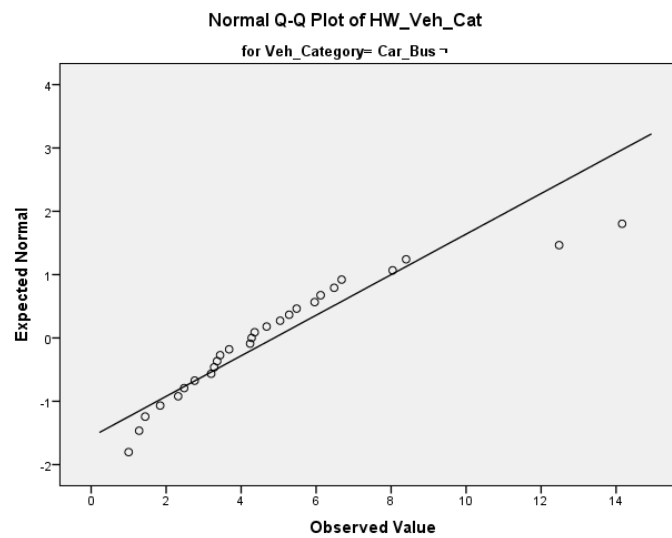


Figure 4.41 - Normal Q-Q plot of Vehicle category Car-Bus

4.6.8 Vehicle Category Car-Cab

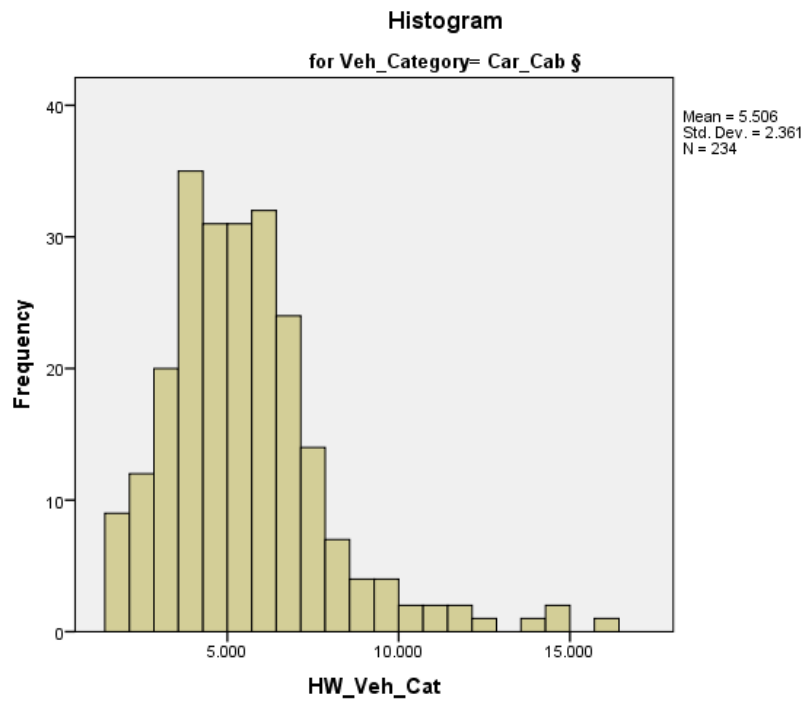


Figure 4.42 - Histogram of vehicle category Car-Cab

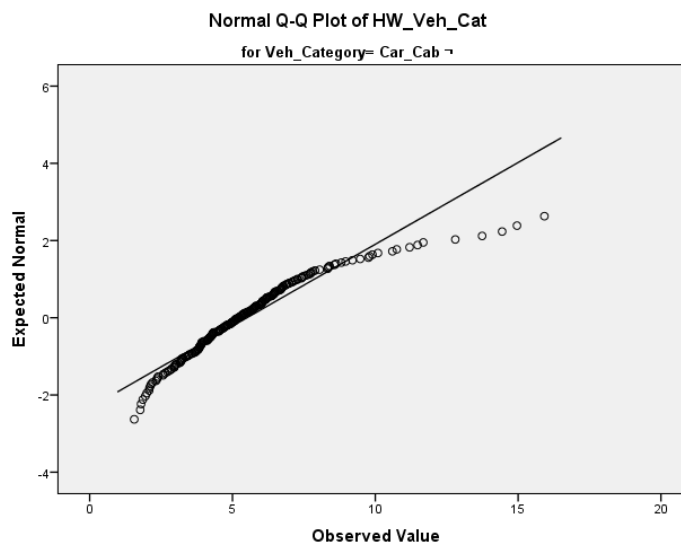


Figure 4.43 - Normal Q-Q plot of Vehicle category Car-Cab

4.6.9 Vehicle Category Car-Car

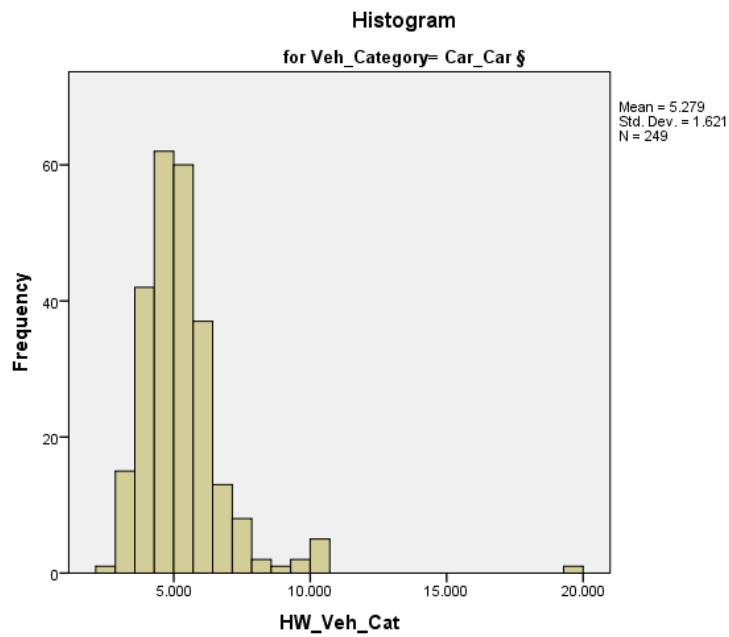


Figure 4.44 - Histogram of vehicle category Car-Car

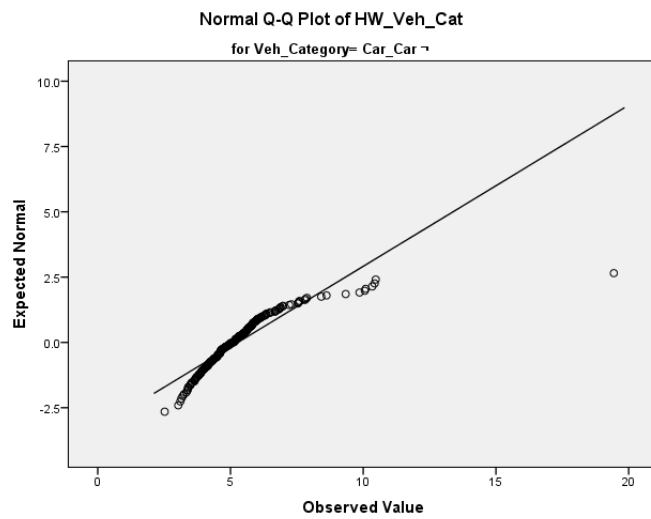


Figure 4.45 - Normal Q-Q plot of Vehicle category Car-Car

4.6.10 Vehicle Category Car-Medium Lorry

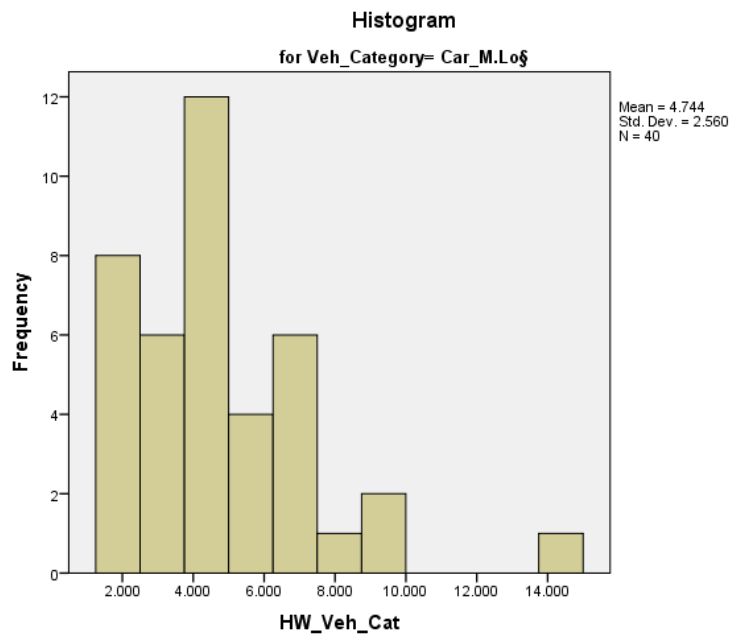


Figure 4.46 - Histogram of vehicle category Car-Medium Lorry

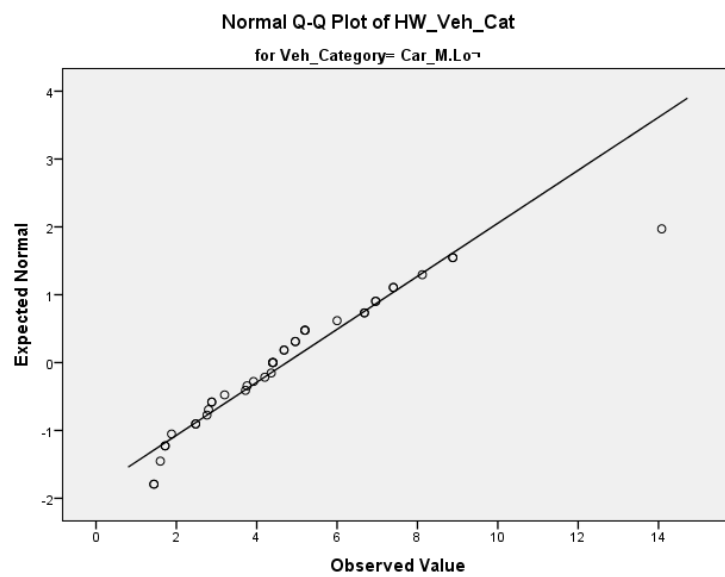


Figure 4.47 - Normal Q-Q plot of Vehicle category Car-Medium Lorry

4.6.11 Vehicle Category Car-Large Lorry

