MALAYSIAN

HIGHWAY CAPACITY MANUAL

2011

HIGHWAY PLANNING UNIT
MINISTRY OF WORKS MALAYSIA

FOREWORD AND ACKNOWLEDGEMENTS

The Highway Planning Unit (HPU) of the Ministry of Works, Malaysia has continued to support studies related to highway capacity for the country to ensure practices of traffic and road engineering in Malaysia is in line with best practices of the world. This study is the third in a series of studies relating to highway capacity that have been executed at the national level. Continuing from previous efforts, this third study has included inter-urban facilities to the urban and suburban facilities from the previous studies.

This second version of the Malaysian Highway Capacity Manual (2011) covers four additional facilities to the additional three from the earlier version, which may described as follows:

Malaysian Highway Capacity Manual 2006 (Version 1)

1) Signalised intersections
2) Unsignalised intersections
3) Urban and suburban arterials

Malaysian Highway Capacity Manual 2011 (Version 2)

1) Two-lane Highways
2) Multilane Highways
3) Basic Segment Expressways
4) Ramps of Expressways

These manuals have been the results of laborious empirical studies carried out to establish related capacity values and relationships best representing the situation in Malaysia. It is the intention of HPU, through these manuals to turn the study findings into guidelines for practitioners to carry out planning, design and for operational analysis purposes. It is also hoped that these manuals shall continue to be a living document, to be supported by more studies, with the ultimate aim of having quality manual and guidelines for the benefit of practitioners. All these are part of our common commitment to provide the best road infrastructure with acceptable operational performance for the RAKYAT.

HPU would like to acknowledge the contribution of many agencies, firms and individuals who have supported and contributed to the study. In particular, HPU would like to recognize the efforts of the consultants from Universiti Sains Malaysia who have been central in the execution of the study as well as in the preparation of this manual. Throughout the study, the

study team has been under the guidance of the Steering and Technical Committee, to which HPU expresses it utmost appreciation.

This project is supervised by a steering committee with the following participants:

i.	Dato' Ir. Dr. Azmi Hassan	*Pengarah, Bahagian Perancang Jalan, Kementerian Kerja Raya, (2008 - 2011).*
ii.	Datuk Ir. Md Amir Kasim	*Mantan Pengarah, Bahagian Perancang Jalan, Kementerian Kerja Raya, (2007- 2008).*
iii.	Yap Ban Poe	*Ketua Penolong Pengarah Kanan (T), Bahagian Perancang Jalan, Kementerian Kerja Raya.*
iv.	Hj. Jamaludin Abdul Rahim	*Ketua Penolong Pengarah Kanan, Bahagian Perancang Jalan, Kementerian Kerja Raya, (2007 - 2009).*
v.	Jawahar Nehru a/l Sockalingam	*Penolong Pengarah Kanan (T), Bahagian Perancang Jalan, Kementerian Kerja Raya.*
vi.	Mohd Riduan Bin Che Musa	*Penolong Pengarah (T), Bahagian Perancang Jalan, Kementerian Kerja Raya.*
vii.	Mohd Syukri Md. Hanafiah	*Penolong Pengarah (T), Bahagian Perancang Jalan, Kementerian Kerja Raya, (2007 - 2009).*
viii.	Pn. Adibah Mat Kasa	*Bahagian Pengurusan dan Perolehan Kerajaan, Kementerian Kewangan.*

ix.	Ir Umi Kalthum Ahmad	*Bahagian Konsultatif & Referal Teknikal, Unit Penyelarasan dan Pelaksanaan (ICU), Jabatan Perdana Menteri.*
x.	Datin. Ir. Hajjah Mariyam Ismail	*Pengarah, Seksyen Pengurusan Nilai, Unit Perancang Ekonomi, Jabatan Perdana Menteri.*
xi.	Zulkefly Haji Idris	*Cawangan Jalan, Jabatan Kerja Raya*
xii.	Ir. Abdul Rahman Baharuddin	*Ketua Penolong Pengarah Kanan, Cawangan Kejuruteraan Jalan dan Geoteknik, Jabatan Kerja Raya.*
xiii.	Ir. Mohd Azahar Don	*Ketua Penolong Pengarah Kanan, Cawangan Kejuruteraan Jalan dan Geoteknik, Jabatan Kerja Raya.*
xiv.	Mahdan Ahmad	*Pengarah Perancangan, Lembaga Lebuhraya Malaysia, Kementerian Kerja Raya.*
xv.	Dr. Leong Lee Vien	*Pengurus Projek, Universiti Sains Malaysia, USM*
xvi.	Prof. Dr. Ahmad Farhan Mohd Sadullah	*Universiti Sains Malaysia, USM*
xvii.	Prof. Dr. Wan Hashim Wan Ibrahim	*Universiti Malaysia Sarawak, UNIMAS*
viii.	Prof. Dr. Meor Othman Hamzah	*Universiti Sains Malaysia, USM*
xix.	Prof. Madya Dr. Othman Che Puan	*Universiti Teknologi Malaysia, UTM*
xx.	Dr. Hussain Hamid	*Universiti Putra Malaysia, UPM*
xxi.	Prof. Madya Ir. Adnan Zulkiple	*Universiti Malaysia Pahang, UMP*
xxii.	Prof. Dr. Amiruddin Ismail	*Universiti Kebangsaan Malaysia, UKM*
xiii.	Prof. Ir. Mohamed Rehan Karim	*Universiti Malaya, UM*
xiv.	Dr. Muhammad Akram Adnan	*Universiti Teknologi Mara, UiTM*

TABLE OF CONTENTS

CHAPTER 3: TWO-LANE HIGHWAYS

CHAPTER 4: MULTILANE HIGHWAYS

CHAPTER 5: BASIC SEGMENT EXPRESSWAYS

CHAPTER 6: RAMPS

REFERENCES

GLOSSARY

LIST OF FIGURE

CHAPTER 1: INTRODUCTION

CHAPTER 2: CONCEPTS

CHAPTER 3: TWO-LANE HIGHWAYS

CHAPTER 4: MULTILANE HIGHWAYS

CHAPTER 5: BASIC SEGMENT EXPRESSWAYS

CHAPTER 6: RAMPS

LIST OF TABLE

CHAPTER 1: INTRODUCTION

CHAPTER 2: CONCEPTS

CHAPTER 3: TWO-LANE HIGHWAYS

CHAPTER 4: MULTILANE HIGHWAYS

CHAPTER 5: BASIC SEGMENT EXPRESSWAYS

CHAPTER 6: RAMPS

CHAPTER 1

INTRODUCTION

CHAPTER 1

1.0 INTRODUCTION

CONTENTS

FIGURES

TABLE

1.1 INTRODUCTION

This is the second volume of the Malaysian Highway Capacity Manual. The first volume of the manual was published in 2006, scoping in three major facilities namely signalised intersections, unsignalised intersections and urban and suburban arterials. This manual will cover inter-urban facilities namely two-lane highways, multilane highways, midsection and ramps for expressways. The preceding project, entitled the "Traffic Study Malaysia" completed in 1996 had concluded that the US Highway Capacity Manual (U.S. HCM), which has been extensively used in the highway design standards for Malaysia, may no longer be suitable. As a consequent, the first stage of the Malaysian Highway Capacity Study was carried out by the Ministry of Works in 1996 focussing on the urban and suburban facilities.
Preliminary studies on Malaysian travel behaviour showed that there are many distinct differences as compared to conditions in other countries, hence advocating the initiative to have our own Malaysian Highway Capacity Manual, based on researches, carried out in Malaysia. Figure 1.1 illustrates the general approach being used in carrying out the study towards establishing the Malaysian Highway Capacity Manual.

As illustrated in Figure 1.1, the first stage in the development of the Malaysian Highway Capacity Manual is to provide justification that the proposed new manual is needed for Malaysia. Therefore, the suitability and validity of the U.S. HCM were empirically checked based on Malaysia traffic condition. Due to the time constraint and a wide range of scope to be elaborated in the manual, there is a need to identify and determine which facilities are most important in order to fulfil the need of Malaysian road and travel behaviour.

In order to perform its function the Malaysian Highway Capacity Manual has come out with its own formulation and correction factors based on an intensive research conducted in various states throughout Malaysia. It is a continuous effort to improve and update the manual based on academic and research findings. It is important to keep on improving the manual because it has a significant impact on design and on traffic specification. As an extension to the previous work, the Ministry of Works has embarked upon a second study the "Malaysian Highway Capacity Study" Stage 3 (Inter Urban) which commenced in 2007. The scopes of this inter urban study includes two-lane highways, multilane highways, basic segment of expressways and ramp of expressways.

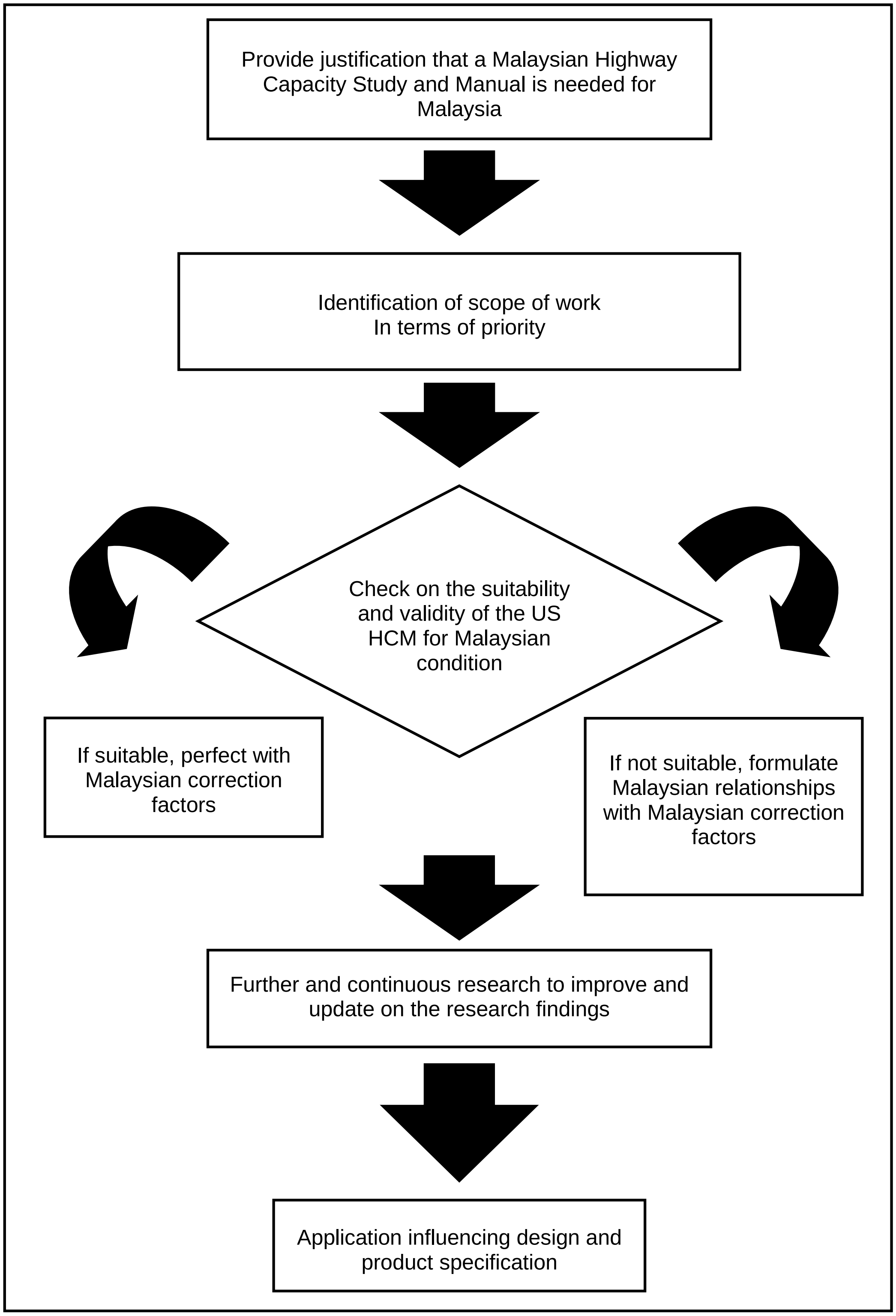


Figure 1.1: Approaches for the Malaysian Highway Capacity Study

1.1.1 PURPOSE OF THE MANUAL

The Malaysian Highway Capacity Manual (MHCM) provides transportation practitioner and researchers with a consistent and maintained system of techniques for the evaluation of the quality of service on two-lane highway, multilane highway, basic segment and ramps expressways specific to Malaysian road condition. The purpose of this manual is to provide logical methods to measure the performance of highways for each study facilities and to assure that practitioners have access to the latest research result as well as to present sample problems. The parameters and procedures in this manual provide a systematic and consistent method for assessing the capacity and quality of service for the transportation facilities.

1.1.2 SCOPE OF THE MANUAL

The scope of this manual is focuses on rural and suburban highways in Peninsular Malaysia. The roads only cover for level terrain condition. This manual presents operational capacity analysis techniques for the following facilities:

a. Rural and Suburban Highways (Uninterrupted flow facilities)
   i. Two-Lane Rural and Suburban Highways
   ii. Multilane Rural and Suburban Highways

b. Expressways (Uninterrupted flow facilities)
   i. Basic Expressway Sections
   ii. Ramp Expressways

Apart from that, the procedure presented in this manual are applied to calculation for individual road segment. A road segment must be between and are unaffected by major intersection and far from signal control devices. Also, the road segment used for analysis must have similar geometric characteristic along that stretch of road. Figure 1.2 shows the general scope of this manual.

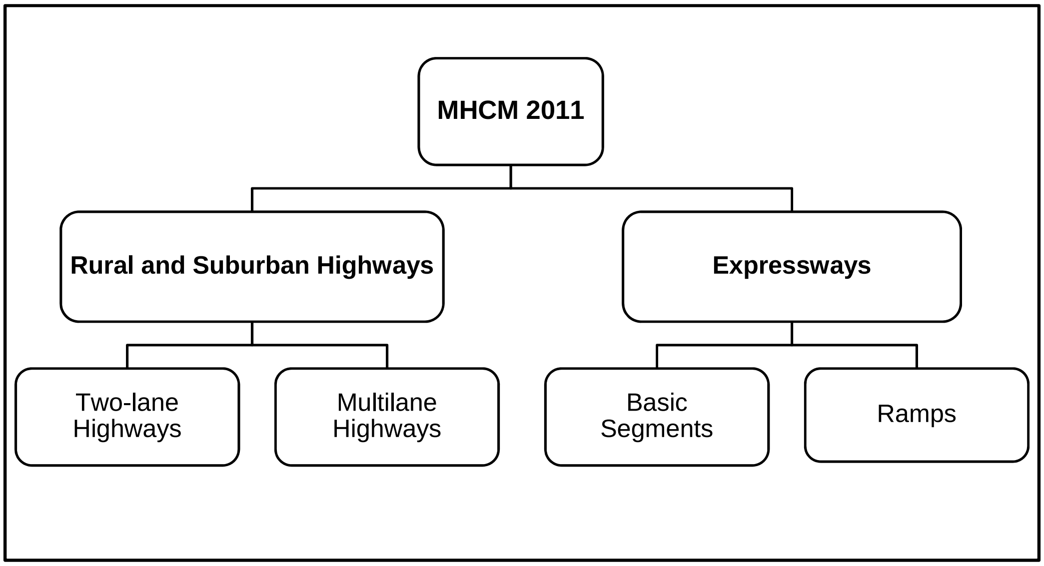


Figure 1.2: General scope of the manual

1.1.3 ORGANISATION OF THE MANUAL

The Malaysian Highway Capacity Manual contains 6 chapters and identified in Table 1.1.

Table 1.1: Organisation of the Malaysian Highway Capacity Manual

Chapter	Description/Facility Type
Chapter 1	Introduction
Chapter 2	Concepts
Chapter 3	Two-Lane Highways
Chapter 4	Multilane Highways
Chapter 5	Basic Segment of Expressways
Chapter 6	Ramps on Expressway

In Chapter 1, the role and importance of capacity analysis are described and user guidelines for application are provided.

In Chapter 2, concept, traffic characteristics and basic variables related to capacity are identified and their values and relationship as observed throughout Peninsular Malaysia are discussed.

Chapters 3 through 6 are the basic procedural chapters of the manual. They are organised according to the type of facility presented in Table 1.1.

Each of the procedural chapters is generally organised in four distinct parts:

1. *Introduction*: The basic characteristics of the facility are described.

2. *Concepts*: concepts and main characteristic that affect the capacity and level performance of the road facility are discussed.

3. *Methodologies*: The basic components of the analysis procedure to be applied to the specific facility are presented in the form of tabular and graphical information needed to complete the analysis are included.

4. *Worksheets*: These worksheets have been designed to aid users to apply the recommendation from the manual.

