A ROAD CAPACITY ASSESSMENT STUDY

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UNIVERSITI TUNKU ABDUL RAHMAN

A ROAD CAPACITY ASSESSMENT STUDY

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Civil Engineering with Honours

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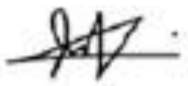
DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : 

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APPROVAL FOR SUBMISSION

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ABSTRACT

Transport planners often encounter difficulties in the estimation of capacity for minor roads due to the lack of standard approaches to be applied. This study aims to promote the design and planning of sustainable traffic facilities with the development of models for capacity estimation of minor roads and the identification of factors affecting traffic flow and capacity. A total of thirty sites that are minor roads from Bandar Sungai Long, Bandar Mahkota Cheras and Maluri are selected for traffic data collection during AM peak hour of 8 am to 9 am. Fundamental Diagram approach and multiple linear regression analysis are adopted as the analysis methods. The result shows that the capacity model developed is significant in estimating the capacity of minor roads with the type of road, type of carriageway, and speed limit as the statistically significant predictor variables. The traffic density, average travel speed, type of road, and type of carriageway are the factors that may impact the traffic flow on the roads. The basic factors affecting the road capacity of minor roads are: type of road, type of carriageway, and speed limit. It is also discovered that the type of carriageway is the key factor that has the greatest impact on the capacity of minor roads, followed by the type of road and the speed limit.

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LIST OF SYMBOLS / ABBREVIATIONS

HCM	Highway Capacity Manual
pcu	passenger car unit
c_{adj}	specific mass flow rate, pcu/h
c	base capacity of segment, pcu/h
CAF	capacity adjustment factor
c_{dATS}	capacity in the analysis direction under prevailing conditions based on ATS, pcu/h
c_{dPTSF}	capacity in the analysis direction under prevailing conditions based on PTSF, pcu/h
f_g	grade adjustment factor for PTSF/ATS determination
f_{HV}	heavy vehicle adjustment factor for PTSF/ATS determination
C	maximum one-way hourly capacity, pcu/h
I	ideal hourly capacity, pcu/h
R	roadways reduction factor
T	traffic reduction factor
Pc	estimated percentage of commercial vehicles that are classified as medium and heavy goods trucks and have an unladen weight of more than 1.5 tonnes, %
VAM	Van Aerde Model
C_i	estimated capacity for location I, veh/h
u_i	space mean speed for location i, km/h
$u_{f,i}$	free flow speed for location i, km/h
c_i	headway constant coefficients for i = 1, 2, 3
u_c	speed at capacity, km/h
q_c	denotes the flow at capacity, veh/h
k_j	jam density, pcu/km
$F_c(q)$	capacity distribution function
q	observed traffic volume, veh/h/l
c	capacity, veh/h
PLM	Product Limit Method
$F(t)$	distribution function of lifetime

T	lifetime
$S(t)$	survival function
$\hat{S}(t)$	estimated survival function
n_j	number of individuals with a lifetime $T \geq t_j$
d_j	number of deaths at time t_j
q_i	traffic volume in interval i, veh/h
k_i	number of intervals with a traffic volume of $q \geq q_i$
d_i	number of breakdowns at a volume of q_i
$\{B\}$	set of breakdown intervals
$f_c(q_i)$	density function of capacity
$F_c(q_i)$	cumulative distribution function of capacity
n	number of intervals
δ_i	1 and 0 if interval i is uncensored and censored respectively
SFI	sustained flow index, veh/h
$S_c(q_i)$	probability of survival at volume q_i
q_{opt}	optimum volume, veh/h
β	shape parameters of the fitted Weibull distribution
α	scale parameters of the fitted Weibull distribution
h_p	time headway between vehicle *P* and its next vehicle, s
h_m	mean headway for all the vehicles, s/veh
q	flow rate of vehicle, veh/h
n	number of vehicles pass through the section during time *t*
C	road capacity, veh/h
q_c	capacity value, veh/h
i	length of cycle period over which a maximum flow rate is identified
V_c	speed of car, km/h
V_i	speed of ith type vehicle, km/h
A_c	static area of a car, m^2
A_i	static area of *i*th type of vehicle, m^2
V_m	mean stream speed, km/h
k	total number of vehicle categories available in the stream
v_i	speed of vehicle of category *i*, km/h

n_i	number of vehicles of category *i*
q	traffic flow, pcu/h
k	traffic density, pcu/km
u	average speed, km/h
a	type of road
b	type of carriageway
u_0	speed corresponding to maximum flow, km/h
q_{cap}	maximum flow rate, pcu/h
k_{cap}	capacity density, pcu/km
V_i	demand volume for full peak hour, veh/h
f_c	traffic composition factor
PHF	peak hour factor
S	average travel speed, km/h
v_i	flow rate, pc/h/ln
S	speed limit, km/h
C	capacity, pcu/h
f_{LW}	adjustment for lane width, km/h
f_{LC}	adjustment for lateral clearance, km/h
f_{APD}	adjustment for access point density, km/h
f_{LP}	adjustment for lane position, km/h
q_c	total cars
q_l	total lorries
q_t	total trailers
q_b	total buses
q_m	total motorcycles

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

The transport system in Malaysia, in the form of public transport infrastructure, construction of highways, and so on, has been developing at a remarkable rate over the years. As a developing country, development in transport systems, such as enhancement in effective transportation infrastructure, could assist in boosting the national economy. The government has allocated a substantial budget of RM 3.5 billion for infrastructure projects in Budget 2022 and outlined plans for an enormous transport development programme (Tan, 2021). Other than that, the demand for road transportation in our country has been increasing, which could be proven by the increase in road network length coverage, the total number of active vehicles, and so on. As of the year 2021, the road network of Malaysia has covered 290 099.384 km, where 247 027.612 km of it is state roads and 20 017.966 km of it is federal roads, as shown in Figure 1.1 (Jabatan Kerja Raya Malaysia, 2021).

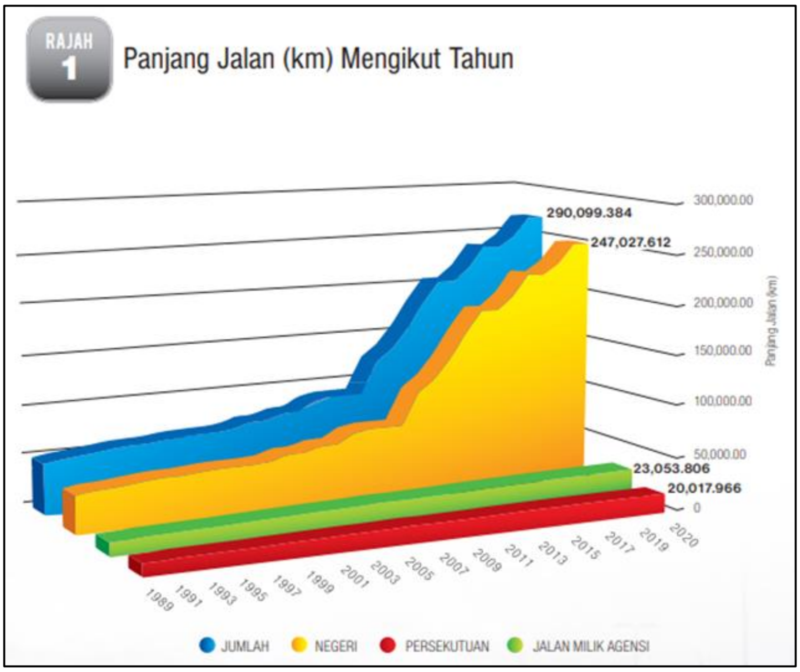


Figure 1.1: Road Length of Malaysia for the Year 2021 (Jabatan Kerja Raya Malaysia, 2021).

The total number of active vehicles in our country has also reached 23 million units up to September 2021, as estimated by Jabatan Pengangkutan Jalan Malaysia (Lim, 2022). However, the increase in road transportation demand has also resulted in various transport issues in urban areas, especially traffic congestion. The traffic congestion issue nowadays has doubled compared to the pre-pandemic period in 2019 since more people started to return to their workplaces. Transport issues arising from the high transport demand are to be tackled with the effective planning and design of highways and minor roads.

Traffic flow is said to be in congestion or poor when the traffic demand of a roadway segment exceeds the capacity of the road. Traffic users will experience unsteady speed and require a high level of vigilance with no comfort in driving in the situation when the road capacity is insufficient for high traffic volume on the road. In order to eliminate this issue, proper design, planning, and mitigation for transportation facilities are necessary to ensure that the traffic volume will not exceed the capacity of the existing roads. Hence, the estimation of road capacity plays an essential role in evaluating how capable a roadway segment is in carrying traffic before proposing practical and effective planning to serve the requirement of the projected traffic.

1.1.1 Capacity

The capacity of a road is defined as the maximum amount of vehicles that can traverse a specific point within a given time period under traffic, control conditions, and roadways that prevail (Transportation Research Board, 2016). It is noted that this definition of capacity is in accordance with the assumption that the operations of downstream traffic, such as the traffic backing up into the point of analysis, have no effect on it. Prevailing traffic, control conditions, and road facility that defines capacity should be fairly uniform for any part of the road section analysed. This is because any alter under the conditions that are prevailing will change the capacity of the road. The definition of capacity is based on reasonable expectancy. In other words, a facility's claimed capacity is a flow rate that can be consistently met during peak periods of adequate demand.

1.1.2 Methods of Road Capacity Estimation

There are various methods available in the estimation of road capacity for different types of roads, which could be found in sources such as the US Highway Capacity Manual (USHCM), Malaysia Highway Capacity Manual (MHCM), Road Traffic Volume Malaysia, and so on. These methods are being reviewed and will be evaluated to contribute to the development of a road capacity model in this study.

In order to allow researchers and transportation to assess the service quality of road facilities such as two-lane highways, basic segments, multilane highways, and so on, Highway Capacity Manual has come out with a system of methodologies that is consistent and applicable. The objective of the manual is to present sample problems, ensure that practitioners can gain access to the most recent research findings, and provide logical techniques to measure the performance of roadways for each study facility. In US Highway Capacity Manual (USHCM) and Malaysia Highway Capacity Manual (MHCM), the estimation of road capacity will be conducted based on the base capacity specified for different types of roads in the manuals. The base capacity values presented in the manual are only the base values where these values represent ideal conditions such as ideal roadway geometry, a traffic stream consisting wholly of passenger cars, and good weather. The actual capacity of a road under non-ideal conditions, such as the presence of trucks, severe weather, and constrained shoulder width, will be reduced from the base value. The Highway Capacity Manual provides methods that can calibrate the road capacity to account for local conditions.

Road Traffic Volume Malaysia (RTVM) offers comprehensive information about Malaysia's road traffic, which is a great source of information for those making public and private sector decisions about the development of transportation infrastructure. It provides traffic-related information about our country, such as traffic census station locations, road traffic volume, annual traffic growth rate, and so on. The method of estimating the maximum hourly capacity of the road facility is also specified, where the capacity will be computed based on three parameters in this method. The parameters are the ideal hourly capacity, roadways reduction factor, and traffic reduction factor.

The Van Aerde model requires the points of data for speed flow to be fitted by a mathematical model where a speed-density relationship in linear form is assumed. It is a model which consists of four parameters that provide higher levels of independence to obtain the different behaviour over various regimes and types of the facility (Rakha and Crowther, 2002). A nonlinear regression analysis technique that is used in a software application is able to calibrate this model, which needs four input parameters.

The Product Limit Method (PLM), which is used to forecast when mechanical parts will break down or how long a human life will last, is based on lifetime data analysis study (Asgharzadeh and Kondyl, 2018). This model is linked to the breakdown flow rate and other flow rates, which would not lead to the occurrence of a breakdown. There may be some intervals that are larger than the threshold where; they are known as censored data. Similar to how the capacity is assessed as the lifetime for an analysis of lifetime data is related to the breakdown of traffic, it is regarded as an event of failure. The distribution function's parameters, which contain the censored data, can then be estimated using the statistics of this lifespan analysis.

The volume of traffic and the survival function’s value at the volume under consideration are multiplied to yield the Sustained Flow Index (SFI). The volume when the SFI value reaches its maximum will be the capacity in this method (Shojaat, et al., 2016). Flow rate under the optimum condition that maximises the SFI value will subsequently be determined by taking into account that the probability distribution function is based on the Weibull distribution. Previous research studies recommend using the Weibull distribution will be the most effective distribution to depict the freeways’ distribution of capacity.

1.1.3 Traffic Principles and Basic Variables

Before the estimation of the road capacity can be carried out, it is essential to understand the traffic principles and basic traffic variables since the application of various methods for road capacity estimation will usually require basic knowledge and information from these principles.

The first traffic principle to be introduced is the headway and spacing principle in traffic. The definition of headway is the amount of time, typically measured in seconds, that passes between two cars when they pass a particular location on a road or lane. The distance between succeeding vehicles taken from the front bumper to the front bumper, which is typically expressed in metres, is referred to as spacing (Highway Planning Unit Ministry of Works Malaysia, 2011). The speed is the basis for the link between average headway and average spacing in a traffic stream. Flow rate and density of traffic could also be computed with the average spacing and average spacing, which indicates that the average headway of the traffic stream could influence the flow rate of a stream where the higher the value of average headway, the lower the value of stream flow rate and vice versa.

Other than that, passenger car equivalent is also a significant fundamental in representing varying effects of mixed vehicle types with the conversion of a traffic stream with a variety of vehicle types into a stream that is equivalent and entirely made up of passenger cars. The number of passenger vehicles which a single heavy vehicle of a certain type can move for particular traffic, road facility, and control conditions will serve as its definition. (Highway Planning Unit Ministry of Works Malaysia, 2011). According to Malaysia Highway Capacity Manual, vehicles are categorised into five types of classifications which are from class 1 to class 5.

Passenger car unit (pcu) is the term that is frequently used for measuring the capacity of the road and for taking into consideration the varying composition of vehicular traffic on a road/junction. For the purpose of practical measurement, the counted vehicle from the traffic survey is required to be converted into passenger car units. The passenger car unit conversion factor, which is applied for converting different vehicle types into passenger car units, is prescribed in Arahan Teknik (Jalan) 8/86 - A Guide on Geometric Design of Roads.

One of the basic traffic variables which will be introduced is the volume and flow rate in traffic. Volume is defined as the total number of vehicles passing through a given point or section of a highway or lane under a given time or interval. The equal hourly rate at which vehicles cross a specific location on a highway or segment of roadway over a specific time period is the definition of flow rate (Highway Planning Unit Ministry of Works Malaysia, 2011). Besides that, the peak hour factor is one of the significant concepts under the volume and flow rate principle, where it is the traffic flow that varies in an hour's time. The evaluation of capacity and other parameters usually requires the application of traffic volume under the peak hour since it reflects the period that is the most critical.

In addition, the next basic traffic variable to be discussed will be speed which is an essential principle in measuring the traffic performance of a road system. The definition of speed is the motion rate which is termed as distance per unit of time (Highway Planning Unit Ministry of Works Malaysia, 2011). A single characteristic speed does not exist in a traffic stream since vehicles usually travel at different speeds in a traffic stream. In order to characterise the distribution of individual vehicle speeds as a whole, a number of average values may be adapted. The average or mean speeds can be classified into space mean speed and time mean speed consisting of various values based on different physical significance. The speed being observed at some designated point along the road is the time mean speed, which is also known as the average spot speed. Time mean speed can be calculated by the sum of the measure spot speeds divided by the number of measurements. The space mean speed is the average speed that is related to the average time of travel of vehicles to pass over a roadway segment. The foundation of many planning models that are applied to calculate the average running speed, free-flow speed, and trip speed will be the space mean speed.

Density is an essential basic variable in traffic since it functions in categorising the traffic operations' quality. It depicts the flexibility to move about within the flow of traffic. Although density cannot be directly observed in the field, it can be inferred using speed-flow relationships.

1.1.4 Fundamental Relationships of Speed, Flow and Density

There is a relationship between the speed, density and flow of traffic, and it is significant to understand the concept behind their relationships. Parabolic curves are used to illustrate the relationship between speed, density and traffic flow.

It is known that the density will be zero when the flow rate equals zero since it indicates no vehicles are travelling on the highway. In this scenario, there will be minimum interaction between vehicles which allows the road users to travel at the maximum speed possible. The absolute maximum speed could be captured under this situation, where this speed is known as the free-flow speed. Furthermore, density will increase from zero when the flow rate starts to increase from zero since it shows that there is an increase in the vehicles' number travelling on a highway. At the same time, the increase in vehicle interaction will also result in a reduction in speed. As the flow rate continues to increase until it reaches a maximum value, any further increase in the traffic flow rate will lead to a decrease in speed and flow rate. When the density reaches the jam density, the flow rate and speed will eventually equal zero. Under this situation, vehicles will be queuing from end-to-end, which leads to restricted movement of vehicles on the highway.

1.1.5 Level of Service

The traffic stream could operate under different levels of performance, and it is important to specify these levels systematically. Hence, the basis of the level of service (LOS) is being introduced, where it is a quality metric that represents the operational state of a stream of traffic in terms of service measures, including travel time and speed, freedom of movement, delays in traffic, and convenience and comfort. There will be six LOS for each type of traffic facility that covers the range of operating conditions wholly. They are designated using an A to F letter scale where the best operating performance will be LOS A, and the worst operating performance will be LOS F. It is noted that LOS A through LOS E reflects the situation where the volume of traffic is less than the specified capacity of traffic facilities while LOS F indicates the occurrence of forced conditions, or the capacity is being exceeded. Every level of service denotes a variety of operational states for a certain kind of facility.

1.1.6 Factors Affecting Capacity and Level of Service

In order to have greater control over the operation and planning of traffic facilities, the factors affecting the level of service and road capacity are to be learned. The major factors affecting the level of service and capacity include base conditions, roadway conditions, traffic conditions, control conditions and weather conditions. First of all, the base conditions, which is one of the factors here, means the standard conditions specified where modification is necessary to consider for the prevailing conditions which are not matching (Highway Planning Unit Ministry of Works Malaysia, 2011).

For the factor of roadway conditions, it comprises geometric and other elements. Under some circumstances, roadway conditions can influence the capacity of a road when the performance measure, such as speed or free-flow speed of the road segment, might be impacted in other circumstances.

In most Asian countries, the existence of mixed traffic is common. Passenger cars, medium-heavy vehicles, trailers, large buses, and motorcyclists are among the frequent vehicle categories in mixed traffic. Each type of vehicle performs differently on the road, which results in varying impacts for the traffic condition; hence it is essential to convert them to passenger vehicles that consist of an equivalent number by the application of passenger car equivalents.

Controlling the timing for specific traffic flows to travel is crucial for interrupted-flow facilities' capacity, level of service, and service flow rates (Transportation Research Board, 2016). The traffic signal is the most important sort of control. Operations are impacted by the control type being used, signal phasing, cycle duration, green time allocation, and the connection with adjacent control measures. Capacity is also influenced by yield and stop signs but in a less predictable manner.

Adverse weather such as rain, heavy fog, and snow is potential to affect the visibility on the road. The impact of adverse weather, in turn, decreases the capacity of a lane or roadway, reduces the traffic speed of vehicles, leads to the delay in travel time of road users, and also increases the accident risk on the road.

1.1.7 Road Classifications

Road hierarchy is crucial because it could assist in clarifying policies pertaining to the highway features of individual planning decisions made on properties served by the particular road. Based on the designation of a road in the hierarchy, additional specific planning criteria could be created and used, such as the design speed, carriageway width, frontage access, pedestrian control, intersection management, and so on. In this manner, each level of the classifications of roads would have defined planning objectives, and the traffic management policies and development control would support each other (Highway Planning Unit Ministry of Works Malaysia, 2011). According to the role of each road, they have their own function, and transportation will serve as the most basic function of a road. By further dividing the function, two sub-functions could exist, which are mobility and accessibility. Nevertheless, these two sub-functions are under a trade-off relation, which means that one of them is to be limited in order to improve the other. In rural areas, road facilities are classified into five categories: principal road, expressway, secondary road, highway, and minor road. Collector, local street, expressway, and arterial are the four sorts of roads that exist in urban areas.

Among all of the types of roads mentioned, some of them are major roads where the methods of estimation of road capacity for these roads are specified in various manuals. These roads are comprised of expressway, highways, primary roads, secondary roads, and arterials. An expressway is a divided highway designed for through traffic, complete with grade separations at each intersection and complete access control. Interstate highways are applied in rural areas for through traffic and make up the fundamental structure of the national fast-moving road transportation system. Highways make up the national interstate network to serve traffic volumes under intermediate conditions and also to supplement the expressway system. Usually, they connect the nation's capital, state capitals, major urban centres, and exit or entry points to the nation directly or indirectly. Highways provide lengthy to moderately long trip lengths. Although it is not as critical as on an expressway, a high to medium speed is still required.

Primary roads account for the main thoroughfares that make up the state’s fundamental network of road transportation systems. They also provide medium travel speeds and trip lengths that are intermediate, where their partial access control ensures smooth traffic. They typically connect district capitals, other major towns, and state capitals. Within a District or Regional Development Area, secondary roads make up the main roadways that form the core network of the road transportation system. With control over partial access, they provide intermediate trip lengths. The largest towns in the district or regional development area are typically connected by them. For through traffic in urban areas, a continuous route within partial access control is referred to as an arterial. It mostly transports traffic from residential areas to areas near the central business district or from one section of a city to another without intending to enter the city centre. Identifiable neighbourhoods could not be accessed via arterials. Since arterial transports a large volume of traffic, smooth traffic flow is crucial.

On the other hand, there are some types of roads that lack standard methods and guidelines in the estimation of their road capacity. These roads are minor roads, collectors, and local streets. Minor roads apply to all of the roads except for the roads mentioned above in the rural areas. Within a Land Scheme or other rural area that is sparsely populated, they make up the fundamental road network. Additionally, they consist of roads with unique purposes, such as access roads to microwave stations, security roads, or roads leading to resorts. They provide access without control and primarily serve local traffic with short trip distances.

A road with control over partial access that is designed for the purpose of a distributor or collector of traffic between the local road network and arterial is known as a collector road. They are the major thoroughfares that enter and connect recognisable neighbourhoods, industrial areas and commercial areas. The primary purpose of the local street system, which is the neighbourhood's fundamental network is to provide direct access to an adjacent territory. Since they connect to the collector road, they serve only short trip lengths, and there should be through traffic for the local street.

1.2 Importance of the Study

After learning about the fundamental traffic principles and the concept behind road capacity, the significance of capacity analysis in the design, planning and operation of facilities is to be discussed. Capacity analysis inspects the points or segments of a facility with traffic, roadway and control conditions that are uniform in identifying the capacity; thus, there will be different capacities for segments with different prevailing conditions. It is essential in serving as a fundamental for determining the class of facilities, lane width, number of lanes and so on in consideration of various traffic parameters. Other than that, the study of road capacity could also contribute to the effective planning for enhancement of geometric elements, traffic management measures and traffic control devices. Capacity studies could assess the adequacy of the existing facility network under the existing traffic volume so that this information could be applied for increased effectiveness of transportation planning.

1.3 Problem Statement

The methods for the estimation of major roads such as highways, expressways and arterial roads are available and provided in the traffic manuals. Transport planners usually have no issue in the estimation of the capacity for major roads since the methods are standardised and clearly stated in various traffic manuals. However, there will always be a problem in the estimation of road capacity for minor roads, such as those around the residential areas or surrounding commercial areas. This is because the theory and approaches for estimating road capacity in the traffic manuals are limited to the estimation of major roads only, where they do not go into as much detail as for the estimation methods of minor roads. This results in difficulty in estimating the road capacity for minor roads such as collector roads, distributor roads and local roads in our country since there is a lack of a standard approach and theory to be applied in the road capacity estimation.

Besides that, it is essential to determine the factors that will affect road capacity so as to take into account the factors identified in the estimation of road capacity. For example, it is interesting to know whether the type of carriageway, which are the single carriageway and dual carriageway, will have any impact on the road capacity. The impact of the number of lanes of minor roads on the road capacity is also to be determined. In order to eliminate the difficulties in the estimation of minor roads, this study reviews and compare the available methods in the estimation of various roadways, investigate the application and pros and cons of the methods and assess the suitability of these methods to be adapted in the estimation of road capacity for the minor road. These initiatives are conducted in view of developing a suitable model that is applicable in the estimation of road capacity for minor roads.

1.4 Aim and Objectives

The aim of this study is to promote the design and planning of sustainable traffic facilities with a precise estimation of capacity for all types of traffic facilities. Two of the main objectives of this study are as below:

(i) To develop capacity model for minor roads.

(ii) To determine the factors that affect road capacity.

1.5 Scope and Limitation of the Study

Limiting the scope of the study is significant to imply the location, size and other factors concerned in the estimation of road capacity. First of all, the scope for the type or road selected for this study are minor roads that include collector/distributor roads and local roads. Besides that, the scope for the location of the sites selected are sub-urban area. In term of the limitations of this study, only AM peak hour of 8 am to 9 am is selected as the time of traffic data collection. Other than that, only thirty sites are selected for this study due to time and resource constraint. The length of road sections to be studied is also being limited to a maximum of 100 m for ease of data collection. Lastly, only geometric and physical factors of the road facilities are taken into account in determining the factors affecting road capacity for this study.

1.6 Contribution of the Study

This study is the first study in Malaysia that develops the capacity model for minor roads such as collector/distributor and local roads. These minor roads have the speed limit of 30 km/hr to 70 km/hr. Currently, the MHCM provides only the method to estimate the road capacity for arterial road or highway which has the free flow speed of 60 km/h and above. This research study not only closes the research gap, but also provides an important reference to the engineer who needs the road capacity information in the traffic analysis and planning.

1.7 Outline of the Report

This report consists of a total of 5 chapters. Chapter 1 is the introduction part, which consists of the background, importance of the study, problem statement, aim and objectives, and scope and limitation of this research. Chapter 2 is the literature review which comprises the literature that is relevant to the area of research for this study. Chapter 3 is the methodology, where the information on the research method that is applied is being organised and described in this chapter. Chapter 4 is the results and discussion where the findings that are relevant and appropriate for the problems of this study are analysed. Chapter 5 is the conclusions and recommendations, where the conclusions from the findings of the research is being drawn, and the recommendations for further research are also mentioned.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

It is significant to review and evaluate the methods of road capacity estimation available for our country and other countries around the globe. This is because the development of a road capacity estimation model, which is capable of being adopted on minor roads, requires references and comparisons of various methods available in terms of their methodology, suitability for local conditions, factors affecting the application of the methods and the advantages and disadvantages of the methods. The literature review for this study will be discussed in this chapter. This chapter shows the methods of road capacity estimation studied where it is composed of the application in Malaysia and other overseas countries. The factors affecting road capacity will also be studied from other research, which may be beneficial for this study.

2.2 Methods of Road Capacity Estimation

The approaches of road capacity estimation applied in other research in Malaysia and other countries around the world will be reviewed in this sub-chapter.

2.2.1 Highway Capacity Manual Method

An organised and consistent method for evaluating the level of service and capacity for the transportation facilities is provided by the parameters and procedures from the manual.

In Malaysia Highway Capacity Manual (MHCM), the values of road capacities for two-lane highways, multilane highways and basic segment expressways under base conditions are provided. Regression analyses are conducted with the data of speed, flow and density where trend lines that show the speed-flow and density-flow relationships were plotted. The data of the regression analysis are segregated according to different ranges of free-flow speed; hence the values of capacities for various types of roads under base conditions vary with the free-flow speed of vehicles. In low-volume conditions where drivers are not limited by other vehicles' presence or downstream traffic control systems and can move at their desired pace, free-flow speed is the vehicles' average speed on a certain segment. The speed-flow relationship for various types of roads is shown in the MHCM 2011, which is based on the empirical data collected at rural and suburban for the various types of roads in Malaysia. The trend lines for each type of road are different, but most of them show a decrease in average travel speed when the flow rate is increased. The relationship between average travel speed with flow rate for two-lane highways is shown in Figure 2.1.

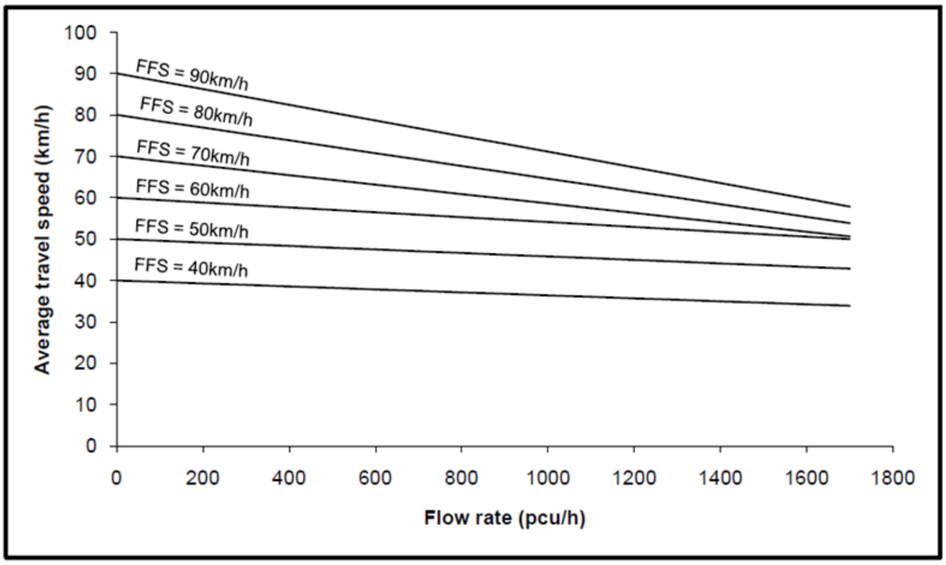


Figure 2.1: Relationship Between Average Travel Speed with Flow Rate for Two-Lane Highways (Highway Planning Unit Ministry of Works Malaysia, 2011).

The speed-flow relationship has a parabolic curve with horizontal axis symmetry in theory, but it is impossible to achieve a continuous curve in practice. From the relationship plotted in accordance with the empirical data obtained, the average travel speed will decrease with an increasing flow rate on two-lane highways. While trend lines displayed for free-flow speeds of 70, 80, and 90 km/h have the same gradient as flow rates approach capacity, the reductions in speeds are constant for free-flow speeds of 40, 50, and 60 km/h as flow rates approach capacities. For two-lane highways, the speed-flow relationship shows that the capacity is constant at 1700 pcu/h for each direction of travel for the range of free-flow speed. Figure 2.2 shows the speed-flow relationship on multilane highways in Malaysia.

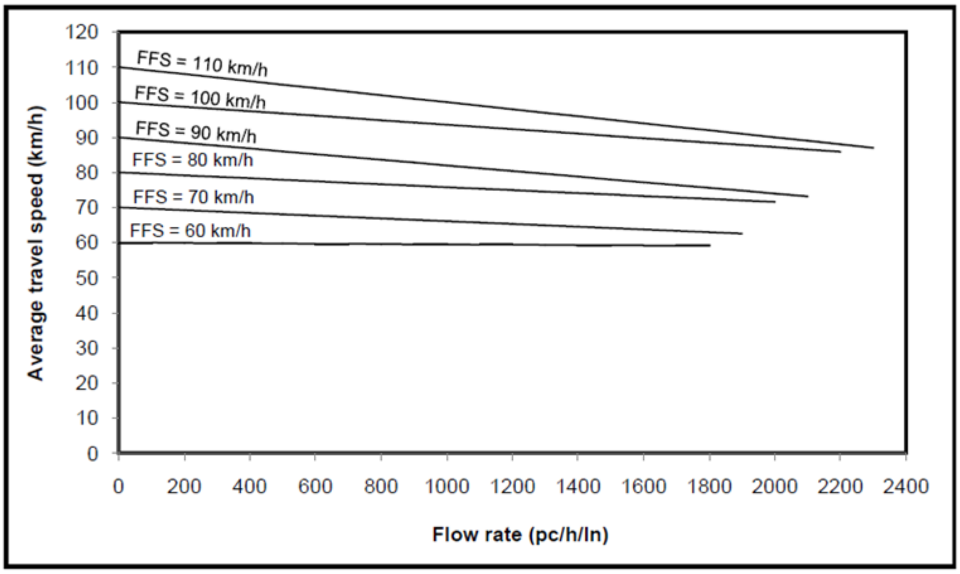


Figure 2.2: Relationship Between Average Travel Speed with Flow Rate for Multilane Highways (Highway Planning Unit Ministry of Works Malaysia, 2011).

According to the speed-flow relationship illustrated in Figure 2.2, the average travel speed decreased as the flow rate increased. For every free-flow speed, the speed decreases do not occur consistently. In general, the higher the value of free-flow speed, the speed decline becomes greater as the flow rate approaches capacity. It is determined in the manual that the capacity values of multilane highways for free-flow speeds of 60, 70, 80, 90, 100 and 110 km/h are 1800, 1900, 2000, 2100, 2200 and 2300 pcu/h/ln, respectively where slight modifications were adopted in these values based on the values applied in USHCM 2000.

The relationship between flow rate with average travel speed for two-basic segment expressways is depicted in Figure 2.3.

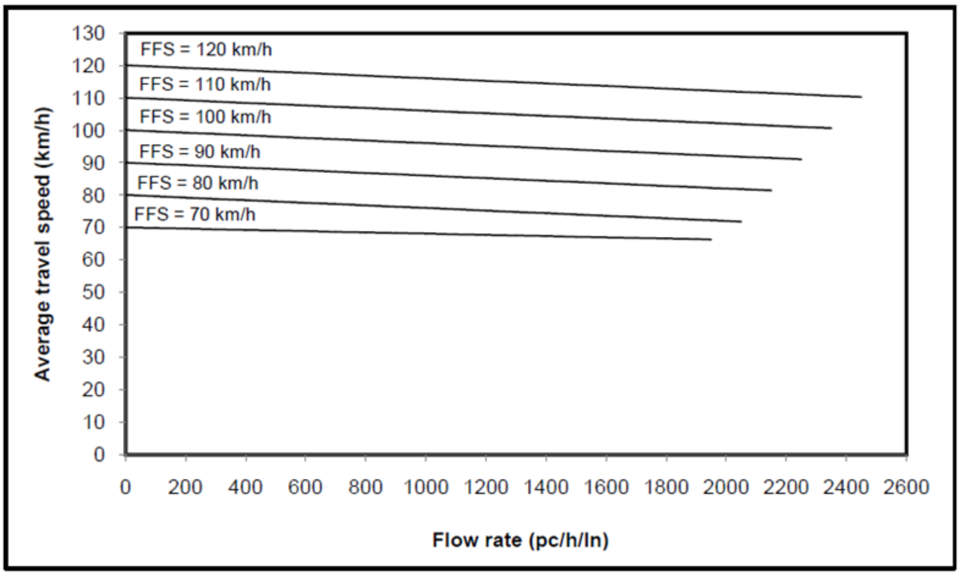


Figure 2.3: Relationship Between Average Travel Speed with Flow Rate for Basic Segment Expressways (Highway Planning Unit Ministry of Works Malaysia, 2011).

According to the speed-flow relationship depicted in Figure 2.3, average travel speeds declined as flow rates rose, and these decreases were fairly consistent for all free-flow speeds except for those above 70 km/h. The values of capacity for basic segment expressways with the free-flow speed of 70, 80, 90, 100, 110 and 120 km/h are identified to be 1950, 2050, 2150, 2 250, 2350 and 2450 pcu/h/ln, respectively in the manual.

The values of road capacities for two-lane highways, multilane highways and basic freeway segments under base conditions are also provided in USHCM 2010 and 2016. The base capacities represent the ideal conditions of a road facility where capacity-reducing effects are absent. For instance, it is assumed that there are no heavy vehicles, no additional friction effects from the poor pavement and no effects from nonrecurring sources of congestion. However, road capacity varies stochastically in a real-life situation where the values may be smaller or larger for any given location. Hence, the calibration of the base capacity to reflect local conditions is essential, and the manuals provide a method for the adjustment of capacity values. Table 2.1 shows the multilane highway segment and basic freeway capacity under base conditions which are provided by USHCM.

Table 2.1: Basic Freeway and Multilane Highway Segment Capacity under Base Conditions (Transportation Research Board, 2016).