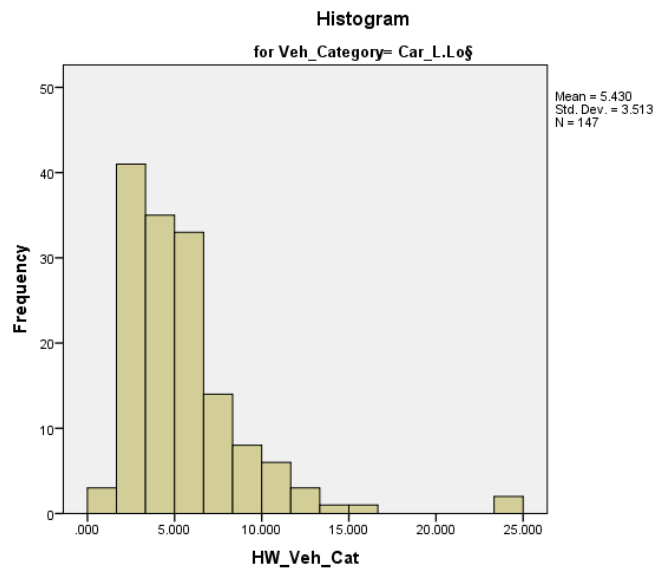


Figure 4.48 - Histogram of vehicle category Car-Large Lorry

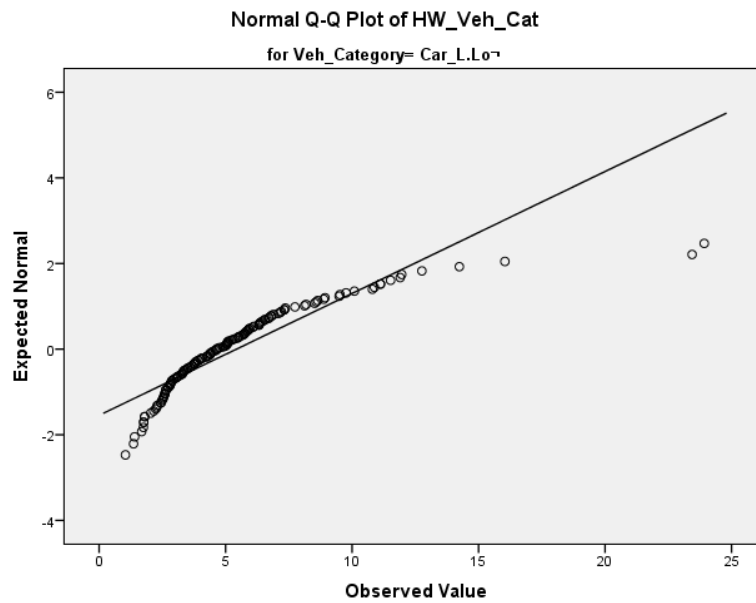


Figure 4.49 - Normal Q-Q plot of Vehicle category Car-Large Lorry

4.6.12 Vehicle Category Large Lorry

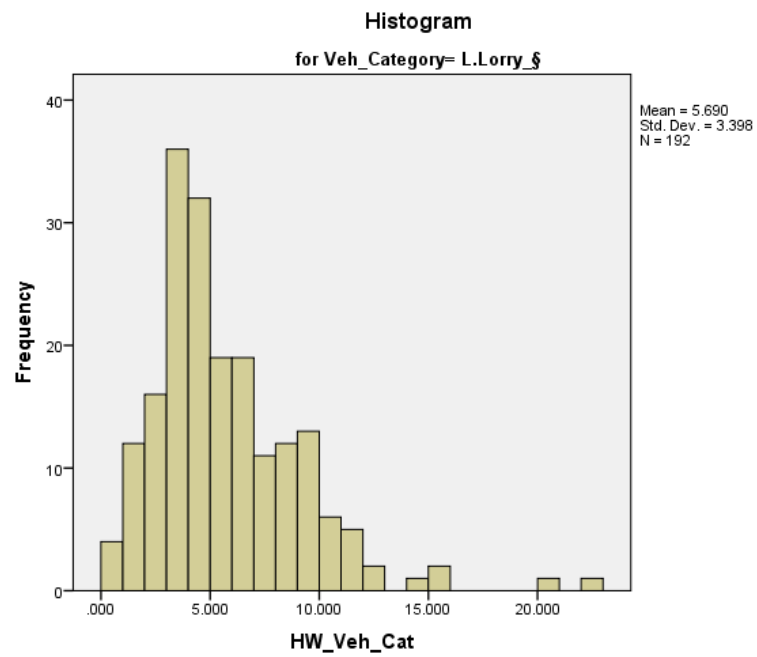


Figure 4.50 - Histogram of vehicle category Large Lorry

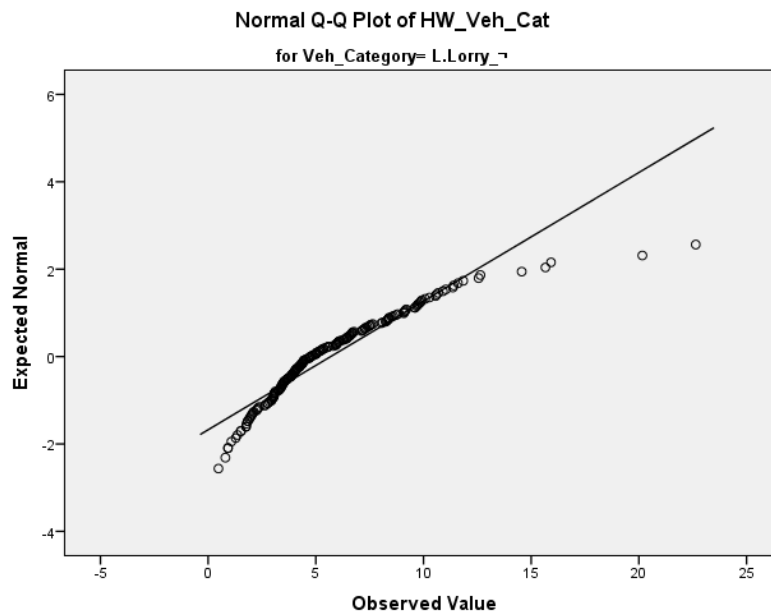


Figure 4.51 - Normal Q-Q plot of Vehicle category Large Lorry

4.6.13 Vehicle Category Medium Lorry

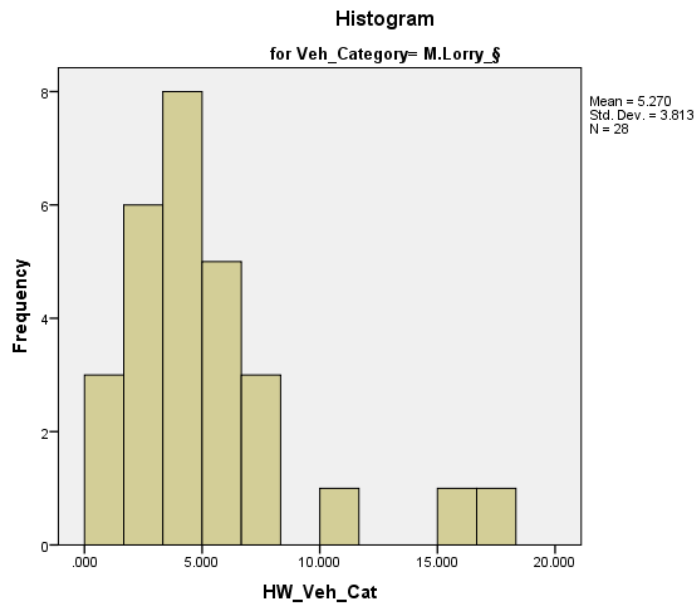


Figure 4.52 - Histogram of vehicle category Medium Lorry

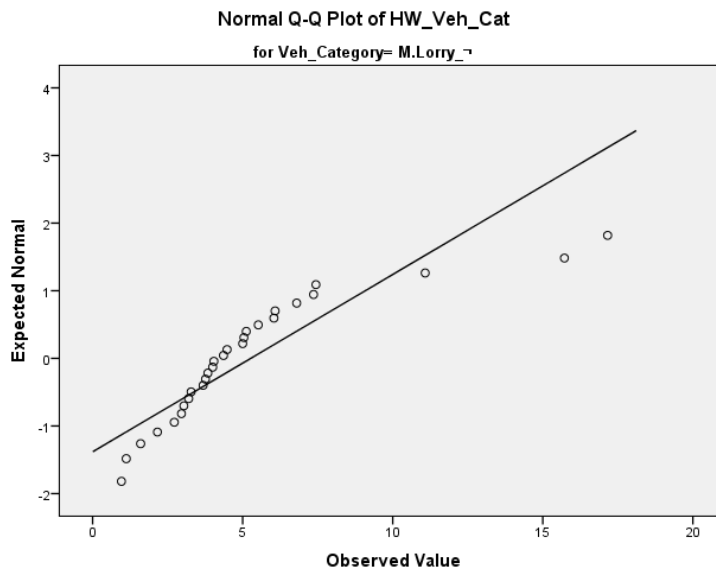


Figure 4.53 - Normal Q-Q plot of Vehicle category Medium Lorry

Then checked the similarities between different flow categories. As mentioned earlier parametric and non-parametric tests were used.