1.2 USER GUIDELINES

This Highway Capacity Manual is only used to measure the performance of existing roads based on Malaysian road conditions. This manual enables the user to predict the traffic performance and capacity of a road segment for a given set of traffic, geometric and environmental conditions. Desired level performance based on traffic flow and environment conditions of highways can be successfully determined with the input data of the road geometry. Then, by following the steps provided in this manual, user or practitioner can determine the free-flow speed as well as the level performance of the road segment. The user of the manual will thus include transportation planner, traffic engineer and highway engineers in transport and highway administrations as well as in consulting companies.

Apart from that, worksheets are also provided for each type of traffic facility for recording of the input data as well as for the different calculation steps. Sample calculations are included at the end of each facility chapter and is hoped to give useful guidance on the utilisation of the manual.

CHAPTER 2

CONCEPTS

CHAPTER 2

2.0 CONCEPTS

CONTENTS

FIGURES

TABLES

2.1 INTRODUCTION

In this chapter, an overview of the uninterrupted facilities was discussed. This chapter also discusses various traffic characteristics. It is important to recognize the impact of these parameters to the facilities, especially some of the impact due to the unique behaviour of local conditions.

2.1.1 UNINTERRUPTED FACILITIES

Highways in Malaysia are divided into two types of facilities, which are interrupted, and uninterrupted flow facilities. This study focused mainly on uninterrupted flow facilities. Uninterrupted flow facilities are highways that are not point by fixed operation, which is far from signal or stop sign. According to U.S. HCM 2000, an uninterrupted flow facility is facilities that have no fixed causes of delay or interruption external to the traffic stream. Generally, uninterrupted flow is far from the central of the city and is usually located at rural and suburban road. Interrupted flow is located at suburban and urban area with presence of signal control.

This Malaysian Highway Capacity Manual is focused on rural and suburban highways and expressways in Malaysia. Traffic operations on rural and suburban areas are different with urban areas. In rural and suburban areas, traffic flows are usually not constrained by traffic control devices. According to U.S. HCM 2000, rural area is an area with widely scattered development and a low density of housing and employment while suburban area is an area with a mixture of densities for housing and employment, where high-density non-residential development is intended to serve the local community. Figure 2.1 shows the definition and typical locations of rural, suburban and urban areas. Urban areas are located at the central of the city and generally, they have high densities of development or concentration of population. U.S. HCM 2000 defines urban area as an area with relatively high density of driveway access and with traffic signals no farther than 3.0 km apart.

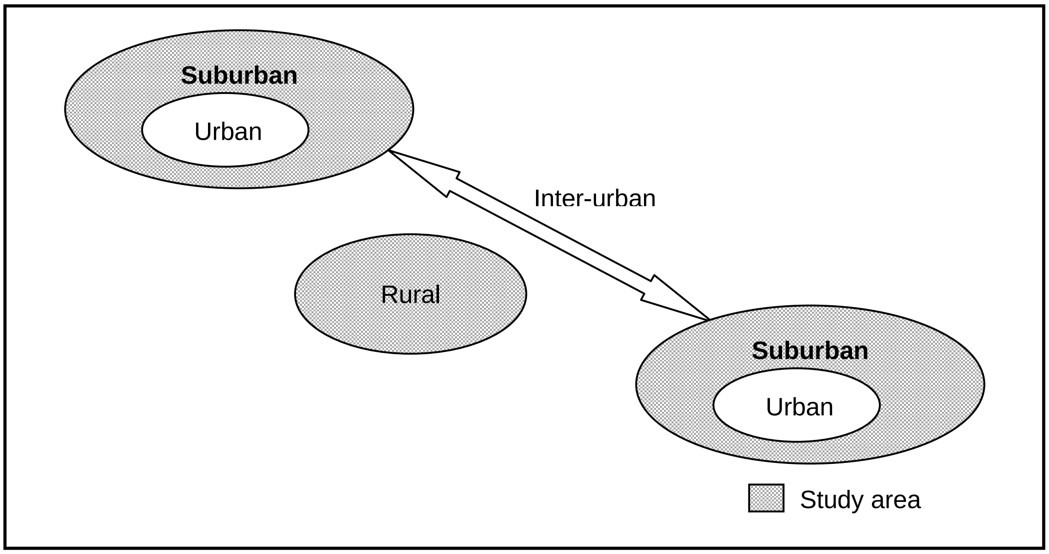


Figure 2.1: Illustration of rural, suburban and urban areas

2.1.2 ROAD SEGMENTS

A road segment is defined as a length of road. Usually, road segment is used when selecting the site and before instruments are being setup for data collection. Suggested road segment for this manual were selected based on the following criteria:

- The segment lengths are limited to 3.5 km for two-lane and multilane highways. If the segments are too long, the effects of speed are different. On the other hand, the segment cannot be less than 3.2 km as U.S. HCM 2000 had defined the rural and suburban highway spacing between signalized should be more than 3.2 km. Bang et al. (1996) observed speed data from specially designated long-based rural and suburban highway sites ranging from 3 km to 7 km. Tseng et al. (2005) collected data for multilane rural and suburban highways at segments that have spacing between signalised intersections in between 0.4 km to 5 km. The reason Tseng et al. (2005) collected data for a distance less than 3.2 km was to enable to calibrate the minimum length of segment where the speeds of vehicles were stable. He found that the speed increased rapidly when the spacing between signalized intersections increased from 0.4 km to about 2.5 km, after which (about 3.2 km) the speed record reached a steady value.
- For basic segment expressways, segment lengths are limited to 10 km (5 km upstream and 5 km downstream) in which the expressway segment is located.

- Every segment should be at least 1 km from signalised intersections or major intersections. This is to eliminate the effects of stopping or slow vehicles due to crossing behaviour at signalized intersection or major intersection.

Figure 2.2 and 2.3 shows the schematic drawing of road segments for two-lane and multilane highways while Figure 2.4 shows the schematic drawing of road segment for basic segment expressway.

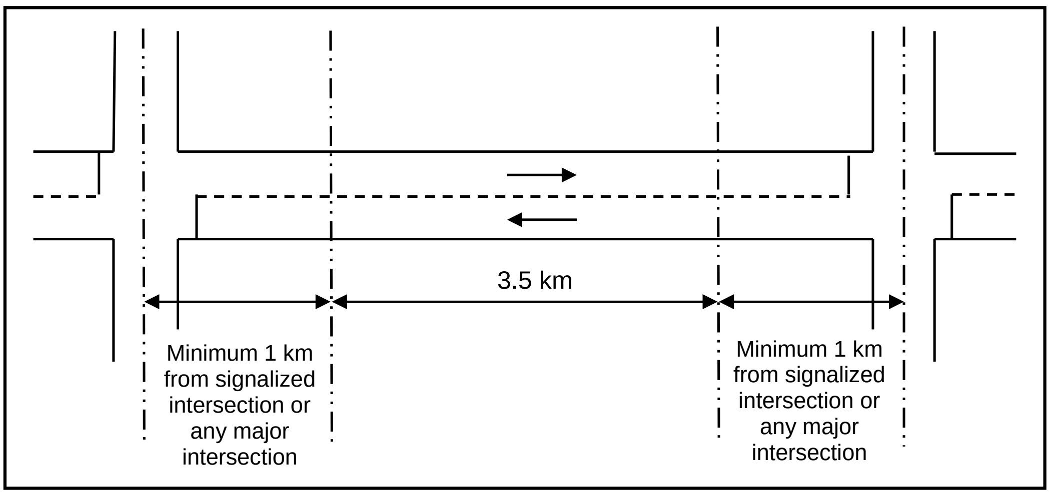


Figure 2.2: Segment length for two-lane highways

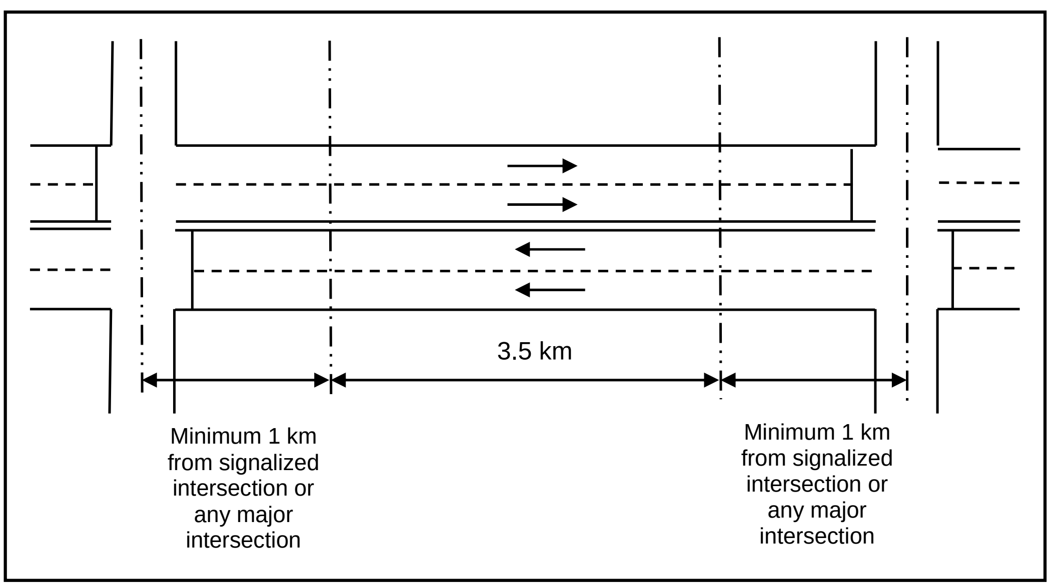


Figure 2.3: Segment length for multilane highways

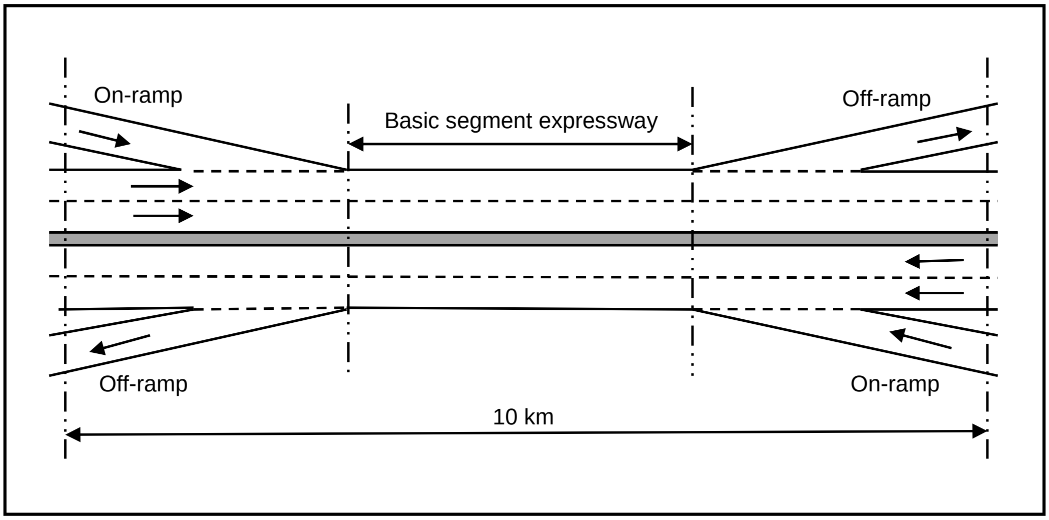


Figure 2.4: Segment length for basic segment expressways

2.2 TRAFFIC PRINCIPLES

2.2.1 HEADWAY AND SPACING

Headway is the time between successive vehicles as they pass a point on a lane or roadway while spacing is the distance between successive vehicles, usually measured from front bumper to front bumper. Figure 2.5 shows the definition of headway and spacing.

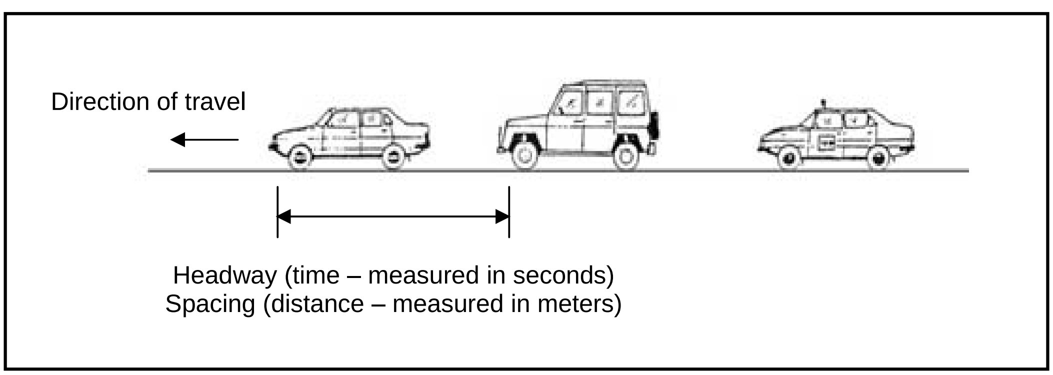


Figure 2.5: Illustration of headway and spacing

The relationship between average headway and average spacing in a traffic stream depends on speed as shown in the following equation:

$$Headway\ (s/veh) = \frac{spacing\ (m/veh)}{speed\ (m/s)} \tag{2.1}$$

Average headway and average spacing can also be used to compute flow rate and density as shown in the equations below.

$$Flow\ rate\ (veh/h) = \frac{3600}{headway\ (s/veh)} \tag{2.2}$$

$$Density\ (veh/km) = \frac{1000}{spacing\ (m/veh)} \tag{2.3}$$

Average headway of the traffic stream also affects the flow rate of the stream. The smaller the value of the average headway, the higher is the value of flow rate of the stream. A small headway indicates very high traffic volume.

2.2.2 VOLUME AND FLOW RATE

According to U.S. HCM 2000, volume is defined as the total number of vehicles that pass over a given point or section of a lane or highways during a given time or interval. Volume on highways often varies daily, weekly and monthly.

Flow rate is defined as the equivalent hourly rate at which vehicle pass over a given point or section of highways during a given time interval. Generally, flow rate estimation involves sampling in time less than 1 hour, usually 15-minutes and expressed in vehicle per hour (veh/h). It is important to take account of the consequent uncertainty when estimating the flow rate.

2.2.2.1 Peak Hour Factor

Peak hour factor is a variation of traffic flow within an hour. Typically, the peak-hour traffic volume is used in evaluating capacity and other parameters because it represents the most critical period. Peak hour factor is estimated using the peak flow rates and hourly volume.

The relationship between flow rate and peak hour factor is as shown in equation 2.4.

$$PHF = \frac{Hourly\ volume}{Peak\ flow\ rate} \quad (2.4)$$

Equation 2.5 is used to estimate peak hour factor if 15-minutes periods are used.

$$PHF = \frac{V}{4 \times V_{15}} \quad (2.5)$$

Where

PHF = Peak-hour factor

V = Hourly volume (veh/h)

V_{15} = Volume during the peak 15-minutes of the peak hour (veh/15-minutes)

Equation 2.6 is used to convert a peak-hour volume to a peak flow rate and peak hour factor is known.

$$v = \frac{V}{PHF} \quad (2.6)$$

Where

v = Flow rate for a peak 15-minutes period (veh/h)

V = Peak-hour volume (veh/h)

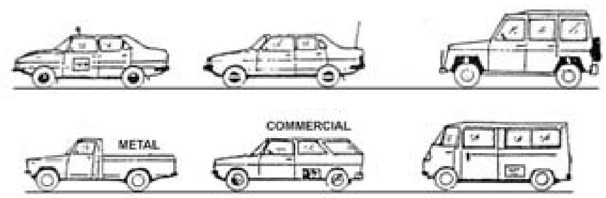
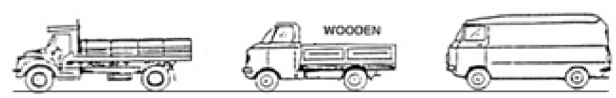
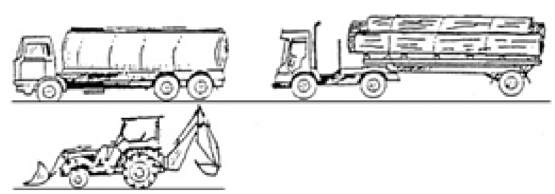
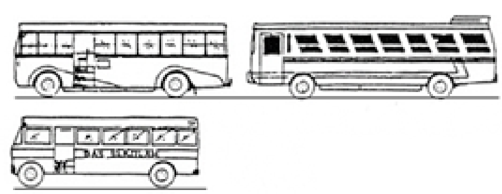
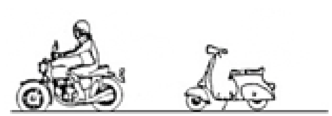
PHF = Peak-hour factor

2.2.2.2 Passenger Car Equivalents

Passenger car equivalent is defined as the number of passenger cars displaced by a single heavy vehicle of a particular type under specific road, traffic and control conditions (Transportation Research Board, 2000).