Free Flow Speed (mi/h)	Capacity of Basic Freeway Segments (pcu/h/ln)	Capacity of Multilane Highway Segments (pcu/h/ln)
75	2400	NA
70	2400	2300
65	2350	2300
60	2300	2200
55	2250	2100
50	NA	2000
45	NA	1900

The base capacities of basic freeway segments for free-flow speeds of 55, 60, 65, 70, and 75 mi/h are determined to be 2250, 2300, 2350, 2400 and 2400 pcu/h/ln, respectively. For multilane highways, the base capacities for free-flow speeds of 45, 50, 55, 60, 65 and 70 mi/h are determined to be 1900, 2000, 2100, 2200, 2300 and 2300 pcu/h/ln, respectively. Before the adjustment of capacity for local conditions, it is significant to identify the factors that contribute to the reduction of capacity for multilane highways and basic segment expressways. The capacity adjustment factors are then calibrated based on the conditions of the road facilities studies to be adapted in the base capacity for adjustment. A local calibration study or judgement from an expert is necessary to come up with an acceptable estimate of roadway performance in the absence of generalised national data on the capacity-reducing effects. The resulting segment capacity ought to be interpolated as well due to the possibility of ranging between various FFS values. The capacity of a basic freeway segment can be adjusted, as shown in equation 2.1 below.

$$c_{adj} = c \times CAF \tag{2.1}$$

where

c_{adj} = specific mass flow rate, pcu/h

c = base capacity of segment, pcu/h

CAF = capacity adjustment factor

Weather, incidents, work zones, driver population, calibration modifications, and other factors can all be included in the CAF. Since there is no empirical study that applies these effects to multilane highways, it is not possible to modify the speed-flow equation using these CAFs for any roadway portions.

For the case of two-lane highways, the manual provided that its capacity value under base condition is 1700 pcu/h in one direction, and the value is limited to 3200 pcu/h for the total of both directions. The maximum opposing flow is limited to 1500 pcu/h when a capacity of 1700 pcu/h is reached in one direction due to the interactions between directional flows. Relevant adjustment factors are also applied to the two-lane highways' base capacity to estimate the capacity under prevailing conditions. The capacity estimation for two-lane highways can be based on either Average Travel Speed (ATS) or Percent Time-Spent-Following (PTSF), as shown in equations 2.2 and 2.3 below.

$$c_{dATS} = 1700 f_{g,ATS} f_{HV,ATS} \tag{2.2}$$

$$c_{dPTSF} = 1700 f_{g,PTS} f_{HV,PTSF} \tag{2.3}$$

where

c_{dATS} = capacity in the analysis direction under prevailing conditions in accordance with ATS, pcu/h

c_{dPTSF} = capacity in the analysis direction under prevailing conditions in accordance with PTSF, pcu/h

f_g = grade adjustment factor for PTSF/ATS determination

f_{HV} = heavy vehicle adjustment factor for PTSF/ATS determination

The adaption of a heavy vehicle adjustment factor for ATS and grade adjustment factor for ATS on the base capacity will yield the capacity in the analysis direction under prevailing conditions based on ATS, while the adaption of a heavy vehicle adjustment factor for PTSF and grade adjustment factor for PTSF on the base capacity will yield the capacity in the analysis direction under prevailing conditions based on PTSF. The class of highways will decide the need for computation for each type of capacity.

2.2.2 Road Traffic Volume Malaysia (RTVM)

Road Traffic Volume Malaysia (RTVM) specified an equation in the estimation of the maximum hourly traffic capacity of road facilities. This equation that yields the estimated road capacity value will be computed based on three parameters which are the ideal hourly capacity, the roadways reduction factor and the traffic reduction factor. The equation of maximum hourly traffic capacity estimation in RTVM is shown as follows in equation 2.4.

$$C = I \times R \times T \tag{2.4}$$

where

C = maximum one-way hourly capacity, pcu/h

I = ideal hourly capacity, pcu/h

R = roadways reduction factor

T = traffic reduction factor

The capacity for two-lane, two-way, and multilane highways under ideal conditions is defined in RTVM, and it is 2800 pcu/h for the total of two-lane highways and 2000 pcu/h for each lane of a multilane highway as shown in Table 2.2 below.

Table 2.2: Ideal Hourly Capacity for Multilane and Two-Lane Highways (Ministry of Works Malaysia, 2020).

Road Type	**Passenger Vehicle Units (PCU) per Hour**
Multilane	2000 per lane
Two-lane (both ways)	2800 for both ways

The carriageway roadway reduction factor could be obtained based on the carriageway width and paved shoulder width of the road facility through the interpolation of Table 2.3 shown below.

Table 2.3: Carriageway Roadway Reduction Factor (Ministry of Works Malaysia, 2020).

Carriageway Width	**Paved Shoulder Width**			
	2.00 m	**1.50 m**	**1.25 m**	**1.00 m**
7.5 m	1.00 m	0.97 m	0.94 m	0.90 m
7.0m	0.88 m	0.86 m	0.83 m	0.79 m

The computation of the traffic reduction factor will require information on the type of terrain of the road facility studied. This is because different equations are designated for different types of terrain as specified in RTVM. Equation 2.5, 2.6 and 2.7 show the equations to calculate the traffic reduction factor for mountainous, rolling and flat terrain of the road.

$$T = 100/(100 + 5Pc) \tag{2.5}$$

$$T = 100/(100 + 2Pc) \tag{2.6}$$

$$T = 100/(100 + Pc) \tag{2.7}$$

where

T = traffic reduction factor

Pc = estimated percentage of commercial vehicles that are classified as medium and heavy goods trucks and have an unladen weight of more than 1.5 tonnes, %

2.2.3 Van Aerde Model

In order to obtain the range of behaviour across various regimes and types of facilities, Van Aerde proposed the four-parameter Van Aerde model (VAM) that provides higher levels of independence. The approach is in accordance with a simple car-following model that utilises the smallest headway gap between adjacent cars. The headway is comprised of a constant term, a term that is based on the distinction between the speed at any given moment and the free-flow speed, and also a term that relies on the speed under any given time. The functional form of VAM is given by equation 2.8 below.

$$C_i = \frac{u_i}{c_1 + \frac{c_2}{u_{f,i} - u_i} + c_3 u_i} \tag{2.8}$$

where

C_i = estimated capacity for location I, veh/h

u_i = space mean speed for location i, km/h

$u_{f,i}$ = free flow speed for location i, km/h

c_1, c_2, c_3 = headway constant coefficients.

The parameters of the model are computed by applying the equations below.

$$m = \frac{2u_c - u_f}{(u_f - u_c)^2} \tag{2.9}$$

$$c_1 = mc_2 \tag{2.10}$$

$$c_2 = \frac{1}{k_j\left(m + \frac{1}{u_f}\right)^2} \tag{2.11}$$

$$c_3 = \frac{-c_1 + \frac{u_c}{q_c} - \frac{c_2}{u_f - u_c}}{u_c} \tag{2.12}$$

where

u_c = speed at capacity, km/h

q_c = denotes the flow at capacity, veh/h

k_j = jam density

After the model has been calibrated, the capacity is established as the maximum flow shown by the calibrated speed-flow curve. This method's simplicity makes it relatively simple to programme.

A nonlinear regression analysis technique that is applied in software like SPD_CAL can calibrate this model. (Modi, et al., 2014). The four parameters are calibrated by this programme which include the speed at capacity, free-flow speed, jam density and capacity for a set of data provided by solving an optimisation problem. The programme makes certain initial assumptions regarding the values of these four parameters before computing the error function for this initial solution in order to reach the values calibrated for these parameters. Then, by using a heuristic hill-climbing technique, the values of the speed at capacity, free-flow speed, jam density and capacity are varied iteratively, and the optimum parameters are chosen that minimise the summation of squared orthogonal error. The estimated capacity parameter, which corresponds to the peak of the fitted function along the speed-flow data plot, is deemed to be the capacity estimate of the road facility.

Li and Laurence (2015) applied the Van Aerde model as one of the capacity estimation approaches being compared in determining the best method to estimate capacity from Intelligent Transportation Systems (ITS) data. In terms of data requirements, modelling effort requirements, anticipated parameter values, theoretical underpinnings, and statistical fluctuations over time and between geographically varied localities, the Van Aerde model is compared to other widely used capacity estimation methodologies. Two test beds were used to test VAM; one was in San Diego, California, and consisted of data for a hundred and twelve workdays, while the other was in Shang Hai, China, and consisted of data for eighty-one workdays. For the study site at San Diego, it is the section westbound of Interstate 405 (I405) where at the detector position, four lanes and an upstream off-ramp may be observed. Its posted speed limit is 110 km/h, and the region is mainly urban which is frequently congested. For the study site at Shang Hai, it is the section at eastbound of the InnerRing Expressway situated at the Wuning crossroad. The speed limit posted is 80 km/h, and it consists of two main lanes. The speed-flow relationships for both San Diego and Shang Hai sites were plotted, and the capacities were estimated. The boxplots and histograms of the estimated capacities for San Diego and Shang Hai were also constructed to identify the overall capacity at each site. From boxplots and histograms of the capacities of from Van Aerde approach for San Diego, the daily capacity is seen to be in the range of 1732 to 2580 veh/h/ln and its standard deviation value is 213 veh/h/ln. Additionally, the Van Aerde capacity consists of a bimodal distribution is leftskewed and has a kurtosis value of -1.2. This was thought to have happened as a result of the nine days during which a capacity decline was noticed. From the boxplots and histograms of the capacities of from Van Aerde method for Shang Hai, the daily capacity values estimated with the application of this approach is determined to be ranging from 1986 to 2178 veh/h/ln with a standard deviation of 47 veh/h/ln and a mean of 2066 veh/h/ln. The study determined that the VAM provides a capacity estimation that is 7 % closer to the HCM capacity as compared with other methods. By regressing all of the flow rate data over a single day, the Van Aerde approach is able to calculate the theoretical capacity value. The study discovered that the VAM could be utilised to determine deterministic capacity across the research period because it is not directly related to breakdown events. This methodology, which is in accordance with the idea of traffic flow, excludes the requirement of the user to know the current state of traffic flow on a freeway beforehand. Additionally, it is simple to automate and is especially beneficial for sites with consistent traffic flow, like the one in San Diego.

Van Aerde model was one of the approaches used by Modi et al. (2014) in capacity estimation for assessing the non-weaving freeway segments' capacity on Florida freeways. For the purpose of gathering and analysing data, five Florida regional areas—Jacksonville, Orlando, Fort Lauderdale, Tampa, and Miami—were chosen. A number of twenty-two freeway segments from these five regional locations were selected for analysis, where six of them are from Jacksonville, the other six from Miami, five from Orlando, four from Tampa and one from Fort Lauderdale. Datasets with the volumes, speeds, and occupancy for all the chosen sites on Florida's freeways were obtained for the VAM approach. Based on the VAM requirement, five-minute data were transformed into one-hour flow rates and speeds. All of the calibration parameters were estimated using the VAM approach, which was implemented in the sets of data for each of the chosen sites. The free flow speed and capacity of all the studied sites, which are the parameters of estimation, were computed. The capacity estimations obtained from the VAM method were compared with the values of capacity specified by the HCM. The result of the study shows that the capacity point of VAM is at a flow rate that is significantly lower than most of the other flow-rate points, which could be consistently seen from the plots for every other site. This outcome is predicted since the VAM will be centred through the mass of points in order to allow a speed-flow curve to be fitted, which yields a statistically satisfactory fit. The capacity values that were observed to differ between the VAM technique and HCM values typically ranged from 3 % to 53 %. From the study, it can be concluded that the VAM analytical approach yields a range of capacity values that are reliable which are in the lower bound. This approach is nevertheless suitable for determining general capacity estimates, even though it is not as suited as the stochastic estimating method for comprehensive analyses of operational treatments. Some of the advantages of VAM are it excludes the need to identify breakdowns, it is the basis of traffic flow theory, and it is flexible in the adoption of various kinds of freeways.

Van Aerde method was one of the highway capacity estimation methods that were compared to other methods in the study by Asgharzadeh and Kondyli (2018). Utilising the information gathered from several ongoing merging bottlenecks in the Kansas City metropolitan region, the approach will be evaluated. In this study, several freeway merging junctions in the Kansas City metro areas were analysed. The sites under examination had a speed restriction of 60 to 65 mph and three to four lanes of traffic, respectively. The speed-flow data measured on the field and the Van Aerde curve were plotted. The capacity in the VAM is taken to be the highest volume on the speed-flow curve fitted. The fitted Van Aerde curves and speed-flow graphs for each of the examined merge intersections were also shown. It was observed that the curves were different for various sites where the congested regime was not fully captured, and it may be due to the detector located further downstream of the merge; hence the queuing conditions were not captured there. The freeway capacity results show that VAM yielded higher capacity estimated as compared to other methods. The reason for this is that this approach is based on maximum flows, which may or may not match the breakdown flows that have been recorded. The Van Aerde approach also offered the closest estimates to the typical pre-breakdown flow rates in contrast to the other methods. The study concluded that the VAM, despite how convenient its application, cannot accurately represent the capacity of the freeway since it does not take into account breakdown flow distribution or the breakdown events. In addition, the overall speed-flow scatter diagram has an essential impact on the calibration of the Van Aerde estimated values. A single estimate of capacity may not be suitable in these circumstances since it is difficult to determine the location of the real speed drop and the corresponding capacity.

2.2.4 Product Limit Method

The Product Limit Method (PLM) is depended on lifetime statistics and was initially researched to assess the variation in capacity values. Finding the breakdown events on the freeway segments is one of the important components of data analysis. These occurrences are often found by keeping an eye out for rapid declines in speed below a specific threshold or abrupt alterations in measures or relationships of traffic flow, such as occupancy, speed, and the correlation between occupancy and volume. Understanding the capacity distribution function is essential for applying the idea of freeway capacity randomness in PLM. The capacity distribution function is defined by equation 2.13 below.

$$F_c(q) = p(c \leq q) \tag{2.13}$$

where
$F_c(q)$ = capacity distribution function
q = observed traffic volume, veh/h/l
c = capacity, veh/h

A method was proposed that depended on an analogy to the statistics of analysis on the lifetime data. In its simplest form, this statistic serves to describe the statistical characteristics of the length of human life. Additionally, it is frequently used to evaluate the robustness of technical components. Equation 2.14 below shows the lifetime distribution function in this instance.

$$F(t) = 1 - S(t) \tag{2.14}$$

where
$F(t)$ = distribution function of lifetime

T = lifetime

$S(t)$ = survival function

Lifetime distributions are frequently approximated using short-term trials. As a result, it is impossible to assess the lifespan of some members of the sample since they last longer than the time allotted for the experiment. The only thing that can be said is that this lifespan exceeds the length of the experiment. Even so, this knowledge is helpful, and they are referred to as "censored data."

The statistics of lifetime data analysis can be utilised to predict distribution functions based on samples that contain censored data. The equation for the estimated survival function is as below:

$$\hat{S}(t) = \prod_{j:t_j<t} \frac{n_j - d_j}{n_j} \qquad (2.15)$$

where

$\hat{S}(t)$ = estimated survival function

n_j = number of individuals with a lifetime $T \geq t_j$

d_j = number of deaths at time t_j

By transferring to capacity analysis with both equation 2.14 and equation 2.15, the distribution function of capacity can be written as below.

$$F_c(q) = 1 - \prod_{i:q_j \leq q} \frac{k_i - d_i}{k_i} \quad i \in \{B\} \qquad (2.16)$$

where

$F_c(q)$ = distribution function of capacity

q = traffic volume, veh/h

q_i = traffic volume in interval i, veh/h

k_i = intervals number with a traffic volume of $q \geq q_i$

d_i = number of breakdowns at a volume of q_i

$\{B\}$ = set of breakdown intervals

The distribution parameters were calculated after the Weibull distribution was fitted once the breakdown probability models for each site were created using the PLM (Asgharzadeh and Kondyl, 2018).

Asamer and Reinthaler (2010) applied the Product Limit Method to assess changes in urban road traffic characteristics under adverse weather conditions such as rain and snow. Free flow speed and capacity, which are fundamental for defining the operation of traffic networks and establishing macroscopic traffic models, are the traffic characteristics investigated. The approaches are based on averaged flow and speed readings from local sensors. The traffic data utilised in this study were obtained from thirty-five fixed roadside sensors (loop sensors) on main roadways (arterial and ring roads) in the vicinity of a signalized crossroads in the Vienna urban area. Except for urban freeways, the speed limit in the entire city of Vienna is 50 km/h. The sensors provided data at one-minute aggregation intervals where the vehicle speed was averaged, and the traffic flow was accumulated. PLM is employed in this work for main urban roads under various weather circumstances, just as it was used for calculating capacity on freeways under various lighting situations. A theoretical distribution was fitted after getting an empirical probability distribution using the PLM. The distribution is truncated across a specific traffic flow; hence this was required. This is because the observations with the highest traffic flow that happened during the test time had censored values. For two types and a variety of numbers of precipitation for each location, the PLM estimate of the survival function and the Weibull distribution fitting has been carried out, and the results of the study are shown. The result of the study concluded that PLM is applicable to aggregated traffic metrics as long as the aggregation interval is under 15 minutes. The ratio between the duration of a green phase and the cycle length at the signalized intersection at the end of the connection is a key factor in determining the estimated capacity on urban roadways. The approach is thus limited to signal phases that are constant. Additionally, estimated capacity values are only valid for intervals of 15 minutes. Higher aggregation intervals would result in a reduced capacity.

The Product Limit Method was applied by Shao (2011) as a procedure for the capacity estimation of a freeway section according to the stochastic concept of freeway capacity. The flow rate of traffic is categorised into a number of intervals in accordance with the collected data and the need for accurate capacity estimation in this study. The distribution of traffic breakdown flow was calculated using maximum likelihood estimation based on the data. The capacity compute model was then built using a concept of capacity based on the probability of breakdown. The field data for this study were recorded on the third ring in Beijing City, China, with the utilisation of microwave detectors. The third ring has an 80 km/h posted speed restriction. During evening and morning peak hours, traffic is typically high, and breakdowns are common. In this study, data from a one-month period are used for both traffic directions. It is known that there is some distinction between lifetime data and traffic data where the real individual death times can theoretically be observed with lifetime data, but for the traffic flow, breakdown often lags the traffic flow rate. Additionally, there are "censored" observations, which are used to explain why the explicit lifetimes of some persons are not visible in the lifespan data. Therefore, it is not suitable to estimate the capacity using the traffic flow rate observed for all time intervals and only breakdown flow rates ought to be applied. The Monte-Carlo approach is used to simulate traffic flow according to data collection and analysis, and simulated data was applied to validate the method and show how the freeway capacity estimation is done using the procedure. The outcomes of the study show that the lifetime table approach in PLM and the recommended process are workable and appropriate.

Ben-Edigbe, Alhassan and Aminu (2013) applied and compared four direct empirical capacity estimation methods, which include the Product Limit Method. The efficacy of each method is assessed by applying the data for off-peak, peak period and transition to the peak. The data used in this study was obtained from federal roads in Johor Bahru, which is 23 km away from Universiti Teknologi Malaysia. The J5 is a dual-carriageway road that runs from Johor’s southern state to Kedah’s northern state and alongside the west coast of peninsula Malaysia. Three categories of vehicles were separated into passenger cars, light vans, and trucks/buses/coaches. During the time period, 1

316 834 vehicles were recorded, of which 10.23 % were motorcycles, and 75.80 % were cars (light category). In the traffic stream, there were 10.46 % other vehicles (in the medium category) and 3.51 % trucks (in the heavy category). For PLM, the cumulative distribution function was identified based on the data obtained. The capacity value is then calculated using the highest flows found in the profiles. Utilising data on volumes and speeds, the PLM calculates the capacity value. The probabilities of capacity, q_c being higher than any flow rate, q, were also computed. The flow rates were split into two groups: for flow rate values being below the capacity and values for flow rates at or over capacity using the median volume as the basis to define the capacity. The cumulative distribution function's subsequent plot was also displayed, and the capacity value for PLM is taken to be the 90^{th} percentile value for the cumulative distribution function. PLM requires indirect data handling since it is modelled and projected to the capacity level, indicating that the value this approach returns are futuristic values that were not obtained on the facility. The PLM's off-peak and transition-to-peak approaches produced no output. This makes sense, given that the off-peak and transition-to-peak data do not have extreme values as needed for the method to work. The result of the study concluded that the PLM’s ability to anticipate outcomes is limited because inconsistent results are produced by the method's arbitrary selection of the values of capacity from the cumulative distribution function. Additionally, as the technique specified, the PLM can only be used to model data with extreme values; thus, not all volume data can be applied with this approach.

2.2.5 Sustained Flow Index

The Sustained Flow Index (SFI) was introduced by Shojaat et al. as a method in an extension of the PLM. The product for a volume of traffic and "survival probability," or the possibility that the flow of traffic will continue at this volume, is used to define this measure. This approach will require estimating the capacity distribution functions for the road facilities studied before obtaining the final SFI value. The parametric and nonparametric capacity distribution functions for facilities could be estimated using models for censored data by drawing comparisons between the analysis of lifetime data and capacity analysis. The product limit approach for capacity analysis is employed in a transferred form to estimate the nonparametric distribution function where the equation applied is the same equation as shown in equation 2.16. A complete distribution function can only be constructed using this method if the maximum measured flow results in a breakdown. Rarely is a complete distribution function attained because that is not the case. In light of the fact that the estimated distribution function is a step function, where an increase in breakdown probability depends solely on the occurrence of a breakdown, it is advised to gather a sizable sample size in order to provide a trustworthy breakdown probabilities estimation at higher volumes. The maximum likelihood estimation technique is used for parametric estimation of the distribution function of capacity since the dependent variable is dichotomous. As a result, the type of capacity distribution is presumptively assumed, and the log-likelihood values are compared by a trial of various distributions. The distribution type that has the highest log likelihood value is chosen as the one from which the capacity has most likely come (Shojaat, et al., 2016). The capacity analysis's log-likelihood function is stated in equation 2.17 as follows.

$$\ln(L) = \sum_{i=1}^{n}\{\delta_i \cdot ln[f_c(q_i)] + (1-\delta_i) \cdot ln[1-F_c(q_i)]\} \qquad (2.17)$$

where

$f_c(q_i)$ = density function of capacity

$F_c(q_i)$ = cumulative distribution function of capacity

n = number of intervals

δ_i = 1 and 0 if interval i is uncensored and censored respectively

The capacity distribution function, which represents the stochastic character of capacity, is taken into consideration by the SFI as a metric of roadway performance. The capacity distribution function, which represents the stochastic character of capacity, is taken into consideration by the SFI as a metric of motorway performance. SFI is the product of the volume of traffic and the survival function’s value at the volume where it is the breakdown probability’s complement, or, to put it another way, the likelihood that the traffic volume is able to sustain without a breakdown. As a result, the SFI is the maximum theoretical average volume that is able to be sustained in fluid traffic under uncertain capacity conditions if the pre-breakdown volumes that do not represent desirable flow conditions are set to zero. The equation of SFI is shown below.

$$SFI = q_i \cdot S_c(q_i) = q_i \cdot (1 - F_c(q_i)) \quad (2.18)$$

where
SFI = Sustained Flow Index, veh/h
$S_c(q_i)$ = probability of survival at volume q_i
$F_c(q_i)$ = probability of breakdown at volume q_i
q_i = traffic volume in interval i, veh/h

The volume at which SFI is maximised is how this method defines capacity. If the Weibull distribution is considered for the breakdown probability function, the optimal flow rate (capacity) at which the SFI is maximised is shown in equation 2.19 below.

$$q_{opt} = \beta \left(\frac{1}{\alpha}\right)^{\frac{1}{\alpha}} \quad (2.19)$$

where
q_{opt} = optimum volume
β = shape parameters of the fitted Weibull distribution
α = scale parameters of the fitted Weibull distribution

A study was undertaken by Shojaat et al. (2018) to determine the reliability of the ideal volume recommended as a fair capacity estimate. Based on a sizable sample of freeway data from the United States, a thorough comparison between optimal volumes and conventional capacity estimations is made. The conventional capacity estimates, capacity distribution functions, and optimal volumes are being estimated and compared for freeway bottleneck sections in the United States. Based on traffic flow data collected at 5-minute intervals from nineteen urban freeway bottleneck areas in California, an empirical analysis was carried out for the comparison between the capacity values yielded with the conventional and stochastic approaches. The analysis of long-term speed contour plots was used to identify only unique bottlenecks in order to prevent spillbacks from downstream from affecting the capacity estimation. For each area under consideration, deterministic and stochastic capacities were estimated using a uniform sample size of one year. This enormous sample size made it possible to observe enough traffic breakdowns at each bottleneck section to accurately develop a distribution function of capacity. Both parametric and non-parametric capacity distribution functions were evaluated in order to determine the optimal volumes by maximising the SFI. The Weibull distribution was taken into account to calibrate the parametric distribution function. Optimal volumes and their accompanying breakdown probabilities were computed after the parameters had been calibrated. The same four-lane freeway section's SFI graph with the Van Aerde model superimposed was displayed. The results imply that the maximising of the SFI in getting the optimum volumes can be considered to be appropriate capacity estimates because they are typically within a fair range of conventional capacity estimates.

Shojaat et al. (2016) applied the Sustained Flow Index method in presenting a new indicator of freeway performance based exclusively on a stochastic method of capacity computation. New methods to apply the concept of randomness for highway operation analysis are needed because conventional operational performance measurements for the assessment of traffic flow on freeways often ignore the capacity's randomness. The SFI is an objective measure that represents the stochastic character of capacity in addition to being a new, more descriptive statistic to assess freeway performance. Volume and capacity are no longer required to be taken into account separately when using the SFI. The SFI estimates the ideal flow of a randomised system, which is crucial and valuable since it allows for the implementation of measures such as ramp metering and vehicle routing that will increase revenue and reduce user travel delays. German freeway traffic data samples were applied in this study. A number of eight four-lane motorway sections with a high share of commuter traffic and frequent breakdowns were chosen for investigation using large data samples from previous studies. Double inductive loop detectors were used to gather volume and speed data for each cross-section, which were then combined into 5-min intervals for analysis. Estimating the mathematical equations of the SFI required the parameters of the Weibull, gamma and normal distributions that are calibrated for each freeway segment. In order to determine whether the link between the two is impacted by the distribution type anticipated for capacity, the optimal volumes and the predicted values of the capacities for various distribution functions were also determined. The empirical findings demonstrate that the method of distribution affects the relationship between the optimal volume and the anticipated value of capacity. The SFI can also be used to optimise ramp metering approach and vehicle routing in emergency scenarios in addition to being a quantitative performance metric.

The Sustained Flow Index method, which is one of the breakdown probability methods, was applied by Uswaththa et al. (2021) to determine whether the breakdown probability approach is applicable in determining highway capacity under heterogeneous situations. Numerous studies have demonstrated the stochastic or probabilistic nature of freeway capacity, which is linked to the likelihood that traffic flow breakdowns may occur. However, there is a gap in the study on the use of the breakdown probability approach to estimate the capacity of multilane roadways under diverse traffic conditions that exist in Asian countries such as India and Sri Lanka. The traffic data applied in this study has consisted of two locations in Sri Lanka which are the New Kelani Bridge and A4 Highway Pannipitaya. Both of them are multilane highways that consist of two lanes in each direction of the highway. The SFI method was applied for three criteria of breakdown identification which were criteria one, two, and three. In criteria one, two, and three, the breakdown condition will arise when the average vehicle speed drops to 75 %, 70 %, and 60 % of the location's free-flow speed, respectively. For the New Kelani Bridge and Pannipitiya locations, the capacities obtained using SFI were 1841 pcu/h/ln and 1343 pcu/h/ln, respectively. In order to determine the best criterion for the conditions of heterogeneous traffic flow, these processes of capacity estimation were also performed for the breakdown criteria two and three. The study's findings demonstrated that, of the three criteria, the cumulative distribution function for the Pannipitiya locations and New Kelani

Bridge, respectively, under the SFI method, is best fitted by the first and second criteria. It is clear that the breakdown probability methodology yields lower capacity values when compared to the traditional conventional methodologies that were utilised to calculate the multilane roadway capacities. These capacity numbers provide a more accurate depiction of the operating roadway capacity, which will increase the likelihood that the road capacity can be estimated more precisely.

2.2.6 Headway Method

Headway, which is typically defined in fractions of seconds, is the time separation of vehicles in a traffic stream. Time gaps are taken from one vehicle's rear to the front of the next, while headways are calculated between common points or succeeding cars. Headway is an essential parameter in the analysis of traffic characteristics at the microscopic level, just as traffic flow is in the analysis of traffic characteristics at the macro level. The reason for this is that the headways distribution is crucially taken into account when assessing driver behaviour, vehicle attributes, and traffic flow circumstances, as well as when figuring out the road capacity. The assumption underlying headway estimating methods is that traffic is divided into two categories: forced flow, or traffic that follows each other closely, and traffic that arrives under free flow. The bases for capacity estimation with a headway approach are shown in the equations below.

$$h_m = \sum \frac{h_p}{n} \tag{2.20}$$

$$q = \frac{1}{h_m} \tag{2.21}$$

where

h_p = time headway between vehicle *P* and its next vehicle, s

h_m = mean headway for all the vehicles, s/veh

q = flow rate of vehicle, veh/h

n = number of vehicles pass through the section during time *t*

The equation above implies that the reciprocal of the minimum headway could be done to estimate the maximum flow of traffic. If the headway distribution of the vehicles is established as a mathematical model, then it would be able to predict the minimum mean headway and capacity. With the division of 3600 seconds per hour by the mean headway, h_m in equation 2.20, the road capacity can be computed as shown in equation 2.22 below (Qasim, et al., 2020).

$$C = 3600/h_m \tag{2.22}$$

where

C = road capacity, veh/h

h_m = mean headway for all the vehicles, s/veh

Sohrabi, Ovaici and Ghanbarikarekani (2016) implemented the Headway Method in the capacity estimation of basic freeway sections in a developing country. The time Headway Method was applied in this study to take into account all aspects that are more meaningful in developing countries, such as observation period, data requirement and location choice. The macroscopic and microscopic data types that were collected in the basic freeway section of Iran were both used in this study. Mean speed, mean headway and mean flow are macroscopic parameters, while vehicle acceleration rate and speed have been recorded as microscopic parameters. The gathered information is available as the mean headway of 5-minute intervals. The collected data were then filtered before the modelling of function determination, which will be analysed based on its validity, reasonability and applicability. For a simple 3-lane freeway section, the capacity values have been estimated for each lane and the overall section based on the relationship between headway and flow rate. The result of the study showed that the capacity estimated using the headway model for the basic freeway section is 6099 vehicles per hour for 3 lanes which is 12 % less than the HCM's value. The variance in capacity may be due to the factors such as driver behaviour and vehicle performance in Iran. The study concluded that by simulating the behaviour of drivers in Iran's freeways' congested flow, the headway model might be employed in many behavioural and safety research.

The Headway Method was one of the empirical methods adopted by Suresh and Umadevi (2014) to investigate the fundamentals of traffic flow and evaluate the capacity of a midblock section in urban areas, specifically a two-lane divided cross-section. Ten mid-block sections of four-lane divided (two lanes on both sides) roadways in Chennai city served as the collection sites for the data of this study. The advantages of the video recording approach over the manual and traditional methods of data collecting led to its usage for data collection. To choose the site, a reconnaissance assessment was first conducted. All ten survey locations' road names, carriageway width, peak hour, and peak hour traffic (numbers and pcu) are tabulated in a table. The result of the study showed that the traffic volume on the chosen two-lane split roadways varies from 3186 veh/h to 9975 veh/h during peak hours. It concluded that the direct empirical approach applying the fundamental traffic characteristics observed, such as headway, is applicable to capacity estimation, and the headway model was observed to yield the highest capacity estimated. The significant alteration in the flow characteristics and the driver's behaviour may be the cause of the greater capacity value.

Qasim et al. (2020) estimated the road capacity according to the headway time to take into account that road user behaviour is the primary component of the microsystem of traffic analysis. In order to reflect the driving behaviour in each lane, the lane position is also taken into account when creating the capacity headway model. Palestine Street, which is a multilane highway in Baghdad City, was selected as the site study for simulating the characteristics of multilane urban highways. To reflect the high traffic flow level, data on the features of the headway time, vehicle volume, and roadway are gathered during peak hours. Multiple regression, a statistical approach applied to determine the link between contributed variables in order to generate a model that is predicted at a selected level of confidence, was applied to construct the Headway Time-Flow Model, and the validity of the model was tested. The estimated capacity using the headway model for each lane of the multilane highway studied was compared with the values obtained using the HCM model. The findings demonstrate that the HCM capacity model overestimates capacity because it ignores driver behaviour, which is taken into account in this study utilising headway time. The results of this study also reveal that the lane position has an impact on the capacity value, contrary to the HCM techniques' assumption that the average capacity is the same for all lanes.

2.2.7 Volume Method (Selected Maxima Method)

The only input used to estimate capacity is the observed traffic volume for the Fundamental Diagram or also known as the Selected Maxima Method. The capacity is estimated using the known highest traffic volumes that have been observed over a period of time in the observed extreme value technique. The data to be used for this approach is the hourly traffic volume of flow rates measured in an averaging interval of less than an hour. The fundamental assumption behind this method is that the road capacity is equal to the observed traffic flow maxima over the course of the entire observation period (Suresh and Umadevi, 2014). Taking the average of the observed maximum day intensities is an illustration of a very simple implementation of the Selected Maxima Method. The volume approach entails gathering data over an extended period of time and determining the maximum flows throughout that time. Until enough data is gathered for analysis, flow rates should be observed over several days. The capacity can be determined from the volume approach using equation 2.23 below.

$$q_c = \sum_i q_i / n \tag{2.23}$$

where

q_c = capacity value, veh/h

q_i = maximum flow rate observed over period *i*

n = cycle numbers

i = cycle period length over which a maximum flow rate is identified

The volume approach was applied by Abdullah and Hua (2017) to estimate the capacity of selected locations. Bottleneck path, maximum flow and the shortest path were identified for the locations selected in this study.

These outputs were determined to reduce the congestion and transportation issues in the locations studied since they were beneficial for transport planners in the decision-making of bottlenecks and allowed drivers to reach their desired destinations in a shorter time when avoiding the routes with traffic congestion at the same time. Two types of data which were the traffic volume and distances were obtained from Bandaraya Mosque, located in Kota Kinabalu, to Kampung Air, with all of the routes between the source and sink node fixed. Data on traffic volume were gathered via manual traffic counting with video recordings, while the Google Earth software was used to gather distance information. The number of vehicles with pcu values was multiplied to get the maximum flows at 5-minute periods in pcu. The maximum flow in 5 minutes in pcu was multiplied by a factor of twelve to determine the total capacity in pcu. The capacity values obtained were then applied to compute the maximum flow by utilising simplex linear programming in Microsoft Excel. The study concluded with the determination of the shortest path of the road network and the identification of the maximum flow value, which was 2598 veh/h.

2.2.8 Fundamental Diagram

This method is built on a Fundamental Diagram, sometimes known as a stream flow diagram. The three traffic parameters that determine how well a road can handle a traffic stream are speed, density, and volume. The speed-volume relationship is frequently used as an effective technique for determining a carriageway's traffic capacity among the three traffic parameters. The capacity is estimated using the relationship between two crucial variables, namely traffic volume and harmonic mean speed. Without converting various vehicle types into a common unit, it is challenging to estimate the traffic volume in heterogeneous traffic flow. Since passenger cars are frequently used as standard vehicles, the conversion factor is also known as the passenger car unit (PCU). Chandra and Kumar (2003) developed the equation to compute the pcu, which is shown in equation 2.24 below.

$$PCU = \frac{V_c/V_i}{A_c/A_i} \tag{2.24}$$

where

V_c = speed of car, km/h

V_i = speed of ith type vehicle, km/h

A_c = static area of a car, m^2

A_i = static area of *i*th type of vehicle, m^2

Therefore, the pcu computation, as shown above, takes into account heterogeneity in the traffic scenario with regard to different vehicle dimensions and their performance by incorporating the speed ratio and area ratio.

There is a significant difference in speed between slow-moving and fast-moving vehicles when there is mixed traffic. As a result, while calculating the speed for mixed traffic, the space mean speed or spot speed, which is usually calculated for homogeneous traffic, cannot be taken into account. Modification is required to suit the traffic condition that is heterogeneous, and the application of a mean stream speed is suggested (Minh, Matsumoto and Sano, 2005). The equation of mean stream speed is given as equation 2.25 below.

$$V_m = \frac{\sum_{i=1}^{k} n_i v_i}{\sum_{i=1}^{k} n_i} \tag{2.25}$$

where

V_m = mean stream speed, km/h

k = total number of vehicle categories available in the stream

v_i = speed of vehicle of category i, km/h

n_i = number of vehicles of category i

After the average stream speed is determined by equation 2.25, it was be plotted against the traffic volume to demonstrate the speed-volume relationship in estimating the road capacity.