Table 4.17 – Parametric state according to the vehicle pair category

Vehicle category	Randomness test results	Normality test results	Parametric/Non-parametric
Car-Car	0.000	0.000	Parametric
Car-Bus	0.689	0.200	Non-parametric
Car-Cab	0.238	0.000	Non-parametric
Car-M.Lorry	0.674	0.017	Non-parametric
Car-L.Lorry	0.284	0.000	Non - Parametric
Cab-Cab	0.407	0.000	Non - Parametric
Cab-Car	0.049	0.000	Parametric
Cab-L.Lorry	1.000	0.000	Non - Parametric
Bus-Car	0.094	0.118	Non - Parametric
M.Lorry-Car	0.563	0.005	Non - Parametric
L.Lorry-L.Lorry	0.646	0.000	Non - Parametric
L.Lorry-Car	0.309	0.000	Non - Parametric
L.Lorry-Cab	0.275	0.000	Non - Parametric

To check the similarity of the Parametric flow category the used test was one-way ANOVA and for Non-parametric, the Kruskal-Wallis test is used.

4.7 Test results of the One-way ANOVA test

Table 4.18 - Test results of One-way ANOVA test

	Sum of squares	df	Mean square	F	Sig
Between groups	1.771	1	1.771	0.169	0.682
Within groups	574.749	55	10.450		
Total	576.519	56			

If the Sig. value is lesser than 0.05 then both groups cannot be combined, and if the Sig. value is higher than 0.05 then both groups can be combined. In the table the Sig. value is 0.682, it is greater than 0.05. Hence the groups that are considered(Car-Bus & Bus-Car) can be combined.

4.8 Test results of Kruskal – Walli’s test

Pairwise Comparisons of Veh_Category

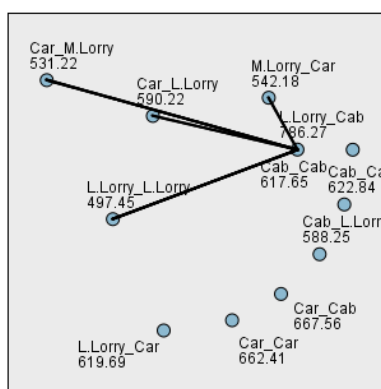


Figure 4.54 – Test results for Kruskal Wallis

Table 4.19 - Test results for Kruskal Wallis

Category	Test statistic	Std. error	Std test statistic	Sig.	Adj.Sig
L.Lorry_L.lorry – Car_M.lorry	33.773	98.056	0.344	0.731	1.000
L.lorry_L.lorry – M.lorry_Car	-44.726	105.041	0.426	0.670	1.000
L.lorry_L.lorry-Cab_L.lorry	90.798	97.249	0.934	0.350	1.000
L.lorry_ L.lorry-Car_ L.lorry	92.772	84.886	1.093	0.274	1.000
L.lorry_ L.lorry-Cab_Cab	120.197	87.826	1.369	0.171	1.000
L.lorry_ L.lorry- L.lorry_Car	122.233	85.151	1.435	0.151	1.000
L.lorry_ L.lorry-Cab_Car	125.387	82.890	1.513	0.130	1.000
L.lorry_ L.lorry-Car_Car	164.957	82.684	1.995	0.046	1.000
L.lorry_ L.lorry-Car_Cab	170.112	82.890	2.052	0.40	1.000
L.lorry_ L.lorry- L.lorry_Cab	288.822	102.840	2.808	0.005	1.000

Car_M.lorry_-M.lorry_Car	-10.954	89.659	-0.122	0.903	1.000
Car_M.lorry_-Cab_L.lorry	57.025	80.390	0.709	0.478	1.000
Car_M.lorry_-Car_L.lorry	58.999	64.891	0.909	0.363	1.000
Car_M.lorry_-Cab_Cab	86.424	8.692	1.258	0.208	1.000
Car_M.lorry_-L.lorry_Car	-88.461	65.237	-1.356	0.175	1.000
Car_M.lorry_-Cab_Car	91.615	62.257	1.472	0.141	1.000
Car_M.lorry_-Car_Car	131.185	61.983	2.116	0.034	1.000
Car_M.lorry_-Car_Cab	136.339	62.257	2.190	0.029	1.000
Car_M.lorry_-L.lorry_Cab	-255.049	87.070	-2.929	0.003	0.224
M.lorry_Car_Car-Cab_L.lorry	46.071	88.776	0.519	0.604	1.000
M.lorry_Car-Car_L.lorry	48.046	75.029	0.640	0.522	1.000
M.lorry_Car-Cab_Cab	75.470	78.341	0.963	0.335	1.000
M.lorry_Car-L.lorry_Car	77.507	75.329	1.029	0.304	1.000
M.lorry_Car-Cab_Car	80.661	72.764	1.109	0.268	1.000
M.lorry_Car-Car_Car	120.231	72.529	1.658	0.097	1.000
M.lorry_Car – Car_Cab	125.386	72.764	1.723	0.085	1.000
M.lorry_Car –L.lorry_Cab	244.096	94.867	2.573	0.010	0.665
Cab_L.lorry-Car_L.lorry	-1.974	63.665	-0.031	0.975	1.000
Cab_L.lorry-Cab_Cab	29.399	67.535	0.435	0.663	1.000
Cab_L.lorry-L.lorry_Car	-31.436	64.017	-0.491	0.623	1.000
Cab_L.lorry-Cab_Car	34.590	60.978	0.567	0.571	1.000
Cab_L.lorry-Car_Car	-74.160	60.698	-1.222	0.222	1.000
Cab_L.lorry-Car_Cab	-79.314	60.978	-1.301	0.193	1.000
Cab_L.lorry-L.lorry_Cab	-198.024	86.160	-2.298	0.022	1.000
Car_L.lorry-Cab_Cab	27.424	48.055	0.571	0.568	1.000
Car_L.lorry-L.lorry_Car	-29.461	42.970	-0.686	0.493	1.000
Car_L.lorry-Cab_Car	32.615	38.295	0.852	0.394	1.000
Car_L.lorry-Car_Cab	72.185	37.848	1.907	0.056	1.000
Car_L.lorry-L.lorry_Cab	77.340	38.295	2.020	0.043	0.423
Cab_Cab-L.lorry_Car	-196.050	71.915	-2.726	0.006	1.000
Cab_Cab-Cab_Car	-2.037	48.521	-0.042	0.967	1.000
Cab_Cab-Car_Car	-5.191	44.434	-0.117	0.907	1.000

Cab_Cab-Car_Cab	-44.761	44.049	-1.016	0.310	1.000
Cab_Cab-L.lorry_Cab	-168.625	75.363	-2.237	0.025	1.000
L.lorry_Car-Cab_Car	3.154	38.879	0.081	0.935	1.000
L.lorry_Car-Car_Car	42.724	38.438	1.112	0.266	1.000
L.lorry_Car-Car_Cab	47.878	38.879	1.231	0.218	1.000
L.lorry_Car-L.lorry_Cab	166.588	72.228	2.306	0.021	1.000
Cab_Car-Car_Car	-39.570	33.130	-1.194	0.232	1.000
Cab_Car-Car_Cab	-44.724	33.640	-1.329	0.184	1.000
Cab_Car-L.lorry_Cab	-163.434	69.548	-2.350	0.019	1.000
Car_L.lorry-L.lorry_Car	-29.461	42.970	-0.686	0.493	1.000
Car_L.lorry-Cab_Car	32.615	38.295	0.852	0.394	1.000
Car_L.lorry-Car_Car	72.185	37.848	7.907	0.056	1.000
Car_L.lorry-Car_Cab	77.340	38.295	2.020	0.043	1.000
Car_L.lorry-L.lorry_Cab	-196.050	71.915	-2.726	0.006	0.423
Cab_Cab – L.lorry_Car	-2.037	48.521	-0.042	0.967	1.000
Cab_Cab -Cab_Car	-5.191	44.434	-0.117	0.907	1.000
Cab_Cab-Car_Car	-44.761	44.049	-1.016	0.310	1.000
Cab_Cab -Car_Cab	-49.915	44.434	-1.123	0.261	1.000
Cab_Cab -L.lorry_Cab	-168.625	75.363	-2.237	0.025	1.000
L.lorry_Car-Cab_Car	3.154	38.879	0.081	0.935	1.000
L.lorry_Car-Car_Car	42.724	38.438	1.112	0.266	1.000
L.lorry_Car-Car_Cab	47.878	38.879	1.231	0.218	1.000
L.lorry_Car-L.lorry_Cab	166.588	72.228	2.306	0.021	1.000
Cab_Car-Car_Car	-39.570	33.130	-1.194	0.232	1.000
Cab_Car-Car_Cab	-44.724	33.640	-1.329	0.184	1.000
Cab_Car-L.lorry_Cab	-163.3-434	69.548	-2.350	0.019	1.000
Car_Car-Car_Cab	5.154	33.130	0.156	0.876	1.000
Car_Car-L.lorry_Cab	-123.865	69.302	-1.787	0.074	1.000
Car_Cab-L.lorry_Cab	-118.710	69.548	-1.707	0.088	1.000

If the Adj. Sig. value is lesser than 0.05 then the considering two groups cannot be combined, and if the Adj. Sig. value is higher than 0.05 then the considering two groups

can be combined. In the table most of the Adj.Sig. values are 1.00, which is greater than 0.05. Hence all the groups that are considered(L.Lorry – L. Lorry & Car-M.Lorry, L.Lorry – L.Lorry & M.Lorry-Car, L.Lorry – L.Lorry & Cab-L.Lorry, L.Lorry – L.Lorry & Car-L.Lorry, L.Lorry – L.Lorry & Cab-Cab, L.Lorry – L.Lorry & L.Lorry-Car, L.Lorry – L.Lorry & Cab-Car, L.Lorry – L.Lorry & Car-Car, L.Lorry – L.Lorry & Car-Cab, Car – M.Lorry & M.Lorry-Car, etc.) can be combined.

According to the test results of the one-way ANOVA test and Kruskal Wallis tests all the Sig and Adj. Sig values are greater than 0.05. Hence the groups can be combined. So, considering groups separately is not necessary. Therefore Car-Bus & Bus-Car is considered as group “A” and the rest of the groups are considered as another group as “B”. Using Easy-fit software, based on K-S test the distributions are ranked to each flow category separately.