Passenger car equivalents are used to represent varying effects of mixed vehicle types by converting a traffic stream comprising of various vehicle types into an equivalent traffic stream comprising entirely of passenger cars. This manual is very important as a guide for engineers to determine the passenger car equivalents for uninterrupted facilities based on Malaysian traffic conditions. The main idea of developing the new values of passenger car equivalent is to generate a more current and reliable passenger car equivalent values. In this manual, vehicles are categorizes into five types of classifications as shown in Table 2.1.

Table 2.1: Vehicle classifications

Vehicle class	Vehicle type
Class 1: Cars/Small Vans/ Utilities	
Class 2: Lorries (with 2 axles)/ Large Vans	
Class 3: Large lorry, trailers, heavy vehicles with 3 axles and more	
Class 4: Buses	
Class 5: Motorcycles	

2.2.3 SPEED

Speed is a fundamental measurement of the traffic performance on the road system. Speed is defined as a rate of motion, in distance per unit of time. In a moving traffic stream, each vehicle travels at a different speed. Thus, the traffic stream does not have a single characteristic speed but rather a distribution of individual vehicle speeds. From a distribution of discrete vehicle speed, a number of “average” or “typical” values may be used to characterize the traffic stream as a whole. Average or mean speeds can be computed based on time mean speed or space mean speed, yielding two different values with differing physical significance. Unit of speed are expressed in kilometres per hour (km/h). Figure 2.6 shows the different types of speed.

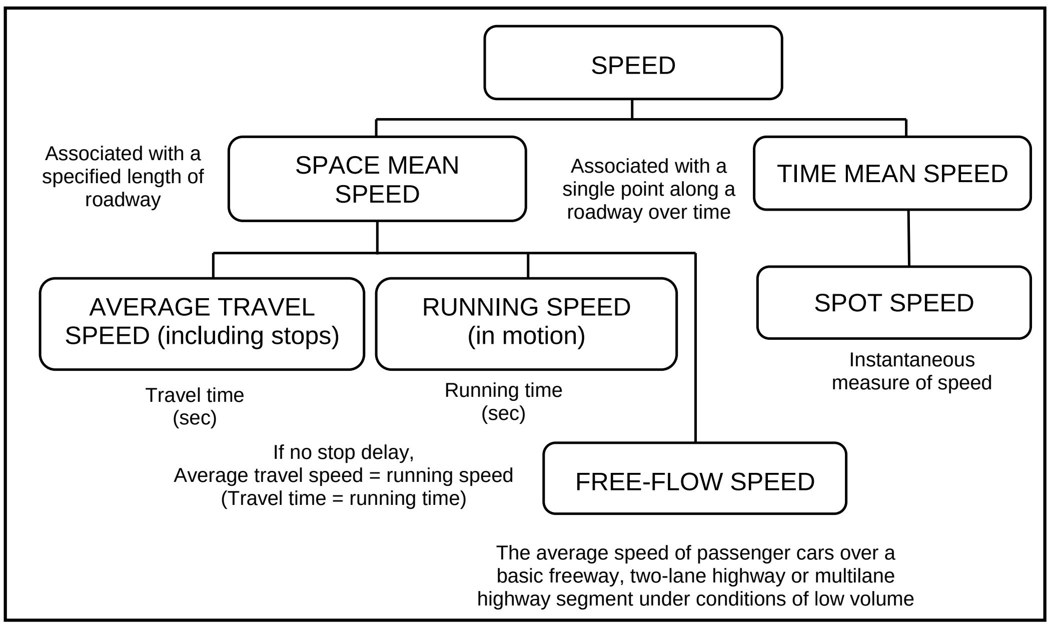


Figure 2.6: Different types of speed

2.2.3.1 Time Mean Speed

Time mean speed is the arithmetic mean of the speeds observed at some designated point along the road also referred to as the average spot speed. Time mean speed can be computed as the sum of the measure spot speeds divided by the number of measurement. The individual speeds of vehicles passing a point are recorded and averaged arithmetically.

2.2.3.2 Space Mean Speed

A term to represent an average speed based on the average travel time of vehicles to traverse a segment of roadway. It is called a space mean speed because it is the average time each vehicle spends in the defined roadway segment or space. Space mean speed is the basic of many planning model that are used to estimate average travel speed, average running speed and free-flow speed.

Average travel speed in a traffic stream is measured based on travel time observed on a given length of road which is the length of segment divided by the average travel time of vehicles traversing the segment. Average running speed in a traffic stream is measured based on the observation of vehicle travel times traversing a section of highways of known length. It is the length of segment divided by the average running time of vehicles to traverse the segment. Running time only takes into consideration when the vehicle is in motion.

Free-flow speed is the speed of vehicle when driver tend to drive at their desire speed and not interfered by other vehicle or not constrained by control devices. The vehicle can move freely with its own comfortable speed and from other point of view, free-flow speed is the average speed that a vehicle would travel if there were no congestion or other adverse conditions (Burris and Patil, 2008). The free-flow speed can be measured in the field under condition of low volume. However for this study, free-flow speed was measured as the speed of vehicles when they travel along the road segment with headway more than 8 s.

Figure 2.7 shows a typical relationship between time mean speed and space mean speed by Drake et al.(1967) that was presented in U.S. HCM 2000 (Transportation Research Board, 2000). This model shows space mean speed is always less than time mean speed but the difference decreases as the absolute value of speed increases. Based on the statistical analysis of observed data, this relationship is useful because time mean speeds often are easier to measure in the field as compare to space mean speed.

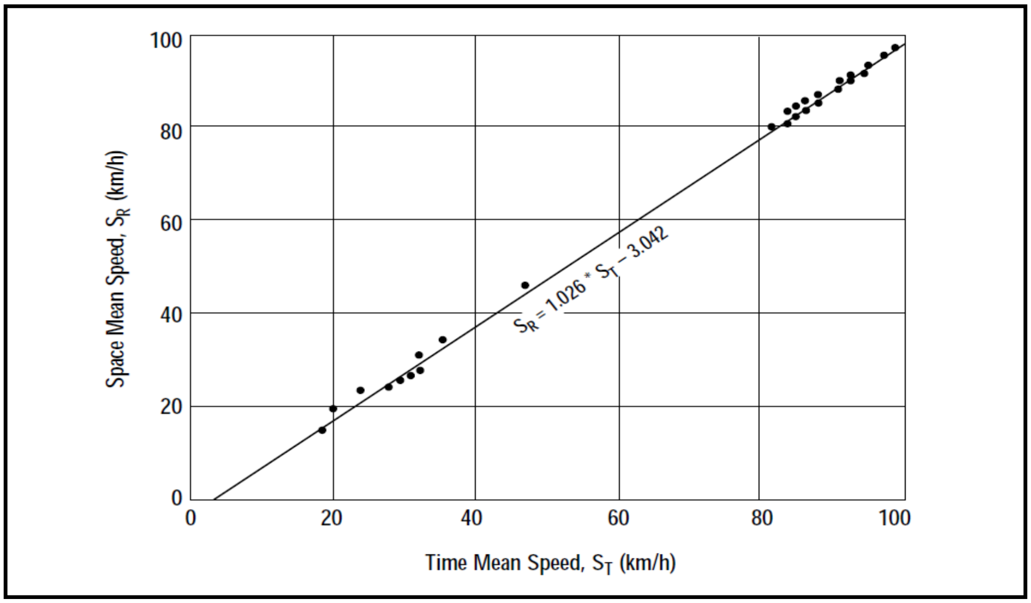


Figure 2.7: Relationships between times mean and space mean speed (Transportation Research Board, 2000)

The development of mathematical equations to represent relationship between time mean speed and space mean speed for uninterrupted flow facilities in Malaysia has gone through several stages. Table 2.2 shows the recommended estimating space mean speed, from time mean speed, for Malaysian road conditions.

Table 2.2: Model for estimating space mean speed, $\overline{V}_s$ from time mean speed, $\overline{V}_t$ for Malaysian conditions

Facilities	Models	R^2	Upper limit for ≥ (km/h)
Two-lane highways		0.881	106.50
Multilane highways		0.842	120.38
Basic segment expressways		0.906	145.00

2.2.4 DENSITY

Density is a traffic parameter because it categorizes the quality of traffic operations. It reflects the freedom to manoeuvre within the traffic stream. However, density is very difficult to observe directly in the field but it can be estimated using speed-flow relationships. Sometimes, roadway occupancy is used as a surrogate measure for density because it is easier to calculate and measure.

Density can be computed from the flow rate and average travel speed of vehicles using the equation below.

$$D = \frac{v}{S} \qquad (2.7)$$

Where

D = Density (pc/km)

v = Flow rate (pc/h)

S = Average travel speed (km/h)

2.2.5 FUNDAMENTAL RELATIONSHIPS OF SPEED, FLOW AND DENSITY

Fundamental relationships among speed, flow rate and density are shown in Figure 2.8. Speed in the figure refers to space mean speed. Based on the curves shown in the figure, a zero flow rate occur under two different scenarios. First is when flow rate is zero, density is also equal to zero, as there are no vehicles travelling on the highway. Drivers are then free to travel at the maximum possible speed as there is very little interaction between vehicles, during which the absolute maximum speed is obtained and this speed is known as the free-flow speed. The magnitude of free-flow speed depends on the physical characteristics of the highway (Garber and Hoel, 2001).

As flow rate increases from zero, density will also increase from zero as there are more vehicles on the highway. Also, when this happen, speed will decline as there will be more interaction between vehicles. The flow rate will increase until it reaches a maximum value, Q_{max} (maximum flow rate is the capacity of the highway), upon which further continuous increase in density will result in reduction of flow rate and speed, which will eventually be zero when density is equal to jam density, D_j. When this happen, there will be no movement of vehicles on the highway (hence flow rate and speed equal to zero) as vehicles will be queuing from end-to-end. However, according to U.S. HCM 2000, even though the curves shown in the figure are continuous, it is unlikely that the full range of the functions will appear at any particular location.

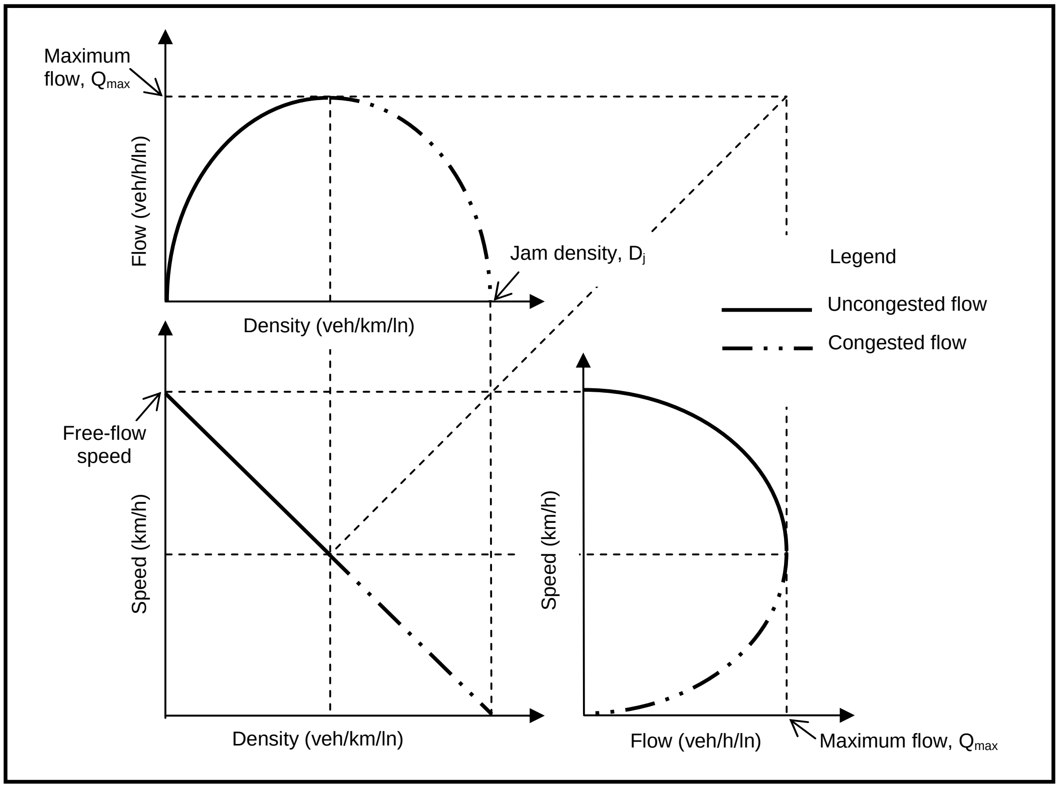


Figure 2.8: General relationships among speed, flow rate and density

2.3 CAPACITY AND LEVEL OF SERVICE (LOS)

2.3.1 CAPACITY

Base on U.S. HCM 2000, capacity of a facility is the maximum hourly rate at which persons or vehicles reasonably can expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions.

2.3.2 LEVEL OF SERVICE (LOS)

According to U.S. HCM 2000, level of service is defined as a qualitative description of operating conditions within a traffic stream based on service measure including travel flow, travel speed, freedom to manoeuvre safely, driver comfort and convenience. Levels of service are designated “A” through “F” from best to worst, covering the entire range of traffic operating conditions. Level of service “A” through “E” generally represents conditions where traffic volumes are at less than the facilities capacity, while level of service “F” represents conditions where capacity is exceeded and or forced conditions exist. Each level of service represents a range of operating condition on a particular type of facilities. The definitions of each level of service, A through F based on U.S. HCM 2000 are as follows:

LOS A Free-flow traffic with individual users virtually unaffected by the presence of others vehicle in the traffic stream. This is a condition of free flow with low volume and high speed of vehicle travel on the highways.

LOS B Stable traffic flow with a high degree of freedom to select speed and operating condition but with some influence from the other users.

LOS C Restricted flow that remain stable but with significant interaction with others in the traffic stream. The general level of comfort and convenience decline noticeable at this level. Speed and manoeuvrability are closely controlled by the higher volume. Most of the drivers are restricted in their freedom to select their own speed, change lane or pass.

LOS D High-density flow in which speed and freedom to manoeuvre are severely restricted and comfort and convenience have decline even though flow remain stable. This level represent unstable flow with operating speed are being maintain, though considerably affected by changes in operating condition.

LOS E Unstable flow at or near capacity levels with poor levels of comfort and convenience. This level represents operating at lower operating speed with volume with at or near the capacity of the highways. Flow is unstable and stoppage may occur for a momentary duration.

LOS F Forced traffic flow in which the amount of traffic approaching a point exceeds the amount that can be served. LOS F is characterising by poor time travel, low comfort, convenience, and increase accident exposure. This condition describes a force flow operation at low speed where volumes are below the capacity. Speed is reduced substantially and stoppage may occur for short or long periods of time because of the downstream condition

2.3.3 FACTORS AFFECTING CAPACITY AND LOS

2.3.3.1 Base Conditions

Many of the procedures in this manual provide a formula or simple tabular or graphic presentations for a set of specified standard conditions, which must be adjusted to account for prevailing conditions that do not match. According to U.S. HCM 2000, base conditions are assumed as good weather, good pavement conditions, and users are familiar with the facility with no impediments to the flow of traffic. Base conditions for uninterrupted-flow facilities include the following:

Two-lane highways

Base conditions:

- Lane width of 3.65 m
- Lateral clearance (paved and unpaved shoulder) wider than or equal to 1.8 m
- No “no-passing zones”
- No impediment to through traffic due to traffic control or turning vehicles
- Level terrain

Multilane highways

Base conditions:

- Lane width greater than or equal to 3.65 m
- Shoulder width greater than or equal to 1.80 m
- Median clearance wider than or equal to 1.80 m
- No direct access points along the roadway
- Level terrain

Basic segment expressways

Base conditions:

- Lane width greater than or equal to 3.75 m
- Shoulder width greater than or equal to 3.0 m
- Median clearance wider than or equal to 1.0 m
- Minimum interchange spacing of 5 km (in rural areas)
- Level terrain

2.3.3.2 Roadway Conditions

Roadway condition includes geometric and other element. Roadways condition can affect a performance measure such as the speed or free-flow speed of the road segment. However, the capacity and maximum flow rate of the facilities were not be affected by roadway condition (Transportation Research Board, 2000).

Roadway factors include the following:

- Type of facilities (two lane highways, multilane highways, basic segment expressways and ramp expressways)
- Number of lanes
- Lane width
- Shoulder width and median clearance (lateral clearance)
- Design speed

Refer to chapters 3, 4, 5 and 6 for each corresponding type of facility.

2.3.3.3 Traffic Conditions

Mixed traffic is a common situation in most Asian countries. The vehicle types commonly found in a mixed traffic includes but not limited to passenger cars (including taxis, small vans and utilities), medium heavy vehicles (including mini buses), trailers (with more than 2 axles), large buses and motorcycles.

Heavy vehicles such as trailers in traffic stream may affect the flow of traffic because they are larger than passenger cars and motorcycles; and occupy more roadways space. Heavy vehicles have poor operating capabilities compared with passenger cars particularly with respect to acceleration, deceleration, and the ability to maintain speed on upgrades.