Minh, Sano and Matsumoto (2005) developed speed-flow relationships for locations selected for research that addresses a thorough investigation of motorcycle behaviour. In order to illustrate the characteristics of motorcycle speed and time headway in relation to traffic flow, statistical analyses of the actual data were used. The criteria for data collection, including undivided roadways, exclusive motorcycle lanes and mixed traffic, were found to be met in four places in Hanoi, Vietnam. For locations 1 and 2, the type of road facility is four-lane divided roadways with raised medians, while for locations 3 and 4 the type of road facility is two-lane undivided streets. The speed-volume relationships for all four locations were plotted in the same graph for comparison. The result of the study showed that each location's fluctuation in traffic volume is unique due to its various lane lengths and other unique features. The location with an undivided roadway tends to have lower speeds since the drivers decreased their speeds to avoid any occurrence of accidents from opposing traffic. The mean speed is also higher for locations consisting of wider lane widths. It can be concluded that the speed volume approach is effective in assessing the factors or driver behaviour that affect the road capacity or speed of traffic.

The Fundamental Diagram method was applied by Jain, Mane, Arkatkar and Joshi (2019) for capacity estimation on undivided hilly roads that consist of two-lane under prevailing heterogenous traffic conditions. Four distinct study sections with varying gradient magnitudes between Saputara and Waghai town, located in the State of Gujarat, India, were chosen. The magnitude of the gradient was in the range of 2 % to 7 % for the roadway sections studied. In order to estimate capacity utilising 5-minute flow rate values as well as the other macroscopic factors, Fundamental Diagrams were created using Geenshield's model for four separate sections. The result of the study showed that the capacity value of road facilities increased as the gradient decreased. The capacity of the roads studied with varying gradients was found to be falling in the range of 1800 to 2700 pcu/h. Comparison of capacity values for hilly terrain from other nations, such as China, also implied that the capacity values of this study were more consistent and lay in the range of capacity values of the corresponding countries. Hence, the 5-min interval flow data applied for the estimation of capacity values using the Fundamental Diagram method is realistic.

Chandra and Kumar (2003) implemented the Fundamental Diagram method to assess the effect of lane width on capacity values under mixed traffic conditions. Ten two-lane road segments that are minor roads in various regions of India were the sites of data collection for this study. The carriageway's width, which is the total width of the road with a paved surface without its shoulder are ranging from 5.5 m to 8.8 m. At each road section, the pcus of all the vehicles, which were classified into nine different categories, were estimated. The capacity of all the two-lane sections that consisted of different carriageway widths was determined by the speed-volume approach, and a plot between the capacity and carriageway width was constructed. The result of the study showed that the pcu for a particular vehicle type increase linearly with road width. This is explained by the fact that broader roads allow for more mobility and, as a result, have higher speed differences between cars and other types of vehicles. The total width of the roadway increases the capacity of a two-lane road as well, and the two have a second-degree curve in their relationship. The adjustment factors for lanes with inadequate widths are derived using this relationship, where the outcomes were evaluated against existing research.

2.3 Factors Affecting Road Capacity

In order to develop an effective and applicable model for road capacity estimation, the factors that may impact the capacity values of various types of road facilities are to be studied and taken into account. The Highway Capacity Manual (HCM) specified a few factors that affected road capacity and categorised them under four conditions. These conditions are comprised of base conditions, roadway conditions, traffic conditions, and control conditions. Other than the conditions mentioned, conditions or factors that may bring an impact on the capacity values of the roadway should be assessed and identified to yield an accurate calibration factor to be adopted in the capacity estimation model.

Abdel-Aal, El-Maaty and Samra (2018) conducted a study to assess the factors that lead to the decrease in road capacity under non-ideal conditions in Egypt. The factors such as heavy vehicles, environmental factors, lane width and driver population were simulated through a case study utilising SYNCHRO software and the outcomes were discussed. The region chosen for this study is located on Abo-Qir Street in Alexandria, Egypt, between the U-turns at the intersections of Al-Ibrahimia and Ahmed Lutfi Esayed. The factors that result in decreased road capacity in Egypt's non-ideal circumstances are broken down into three categories which are the factors managed by the simulation software that will not be included in the capacity equation, factors involved in the calibration process, known or unknown; and known factors that are added to the capacity equation with their original values or changed values based on the circumstances. The factors under the first category included the number of lanes, lane width, design speed and so on; the factor under the second category was the driver population; and the factors under the third category were weather, median type and surface condition. The result of the study showed that any incident in the location studied that closes one of the three lanes in one direction will lead to a 33 % capacity reduction. It also concluded that accidents had a considerable impact on the overall delay, fuel consumption, and queue length; when one of the three lanes was closed, the overall delay increased by 85%, fuel consumption climbed by 300 %, and the maximum queue length grew by 2000 %. The total delay increased by 100 %, the fuel usage by 1000 %, and the maximum wait length grew by 8000 % when two of the three lanes were closed. In the simulation, several values of this factor are tested until the visual representation of the traffic circumstances is close to reality. The calibration factor's ideal value has been determined to be 0.817.

The impact of median U-turns on the capacity of Thailand's multilane primary highways was evaluated by Chaipanha, Tanwanichkul and Pitaksringkarn (2018) with the utilisation of traffic micro-simulation models. The model accurately depicts reality in terms of the infrastructure network, traffic demand, and driver behaviour, which helps to overcome survey constraints and complicated phenomena that are challenging to evaluate mathematically. For the purpose of estimating the capacity of multilane primary highways, the maximum capacity was determined as both a base estimation and the prevailing condition. Four-lane and six-lane highways were chosen as the sections for this study in order to examine the effect of median U-turns on the capacity of multilane primary highways. Results from the micro-simulation model were discovered to be considerably less than those from the HCM 2010 approach. This shows that the highway capacities produced by the micro-simulation modelling from survey database circumstances were different from those of HCM 2010. Hence, by taking into account a median U-turn factor, micro-simulation models were created to ascertain and estimate the maximum capacity for the base and scenario conditions. Because they were unaffected by any influences, the capacity estimates of the six-lane and four-lane primary highway findings under the base conditions were both marginally higher than those of the HCM 2010 computation. The capacity values for each type of primary roadway under the prevailing conditions, however, were much lower than those of the HCM 2010 approach. This was caused by the influence of traffic characteristics and other factors that disrupted the flow of traffic.

. The influence of the number of lanes on the capacity of the highway was investigated by Yang and Zhang (2005). A deeper knowledge of the relationship between highway capacity and its corresponding number of lanes was methodologically offered in this study on the basis of the statistical analysis of the survey. For modelling the effect of the number of lanes on capacity, a single-factor variance analysis was applied. The studied areas selected were the urban location in the north of Beijing in China. Following panel observations, it was decided that the data would be collected from three different types of divided and uninterrupted highway sections, each with two, three, and four lanes. The observations on average capacity per lane for the different lanes of highways were tabulated in a table, and it can be observed that the means of observations on various highways clearly differ from one another. It is evident that as the number of lanes increases, the average capacity per lane gradually decreases, according to the result of the study. By analysing the variations in traffic characteristics on different highways, the reason for the result yielded may be due to the increased chances of lane-switching and increased interaction between vehicles with the increasing number of lanes on the highway.

2.4 Summary

The methods of road capacity estimation are reviewed from an adequate number of research conducted in our country or overseas country in this chapter. The methods reviewed are comprised of the Van Aerde model, Product Limit Method, Sustained Flow Index, Headway Method, Volume Method and Fundamental Diagram method. The significant information related to the methods of road capacity estimation applied in the research reviewed is recorded in this chapter. The concluded results for each of the literature reviewed are also summarised in this chapter. The factors affecting road capacity, which is one of the fields of interest in this study are being reviewed. The Fundamental Diagram method was applied to estimate the capacity of minor roads in the research reviewed; however, this method was applied only to determine the overall capacity value and demonstrate the speed-volume relationship in the traffic flow. There is a lack of a model that can be applied to estimate the capacity of minor roads with basic traffic predictors from the research reviewed.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter covers the data-gathering method to be applied and the methodology implemented in the model development will be explained.

3.2 Flowchart

The step-by-step procedure conducted in this study is shown in Figure 3.1.

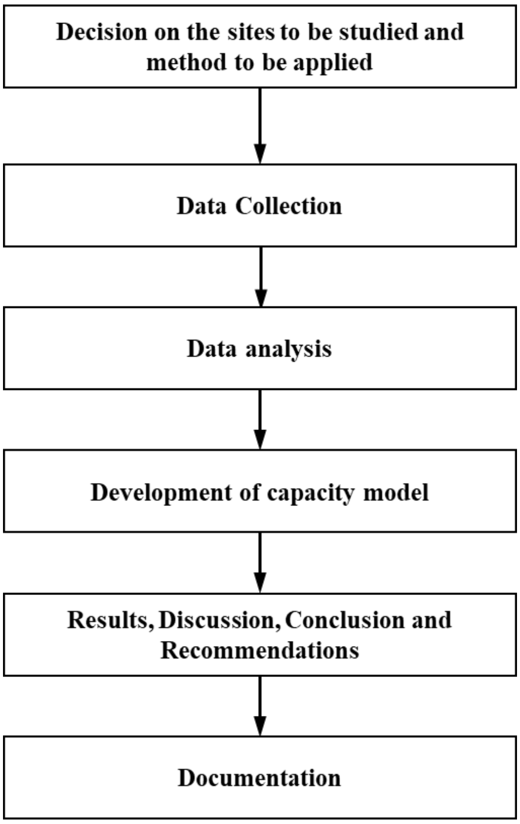


Figure 3.1: Flowchart of Methodology.

Based on the flowchart shown above, the conduction of the methodology for this study started with the selection of sites for traffic data collection and the method to be applied in estimating road capacity. After that, the traffic data collection at the selected sites with the necessary equipment and tools was conducted. After that, a capacity estimation model for minor roads was developed and assessed to ensure that the aim and objectives of this study were achieved. The relevant results, discussions, conclusion, and recommendations of this study were prepared in the report which was followed by the documentation of the entire report. The details of the procedure are described in the sub-sections below.

3.3 Sites Selection

The type of roads of interest in this study is collector or distributor roads and local roads due to the issues arising from the lack of a standard methodology and theory in the capacity estimation of the minor roads in our country as mentioned in the previous chapter. Other than that, the factors affecting road capacity were taken into account in the selection of a suitable site. One of the site selection criteria is sub-urban area since these areas have more minor roads as compared to Kuala Lumpur City Centre. Besides that, the roads that are classified as collector/distributor road and local road according to road hierarchy in road design are selected as the sites. Other than that, the diversity of the road type is considered in sites selection such as the roads that comprise of single carriageway or dual carriageway. The sites selected are also at the mid-block of the roads which are free from roadside parking, bus stop and intersection. After looking into the possible areas to conduct this research, three areas located in Kuala Lumpur were selected which are Bandar Sungai Long, Bandar Mahkota Cheras and Maluri. The reasons for these areas to be selected are to ensure the diversity of the results of the traffic data collected for various areas with different traffic stream characteristics. Table 3.1 shows the sites selected for this study and their corresponding satellite and street views.

Table 3.1: Satellite and Street Views of Sites Selected.

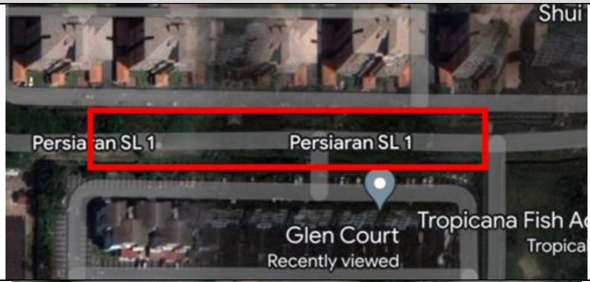
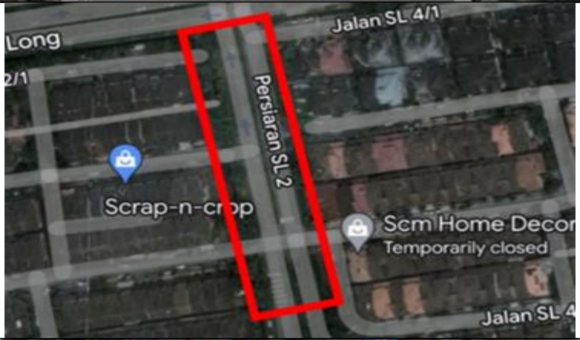
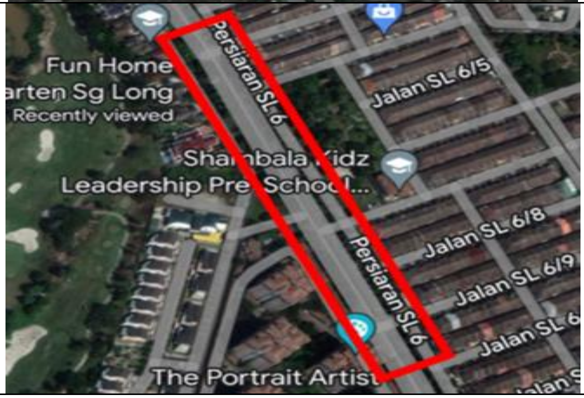
No.	Site	Carriageway and Road Type	Area	Satellite View	Street View
1	Persiaran Sungai Long 1	2-Lane Single Carriageway, Local Road	Bandar Sungai Long		
2	Persiaran Sungai Long 2	2-Lane Dual Carriageway, Collector/ Distributor Road	Bandar Sungai Long		
3	Jalan Sungai Long (near Green Acre Park)	2-Lane Dual Carriageway, Collector/ Distributor Road	Bandar Sungai Long		

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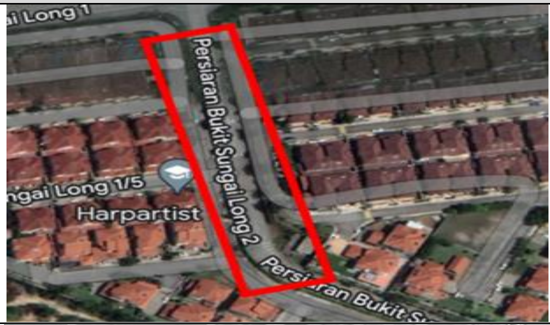
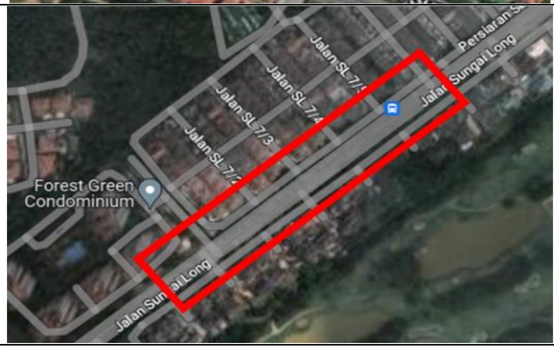
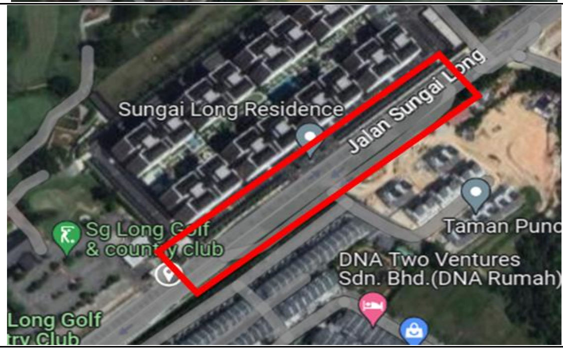
Table 3.1: Satellite and Street Views of Sites Selected. (Continued)

No.	Site	Carriageway and Road Type	Area	Satellite View	Street View
4	Persiaran Bukit Sungai Long 2	3-Lane Single Carriageway, Local Road	Bandar Sungai Long		
5	Jalan Sungai Long (near Forest Green Condominium)	2 Lane-Dual Carriageway, Collector/ Distributor Road	Bandar Sungai Long		
6	Jalan Sungai Long (near Sungai Long Residence)	2 Lane-Dual Carriageway, Collector/ Distributor Road	Bandar Sungai Long		

(Continued on next page.)

Table 3.1: Satellite and Street Views of Sites Selected. (Continued)

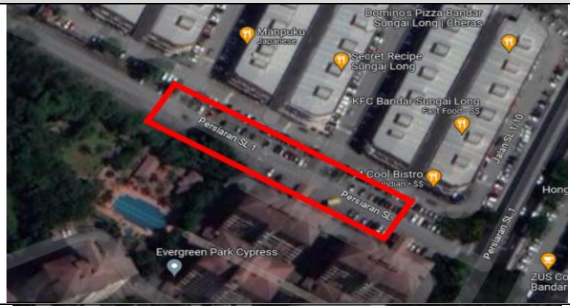
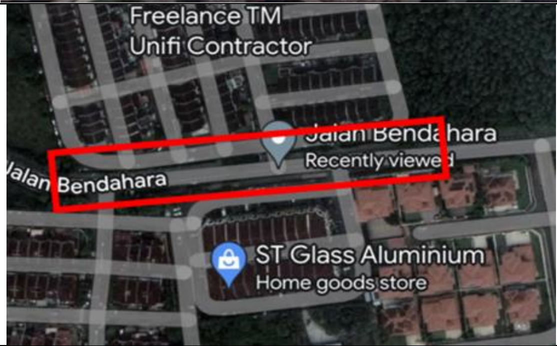
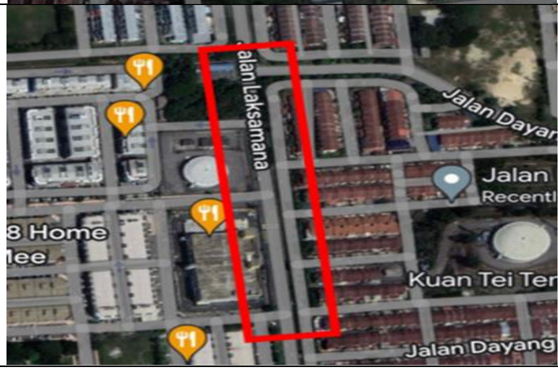
No.	Site	Carriageway and Road Type	Area	Satellite View	Street View
7	Persiaran SL 1	2 Lane-Single Carriageway, Local Road	Bandar Sungai Long		
8	Jalan Bendahara	4-Lane Single Carriageway, Collector/ Distributor Road	Bandar Mahkota Cheras		
9	Jalan Laksamana	4-Lane Single Carriageway, Local Road	Bandar Mahkota Cheras		

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Table 3.1: Satellite and Street Views of Sites Selected. (Continued)

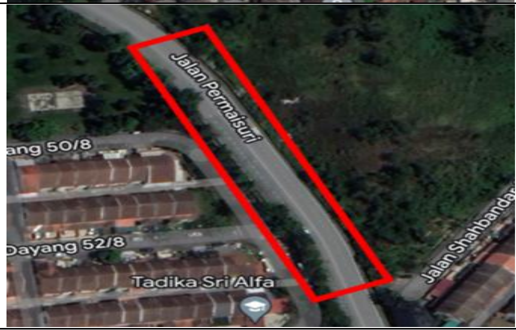
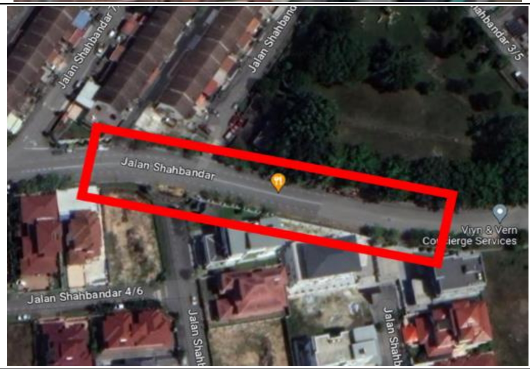
No.	Site	Carriageway and Road Type	Area	Satellite View	Street View
10	Persiaran Mahkota Cheras 1	3-Lane Dual Carriageway, Collector/ Distributor Road	Bandar Mahkota Cheras		
11	Jalan Permaisuri	3-Lane Single Carriageway, Collector/ Distributor Road	Bandar Mahkota Cheras		
12	Jalan Shahbandar	4-Lane Single Carriageway, Local Road	Bandar Mahkota Cheras		

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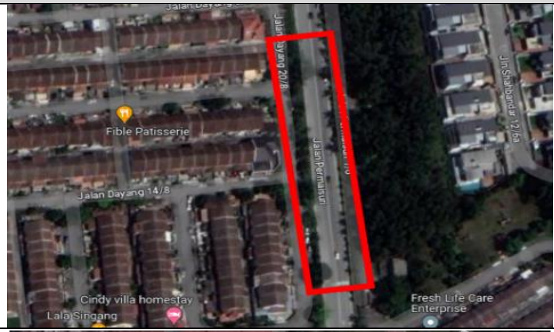
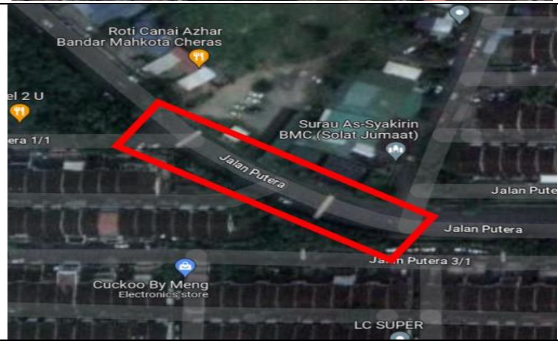
Table 3.1: Satellite and Street Views of Sites Selected. (Continued)

No.	Site	Carriageway and Road Type	Area	Satellite View	Street View
13	Jalan Permaisuri	4-Lane Single Carriageway, Local Road	Bandar Mahkota Cheras		
14	Jalan Dayang	2-Lane Single Carriageway, Local Road	Bandar Mahkota Cheras		
15	Jalan Putera	2-Lane Single Carriageway, Local Road	Bandar Mahkota Cheras		

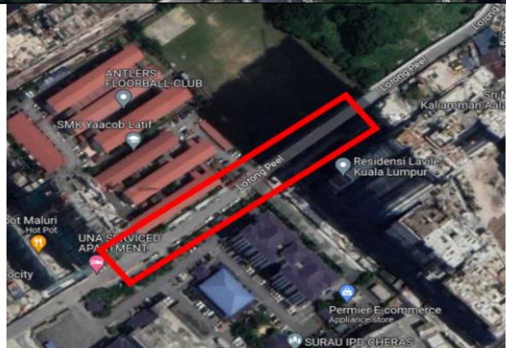
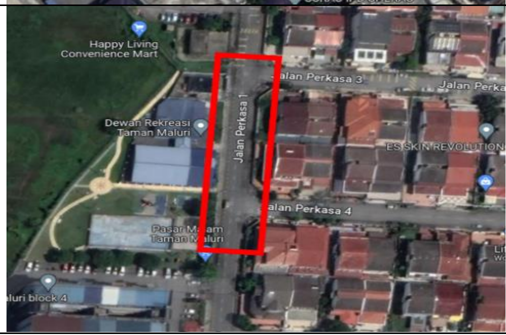
(Continued on next page.)

Table 3.1: Satellite and Street Views of Sites Selected. (Continued)

No.	Site	Carriageway and Road Type	Area	Satellite View	Street View
16	Jalan Inang	2-Lane Single Carriageway, Local Road	Bandar Mahkota Cheras		
17	Jalan Cochrane	3-Lane Dual Carriageway, Collector/ Distributor Road	Maluri		
18	Jalan Perkasa	3-Lane Dual Carriageway, Collector/ Distributor Road	Maluri		

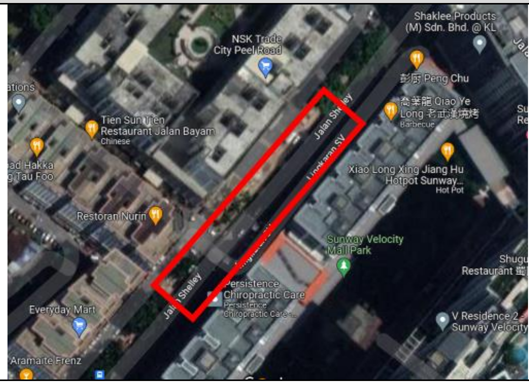
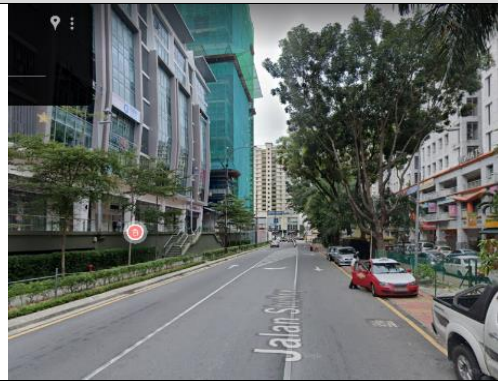
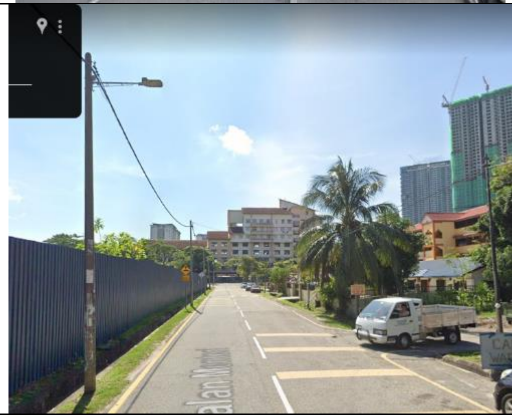
(Continued on next page.)

Table 3.1: Satellite and Street Views of Sites Selected. (Continued)

No.	Site	Carriageway and Road Type	Area	Satellite View	Street View
19	Lorong Shahbandar	2-Lane Single Carriageway, Local Road	Maluri		
20	Lorong Peel	2-Lane Single Carriageway, Local Road	Maluri		
21	Jalan Perkasa 1	2-Lane Single Carriageway, Local Road	Maluri		

(Continued on next page.)

Table 3.1: Satellite and Street Views of Sites Selected. (Continued)

No.	**Site**	**Carriageway and Road Type**	**Area**	**Satellite View**	**Street View**
22	Jalan Shelley	3-Lane Single Carriageway, Local Road	Maluri		
23	Jalan Menteri	2-Lane Single Carriageway, Local Road	Maluri		

Each of the dual carriageway roads selected in data collection contributes to two sites with two sets of data since both of the carriageways in dual carriageway do not interfere with one another in terms of traffic flow. From Table 3.1, fourteen of the roads selected for data collection are dual carriageway and sixteen of the roads selected are single carriageway which made up a total of thirty sites originating from the three areas mentioned. A number of eleven sites selected are from Bandar Sungai Long, ten sites are from Bandar Mahkota Cheras and the remaining nine sites are from Maluri. Among the sites selected, sixteen of them are collector or distributor roads while fourteen of them are local roads. These roads were selected to ensure that sufficient traffic data could be collected in the capacity estimation model development. All of the roads selected are surrounded by residential and commercial areas which also possess minor road characteristics at the same time.

3.4 Data Collection Schedule

The scheduling of the data collection was arranged based on a few conditions to ensure that the data is applicable to this research. As mentioned in the previous sub-chapter, the sites selected consist of twenty-three roads in different locations where fourteen of the roads are dual carriageway and the remaining roads are single carriageway. In the case of a dual carriageway, it is considered as a roadway that consists of carriageways with opposing-direction traffic which is divided by a median. Hence, the scheduling of the data collection has allocated two days for the dual carriageway roads which contributed to two sets of data being collected. There were thirty days of traffic data collection to complete the data collection of sixteen single carriageway roads and fourteen dual carriageway roads. Besides that, most of the data collection was conducted between Tuesday to Thursday and any official holidays were excluded in the scheduling of data collection to ensure that the traffic flow of the sites has minimum fluctuation on the day of data collection. The morning peak hour of 8 am to 9 am with the interval of 15-minute periods was adopted to obtain the traffic flow rate in this study. Table 3.2 shows the scheduled date for the sites selected for data collection.

Table 3.2: Scheduled Date and Time for Data Collection.

No.	Site	Bound Direction of Road	Date (Day)
1	Persiaran Sungai Long 1	Eastbound and Westbound	2023-01-03 (Tuesday)
2	Persiaran Sungai Long 2	Northbound	2023-01-04 (Wednesday)
3	Persiaran Sungai Long 2	Southbound	2023-01-05 (Thursday)
4	Jalan Bendahara	Eastbound and Westbound	2023-01-10 (Tuesday)
5	Jalan Cochrane	Westbound	2023-01-11 (Wednesday)
6	Jalan Perkasa	Westbound	2023-01-12 (Thursday)
7	Jalan Cochrane	Eastbound	2023-01-17 (Tuesday)
8	Jalan Perkasa	Eastbound	2023-01-18 (Wednesday)
9	Persiaran Bukit Sungai Long 2	Northbound and Southbound	2023-01-19 (Thursday)
10	Jalan Sungai Long (near Green Acre Park)	Northbound	2023-02-02 (Thursday)
11	Jalan Sungai Long (near Green Acre Park)	Southbound	2023-02-07 (Tuesday)
12	Jalan Laksamana	Northbound and Southbound	2023-02-08 (Wednesday)
13	Persiaran Mahkota Cheras 1	Northbound	2023-02-09 (Thursday)
14	Persiaran Mahkota Cheras 1	Southbound	2023-02-15 (Wednesday)
15	Jalan Permaisuri (collector/distributor road)	Northbound and Southbound	2023-02-16 (Thursday)
16	Jalan Sungai Long (near Forest Green Condominium)	Northbound	2023-02-21 (Tuesday)
17	Jalan Sungai Long (near Forest Green Condominium)	Southbound	2023-02-22 (Wednesday)
18	Jalan Sungai Long (near Sungai Long Residence	Northbound	2023-02-23 (Thursday)
19	Jalan Sungai Long (near Sungai Long Residence	Southbound	2023-02-28 (Tuesday)
20	Jalan Permaisuri (local road)	Northbound and Southbound	2023-03-01 (Wednesday)
21	Persiaran SL 1	Northbound and Southbound	2023-03-02 (Thursday)
22	Lorong Shahbandar	Eastbound and Westbound	2023-03-07 (Tuesday)

(Continued on next page.)

Table 3.2: Scheduled Date and Time for Data Collection. (Continued)

No.	Site	Bound Direction of Road	Date (Day)
23	Lorong Peel	Northbound and Southbound	2023-03-08 (Wednesday)
24	Jalan Perkasa 1	Northbound and Southbound	2023-03-09 (Thursday)
25	Jalan Shahbandar	Eastbound and Westbound	2023-03-14 (Tuesday)
26	Jalan Dayang	Eastbound and Westbound	2023-03-15 (Wednesday)
27	Jalan Putera	Northbound and Southbound	2023-03-16 (Thursday)
28	Jalan Inang	Eastbound and Westbound	2023-03-21 (Tuesday)
29	Jalan Shelley	Northbound and Southbound	2023-03-22 (Wednesday)
30	Jalan Menteri	Eastbound and Westbound	2023-03-23 (Thursday)

3.5 Data Collection Method

The traffic data for this study was collected through video recording technique since it possesses greater benefits over the conventional and manual method of traffic data collection. The video recording approach was applied instead of the manual method since the manual method is time-consuming, prone to error and requires huge manpower in data collection (Arun, Velmurugan and Errampalli, 2013). The video recording data collection was conducted on weekdays during the morning peak hours at the mid-block section of the road selected. Marking was done on the road to specify the desired length of the mid-block section studied. The video camera was positioned at a vantage location around the site to ensure that the equipment was able to collect the traffic data over the full stretch of the road studied. In terms of the gathering of necessary geometric data, such as the width of the road, the manual approach utilising the measuring tapes was conducted at the site. Besides that, the distance of a certain stretch of road at the site which is displayed on the screen of the video recorder was measured and marked with visible objects for the purpose of traffic average speed and density computation. Figure 3.2 shows the set-up of the video recorder at Jalan Sungai Long near Sungai Long Residence.

Figure 3.2: Set-up of Video Recorder at Jalan Sungai Long near Sungai Long Residence.

3.6 Methods of Capacity Estimation

The Fundamental Diagram approach was selected to be applied in this study to estimate road capacity among all of the methods reviewed. The reason for this is that the Fundamental Diagram is a conventional approach used in road capacity estimation. The other approaches such as the Product Limit Method and Sustained Flow Index require the computation of data in an intensive manner, and they are not suitable to be applied for sites with low amounts of breakdown observation. Van Aerde model is also inefficient in segments that do not fully represent the range of congested or uncongested conditions (Asgharzadeh and Kondyl, 2018). Other than that, multiple linear regression analysis is also conducted to determine the factors that may affect the traffic flow of minor roads. After the development of the models and the Fundamental Diagrams, the Level of Service (LOS) of the sites selected was determined using the main model and other approaches reviewed for comparison.

3.6.1 Traffic Parameters Computation

Three main parameters were obtained for this approach from the studied site, and they are the mean stream speed or average traffic speed that is expressed in km/h, the traffic flow that is expressed in pcu/h and the traffic density that is expressed in pcu/km. The spot speed or space mean speed that is usually applied in this approach could not be used in this situation with mixed traffic since they are only applicable in homogeneous traffic. The reason behind this is due to the fact that significant speed difference exists between vehicles that are moving slowly and moving fast in mixed traffic. Hence, in order to cater for the heterogeneous traffic condition, modification is necessary, and the mean stream speed is recommended to be applied. The equation of mean stream speed is shown below.

$$V_m = \frac{\sum_{i=1}^{k} n_i v_i}{\sum_{i=1}^{k} n_i} \tag{3.1}$$

where

V_m = mean stream speed, km/h

k = total number of vehicle categories available in the stream

v_i = speed of vehicle of category i, km/h

n_i = number of vehicles of category i

The equal hourly rate at which vehicles cross a specific location or roadway stretch during a specific period of time is referred to as the flow rate. Flow rate estimation usually requires sampling over a shorter period of time – typically 15 minutes and is expressed in terms of vehicles per hour. However, the computation of traffic flow is to take into account the varying influences of the mixed vehicles travelling on the road studied. Hence, the passenger car unit (pcu) was applied for the purpose of converting a traffic stream comprised of different types of vehicles into a traffic stream that is equivalent and consists of passenger cars entirely. It is also significant to record the traffic composition observed at the stretch of road studied to determine the composition of each type of vehicle during the data collection period. The vehicles travelling in the traffic stream of the site were categorised into car, motor, small lorry, large lorry and bus in this study. The conversion factor for passenger car unit for different standards is provided by Arahan Teknik (Jalan) 8/86 - A Guide on Geometric Design of Roads and is shown in Table 3.3 below.

Table 3.3: PCU Conversion Factors for Various Vehicles (Roads Branch Public Works Department Malaysia, 2015).

Type of Vehicle	**Equivalent Value in p.c.u's**			
	Rural Standards	**Urban Standards**	**Round About Design**	**Traffic Signal Design**
Passenger Cars	1.00	1.00	1.00	1.00
Motorcycle	1.00	0.75	0.75	0.33
Light Vans	2.00	2.00	2.00	2.00
Medium Lorries	2.50	2.50	2.80	1.75
Heavy Lorries	3.00	3.00	2.80	2.25
Buses	3.00	3.00	2.80	2.25

The traffic density of the sites was computed by referring to the video recorded for each of the sites. The parameter required to compute the traffic density is the distance headway or spacing which is the distance between successive vehicles. Since the distance of a certain stretch of road at the site which is displayed on the screen of the video recorder was being measured and marked with visible objects, the distance between the successive vehicles could be captured, and by reviewing the full length of the video recorded, the average distance headway was obtained. Equation 3.2 shows the computation of traffic density with the average distance headway.

$$k = \frac{1000}{\bar{s}} \tag{3.2}$$

where

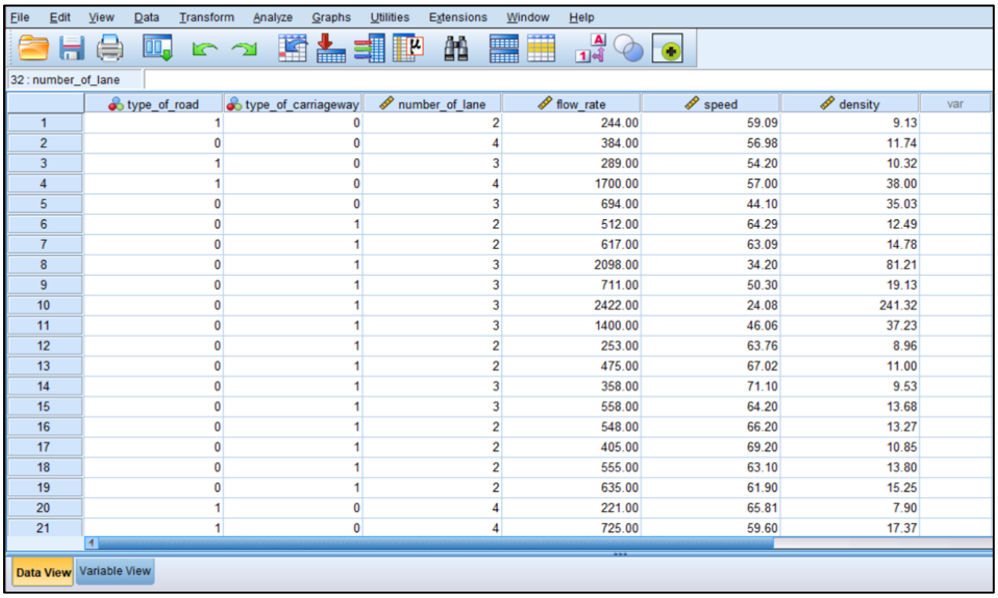
k = traffic density, pcu/km

$\bar{s}$ = average distance headway, m/pcu

With the computation of the average stream speed and traffic flow from the traffic data being completed, the relationship between average stream speed and traffic flow with traffic density was developed for the selected road in this study. Flow-density Fundamental Diagram and speed-density Fundamental Diagram were constructed to determine the essential traffic parameters for estimating road capacity.