4.8.1 Car-Bus & Bus-Car vehicle pair category(A)

Table 4.20 - Results of K-S test for Car-Bus & Bus-Car vehicle pair category(A)

Dagum					
Kolmogorov- Smirnov					
Sample size	57				
Statistic	0.06606				
P-Value	0.95072				
Rank	1				
α	0.2	0.1	0.05	0.03	0.01
Critical Value	0.13919	0.15906	0.17669	0.19758	0.21199
Reject?	No	No	No	No	No

According to Figure 4.71, the selected distribution type is “Dagum”. The symbol α is the significant value mentioned earlier as 0.05. According to 0.05, the relevant critical value

is 0.17669. The Statistic value mentioned(0.06606) is lesser than the critical value(0.17669). That's the reason why the reject criteria have indicated 'No'.

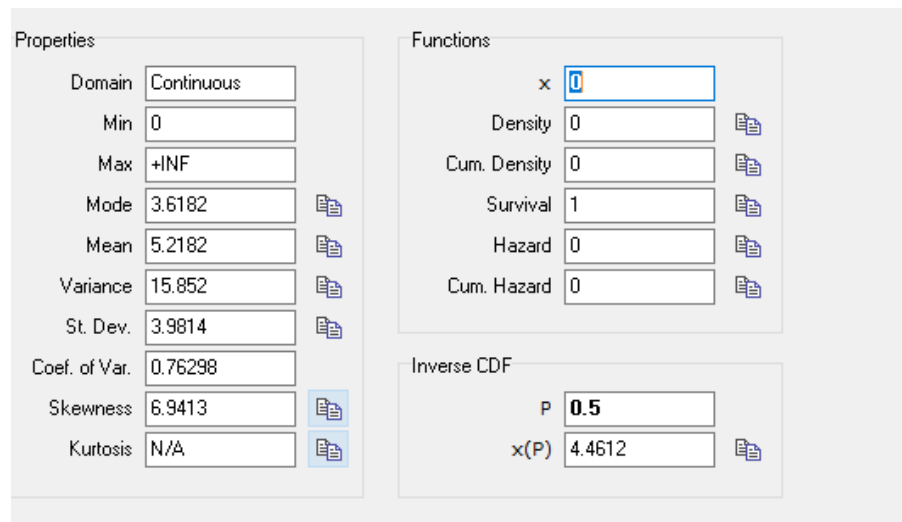


Figure 4.55 - Properties of distribution of Car-Bus & Bus-Car vehicle pair category(A)

Figure 4.72 describes the property distribution gathered from the software. The mean for the Car-Cab & Cab-Car vehicle pair category is 5.22s and the mode is 3.62s. 50% percentile value(median) is 4.46s.

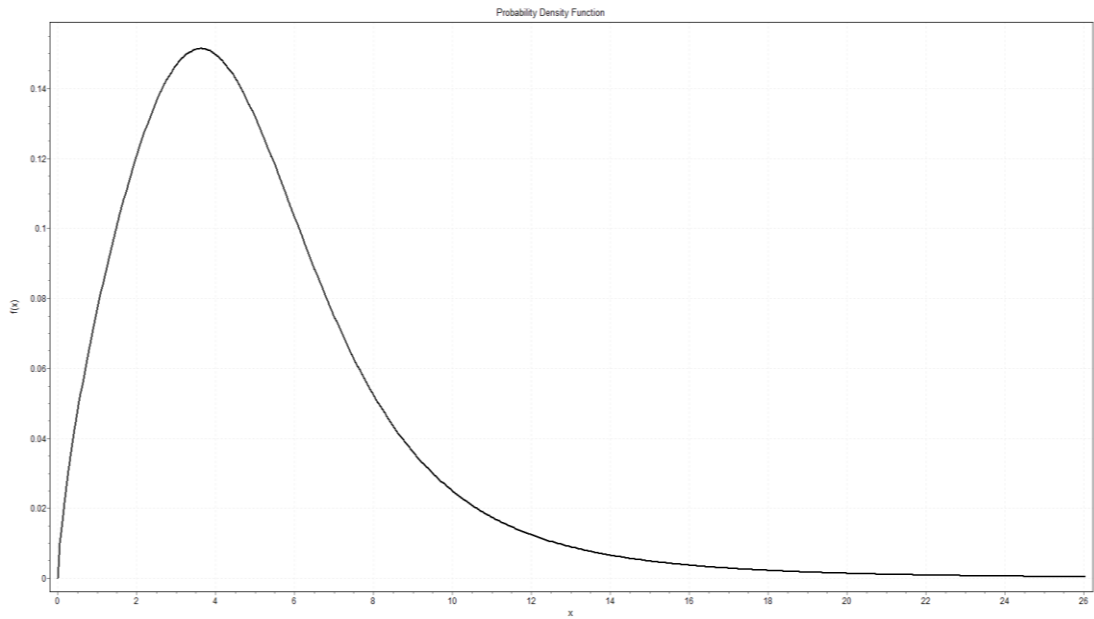


Figure 4.56 - Probability density function Curve for Car-Bus & Bus-Car vehicle pair category(A)

The estimated parameters that were used to create the curve are shown below,

$$p = 0.4874$$

$$a = 3.4609$$

$$b = 6.2124$$

Probability density function can be identified using this curve and also from the equation stated for Dagum distribution down below.

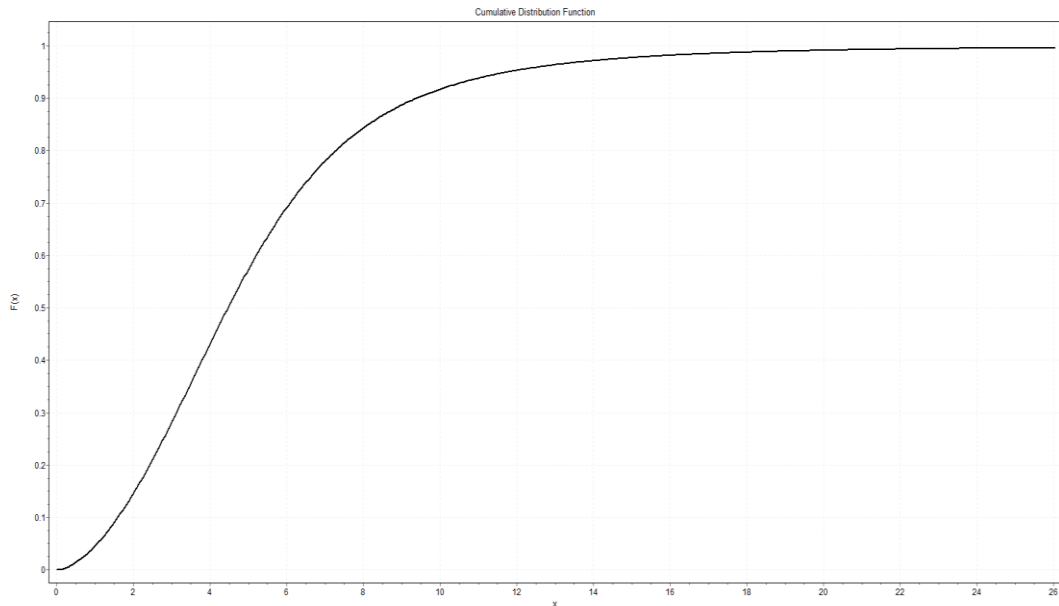


Figure 4.57 - Cumulative Density Function Curve for Car-Bus & Bus-Car vehicle pair category(A)

The estimated parameters that were used to create the curve are shown below,

$$p = 0.4874$$

$$a = 3.4609$$

$$b = 6.2124$$

The cumulative density function can be identified using this curve and also from the Dagum distribution equation mentioned.

4.8.2 “B” Vehicle pair category

Table 4.21 - Results of K-S test for “B” Vehicle pair category

Burr	
Kolmogorov- Smirnov	
Sample size	1260
Statistic	0.02162
P-Value	0.59104

Rank	1				
α	0.2	0.1	0.05	0.03	0.01
Critical Value	0.03023	0.03445	0.03826	0.04276	0.04589
Reject?	No	No	No	No	No

According to the figure the selected distribution type is “Burr”. The symbol α is the significant value mentioned earlier as 0.05. According to 0.05, the relevant critical value is 0.03826. The statistic value mentioned(0.02161) is lesser than the critical value(0.03826). That’s the reason why the reject criteria have indicated ‘No’.

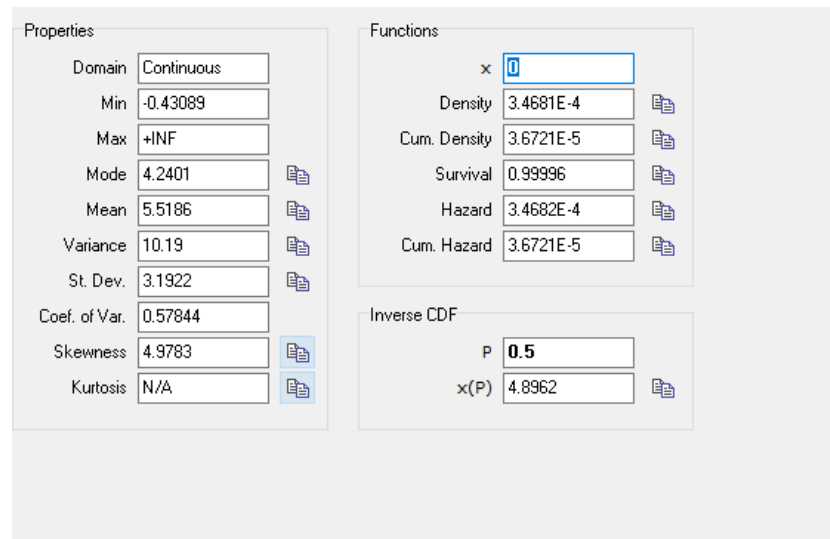


Figure 4.58 -: Properties of distribution of “B” Vehicle pair category

Figure 4.76 describes the property distribution gathered from the software. The mean value of the time headway distribution for the “B” Vehicle pair category is 5.52s and the mode of the time headway distribution is 4.24s. 50% percentile value(median) is 4.99s.