As such, passenger car equivalents (as explained in Section 2.2.2.2) are used to convert each type of vehicle in a mixed flow to an equivalent number of passenger cars.

CHAPTER 3

TWO-LANE HIGHWAYS

CHAPTER 3

3.0 TWO-LANE HIGHWAYS

CONTENTS

FIGURES

TABLES

3.1 INTRODUCTION

A two-lane highway is an undivided roadway with two lanes, one for each direction of the traffic flow. Passing a slower vehicle requires the use of the opposing lane as sight distance and gaps in the opposing stream permit (Transportation Research Board, 2000). Two performance measures to describe service quality for two-lane highways are the “Average travel speed (ATS)” and “Percent time-spent-following (PTSF)”. In Malaysia, usually two-lane highways are located in rural areas and are connected with each other through a network. Figure 3.1 shows a typical two-lane highway in Malaysia.

Figure 3.1: Two-lane highway in Malaysia

The base conditions for two-lane highways are as follows:

- Lane width greater than or equal to 3.65 m
- Lateral clearance (paved and unpaved shoulder) wider than or equal to 1.80 m
- No “no-passing zones”
- No impediment to through traffic due to traffic control or turning vehicles
- Level terrain

3.2 CONCEPTS AND DEFINITIONS

3.2.1 FREE-FLOW SPEED

Free-flow speed is the term used to describe the average speed that a motorist would travel if there were no congestion or other adverse conditions (such as bad weather). According to U.S. HCM 2000, free-flow speed will be lower on sections of highway with restricted vertical or horizontal alignment and it tends to be lower when posted speed limits are lower. To measure free-flow speed at sites, speeds for unobstructed vehicles with headway to the nearest vehicle in front of more than 8 s with no recent or immediate meeting with a vehicle in the opposing direction were considered as free-flow speed. Factors affecting free-flow speed are lane width, shoulder width, no-passing zone and access point density.

3.2.1.1 Lane Width and Shoulder Width

Lane width is the width of a lane in which a vehicle travels along the roadway. The base conditions for two-lane highways with regards to lane width is 3.65 m, as such lane widths less than 3.65 m will reduce travel speeds. On the other hand, lane widths with more than 3.65 m are not considered to increase speed greater than the base level.

As for the shoulder width, the base conditions for two-lane highways is 1.80 m, as such narrow shoulders with width less than 1.80 m will reduce travel speeds, but wide shoulders with width more than 1.80 m are not considered to increase speed greater than the base level.

3.2.1.2 Access Point Density and No-Passing Zone

For two-lane highways, the access point density is found by dividing the total number of intersections and driveways on both sides of the roadway segment by the length of the segment in kilometres. An intersection or driveway should only be included if it influences traffic flow; access points unnoticed by the driver or with little activity should not be included. No-passing zone is defined as the percentage of the length of the segment where overtaking is prohibited. Figure 3.2 illustrates the definition of access point and no-passing zone at a site.

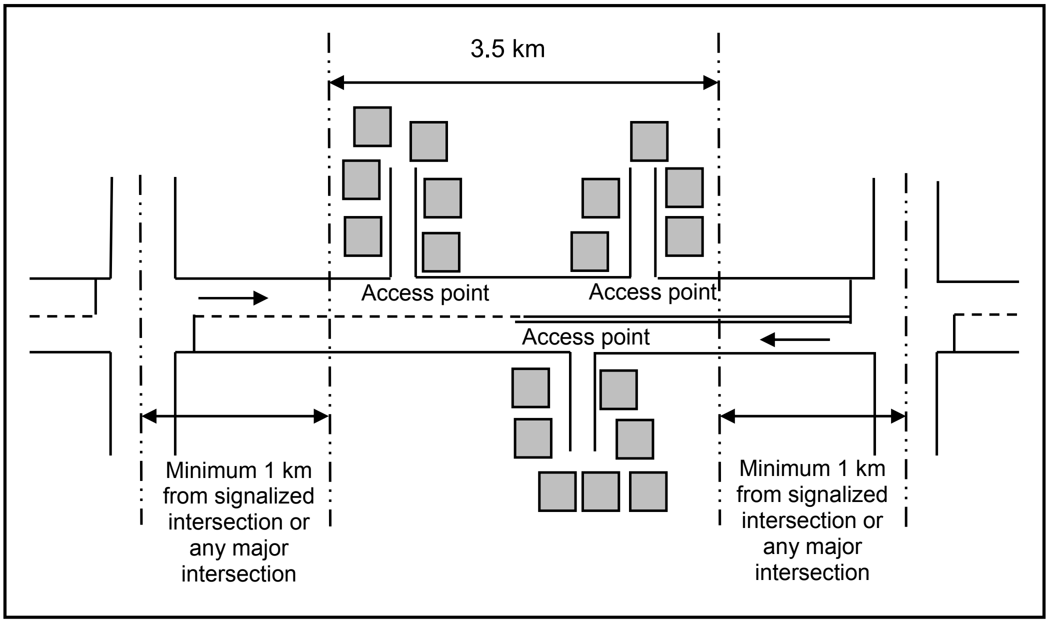


Figure 3.2: Illustration of access points and no-passing zone

3.2.2 PEAK HOUR FACTOR

Typically, the peak-hour traffic volume is used in evaluating capacity and other parameters because it represents the most critical time period. Analysis of level of service is based on peak rates of flow occurring within the peak hour because substantial short-term fluctuations typically occur during an hour. Common practice is to use a peak 15-minutes rate of flow. Flow rates are usually expressed in vehicles per hour, not vehicles per 15-minutes.

The relationship between the peak 15-minutes flow rate and the full hourly volume is given by the peak hour factor.

$$PHF = \frac{v}{4 \times v_{15-minutes\ peak}} \tag{3.1}$$

Where

PHF	=	Peak hour factor
v	=	Hourly volume
$v_{15-minutes\ peak}$	=	Peak fifteen-minutes volume

3.2.3 TRAFFIC COMPOSITION FACTOR

According to Akcelik (1981), the traffic composition factor (f_c) is a weighted average determined by the proportions of various vehicle types. The traffic composition factor, f_c was calculated using equation (3.2).

$$f_c = \frac{\sum e_i q_i}{q} \tag{3.2}$$

Where

q_i = Flow in vehicles for vehicle type *i*

q = Total flow ($\sum q_i$)

e_i = Passenger car equivalent of vehicle type *i*

Therefore, passenger car equivalents derived in this manual were used to calculate the traffic composition factor in equation (3.2). In this manual, vehicles are being categorized into five types of classifications as shown in Table 3.1.

Table 3.1: Vehicle classifications

Vehicle class	Vehicle type
Class 1	Cars/Small Vans/ Utilities
Class 2	Lorries (with 2 axles)/ Large Vans
Class 3	Large lorry, trailers, heavy vehicles with 3 axles and more
Class 4	Buses
Class 5	Motorcycles

3.2.4 AVERAGE TRAVEL SPEED

Average travel speed is defined as the length of the roadway segment under consideration divided by the average total travel time for all vehicles to traverse that segment during some designated time interval. Average travel speed reflects the mobility function of a two-lane highway. Average travel speed can be estimated in the field by travel time studies or, less accurately, by measurement of spot speeds.

Three main factors which affect average travel speed are the free-flow speed, adjustment for percentage of no-passing zones and the passenger car equivalents for flow for peak 15-minutes period. When free-flow speed increases, average travel speed increases. On the other hand, when the adjustment for percentage of no-passing zones and the passenger car equivalents for flow for peak 15-minutes period increases, the average travel speed decreases.

Figure 3.3 shows the relationship between average travel speed and flow rate. The y-intercept represents the value of free-flow speed in the direction of analysis. Theoretically, the speed-flow relationship is a parabolic curve with horizontal axis symmetry but in reality, a continuous curve is impossible to attain. Also, according to U.S. HCM 2000, it is unlikely that the full range of the functions will appear at any particular location especially for rural highways. Based on the empirical data collected at rural and suburban two-lane highways in Malaysia, the average travel speed will decrease with increasing flow rate. The reductions in speeds are consistent for free-flow speed of 40, 50 and 60 km/h as flow rates approach capacities while trend lines plotted for free-flow speed of 70, 80 and 90 km/h have the same gradient as flow rates approach capacities.

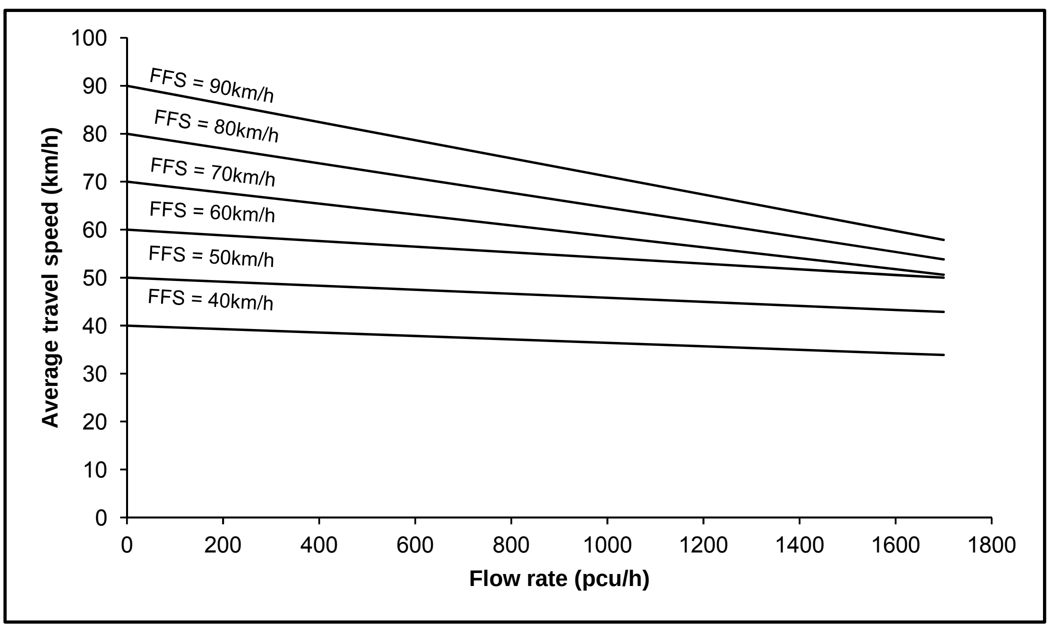


Figure 3.3: Relationship average travel speed with flow rate

3.2.5 PLATOONING

On two-lane highway with passing restrictions, user discomfort and dissatisfaction will be caused by the inability of the driver to drive at their desired speed because of a slower lead vehicle. Drivers that are travelling at less than their desired speed due to lack of passing opportunities will cause formation of platoons. Platooning is an important phenomenon on two-lane highways as it is directly related to percent time-spent-following which is one of the performance measures used to describe service quality. In practical terms, vehicular platoons have mostly been defined in terms of time headway.

3.2.6 PERCENT TIME-SPENT-FOLLOWING

Percent time-spent-following represents the freedom to manoeuvre and the comfort and convenience of travel. It is the average percentage of travel time that vehicles must travel in platoons behind slower vehicles due to inability to pass. The current U.S. HCM procedures suggest a surrogate measure in estimating percent time-spent-following in the field, that is, the percentage of vehicles travelling with headways of less than 3 s. Analysis of platooning behaviour has shown that 3 s is the best headway value to represent following behaviour in Malaysia. Adjustment for percent time-spent-following is mainly due to the effect of percentage of no-passing zone and opposing flow rate.

3.2.7 BASE PERCENT TIME-SPENT-FOLLOWING (BPTSF)

Base percent time-spent-following is the percent time-spent-following for base conditions. The relationship between base percent time-spent-following and directional flow rate is as shown in Figure 3.4. The curve in the graph shows the effect of directional flow rate on base percent time-spent-following is an exponential function that passed through the origin and asymptotically approached percent time-spent-following of 100%.

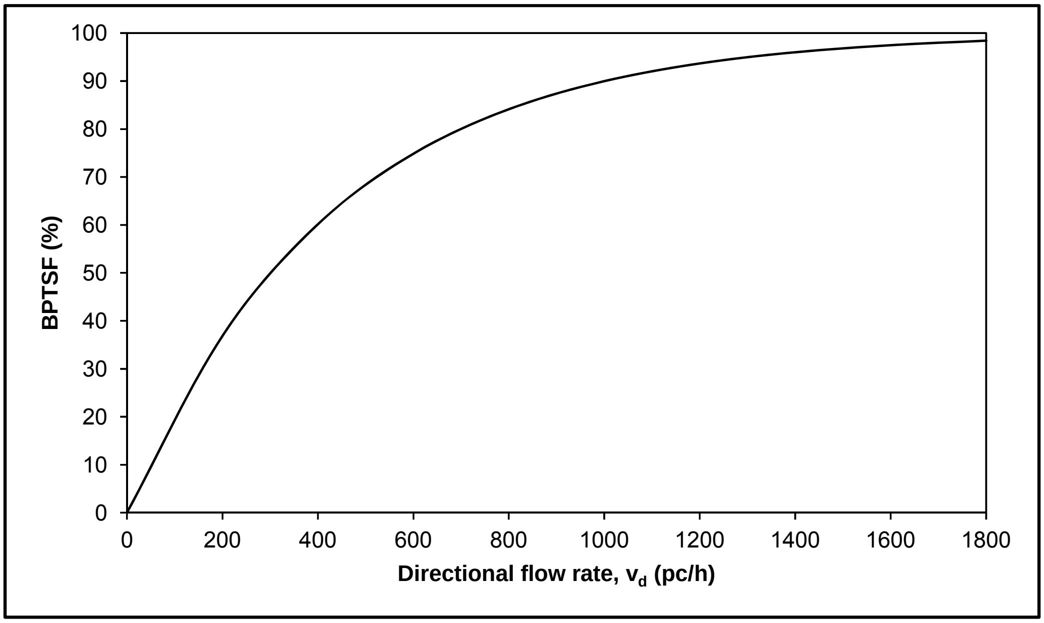


Figure 3.4: Relationship of base percent time-spent-following with flow rate

3.2.8 VOLUME-TO-CAPACITY (V/C) RATIO

Volume-to-capacity (v/c) ratio is a conventional level of services measure for roadways, comparing roadway demand with roadway supply. The volume-to-capacity ratios are calculated by dividing the volume for the peak 15-minutes by the capacity for two-lane highway. The capacity of a two-lane highway is 1,700 pc/h for each direction of travel.

3.2.9 LEVEL OF SERVICE (LOS)

For two-lane highways, the primary measures of services quality are average travel speed and percent time-spent-following.

LOS A characterises the highest quality of service, when motorists are able to travel at their desired speed. The average speed is 70 km/h or more. At this situation, drivers have the opportunity to do passing activity to maintain this speed, so that the formations of platoon are rare. Drivers are delayed no more than 35 percent of their travel time by slow moving vehicles.

LOS B describes further increase in flow and will increase the platoon formation and size. The average speed exceeds of 60 km/h. The demand for passing to maintain desired speeds becomes significant and approximates the passing capacity at the lower boundary of LOS B. Percent time-spent-following may reach 50 percent.

LOS C characterises the traffic flow with speeds of 50 km/h. Drivers are delayed in platoons up to 65 percent of the time. Although traffic flow is stable, it is susceptible to congestion due to slow moving vehicles.

At LOS D, traffic flow is unstable. At this stage, average travel speeds exceed 40 km/h. Traffic speed is decrease by the increasing volume.

LOS E describes the traffic flow conditions have percent time-spent-following greater than 80 percent and the speeds may drop below 30 km/h. The opportunity for drivers to overtake the car in front is impossible.

LOS F characterises the traffic demand exceeds capacity and will cause heavily congested flow.

3.3 METHODOLOGY

Figure 3.5 shows the inputs that are required in determining the capacity and level of service for two-lane highways. Two main criteria to be considered in the analysis are average travel speed and percent time-spent-following. In this manual, some issues such as the effect of motorcycles in two-lane highways and the unique behaviour of Malaysian road users were taken into consideration.