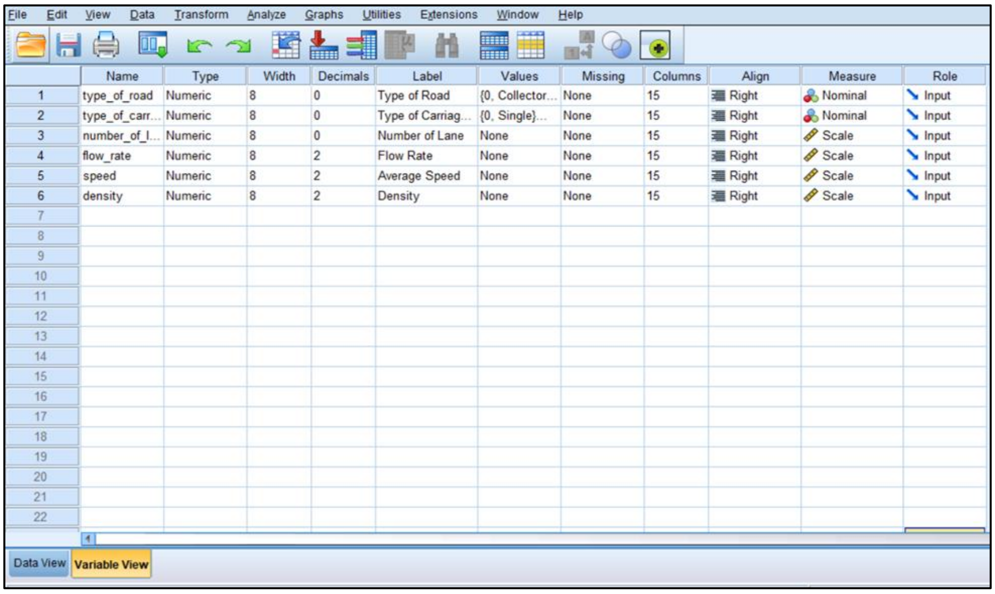
3.6.2 Software Applied in Models and Fundamental Diagrams Development

In the development of models and Fundamental Diagrams to estimate road capacity and determine factors affecting traffic flow, the application of suitable software is required to ensure the objectives of this study could be achieved. IBM® SPSS® Statistics was selected as the software to be applied in this study. It is a Windows-based programme used for data entry, analysis, and the creation of tables and graphs. It provides an intuitive interface and a robust set of features that enable its users to rapidly extract actionable insights from their data. Statistical analysis, multiple linear regression analysis and graph creation which were conducted in this study could be done using the SPSS software. There are two methods to view data in SPSS, and you can switch between them using the "Data View" and "Variable View" tabs on the window's bottom left. The "Data View" tab, which is the most helpful for viewing the actual values reported in the dataset, displays the variables in columns and each observation in rows. In the "Variable View", SPSS displays each variable as a row and lists further details about it in a series of columns, including "Name", "Type", and "Label". Figure 3.3 shows the input of the traffic data in "Data View" while Figure 3.4 shows the details and information of the traffic parameters in "Variable View".



	type_of_road	type_of_carriageway	number_of_lane	flow_rate	speed	density	var
1	1	0	2	244.00	59.09	9.13	
2	0	0	4	384.00	56.98	11.74	
3	1	0	3	289.00	54.20	10.32	
4	1	0	4	1700.00	57.00	38.00	
5	0	0	3	694.00	44.10	35.03	
6	0	1	2	512.00	64.29	12.49	
7	0	1	2	617.00	63.09	14.78	
8	0	1	3	2098.00	34.20	81.21	
9	0	1	3	711.00	50.30	19.13	
10	0	1	3	2422.00	24.08	241.32	
11	0	1	3	1400.00	46.06	37.23	
12	0	1	2	253.00	63.76	8.96	
13	0	1	2	475.00	67.02	11.00	
14	0	1	3	358.00	71.10	9.53	
15	0	1	3	558.00	64.20	13.68	
16	0	1	2	548.00	66.20	13.27	
17	0	1	2	405.00	69.20	10.85	
18	0	1	2	555.00	63.10	13.80	
19	0	1	2	635.00	61.90	15.25	
20	1	0	4	221.00	65.81	7.90	
21	1	0	4	725.00	59.60	17.37	

Figure 3.3: "Data View" with Traffic Data Input in SPSS Software.



	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	type_of_road	Numeric	8	0	Type of Road	{0, Collector...	None	15	Right	Nominal	Input
2	type_of_carr...	Numeric	8	0	Type of Carriag...	{0, Single}...	None	15	Right	Nominal	Input
3	number_of_l...	Numeric	8	0	Number of Lane	None	None	15	Right	Scale	Input
4	flow_rate	Numeric	8	2	Flow Rate	None	None	15	Right	Scale	Input
5	speed	Numeric	8	2	Average Speed	None	None	15	Right	Scale	Input
6	density	Numeric	8	2	Density	None	None	15	Right	Scale	Input

Figure 3.4: "Variable View" with Traffic Parameters Details in SPSS Software.

After inputting the required data and information into the software, the multiple linear regression analysis was conducted to yield the output of the analysis with a few tables generated by the software. Figure 3.5 shows the tab displayed in SPSS software prior to multiple linear regression analysis.

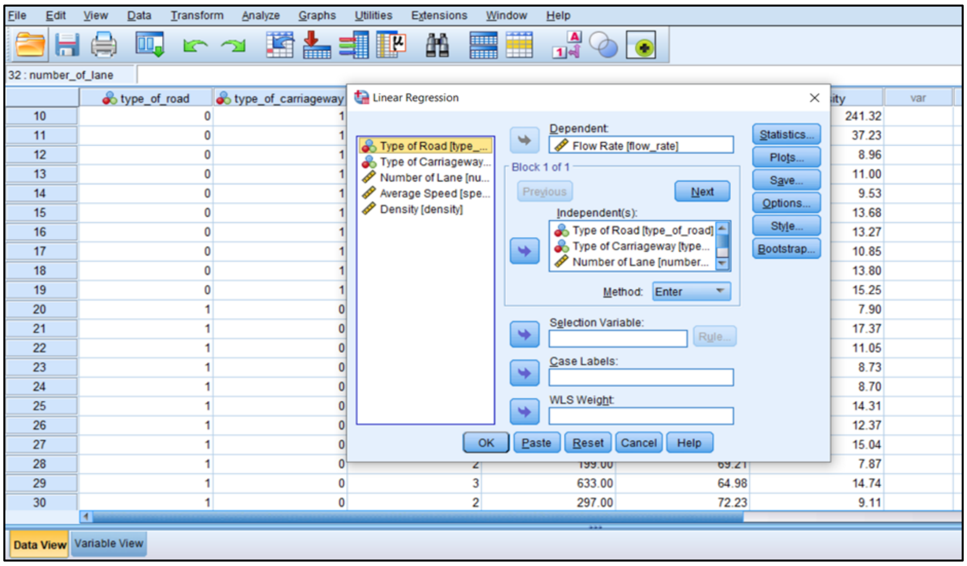


Figure 3.5: Selection of Dependent and Independent Variables for Regression Analysis in SPSS Software.

The construction of the Fundamental Diagrams was done by utilising the graph creation function in the SPSS software. Figure 3.6 shows the tab displayed in the software for the selection of variables as x-axis and y-axis prior to generating the desired plotting of the graph.

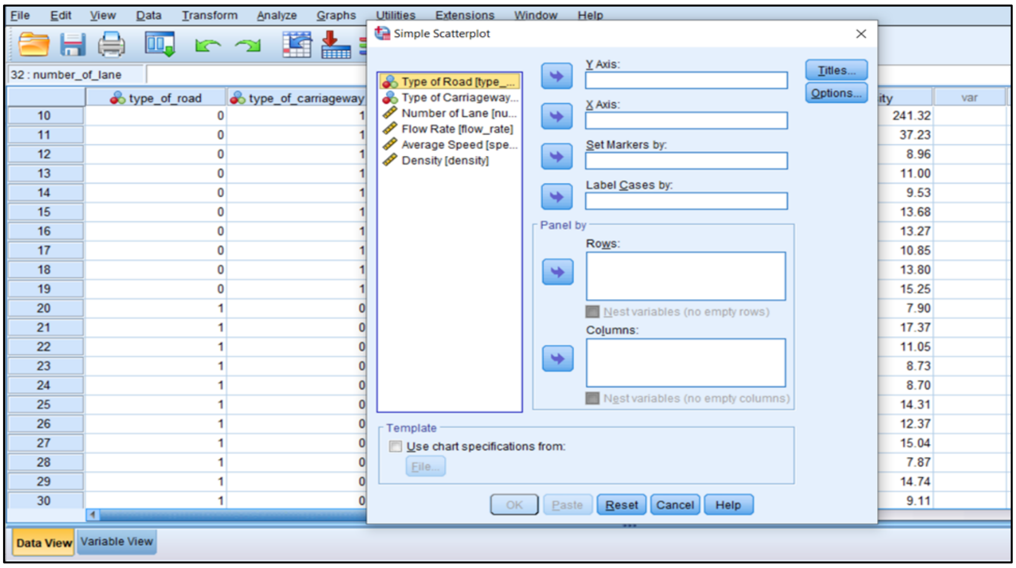


Figure 3.6: Selection of Variables as X-axis and Y-axis for Graph Plotting in SPSS Software.

3.6.3 Multiple Linear Regression Analysis

Multiple linear regression is a statistical method used to predict the result of a variable according to the values of two or more other variables (Hayes, 2022). The technique allows analysts to determine the variation in the model as well as the corresponding contributions of each independent variable to the variance as a whole. Multiple linear regression was conducted in this study to determine the factors that may alter the capacity of a road and to identify the relationships between various independent variables and the dependent variable to be forecasted. Multiple linear regression was first carried out to determine the significance of each of the factors affecting traffic flow before applying the Fundamental Diagram method to estimate road capacity. Other than that, a general equation from multiple linear regression analysis was developed to estimate the traffic flow and be applied in computing the road capacity by altering the value of the traffic parameters in the equation reasonably.

3.6.3.1 Dependent Variable and Independent Variables

The goal of this study is to create a model that forecasts the relationship between a dependent variable and a number of independent factors. The dependent variable is what is attempted to forecast, and the independent variables are those that might have an impact on the dependent variable. This means that the potential factors that may affect the capacity of a road are to be taken into account while creating a model in this study. In order to effectively represent the relationship between the variables in our model, all pertinent independent variables were included. In addition, the potential confounding effects of other variables on how independent variables and dependent variables are related were taken into account by introducing sufficient independent variables in the model. This contributes to the development of a more precise model that can more accurately forecast the correlation between the variables. In this study, the dependent variable was traffic flow while the independent variables were the type of road, number of lanes, type of carriageway, average speed and density.

Different types of roads are designed with distinct characteristics to serve various purposes. This supports the fact that the type of road could be one of the factors that may affect road capacity. Local roads and collector or distributor roads are the type of roads being selected for data collection in this study since a model that could contribute to estimating road capacity for minor roads is wished to be developed.

In order to distinguish between the carriageways as single carriageway or dual carriageway, it is necessary to determine the presence of a median in the roadway. A single carriageway is an undivided highway without a central reservation while a dual carriageway is a divided highway with carriageways with opposing lanes of traffic that are divided by a median. The type of carriageway for a roadway could affect the road capacity in several ways. By lowering the possibility of head-on collisions between vehicles moving in the opposite direction, the presence of a median can increase road capacity by allowing for higher travel speeds and more traffic to flow through the road. However, the existence of medians can also have some detrimental effects on the capacity of the road when there is an excess of medians, or they are too wide. Hence, the type of carriageway is one of the factors to be studied to determine its relationship with the capacity of a road.

It is known that the number of lanes on a road can also significantly affect its capacity. In general, a road’s capacity may be increased by adding more lanes because it gives traffic more space to move and pass each other. A higher number of lanes can handle more vehicles, reducing traffic congestion and delays while allowing for more traffic to flow through the road.

Higher average vehicle speeds could lead to higher road capacity since vehicles are able to travel at higher speeds which cover greater distance travelled over a period, allowing a higher volume of traffic to pass through. Besides that, vehicles travelling at higher speeds can influence lane utilisation on a road facility since they are more likely to fully utilise the lanes available, enhancing efficient usage of road space and reducing the blockage of the lane. These could increase the overall road capacity which maximises the number of vehicles that can travel in a given direction. In this study, the average speeds of vehicles are collected at the sites selected to determine their impact on road capacity.

Traffic density plays a crucial role in determining road capacity and is one of the variables to be studied in this research. The available space on the road reduces when the traffic density increases which results in the reduction of road capacity. This is because vehicles require more space for stopping and manoeuvring safely when they are closely spaced, leading to increased congestion and lower travel speed. Conflicts between vehicles such as turning movements and lane changing may be increased with higher traffic density, which may further affect the road capacity.

3.6.3.2 Output of Multiple Linear Regression Analysis by SPSS Software

After the multiple linear regression analysis has been conducted with the SPSS software, the outcome of the analysis was presented in a few tables generated by the software. The tables of interest to interpret and understand the result of the analysis are comprised of the Model Summary table, ANOVA table and Coefficients table.

Firstly, the value of R, or the multiple correlation coefficient, may be viewed in the "R" column of the Model Summary table. The R-value illustrates the relationship between the dependent and independent variables. An R-value greater than 0.4 indicates that the model has a good level of prediction of the dependent variable and could be further analysed. The R^2 value which is known as the coefficient of determination could be obtained from the "R Square" column. This value displays the overall variance for the dependent variable that the independent factors could account for. A value greater than 0.5 suggests that the model is capable of determining the relationship. The value from the "Adjusted R Square" column demonstrates the results' generalisability, such as the degree to which the sample results diverge from the population in multiple regression. A minimal difference between the R-square and adjusted R-square is desired.

Moving on to the ANOVA table generated by SPSS software, the information in this table is essential in deciding if the model is significant enough to predict the outcome. In this table, two elements are relevant for the interpretation of the results, and they are the p-value and F-ratio. The p-value is the value shown in the “Sig.” column which determines the significance of the model. A 95 % confidence interval is usually selected in the study which means that the p-value should be less than 0.05 for the result to be significant. The F-ratio could be determined from the “F” column where it displays the improvement in the variable's prediction by fitting the model after taking the model's correctness into account.

In the Coefficients table, the strength of the variables' relationship where the variable's significance in the model and the degree with which it affects the dependent variable are demonstrated. One of the essential elements in this table is the p-value from the "Sig." column which is required for the hypothesis testing of the study. The p-value for each variable will decide whether the null hypothesis will be rejected. A p-value less than 0.005 implies that the null hypothesis for the particular variable is rejected and vice versa. A variable is said to be statistically significant and has an impact on the dependent variable only if the null hypothesis is rejected. Besides that, the values in the "B" column of the "Unstandardised Coefficients" are essential in generating the equation that predicts the dependent variable. It demonstrates how much the dependent variable fluctuates with an independent variable under the condition where all other independent variables are maintained constant.

3.6.4 Fundamental Diagram

The development of a Fundamental Diagram is essential in determining the relationship between traffic speed, flow, and density in this study. Flow-density Fundamental Diagram and speed-density Fundamental Diagram were developed in this study to determine the relationship between these traffic parameters for minor roads. Figure 3.7 shows an example of a flow-density Fundamental Diagram extracted from the Malaysia Highway Capacity Manual.

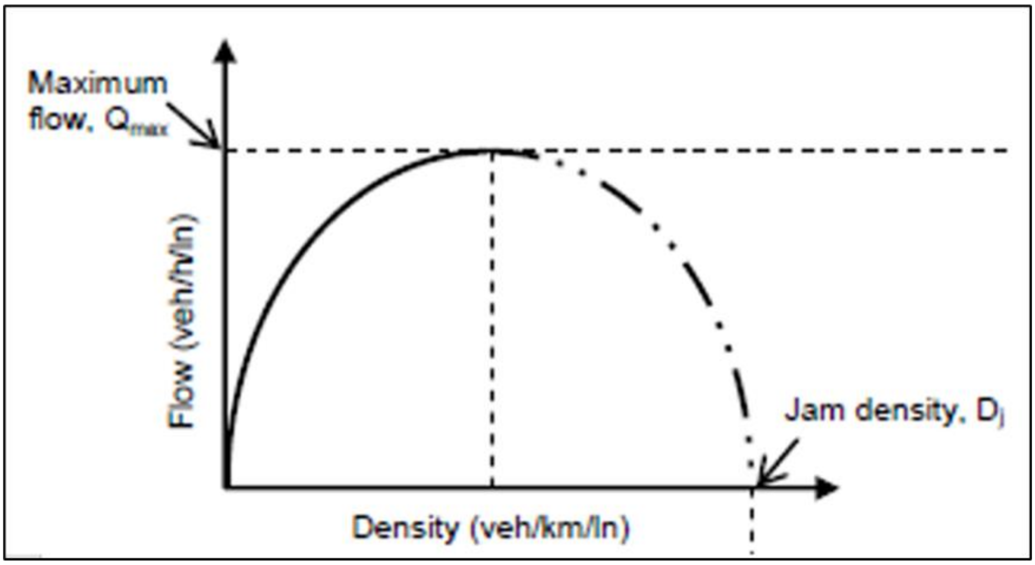


Figure 3.7: Flow-Density Fundamental Diagram (Transportation Research Board, 2016).

Based on Figure 3.7, it is determined that the flow-density Fundamental Diagram displays a parabolic curve with a maximum vertex. This implies that the equation of this diagram is in the form below:

$$q = \beta_1 k^2 + \beta_2 k + c \tag{3.3}$$

where
q = traffic flow, pcu/h
k = traffic density, pcu/km
β = coefficient
c = y-intercept

The maximum vertex represents the maximum flow, q_{cap} which is the capacity of a roadway. Hence, the road capacity value was determined from this diagram by differentiating equation 3.3 and equating it to zero as shown below:

$$\frac{dq}{dk} = 0 \tag{3.4}$$

where

q = traffic flow, pcu/h

k = traffic density, pcu/km

3.7 Summary

The flowchart of methodology, location of the sites, data collection method, the method applied for capacity estimation and software applied are all included in this chapter. The sites for this study were within Bandar Sungai Long, Bandar Mahkota Cheras and Maluri and the roads selected were minor roads comprised of collector or distributor roads and local roads. The video recording approach and manual approach using measuring tape were applied for traffic data and geometric data collection for this study. Multiple linear regression analysis was carried out to create the models for estimating traffic flow and determining the factors affecting traffic flow. The Fundamental Diagram approach is selected to be applied in this study among all the methods reviewed. Besides that, the workflow for the methodology of this study is illustrated in a flowchart. The timeline and duration for each work are also mentioned in the gantt chart and the major phases in the planning consist of data collection, analysis, model development and final report preparation.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The results of the data collected are then tabulated accordingly before data analysis and the development of models and Fundamental Diagrams. This chapter covers the development of the main model and the sub-models and the construction of Fundamental Diagrams for the models to estimate the road capacity and factors that may affect the traffic flow of the minor roads. The comparison of the results of the Level of Service (LOS) between the main model and the other approaches reviewed is also conducted in this chapter. The model for capacity estimation of minor roads is then developed and the factors affecting the road capacity are determined.

4.2 Results of Traffic Data Collected

A road capacity estimation model is to be developed and the factors affecting road capacity are to be determined to achieve the objectives of this study. After collecting the required traffic data from the sites selected, the data was analysed and applied for models and Fundamental Diagrams development. The traffic parameters that are essential for this study are also being computed based on the data collected. The traffic data collected from the thirty sites and the computed traffic parameters that are required for the model development are shown in Table 4.1.

Table 4.1: Traffic Data Collected for the Thirty Sites.

No.	Area	Name	Type of Road	Type of Carriageway	Number of Lanes	Average Flow Rate (pcu/h)	Average Speed (km/h)	Density (pcu/km)
1	Bandar Sungai Long	Persiaran Sungai Long 1	Local Road	Single	2	244	59.09	9.13
2		Persiaran Bukit Sungai Long 2	Local Road	Single	3	289	54.20	10.32
3		Persiaran SL 1	Local Road	Single	2	413	64.30	11.05
4		Persiaran Sungai Long 2 (Northbound)	Collector/Distributor Road	Dual	2	512	64.29	12.49
5		Persiaran Sungai Long 2 (Southbound)	Collector/Distributor Road	Dual	2	617	63.09	14.78
6		Jalan Sungai Long, near Green Acre Park (Northbound)	Collector/Distributor Road	Dual	2	253	63.76	8.96
7		Jalan Sungai Long, near Green Acre Park (Southbound)	Collector/Distributor Road	Dual	2	475	67.02	11.00
8		Jalan Sungai Long, near Forest Green Condominium (Northbound)	Collector/Distributor Road	Dual	2	548	66.20	13.27
9		Jalan Sungai Long, near Forest Green Condominium (Southbound)	Collector/Distributor Road	Dual	2	405	69.20	10.85
10		Jalan Sungai Long, near Sungai Long Residence (Northbound)	Collector/Distributor Road	Dual	2	555	63.10	13.80

(Continued on next page.)

Table 4.1: Traffic Data Collected for the Thirty Sites. (Continued)

No.	Area	Name	Type of Road	Type of Carriageway	Number of Lanes	Average Flow Rate (pcu/h)	Average Speed (km/h)	Density (pcu/km)
11	Bandar Sungai Long	Jalan Sungai Long, near Sungai Long Residence (Southbound)	Collector/Distributor Road	Dual	2	635	61.90	15.25
12	Bandar Mahkota Cheras	Jalan Laksamana	Local Road	Single	4	1700	57.00	38.00
13		Jalan Shahbandar	Local Road	Single	4	221	65.81	7.90
14		Jalan Permaisuri	Local Road	Single	4	725	59.60	17.37
15		Jalan Dayang	Local Road	Single	2	499	67.78	12.37
16		Jalan Putera	Local Road	Single	2	660	65.73	15.04
17		Jalan Inang	Local Road	Single	2	199	69.21	7.87
18		Jalan Bendahara	Collector/Distributor Road	Single	4	384	56.98	11.74
19		Jalan Permaisuri	Collector/Distributor Road	Single	3	725	59.60	17.37
20		Persiaran Mahkota Cheras 1 (Northbound)	Collector/Distributor Road	Dual	3	358	71.10	9.53
21		Persiaran Mahkota Cheras 1 (Southbound)	Collector/Distributor Road Road	Dual	3	558	64.20	13.68

(Continued on next page.)

Table 4.1: Traffic Data Collected for the Thirty Sites. (Continued)

No.	Area	Name	Type of Road	Type of Carriageway	Number of Lanes	Average Flow Rate (pcu/h)	Average Speed (km/h)	Density (pcu/km)
22	Maluri	Lorong Shahbandar	Local Road	Single	2	261	69.82	8.73
23		Lorong Peel	Local Road	Single	2	275	68.72	8.70
24		Jalan Perkasa 1	Local Road	Single	2	558	59.92	14.31
25		Jalan Shelly	Local Road	Single	3	633	64.98	14.74
26		Jalan Menteri	Local Road	Single	2	297	72.23	9.11
27		Jalan Cochrane (Eastbound)	Collector/Distributor Road	Dual	3	2098	34.20	81.21
28		Jalan Cochrane (Westbound)	Collector/Distributor Road	Dual	3	711	50.30	19.13
29		Jalan Perkasa (Westbound)	Collector/Distributor Road	Dual	3	2422	24.08	241.32
30		Jalan Perkasa (Eastbound)	Collector/Distributor Road	Dual	3	1400	46.06	37.23

From Table 4.1, it is observed that traffic data including the type of road, number of lanes, type of carriageway, average speed and density for the sites are tabulated. These are the independent variables or factors that may affect the road capacity which are to be studied in this research. As mentioned in the previous chapter, the sites selected are comprised of sixteen collector or distributor roads and fourteen local roads in terms of the type of roads while in terms of the type of carriageway, sixteen of the roads are dual carriageway and fourteen of the roads are single carriageway. When considering the variables of type of road and type of carriageway in the site's selection, it is essential to ensure that each category in the variables is of equal or nearly equal amount so as to ensure that there are sufficient data points during the development of the sub-model. Hence, a 16:14 ratio is adopted in the selection of the type of roads and type of carriageway for the sites to be studied. From Table 4.1, it could be observed that among the three areas for sites, Bandar Sungai Long is the area having the most collector or distributor roads and dual carriageway roads with a number of seven sites for each variable. Bandar Mahkota Cheras is the area having the most local roads and single carriageway roads with a number of six and eight sites for each of the variables respectively.

4.3 Statistical Analysis

Statistical analysis is the science of gathering, investigating and visualizing vast amounts of data in order to identify the underlying trends and patterns. Descriptive statistical analysis is one of the main types of statistical analysis which sums up a particular data set that may be a representation of the entire population or a sample of the population. The two types of categories under descriptive statistical analysis are measures of variability and central tendency. In this study, the measures of central tendency conducted comprise of mean, mode and median while the measures of variability include standard deviation, range, variance and minimum and maximum variables. Other than the measures of variability and central tendency, the 95th percentile of the variables are also determined. Table 4.2 shows the results of the descriptive statistical analysis conducted for the variables of the number of lanes, average flow rate, average speed and density with the application of IBM® SPSS® Statistics software.

Table 4.2: Results of Statistical Analysis.

Statistics

		Number of Lane	Flow Rate	Average Speed	Density
N	Valid	30	30	30	30
	Missing	0	0	0	0
Mean		2.57	653.3000	60.2657	24.4637
Median		2.00	530.0000	63.9800	12.8800
Mode		2	558.00	24.08[a]	7.87[a]
Std. Deviation		.728	543.04856	10.97575	43.46300
Variance		.530	294901.734	120.467	1889.032
Range		2	2223.00	48.15	233.45
Minimum		2	199.00	24.08	7.87
Maximum		4	2422.00	72.23	241.32
Percentiles	95	4.00	2243.8000	71.6085	153.2595

a. Multiple modes exist. The smallest value is shown

From Table 4.2 it is determined that the mean which is the average of a set of data, for the variables of the number of lanes, average flow rate, average speed and density are 2.57, 653.30 pcu/h, 60.27 km/h and 24.46 pcu/km respectively. The median which is the middle of the set of numbers for the number of lanes, average flow rate, average speed and density are 2.00, 530.00 pcu/h, 63.98 km/h and 12.88 pcu/km respectively. The mode which is the most common number in a set of data for the number of lanes, average flow rate, average speed and density are 2.00, 558.00 pcu/h, 24.08 km/h and 7.87 pcu/km respectively. The standard deviation which measures how far apart data points are in a set of data for the number of lanes, average flow rate, average speed and density is 0.728, 543.05 pcu/h, 10.98 km/h and 43.46 pcu/km respectively. The variance which denotes the mean squared difference between the data points for the number of lanes, average flow rate, average speed and density are 0.53, 294 901.73 pcu^2/h^2, 120.47 km^2/h^2 and 1889.03 pcu^2/km^2 respectively. The range which is the difference between the highest and lowest values for the number of lanes, average flow rate, average speed and density are 2, 2223 pcu/h, 48.15 km/h and 233.45 pcu/km respectively. In terms of the average flow rate recorded, Jalan Perkasa (Westbound) from Maluri is the site with the maximum average flow rate while Jalan Inang from Bandar Mahkota Cheras is the site with the minimum average flow rate at the values of 199 pcu/h and 2422 pcu/h respectively. The traffic data tabulated shows that Jalan Menteri from Maluri is the site with the highest average speed while Jalan Perkasa (Westbound) from Maluri is the site with the lowest average speed at the values of 72.23 km/h and 24.08 km/h respectively. It is also determined that Jalan Perkasa (Westbound) from Maluri is the site with the maximum density while Jalan Inang from Bandar Mahkota Cheras is the site with the minimum density at the values of 241.32 pcu/km and 7.87 km/h respectively. Most of the sites selected have two or three lanes regardless of their type of carriageway and type of road. However, this is not the case for Jalan Laksamana, Jalan Shahbandar, Jalan Permaisuri and Jalan Bendahara which have four lanes and all of them are from Bandar Mahkota Cheras. A number that is greater than 95% of the numbers in a given set is considered the 95th percentile. The 95th percentile for the number of lanes, average flow rate, average speed and density is 4.00, 2243.80 pcu/h, 71.61 km/h and 153.26 pcu/km, respectively.

4.4 Model Development

After the statistical analysis of the traffic data collected for the thirty sites is completed, the development of the model for this study is proceeded using all of the necessary data.

4.4.1 Main Model

The main model to be developed for this study employs the traffic data from all thirty sites before determining what other sub-models could be developed from the findings and analysis of the main model constructed.

4.4.1.1 Multiple Linear Regression Analysis

Multiple linear regression was conducted for the models to be developed to determine the significance of the models and identify the factors that are significant in affecting road capacity. These factors include type of road, type of carriageway, number of lanes, traffic density and average vehicle speed. The dependent variable for the multiple linear regression is the traffic average flow rate since a general equation to estimate the traffic flow is to be developed and applied to predict the capacity of the minor road. The data collected for thirty sites is being inputted into the IBM® SPSS® Statistics software for multiple regression analysis as the main model of this study. The output for a multiple regression analysis comes in three main tables to understand the results of the analysis.

Table 4.3 shows the Model Summary table generated by SPSS for the main model of this study.

Table 4.3: Model Summary Table for Main Model.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.902[a]	.813	.774	258.33510

a. Predictors: (Constant), Density, Number of Lane, Type of Road, Average Speed, Type of Carriageway

Based on Table 4.3, the value of R, the multiple correlation coefficient is 0.902 which is good since it is greater than 0.4. It suggests a good level of prediction of the dependent variable and the model could be further analysed. In the case of this model, the R^2 value which is known as the coefficient of determination is determined to be 0.813. A value higher than 0.5 shows the capability of the model in determining the relationship; hence, 81.3 % of the variability of our dependent variable is explained by our independent factors. The adjusted R-square in this modal is determined to be 0.774 which is good since it is close to the R-value. After interpreting the values mentioned, the results in the model summary table are satisfactory to move on to the next stage of analysis.

The second main table generated by a linear regression analysis in SPSS is the ANOVA table as shown in Table 4.4.

Table 4.4: ANOVA table for Main Model.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6950461.716	5	1390092.343	20.829	<.001[b]
	Residual	1601688.584	24	66737.024		
	Total	8552150.300	29			

a. Dependent Variable: Flow Rate

b. Predictors: (Constant), Density, Number of Lane, Type of Road, Average Speed, Type of Carriageway

Based on Table 4.4, the p-value is determined to be less than 0.001 indicating that a statistically substantial portion of the variance in the outcome has been accounted for by the model. The model is said to be significant in estimating the outcome of the dependent variable, traffic flow since the p-value is less than 0.05. The F-ratio of this model is 20.829 which is greater than one, implying that this model is efficient.

Table 4.5 shows the Coefficients table which is the third main table generated by a linear regression analysis in SPSS.

Table 4.5: Coefficients Table for Main Model.

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95.0% Confidence Interval for B Lower Bound	95.0% Confidence Interval for B Upper Bound
1	(Constant)	1730.164	668.772		2.587	.016	349.887	3110.441
	Type of Road	-464.682	220.464	-.434	-2.108	.046	-919.697	-9.666
	Type of Carriageway	546.019	219.658	.510	2.486	.020	92.667	999.372
	Number of Lane	125.855	77.457	.169	1.625	.117	-34.008	285.719
	Average Speed	-25.163	8.632	-.509	-2.915	.008	-42.978	-7.348
	Density	4.480	1.992	.359	2.250	.034	.370	8.591

a. Dependent Variable: Flow Rate

In the case of this main model, it is observed that p-values for the variable type of road, type of carriageway, number of lanes, average speed and density are 0.046, 0.020, 0.117, 0.008 and 0.034 respectively. Among these independent variables, only the variable number of lanes is having a p-value greater than 0.05. This indicates that the null hypothesis for all of the variables is rejected except for the variable number of lanes. All of the independent variables in this model except the number of lanes are said to be significant and have an impact on the traffic flow rate. From Table 4.5, the unstandardised coefficient for the type of road, type of carriageway, number of lanes, average speed and density are -464.682, 546.019, 125.855, -25.163 and 4.480 respectively. This means that: when the type of road is a collector or distributor road, the traffic flow rate decreases by 464.682 pcu/h; when the type of carriageway is dual carriageway, the traffic flow rate increases by 546.019 pcu/h; with a one-unit increase in the number of the lane, the traffic flow rate increases by 125.855 pcu/h; with a one-unit increase in average speed, the traffic flow rate decreases by 25.163 pcu/h; with a one-unit increase in density, the traffic flow rate increases by 4.48 pcu/h. The unstandardised coefficient with the value of 1730.164 from the “(Constant)” row is the y-intercept of the model. The model that forecasts the dependent variable could then be generated from the unstandardised coefficient and y-intercept obtained from this table. However, before generating the general equation of the main model, it is to be noted that the hypothesis testing conducted previously shows that the variable number of lanes is not significant in predicting the outcome. Thus, this variable may be excluded from the equation to be generated so as to ensure the reliability of the model. The general equation of the main model is then:

$$q = 1730.164 + 4.48k - 25.163u - 464.682a + 546.019b \quad (4.1)$$

where

q = traffic flow, pcu/h

k = traffic density, pcu/km

u = average speed, km/h

a = type of road

b = type of carriageway

Based on the multiple linear regression analysis of this study, it could be concluded that the factors that may affect the traffic flow of minor roads are density, average speed of vehicles, type of road and type of carriageway.

4.4.1.2 Flow-Density Fundamental Diagram

After conducting the multiple linear regression to identify the significance of the model and the factors that may impact the road capacity, the Fundamental Diagram that demonstrates the relationship between the basic parameters of traffic flow. In this study, the Fundamental Diagram of the flow-density relationship and speed-density relationship is plotted with the traffic data collected at the thirty sites.

A flow-density Fundamental Diagram is useful in the analysis and modelling of traffic behaviour on roadways for traffic engineering and transportation planning. It can provide insights into the flow of traffic, the capacity of the roadway and traffic congestion level. It enables traffic engineers to determine a road's ideal operating parameters, such as the average flow rate that minimises delay and maximises efficiency. The Fundamental Diagram of the flow-density relationship for this study that is generated by the graph function of SPSS software is shown in Figure 4.1.