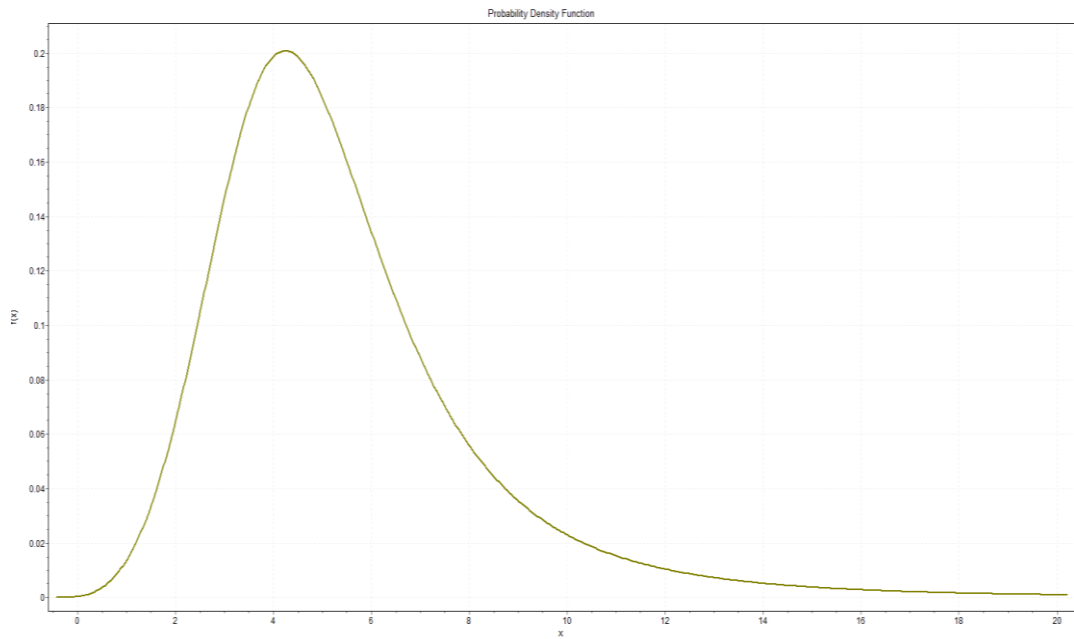


Figure 4.59 - Probability density function Curve for “B” Vehicle pair category

The estimated parameters that were used to create the curve are shown below,

$$\lambda = 0.946$$

$$c = 4.0698$$

$$k = 5.227$$

The probability density function can be identified using this curve and also from the equation stated for the Burr distribution.

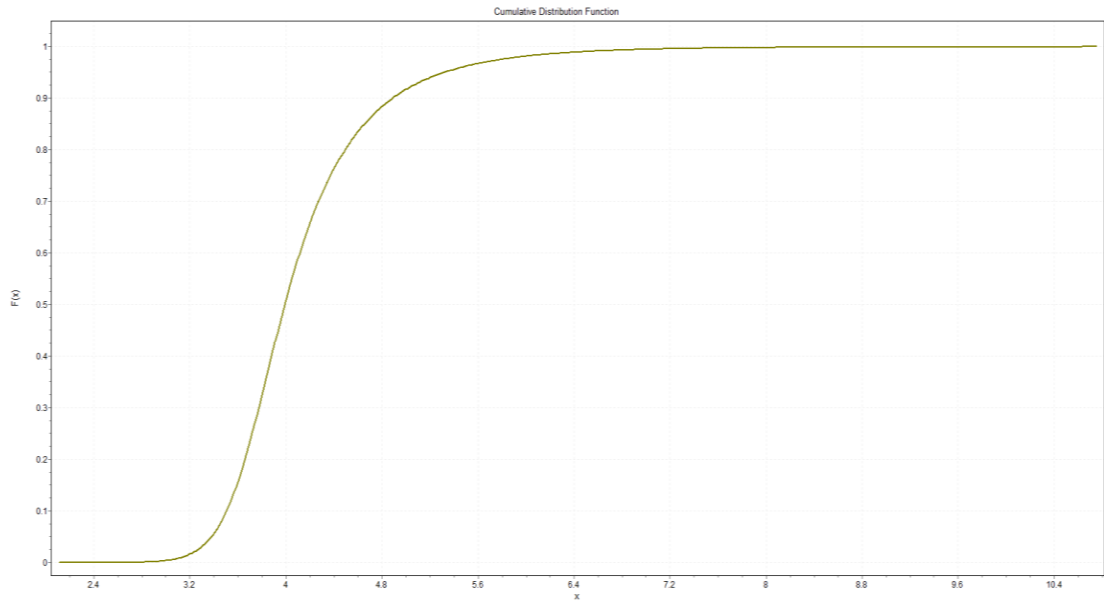


Figure 4.60 - Cumulative Density Function Curve for “B” Vehicle pair category

The estimated parameters that were used to create the curve are shown below,

$$\lambda = 0.946$$

$$c = 4.0698$$

$$k = 5.227$$

The cumulative density function can be identified using this curve and also from the equation stated for the Burr distribution. Vehicle pair information can be summarized using the below table.

Table 4.22 – Summarized properties of vehicle pair categories

Vehicle Pair	Mean	Mode	Median	Best fitted distribution
Vehicle pair ‘A’	5.22s	3.62s	4.46s	Dagum
Vehicle pair ‘B’	5.52s	4.24s	4.99s	Burr

4.9 Limitations of research

- Chandra's approach for calculating PCU considers both the space ratio and the speed ratio while making the computation. Because of the diverse characteristics of traffic flow, the static projected area under consideration may not accurately represent the effective area occupied by a vehicle.
- Data quantity - The amount of data used greatly affects how reliable the results of the study are. In this study, different road segments had fewer automobiles in certain categories than others. As a result, the findings might be skewed in favor of the personality qualities of the drivers of the automobiles who were observed during the investigation. Furthermore, the patterns found may not be indicative of the actual situation due to the relatively small number of places and the varied nature of their attributes.
- Need to consider the congested regions.

4.10 Chapter Summary

This chapter represents all the analysis done inside the study to obtain the goals for the study. At first, the Passenger Car Units are calculated for each vehicle category then the Headway Distribution is gained including the distribution Curve. Then different flow categories are chosen to find headway distribution for separate categories and after that, the state of whether these categories can be combined or not is found by conducting tests using SPSS software. Easy Fit software is used to calculate the distribution models each flow category falls into and to find the probability density function and cumulative density function. Then the headway distribution is found for vehicle pairs using the same process done for flow categories. The results found that the flow categories can not be combined but vehicle pairs can be combined into two groups. It is mentioned as A and B in the chapter.

5 CONCLUSIONS

Chapter One includes the background, problem statement, and objectives of the study within the research design and limitations. The background of the study gives a clear idea about the study and the problem statement indicates why the study is important to Sri Lankan road construction, as expressways are still a new road networking method introduced in Sri Lanka. The study fulfills three objectives, which are to develop a time headway distribution and derive the capacity, also to develop a headway distribution for different flow categories and vehicle pairs. The limitations of the study have been mentioned in the scope and limitation section.

The literature review chapter selected the most suitable literature that can be useful to the study and organized it according to the correct order. First, it describes what headways are and how it's connected to the headway distribution. Since the study is focused on expressways, knowledge of expressways should be gathered. Expressways as well as the difference between highways and expressways, expressways in Sri Lanka are discussed in the second chapter. The next part of the second chapter is mainly related to the methodology and the analysis of the study. Traffic variables and variations are discussed and then the relationship between speed and flow is discussed. In the speed flow section, various model types are addressed including the equations that can be used. Next, the Passenger Car Unit estimating methods are discussed to select the most suitable method for the study. Considering the facts gathered through the literature review, Chandra's method (Chandra, et al., 1995) was chosen as the method to estimate PCU for this research.

The third chapter shows how the relevant data has been gathered for the study by selecting suitable locations. According to the methodology, three areas have been selected from the Southern Expressway and the Colombo-Katunayake Expressway. Then the data collection is done using video recording and the gathered data was used to create a database suitable for the study.

The fourth chapter represents all the analysis done inside the study to obtain the goals for the study. At first, the Passenger Car Units are calculated for each vehicle category then the Headway Distribution is gained including the distribution Curve. Then different flow

categories are chosen to find headway distribution for separate categories and after that, the state of whether these categories can be combined or not is found by conducting tests using SPSS software. Easy Fit software is used to calculate the distribution models each flow category falls into and to find the probability density function and cumulative density function. Then the headway distribution is found for vehicle pairs using the same process done for flow categories. The results found that the flow categories cannot be combined but vehicle pairs can be combined into two groups. It is mentioned as A and B in the chapter.

5.1 Research Output

The study was performed to investigate the time headway distribution in expressways in Sri Lanka. To find out the optimal distribution model for each headway type, the study considered 61 common distribution models. Research outputs are summarized below.

5.1.1 PCU values

Table 5.1 - PCU Values new table

Vehicle Category	PCU Values
Car	1
Van	1.14
LGV	1.34
MBU	2.20
LBU	4.34
MG1	2.39
MG2	3.41
Truck	5.64

5.1.2 Time Headway distribution for considering all vehicles

Burr

Mean = 5.38s

Mode = 4.80s

50% of Time Headway = 5.10s

90% of Time Headway = 7.23s.

5.1.3 Headway Distribution for different flow categories

Table 5.2 – Headway distribution models and properties for different flow categories

Flow Category PCU/5min/ln	The most appropriate distribution model	Mean (s)	Mode (s)	Median (s)
20 – 40	Dagum	8.87	10.48	9.30
40 – 60	Frechet	6.32	5.87	6.14
60 – 80	Generalized Extreme Value	5.07	4.93	5.02
80 – 100	Burr	4.12	3.04	3.99
100 - 120	Pert	3.43	3.40	3.43

5.1.4 Headway Distribution for different vehicle pairs

Table 5.3 – Headway distribution models and properties for Vehicle pairs

Vehicle Pair	Mean (s)	Mode (s)	Median (s)	The most appropriate distribution model
Vehicle pair ‘A’	5.22	3.62	4.46	Dagum
Vehicle pair ‘B’	5.52	4.24	4.99	Burr

According to the study, the headway distribution of various flow categories varies from one another. PCU/ln/5min of 20-40 has a "Dagum" distribution, 40-60 has a "Frechet" distribution, 60-80 has a "Generalized Extreme Value" distribution, 80-100 has a "Burr" distribution, and 100-120 has a "Pert" distribution.