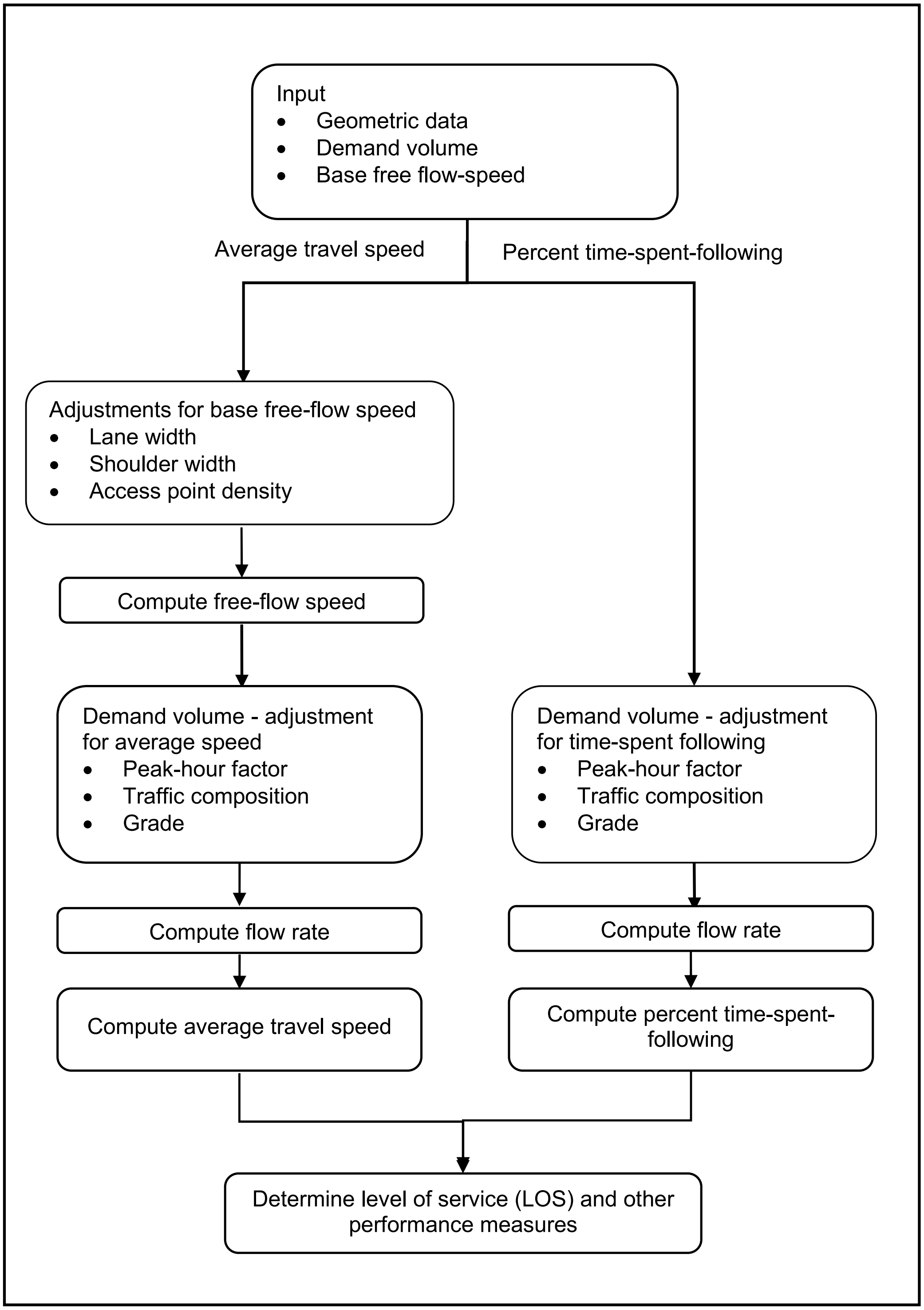


Figure 3.5: Two-lane highway methodology

3.3.1 DETERMINING FREE-FLOW SPEED

In order to estimate free-flow speed, the operating conditions of the facility must be characterised in terms of a base free-flow speed that reflects the character of traffic and the alignment of the facility. According to the U.S. HCM 2000, speed limit is one factor that affects free-flow speed. The design speed and posted speed limit of the facility may then be considered in determining the base free-flow speed. However, the design speeds and speed limits for many facilities are not based on current operating conditions. Nevertheless, estimates of base free-flow speed can be developed based on speed data and local knowledge of operating conditions on similar facilities. In this manual, the value recommended for base free-flow speed is 90 km/h depending on the highway's characteristics.

This manual has provided a model to determine free-flow speed based of base free-flow speed, with some adjustments based on the conditions of road and traffic characteristics in Malaysia. Equation (3.3) shows the equation to calculate free-flow speed.

$$FFS = BFFS - f_{LS} - f_{APD} - f_m \qquad (3.3)$$

Where

$BFFS$ = Base free-flow speed (km/h)

f_{LS} = Adjustment for lane width and shoulder width (km/h)

f_{APD} = Adjustment for access points (km/h)

f_m = Adjustment for motorcycles (km/h)

The first two adjustment factors considered in estimating free-flow speed are lane width and shoulder width. Two-lane highways with values of 3.65 m for lane width and 1.8 m for shoulder width were identified as base conditions. Table 3.2 show the adjustment for lane width and paved shoulder. For example, for two-lane highway that has 3.50 m lane width and 1.60 m paved shoulder, the reduction in free-flow speed is 1.4 km/h.

Table 3.2: Free-flow speed reduction for lane width and paved shoulder width

Lane width (m)	Reduction in free-flow speed (km/h)									
	Paved shoulder (m)									
	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	≥ 1.8
2.60	11.0	10.4	9.7	9.0	8.4	7.7	7.0	6.3	5.7	5.0
2.70	10.6	9.9	9.2	8.6	7.9	7.2	6.5	5.9	5.2	4.5
2.80	10.1	9.4	8.8	8.1	7.4	6.7	6.1	5.4	4.7	4.0
2.90	9.6	8.9	8.3	7.6	6.9	6.3	5.6	4.9	4.2	3.6
3.00	9.1	8.5	7.8	7.1	6.5	5.8	5.1	4.4	3.8	3.1
3.10	8.7	8.0	7.3	6.7	6.0	5.3	4.6	4.0	3.3	2.6
3.20	8.2	7.5	6.9	6.2	5.5	4.8	4.2	3.5	2.8	2.1
3.30	7.7	7.0	6.4	5.7	5.0	4.4	3.7	3.0	2.3	1.7
3.40	7.2	6.6	5.9	5.2	4.6	3.9	3.2	2.5	1.9	1.2
3.50	6.8	6.1	5.4	4.8	4.1	3.4	2.7	2.1	1.4	0.7
≥ 3.65	6.1	5.4	4.7	4.0	3.4	2.7	2.0	1.3	0.7	0.0

The other adjustment factor is access point density. Table 3.3 list the adjustment for access point density. In estimating access point density, only intersection that influences traffic flow are included. The access point density is estimated by dividing the total number of intersection on both sides of the roadway segment by the length of segment in kilometres.

Table 3.3: Free-flow speed reduction for access point density

Access points/km	Reduction in free-flow speed (km/h)
0	0.0
2	2.4
4	4.8
6	7.1
8	9.5
10	11.9
12	14.3

In terms of Malaysian road condition and traffic behaviour, there is a need to consider the existing of motorcycles for the analysis especially when the percentage of motorcycles is high. If motorcycles were to be considered in the estimation of free-flow speed, the mean free-flow speed will be lower than the mean free-flow speed estimated without motorcycles. Table 3.4 shows the reduction of free-flow due to the presence of motorcycles.

Table 3.4: Reduction in free-flow speed based on proportion of motorcycles

Proportion Motorcycles	Reduction in free-flow speed (km/h)	
	Base free-flow speed estimated based all vehicles except motorcycles	Base free-flow speed estimated based on passenger cars only
0.0	0.0	0.0
0.1	1.3	1.5
0.2	2.5	2.9
0.3	3.8	4.4
0.4	5.1	5.9
0.5	6.3	7.3

3.3.2 DETERMINING DEMAND FLOW RATE

There are three adjustments which must be made to hourly demand volumes to obtain the equivalent passenger car flow rate used in level of service analysis. The three adjustments are peak hour factor, the grade adjustment factor and traffic composition factor.

The demand flow rate for the peak 15-minutes period in the direction analyzed is determined using equation (3.4).

$$v_d = \frac{V_d \times f_c}{PHF \times f_G} \tag{3.4}$$

Where

v_d = Passenger car equivalent flow rate for the peak 15-minutes period in the directional analyzed (pc/h)

V_d = Demand volume for the full peak hour in the directional analyzed (veh/h)

Opposing demand flow rate also will be considered in directional analysis. The opposing demand flow rate is computed using equation (3.5) as shown below:

$$v_o = \frac{V_o \times f_c}{PHF \times f_G} \tag{3.5}$$

Where

v_o = Passenger car equivalent flow rate for the peak 15-minutes period in the opposing direction of travel (pc/h)

V_o = Demand volume for the full peak hour in the opposing direction of travel (veh/h)

3.3.2.1 Peak Hour Factor

Analysis of level of service is based on peak rates of flow occurring within the peak hour because substantial short-term fluctuations typically occur during an hour. Common practice is to use a peak 15-minutes rate of flow. However, flow rates are usually expressed in vehicles per hour, not vehicles per 15-minutes. Peak hour factor represents the variation in traffic flow within an hour.

If possible, the peak hour factor should be determined from local field data, but if field data are not available, the values recommended in this manual can be used. In this manual, a model was developed to estimate the peak hour factors as a function of traffic flow. The recommended model is as show in equation (3.6) and the recommended peak hour factor values based on traffic flow in veh/h are as shown in Table 3.5.

$$PHF = \frac{2}{1 + e^{-2(0.00114V + 0.94689)}} - 1 \quad (3.6)$$

Where

PHF = Peak hour factor

V = Traffic flow (veh/h)

Table 3.5: Recommended peak hour factor based on flow rate for two-lane highways

Flow (veh/h)	Peak hour factor
≤ 200	0.826
300	0.859
400	0.886
500	0.908
600	0.926
700	0.941
800	0.953
900	0.962
1000	0.970
1100	0.976
1200	0.981
1300	0.985
1400	0.988
1500	0.990
1600	0.992
≥ 1700	0.994

3.3.2.2 Grade Adjustment Factor

For grade adjustment factor, it is suggested to adopt the values used in U.S. HCM 2000, because it is very difficult to find representative sites for other types of terrain in Malaysia as most of the two-lane highways are located on flat terrain. Based on U.S. HCM 2000, the grade adjustment factor accounts for the effect of the terrain on travel speeds and percent time-spent-following. Table 3.6 and Table 3.7 show the grade adjustment factor for estimating average travel speeds and percent time-spent-following respectively.

Table 3.6: Grade adjustment factor (f_g) to determine speeds for rolling terrain

Range of directional flow rate (pc/h)	Grade adjustment factor, f_G
0 – 300	0.71
> 300 – 600	0.93
> 600	0.99

Table 3.7: Grade adjustment factor (f_g) to determine percent time-spent-following for rolling terrain

Range of directional flow rate (pc/h)	Grade adjustment factor, f_G
0 – 300	0.77
> 300 – 600	0.94
> 600	1.00

3.3.2.3 Traffic Composition Factor

Passenger car equivalent values derived in this manual were used to calculate the traffic composition factor. Passenger car equivalents are used to represent varying effects of mixed vehicle types by converting a traffic stream comprising of various vehicle types into an equivalent traffic stream comprising entirely of passenger cars. Headway ratio method was used to derive the passenger car equivalents. Only vehicles travelling in a platoon were considered in the calculation of passenger car equivalents. Passenger car equivalents for two-lane highways are as shown in Table 3.8.

Table 3.8: Passenger car equivalents for two-lane highways

Vehicle class	Vehicle type	Passenger car equivalents
Class 1	Cars/Small Vans/ Utilities	1.00
Class 2	Lorries (with 2 axles)/ Large Vans	1.44
Class 3	Large lorry, trailers, heavy vehicles with 3 axles and more	1.83
Class 4	Buses	1.93
Class 5	Motorcycles	0.96

As such, traffic composition factor can be calculated based on the passenger car equivalents shown in Table 3.8 by using equation (3.7).

$$f_c = \frac{q_c + 1.44q_l + 1.83q_t + 1.93q_b + 0.96q_m}{V_i} \quad (3.7)$$

Where

q_c = Flow in vehicles for car
q_l = Flow in vehicles for lorry
q_t = Flow in vehicles for trailer
q_b = Flow in vehicles for bus
q_m = Flow in vehicles for motor
V_i = Total flow ($\sum q_i$)

3.3.3 DETERMINING AVERAGE TRAVEL SPEED

Free-flow speed, passenger car equivalent flow rate for peak 15-minutes period and adjustment for no-passing zone are required in estimating average travel speed. The free-flow speed used in estimating average travel speeds is the value estimated with equation (3.8). The demand flow rate for estimating average travel speed is determined with equation (3.4) using the value of f_c computed with the passenger car equivalents in Table 3.8.

The model to estimate average travel speed is base on directional analysis as shown in the following equation:

$$ATS = FFS - 0.009v_d - f_{np} \quad (3.8)$$

Where

FFS = Free flow speed (km/h)

v_d = Passenger car equivalent flow rate for peak 15-minutes period in the analysis direction (pc/h)

f_{np} = Adjustment for no-passing zone (km/h)

Table 3.9 lists the speed reduction based on no-passing zone and opposing demand flow rate. The maximum value of f_{np} is 2.41 km/h.

Table 3.9: Reduction in average travel speed based on no-passing zone and opposing demand flow rate

Opposing demand flow rate, v_o (pc/h)	Reduction in average travel speed					
	No-passing zone (%)					
	0	20	40	60	80	100
≤ 200	0.00	0.48	0.97	1.45	1.93	2.41
300	0.00	0.32	0.64	0.97	1.29	1.61
400	0.00	0.24	0.48	0.72	0.97	1.21
500	0.00	0.19	0.39	0.58	0.77	0.97
600	0.00	0.16	0.32	0.48	0.64	0.80
700	0.00	0.14	0.28	0.41	0.55	0.69
800	0.00	0.12	0.24	0.36	0.48	0.60
900	0.00	0.11	0.21	0.32	0.43	0.54
1000	0.00	0.10	0.19	0.29	0.39	0.48
1100	0.00	0.09	0.18	0.26	0.35	0.44
1200	0.00	0.08	0.16	0.24	0.32	0.40
1300	0.00	0.07	0.15	0.22	0.30	0.37
1400	0.00	0.07	0.14	0.21	0.28	0.34
1500	0.00	0.06	0.13	0.19	0.26	0.32
1600	0.00	0.06	0.12	0.18	0.24	0.30
≥ 1700	0.00	0.06	0.11	0.17	0.23	0.28

3.3.4 DETERMINING BASE PERCENT TIME-SPENT-FOLLOWING

Base percent time-spent-following is the percent time-spent-following for base conditions and therefore must be estimated before computing percent time-spent-following. The equation used to estimate base percent time-spent-following is as shown in the equation (3.9).

$$BPTSF = 100(1 - e^{-0.002v_d}) \qquad (3.9)$$

Where

v_d = Passenger car equivalent flow rate for peak 15-minutes period in the analysis direction (pc/h)

3.3.5 DETERMINING PERCENT TIME-SPENT-FOLLOWING

The percent time-spent-following is estimated from the opposing demand flow rate and the percentage of no-passing zones. The opposing demand flow rate is determined with equation (3.5) using the value of f_c computed with passenger-car equivalents from Table 3.8. Percent time-spent-following can be determining using the equations (3.10). Base percent time-spent-following used in estimating percent time-spent-following is the value estimated with equation (3.9).

$$PTSF = BPTSF + f_{np} \quad (3.10)$$

Where

$BPTSF$ = Base percent time-spent-following (%)

f_{np} = Adjustment for no-passing zone (%)

The adjustment for the effect on percent time-spent-following of percent no-passing zones and opposing demand flow rate, v_o based on directional analysis is as shown in Table 3.10.

Table 3.10: Adjustment for the effect on percent time-spent-following of percent no-passing zones based on opposing flow rate, v_o

Opposing demand flow rate, v_o (pc/h)	Increase in percent time-spent-following					
	No-passing zone (%)					
	0	20	40	60	80	100
≤ 200	0.00	4.36	8.72	13.08	17.44	21.80
300	0.00	2.91	5.81	8.72	11.63	14.53
400	0.00	2.18	4.36	6.54	8.72	10.90
500	0.00	1.74	3.49	5.23	6.98	8.72
600	0.00	1.45	2.91	4.36	5.81	7.27
700	0.00	1.25	2.49	3.74	4.98	6.23
800	0.00	1.09	2.18	3.27	4.36	5.45
900	0.00	0.97	1.94	2.91	3.88	4.84
1000	0.00	0.87	1.74	2.62	3.49	4.36
1100	0.00	0.79	1.59	2.38	3.17	3.96
1200	0.00	0.73	1.45	2.18	2.91	3.63
1300	0.00	0.67	1.34	2.01	2.68	3.35
1400	0.00	0.62	1.25	1.87	2.49	3.11
1500	0.00	0.58	1.16	1.74	2.33	2.91
1600	0.00	0.55	1.09	1.64	2.18	2.73
≥ 1700	0.00	0.51	1.03	1.54	2.05	2.56

3.3.6 DETERMINING LEVEL OF SERVICE (LOS) BASED ON AVERAGE TRAVEL SPEED AND PERCENT TIME-SPENT-FOLLOWING

The maximum speed for average travel speed is 90 km/h due to the reason that the speed limit for rural and suburban two-lane highways in Malaysia is 90 km/h. Level of service is determined based on percent time-spent-following and average travel speed shown in Table 3.11 or by locating the point corresponding to the estimated average travel speed and percent time-spent-following in Figure 3.6.