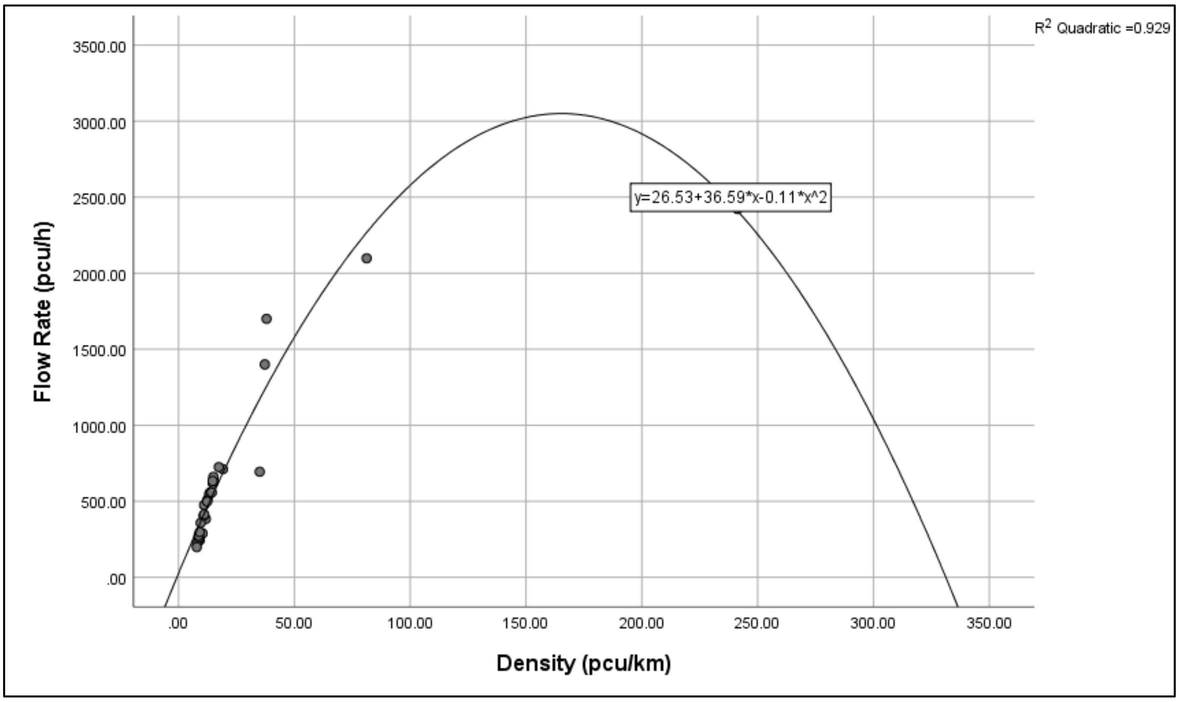


Figure 4.1: Flow-Density Fundamental Diagram for Main Model.

From Figure 4.1, it could be observed that the Fundamental Diagram exhibits a symmetrical inverted U-shaped curve which implies that it is a parabola represented by a quadratic function. The parabolic curve starts from the origin and increases gradually at lower densities until peaking at a certain density. Following the peak density, the average flow rate then declines, demonstrating the phenomenon of reduced traffic flow as a result of traffic congestion. The flow-density curve's parabolic shape is based on the idea that vehicle spacing, which is related to density, and speed both affect the traffic flow. Vehicles can move around freely and engage with each other infrequently at low densities, leading to high average flow rates. The average flow rate declines when density rises as a result of interactions between vehicles and slower-moving traffic. Low speeds and frequent stops in congested traffic at very high densities cause average flow rates to further decline. The R-square value is found to be 0.929 from this Fundamental Diagram which is relatively high and indicates that 92.9% of the variability of the traffic average flow rate is explained by the traffic density. There are a few special points on the curve to be noted that are essential in the estimation of road capacity of this study. The traffic flow, q drops to zero (q = 0) when the density, k is close to zero (k = 0) due to the nearly empty state of the road. The traffic flow also becomes zero (q = 0) at the density when the road is jammed (k = k_j) since minimum movement is experienced by the vehicles. The maximum average flow rate is the capacity of the road, q_{cap} while the density when the traffic flow peaks is the optimal density or capacity density, k_{cap}. Hence, the maximum average flow rate, q_{cap} from the Fundamental Diagram plotted is to be calculated so as to estimate the road capacity for this study. The corresponding equation of the parabolic curve could be applied in computing the capacity density, k_{cap} which is required to calculate the road capacity. The equation of the flow-density Fundamental Diagram is:

$$q = 26.53 + 36.59k - 0.11k^2 \tag{4.2}$$

Since this equation is a quadratic function, the flow at capacity, q_{cap} could be determined by differentiating the function. Due to the fact that differentiation provides details regarding the gradient of the graph of a function, it is known that it can be used to locate points on a graph where the gradient is zero. The points obtained by equating zero to a differentiated function frequently correspond to the function's maximum or minimum values. In the case of this study, the gradient of the graph is given by $\frac{dq}{dk}$ and the traffic density at capacity, k_{cap} could be calculated with the equation:

$$\frac{dq}{dk} = 0 \quad (4.3)$$

The capacity density, k_{cap} for the main model of this study is determined to be 166.32 pcu/km. With the capacity density, k_{cap} being determined, the maximum flow rate, q_{cap} can then be calculated by inserting the density at capacity into the model of the flow-density Fundamental Diagram. The maximum flow rate, q_{cap} is then computed as 3609 km/h. This value represents the road capacity estimated based on the flow-density model developed from the traffic data collected at thirty of the sites. Other than that, the jam density, k_j of this study could also be determined with the equation by assigning zero to the traffic flow rate that is the left-hand side of the equation. The jam density, k_j of the main model is then determined to be 333.36 pcu/km. The values of capacity density, k_{cap} and jam density, k_j provides essential information in the congestion identification of the traffic flow. This is because these values tell the range of densities where congestion occurs and for the case of this study, it is between 166.32 pcu/km to 333.36 pcu/km.

4.4.1.3 Speed-Density Fundamental Diagram

The Fundamental Diagram of the speed-density relationship for this study that is generated by the graph function of SPSS software is shown in Figure 4.2.

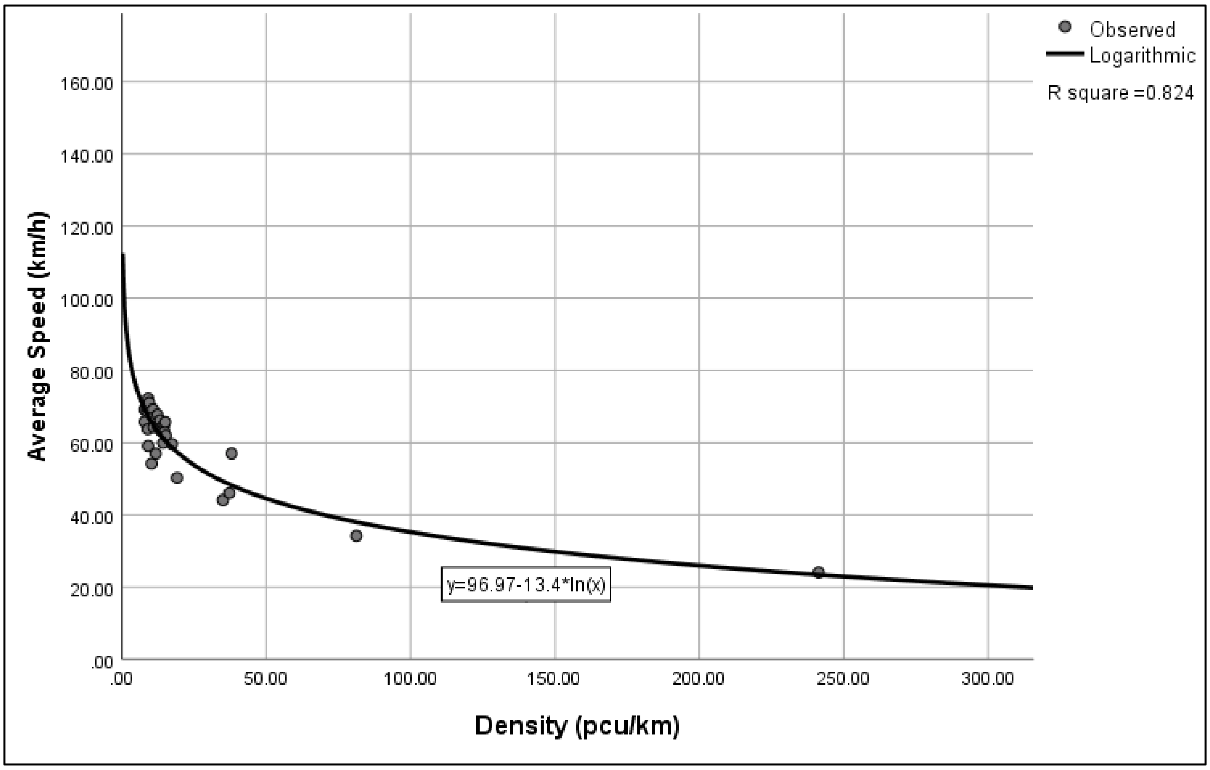


Figure 4.2: Speed-Density Fundamental Diagram for Main Model.

The speed-density Fundamental Diagram can provide insights into how variations in traffic density affect traffic speed under different traffic characteristics. It relates the drivers' chosen speed to the density of vehicles in their vicinity. As a result, the relationship is frequently utilised in traffic flow theory to model drivers' car-following behaviour and comprehend how drivers alter their speeds in reaction to traffic in their proximity. A road's or a transportation system's performance can be assessed using the speed-density Fundamental Diagram. Traffic engineers can evaluate the performance of a roadway by contrasting the actual speed-density relationship observed in the field or via simulation with an idealised or desired speed-density relationship.

From Figure 4.2, the R-square value is found to be 0.824 implying that 82.4% of the variability of the average speed is explained by the traffic density. It could be observed that the curve in the Fundamental Diagram starts with a steep downward slope from the positive infinity initially. This indicates that the values on the y-axis decrease significantly for relatively small changes on the x-axis. When the curve reaches the range of average speed between 80 km/h to 40 km/h, the slope gradually decreases and approaches a specific point where it extends indefinitely in a horizontal line. The characteristic of the curve in the Fundamental Diagram is said to exhibit a logarithmic function which is similar to Greenberg's speed-density traffic model. This model employed hydrodynamic analogy to combine motion's equations and one-dimensional compressive flow in deriving the equation below:

$$u = u_0 \ln\left(\frac{k_j}{k}\right) \tag{4.4}$$

where
u_0 = speed corresponding to maximum flow, km/h
k_j = jam density, pcu/km

Due to the reason that this model could be derived analytically and displays better goodness of fit as compared to Greenshield's model, it has gained good popularity. However, this model has a drawback in its ability to predict speed at lower densities or free-flow speed. This is because the speed tends to increase to infinity as density approaches zero. The equation of the speed-density Fundamental Diagram for the main model is:

$$u = 96.97 - 13.4 \ln(k) \tag{4.5}$$

By inserting the jam density, k_j determined from the flow-density Fundamental Diagram into this equation, the following equation could be derived:

$$u - 19.13 = 13.4 \ln\left(\frac{k_j}{k}\right) \tag{4.6}$$

This equation is similar to the Greenberg's model, but it is to be noted that the coefficient 13.4 may not be the speed corresponding to maximum flow, u_0 since the traffic speed computed from the left-hand side of this equation traffic speed has a constant difference of 19.13 km/h from the actual traffic speed. Other than that, equation 4.5 could also be applied to predict the traffic condition when the velocity is equal to zero. This implies that the traffic density when the average traffic speed is zero could be computed by equating the average speed variable as zero, which is the left-hand side of the equation. The traffic density when the average traffic speed equals zero is calculated to be 1389.32 pcu/km.

4.4.2 Collector/Distributor Road Model

Based on the results of the multiple regression analysis conducted for the main model, it is noticed that the type of road is one of the variables that are significant in affecting the traffic flow of minor roads. Thus, it is interesting to know the traffic pattern of the sites that consist of only one type of road among the two types of roads selected for this study. A sub-model with the traffic data from only one type of road is of interest to be developed so that a comparison between a sub-model and a main model in terms of various aspects could be conducted. The main purpose of doing so is to observe the change in the capacity value for a particular type of minor road which contributes to estimating the capacity for the particular type of road. In addition, the factors significant in altering the traffic flow of a particular type of minor road are also to be identified.

The first sub-model which relates to the variable type of road to be developed is the collector or distributor road model. This sub-model only considers all of the traffic data from the sites with the type of road of collector or distributor road.

4.4.2.1 Multiple Linear Regression Analysis

Among the thirty sites selected, sixteen of the sites are collector or distributor roads and the traffic data collected for these sites are applied in the multiple linear regression analysis and the development of the Fundamental Diagrams. The independent variables for this regression analysis are the type of carriageway, number of lanes, traffic density and average vehicle speed. The three main tables generated by the multiple regression analysis using SPSS software are interpreted in this sub-chapter.

The Model Summary table generated for the collector or distributor road model is shown in Table 4.6.

Table 4.6: Model Summary Table for Collector/Distributor Road Model.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.969[a]	.939	.917	181.40303

a. Predictors: (Constant), Type of Carriageway, Density, Number of Lane, Average Speed

From Table 4.6, the value of R which is the multiple correlation coefficient is determined to be 0.969. This value is satisfactory for the sub-model since it is greater than 0.4 which suggests a high level of predictive accuracy for the dependent variable and is open to further analysis. The R^2 value which is the coefficient of determination is found to be 0.939. This value is higher than 0.5 which proves the model's ability to recognise the relationship and 93.9% of the variability of the dependent variable could be explained by the independent variables. The value for the adjusted R-square of this sub-model is 0.917 which is satisfactory since the value is close to the R-value. By comparing these values with the values from the Model Summary table of the main model, it is identified that the R-value, R^2 value and adjusted R-square for this sub-model are higher than the corresponding values for the main model. This indicates that this sub-model possesses a greater correlation between the predicted values and the observed values of the dependent variable and has a greater capability to identify the relationship between the variables. The collector/distributor road model is better at capturing the underlying patterns of the traffic data and the explanation of this statement is that all of the traffic data applied is from the same type of road where the characteristics of the collector or distributor road have formed a traffic pattern with traffic parameters such as traffic density and average speed that are more interrelated to each other.

Table 4.7 shows the ANOVA table generated by the multiple linear regression analysis for this sub-model.

Table 4.7: ANOVA Table for Collector/Distributor Road Model.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5585983.293	4	1396495.823	42.438	<.001[b]
	Residual	361977.645	11	32907.059		
	Total	5947960.937	15			

a. Dependent Variable: Flow Rate

b. Predictors: (Constant), Type of Carriageway, Density, Number of Lane, Average Speed

From this table, it is found that the p-value of this model is less than 0.001. Since the p-value is less than 0.05, this sub-model is said to be significant in determining the outcome of the dependent variable. The F-ratio of this sub-model is determined to be 42.438 which is greater than one suggesting that this model is satisfactory in terms of its efficiency. After comparing the p-value of this sub-model with the main model, it is determined that both of the models have a similar p-value. This implies that both of the models have a similar significance level in predicting the traffic flow of a roadway despite the fact that the traffic data applied in the sub-model is nearly half of the total traffic data applied in the main model.

The Coefficients table generated for this sub-model is shown in Table 4.8.

Table 4.8: Coefficients Table for Collector/Distributor Road Model.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	2084.545	635.364		3.281	.007	686.118	3482.973
	Density	2.055	1.573	.190	1.306	.218	-1.408	5.519
	Average Speed	-36.240	7.287	-.774	-4.973	<.001	-52.278	-20.201
	Number of Lane	67.982	105.464	.068	.645	.532	-164.143	300.106
	Type of Carriageway	594.202	179.508	.322	3.310	.007	199.108	989.295

a. Dependent Variable: Flow Rate

Based on the results in Table 4.8, it is identified that the p-values for the variable density, average speed, number of lanes and type of carriageway are 0.218, < 0.001, 0.532 and 0.007 respectively. This suggests that average speed and type of carriageway are the only independent variables that are significant and have an impact on the traffic flow rate. On the other hand, the unstandardised coefficients for density, average speed, number of lanes and type of carriageway are 2.055, -36.240, 67.982 and 594.202, respectively. This indicates that: with a one-unit increase in density, the traffic flow rate increases by 2.055 pcu/h; with a one-unit increase in average speed, the traffic flow rate decreases by 36.240 pcu/h; with a one-unit increase in the number of lanes, the traffic flow rate increases by 67.982 pcu/h; when the type of carriageway is dual carriageway, the traffic flow rate increases by 594.202 pcu/h. The y-intercept of the model is also identified to be 2084.545 from the table. Since the traffic density and number of lanes are the independent variables that are not significant in this sub-model, they may be excluded from the equation of the model to obtain a more reliable model. The general equation of this sub-model is then:

$$q = 2084.545 - 36.24u + 594.202b \tag{4.7}$$

The results of the multiple linear regression analysis for the collector or distributor road model show that the factors that may impact the traffic flow of the collector or distributor road are average speed and type of carriageway. The difference in the factors that may affect the traffic flow between the sub-model and the main model is determined to be the traffic density after comparing the factors for both of the models. It suggests that the changes in the traffic density have a relatively smaller effect on the traffic flow as compared to other types of roads when it comes to the case of a collector or distributor road.

4.4.2.2 Flow-Density Fundamental Diagram

After conducting the multiple linear regression analysis on the collector or distributor road model, the Fundamental Diagram of the flow-density relationship is to be developed. It is to be noted that sixteen traffic data out of the thirty sites which are collector or distributor roads is being used in developing the Fundamental Diagram. The flow-density Fundamental Diagram of this sub-model is generated by the SPSS software as shown in Figure 4.3.

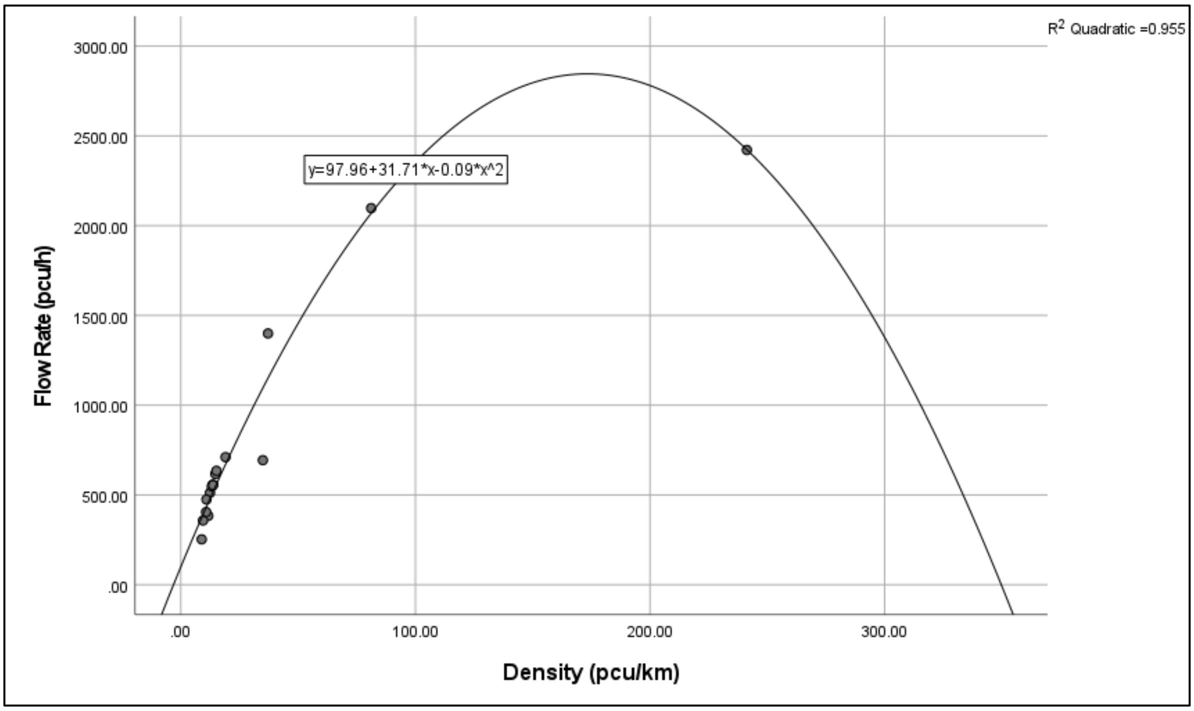


Figure 4.3: Flow-Density Fundamental Diagram for Collector/Distributor Road Model.

The Fundamental Diagram developed also displays a parabolic curve that is represented by a quadratic function. The R-square value is found to be 0.955 which is relatively high and implies that 95.5% of the variability of the traffic flow rate is explained by the traffic density. The R-square value of the flow-density Fundamental Diagram for this sub-model is higher than the main model thus the sub-model has a better fit of the traffic data and explains a larger proportion of the variability in the traffic flow. Other than that, the equation of the flow-density Fundamental Diagram for this sub-model is identified to be:

$$q = 97.96 + 31.71k - 0.09k^2 \tag{4.8}$$

To compare the flow-density Fundamental Diagram between this sub-model and the main model, the maximum flow rate, q_{cap} and traffic density at the capacity of the sub-model is to be computed. By equating the differentiated equation with zero, the density at capacity for the collector or distributor road studied could be calculated. The traffic density at capacity, k_{cap} is calculated as 176.17 pcu/km for the case of this model. Inserting the value of capacity density, k_{cap} into the equation yields the maximum flow rate, q_{cap}. The maximum flow rate, q_{cap} is computed as 2891 pcu/h which represents the capacity for the collector or distributor road studied. By assigning zero to the traffic flow rate, the jam density, k_j for this sub-model is identified to be 355.39 pcu/km. This implies that the range of densities where the traffic users experience congestion is between 176.17 pcu/km to 355.39 pcu/km. When being compared to the values of the main model, it is determined that the collector or distributor road model has a greater value for its capacity density, k_{cap} and jam density, k_j. This suggests that the collector or distributor road may be capable of handling a higher volume of vehicles without causing delays or congestion when compared to other minor roads. In addition, the higher jam density, k_j of the sub-model implies that in the event of traffic congestion, the collector or distributor road may have a higher concentration of vehicles that are either moving slowly or stopped when compared to other minor roads. The main model is found to be having a higher capacity as compared to this sub-model which is possibly due to the greater scattering of its traffic data from various sites since it is developed with a greater amount of traffic data that results in a higher vertex of the parabola in the Fundamental Diagram.

4.4.2.3 Speed-Density Fundamental Diagram

The development of the speed-density Fundamental Diagram for collector or distributor roads employs sixteen traffic data out of the thirty sites which are collector or distributor roads.

Figure 4.4 shows the speed-density Fundamental Diagram of this sub-model generated by SPSS.

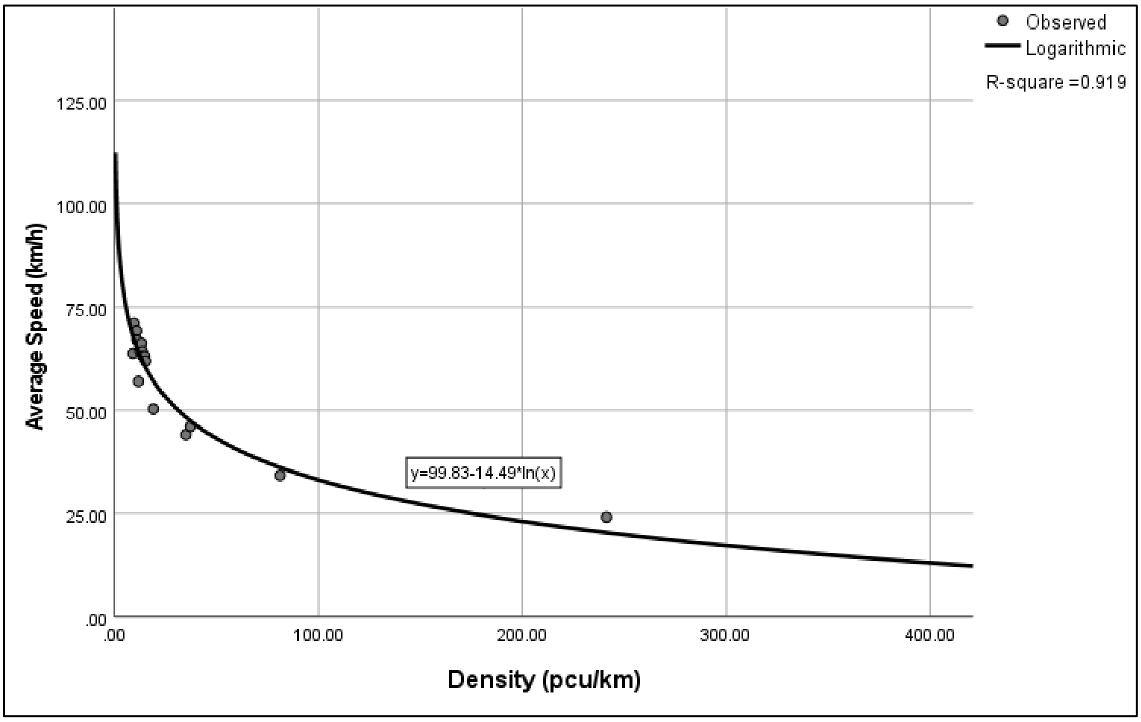


Figure 4.4: Speed-Density Fundamental Diagram for Collector/Distributor Road Model.

Similar to the main model, the curve in this Fundamental Diagram also exhibits a logarithm function that is identical to Greenberg's speed-density traffic model.

The R-square value is found to be 0.919 which is relatively high and implies that 91.9% of the variability of the traffic average speed is explained by the traffic density. The speed-density Fundamental Diagram for this sub-model has a higher R-square value than the main model, making it to have a better fit for the traffic data and one that accounts for a greater percentage of the variability in the average traffic speed. The equation of the speed-density Fundamental Diagram for this sub-model is:

$$u = 99.83 - 14.49\ln(k) \qquad (4.9)$$

In order to derive an equation that is similar to Greenberg's model, the jam density, k_j determined from the flow-density Fundamental Diagram is to be inserted into this equation. The equation derived is as follows:

$$u - 14.73 = 14.49 \ln\left(\frac{k_j}{k}\right) \tag{4.10}$$

It should be noted that due to the traffic speed estimated from the left-hand side of this equation having a continuous difference of 14.73 km/h from the actual traffic speed, the coefficient 14.49 may not be the speed corresponding to maximum flow, u_0. Besides that, by setting the average speed, which is the left-hand side of equation 4.9 to zero, it is possible to calculate the traffic density when the average traffic speed is zero. The traffic density when the average traffic speed equals zero is identified to be 981.99 pcu/km. This traffic density value is lower than the value of the main model; thus, it is determined that the collector or distributor road have a lower volume of vehicles on a particular stretch of road in a standstill traffic.

4.4.3 Local Road Model

After developing a sub-model with the application of collector or distributor road, the analysis proceeds with the development of a sub-model employing the traffic data from the sites that are local roads.

4.4.3.1 Multiple Linear Regression Analysis

A number of fourteen out of the thirty sites are local roads, and the traffic data gathered for these sites is used in the analysis of multiple linear regression and the plotting of the Fundamental Diagrams. The number of lanes, traffic density and average vehicle speed are the independent variables for the regression analysis of this sub-model. It is to be noted that the variable type of carriageway is not considered in this analysis since all of the local roads selected in this study have only one type of carriageway which is the single carriageway. The subsequent section provides an interpretation of the three primary tables that were produced by the multiple regression analysis performed with the SPSS software.

Table 4.9 depicts the Model Summary table generated for the local road model.

Table 4.9: Model Summary Table for Local Road Model.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.996[a]	.992	.989	39.92933

a. Predictors: (Constant), Density, Average Speed, Number of Lane

From Table 4.9, the multiple correlation coefficient, R, is determined to have a value of 0.996. This value is satisfactory for the sub-model because it is greater than 0.4, indicating a high level of predictive accuracy for the dependent variable and allowing for further analysis. The coefficient of determination, R^2, is determined to be 0.992. This value is greater than 0.5, demonstrating the model's ability to identify the relationship, and 99.2% of the variability of the dependent variable can be attributed to the independent variables. This sub-model's adjusted R-square value is 0.989, which is satisfactory because it is near to the R-value. Comparing these values to those from the Model Summary table of the main model reveals that the R-value, R^2 value, and adjusted R-square for this sub-model are greater than the corresponding values for the main model. This demonstrates that this sub-model has a higher correlation between the predicted and observed values of the dependent variable and a greater capacity to identify the relationship between the variables. Similar to the case of the collector or distributor road model, the local road model performs better at capturing the underlying patterns of the traffic data and the reason for this is the higher similarity in the traffic parameters pattern from the same type of road and the lesser number of independent variables in the analysis of this sub-model. The characteristics of local roads also restrict the fluctuation of the traffic parameters which enhances their relationship with each other.

The ANOVA table produced by the multiple linear regression analysis for this sub-model is displayed in Table 4.10.

Table 4.10: ANOVA Table for Local Road Model.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1956310.203	3	652103.401	409.009	<.001[b]
	Residual	15943.511	10	1594.351		
	Total	1972253.714	13			

a. Dependent Variable: Flow Rate

b. Predictors: (Constant), Density, Average Speed, Number of Lane

The p-value for this model is determined from this table to be less than 0.001. This sub-model is considered significant in predicting the outcome of the dependent variable because the p-value is less than 0.05. The F-ratio for this sub-model, which was found to be 409.009 and greater than one, indicates that the model's effectiveness is good. When the p-values of this sub-model and the main model are compared, it is found that their p-values are comparable. This suggests that both models are equally significant in predicting the traffic flow of a roadway, despite the fact that the traffic data used in the sub-model is less than half that used in the main model.

Table 4.11 depicts the generated Coefficients table for this sub-model.

Table 4.11: Coefficients Table for Local Road Model.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-418.767	182.752		-2.291	.045	-825.964	-11.570
	Number of Lane	-2.902	16.221	-.006	-.179	.862	-39.045	33.241
	Average Speed	3.841	2.480	.053	1.549	.152	-1.685	9.367
	Density	51.398	1.776	1.024	28.945	<.001	47.442	55.355

a. Dependent Variable: Flow Rate

The p-values for the variable number of lanes, average speed, and density are determined to be 0.862, 0.152, and < 0.001, respectively, based on the results presented in Table 4.11. This suggests that traffic density is the only independent variable with a significant influence on the local road's traffic flow. Other than that, the unstandardised coefficients for the number of lanes, average speed, and density are -2.902, 3.841 and 51.398, respectively. This implies that: with a one-unit increase in the number of lanes, the traffic average flow rate decreases by 2.902 pcu/h; with a one-unit increase in average speed, the traffic flow rate increases by 3.841 pcu/h; with a one-unit increase in density, the traffic flow rate increases by 51.398 pcu/h. The y-intercept of the model is also found to be -418.767 from Table 4.11. In order to achieve a model with greater reliability, the independent variables number of lanes and average speed may be excluded from the equation of the model since they are found to be insignificant. The general equation of this local road model is then:

$$q = 51.398k - 418.767 \tag{4.11}$$

The findings of the multiple linear regression analysis for the local road model indicate that the local road traffic density is a factor that may have an impact on traffic flow. By analysing the factors for the two models, it is found that the average speed distinguishes the factors that could influence traffic flow between this sub-model and the main model. It implies that, in the case of a local road, changes in the traffic's average speed have a significantly smaller impact on the flow of traffic than they would on other types of roads.

4.4.3.2 Flow-Density Fundamental Diagram

After undertaking a multiple linear regression analysis on the local road model, the flow-density relationship's Fundamental Diagram is to be created. Notably, fourteen traffic data from the thirty research locations that are local roads is being utilised to develop the Fundamental Diagram. The SPSS software generates the flow-density Fundamental Diagram of this sub-model, as shown in Figure 4.5.

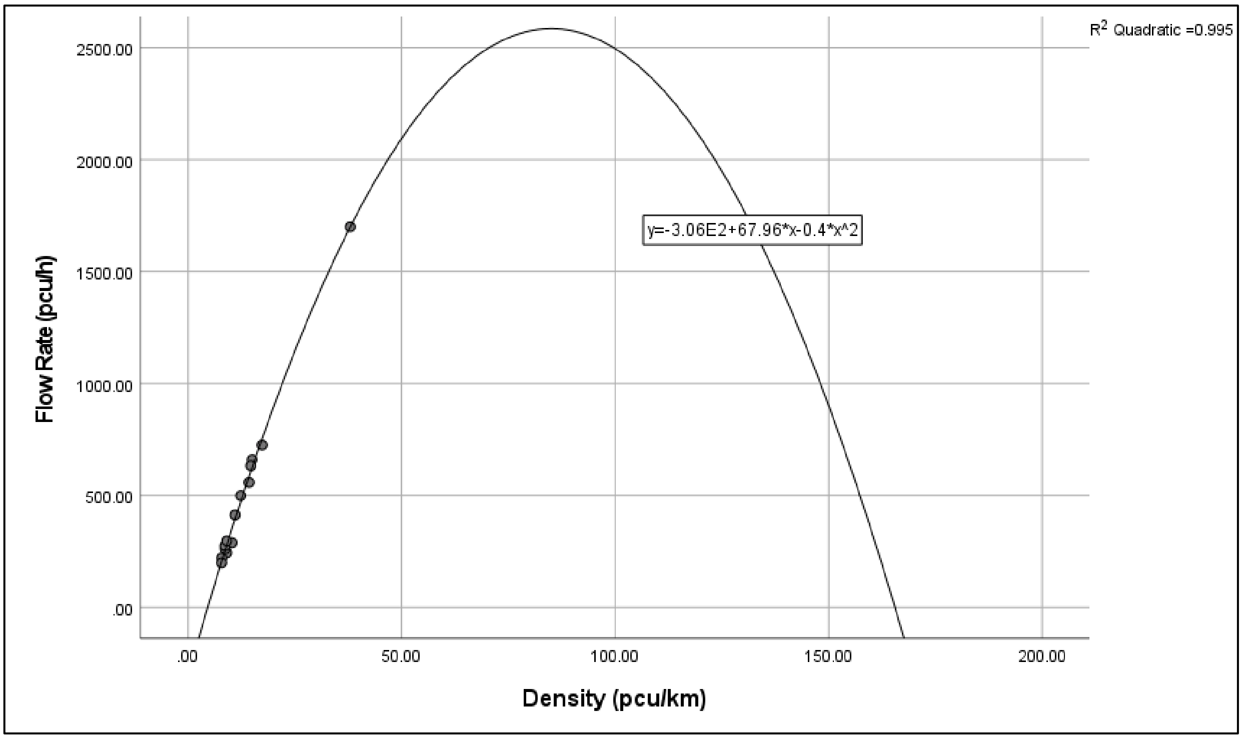


Figure 4.5: Flow-Density Fundamental Diagram for Local Road.

A parabolic curve represented by a quadratic function is also illustrated in this Fundamental Diagram. The R-square value of 0.995 indicates that the traffic density explains 99.5% of the variance in the traffic flow rate. The R-square value of the flow-density Fundamental Diagram for this sub-model is greater than that of the main model, indicating that the sub-model better fits the traffic data and explains a greater proportion of the variance in the traffic flow. Aside from this, the flow-density Fundamental Diagram equation for this sub-model is identified as follows:

$$q = 67.96k - 0.4k^2 - 306 \tag{4.12}$$

The computation of the maximum flow rate, q_{cap} and traffic density at the capacity of the sub-model is to be done before the comparison of the flow-density Fundamental Diagram between this sub-model and the main model. The calculated traffic density at capacity, k_{cap}, for this model is 84.95 pcu/km. Entering the capacity density value, k_{cap} into the equation yields the maximum flow rate, q_{cap}. The calculated maximum flow rate, q_{cap} is 2581 pcu/h, which represents the capacity of a local road. By setting the traffic flow rate to zero, the jam density, k_j for this sub-model is determined to be 165.27 pcu/km. This indicates that the range of densities where traffic congestion occurs is between 84.95 and 165.27 pcu/km. Comparing the values of the local road model to the main model reveals that the local road model has lesser values for all of the essential values in this Fundamental Diagram. This shows that local roads can accommodate fewer vehicles within a given period of time where its tolerance to the occurrence of traffic congestion is lower since a lower level of traffic density could lead to delays, and it exhibits a smaller range of densities before congestion happens. This could be explained by the limitation of local roads since they tend to have a lesser number of lanes, smaller road width, limited road shoulder and so on which influence the performance of local roads in handling a greater volume of vehicles.

4.4.3.3 Speed-Density Fundamental Diagram

The establishment of the speed-density Fundamental Diagram for local roads also utilises traffic data from fourteen of the thirty sites that are local roads. Figure 4.6 depicts the SPSS-generated speed-density Fundamental Diagram for this sub-model.