Moreover, the study suggests that vehicle pairs can be divided into two groups based on headway distribution. The combination of Car-Bus and Bus-Car is considered in group "A", while the remaining groups are considered in another group called "B". Group A has a "Dagum" distribution, and Group B has a "Burr" distribution.

And also PCU values were calculated using Chandra's method for expressways and it can be used for future studies.

In conclusion, headway distribution is crucial to maintaining effective, efficient, and sustainable transportation networks. Transportation stakeholders can increase road safety, reduce traffic, increase capacity, and improve the overall travel experience for road users by giving priority to the management and optimization of headway distribution.

For road safety, headway distribution must be done correctly. Maintaining a safe distance between cars lowers the risk of crashes, especially rear-end incidents. Headway distribution can be understood and managed to reduce the likelihood of collisions, injuries, and fatalities on roads, particularly on fast expressways.

The capacity of roadways is maximized through efficient headway distribution management. Increased traffic throughput enables more vehicles to pass along a given stretch of road in a given amount of time by reducing needless pauses between vehicles. In order to handle the increasing traffic needs in urban and suburban areas, this optimization is essential.

It is becoming even more important to comprehend headway distribution as autonomous vehicle technology advances. For safe and effective operation, autonomous cars require exact distance and communication with neighboring vehicles. The development of algorithms and protocols for autonomous vehicle control systems is influenced by research on headway distribution.

As a result, the output of the results can be used to enhance capacity, reduce traffic, and serve as a valuable resource for autonomous car technology.

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7 APPENDIX

7.1 Calculation of projected areas of vehicle categories

property	alto 800	honda vezel	toyota aqua	honda fit gp 5	nissan xtrail-hybrid	suzuki stingray
length	3.395	4.295	4	4.1	4.64	3.54
width	1.515	1.77	1.69	1.695	1.82	1.62
height	1.475	1.605	1.45	1.54	1.715	1.695
area	5.143425	7.60215	6.76	6.9495	8.4448	5.7348
avg area	6.772445833					

Figure 6-1: Area calculation of car

Vehicle type	Length	Width	Area
car(SUZUKI wagon R STINGRAY)	3.395	1.475	5.007625
van	4.695	1.695	7.958025
jeep(Hilux 2016)	5.33	1.855	9.88715
light(TATA Ace)	3.8	1.5	5.7
medium(ISUZU)	5.87	2.36	13.8532

heavy(TATA LPK)	7.83	2.4	18.792
multi(standard truck)	13.6	2.46	33.456
mini bus(rosa)	7.73	2.01	15.5373
large bus(ashok leyland)	11.7	2.55	29.835

Figure 6-2: Area calculation of vehicles

Abrutech Software sample output

Timestamp	Frame	Class	Counter	Speed (km/h)	Time Headway (s)	Space Headway (s)	Prev Vehicle
00:00:00	10	CAR	Counter 1	0	0	0	
00:00:02	55	CAR	Counter 1	81.8	1.8	41	CAR
00:00:08	209	MG2	Counter 1	60	6.16	103	CAR
00:00:12	322	CAR	Counter 1	60	4.52	75	MG2
00:00:15	389	CAR	Counter 1	64.3	2.68	48	CAR
00:00:21	546	CAR	Counter 1	69.2	6.28	121	CAR
00:00:29	746	CAR	Counter 1	60	8	133	CAR
00:00:38	961	LGV	Counter 1	90	8.6	215	CAR

00:00:40	1017	CAR	Counter 1	90	2.24	56	LGV
00:00:42	1064	CAR	Counter 1	60	1.88	31	CAR
00:00:47	1190	CAR	Counter 1	75	5.04	105	CAR
00:00:51	1287	CAR	Counter 1	75	3.88	81	CAR
00:00:59	1495	CAR	Counter 1	64.3	8.32	149	CAR

7.2 Recorded Vehicle Database

Vehicle data recorded at Kottawa interchange on 2022.02.27

Time group	flow	Time group	flow	Time group	flow	Time group	flow	Time group	flow	Time group	flow
7.00-7.05	93	8.00-8.05	96	12.05-12.10	57	16.05-16.10	57	17.00-17.05	80	17.55-18.00	55
7.05-7.10	89	8.05-8.10	95	12.10-12.15	61	16.10-16.15	67	17.05-17.10	59		
7.10-7.15	105	8.10-8.15	69	12.15-12.20	70	16.15-16.20	60	17.10-17.15	55		
7.15-7.20	105	8.15-8.20	84	12.20-12.25	58	16.20-16.25	53	17.15-17.20	62		
7.20-7.25	94	8.20-8.25	101	12.25-12.30	53	16.25-16.30	54	17.20-17.25	61		
7.25-7.30	79	8.25-8.30	69	12.30-12.35	70	16.30-16.35	52	17.25-17.30	70		
7.30-7.35	79	8.30-8.35	89	12.40-12.45	52	16.35-16.40	64	17.30-17.35	54		
7.35-7.40	86	8.35-8.40	83	12.45-12.50	74	16.40-16.45	68	17.35-17.40	55		
7.40-7.45	97	8.40-8.45	70	12.50-12.55	57	16.45-16.50	61	17.40-17.45	63		
7.50-7.55	96	8.45-8.50	94	12.55-13.00	58	16.50-16.55	61	17.45-17.50	58		
7.55-8.00	97	12.00-12.05	60	16.00-16.05	62	16.55-17.00	83	17.50-17.55	68		

Vehicle data recorded at E03 Ch. 14+275 on 2021.04.05

Time group	flow	Time group	flow	Time group	flow	Time group	flow	Time group	Flow
6.00-6.05	55	7.20-7.25	88	8.40-8.45	71	16.05-16.10	44	17.25-17.30	75
6.05-6.10	50	7.20-7.25	71	8.45-8.50	69	16.10-16.15	45	17.30-17.35	64
6.10-6.15	49	7.30-7.35	70	8.50-8.55	79	16.15-16.20	76	17.35-17.40	59
6.15-6.20	64	7.35-7.40	91	12.00-12.05	57	16.20-16.25	49	17.55-18.00	38
6.20-6.25	76	7.40-7.45	79	12.05-12.10	59	16.25-16.30	68		
6.25-6.30	74	7.45-7.50	92	12.10-12.15	41	16.30-16.35	63		
6.30-6.35	73	7.50-7.55	96	12.15-12.20	61	16.35-16.40	76		
6.35-6.40	79	7.55-8.00	87	12.20-12.25	59	16.40-16.45	58		
6.40-6.45	64	8.00-8.05	82	12.25-12.30	51	16.45-16.50	72		
6.45-6.50	90	8.05-8.10	77	12.30-12.35	73	16.50-16.55	63		
6.50-6.55	75	8.10-8.15	110	12.35-12.40	61	16.55-17.00	74		
6.55-7.00	102	8.15-8.20	84	12.40-12.45	57	17.00-17.05	44		
7.00-7.05	85	8.20-8.25	73	12.45-12.50	58	17.05-17.10	64		
7.05-7.10	85	8.25-8.30	62	12.50-12.55	55	17.10-17.15	73		
7.10-7.15	78	8.30-8.35	69	12.55-13.00	58	17.15-17.20	72		
7.15-7.20	87	8.35-8.40	81	16.00-16.05	65	17.20-17.25	69		

Vehicle data recorded at E03 Ch.14+275 on 2021.04.06

Time group	flow	Time group	flow	Time group	flow
7.00-7.05	79	8.45-8.50	84	16.35-16.40	69
7.05-7.10	86	8.50-8.55	65	16.40-16.45	60
7.10-7.15	68	8.55-9.00	67	16.45-16.50	75
7.15-7.20	78	12.00-12.05	67	16.50-16.55	59
7.20-7.25	74	12.05-12.10	47	16.55-17.00	80
7.25-7.30	73	12.10-12.15	63		
7.30-7.35	74	12.15-12.20	65		
7.35-7.40	97	12.20-12.25	57		
7.40-7.45	88	12.25-12.30	44		
7.45-7.50	87	12.30-12.35	55		
7.50-7.55	76	12.35-12.40	63		
7.55-8.00	91	12.40-12.45	66		
8.00-8.05	83	12.45-12.50	65		
8.05-8.10	75	12.50-12.55	65		
8.10-8.15	71	12.55-13.00	66		
8.15-8.20	80	16.00-16.05	64		
8.20-8.25	80	16.05-16.10	64		
8.25-8.30	78	16.10-16.15	52		
8.30-8.35	71	16.15-16.20	49		
8.35-8.40	73	16.20-16.25	67		
8.40-8.45	73	16.30-16.35	68		

Vehicle data recorded at E03 Ch.22+700 on 2021.04.09

Time group	flow	Time group	flow	Time group	flow
12.00-12.05	70	16.20-16.25	80	17.40-17.45	54
12.05-12.10	69	16.25-16.30	73	17.45-17.50	71
12.10-12.15	61	16.30-16.35	76	17.50-17.55	53
12.15-12.20	60	16.35-16.40	96	17.55-18.00	65
12.20-12.25	54	16.40-16.45	79		
12.25-12.30	80	16.45-16.50	69		
12.30-12.35	69	16.50-16.55	69		
12.35-12.40	79	16.55-17.00	73		
12.40-12.45	59	17.00-17.05	72		
12.45-12.50	64	17.05-17.10	91		
12.50-12.55	65	17.10-17.15	61		
12.55-13.00	74	17.15-17.20	81		
16.00-16.05	84	17.20-17.25	88		
16.05-16.10	97	17.25-17.30	82		
16.10-16.15	70	17.30-17.35	55		
16.15-16.20	90	17.35-17.40	71		