Table 3.11: LOS criteria based on percent time-spent-following and average travel speed

LOS	Percent time-spent-following (%)	Average travel speed (km/h)
A	≤ 35	≥70
B	≤ 50	≥60
C	≤ 65	≥50
D	≤ 80	≥40
E	> 80	≥30

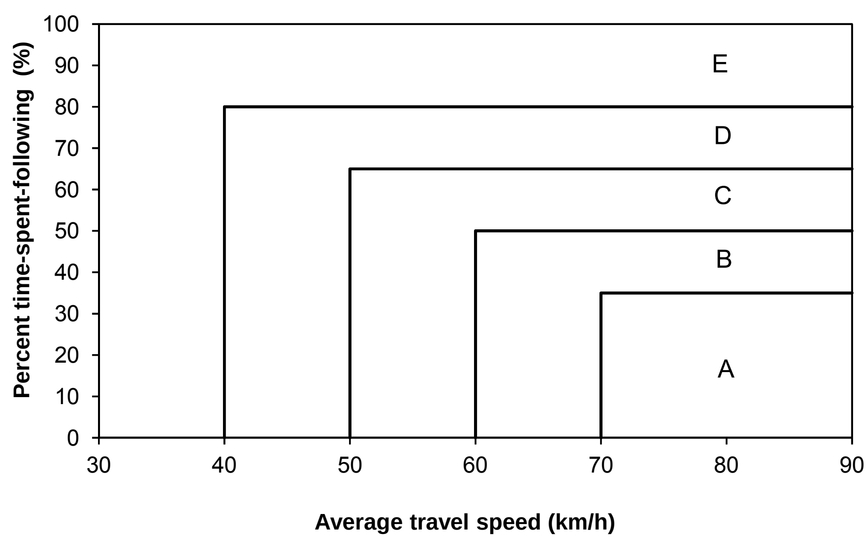


Figure 3.6: LOS criteria for two-lane highway

3.3.7 OTHER PERFORMANCE MEASURE

The other performance measure such as volume-to-capacity (v/c) ratio can be determined by dividing the volume for the peak 15-minutes by the capacity for two-lane highway. The capacity of a two-lane highway is 1,700 pc/h for each direction of travel. If the volume-to-capacity ratio obtained is above 1.00, the facility is considered to have failed. Equation (3.11) shows the formula to calculate the volume-to-capacity ratio.

$$v/c = \frac{v_d}{1700} \tag{3.11}$$

Where

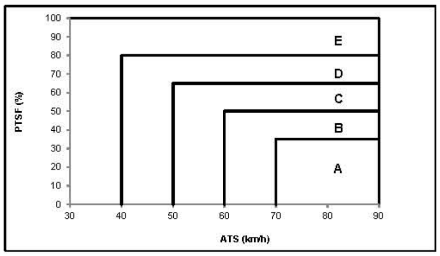
v_d = Passenger car equivalent flow rate for peak 15-minutes period in the analysis direction (pc/h)

3.4 WORKSHEET

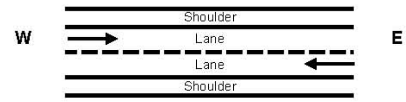
DIRECTIONAL TWO-LANE HIGHWAY SEGMENT WORKSHEET

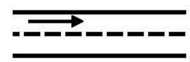
General Information

Analyst		Highway	
Agency or Company		From/ To	
Date Performed		Jurisdiction	
Analysis Time Period		Analysis Year	



Terrain ☐ Level ☐ Rolling



Direction of analysis (EB)	Direction of analysis (WB)
	

		EB	WB
Geometric Input			
Shoulder width, m			
Lane width, m			
Access point density (total access point for both directions per km)			
No-passing zone (Percentage of no-passing zone for direction of analysis)			
Free-Flow Speed			
Base free-flow speed, BFFS (km/h)			
Adjustment for lane width and shoulder width, f_{LS} (km/h)	(Table 3.2)		
Adjusment for access point density, f_{APD} (km/h)	(Table 3.3)		
*Adjustment for motorcycles, f_m (km/h)	(Table 3.4)		
Free-flow speed, FFS (km/h)	$FFS = BFFS - f_{LS} - f_{APD} - f_m$		
Traffic Composition			
Total cars, q_c (veh/h)			
Total lorries, q_l (veh/h)			
Total trailers, q_t (veh/h)			
Total buses, q_b (veh/h)			
Total motorcycles, q_m (veh/h)			
Demand volume for the full peak hour, V_i (veh/h)	$V_i = q_c + q_l + q_t + q_b + q_m$		
Traffic composition factor, f_c	$f_c = \frac{q_c + 1.44q_l + 1.83q_t + 1.93q_b + 0.96q_m}{V_i}$		
Peak Hour Factor			
Peak hour factor, PHF	(Table 3.5)		
Average Travel Speed			
** Grade adjustment factor, f_G	(Table 3.6)		
Directional flow rate, V_i (pc/h)	$v_i = \frac{V_i \times f_c}{PHF \times f_G}$	v_d / v_o	v_d / v_o
Adjustment for no-passing zone, f_{np} (km/h)	(Table 3.9)		
Average travel speed, ATS (km/h)	$ATS = FFS - 0.009v_d - f_{np}$		
Percent Time-Spent-Following			
** Grade adjustment factor, f_G	(Table 3.7)		
Directional flow rate, V_i (pc/h)	$v_i = \frac{V_i \times f_c}{PHF \times f_G}$	v_d / v_o	v_d / v_o
Base percent time-spent-following, BPTSF (%)	$BPTSF = 100(1- e^{-0.002vd})$		
Adjustment for no-passing zone, f_{np} (%)	(Table 3.10)		
Percent time-spent-following, PTSF (%)	$PTSF = BPTSF + f_{np}$		
Level of Service and Other Performance Measure			
Level of service (LOS)			
Volume to capacity ratio, v/c	$v/c = \frac{v_d}{1700}$		

Note

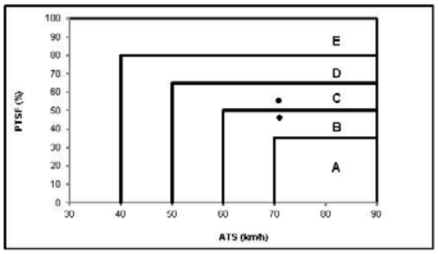
* Only to be considered if motorcycles were to be included in the estimation of free-flow speed.
** For level gradient, $f_G = 1.0$
If v_i (v_d or v_o) ≥ 1700 pc/h, terminate the analysis - the LOS is F

3.5 SAMPLE CALCULATION

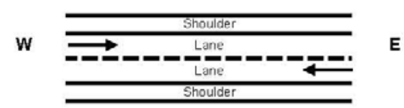
DIRECTIONAL TWO-LANE HIGHWAY SEGMENT WORKSHEET

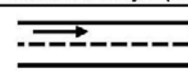
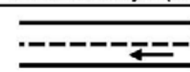
General Information

Analyst	ABC	Highway	M130
Agency or Company	HPU	From/ To	Durian Tunggal to Alor Gajah
Date Performed	12.12.2011	Jurisdiction	
Analysis Time Period		Analysis Year	2011



Terrain [/] Level [ ] Rolling



Direction of analysis (EB)	Direction of analysis (WB)
	

		Direction of analysis (EB)		Direction of analysis (WB)	
Geometric Input					
Shoulder width, m		1.8		1.4	
Lane width, m		3.5		3.7	
Access point density (total access point for both directions per km)		2.86			
No-passing zone (Percentage of no-passing zone for direction of analysis)		20		20	
Free-Flow Speed					
Base free-flow speed, BFFS (km/h)		80		80	
Adjustment for lane width and shoulder width, f_{LS} (km/h)	(Table 3.2)	0.70		1.30	
Adjusment for access point density, f_{APD} (km/h)	(Table 3.3)	3.43			
*Adjustment for motorcycles, f_m (km/h)	(Table 3.4)	0		0	
Free-flow speed, FFS (km/h)	$FFS = BFFS - f_{LS} - f_{APD} - f_m$	**75.87**		**75.27**	
Traffic Composition					
Total cars, q_c (veh/h)		245		109	
Total lorries, q_l (veh/h)		15		14	
Total trailers, q_t (veh/h)		10		4	
Total buses, q_b (veh/h)		1		3	
Total motorcycles, q_m (veh/h)		26		66	
Demand volume for the full peak hour, V_i (veh/h)	$V_i = q_c + q_l + q_t + q_b + q_m$	297		196	
Traffic composition factor, f_c	$f_c = \frac{q_c + 1.44q_l + 1.83q_t + 1.93q_b + 0.96q_m}{V_i}$	1.050		1.049	
Peak Hour Factor					
Peak hour factor, PHF	(Table 3.5)	0.858		0.826	
Average Travel Speed					
** Grade adjustment factor, f_G	(Table 3.6)	1		1	
Directional flow rate, V_i (pc/h)	$v_i = \frac{V_i \times f_c}{PHF \times f_G}$	v_d 363	v_o 249	v_d 249	v_o 363
Adjustment for no-passing zone, f_{np} (km/h)	(Table 3.9)	0.40		0.27	
Average travel speed, ATS (km/h)	$ATS = FFS - 0.009v_d - f_{np}$	**72.20**		**72.76**	
Percent Time-Spent-Following					
** Grade adjustment factor, f_G	(Table 3.7)	1		1	
Directional flow rate, V_i (pc/h)	$v_i = \frac{V_i \times f_c}{PHF \times f_G}$	v_d 363	v_o 249	v_d 249	v_o 363
Base percent time-spent-following, BPTSF (%)	$BPTSF = 100(1 - e^{-0.002vd})$	51.66		39.22	
Adjustment for no-passing zone, f_{np} (%)	(Table 3.10)	3.65		2.45	
Percent time-spent-following, PTSF (%)	$PTSF = BPTSF + f_{np}$	**55.31**		**41.67**	
Level of Service and Other Performance Measure					
Level of service (LOS)		**C**		**B**	
Volume to capacity ratio, v/c	$v/c = \frac{v_d}{1700}$	**0.21**		**0.15**	

Note

* Only to be considered if motorcycles were to be included in the estimation of free-flow speed.
** For level gradient, $f_G = 1.0$
If v_i (v_d or v_o) $\geq$ 1700 pc/h, terminate the analysis - the LOS is F

3.6 CALCULATION STEPS

DIRECTIONAL TWO-LANE HIGHWAY SEGMENT STEP CALCULATION	
For East Bound direction	
1. All input parameters are known and insert into the worksheet.	
2. Compute free-flow speed (use Table 3.2, 3.3, and 3.4).	$FFS = BFFS - f_{LS} - f_{APD} - f_m$ $FFS = 80 - 0.70 - 3.43 - 0 = 75.87$ km/h
3. Determine demand volume for the full peak hour	$V_i = q_c + q_l + q_t + q_b + q_m$ **Analysis Direction** $V_d = 245 + 15 + 10 + 1 + 26 = 297$ veh/h **Opposing Direction** $V_o = 109 + 14 + 4 + 3 + 66 = 196$ veh/h
4. Determine traffic composition	$f_c = \frac{q_c + 1.44q_l + 1.83q_t + 1.93q_b + 0.96q_m}{V_i}$ **Analysis Direction** $f_c = \frac{245 + 1.44(15) + 1.83(10) + 1.93(1) + 0.96(26)}{297} = 1.050$ **Opposing Direction** $f_c = \frac{109 + 1.44(14) + 1.83(4) + 1.93(3) + 0.96(66)}{196} = 1.049$
5. Find the peak hour factor (use Table 3.5).	**Analysis Direction** PHF = 0.858 **Opposing Direction** PHF = 0.826
Average Travel Speed	
6. Determine the grade adjustment factor (use Table 3.6)	**Analysis Direction** $f_G = 1$ **Opposing Direction** $f_G = 1$
7. Compute directional flow rate	$v_i = \frac{Vi \times f_c}{PHF}$ **Analysis Direction** $v_d = \frac{(297)(1.050)}{(0.858)(1)} = 363$ pc/h **Opposing Direction** $v_o = \frac{(196)(1.049)}{(0.826)(1)} = 249$ pc/h
8. Check v_d and v_o with the capcity value of 1700 pc/h	**Analysis Direction** 363 pc/h < 1700 pc/h OK! **Opposing Direction** 249 pc/h < 1700 pc/h OK!
9. Compute average travel speed (use Table 3.9)	$ATS = FFS - 0.009_{vd} - f_{np}$ $ATS = 75.87 - 0.009(363) - 0.40 = 72.20$ km/h
Percent Time-Spent-Following	
10. Determine the grade adjustment factor (use Table 3.7)	**Analysis Direction** $f_G = 1$ **Opposing Direction** $f_G = 1$
11. Compute directional flow rate	$v_i = \frac{Vi \times f_c}{PHF}$ **Analysis Direction** $v_d = \frac{(297)(1.050)}{(0.858)(1)} = 363$ pc/h **Opposing Direction** $v_o = \frac{(196)(1.049)}{(0.826)(1)} = 249$ pc/h
12. Check v_d and v_o with the capcity value of 1700 pc/h	**Analysis Direction** 363 pc/h < 1700 pc/h OK! **Opposing Direction** 249 pc/h < 1700 pc/h OK!
13. Compute base percent time-spent-following	$BPTSF = 100(1- e^{-0.002vd})$ $BPTSF = 100(1- e^{-0.002(363)}) = 51.66\%$
14. Compute percent time-spent-following (use Table 3.10)	$PTSF = BPTSF + f_{np}$ $PTSF = BPTSF + 3.65 = 55.31\%$
15. Determine LOS (use ATS-PTSF graph given in worksheet)	ATS = 77.20 km/h and PTSF = 55.31 % LOS C
16. Compute volume to capacity ratio, v/c	$v/c = \frac{v_d}{1700}$ $v/c = \frac{363}{1700} = 0.21$
17.The similar step calculation is use for West Bound direction	

CHAPTER 4

MULTILANE HIGHWAYS

CHAPTER 4

4.0 MULTILANE HIGHWAYS

CONTENTS

FIGURES

TABLES

4.1 INTRODUCTION

Multilane highways are very common in Malaysia. These highways can either be undivided or divided and it can be more than one lane for each direction. Generally, in Malaysia these highways usually have two lanes in each direction and can either be undivided or divided highways. Divided highways are separated with a rigid or flexible barrier. These barriers may be paved or it might be a landscape median that separates each direction.

Often, multilane highways are located in suburban communities that lead into central cities. Usually these facilities have posted speed limits between 60 to 90 km/h. They may also go along high volume rural corridors connecting two cities or two significant activity centres that generate a substantial number of daily trips. Figure 4.1 shows a typical divided multilane highway and Figure 4.2 shows a typical undivided multilane highway in Malaysia.

Figure 4.1: Example of a divided multilane highway in Malaysia

Figure 4.2: Example of an undivided multilane highway in Malaysia

These base conditions represent the highest operating level of rural and suburban multilane highways and are as follows:

- Lane width greater than or equal to 3.65 m
- Shoulder width greater than or equal to 1.80 m
- A divided highway with median clearance wider than or equal to 1.80 m
- No direct access points along the roadway
- Level terrain

4.2 CONCEPTS AND DEFINITIONS

4.2.1 FREE-FLOW SPEED

Free-flow speed is the speed at which driver feel comfortable to travel along the multilane highways without constrain due to traffic control devices such as traffic light. Free-flow speed is an important parameter to analyse the performance of multilane highways and it is the starting point in the analysis of capacity and level of service (LOS) for uninterrupted flow facilities. To measure free-flow speed at sites, speeds for unobstructed vehicles with headway to the nearest vehicle in front of more than 8 s were considered as free-flow speed. Factors affecting free-flow speed are lane width, lateral clearance and access point density.

4.2.1.1 Lane Width

Lane width is the width of a lane in which a vehicle travels along the roadway. Usually, multilane highways have two lanes per direction (four-lane highways) or three lanes (six-lane highways) per direction. However, in Malaysia, six-lane highways are hardly to be found in rural areas as they are usually located in urban areas or suburban areas with high density movement. The base conditions for multilane highways with regards to lane width is 3.65 m, as such lane widths less than 3.65 m may reduce travel speeds. However, lane widths greater than 3.65 m are not considered to increase speed above the base level. Lane is defined as either outer lane or inner lane based on the position of the lane itself. Figure 4.3 illustrates the lane definition for four-lane divided highway while Figure 4.4 shows the illustration of lane definition for four-lane undivided highway.

Figure 4.3: Illustration of lane positions for four-lane divided highway

Figure 4.4: Illustration of lane positions for four-lane undivided highway

4.2.1.2 Lateral Clearance

Lateral clearance can be classified into two types, which are shoulder clearance or shoulder width and median clearance. In general, shoulder clearance has influence on the free-flow speed of the vehicles travelling on the outer lanes. For example, higher shoulder width encourages higher operating speed and therefore, has lower reduction in free-flow speed. The base conditions for multilane highways with regards to shoulder width is 1.80 m, as such narrow shoulders with width less than 1.80 m will reduce travel speeds at outer lanes, but wide shoulders with width more than 1.80 m will not necessarily increase speed above the base level.