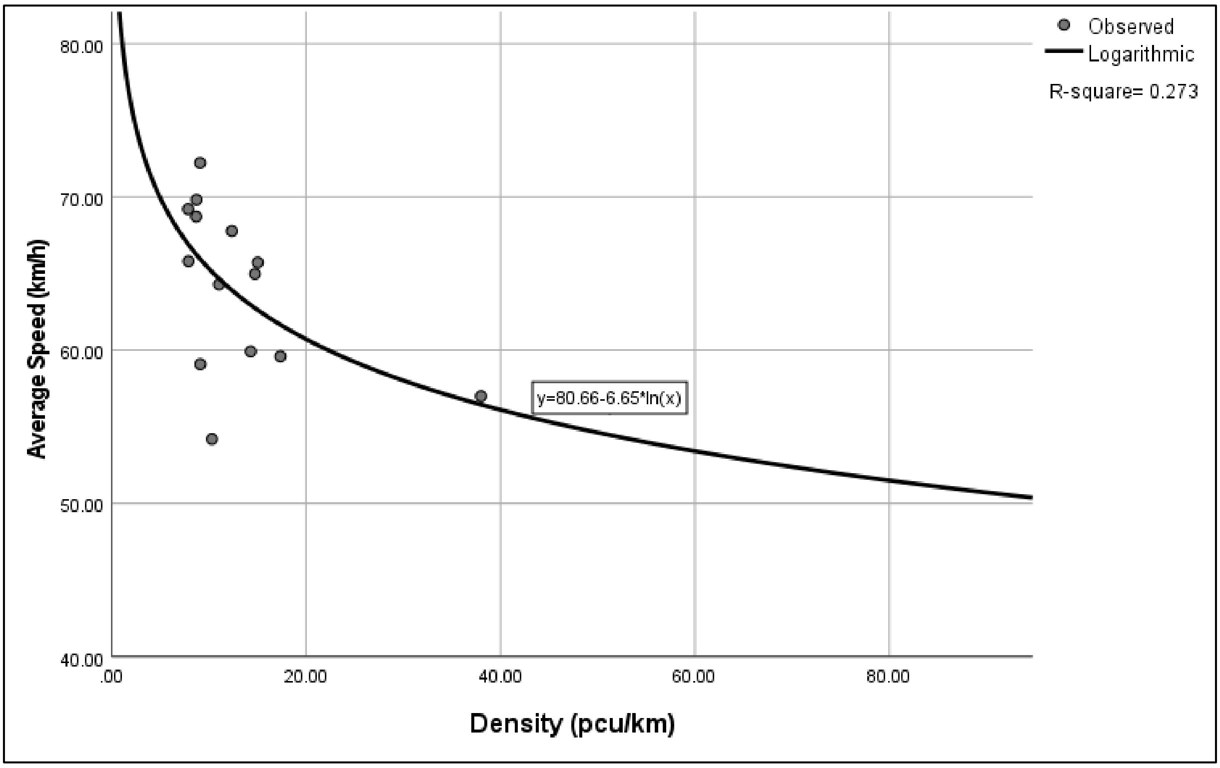


Figure 4.6: Speed-Density Fundamental Diagram for Local Road Model.

This Fundamental Diagram's curve exhibits a logarithmic function identical to Greenberg's speed-density traffic model, just like the main model. Only 27.3% of the variability in the average traffic speed can be explained by the traffic density, based on the R-square value of 0.273 determined from the Fundamental Diagram, which is relatively low. The low R-square value obtained in this Fundamental Diagram may be due to the weak relationship between the independent variable and dependent variable when it comes to a local road. The average vehicle speed of a local road may not be influenced by its traffic density but by other traffic parameters. Local roads possess greater limitations in terms of their characteristics which may result in a greater fluctuation of the traffic data thus yielding an R-square value that is unsatisfactory. The insufficient sites selected as local roads may also be the reason for obtaining the low R-square value. The equation of the speed-density Fundamental Diagram for this sub-model is:

$$u = 80.66 - 6.65\ln(k) \tag{4.13}$$

The jam density, k_j, calculated from the flow-density Fundamental Diagram is to be added to this equation in order to derive an equation that is similar to Greenberg's model. The resulting equation is as follows:

$$u - 46.67 = 6.65 \ln\left(\frac{k_j}{k}\right) \qquad (4.14)$$

It should be noted that the coefficient 6.65 may not be the speed corresponding to maximum flow, u_0 because the traffic speed predicted from the left-hand side of this equation has a constant difference of 46.67 km/h from the actual traffic speed. In addition, it is possible to determine the traffic density when the average traffic speed is zero by setting the average speed, which is the left-hand side of equation 4.13, to zero. The identified traffic density is 183 768 pcu/km when the average traffic speed equals zero. This value is unrealistic for the case of a local road which means that the equation is not applicable in predicting the desired traffic parameter. The reason for yielding the unrealistic value is the weak relationship between the average speed and traffic density on the local roads where the model is not capturing the true underlying relationship between the variables.

4.4.4 Dual Carriageway Model

Other than the type of road, the type of carriageway is another variable that may impact the traffic flow of minor roads. Therefore, it is of interest to know the traffic pattern of sites with only one form of carriageway, either a single or a dual carriageway. It is necessary to construct a sub-model with traffic data from only one type of carriageway so that a comparison can be made between a sub-model and a main model in terms of a variety of factors. The primary objective is to observe the change in the capacity value of a minor road with a specific form of carriageway, which contributes to estimating the minor road's capacity. In addition, the factors that significantly affect the traffic flow on a specific form of carriageway must be identified.

The dual carriageway model is the first sub-model pertaining to the variable type of carriageway that must be developed. This sub-model only considers traffic data from sites that are dual carriageway or contain a median.

4.4.4.1 Multiple Linear Regression Analysis

A number of fourteen out of the thirty selected sites are dual carriageway roads, and the traffic data obtained for these sites are used in the multiple linear regression analysis and the creation of the Fundamental Diagrams. Traffic density, average speed, and number of lanes serve as the independent variables in this regression analysis. The variable type of road is not included as one of the independent variables due to the reason that all of the dual carriageway roads selected for this study are collector or distributor roads which means that there is only one type of road in the case of this sub-model. The subsequent subchapter interprets the three primary tables produced by the multiple regression analysis using the SPSS software.

The Model Summary table generated for the dual carriageway model is shown in Table 4.12.

Table 4.12: Model Summary Table for Dual Carriageway Model.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.969[a]	.940	.921	186.56957

a. Predictors: (Constant), Number of Lane, Density, Average Speed

From Table 4.12, the value of R which is the multiple correlation coefficient is determined to be 0.969. This value is satisfactory for the sub-model since it is greater than 0.4 which suggests a high level of predictive accuracy for the dependent variable and is open to further analysis. The R^2 value which is the coefficient of determination is found to be 0.94. This value is higher than 0.5 which proves the model's ability to recognize the relationship and 94% of the variability of the dependent variable could be explained by the independent variables. The value for the adjusted R-square of this sub-model is 0.921 which is satisfactory since the value is close to the R-value. By comparing these values with the values from the Model Summary table of the main model, it is identified that the R-value, R^2 value and adjusted

R-square for this sub-model are higher than the corresponding values for the main model. This indicates that this sub-model possesses a greater correlation between the predicted values and the observed values of the dependent variable and has a greater capability in identifying the relationship between the variables. The dual carriageway model is more effective at capturing the underlying patterns of traffic data, and the reason for this is that the dual carriageway road studied are of the same type of road and the presence of a median on a minor road could create a traffic pattern with traffic parameters that are more interrelated to each other at the same time.

The ANOVA table produced by the multiple linear regression analysis for this sub-model is displayed in Table 4.13.

Table 4.13: ANOVA Table for Dual Carriageway Model.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5408900.305	3	1802966.768	51.797	<.001[b]
	Residual	348082.052	10	34808.205		
	Total	5756982.357	13			

a. Dependent Variable: Flow Rate

b. Predictors: (Constant), Number of Lane, Density, Average Speed

The p-value for this model is determined from this table to be less than 0.001. This sub-model is considered significant in predicting the outcome of the dependent variable because the p-value is less than 0.05. The F-ratio of this sub-model is found to be 51.797, which is larger than one, indicating that the model's efficiency is good. It is discovered that both models have a comparable p-value after comparing the p-values of this sub-model and the main model. This suggests that despite the fact that the traffic data used in the sub-model is almost half of the total traffic data used in the main model, both models have a similar degree of significance when predicting the traffic flow of a roadway.

Table 4.14 depicts the Coefficients table generated for this sub-model.

Table 4.14: Coefficients Table for Dual Carriageway Model.

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95.0% Confidence Interval for B Lower Bound	95.0% Confidence Interval for B Upper Bound
1	(Constant)	2920.999	727.017		4.018	.002	1301.105	4540.893
	Density	1.821	1.660	.170	1.097	.298	-1.878	5.520
	Average Speed	-38.452	8.272	-.808	-4.648	<.001	-56.884	-20.020
	Number of Lane	24.308	128.620	.019	.189	.854	-262.274	310.891

a. Dependent Variable: Flow Rate

Table 4.14 demonstrates that the p-values for the variable density, average speed, and number of lanes are 0.298, < 0.001, and 0.854, respectively. This suggests that the average speed is the only substantial independent variable that influences the traffic flow rate. The unstandardised coefficients for density, average speed, and number of lanes are 1.821, -38.452, and 24.308, respectively. This suggests that the traffic flow rate increases by 1.821 pcu/h for each unit increase in density, decreases by 38.452 pcu/h for each unit increase in average speed, and increases by 24.308 pcu/h for each unit increase in the number of lanes. The model's y-intercept is also identified in the table as 2920.999. Since traffic density and number of lanes are insignificant independent variables in this sub-model, they can be removed from the model's equation to produce a more accurate model. Consequently, the general equation for this sub-model is:

$$q = 2920.999 - 38.452u \tag{4.15}$$

The results of the multiple linear regression analysis for the dual carriageway model imply that the average speed may influence the traffic flow on dual carriageway roads. By analysing the two models' factors, it is discovered that the traffic density distinguishes the variables that may impact the traffic flow between this sub-model and the main model. It indicates that, in the case of a road that has a median, changes in the traffic density have a substantially smaller impact on the flow of traffic than they would on the roads without a median.

4.4.4.2 Flow-Density Fundamental Diagram

After performing a multiple linear regression analysis on the dual carriageway model, the flow-density relationship's Fundamental Diagram is to be constructed. A number of fourteen dual carriageway road traffic data from thirty research locations is being utilised to develop the Fundamental Diagram. As shown in Figure 4.7, the SPSS software generates the flow-density Fundamental Diagram of this sub-model. This Fundamental Diagram also displays a parabolic curve represented by a quadratic function.

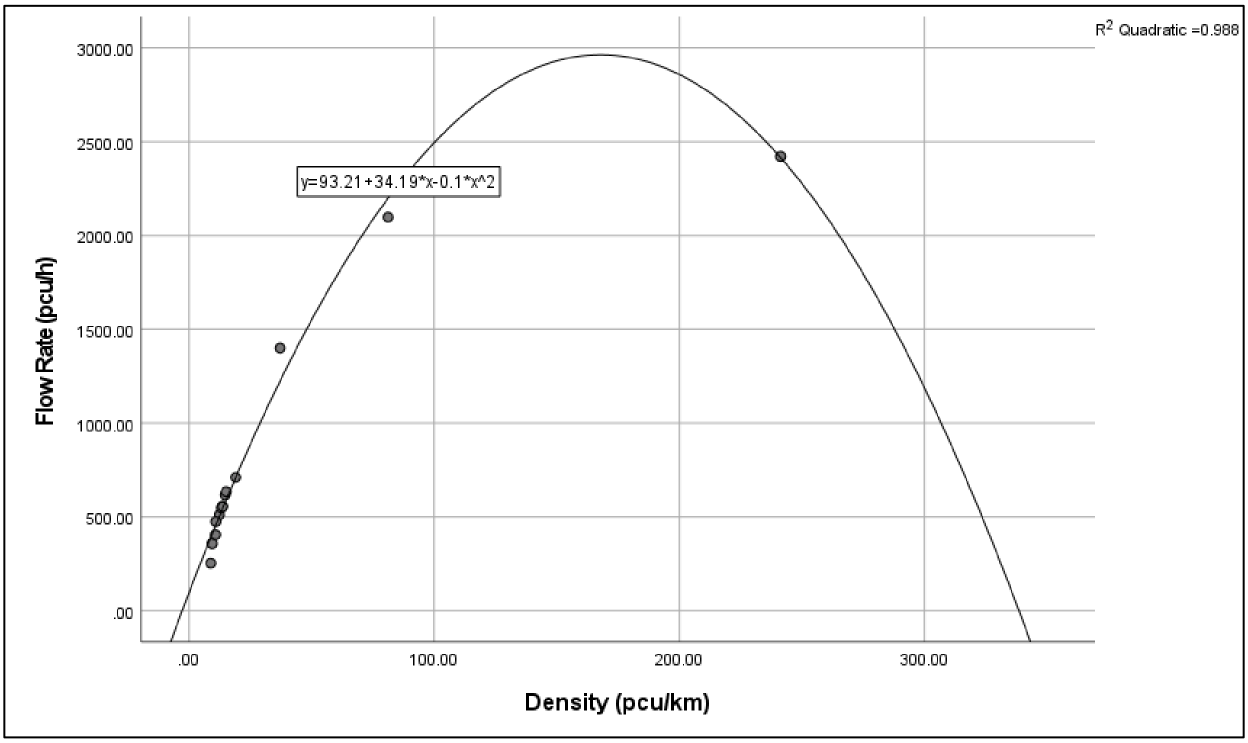


Figure 4.7: Flow-Density Fundamental Diagram for Dual Carriageway Model.

The R-square value of 0.98 indicates that traffic density accounts for 98.8% of the variance in traffic flow rate. The R-square value of this sub-model's flow-density Fundamental Diagram is greater than that of the main model, indicating that the sub-model better suits the traffic data and explains a greater portion of the variability in the traffic flow. Other than that, the following is the flow-density Fundamental Diagram equation for this sub-model:

$$q = 93.21 + 34.19k - 0.1k^2 \tag{4.16}$$

Before comparing the flow-density Fundamental Diagram between this sub-model and the main model, it is necessary to compute the sub-model's maximum flow rate, q_{cap}, and traffic density at capacity, k_{cap}. This model's calculated traffic density at capacity, k_{cap}, is 170.95 pcu/km. The insertion of capacity density, k_{cap} into the equation yields q_{cap}, the maximum flow rate. The computed maximum flow rate, q_{cap}, is 3016 pcu/h, which is the capacity of minor roads with a median. The jam density, k_j for this sub-model is calculated to be 344.60 pcu/km by equating the traffic flow rate to zero. This reveals that the density range where traffic congestion occurs is between 170.95 and 344.60 pcu/km. The comparison of the dual carriageway model and the main model demonstrates that this sub-model has higher capacity density, k_{cap}, and congestion density, k_j, in this Fundamental Diagram. This indicates that the minor road with a median may be able to accommodate a greater volume of vehicles without causing delays or congestion, compared to the minor road without a median. Also, the greater jam density, k_j of the sub-model suggests that the dual carriageway road may have a higher concentration of vehicles that are either travelling slowly or stopped in the event of traffic congestion. The main model is found to have a greater capacity than this sub-model, which is analogous to the case of the collector or distributor road model. This may be due to the greater dispersion of the main model's traffic data from various sites, which results in a higher vertex of the parabola in the Fundamental Diagram.

4.4.4.3 Speed-Density Fundamental Diagram

Traffic data from fourteen of the thirty research locations, which are dual carriageway roads also being used to develop the speed-density Fundamental Diagram for dual carriageways. The fundamental speed-density diagram created by SPSS for this sub-model is shown in Figure 4.8.

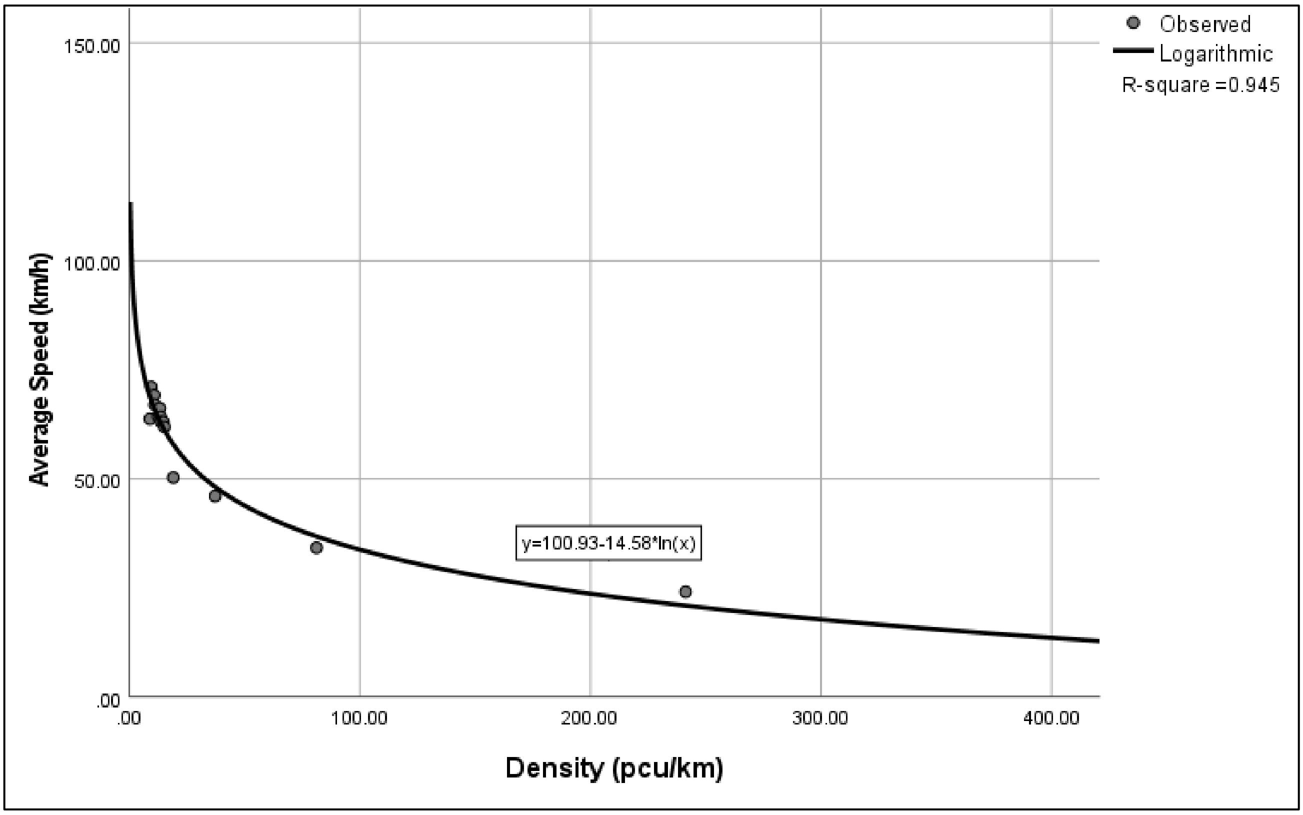


Figure 4.8: Speed-Density Fundamental Diagram for Dual Carriageway Model.

Similar to the main model, the curve in this Fundamental Diagram displays a logarithmic function that is the same as that in Greenberg's speed-density traffic model. A reasonably high R-square score of 0.945 indicates that the traffic density accounts for 94.5% of the variability in the traffic's average speed. The sub-model's speed-density fundamental fits the traffic data better and accounts for a larger proportion of the variability in the average traffic speed than the main model since it has a higher R-square value. For this sub-model, the equation for the fundamental speed-density diagram is:

$$u = 100.93 - 14.58 \ln(k) \tag{4.17}$$

The jam density, k_j, calculated from the flow-density Fundamental Diagram is to be added to this equation in order to derive an equation that is similar to Greenberg's model. The resulting equation is as follows:

$$u - 15.73 = 14.58 \ln\left(\frac{k_j}{k}\right) \tag{4.18}$$

The coefficient 14.58 may not be the speed corresponding to the maximum flow, u_0, because the traffic speed predicted from the left-hand side of this equation has a constant divergence from the actual traffic speed of 15.73 km/h. In addition, it is possible to determine the traffic density when the average traffic speed is zero by setting the average speed, which is the left-hand side of equation 4.17, to zero. The identified traffic density is 1013.09 pcu/km when the average traffic speed equals zero. Due to the fact that this traffic density value is lower than the value for the main model, it is known that the minor roads with median have fewer vehicles on a certain section of road during a traffic jam.

4.4.5 Single Carriageway Model

The analysis moves forward with the development of a sub-model using the traffic data from the sites with the single carriageway road after producing a sub-model using the application of a dual carriageway road.

4.4.5.1 Multiple Linear Regression Analysis

A number of sixteen sites are minor roadways without a median, and the traffic data collected at these sites are utilised in the analysis of multiple linear regression and the construction of the Fundamental Diagrams. The independent variables for the regression analysis of this sub-model are the type of road, number of lanes, traffic density, and average vehicle speed. The three primary tables that were generated by the multiple regression analysis carried out using the SPSS software is interpreted in the upcoming section.

The Model Summary table created for the single carriageway model is shown in Table 4.15.

Table 4.15: Model Summary Table for Single Carriageway Model.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.950[a]	.903	.867	133.81456

a. Predictors: (Constant), Type of Road, Number of Lane, Density, Average Speed

The multiple correlation coefficient, R, is found to have a value of 0.950 in Table 4.15. This result, which is more than 0.4 and indicates a high level of prediction accuracy for the dependent variable, is sufficient for the sub-model and permits further investigation. R^2, the coefficient of determination, is found to be 0.903 in this case. This number is more than 0.5, indicating that the model was successful in detecting the link, and it also indicates that the independent variables are responsible for 90.3% of the variance in the dependent variable. The adjusted R-square for this sub-model is 0.867, which is acceptable because it is close to the R-value. The R-value, R^2 value, and adjusted R-square for this sub-model are higher than the corresponding values for the main model, which can be seen by comparing these numbers to those from the Model Summary table of the main model. This demonstrates that this sub-model is more capable of identifying the relationship between the variables and has a stronger correlation between the predicted and observed values of the dependent variable. Since the characteristics of minor roads without medians have established a traffic pattern with traffic parameters such as traffic density and average speed that are more correlated to each other, the single carriageway model performs better at reflecting the patterns of the traffic data.

Table 4.16 shows the ANOVA table generated by the multiple linear regression analysis for this sub-model.

Table 4.16: ANOVA Table for Single Carriageway Model.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1826255.304	4	456563.826	25.497	<.001[b]
	Residual	196969.696	11	17906.336		
	Total	2023225.000	15			

ANOVA[a]

a. Dependent Variable: Flow Rate

b. Predictors: (Constant), Type of Road, Number of Lane, Density, Average Speed

This table reveals that the p-value for this model is less than 0.001. Since the p-value is less than 0.05, this sub-model is regarded as significant in predicting the outcome of the dependent variable. The F-ratio for this sub-model, which was discovered to be 25.497 and more than 1, shows that the model is effective. It is discovered that this sub-and model's the main model's p-values are similar when compared. This shows that despite the fact that the traffic data utilised in the sub-model is less than half that used in the main model, both models are equally significant for forecasting the traffic flow of a roadway.

The generated Coefficients table for this sub-model is shown in Table 4.17.

Table 4.17: Coefficients Table for Single Carriageway Model.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-1061.307	578.155		-1.836	.094	-2333.817	211.203
	Density	42.304	5.218	1.046	8.106	<.001	30.818	53.789
	Average Speed	12.007	7.905	.237	1.519	.157	-5.391	29.406
	Number of Lane	89.834	45.875	.214	1.958	.076	-11.136	190.805
	Type of Road	-310.237	133.255	-.289	-2.328	.040	-603.529	-16.945

Coefficients[a]

a. Dependent Variable: Flow Rate

Based on the outcomes shown in Table 4.17, the p-values for the variable density, average speed, number of lanes, and kind of road are established to be < 0.001, 0.157, 0.076, and 0.040, respectively. This shows that the independent variables with a major impact on the traffic flow on the single-lane road are traffic density and the type of road. The unstandardised coefficients for density, average speed, number of lanes, and road type are 42.304, 12.007, 89.834, and -310.237, respectively. This suggests that the traffic flow rate increases by 42.304 pcu/h with a one-unit increase in traffic density, 12.007 pcu/h with a one-unit increase in average speed, 89.834 pcu/h with a one-unit increase in lane amount and decreases by 310.237 pcu/h when the type of road is a collector road or distributor road. Table 4.17 also reveals the model's y-intercept to be -1061.307. The variables number of lanes and average speed may be removed from the model's equation when it is determined that they are not significant in order to produce a more reliable model. The single carriageway model's general equation is then:

$$q = 42.304k - 310.237a - 1061.307 \quad (4.19)$$

The density and type of road are the two factors that may have an influence on the traffic flow of a single carriageway road, according to the results of the multiple linear regression analysis for this sub-model. The average vehicle speed is identified as the difference between the factors that may have an impact on traffic flow between the sub-model and the main model after analysing the elements for both models. According to this, minor roads without medians are likely see less of an impact from changes in average vehicle speed than minor roads with medians.

4.4.5.2 Flow-Density Fundamental Diagram

The flow-density relationship's Fundamental Diagram is to be built after performing a multiple linear regression analysis on the single carriageway model. It should be emphasised that the Fundamental Diagram is developed using the traffic data from sixteen minor roads without medians from the thirty research locations. The flow-density Fundamental Diagram for this sub-model is produced by the SPSS software and is displayed in Figure 4.9.

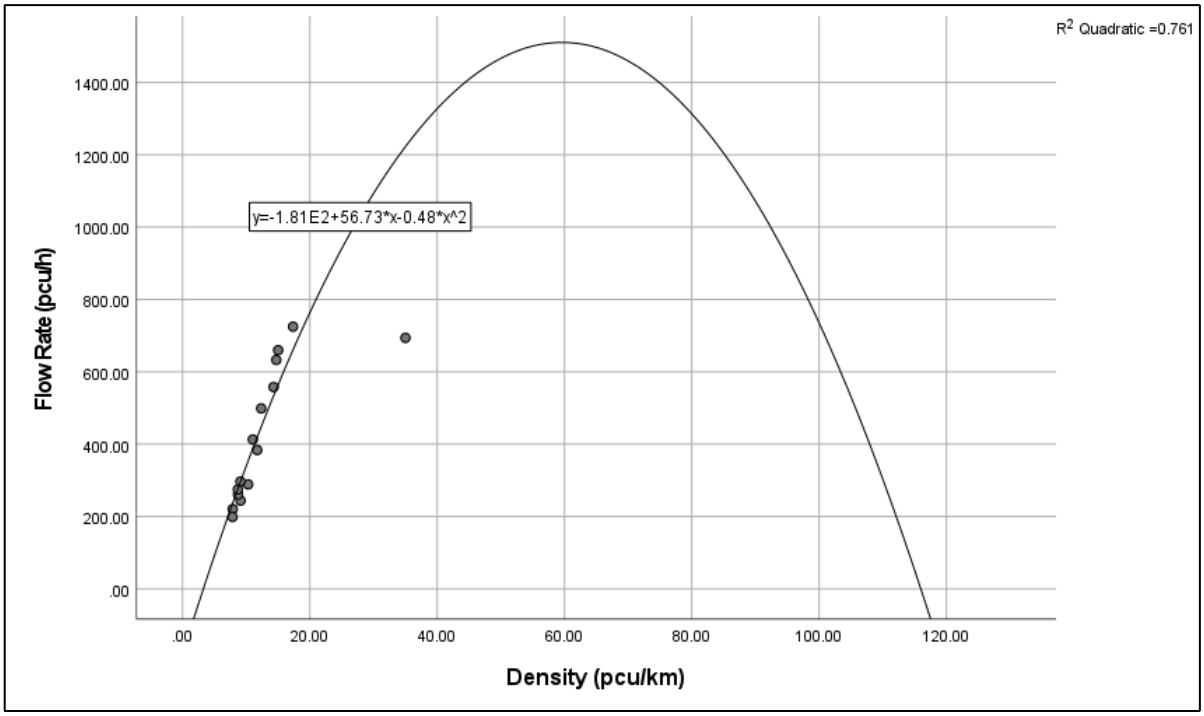


Figure 4.9: Flow-Density Fundamental Diagram for Single Carriageway Model.

This Fundamental Diagram also shows a quadratic function representing a parabolic curve. The traffic density explains 76.1% of the variance in the traffic flow rate, according to the R-square value of 0.761. The sub-model has weaknesses in the fitting of the traffic data and explains a smaller fraction of the variance in the traffic flow, as seen by the lower R-square value of the flow-density Fundamental Diagram for this sub-model than that of the main model. In addition, the following equation represents the flow-density Fundamental Diagram equation for this sub-model:

$$q = 56.73k - 0.48k^2 - 181 \qquad (4.20)$$

Before comparing this sub-flow-density model's Fundamental Diagram with that of the main model, the maximum flow rate, q_{cap}, and traffic density at the capacity of the sub-model must be computed. For this model, the computed traffic density at capacity, k_{cap}, is 59.09 pcu/km. The maximum flow rate, q_{cap}, is obtained by plugging in the capacity density value, k_{cap}. The capacity of the single carriageway roads is represented by the maximum flow rate, q_{cap}, which is calculated to be 1495 pcu/h. The traffic jam density, k_j, for this sub-model is calculated to be 114.91 pcu/km by setting the traffic flow rate to zero. This shows that the densities between 59.09 and 114.91 pcu/km are the ones where traffic congestion occurs. This sub-model has lower values for all of the significant values in this Fundamental Diagram when compared to the main model. Since a lower level of traffic density could cause delays and exhibits a smaller range of densities before congestion develops, this illustrates that a single carriageway can handle fewer cars in a given amount of time where its tolerance to the occurrence of traffic congestion is lower. This could be explained by the restrictions of minor roads without median since the absence of median magnify the drawbacks of the roads in term of safety and efficiency which could eventually affect the traffic flow of the road.

4.4.5.3 Speed-Density Fundamental Diagram

In order to build the speed-density Fundamental Diagram for roads without a median, traffic data from sixteen sites that are single carriageway roads is also being used. The fundamental speed-density diagram created by SPSS for this sub-model is shown in Figure 4.10.

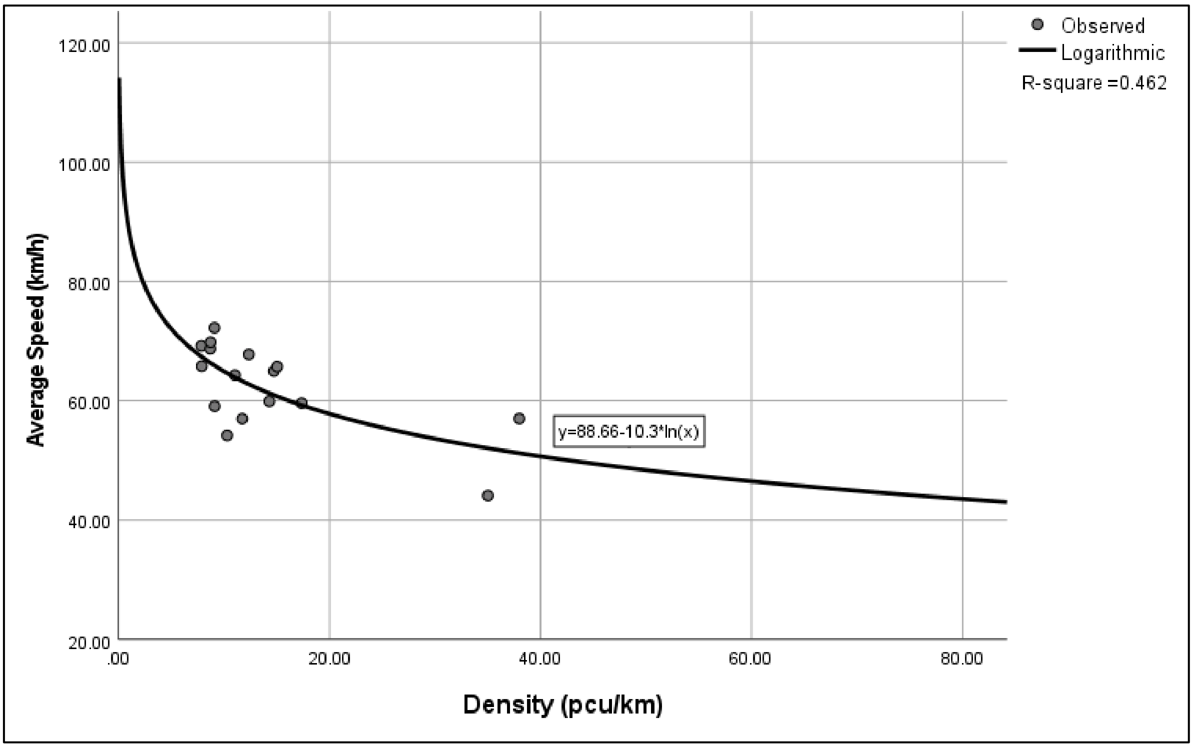


Figure 4.10: Speed-Density Fundamental Diagram for Single Carriageway Model.

This Fundamental Diagram's curve displays a logarithmic function that is similar to the main model and Greenberg's speed-density traffic model. Based on the R-square value of 0.462 obtained from the Fundamental Diagram, only 46.2% of the variability in the traffic average speed can be explained by the traffic density. The weak association between the independent variable and dependent variable when it comes to minor roads without a median may be the cause of the low R-square value found in this Fundamental Diagram. This kind of road's average vehicle speed may not be affected by traffic density, but rather by other traffic-related factors. Single carriageway roads have more limitations in terms of their characteristics, which may cause the traffic statistics to fluctuate more and produce an unacceptable R-square value. The low R-square value could also potentially be due to a lack of study sites with the same characteristics as those included in the analysis. For this sub-model, the equation for the fundamental speed-density diagram is:

$$u = 88.66 - 10.3 \ln(k) \tag{4.21}$$

After inserting the jam density, k_j, calculated from the flow-density Fundamental Diagram into the above equation, the derived equation that is similar to Greenberg's model is shown below:

$$u - 39.79 = 10.3 \ln\left(\frac{k_j}{k}\right) \quad (4.22)$$

Since the traffic speed predicted from the left-hand side of this equation has a constant variation from the actual traffic speed of 39.79 km/h, it should be noted that the coefficient 10.30 may not represent the speed corresponding to maximum flow, u_0. Also, by setting the average speed, which is the left-hand side of equation 4.21, to zero, it is possible to calculate the traffic density when the average traffic speed is zero. When the average traffic speed is zero, the identified traffic density is 6055.94 pcu/km. This value is unreasonable for a minor road without a median, thus the equation cannot be used to estimate the traffic parameter. The model's inability to accurately represent the actual underlying relationship between the variables results in an unrealistic value due to the weak correlation between the average speed and traffic density on minor roads without medians.

4.5 Comparison of Level of Service Results

Now that the main model and sub-models for this study have been developed, it is of interest to determine the Level of Service (LOS) of the sites with the capacity estimated from the main model. Besides that, the other road capacity estimation methods reviewed in this study are also being applied in determining the capacity of the site studied and their corresponding LOS. The purpose of doing so is to allow the comparison of the outcome of the capacity estimation between the model developed and the other available methods reviewed. By determining the LOS of sites using the main model and the other methods, the results of the LOS for each site could be compared and the differences in the outcome could be identified and evaluated. The road capacity estimation methods that are applied in determining the LOS of the sites for comparison purposes are the Malaysia Highway Capacity Manual

(MHCM) method, Road Traffic Volume Malaysia (RTVM) method, Van Aerde method and Headway Method.

4.5.1 LOS Result Based on Main Model

First of all, the LOS of the sites is to be identified by applying the main model of this study. To measure the LOS of a road facility, the volume-to-capacity (V/C) ratio is to be computed by dividing the traffic volume for a road by the capacity of the road. Thus, the road capacity estimated from the main model is used in the calculation of the V/C ratio for all of the sites. The capacity estimated from the main model is 3609 pcu/h which is the value to be applied to determine the LOS in this study. After calculating the V/C ratio for each of the sites, the LOS could then be identified by referring to the LOS indicator table which provides information on the corresponding LOS for different ranges of V/C ratios. The result of LOS determined with the application of the main model on the sites studied is shown in Table 4.18.

Table 4.18: Result of LOS Determined with Main Model.

No.	Name	Average Flow Rate (pcu/h)	V/C Ratio	LOS
1	Persiaran Sungai Long 1	244	0.079	A
2	Persiaran Bukit Sungai Long 2	289	0.094	A
3	Persiaran SL 1	413	0.135	A
4	Persiaran Sungai Long 2 (Northbound)	512	0.167	A
5	Persiaran Sungai Long 2 (Southbound)	617	0.201	A
6	Jalan Sungai Long, near Green Acre Park (Northbound)	253	0.082	A
7	Jalan Sungai Long, near Green Acre Park (Southbound)	475	0.155	A
8	Jalan Sungai Long, near Forest Green Condominium (Northbound)	548	0.178	A
9	Jalan Sungai Long, near Forest Green Condominium (Southbound)	405	0.132	A
10	Jalan Sungai Long, near Sungai Long Residence (Northbound)	555	0.181	A

(Continued on next page.)