Vehicle data recorded at E03 Ch.22+700 on 2021.04.10

Time group	flow	Time group	flow	Time group	flow
6.00-6.05	31	7.35-7.40	60	17.10-17.15	56
6.05-6.10	40	7.40-7.45	63	17.15-17.20	55
6.10-6.15	29	7.45-7.50	70	17.25-17.30	77
6.15-6.20	33	7.50-7.55	59	17.30-17.35	53
6.20-6.25	50	7.55-8.00	62		
6.25-6.30	31	8.00-8.05	64		
6.30-6.35	37	8.05-8.10	56		
6.35-6.40	29	8.10-8.15	68		
6.40-6.45	34	8.15-8.20	69		
6.45-6.50	44	8.20-8.25	61		
6.50-6.55	49	8.25-8.30	61		
6.55-7.00	48	8.30-8.35	68		
7.00-7.05	55	8.35-8.40	56		
7.05-7.10	50	8.40-8.45	56		
7.10-7.15	63	8.45-8.50	61		
7.15-7.20	57	8.50-8.55	70		
7.20-7.25	53	8.55-9.00	73		
7.25-7.30	66	17.00-17.05	65		
7.30-7.35	62	17.05-17.10	62		

Headway data records of vehicle pairs

CAR-CAR	CAR-BUS	CAR-CAB	CAR-M.Lorry	CAR-L.Lorry	CAB-CAB	CAB-CAR	CAB-BUS	CAB-M.Lorry	CAB-L.Lorry	BUS-BUS	BUS-CAR	BUS-CAB	BUS-M.Lorry	BUS-L.Lorry	M.Lorry-M.Lorry	M.Lorry-CAR	M.Lorry-CAB	M.Lorry-BUS	M.Lorry-L.Lorry	L.Lorry-L.Lorry	L.Lorry-CAR	L.Lorry-M.Lorry	L.Lorry-BUS	L.Lorry-CAB	
3.41	4.68	5.34	8.12	4.04	7.88	5.27	3.84	9.56	4.04	1.8	5.6	4.92		2.16		11.08	1.6	6.96							
3.80	6.12	4.34	2.88	2.44	3.64	3.96	6.8	9.44	2.72		6.68	3.92				2.96	1.64								
3.15	12.48	4.54	1.72	2.64	8.64	4.16	2.88	4.72	14.88		3.72	2.4				2.72	10.88								
2.52	6.68	1.8	4.4	2.6	4.92	3.08	1.68	4.96	2.72		5.96	3.48				6.8	6.96								
3.48	3.36	5.83	2.88	3.5	8.72	4.98	16.72	6.2	5.48		7.68					5.04	4.84								
4.14	5.48	2.12	1.72	5.84	7.28	6.27		8.08	3.84		8.54					3.2									
3.82	5.96	4.17	4.4	4.08	1.84	3.34			19.92		9.68					17.16									
3.70	2.32	3.11	3.92	6.54	3.32	2.28			10.32		4.8					3.04									
3.50	6.48	6.38	3.76	7.16	4.16	1.9			3.68		1.52					5									
3.11	1	2.96	2.48	5.04	7.72	1.49			7.04		4.01					5.12									
3.4	4.36	3.6	7.4	4.52	3.04	3.54			20.88		1.04					15.72									
3.92	8.04	3.93	5.2	8.93	11.06	1.83			16.8		3.56					3.68									
3.38	3.44	5.4	5.2	4.4	5.61	3.14			5.04		0.92					4.48									
4.67	3.2	3.18	4.96	1.8	16.88	2.62			1.16		0.76					4.36									
4.17	1.44	3.47	1.44	2.52	10.92	4.27			5.96		1.6					4.04									
3.48	4.28	5.26	6.68	5.92	7.2	3.44			8.32		10.4					3.76									
5.24	1.84	3.44	6.96	5.12	5.7	3.78			1.76		4.56					0.96									
4.38	3.28	1.77	4.68	2.88	1.08	7.46			13.4		3.16					3.28									
4.55	1.28	4.73	8.88	4.64	2.64	2.4			4.96		3.36					6.08									

CAR-CAR	CAR-BUS	CAR-CAB	CAR-M.Lorry	CAR-L.Lorry	CAB-CAB	CAB-CAR	CAB-BUS	CAB-M.Lorry	CAB-L.Lorry	BU S-BUS	BUS-CAR	BUS-CAB	BUS-M.Lorry	BUS-L.Lorry	M.Lorry-M.Lorry	M.Lorry-CAR	M.Lorry-CAB	M.Lorry-BUS	M.Lorry-L.Lorry	L.Lorry-L.Lorry	L.Lorry-CAR	L.Lorry-M.Lorry	L.Lorry-BUS	L.Lorry-CAB
3.98	8.4	2.87	2.48	9.76	3.28	7.56			6.28		3.36					2.16								
3.65	2.48	4.82	7.4	3.32	2.2	6.79			5.6		11					7.44								
5.52	5.28	5.53	5.2	3.36	7.44	4.96			2.8		11.16					4								
5.32	3.68	3.92	4.96	3.36	7.76	4.91			3.12		1.32					1.6								
5.81	4.24	3.22	1.44	5.52	5.04	5.9			6.88		3.12					1.12								
4.6	5.04	6.05	6.68	2.88	7.36	2.9			2.52		3.04					6.04								
5.96	14.16	5.06	6.96	11.9	6.76	6.56			2.04		11.6					3.84								
7.83	2.76	5.6	4.68	7.32	5.96	10.22			6.4		7.52					5.52								
5.88		6.06	8.88	11.96	1.04	7.25			2.72		5.6					7.36								
6.15		3.8	2.76	2.48	9.95	7.28			2.6		3.24													
4.7		3.84	4.36	6.12	16.04	14.08			3.92		8.48													
5.64		5.31	1.88	3.84	6.02	5.51			4.08															
5.21		4.13	3.72	3.12	15.38	3			1.96															
6.52		8.81	2.8	4.28	2.27	4.37			5.04															
6.88		3.92	4.4	10.09	3.48	6.24			11.68															
5.13		6.49	14.08	4	1.72	5.78			9.6															
5.82		2.57	4.2	6.56	2.16	5.8			4.24															
5.69		7.65	1.6	10.88	3.84	4.87			4.6															
6.69		7.11	4.4	8.88	1.6	5.61			2.08															
6.84		3.23	3.2	4.46	11.64	5.07			2.56															
4.46		4.59	6	1.36	3.96	4.75			3.52															
4.52		3.9		6.46	2.04	4.44			2.8															
4.61		6.21		6.36	2.28	3.4			6.4															

CAR-CAR	CAR-BUS	CAR-CAB	CAR-M.Lorry	CAR-L.Lorry	CAB-CAB	CAB-CAR	CAB-BUS	CAB-M.Lorry	CAB-L.Lorry	BUS-BUS	BUS-CAR	BUS-CAB	BUS-M.Lorry	BUS-L.Lorry	M.Lorry-M.Lorry	M.Lorry-CAR	M.Lorry-CAB	M.Lorry-BUS	M.Lorry-L.Lorry	L.Lorry-L.Lorry	L.Lorry-CAR	L.Lorry-M.Lorry	L.Lorry-BUS	L.Lorry-CAB	
7.21		7.43		2.72	8.2	3.59																			
4.5		6		11.52	1.76	5.38																			
5.16		4.83		3.76	3.72	6.17																			
6.06		4.27		3.76	8.58	7.69																			
5.62		4.01		12.76	5.46	4.65																			
5.58		11.68		5.21	10.47	5.06																			
5.48		6.85		3.66	5.12	3.28																			
5.44		6.99		5.88	2.44	4.08																			
5.76		6.46		5.08	5.72	3.63																			
5.31		4.12		6.7	2.12	2.73																			
4.8		6.68		3.52	2.12	6.04																			
5.61		7.72		1.68	3.28	4.96																			
4.91		10.75		2.6	3.04	7.76																			
5.81		12.8		2.64	14.68	4.99																			
6.19		5.2		4.68	10.64	2.32																			
6.41		4.33		6.08	3.16	6.33																			
7.8		3.22		8.18	3.67	5.14																			
5.09		5.72		5.07	1.44	5.48																			
4.62		6.9		2.82	13.24	3.44																			
4.18		3.34		4.76	5.22	5.53																			
4.64		1.86		2.84	5.1	2.87																			
4.44		4.64		5.06	5	1.76																			
4.9		5.77		8.52	5.48	5.22																			
3.88		2.78		7.08	2.56	3.64																			

CAR-CAR	CAR-BUS	CAR-CAB	CAR-M.Lorry	CAR-L.Lorry	CAB-CAB	CAB-CAR	CAB-BUS	CAB-M.Lorry	CAB-L.Lorry	BUS-BUS	BUS-CAR	BUS-CAB	BUS-M.Lorry	BUS-L.Lorry	M.Lorry-M.Lorry	M.Lorry-CAR	M.Lorry-CAB	M.Lorry-BUS	M.Lorry-L.Lorry	L.Lorry-L.Lorry	L.Lorry-CAR	L.Lorry-M.Lorry	L.Lorry-BUS	L.Lorry-CAB	
4.03		1.56		4.4	4.84	2.41																			
3.34		9.76		9.49	1.32	5.72																			
3.87		3.99		16.04	3.81	5.72																			
3.97		3.75		10.8	5.16	4.98																			
4.04		3.49		23.44	18.16	3.64																			
3.89		4.72		6.33	8.16	4.06																			
4.11		3.87		5.72	3.44	4.36																			
4.41		2.58		2.24	8.32	2.84																			
4.23		6.05		5.36	12.38	2.56																			
3.71		2.84		8.64	1.96	4.63																			
4.02		3.66		7.36	11.72	1.68																			
3.64		5.07		9.52	5.28	4.41																			
3.38		3.92		3.28	1.24	3.23																			
3.7		4.83		4.97	3.88	6.01																			
4.32		2.65		2.64	4.88	7.48																			
4.37		14.96		3.3	1.32	7.42																			
3.25		5.5		5.46	3.6	5.91																			
4.24		4.99		7.2	5.2	4.41																			
4.8		7.28		3.76	2.4	9.42																			
4.04		7.08		3.08	8.64	5.86																			
3.8		7.89		1.8	8.32	7.33																			
3.2		6.53		2.3	4	6.79																			
4.15		8.34		3.92	18	3.18																			
4.33		6.88		3.04	2.56	3.52																			