Median clearance is defined as a clearance on the right hand side of the inner lane (from the edge of the travel lane to obstruction in the roadway median). The presence of median clearance has an effect on inner lanes of multilane highways. Decreasing median clearance width will reduce the free-flow speed and for undivided multilane highways, median clearance is considered to be zero. As such, the reduction to the free-flow speed due to the absence of a median will be considered to be 7.5 km/h by default.

4.2.1.3 Access Point Density

Access point is a junction or driveway on the left hand side of a roadway. For the computation in this manual, the total number of junctions and driveways for one direction of the roadway segment is divided by the length of the segment in kilometre and is to be known as access point density. A junction or driveway should only be included if it influences traffic flow; access points unnoticed by the driver or with little activity should not be included. Figure 4.5 shows the diagram of access point along the road segment with the calculation of access point density.

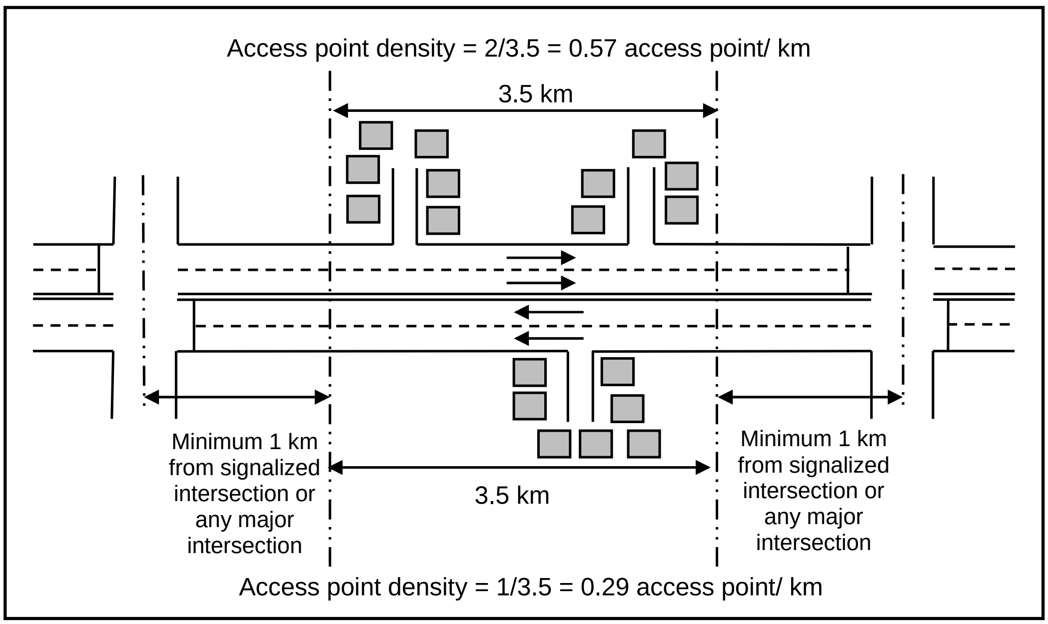


Figure 4.5: Illustration of access point on multilane highways

4.2.2 PEAK HOUR FACTOR

Analysis of level of service is based on peak rates of flow occurring within the peak hour because substantial short-term fluctuations typically occur during an hour. Common practice is to use a peak 15-minutes rate of flow. However, flow rates are usually expressed in vehicles per hour, not vehicles per 15-minutes. Peak hour factor represents the variation in traffic flow within an hour. It is the ratio of the travel volume occurring during an hour to the peak rate of flow during a selected short time period within an hour. The relationship between the peak 15-minutes flow rate and the full hourly volume is given by the peak hour factor.

$$PHF = \frac{v}{4 \times v_{15-minutes\ peak}} \tag{4.1}$$

Where

PHF	=	Peak hour factor
v	=	Hourly volume
$v_{15-minutes\ peak}$	=	Peak fifteen-minutes volume

4.2.3 TRAFFIC COMPOSITION FACTOR

Traffic composition factor is a weighted average determined by the proportions of various vehicle types. The traffic composition factor, f_c was calculated using equation (4.2).

$$f_c = \frac{\sum e_i q_i}{q} \tag{4.2}$$

Where

q_i	=	Flow in vehicles for vehicle type *i*
q	=	Total flow ($\sum q_i$)
e_i	=	Passenger car equivalent of vehicle type *i*

Therefore, passenger car equivalents derived in this manual were used to calculate the traffic composition factor in equation (4.2). In this manual, vehicles are categorizes into five types of classifications as shown in Table 4.1.

Table 4.1: Vehicle classifications

Vehicle class	Vehicle type
Class 1	Cars/Small Vans/ Utilities
Class 2	Lorries (with 2 axles)/ Large Vans
Class 3	Large lorry, trailers, heavy vehicles with 3 axles and more
Class 4	Buses
Class 5	Motorcycles

4.2.4 SPEED-FLOW AND DENSITY-FLOW RELATIONSHIPS

The speed-flow and density-flow relationships for a typical uninterrupted-flow segment on multilane highways are as shown in Figure 4.6 and Figure 4.7 respectively.

In order to assess the speed-flow and density-flow relationships, speed, flow and density data were segregated based on different range of free-flow speed, which are 60 – 69 km/h, 70 – 79 km/h, 80 – 89 km/h, 90 – 99 km/h, 100 – 109 km/h and 110 – 119 km/h. Regression analyses were conducted and trend lines as shown in Figure 4.6 were plotted.

Theoretically, the speed-flow relationship is a parabolic curve with horizontal axis symmetry but in reality, it is unlikely that the full range of the functions will appear at any particular location especially for rural highways (Transportation Research Board, 2000). Based on the empirical data collected at rural and suburban multilane highways in Malaysia, the speed-flow relationship shown in Figure 4.6 indicates that the average travel speed decreased with increasing flow rate. However, the reductions in speeds are not consistent for each free-flow speed. For example, average travel speed with free-flow speed of 110 km/h drop drastically in speed as flow rate approaches capacity of 2300 pc/h/ln while the regression line for average travel speed with free-flow speed of 60 km/h is more flat and only drop a little as flow rate approaches capacity of 1800 pc/h/ln. Generally, the higher the value of free-flow speed, the speed drop becomes greater as flow rate approaches capacity.

Figure 4.7 shows the density-flow relationship obtained for multilane highways. The regression lines plotted in Figure 4.7 indicates that density will increase as the flow rate increase and density varies consistently throughout the range of free-flow speed; as free-flow speed increased, the slope of the regression lines decreased.

The LOS criteria for multilane highways were established based on the speed-flow and density-flow relationships.

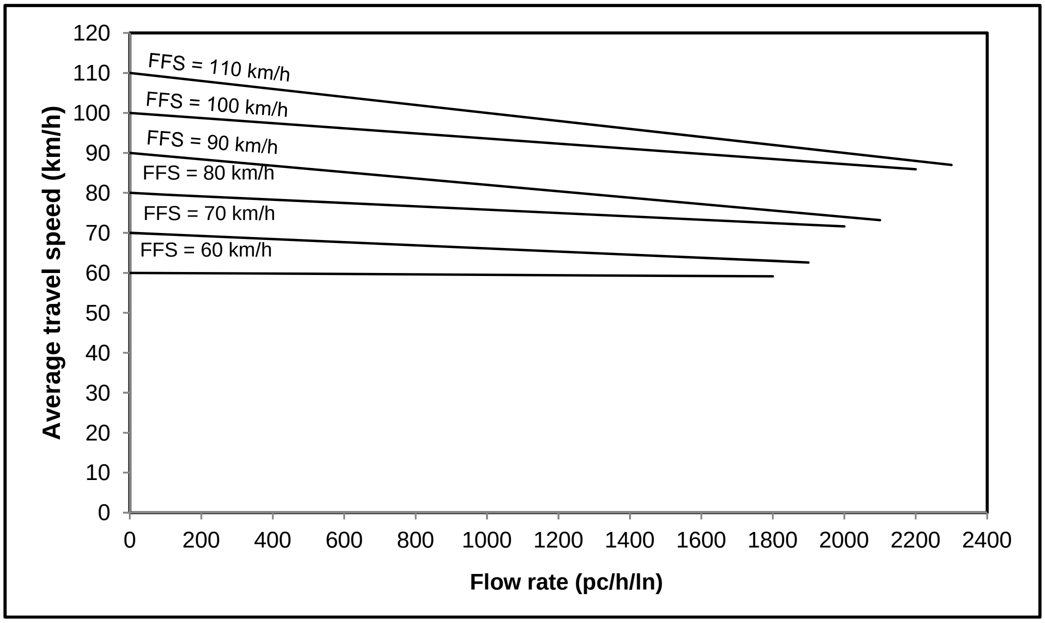


Figure 4.6: Speed-flow relationship on multilane highways

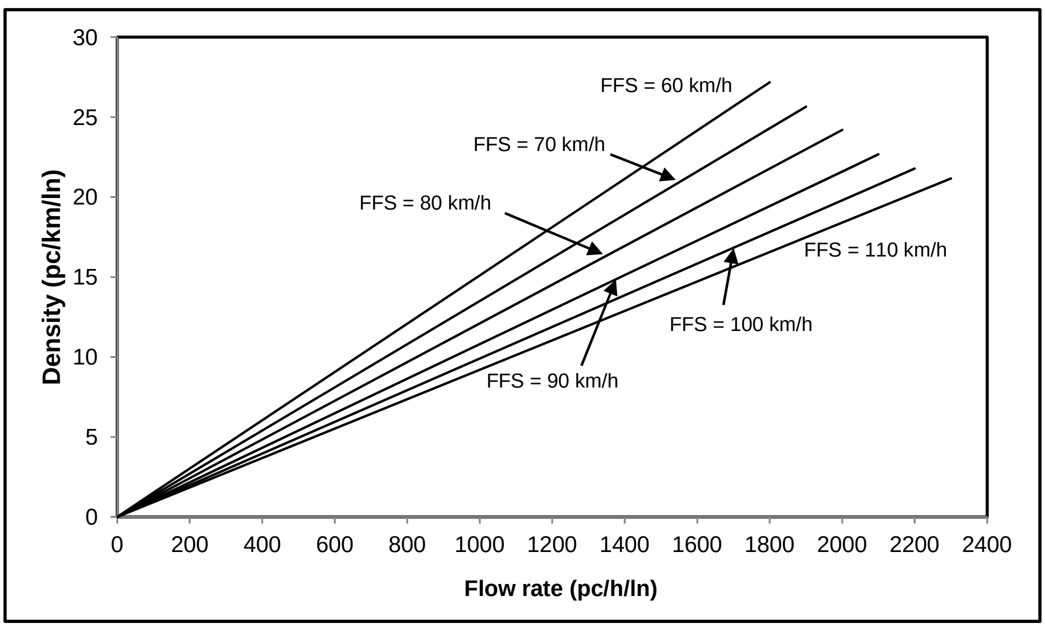


Figure 4.7: Density-flow relationship on multilane highways

4.2.5 LEVEL OF SERVICE (LOS)

Three performance measures were used to assess the operation of multilane highways. They are density, speed and volume to capacity (v/c) ratio.

LOS A describes absolute free flowing conditions where manoeuvrability of vehicles are unaffected by the presence of other vehicles and therefore, drivers are able to travel at their desired speed. Operations are constrained mainly due to the geometric features of the highway. LOS B also characterises free flowing conditions but drivers have slightly less freedom to manoeuvre as the presence of other vehicles becomes noticeable. As traffic volume increase, the ability to manoeuvre within the traffic stream becomes harder and the level of service deteriorates from LOS B to LOS C. Evidently, at LOS C, the influence of traffic density on operations is serious and the presence of other vehicles significantly affects the ability to manoeuvre within the traffic stream.

At LOS D, the ability to manoeuvre becomes seriously restricted due to traffic congestion and travel speed is reduced by increasing volume. Further increase in volume will cause the level of service to deteriorate to LOS E. LOS E represents an unstable condition, in which operations of the highway is at or near capacity. Vehicles are operating with minimum spacing for maintaining uniform flow. If disruptions were not dissipated and volume continues to increase further, level of service will deteriorate to LOS F. LOS F represents forced flow or breakdown flow in which vehicles arrive at a rate greater than the rate at which they are discharged causing the formation of long queue. Operations within the queue are highly unstable as vehicles will experience brief periods of movement followed by stoppages.

4.3 METHODOLOGY

The methodology to determine the level of service for multilane highways is as shown in Figure 4.8. Each parameter in Figure 4.8 was investigated thoroughly based on empirical data and the equations obtained were discussed in subsequent sections of this manual.

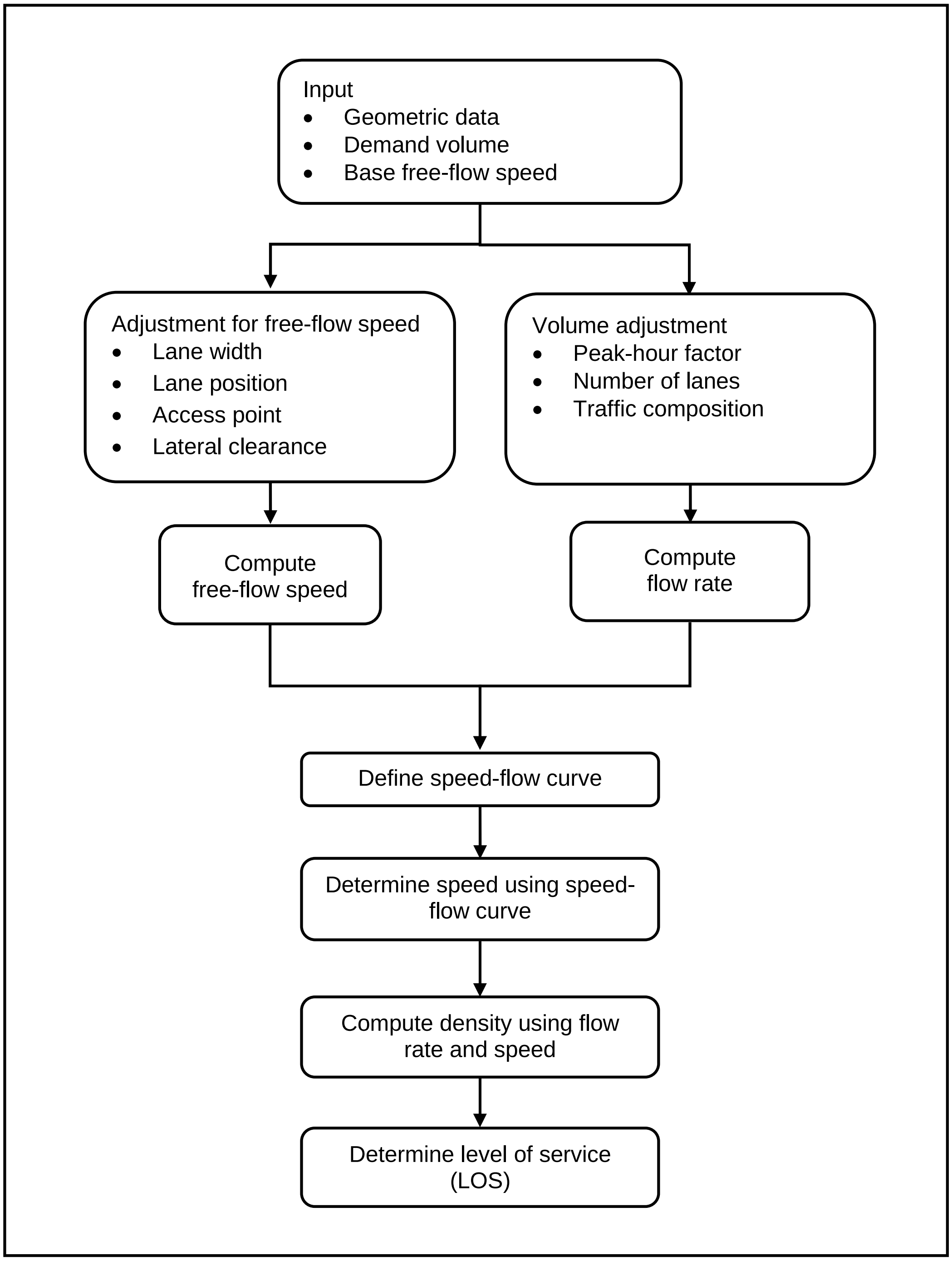


Figure 4.8: Multilane highway methodology

4.3.1 DETERMINING FREE-FLOW SPEED

Free-flow speed is measured based on space mean speed with headway more than 8 seconds. However, in the absence of measured data, free-flow speed can be estimated directly using equation (4.3).

$$FFS = BFFS - f_{LW} - f_{LC} - f_{APD} - f_{LD} \tag{4.3}$$

Where

FFS = Free-flow speed (km/h)

$BFFS$ = Base free flow speed (km/h)

f_{LW} = Adjustment for lane width (Table 4.2)

f_{LC} = Adjustment for lateral clearance, for shoulder width (outer lane) or adjustment for median clearance (inner lane) (Table 4.3)

f_{APD} = Adjustment for access point density (Table 4.4)

f_{LD} = Adjustment for lane position (Table 4.5)

However, in order to estimate free-flow speed, the operating conditions of the facility must be characterised in terms of a base free-flow speed that reflects the character of traffic and the alignment of the facility. Estimates of base free-flow speed can be developed based on speed data and local knowledge of operating conditions on similar facilities. However, when it is not possible to use data from similar roadway, an estimated value might be necessary. In this manual, the value recommended for base free-flow speed is 100 km/h.