Table 4.18: Result of LOS Determined with Main Model. (Continued)

No.	Name	Average Flow Rate (pcu/h)	V/C Ratio	LOS
11	Jalan Sungai Long, near Sungai Long Residence (Southbound)	635	0.207	A
12	Jalan Laksamana	1700	0.554	A
13	Jalan Shahbandar	221	0.072	A
14	Jalan Permaisuri	725	0.236	A
15	Jalan Dayang	499	0.163	A
16	Jalan Putera	660	0.215	A
17	Jalan Inang	199	0.065	A
18	Jalan Bendahara	384	0.125	A
19	Jalan Permaisuri	694	0.226	A
20	Persiaran Mahkota Cheras 1 (Northbound)	358	0.117	A
21	Persiaran Mahkota Cheras 1 (Southbound)	558	0.182	A
22	Lorong Shahbandar	261	0.085	A
23	Lorong Peel	275	0.090	A
24	Jalan Perkasa 1	558	0.182	A
25	Jalan Shelley	633	0.206	A
26	Jalan Menteri	297	0.097	A
27	Jalan Cochrane (Eastbound)	2098	0.684	B
28	Jalan Cochrane (Westbound)	711	0.232	A
29	Jalan Perkasa (Westbound)	2422	0.789	C
30	Jalan Perkasa (Eastbound)	1400	0.456	A

The traffic flow rate and V/C ratio are the essential parameters in determining the LOS of the sites in this approach, thus the values of these parameters computed for each site are shown in Table 4.18. From Table 4.18, it is determined that all of the sites are performing at LOS A except for Jalan Cochrane (Eastbound) and Jalan Perkasa (Westbound) which perform at LOS B and LOS C respectively. This implies that most of the minor roads selected in this study exhibit the highest quality of service and the road users are able to travel at the speed they desire based on the capacity estimated with the main model. In the case of Jalan Cochrane (Eastbound), the LOS determined suggests that there is an additional increase in traffic flow that expands the size and platoon formation on the road. Jalan Perkasa (Westbound) which performs at LOS C is said to be having a stable flow but is susceptible to delays and congestion since vehicles may start to move slowly at this LOS.

4.5.2 LOS Result Based on Malaysia Highway Capacity Manual (MHCM) Method

After yielding the LOS result of the sites with the capacity estimated by the main model, the LOS results using other approaches are to be determined. The Malaysia Highway Capacity Manual (MHCM) method is one of the approaches applied and this method starts by inputting the geometric data, demand volume and base free-flow speed of the road into the multilane highway worksheet. The example of a completed worksheet for one of the sites, Jalan Persiaran Sungai Long 2 is shown in Table A - 1 of Appendix A. The free-flow speed and traffic volume of the road is adjusted based on the data input to compute the free-flow speed and the average flow rate of the road. After that, the LOS of the road could be determined by referring to the graph of LOS criteria for multilane highways using the traffic average flow rate and average travel speed computed. Table 4.19 shows the LOS result of the sites determined with the application of the MHCM method.

Table 4.19: Result of LOS Determined with Malaysia Highway Capacity Manual (MHCM) Method.

No.	Name	V_i (pcu/h)	f_c	PHF	v_i (pcu/h)	Average Speed (km/h)	LOS
1	Persiaran Sungai Long 1	142	0.955	0.833	162.71	59.09	A
2	Persiaran Bukit Sungai Long 2	175	0.982	0.833	206.36	54.20	A
3	Persiaran SL 1	238	0.981	0.847	275.75	64.30	A
4	Persiaran Sungai Long 2 (Northbound)	287	0.993	0.865	329.38	64.29	A
5	Persiaran Sungai Long 2 (Southbound)	353	0.996	0.886	396.70	63.09	A
6	Jalan Sungai Long, near Green Acre Park (Northbound)	146	0.986	0.833	172.89	63.76	A
7	Jalan Sungai Long, near Green Acre Park (Southbound)	276	1.003	0.851	325.18	67.02	A

(Continued on next page.)

Table 4.19: Result of LOS Determined with Malaysia Highway Capacity Manual (MHCM) Method. (Continued)

No.	Name	V_i (pcu/h)	f_c	PHF	v_i (pcu/h)	Average Speed (km/h)	LOS
8	Jalan Sungai Long, near Forest Green Condominium (Northbound)	296	0.994	0.869	338.54	66.20	A
9	Jalan Sungai Long, near Forest Green Condominium (Southbound)	228	0.980	0.843	265.03	69.20	A
10	Jalan Sungai Long, near Sungai Long Residence (Northbound)	296	0.987	0.869	336.03	63.10	A
11	Jalan Sungai Long, near Sungai Long Residence (Southbound)	341	0.984	0.882	380.39	61.90	A
12	Jalan Laksamana	299	0.981	0.870	337.17	57.00	A
13	Jalan Shahbandar	60	0.956	0.833	68.88	65.81	A
14	Jalan Permaisuri	207	0.992	0.836	245.56	59.60	A
15	Jalan Dayang	265	0.977	0.857	302.05	67.78	A
16	Jalan Putera	443	0.976	0.910	475.12	65.73	B
17	Jalan Inang	143	0.975	0.833	167.42	69.21	A
18	Jalan Bendahara	124	1.015	0.833	151.15	56.98	A
19	Jalan Permaisuri	306	1.011	0.872	354.61	44.10	B
20	Persiaran Mahkota Cheras 1 (Northbound)	137	0.985	0.833	162.00	71.10	A
21	Persiaran Mahkota Cheras 1 (Southbound)	226	0.988	0.843	264.88	64.20	A
22	Lorong Shahbandar	172	0.954	0.833	197.00	69.82	A
23	Lorong Peel	181	0.972	0.833	211.31	68.72	A
24	Jalan Perkasa 1	369	0.960	0.891	397.67	59.92	A
25	Jalan Shelley	410	0.958	0.902	435.61	64.98	A
26	Jalan Menteri	226	0.976	0.843	261.76	72.23	A
27	Jalan Cochrane (Eastbound)	337	0.950	0.881	363.28	34.20	B
28	Jalan Cochrane (Westbound)	886	0.958	0.972	873.44	50.30	D
29	Jalan Perkasa (Westbound)	1181	0.936	0.987	1120.22	24.08	F
30	Jalan Perkasa (Eastbound)	373	0.957	0.892	399.99	46.06	B

The demand volume for the full peak hour, V_i, traffic composition factor, f_c, peak hour factor, PHF, average flow rate, v_i and average travel speed, S are the essential parameters in determining the LOS of the sites in this approach and the values of these parameter computed for each site are shown in Table 4.19. From Table 4.19, it is determined that all of the sites are performing at LOS A except for Jalan Putera, Jalan Permaisuri (collector/distributor road), Jalan Cochrane (Eastbound), Jalan Cochrane (Westbound), Jalan Perkasa (Westbound) and Jalan Perkasa (Eastbound) which perform at LOS B, LOS B, LOS B, LOS D, LOS F and LOS B respectively. This result implies that most of the sites exhibit free-flow traffic where road users do not affect each other in the traffic stream. In the case of Jalan Putera, Jalan Permaisuri, Jalan Cochrane (Eastbound) and Jalan Perkasa (Eastbound), these sites exhibit reasonably stable traffic flow conditions but with some impact by others. Jalan Cochrane (Westbound) is characterised as having a high-density flow in which, despite its traffic flow that remains stable, comfort and convenience have decreased and speed and freedom of movement are severely constrained. LOS F of Jalan Perkasa (Westbound) indicates that the traffic demand of this road has exceeded its capacity where heavy congestion flow takes place.

4.5.3 LOS Result Based on Road Traffic Volume Malaysia (RTVM) Method

The next approach is the Road Traffic Volume Malaysia (RTVM) method and this method involves the estimation of the road capacity using equation 2.4. The capacity is estimated based on the information of the road that comprises the type of road, number of lanes, carriageway width and type of terrain. After estimating the road capacity, the V/C ratio of the road is computed, and the LOS is determined by referring to the LOS indicator table. The LOS result of the sites determined with this approach is shown in Table 4.20.

Table 4.20: Result of LOS Determined with Road Traffic Volume Malaysia (RTVM) Method.

No.	Name	Ideal Hourly Capacity, *I*	Roadways Reduction Factor, *R*	Traffic Reduction Factor, *T*	Capacity, *C*	Average Flow Rate (pcu/h)	V/C Ratio	LOS
1	Persiaran Sungai Long 1	2800	0.79	0.99	2190.10	244	0.111	A
2	Persiaran Bukit Sungai Long 2	6000	0.79	0.99	4693.07	289	0.061	A
3	Persiaran SL 1	2800	0.79	0.98	2168.63	413	0.191	A
4	Persiaran Sungai Long 2 (Northbound)	4000	0.83	0.98	3254.90	512	0.157	A
5	Persiaran Sungai Long 2 (Southbound)	4000	0.83	0.99	3287.13	617	0.188	A
6	Jalan Sungai Long, near Green Acre Park (Northbound)	4000	0.83	0.99	3287.13	253	0.077	A
7	Jalan Sungai Long, near Green Acre Park (Southbound)	4000	0.83	0.98	3254.90	475	0.146	A
8	Jalan Sungai Long, near Forest Green Condominium (Northbound)	4000	0.83	0.98	3254.90	548	0.168	A
9	Jalan Sungai Long, near Forest Green Condominium (Southbound)	4000	0.83	0.99	3287.13	405	0.123	A
10	Jalan Sungai Long, near Sungai Long Residence (Northbound)	4000	0.83	0.98	3254.90	555	0.171	A
11	Jalan Sungai Long, near Sungai Long Residence (Southbound)	4000	0.83	0.99	3287.13	635	0.193	A
12	Jalan Laksamana	8000	0.9	0.99	7128.71	1700	0.238	A
13	Jalan Shahbandar	8000	0.9	0.99	7128.71	221	0.031	A
14	Jalan Permaisuri	8000	0.9	0.99	7128.71	725	0.102	A
15	Jalan Dayang	2800	0.79	0.99	2190.10	499	0.228	A

(Continued on next page.)

Table 4.20: Result of LOS Determined with Road Traffic Volume Malaysia (RTVM) Method. (Continued)

No.	Name	Ideal Hourly Capacity, *I*	Roadways Reduction Factor, *R*	Traffic Reduction Factor, *T*	Capacity, *C*	Average Flow Rate (pcu/h)	V/C Ratio	LOS
16	Jalan Putera	2800	0.79	0.99	2190.10	660	0.301	A
17	Jalan Inang	2800	0.79	0.97	2147.57	199	0.092	A
18	Jalan Bendahara	8000	0.9	0.97	6990.29	384	0.055	A
19	Jalan Permaisuri	6000	0.83	0.95	4742.86	694	0.146	A
20	Persiaran Mahkota Cheras 1 (Northbound)	6000	0.83	0.97	4834.95	358	0.074	A
21	Persiaran Mahkota Cheras 1 (Southbound)	6000	0.83	0.97	4834.95	558	0.115	A
22	Lorong Shahbandar	2800	0.9	0.99	2495.05	261	0.104	A
23	Lorong Peel	2800	0.9	0.98	2470.59	275	0.111	A
24	Jalan Perkasa 1	2800	0.9	0.99	2495.05	558	0.224	A
25	Jalan Shelley	6000	0.9	0.99	5346.53	633	0.118	A
26	Jalan Menteri	2800	0.9	0.99	2495.05	297	0.119	A
27	Jalan Cochrane (Eastbound)	6000	0.9	0.98	5294.12	2098	0.396	A
28	Jalan Cochrane (Westbound)	6000	0.9	0.98	5294.12	711	0.134	A
29	Jalan Perkasa (Westbound)	6000	0.9	0.99	5346.53	2422	0.453	A
30	Jalan Perkasa (Eastbound)	6000	0.9	0.98	5294.12	1400	0.264	A

The ideal hourly capacity, *I*, roadways reduction factor, *R* and traffic reduction factor, *T* are the essential parameters applied in estimating the road capacity and the values of these parameters are shown in Table 4.20. From Table 4.20, it is determined that all of the sites are having a V/C ratio that is less than 0.6 which means that they are all performing at LOS A. All of the sites studied are said to be experiencing free-flow traffic and having the highest quality of service based on the outcome of this method.

4.5.4 LOS Result Based on Van Aerde Model

Van Aerde model is the next method adopted to determine the LOS of the sites studied. This method involves the calculation of the headway constant coefficients using equations 2.10, 2.11 and 2.11 which are the parameters required in estimating the road capacity. The road capacity is then being estimated using equation 2.8 where the free flow speed and average travel speed of the road are applied in the calculation. The V/C ratio of the road is calculated after computing the road capacity, and the LOS is obtained based on the LOS indicator table. The LOS outcome for the sites identified using this method is displayed in Table 4.21.

Table 4.21: Result of LOS Determined with Van Aerde Model.

No.	Name	Average Speed (km/h)	c_1	c_2	c_3	Capacity, C_i	Average Flow Rate (pcu/h)	V/C Ratio	LOS
1	Persiaran Sungai Long 1	59.09	0.04	10.17	-0.007	531	244	0.459	A
2	Persiaran Bukit Sungai Long 2	54.2	0.04	10.17	-0.007	513	289	0.563	A
3	Persiaran SL 1	64.3	0.04	1.29	-0.002	854	413	0.484	A
4	Persiaran Sungai Long 2 (Northbound)	64.29	0.04	1.02	-0.001	1039	512	0.492	A
5	Persiaran Sungai Long 2 (Southbound)	63.09	0.04	1.02	-0.001	1215	617	0.507	A
6	Jalan Sungai Long, near Green Acre Park (Northbound)	63.76	0.06	6.79	-0.005	452	253	0.559	A
7	Jalan Sungai Long, near Green Acre Park (Southbound)	67.02	0.04	1.02	-0.001	1002	475	0.474	A
8	Jalan Sungai Long, near Forest Green Condominium (Northbound)	66.2	0.04	0.80	-0.001	1140	548	0.481	A
9	Jalan Sungai Long, near Forest Green Condominium (Southbound)	69.2	0.04	0.83	-0.001	826	405	0.490	A
10	Jalan Sungai Long, near Sungai Long Residence (Northbound)	63.1	0.04	0.93	-0.001	1837	555	0.302	A
11	Jalan Sungai Long, near Sungai Long Residence (Southbound)	61.9	0.05	1.76	-0.002	1337	635	0.475	A
12	Jalan Laksamana	57	0.03	0.31	0.000	2724	1700	0.624	B
13	Jalan Shahbandar	65.81	0.06	5.39	-0.005	465	221	0.476	A
14	Jalan Permaisuri	59.6	0.05	1.76	-0.002	3404	725	0.213	A
15	Jalan Dayang	67.78	0.05	1.68	-0.002	868	499	0.575	A

(Continued on next page.)

Table 4.21: Result of LOS Determined with Van Aerde Model. (Continued)

No.	Name	Average Speed (km/h)	c_1	c_2	c_3	Capacity, C_i	Average Flow Rate (pcu/h)	V/C Ratio	LOS
16	Jalan Putera	65.73	0.06	2.16	-0.002	1121	660	0.589	A
17	Jalan Inang	69.21	0.06	7.56	-0.006	434	199	0.458	A
18	Jalan Bendahara	56.98	0.06	7.44	-0.006	801	384	0.479	A
19	Jalan Permaisuri	44.1	0.06	4.01	-0.004	2288	694	0.303	A
20	Persiaran Mahkota Cheras 1 (Northbound)	71.1	0.06	7.44	-0.006	897	358	0.399	A
21	Persiaran Mahkota Cheras 1 (Southbound)	64.2	0.06	4.94	-0.004	1654	558	0.337	A
22	Lorong Shahbandar	69.82	0.05	11.14	-0.008	453	261	0.575	A
23	Lorong Peel	68.72	0.05	11.85	-0.008	544	275	0.506	A
24	Jalan Perkasa 1	59.92	0.06	3.46	-0.003	109	558	5.123	A
25	Jalan Shelley	64.98	0.06	2.80	-0.003	1133	633	0.559	A
26	Jalan Menteri	72.23	0.04	1.13	-0.002	1022	297	0.291	A
27	Jalan Cochrane (Eastbound)	34.2	0.06	1.73	-0.002	3059	2098	0.686	B
28	Jalan Cochrane (Westbound)	50.3	-0.01	24.05	-0.013	1084	711	0.656	B
29	Jalan Perkasa (Westbound)	24.08	0.05	1.35	-0.002	3165	2422	0.765	C
30	Jalan Perkasa (Eastbound)	46.06	0.06	4.20	-0.004	2103	1400	0.666	B

The headway constant coefficients, c_1, c_2, c_3 and the estimated capacity for road I, *Ci* are the significant parameters in determining the LOS for this approach, thus they are included in Table 4.21. From Table 4.21, it is determined that all of the sites are performing at LOS A except for Jalan Laksamana, Jalan Cochrane (Eastbound), Jalan Cochrane (Westbound), Jalan Perkasa (Westbound) and Jalan Perkasa (Eastbound) which perform at LOS B, LOS B, LOS B, LOS C and LOS B respectively. According to this finding, the majority of the locations have free-flowing traffic, meaning that drivers do not interfere with one another's movements. The traffic flow conditions of Jalan Laksamana, Jalan Cochrane (Eastbound), Jalan Cochrane (Westbound) and Jalan Perkasa (Eastbound) are comparatively stable; however, they experience some impact by other road users. In the case of Jalan Perkasa (Westbound), the restricted traffic flow remains stable yet has a lot of contact with other vehicles in the stream of traffic and there is a drop in overall comfort and convenience for the drivers.

4.5.5 LOS Result Based on Headway Method

The fifth approach applied in determining the LOS of the sites is the Headway Method. In this approach, the mean headway for the vehicles travelling on the road is calculated by referring to the video recorded at the sites. The road capacity is then calculated using equation 2.22 with mean headway as the parameter of this equation. After calculating the road's capacity, the V/C ratio is computed, and the LOS is determined using the LOS indicator table. Table 4.22 displays the LOS results for the sites identified by this method.

Table 4.22: Result of LOS Determined with Headway Method.

No.	Name	Mean Headway h_m	Capacity, C	Average Flow Rate (pcu/h)	V/C Ratio	LOS
1	Persiaran Sungai Long 1	8.40	429	244	0.569	A
2	Persiaran Bukit Sungai Long 2	7.21	499	289	0.578	A
3	Persiaran SL 1	4.35	828	413	0.499	A
4	Persiaran Sungai Long 2 (Northbound)	3.22	1118	512	0.458	A

(Continued on next page.)

Table 4.22: Result of LOS Determined with Headway Method. (Continued)

No.	Name	Mean Headway h_m	Capacity, C	Average Flow Rate (pcu/h)	V/C Ratio	LOS
5	Persiaran Sungai Long 2 (Southbound)	3.20	1125	617	0.548	A
6	Jalan Sungai Long, near Green Acre Park (Northbound)	4.33	831	253	0.304	A
7	Jalan Sungai Long, near Green Acre Park (Southbound)	4.23	851	475	0.558	A
8	Jalan Sungai Long, near Forest Green Condominium (Northbound)	4.32	833	548	0.657	B
9	Jalan Sungai Long, near Forest Green Condominium (Southbound)	4.83	745	405	0.543	A
10	Jalan Sungai Long, near Sungai Long Residence (Northbound)	3.22	1118	555	0.496	A
11	Jalan Sungai Long, near Sungai Long Residence (Southbound)	3.87	930	635	0.682	B
12	Jalan Laksamana	1.26	2857	1700	0.595	A
13	Jalan Shahbandar	6.50	554	221	0.399	A
14	Jalan Permaisuri	2.65	1358	725	0.533	A
15	Jalan Dayang	3.43	1050	499	0.476	A
16	Jalan Putera	3.22	1118	660	0.590	A
17	Jalan Inang	3.87	930	199	0.213	A
18	Jalan Bendahara	3.85	935	384	0.411	A
19	Jalan Permaisuri	3.21	1121	694	0.619	B
20	Persiaran Mahkota Cheras 1 (Northbound)	5.40	667	358	0.537	A
21	Persiaran Mahkota Cheras 1 (Southbound)	3.43	1050	558	0.531	A
22	Lorong Shahbandar	2.95	1220	261	0.213	A
23	Lorong Peel	5.44	662	275	0.416	A
24	Jalan Perkasa 1	3.86	933	558	0.598	A
25	Jalan Shelley	3.11	1158	633	0.547	A
26	Jalan Menteri	4.32	833	297	0.356	A
27	Jalan Cochrane (Eastbound)	1.21	2975	2098	0.705	C
28	Jalan Cochrane (Westbound)	3.02	1192	711	0.596	A

(Continued on next page.)

Table 4.22: Result of LOS Determined with Headway Method. (Continued)

No.	**Name**	**Mean Headway** h_m	**Capacity,** C	**Average Flow Rate (pcu/h)**	**V/C Ratio**	**LOS**
29	Jalan Perkasa (Westbound)	1.06	3396	2422	0.713	C
30	Jalan Perkasa (Eastbound)	1.74	2069	1400	0.677	B

Since mean headway, h_m and capacity estimated, C are the essential parameters in computing the V/C ratio of this approach, the values of these parameters are depicted in Table 4.22. From Table 4.22, it is determined that all of the sites are performing at LOS A except for Jalan Sungai Long near Forest Green Condominium (Northbound), Jalan Sungai Long near Sungai Long Residence (Southbound), Jalan Permaisuri (collector/distributor road), Jalan Cochrane (Eastbound), Jalan Perkasa (Westbound) and Jalan Perkasa (Eastbound) which perform at LOS B, LOS B, LOS B, LOS C, LOS C and LOS B respectively. This result suggests that the majority of the places have free-flowing traffic, which means that vehicles do not obstruct one another's movements. Jalan Sungai Long near Forest Green Condominium (Northbound), Jalan Sungai Long near Sungai Long Residence (Southbound) and Jalan Perkasa (Eastbound) all have rather stable traffic flow conditions; nonetheless, other road users have a slight impact on them. There would be a decrease in overall comfort and convenience for the drivers in the case of Jalan Cochrane (Eastbound) and Jalan Perkasa (Westbound) since the restricted traffic flow is stable but has many interactions between vehicles.

4.6 Summary of LOS Results for All Approaches

The summary of the LOS results of the sites determined from the main model, MHCM method, RTVM method, Van Aerde model and Headway Method are shown in Table 4.23.

Table 4.23: Summary of LOS Results for Main Model, MHCM Method, RTVM Method, Van Aerde Model and Headway Method.

No.	Name	Level of Service (LOS)				
		Main Model	MHCM	RTVM	Van Aerde	Headway
1	Persiaran Sungai Long 1	A	A	A	A	A
2	Persiaran Bukit Sungai Long 2	A	A	A	A	A
3	Persiaran SL 1	A	A	A	A	A
4	Persiaran Sungai Long 2 (Northbound)	A	A	A	A	A
5	Persiaran Sungai Long 2 (Southbound)	A	A	A	A	A
6	Jalan Sungai Long, near Green Acre Park (Northbound)	A	A	A	A	A
7	Jalan Sungai Long, near Green Acre Park (Southbound)	A	A	A	A	A
8	Jalan Sungai Long, near Forest Green Condominium (Northbound)	A	A	A	A	B
9	Jalan Sungai Long, near Forest Green Condominium (Southbound)	A	A	A	A	A
10	Jalan Sungai Long, near Sungai Long Residence (Northbound)	A	A	A	A	A
11	Jalan Sungai Long, near Sungai Long Residence (Southbound)	A	A	A	A	B
12	Jalan Laksamana	A	A	A	B	A
13	Jalan Shahbandar	A	A	A	A	A
14	Jalan Permaisuri	A	A	A	A	A
15	Jalan Dayang	A	A	A	A	A
16	Jalan Putera	A	B	A	A	A
17	Jalan Inang	A	A	A	A	A
18	Jalan Bendahara	A	A	A	A	A
19	Jalan Permaisuri	A	B	A	A	B
20	Persiaran Mahkota Cheras 1 (Northbound)	A	A	A	A	A
21	Persiaran Mahkota Cheras 1 (Southbound)	A	A	A	A	A
22	Lorong Shahbandar	A	A	A	A	A

(Continued on next page.)

Table 4.23: Summary of LOS Results for Main Model, MHCM Method, RTVM Method, Van Aerde Model and Headway Method. (Continued)

No.	Name	Level of Service (LOS)				
		Main Model	MHCM	RTVM	Van Aerde	Headway
23	Lorong Peel	A	A	A	A	A
24	Jalan Perkasa 1	A	A	A	A	A
25	Jalan Shelley	A	A	A	A	A
26	Jalan Menteri	A	A	A	A	A
27	Jalan Cochrane (Eastbound)	B	B	A	B	C
28	Jalan Cochrane (Westbound)	A	D	A	B	A
29	Jalan Perkasa (Westbound)	C	F	A	C	C
30	Jalan Perkasa (Eastbound)	A	B	A	B	B

From Table 4.23, it is known that most of the sites that are minor roads are performing at LOS A regardless of the method applied in determining their LOS. However, it is noticed that some of the sites are performing below LOS A which is between LOS B to LOS F based on the results obtained from various approaches. Jalan Sungai Long near Forest Green Condominium (Northbound), Jalan Sungai Long near Sungai Long Residence (Southbound), Jalan Laksamana, Jalan Putera, Jalan Permaisuri (collector/distributor road), Jalan Cochrane (Eastbound), Jalan Cochrane (Westbound), Jalan Perkasa (Westbound) and Jalan Perkasa (Eastbound) are the sites determined to be performing between LOS B to LOS F. Among these sites, five of them even performed below LOS A more than once which are assessed under different approaches. These sites are Jalan Permaisuri (collector/distributor road), Jalan Cochrane (Eastbound), Jalan Cochrane (Westbound), Jalan Perkasa (Westbound) and Jalan Perkasa (Eastbound) and the frequency of performing between LOS B to LOS F for these sites are 2, 4, 2, 4 and 3 respectively. In addition, the MHCM approach has recorded a site that performs at the worst LOS which is LOS F and it is Jalan Perkasa (Westbound) where it is the only site that performs at LOS F among all of the sites assessed with the approaches applied. The LOS result determined based on the main model is observed to be having two sites that perform below LOS A and they are Jalan Cochrane (Eastbound) and Jalan Perkasa (Westbound). This result is being compared with the results determined based on other approaches in this study. By comparing the result of the main model with the result of the MHCM method, it is revealed that the latter has six sites that perform below LOS A which is an addition of four sites compared to the main model. The MHCM method has two sites performing below LOS A that are in common with the sites of the main model and the rest of the sites that differ from the main model are Jalan Putera, Jalan Permaisuri, Jalan Cochrane (Westbound) and Jalan Perkasa (Eastbound). Moving on to the comparison of the LOS result between the main model and the RTVM approach, it is determined that the result based on the RTVM method has nothing in common with the main model in terms of the sites performing between B to LOS F since none of the sites in this approach is determined to be performing below LOS A. When the LOS results of the main model and the Van Aerde model are compared, the latter has an additional three sites, or a total of five sites, that perform worse than LOS A. A number of two out of five of the sites that perform below LOS A in the Van Aerde model are of the same sites as the one in the main model and the other three sites are Jalan Laksamana, Jalan Cochrane (Westbound) and Jalan Perkasa (Eastbound). A comparison of the LOS results between the main model and the Headway Method suggests that the Headway Method has six sites that perform below LOS A which is an addition of four sites compared to the main model. A number of two out of the six sites in the Headway Method that perform below LOS A are the same sites as the one in the main model, while the other four sites are Jalan Sungai Long near Forest Green Condominium (Northbound), Jalan Sungai Long near Sungai Long Residence (Southbound), Jalan Permaisuri (collector/distributor road) and Jalan Perkasa (Eastbound).

Based on the comparisons conducted, it is revealed that sites determined to be performing below LOS A based on the main model are also identified to be performing below LOS A based on all of the other approaches applied except for the RTVM method. Jalan Perkasa (Westbound) appears to be the site that exhibits the poorest overall performance based on the LOS determined with the approaches. Other than that, the main model is also seen to be having the same exact LOS as the MHCM method and the Van Aerde model in the case of Jalan Cochrane (Eastbound). In the case of Jalan Perkasa (Westbound), the main model is observed to be having the same exact LOS as the Van Aerde model and Headway Method. The traffic flow condition at Jalan Cochrane (Eastbound) and Jalan Perkasa (Westbound) which are described based on their respective LOS identified from the main model may be justified by the actual traffic flow recorded at these sites during data collection. Figure 4.11 and Figure 4.12 illustrates the actual traffic flow extracted from the video recorded during data collection at Jalan Cochrane (Eastbound) and Jalan Perkasa (Westbound) respectively.

Figure 4.11: Traffic Flow Condition at Jalan Cochrane (Eastbound).

Figure 4.12: Traffic Flow Condition at Jalan Perkasa (Westbound).

Based on Figure 4.11 and Figure 4.12 where the images are extracted randomly in the one-hour period of data collection from the video recorded, it is observed that both of the roads have a traffic volume that may fit the description of their respective LOS. Jalan Cochrane (Eastbound) is seen to be having a certain amount of traffic volume that exhibits stable traffic flow with a great degree of flexibility in choosing speed and operating conditions but with some effect from other road users. Jalan Perkasa (Westbound) depicts a higher traffic volume with a restricted flow that is still stable but has a lot of contact with other vehicles in the stream of traffic.

The comparison of the LOS results between the model developed and the other methods shows that the main model has a certain degree of similarity with the Malaysia Highway Capacity Manual method, Van Aerde model and Headway Method in measuring the LOS results of minor roads. This is due to the fact that the main model has yielded a result with two sites performing below LOS A and these two sites are also performing between LOS B to LOS F based on the results of the other approaches mentioned. However, the other approaches have yielded the results with a few more extra sites that perform below LOS A as compared to the result yielded with the main model. It is to be noted that the differences in the outcome of the other methods with the main model do not imply that the main model is not fit to be applied in predicting the road capacity of the minor roads since the goal here is to identify the distinction between the approaches in term of assessing the LOS of a minor road which may contribute in assisting the transport planner in selecting the ideal approach of estimating road capacity based on various situations and conditions.

4.7 Capacity Model

After developing five models that are significant in estimating the traffic flow and constructing five sets of Fundamental Diagrams to determine the capacities for minor roads, the model that could estimate the capacity of a minor road is to be developed to ensure that the objective of this study could be achieved. The equations developed from the models and essential traffic parameters determined from the Fundamental Diagrams are being applied in the development of the road capacity model. It is to be noted that the capacity model developed is to have predictor variables where the information of the variables could be easily obtained by transport planners such as the number of lanes, type of road, type of carriageway and speed limit.

4.7.1 Speed Limit of Sites

Since the speed limit of a particular road is one of the basic predictors that could be easily obtained by the transport planners, it is one of the independent variables included prior to the multiple linear regression to develop the road capacity model. The speed limits of the sites selected for this study are shown in Table A - 2 of Appendix A.

The speed limits of the sites are based on the observation of road signs from Google Map's street view and related information about the surrounding of the sites. Based on Table A - 2 of Appendix A, it is determined that thirteen of the sites have a speed limit of 60 km/h; thirteen of the other sites have a speed limit of 70 km/h; four of the sites have a speed limit of 30 km/h. This implies that the speed limits of the minor roads selected only come in three speed limits which are 30 km/h, 60 km/h and 70 km/h.

4.7.2 Speed Limit Model

The development of a model with road capacity as the dependent variable implies that the capacities of the sites are to be estimated with as much of the sub-models to ensure that the values of the capacity estimated for the sites do not only come in a few values. Hence, it is interesting in developing the speed limit sub-models that could estimate the traffic flow by utilising the traffic data of the sites that have the same speed limit for multiple regression analysis and Fundamental Diagrams developments. Since the sites consist of only three speed limits, the speed limit sub-models to be developed will be the 60 km/h speed limit model, 90 km/h speed limit model and 30 km/h speed limit model.

4.7.2.1 60 km/h Speed Limit Model

The traffic data from the sites with 60 km/h as their speed limits is adopted in the development of this sub-model.

4.7.2.1.1 Multiple Linear Regression Analysis

Among the thirty sites, thirteen of them have a speed limit of 60 km/h; thus, the traffic data of this sub-model comprises the data collected from these sites. The independent variables for the regression analysis of this sub-model are the type of road, type of carriageway, number of lanes, traffic density, and average vehicle speed while the dependent variable is the traffic flow. The three main tables that explain the outcome of the analysis of this sub-model are explained in this sub-chapter.

Table 4.24 depicts the Model Summary table generated for the 60 km/h speed limit model.

Table 4.24: Model Summary Table for 60 km/h Speed Limit Model.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.997[a]	.994	.987	45.93181

a. Predictors: (Constant), Density, Type of Carriageway, Average Speed, Number of Lane, Type of Road

Table 4.24 reveals that the multiple correlation coefficient, R, has a value of 0.997 for this sub-model. This result is satisfactory for this sub-model and allows for further analysis because it is greater than 0.4 and shows a good level of prediction accuracy for the dependent variable. In the case of this model, R^2, or the coefficient of determination, is found to be 0.994. This value is greater than 0.5, demonstrating the model's success in identifying the relationship and demonstrating that the independent variables account for 99.4 % of the variance in the dependent variable. Since it is close to the R-value, the adjusted R-square for this sub-model which is 0.987, is acceptable.

The ANOVA table generated by SPSS software is shown in Table 4.25.

Table 4.25: ANOVA Table for 60 km/h Speed Limit Model.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1617230.070	5	323446.014	153.311	<.001[b]
	Residual	10548.657	5	2109.731		
	Total	1627778.727	10			

a. Dependent Variable: Flow Rate

b. Predictors: (Constant), Density, Type of Carriageway, Average Speed, Number of Lane, Type of Road

The p-value for this model is less than 0.001, according to Table 4.25. The significance of this sub-model in predicting the outcome of the dependent variable is determined by the p-value, which is less than 0.05. The model is effective, as evidenced by the F-ratio for this sub-model, which was found to be 153.311.

The Coefficients table for this sub-model is displayed in Table 4.26.

Table 4.26: Coefficients Table for 60 km/h Speed Limit Model.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-562.284	290.899		-1.933	.111	-1310.064	185.496
	Type of Road	-805.472	96.040	-.933	-8.387	<.001	-1052.350	-558.594
	Type of Carriageway	839.430	95.603	.842	8.780	<.001	593.674	1085.186
	Number of Lane	-11.040	42.458	-.019	-.260	.805	-120.183	98.102
	Average Speed	6.437	3.864	.115	1.666	.157	-3.495	16.370
	Density	51.698	2.987	1.293	17.309	<.001	44.021	59.376

a. Dependent Variable: Flow Rate

The p-values for the variable type of road, type of carriageway, number of lanes, average speed and traffic density are determined to be < 0.001, < 0.001, 0.805, 0.157 and < 0.001, respectively, based on the results provided in Table 4.26. This demonstrates that the type of road, type of carriageway and traffic density are the independent variables with a significant influence on the traffic flow on the minor road with a 60 km/h speed limit. The unstandardised coefficients for the type of road, type of carriageway, number of lanes, average speed and traffic density are found to be -805.472, 839.43, -11/04, 6.437 and 51.698, respectively. This suggests that the traffic flow rate decreases by 805.472 pcu/h when the type of road is a collector or distributor road; increases by 839.43 pcu/h when the type of carriageway is dual carriageway; decreases by 11.04 pcu/h with a one-unit increase in lane number; increases by 6.437 pcu/h with a one-unit increase in average speed; increases by 51.698 pcu/h with a one-unit increase in density. The y-intercept of this sub-model is also determined to be -562.284. Since the variables number of lanes and average speed are found to be insignificant in this sub-model, they may be removed from the model's equation to yield a model with higher reliability in predicting traffic flow. The general equation of this sub-model is then:

$$q = 51.698k - 805.472a + 839.43b - 562.284 \qquad (4.23)$$

The result of the multiple linear regression analysis of the 60 km/h speed limit model shows that the traffic density, type of road and type of carriageway may be the factors affecting the traffic flow of the minor road with a speed limit of 60 km/h.