CAR-CAR	CAR-BUS	CAR-CAB	CAR-M.Lorry	CAR-L.Lorry	CAB-CAB	CAB-CAR	CAB-BUS	CAB-M.Lorry	CAB-L.Lorry	BUS-BUS	BUS-CAR	BUS-CAB	BUS-M.Lorry	BUS-L.Lorry	M.Lorry-M.Lorry	M.Lorry-CAR	M.Lorry-CAB	M.Lorry-BUS	M.Lorry-L.Lorry	L.Lorry-L.Lorry	L.Lorry-CAR	L.Lorry-M.Lorry	L.Lorry-BUS	L.Lorry-CAB	
4.65		1.95		3.2	15.56	4.02																			
6.85		5.7		6.32	2.56	4.32																			
5.41		4.51		3.28	12.4	3.73																			
8.42		3.84		3.68	3.32	19.28																			
5.17		6.1		4.38		8.05																			
4.73		2.15		2.6		7.24																			
6.71		6.12		6.8		3.71																			
7.58		8.05		5.08		6.44																			
4.6		5.78		3.6		5.33																			
5.39		4.94		5		4.2																			
5.6		9.8		5.92		8.65																			
5.78		3.89		2.56		3.05																			
5.92		2.72		2.16		2.56																			
5.63		6.44		4.28		3.52																			
7.54		8.33		5.97		7.41																			
6.71		6.7		8.58		5.07																			
4.66		4.3		6.72		2.19																			
6.48		7.15		2.8		5.09																			
5.68		6.58		11.12		5.6																			
5.43		5.73		3.92		6.8																			
4.91		5.36		7.74		2.47																			
5.85		3.72		14.24		4.8																			
5.42		3.03		6.4		5.15																			
5.48		7.76		5.8		2.86																			

CAR-CAR	CAR-BUS	CAR-CAB	CAR-M.Lorry	CAR-L.Lorry	CAB-CAB	CAB-CAR	CAB-BUS	CAB-M.Lorry	CAB-L.Lorry	BUS-BUS	BUS-CAR	BUS-CAB	BUS-M.Lorry	BUS-L.Lorry	M.Lorry-M.Lorry	M.Lorry-CAR	M.Lorry-CAB	M.Lorry-BUS	M.Lorry-L.Lorry	L.Lorry-L.Lorry	L.Lorry-CAR	L.Lorry-M.Lorry	L.Lorry-BUS	L.Lorry-CAB	
4.51		4.11		1.4		10.22																			
5.81		5.68		5.68		5.73																			
5.46		4.53		5.28		5.74																			
4.51		5.1		8.12		3.75																			
4.3		5.82		2.44		5.04																			
5.3		5.94		4.89		5.95																			
4.53		4.16		6.81		3.43																			
5.73		6		6.89		8.84																			
5.96		3.85		7.32		2.68																			
4.97		2.08		2.74		2.84																			
4.36		4.74		1.75		5.62																			
3.66		2		3.44		3.38																			
4.65		7.41		2.54		6.84																			
4.23		5.1		1.76		2.31																			
3.76		5.52		2.28		2.67																			
3.66		4.32		4.24		10.4																			
4.99		5.1		5.51		4.51																			
3.03		3.91		4.4		5.28																			
3.55		10.09		4.6		3.28																			
4.08		3.84		11.12		5.16																			
3.8		7.57		5.76		3.8																			
3.54		5.63		2.81		4.44																			
4.09		5.12		3.8		4.1																			
3.92		2.32		2.96		7.44																			

CAR-CAR	CAR-BUS	CAR-CAB	CAR-M.Lorry	CAR-L.Lorry	CAB-CAB	CAB-CAR	CAB-BUS	CAB-M.Lorry	CAB-L.Lorry	BUS-BUS	BUS-CAR	BUS-CAB	BUS-M.Lorry	BUS-L.Lorry	M.Lorry-M.Lorry	M.Lorry-CAR	M.Lorry-CAB	M.Lorry-BUS	M.Lorry-L.Lorry	L.Lorry-L.Lorry	L.Lorry-CAR	L.Lorry-M.Lorry	L.Lorry-BUS	L.Lorry-CAB	
3.92		5.24		4.64		8.22																			
3.87		13.74		5.76		5.78																			
4.35		6.64		2.88		19.92																			
4.53		6.16		1.76		4.32																			
4.79		8.62		6.32		6.66																			
4.55		6.73		2.04		5.2																			
4.48		5.07		5.6		13.01																			
4.99		5.01		23.92		6.92																			
5.33		6.47				2.38																			
5.29		5.67				6.27																			
5.78		6.21				4.06																			
5.21		6.72				7.33																			
5.21		3.81				4.39																			
7.88		8.96				3.72																			
7.55		6.32				17.68																			
6.89		6.77				7.49																			
6.01		5.63				9.12																			
5.07		2.4				2.2																			
5.32		9.9				5.36																			
5.71		7.27				4.41																			
6.35		2.96				3.58																			
6.11		6.4				3.61																			
5.12		4.93				4.16																			

CAR-CAR	CAR-BUS	CAR-CAB	CAR-M.Lorry	CAR-L.Lorry	CAB-CAB	CAB-CAR	CAB-BUS	CAB-M.Lorry	CAB-L.Lorry	BUS-BUS	BUS-CAR	BUS-CAB	BUS-M.Lorry	BUS-L.Lorry	M.Lorry-M.Lorry	M.Lorry-CAR	M.Lorry-CAB	M.Lorry-BUS	M.Lorry-L.Lorry	L.Lorry-L.Lorry	L.Lorry-CAR	L.Lorry-M.Lorry	L.Lorry-BUS	L.Lorry-CAB	
6.8		5.76				2.55																			
5.14		4.95				3.13																			
19.44		5.18				4.11																			
4.64		4.43				4.27																			
5.66		4.23				4.71																			
4.18		2.09				3.03																			
5.78		4.21				6.94																			
4.24		2.2				12.16																			
5.64		4.3				3.44																			
6.13		4.68				4.05																			
5.64		4.99				6.5																			
5.56		2.37				4.41																			
6.98		4.29				5.93																			
4.61		6.19				4.54																			
4.6		6.16				3.38																			
5.32		5.42				2.71																			
5.85		5.32				4.82																			
5.55		5.43				4.88																			
5.32		7.49				6.21																			
4.63		6.79				5.65																			
4.73		4.24				5.73																			
4.8		6.76				3.86																			
5.19		3				3.28																			
4.16		5.94				6.67																			

CAR-CAR	CAR-BUS	CAR-CAB	CAR-M.Lorry	CAR-L.Lorry	CAB-CAB	CAB-CAR	CAB-BUS	CAB-M.Lorry	CAB-L.Lorry	BUS-BUS	BUS-CAR	BUS-CAB	BUS-M.Lorry	BUS-L.Lorry	M.Lorry-M.Lorry	M.Lorry-CAR	M.Lorry-CAB	M.Lorry-BUS	M.Lorry-L.Lorry	L.Lorry-L.Lorry	L.Lorry-CAR	L.Lorry-M.Lorry	L.Lorry-BUS	L.Lorry-CAB	
5.01		11.48				5.53																			
5.51		3.7				7.29																			
4.3		2.97				6.01																			
5.17		4.31				2.35																			
4.49		7.44				3.79																			
3.96		6.04				6.28																			
4.89		7.2				4.54																			
4.76		9.2				16																			
4.22		6.48				3.28																			
5.62		10.6				8.29																			
4.62		5.21				9.68																			
6.33		8.4				21.9 2																			
4.6		11.2				4.24																			
5.97		14.44				10																			
4.63		9.47				7.09																			
6.27		6.03				24.1 6																			
4.65		3.28				8.99																			
6.02		7.73				9.44																			
5		4.78				5.44																			
9.34		5.36				5.44																			
10.47		3.74				12.1 6																			
10.43		3.56				9.16																			
7.6		4.92				5.12																			

CAR-CAR	CAR-BUS	CAR-CAB	CAR-M.Lorry	CAR-L.Lorry	CAB-CAB	CAB-CAR	CAB-BUS	CAB-M.Lorry	CAB-L.Lorry	BU S-BUS	BUS-CAR	BUS-CAB	BUS-M.Lorry	BUS-L.Lorry	M.Lorry-M.Lorry	M.Lorry-CAR	M.Lorry-CAB	M.Lorry-BUS	M.Lorry-L.Lorry	L.Lorry-L.Lorry	L.Lorry-CAR	L.Lorry-M.Lorry	L.Lorry-BUS	L.Lorry-CAB	
10.06		8.57				5.15																			
9.86		4.26				10.28																			
10.34		8.36				6.64																			
10.09		3.39				5.52																			
8.62		6.01				5.55																			
7.29		3.81				8.38																			
5.85		4.64				5.82																			
6.18		4.69				4.01																			
6.67		6.69				2.73																			
5.2		6.4				4.03																			
5.85		6.98				6.32																			
5.56		15.92				2.88																			
4.85		3.17				13.18																			
5.14		7.82				1.73																			
5.44		6.2				1.6																			
4.34		4.54				4.8																			
4.18		4.58				2.81																			
5.83		5.3				6.13																			
5.13		4.16				4.68																			
4.88		6.28				4.51																			
5.93		2.35				3.32																			
5.56		5.92				8.27																			
5.21																									

CAR-CAR	CAR-BUS	CAR-CAB	CAR-M.Lorry	CAR-L.Lorry	CAB-CAB	CAB-CAR	CAB-BUS	CAB-M.Lorry	CAB-L.Lorry	BUS-BUS	BUS-CAR	BUS-CAB	BUS-M.Lorry	BUS-L.Lorry	M.Lorry-M.Lorry	M.Lorry-CAR	M.Lorry-CAB	M.Lorry-BUS	M.Lorry-L.Lorry	L.Lorry-L.Lorry	L.Lorry-CAR	L.Lorry-M.Lorry	L.Lorry-BUS	L.Lorry-CAB	
5.01																									
4.97																									
5.61																									
6																									
5.19																									
4.75																									
4.42																									
4.98																									
6.01																									
5.68																									
6.32																									
4.15																									
6.25																									