4.7.2.1.2 Flow-Density Fundamental Diagram

The flow-density Fundamental Diagram of the 60 km/h speed limit model is to be built to yield another equation that could determine the capacity of the sites. Traffic data from thirteen sites with a speed limit of 60 km/h are applied in constructing the flow-density Fundamental Diagram as shown in Figure 4.13.

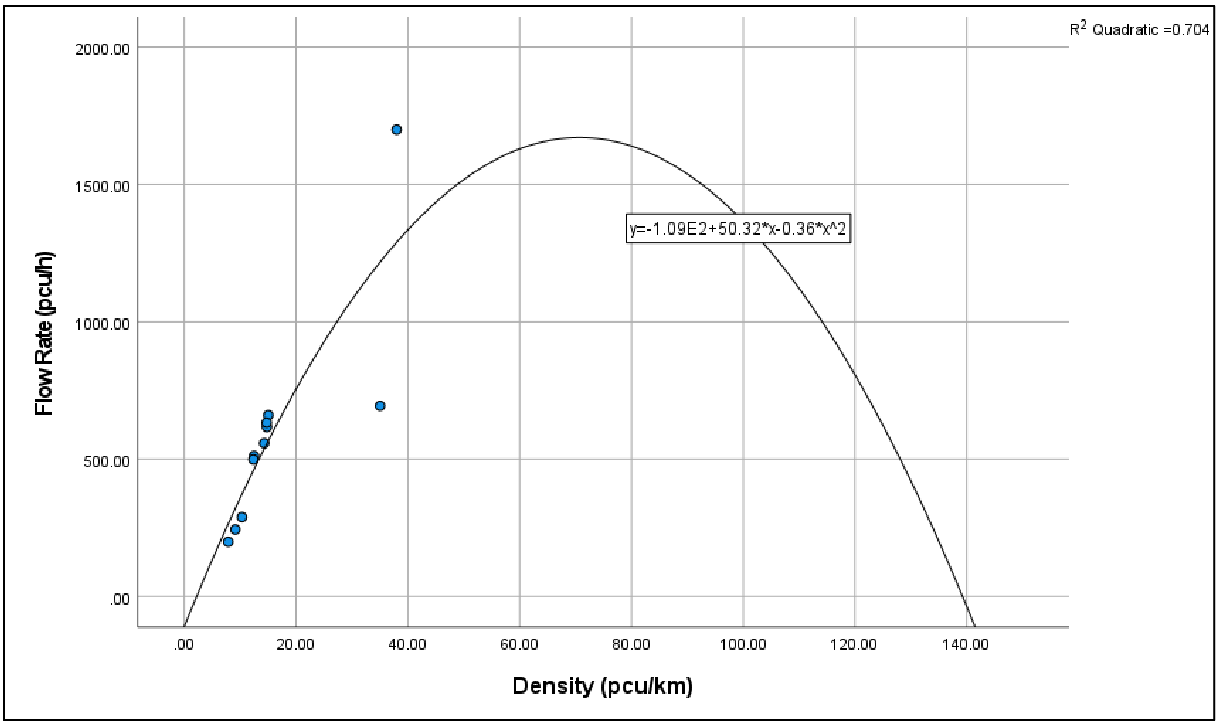


Figure 4.13: Flow-Density Fundamental Diagram for 60 km/h Speed Limit Model.

The R-square value of this Fundamental Diagram is found to be 0.704 based on Figure 4.13 which implies that the traffic density explains 70.4 % of the variance in the traffic flow. Besides that, the equation for the parabolic curve in this diagram is determined as follows:

$$q = 50.32k - 0.36k^2 - 109 \tag{4.24}$$

To estimate the capacity for the minor road with a 60 km/h speed limit, the capacity density, k_{cap} and the maximum flow rate, q_{cap} of this model are to be computed. The capacity density, k_{cap} of this model is calculated as 69.89 pcu/km using the differentiated equation 4.24. By inserting this value into the equation, the maximum flow rate, q_{cap} is determined to be 1649 pcu/h. By setting the traffic flow rate to zero, the traffic jam density, k_j, for this sub-model is calculated to be 137.58 pcu/km. This demonstrates that the densities in which traffic congestion occurs are between 69.89 and 137.58 pcu/km.

4.7.2.2 70 km/h Speed Limit Model

After the construction of the 60 km/h speed limit model, the following sub-model is developed using traffic data from research locations with 70 km/h speed limits.

4.7.2.2.1 Multiple Linear Regression Analysis

A number of thirteen research locations have a speed limit of 70 km/h; therefore, the traffic data for this sub-model consists of data collected from these sites. The independent variables for the regression analysis of this sub-model are the type of road, type of carriageway, number of lanes, traffic density, and average vehicle speed, with traffic flow serving as the dependent variable. This subchapter presents the three primary tables that explain the outcome of the analysis of this sub-model.

Table 4.27 displays the Model Summary table for this sub-model that is generated by SPSS software.

Table 4.27: Model Summary Table for 70 km/h Speed Limit Model.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.969[a]	.939	.905	204.35286

a. Predictors: (Constant), Density, Number of Lane, Type of Road, Average Speed, Type of Carriageway

The multiple correlation coefficient, R, has a value of 0.969 according to Table 4.27 for this sub-model. This result is adequate for this sub-model and permits further analysis because it is greater than 0.4 and demonstrates a high level of accuracy in predicting the dependent variable. R^2, or the coefficient of determination, is discovered to be 0.939 for this model. This value is greater than 0.5, indicating that the model successfully identified the relationship and that the independent variables explain 93.9 % of the variance in the dependent variable. This sub-model's adjusted R-square is 0.905, which is an acceptable value given that it is close to the R-value.

The ANOVA table for this sub-model is displayed in Table 4.28.

Table 4.28: ANOVA Table for 70 km/h Speed Limit Model.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5782997.574	5	1156599.515	27.696	<.001[b]
	Residual	375840.826	9	41760.092		
	Total	6158838.400	14			

a. Dependent Variable: Flow Rate

b. Predictors: (Constant), Density, Number of Lane, Type of Road, Average Speed, Type of Carriageway

According to Table 4.28, the p-value for this model is below 0.001. The significance of this sub-model's ability to predict the outcome of the dependent variable is determined by the p-value, which is less than 0.05. The F-ratio for this sub-model, which was determined to be 27.696, demonstrates the model's efficacy.

Table 4.29 depicts the Coefficients table for this sub-model.

Table 4.29: Coefficients Table for 70 km/h Speed Limit Model.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	2837.360	1014.923		2.796	.021	541.445	5133.274
	Type of Road	-313.214	255.792	-.166	-1.224	.252	-891.856	265.429
	Type of Carriageway	461.028	305.645	.288	1.508	.166	-230.390	1152.446
	Number of Lane	21.661	148.030	.025	.146	.887	-313.206	356.528
	Average Speed	-39.427	8.990	-.801	-4.385	.002	-59.765	-19.090
	Density	1.685	1.812	.153	.930	.377	-2.414	5.784

a. Dependent Variable: Flow Rate

Based on the findings in Table 4.29, it is found that the p-values for the variables type of road, type of carriageway, number of lanes, average speed, and traffic density are, respectively, 0.252, 0.166, 0.887, 0.002, and 0377. This illustrates that the independent variables with a substantial impact on the traffic flow on the minor road with a 70 km/h speed limit are the average speed. The unstandardised coefficients for the type of road, type of carriageway, number of lanes, average speed, and traffic density are discovered to be -313.214, 461.028, 21.661, -39.427, and 1.685, respectively. In accordance with this, the traffic flow rate decreases by 313.214 pcu/h when the road type is a collector or distributor road, increases by 461.082 pcu/h when the type of carriageway is a dual carriageway, increases by 21.661 pcu/h with an increase in lane number, decreases by 39.427 pcu/h with an increase in average speed, and increases by 1.685 pcu/h with an increase in density. Additionally, the y-intercept of this sub-model is found to be 2837.36. Since the average traffic speed is the only significant variable in this sub-model, the other variables may be removed to produce a model that is more reliable at forecasting traffic flow. Following that, the general equation for this sub-model is:

$$q = 2837.36 - 39.427u \tag{4.25}$$

The outcome of the multiple linear regression for the 70 km/h speed limit model shows that the average speed may be the factor affecting the traffic flow of the minor road with a speed limit of 70 km/h.

4.7.2.2.2 Flow-Density Fundamental Diagram

The 70 km/h speed limit model's flow-density Fundamental Diagram needs to be constructed in order to ascertain the possible capacity of the research locations. As illustrated in Figure 4.14, the flow-density Fundamental Diagram was created using traffic data from thirteen locations with a 70 km/h speed restriction.

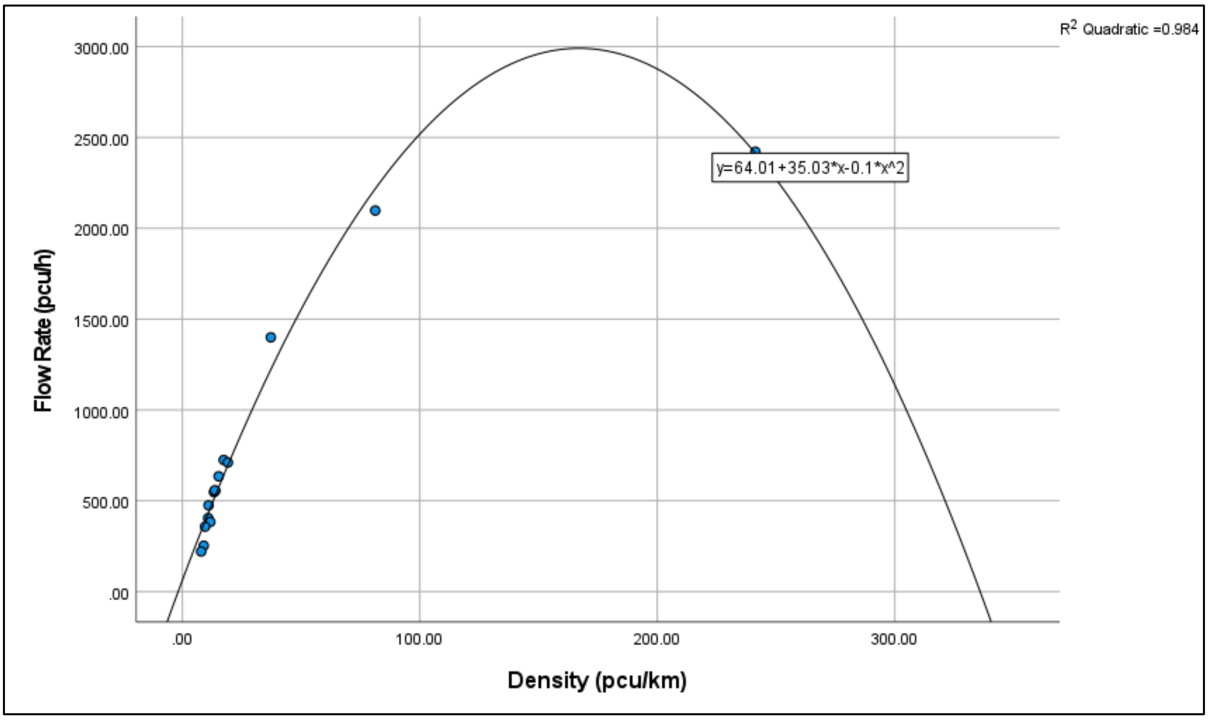


Figure 4.14: Flow-Density Fundamental Diagram for 70 km/h Speed Limit Model.

Based on Figure 4.14, the R-square value of this Fundamental Diagram is determined to be 0.984, which suggests that the traffic density accounts for 98.4% of the variance in the traffic flow. In addition, the following equation is determined to represent the parabolic curve in this diagram:

$$q = 35.03k - 0.1k^2 - 64.01 \tag{4.26}$$

The capacity density, k_{cap}, and the maximum flow rate, q_{cap}, of this model must be calculated in order to determine the capacity for the minor road with a 70 km/h speed limit. By differentiating equation 4.26 and equating it to zero, the capacity density, k_{cap} is computed as 175.15 pcu/h. The maximum flow rate, q_{cap}, is found to be 3132 pcu/h by entering the capacity density value into the equation. In the case of this sub-model, the traffic jam density, k_j, is computed to be 348.46 pcu/km by setting the traffic flow rate to zero. This reveals that the densities between 175.15 pcu/km and 348.46 pcu/km are the densities where traffic congestion occurs on minor roads with a 70 km/h speed limit.

4.7.2.3 30 km/h Speed Limit Model

In the case of this sub-model, only three of the sites have a speed limit of 30 km/h which means that only three traffic data could be applied for the development of the model. After conducting the multiple linear regression analysis using the applicable traffic data, it is determined that the model has a p-value greater than 0.05. This implies that this model is insignificant in predicting the traffic flow of the minor road with a 30 km/h speed limit. Hence, this model is excluded from the sub-model and the road capacity for the sites with a 30 km/h speed limit is based on the capacity value computed with other models.

4.7.3 Summary of Models Developed

After conducting the multiple linear regression analysis and Fundamental Diagrams construction for all of the models, the general equations and essential findings of the models are summarised in Table 4.30 and Table 4.31.

Table 4.30: Summary of Multiple Linear Regression Analysis.

Multiple Linear Regression Analysis			
Model		**Equation**	**Factors Affecting Traffic Flow**
Main		$q = 1730.164 + 4.48k - 25.163u - 464.682a + 546.019b$	Density, average speed, type of road, type of carriageway
Type of Road	Collector/Distributor Road	$q = 2084.545 - 36.24u + 594.202b$	Average speed, type of carriageway
	Local Road	$q = 51.398k - 418.767$	Density
Type of Carriageway	Dual Carriageway	$q = 2920.999 - 38.452u$	Average speed
	Single Carriageway	$q = 42.304k - 310.237a - 1061.307$	Density, type of road
Speed Limit	60 km/h	$q = 51.698k - 805.472a + 839.43b - 562.284$	Density, type of road, type of carriageway
	70 km/h	$q = 2837.36 - 39.427u$	Average speed

The general equations to estimate traffic flow for the models generated by multiple linear regression analysis are shown in Table 4.30. Besides that, the factors that may affect the traffic flow of minor roads according to each of the models are also displayed. It is identified that the main model has the most factors that may affect the traffic flow which comprises traffic density, the average speed of vehicles, type of road and type of carriageway. Both the collector/distributor road model and single carriageway model have two factors that may affect its traffic flow where the factors for the collector/distributor road model are average speed and type of carriageway while the factors for single carriageway model are density and type of road. For the case of the speed limit models, it is identified the factors affecting the traffic flow for the 60 km/h speed limit model are density, type of road and type of carriageway while for the 70 km/h speed limit model, the factor is average speed.

Table 4.31: Summary of Fundamental Diagram.

Fundamental Diagram					
Model		**Equation**	**Capacity, q_{cap}**	**Capacity Density, k_{cap}**	**Jam Density, k_j**
Main		$q = 26.53 + 36.59k - 0.11k^2$	3609	166.32	333.36
Type of Road	Collector/Distributor Road	$q = 97.96 + 31.71k - 0.09k^2$	2891	176.17	355.39
	Local Road	$q = 67.96k - 0.4k^2 - 306$	2581	84.95	165.27
Type of Carriageway	Dual Carriageway	$q = 93.21 + 34.19k - 0.1k^2$	3016	170.95	344.6
	Single Carriageway	$q = 56.73k - 0.48k^2 - 181$	1495	59.09	114.91
Speed Limit	60 km/h	$q = 50.32k - 0.36k^2 - 109$	1649	69.89	137.58
	70 km/h	$q = 35.03k - 0.1k^2 - 64.01$	3132	175.15	348.46

From Table 4.31 it is revealed that the main model has the highest road capacity estimated with the flow-density Fundamental Diagram at a value of 3609 pcu/h while the single carriageway model has the lowest road capacity at a value of 1495 pcu/h. For the capacity density, k_{cap}determined from the flow-density Fundamental Diagram, the collector/distributor road model is found to be having the highest value at 176.17 pcu/km while the local road has the lowest value at 84.95 pcu/km. In addition, the collector/distributor road model yielded the highest jam density, k_j from its Fundamental Diagram at 355.39 pcu/km while the single carriageway model yielded the lowest highest jam density, k_j from its Fundamental Diagram at 114.91 pcu/km.

4.7.4 Capacity of Sites

A total of twelve equations are developed from all of the sub-models with multiple regression analysis and Fundamental Diagram constructions. These sub-models comprise those related to the type of road, type of carriageway and speed limit of a minor road. The capacity of the sites could now be computed since the sub-models' equations are being developed in a manner where the dependent variable of the equations is traffic flow, q. This could be done by inserting the appropriate value of the predictor variables in the equations. For instance, the independent variables of the equations of the sub-models comprise traffic density and the average speed of vehicles. In the condition when the traffic flow on a road reaches its maximum capacity, it is known that the average speed of the vehicles on the road is zero and the capacity density, k_{cap} is the density of the road. Hence, by inserting these values into the equations, the maximum flow rate or the capacity of the road could be determined. It is to be noted the type of road, type of carriageway and speed limit for the sites are different from each other. Thus, a total of six equations are applied in calculating the capacity of each of the sites based on their type of road, type of carriageway and speed limit. The capacity model to be developed will be able to estimate the capacity per direction of a minor road to yield a model with higher reliability according to the findings in this study. It is to be noted that the capacities computed using the sub-models' equations are in per carriageway basis but not per lane basis. This means that the capacities calculated consist of the sum of the capacities of all of the lanes that exist in a carriageway of a road. In the case of a dual carriageway road, the road comprises lanes from only a single direction of bound since the opposite direction of the road is separated by a median; hence, the capacity computed for a dual carriageway road is the capacity per direction of the road. In the case of a single carriageway road, the road comprises lanes from both directions of bound; hence, the capacity computed from the equation is to be multiplied by the ratio of the lanes per direction to yield the capacity per direction of the road. Table 4.32 shows the capacities calculated using the sub-models' equations for the sites.

Table 4.32: Capacities of Sites Calculated with Sub-Models' Equations.

No.	**Name**	**Type of Road**	**Type of Carriageway**	**Speed Limit (km/h)**	**Capacity (pcu/h)**					
					Multiple Linear Regression			**Fundamental Diagram**		
					Type of Road	**Type of Carriageway**	**Speed Limit**	**Type of Road**	**Type of Carriageway**	**Speed Limit**
1	Persiaran Sungai Long 2 (Northbound)	Collector/Distributor Road	Dual	60	2679	2921	3085	2891	3016	1649
2	Persiaran Sungai Long 2 (Southbound)	Collector/Distributor Road	Dual	60	2679	2921	3085	2891	3016	1649
3	Jalan Sungai Long, near Green Acre Park (Northbound)	Collector/Distributor Road	Dual	70	2679	2921	2837	2891	3016	3132
4	Jalan Sungai Long, near Green Acre Park (Southbound)	Collector/Distributor Road	Dual	70	2679	2921	2837	2891	3016	3132
5	Jalan Sungai Long, near Forest Green Condominium (Northbound)	Collector/Distributor Road	Dual	70	2679	2921	2837	2891	3016	3132
6	Jalan Sungai Long, near Forest Green Condominium (Southbound)	Collector/Distributor Road	Dual	70	2679	2921	2837	2891	3016	3132
7	Jalan Sungai Long, near Sungai Long Residence (Northbound)	Collector/Distributor Road	Dual	70	2679	2921	2837	2891	3016	3132
8	Jalan Sungai Long, near Sungai Long Residence (Southbound)	Collector/Distributor Road	Dual	70	2679	2921	2837	2891	3016	3132
9	Jalan Bendahara	Collector/Distributor Road	Single	70	1043	564	1419	1446	748	1566

(Continued on next page.)

Table 4.32: Capacities of Sites Calculated with Sub-Models' Equations. (Continued)

No.	Name	Type of Road	Type of Carriageway	Speed Limit (km/h)	Capacity (pcu/h)					
					Multiple Linear Regression			Fundamental Diagram		
					Type of Road	Type of Carriageway	Speed Limit	Type of Road	Type of Carriageway	Speed Limit
10	Jalan Permaisuri	Collector/Distributor Road	Single	60	1390	752	1891	1927	997	1099
11	Persiaran Mahkota Cheras 1 (Northbound)	Collector/Distributor Road	Dual	60	2679	2921	3085	2891	3016	1649
12	Persiaran Mahkota Cheras 1 (Southbound)	Collector/Distributor Road	Dual	60	2679	2921	3085	2891	3016	1649
13	Jalan Cochrane (Eastbound)	Collector/Distributor Road	Dual	70	2679	2921	2837	2891	3016	3132
14	Jalan Cochrane (Westbound)	Collector/Distributor Road	Dual	70	2679	2921	2837	2891	3016	3132
15	Jalan Perkasa (Westbound)	Collector/Distributor Road	Dual	70	2679	2921	2837	2891	3016	3132
16	Jalan Perkasa (Eastbound)	Collector/Distributor Road	Dual	70	2679	2921	2837	2891	3016	3132
17	Persiaran Sungai Long 1	Local Road	Single	60	1309	719	1526	1291	748	825
18	Persiaran Bukit Sungai Long 2	Local Road	Single	60	1745	959	2034	1721	997	1100
19	Persiaran SL 1	Local Road	Single	30	1309	719	-	1291	748	-
20	Jalan Laksamana	Local Road	Single	60	1309	719	1526	1291	748	825
21	Jalan Shahbandar	Local Road	Single	70	1309	719	1419	1291	748	1566
22	Jalan Permaisuri	Local Road	Single	70	1309	719	1419	1291	748	1566
23	Jalan Dayang	Local Road	Single	60	1309	719	1526	1291	748	825

(Continued on next page.)

Table 4.32: Capacities of Sites Calculated with Sub-Models' Equations. (Continued)

No.	**Name**	**Type of Road**	**Type of Carriageway**	**Speed Limit (km/h)**	**Capacity (pcu/h)**					
					Multiple Linear Regression			**Fundamental Diagram**		
					Type of Road	**Type of Carriageway**	**Speed Limit**	**Type of Road**	**Type of Carriageway**	**Speed Limit**
24	Jalan Putera	Local Road	Single	60	1309	719	1526	1291	748	825
25	Jalan Inang	Local Road	Single	60	1309	719	1526	1291	748	825
26	Lorong Shahbandar	Local Road	Single	30	1309	719	-	1291	748	-
27	Lorong Peel	Local Road	Single	30	1309	719	-	1291	748	-
28	Jalan Perkasa 1	Local Road	Single	60	1309	719	1526	1291	748	1566
29	Jalan Shelley	Local Road	Single	60	1745	959	2034	1721	997	1100
30	Jalan Menteri	Local Road	Single	30	1309	719	-	1291	748	-

In Table 4.32, the highlighted cells represent the maximum capacities calculated among all of the equations applied for the sites which are the values to be taken in the development of the capacity model. It is determined that the highest capacity recorded is 3132 pcu/h while the lowest capacity recorded is 564 pcu/h. Besides that, it is found that the speed limit model from the Fundamental Diagram has yielded the highest capacity value among all of the sub-models for fourteen sites. The speed limit model from multiple linear regression has yielded the highest capacity value as compared to the other sub-models for eleven sites. The type of road model from multiple linear regression and Fundamental Diagram have yielded the highest capacity values among the other sub-models for four sites and one site respectively. The range of maximum road capacities for all of the collector/distributor roads is the same as the range for all of the dual carriageway roads and the range of all of the roads with 70 km/h speed limit which is between 1566 pcu/h to 3132 pcu/h. The range of maximum road capacities for all of the local roads is also the same as the range for all of the single carriageway roads which is between 1309 pcu/h to 2034 pcu/h. The range of maximum road capacities for all of the roads with 60 km/h speed limit is between 1526 pcu/h to 3085 pcu/h. In the case of the roads with 30 km/h speed limit, the maximum capacity value only comes in 1309 pcu/h.

4.7.5 Multiple Linear Regression Analysis

After determining the maximum road capacities for all of the sites, a road capacity model is to be developed with multiple linear regression using SPSS software. It is interesting to develop a model that could estimate the capacity of minor roads based on the basic information of the road that could be obtained easily such as the number of lanes, speed limit, type of road and type of carriageway for the efficiency of the traffic planner. Thus, the predictor variables for this capacity model are the number of lanes, speed limit, type of road and type of carriageway. The dependent variable of the model is the capacity per direction indicating that the capacity value estimated accounts for the sum of the capacities for all of the lanes in a single direction of road. The development of the capacity model applies the traffic data from a single direction for each of the roads; hence the traffic data for twenty-three out of the thirty sites is applied in the multiple linear regression analysis.

The Model Summary table for the capacity model is depicted in Table 4.33.

Table 4.33: Model Summary Table for Capacity Model.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.996[a]	.993	.991	75.89882

a. Predictors: (Constant), Number of Lane, Speed Limit, Type of Carriageway, Type of Road

According to Table 4.33, the multiple correlation coefficient, R, is determined to be 0.996 which is favourable as it is higher than 0.4. It implies a higher degree of dependent variable prediction, and the model may be subjected to further analysis. The coefficient of determination, R^2, for this model, is found to be 0.993 which is greater than 0.5. This result shows that 99.3 % of the predictor variables are capable of explaining the variability of the dependent variable. The adjusted R-square for this model is found to be 0.991 which is close to the R-value; thus, this value is acceptable. Based on the interpretation of the Model Summary table for this model, it is determined that the results of the table are satisfactory to advance to the next level of analysis.

The ANOVA table for the capacity model is displayed in Table 4.34.

Table 4.34: ANOVA Table for Capacity Model.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	12463614.57	4	3115903.643	540.896	<.001[b]
	Residual	92170.094	16	5760.631		
	Total	12555784.67	20			

a. Dependent Variable: Capacity

b. Predictors: (Constant), Number of Lane, Speed Limit, Type of Carriageway, Type of Road

Based on Table 4.34, it is found that the p-value is less than 0.001, indicating a significant fraction of the variance in the outcome has been accounted for by the model. This model is considered to be significant in estimating road capacity since the p-value is less than 0.005. The F-ratio of this model is found to be greater than one at a value of 540.896 indicating that this model is efficient.

Table 4.35 shows the Coefficients table generated by the SPSS software for the capacity model.

Table 4.35: Coefficients Table for Capacity Model.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	1146.334	76.433		14.998	<.001	984.304	1308.364
	Type of Road	204.329	65.065	.131	3.140	.006	66.398	342.260
	Type of Carriageway	1358.338	63.122	.828	21.519	<.001	1224.527	1492.150
	Speed Limit	6.032	1.466	.112	4.115	<.001	2.924	9.139
	Number of Lane	1.885	41.385	.002	.046	.964	-85.848	89.617

a. Dependent Variable: Capacity

Based on the outcomes shown in Table 4.35, it is found that the p-values for the variable type of road, type of carriageway, speed limit and number of lanes are 0.006, < 0.001, < 0.001 and 0.964, respectively. This shows that all of the independent variables in this model are significant in estimating the road capacity except for the variable number of lanes. In addition, the unstandardised coefficients for the type of road, type of carriageway, speed limit and the number of lanes are 204.329, 1358.338, 6.032 and 1.885, respectively. The y-intercept of this model is also determined to be 1146.334. Since the number of lanes is the predictor variable that is not significant in estimating the road capacity based on the findings of the multiple linear regression analysis, it is excluded from the model's equation to enhance the capability of the model in capacity estimation. The general equation of the capacity model is then:

$$C = 204.329a + 1358.338b + 6.032S + 1146.334 \quad (4.27)$$

where
C = capacity, pcu/h
S = speed limit, km/h

4.8 Interpretation of the Capacity Model Developed

After conducting the multiple linear regression analysis on the required traffic data of the selected sites, the capacity model of this study is finally being developed as in equation 4.27. It is to be noted that there are two predictor variables in the capacity model equation that are dimensionless, and they are the type of road and the type of carriageway. When applying this model for capacity estimation, the inputs for the dimensionless variables should be either "0" or "1" only. This is because the input "0" in the variables type of road and type of carriageway implies that the type of road is a local road, and the type of carriageway is a single carriageway while the input "1" indicates that the type of road is a collector/distributor road, and the type of carriageway is a dual carriageway. Besides that, the coefficients of the capacity model suggest that when the type of road is a collector or distributor road, the road capacity increases by 204.329 pcu/h; when the type of carriageway is dual carriageway, the road capacity increases by 1358.338 pcu/h; with a one-unit increase in the speed limit, the road capacity increases by 6.032 pcu/h; with a one-unit increase in the number of lanes, the road capacity increases by 1.885 pcu/h. The y-intercept of the model also tells that the minimum capacity of a minor road is 1146.334 pcu/h. The equation of the capacity model implies that the type of carriageway, type of road and speed limit are the basic factors that may affect the road capacity of a minor road. The type of carriageway is determined to be the factor that has the greatest impact since it has the greatest coefficient value in the equation, followed by the type of road and the speed limit. Since the outcome of the SPSS shows that the capacity model developed is significant, this model is said to be applicable in estimating the capacity of minor roads in per direction basis.

4.9 Summary

The required analysis and approaches are being conducted in this chapter to achieve the objectives of this study. The findings of the analysis and traffic parameters computed are also discussed in this chapter. Prior to the development of the capacity model, one main model and a total of 6 sub-models are being developed and they are the collector/distributor road model, local road model, dual carriageway model, single carriageway model, 60 km/h speed limit model and 70 km/h speed limit model. Multiple linear regression analysis and Fundamental Diagram constructions are being applied to generate the model that could estimate the traffic flow rate of minor roads. The result of the level of service for the sites that are determined using the main model is also being compared with the results determined using other approaches. After determining the maximum capacities for the sites using the equations of the sub-models, the model for capacity estimation of minor roads is finally being developed and the model is proven to be significant based on the outcome of the SPSS software. The factors affecting traffic flow and capacity of a minor road under different conditions are also determined and discussed in this chapter.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In conclusion, the study on road capacity assessment offers valuable insights into the design and planning of traffic facilities through the development of the road capacity model and the identification of factors affecting road capacity. The assessment of road capacity allows the evaluation of the current traffic flow of the road which is crucial in solving traffic issues such as delays and congestion. This study has provided a model for capacity estimation of minor roads with the type of road, type of carriageway and speed limit being the predictors of the model. The capacity model developed in this study for capacity estimation of minor roads is novel in Malaysia. Transport planners are able to predict the capacity of a minor road with the basic information of the road since the predictor variables of the model could be obtained easily for most of the roads. Besides that, the factors affecting traffic flow and the capacity of the minor road were also determined in this study. The factors affecting traffic flow are the traffic density, average travel speed, type of road and type of carriageway. The basic factors affecting the road capacity are the type of road, type of carriageway and speed limit. The factor that has the greatest impact on the capacity of minor roads was determined to be the type of carriageway, followed by the type of road and the speed limit. By understanding the factors mentioned, effective solutions could be developed so as to alleviate traffic congestion and enhance road safety for the well-being of traffic users. The estimation of capacity for minor roads such as collector or distributor roads and local roads is essential in transport planning since minor roads provide access between residential and commercial areas in urban locations. The importance of road capacity assessment is highlighted in this study in view of ensuring the continuous operation and improvement of road networks to fulfil the needs of local businesses and communities in a safe and efficient way.

5.2 Recommendations for Future Work

There are several recommendations for the study on road capacity assessment that could further improve the overall process of achieving the objectives of the study. First of all, it is recommended that future studies should consider increasing the sample sizes which is the number of sites for data collection to ensure that the model developed for capacity estimation has a higher degree of significance. The representativeness of the data will be enhanced, and the reliability of the model developed will be higher when a greater number of traffic data from various locations is applied in the development process of the model. Besides that, the application of advanced technology and tools in traffic data collection is recommended to ensure the accuracy of the data and enhance the efficiency of the data collection process. Researchers of future studies may look into equipment such as portable speed cameras and drones that will ease the process of traffic data collection and computation of the traffic parameters. Other than that, it is recommended that the scheduling of the traffic data collection should be conducted effectively in the initial stage to prevent any undesired events. During the scheduling process, it should be ensured that the time selected for data collection is appropriate with minimum fluctuation of traffic flow and it should be during the time when the potential occurrence of undesired weather events is minimum. The traffic data collection is also recommended to be conducted for both AM peak hour and PM peak hour for the sites selected. This is to ensure that the maximum traffic flow and traffic parameters could be recorded to enhance the accuracy of the results instead of only relying on data from a single peak period hour. In addition, it is recommended that future studies should look into more factors that are potential to affect road capacity. The effects of factors such as lane width, the existence of road hump, road shoulder width and more on the road capacity should be examined by collecting the corresponding data on-site and conducting a multiple linear regression analysis with the data collected.

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APPENDICES

Appendix A: Tables

Table A - 1: Example of Completed Malaysia Highway Capacity Manual Worksheet for Persiaran Sungai Long 2.

MULTILANE HIGHWAY (DIVIDED) WORKSHEET				
General Information				
Analyst	**Lum Li Kai**	Highway		
Agency or Company		From/To	**Persiaran Sungai Long 2**	
Date Performed	**2023-01-05**	Jurisdiction		
Analysis Time Period	**AM**	Analysis Year	**2023**	
Geometric Input				
	East Bound		**West Bound**	
	Outer	**Inner**	**Outer**	**Inner**
Lane width, m	3.7	3.7	4	4
Shoulder width, m	0.8		0.8	
Median clearance, m		0.8		0.8
Access points density (per km)	4		3	
Free-Flow Speed				
Base free-flow speed, BFFS (km/h)	100		100	
Adjustment for lane width, f_{LW} (km/h)	0	0	0	0
Adjustment for lateral clearance, f_{LC} (km/h)	4.1	4.1	4.1	4.1
Adjustment for access point density, f_{APD} (km/h)	10.3		10.3	
Adjustment for lane position, f_{LP} (km/h)	20.3		20.3	
Free-flow speed, (km/h)	65.3	85.6	65.3	85.6
Traffic Composition				
Total cars, q_c (veh/h)	258	202	241	327
Total lorries, q_l (veh/h)	3	2	3	3
Total trailers, q_t (veh/h)	0	0	0	0

(Continued on next page.)

Table A - 1: Example of Completed Malaysia Highway Capacity Manual Worksheet for Persiaran Sungai Long 2. (Continued)

MULTILANE HIGHWAY (DIVIDED) WORKSHEET				
Traffic Composition				
Total buses, q_b (veh/h)	2	0	0	0
Total motorcycles, q_m (veh/h)	24	20	22	23
Demand volume for the full peak hour, V_i	287	224	266	353
Traffic composition factor, f_c	0.993	0.990	0.993	0.996
Peak Hour Factor				
Peak hour factor, PHF	0.865	0.844	0.863	0.886
Level of Service				
Flow rate, v (pc/h/ln)	329.38	263.04	306.09	396.70
Average travel speed, S (km/h)	64.29	64.29	63.09	63.09
Density, D (pc/km/ln)	5.12	4.09	4.85	6.29
LOS (choose the worse LOS for each direction)	A	A	A	A

Table A - 2: Speed Limits of the Sites Selected.

No.	**Name**	**Speed Limit (km/h)**
1	Persiaran Sungai Long 2 (Northbound)	60
2	Persiaran Sungai Long 2 (Southbound)	60
3	Jalan Sungai Long, near Green Acre Park (Northbound)	70
4	Jalan Sungai Long, near Green Acre Park (Southbound)	70
5	Jalan Sungai Long, near Forest Green Condominium (Northbound)	70
6	Jalan Sungai Long, near Forest Green Condominium (Southbound)	70
7	Jalan Sungai Long, near Sungai Long Residence (Northbound)	70
8	Jalan Sungai Long, near Sungai Long Residence (Southbound)	70
9	Jalan Bendahara	70
10	Jalan Permaisuri	60
11	Persiaran Mahkota Cheras 1 (Northbound)	60
12	Persiaran Mahkota Cheras 1 (Southbound)	60
13	Jalan Cochrane (Eastbound)	70
14	Jalan Cochrane (Westbound)	70
15	Jalan Perkasa (Westbound)	70
16	Jalan Perkasa (Eastbound)	70
17	Persiaran Sungai Long 1	60
18	Persiaran Bukit Sungai Long 2	60
19	Persiaran SL 1	30
20	Jalan Laksamana	60
21	Jalan Shahbandar	70
22	Jalan Permaisuri	70
23	Jalan Dayang	60

(Continued on next page.)

Table A - 2: Speed Limits of the Sites Selected. (Continued)

No.	**Name**	**Speed Limit (km/h)**
24	Jalan Putera	60
25	Jalan Inang	60
26	Lorong Shahbandar	30
27	Lorong Peel	30
28	Jalan Perkasa 1	60
29	Jalan Shelley	60
30	Jalan Menteri	30