Table 4.2 presents the adjustment of lane width to estimate the free-flow speed for multilane highways. The base condition with regard to lane width for multilane highways is 3.65 m. Lane width less than 3.65 m will reduce free-flow speed but lane width greater than 3.65 m is assumed to have no effect on free-flow speed.

Table 4.2: Free-flow speed reduction for lane width

Lane width (m)	Reduction in free-flow speed (km/h)
3.30	14.7
3.40	10.5
3.50	6.3
3.60	2.1
≥ 3.65	0.0

Table 4.3 shows the speed reduction due to lateral clearance; shoulder width for outer lane and median clearance for inner lane. Lateral clearance from the left edge of outer lane is the shoulder width while from the right edge of inner lane is the median clearance. The base condition with regard to lateral clearance for multilane highways is 1.80 m. Lateral clearance with width less than 1.80 m will reduce free-flow speed but lateral clearance greater than 1.80 m is assumed to have no effect on free-flow speed. For undivided multilane highways, the lateral clearance on the right edge is always zero with a reduction of 7.5 km/h.

Table 4.3: Free-flow speed reduction for shoulder width (for outer lane) or median clearance (for inner lane)

Lateral clearance (m)	Reduction in free-flow speed (km/h)
0.00	7.5
0.10	7.0
0.20	6.6
0.30	6.2
0.40	5.8
0.50	5.4
0.60	5.0
0.70	4.6
0.80	4.1
0.90	3.7
1.00	3.3
1.10	2.9
1.20	2.5
1.30	2.1
1.40	1.7
1.50	1.2
1.60	0.8
1.70	0.4
≥ 1.80	0.0

Table 4.4 shows the adjustment for access point density. The access point density is determined by dividing the total number of access points on the left side of the roadway in the direction of travel by the segment length. An intersection or driveway should only be included if it influences traffic flow.

Table 4.4: Free-flow speed reduction for access point density

Access points/km	Reduction in free-flow speed (km/h)
0.0	0.0
1.0	3.4
2.0	6.9
≥ 3.0	10.3

Table 4.5 shows the reduction due to the lane position. Table 4.5 indicates that free-flow speed will be reduced by 20.3 km/h if it is an outer lane.

Table 4.5: Free-flow speed reduction for lane position

Lane position	Reduction in free-flow speed (km/h)
Inner	0.0
Outer	20.3

4.3.2 DETERMINING DEMAND FLOW RATE

Adjustments must be made to hourly demand volumes to obtain the equivalent passenger car flow rate used in LOS analysis. For multilane highways, the flow rate is affected by vehicle composition and the equation to estimate flow rate (v_i) is as follows:

$$v_i = \frac{V_i \times f_C}{PHF} \tag{4.4}$$

Where

v_i = Flow rate (pc/h/ln)

V_i = Hourly volume (veh/h)

PHF = Peak hour factor

f_C = Traffic composition factor

4.3.2.1 Peak Hour Factor

The peak-hour traffic volume is used in evaluating capacity and other parameters because it represents the most critical time period. Analysis of level of service is based on peak rates of flow occurring within the peak hour because substantial short-term fluctuations typically occur during an hour. Common practice is to use a peak 15-minutes rate of flow. However, flow rates are usually expressed in vehicles per hour, not vehicles per 15-minutes. The application of peak hour factor accounts for this phenomenon. The higher values tend to occur as demand approaches capacity on the facility. Based on Malaysian road conditions, the equation to estimate peak hour factor is as shown in equation (4.5) and the recommended values for peak hour factor based on traffic flow in veh/h are as shown in Table 4.6.

$$PHF = \frac{2}{1 + e^{-2(0.001366V + 0.9248)}} - 1 \quad (4.5)$$

Where

PHF = Peak hour factor

V = Traffic flow (veh/h)

Table 4.6: Recommended peak hour factor based on flow rate for multilane highways

Flow (veh/h)	Peak hour factor
200	0.8330
300	0.8703
400	0.8998
500	0.9228
600	0.9407
700	0.9546
800	0.9652
900	0.9734
1000	0.9797
1100	0.9845
1200	0.9882
1300	0.9910
1400	0.9932
1500	0.9948
1600	0.9960
1700	0.9970
1800	0.9977
1900	0.9982
2000	0.9987
2100	0.9990
2200	0.9992
≥ 2300	0.9994

4.3.2.2 Traffic Composition Factor

Traffic composition factor is a weighted average determined by the proportions of various vehicle types. Passenger car equivalents are used in the calculation of traffic composition factor. Passenger car equivalent is the number of passenger cars displaced by a single heavy vehicle of a particular type under specified roadway, traffic, and control conditions. Headway ratio method was used to derive the passenger car equivalents. Only vehicles travelling in a platoon were considered in the calculation of passenger car equivalents. Passenger car equivalents for multilane highways are as shown in Table 4.7.

Table 4.7: Passenger car equivalents for multilane highways

Vehicle class	Vehicle type	Passenger car equivalents
Class 1	Cars/Small Vans/ Utilities	1.00
Class 2	Lorries (with 2 axles)/ Large Vans	1.58
Class 3	Large lorry, trailers, heavy vehicles with 3 axles and more	1.76
Class 4	Buses	1.65
Class 5	Motorcycles	0.84

As such, traffic composition factor can be calculated based on the passenger car equivalents shown in Table 4.7 by using equation (4.6).

$$f_c = \frac{q_c + 1.58q_l + 1.76q_t + 1.65q_b + 0.84q_m}{V_i} \quad (4.6)$$

Where

q_c = Flow in vehicles for car

q_l = Flow in vehicles for lorry

q_t = Flow in vehicles for trailer

q_b = Flow in vehicles for bus

q_m = Flow in vehicles for motor

V_i = Total flow ($\sum q_i$)

4.3.3 DETERMINING LEVEL OF SERVICE (LOS)

The criteria of level of service for multilane highways are based on the values of free-flow speed and flow rate for each individual lane. The capacity values determined in this manual for free-flow speed of 60, 70, 80, 90, 100 and 110 km/h are 1800, 1900, 2000, 2100, 2200 and 2300 pc/h/ln respectively. These values were adopted with slight modifications from the values used in U.S. HCM 2000. Table 4.8 shows the average speed, the maximum value of v/c, the maximum density and the corresponding maximum service flow rate for each LOS.

Table 4.8: LOS criteria for multilane highways

Base free-flow speed (km/h)	Criteria	LOS				
		A	B	C	D	E
110	Maximum density (pc/km/ln)	7	11	16	22	26
	Average speed (km/h)	102.9	99.1	95.0	90.5	87.0
	Maximum volume to capacity ratio (v/c)	0.31	0.47	0.66	0.87	1.00
	Maximum service flow rate (pc/h/ln)	720	1090	1520	1990	2300
100	Maximum density (pc/km/ln)	7	11	16	22	26
	Average speed (km/h)	95.7	93.6	91.3	87.3	84.6
	Maximum volume to capacity ratio (v/c)	0.30	0.47	0.66	0.87	1.00
	Maximum service flow rate (pc/h/ln)	670	1030	1460	1920	2200
90	Maximum density (pc/km/ln)	7	11	16	22	28
	Average speed (km/h)	85.7	82.7	79.4	76.8	74.0
	Maximum volume to capacity ratio (v/c)	0.29	0.43	0.60	0.80	1.00
	Maximum service flow rate (pc/h/ln)	600	910	1270	1690	2100
80	Maximum density (pc/km/ln)	7	11	16	22	28
	Average speed (km/h)	78.6	76.4	75.0	73.2	71.0
	Maximum volume to capacity ratio (v/c)	0.28	0.42	0.60	0.81	1.00
	Maximum service flow rate (pc/h/ln)	550	840	1200	1610	2000
70	Maximum density (pc/km/ln)	7	11	16	22	30
	Average speed (km/h)	68.6	67.3	66.3	64.1	63.3
	Maximum volume to capacity ratio (v/c)	0.25	0.39	0.56	0.74	1.00
	Maximum service flow rate (pc/h/ln)	480	740	1060	1410	1900
60	Maximum density (pc/km/ln)	7	11	16	22	31
	Average speed (km/h)	60.0	60.0	59.4	59.5	59.0
	Maximum volume to capacity ratio (v/c)	0.23	0.37	0.53	0.73	1.00
	Maximum service flow rate (pc/h/ln)	420	660	950	1310	1800

Apart from Table 4.8, LOS for a multilane highway can also be determined directly from Figure 4.9 based on free-flow speed and flow rate. The procedure is as follows:

- Based on either measured or estimated free-flow speed, construct an appropriate speed-flow curve of the same shape as the typical curves shown in Figure 4.9. The curve should intercept the y–axis at the free-flow speed.
- Based on the flow rate, v_i, read up to the free-flow speed curve indentified previously and determine the average passenger-car speed and LOS corresponding to that point.
- Also, based on speed and flow, density can be determined according to equation (4.7).

$$D = \frac{v_i}{S} \tag{4.7}$$

Where

D	=	Density (pc/km/ln)
v_i	=	Flow rate (pc/h/ln)
S	=	Average passenger car travel speed (km/h)

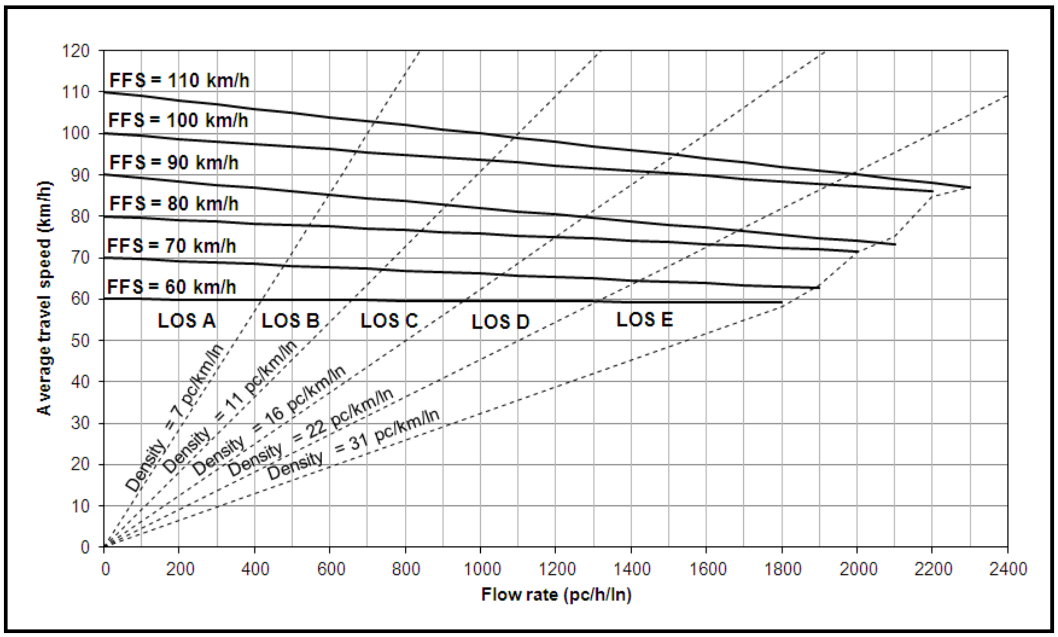


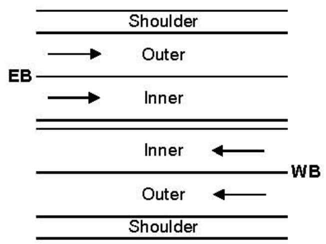
Figure 4.9: LOS criteria for multilane highways

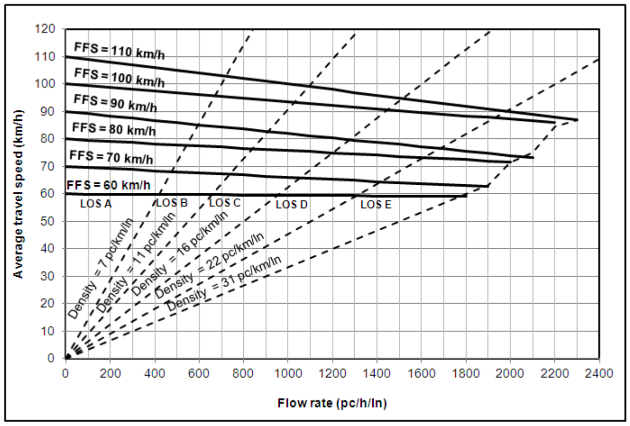
4.4 WORKSHEETS

MULTILANE HIGHWAYS (UNDIVIDED) WORKSHEET

General Information

Analyst	________	Highway	________
Agency or Company	________	From/To	________
Date Performed	________	Jurisdiction	________
Analysis Time Period	________	Analysis Year	________



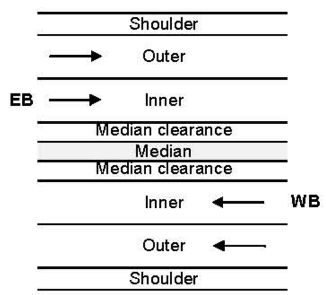


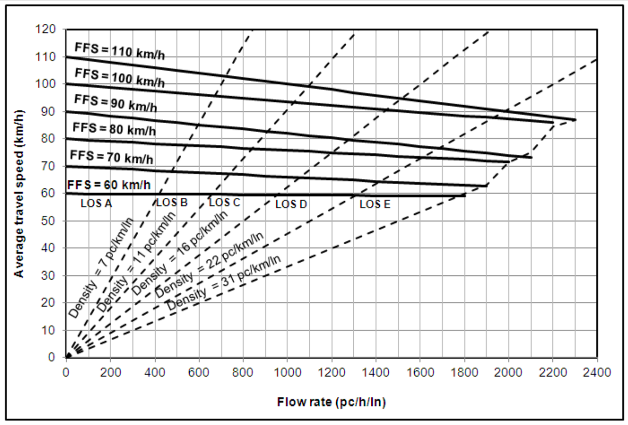
Geometric Input		East Bound		West Bound	
		Outer	**Inner**	**Outer**	**Inner**
Lane width, m					
Shoulder width, m					
Median clearance, m			0.00		0.00
Access points density (per km)					
Free-Flow Speed					
Base free-flow speed, BFFS (km/h)					
Adjustment for lane width, f_{LW} (km/h)	(Table 4.2)				
Adjustment for lateral clearance, f_{LC} (km/h)	(Table 4.3)		7.50		7.50
Adjustment for access point, f_A (km/h)	(Table 4.4)				
Adjustment for lane position, f_{LD} (km/h)	(Table 4.5)				
$FFS = BFFS - f_{LW} - f_{LC} - f_A - f_{LD}$ (km/h)					
Traffic composition					
Total cars, q_c (veh/h)					
Total lorries, q_l (veh/h)					
Total trailers, q_t (veh/h)					
Total buses, q_b (veh/h)					
Total motorcycles, q_m (veh/h)					
Demand volume for the full peak hour, V_i (veh/h)	$V_i = q_c + q_l + q_t + q_b + q_m$				
Traffic composition factor, f_c	$f_c = \frac{q_c + 1.58q_l + 1.76q_t + 1.65q_b + 0.84q_m}{V_i}$				
Peak Hour Factor					
Peak hour factor, PHF	(Table 4.6)				
Level of Service					
Flow rate, v_i (pc/h/ln)	$v_i = \frac{V_i \times f_c}{PHF}$				
Average travel speed, S (km/h)					
Density, D	$D = \frac{v_i}{S}$				
LOS (choose the worse LOS for each direction)					

MULTILANE HIGHWAYS (DIVIDED) WORKSHEET

General Information

Analyst		Highway	
Agency or Company		From/To	
Date Performed		Jurisdiction	
Analysis Time Period		Analysis Year	





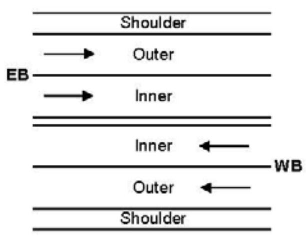
	East Bound		West Bound	
	Outer	Inner	Outer	Inner
Geometric Input				
Lane width, m				
Shoulder width, m				
Median clearance, m				
Access points density (per km)				
Free-Flow Speed				
Base free-flow speed, BFFS (km/h)				
Adjustment for lane width, f_{LW} (km/h) (Table 4.2)				
Adjustment for lateral clearance, f_{LC} (km/h) (Table 4.3)				
Adjustment for access point, f_A (km/h) (Table 4.4)				
Adjustment for lane position, f_{LD} (km/h) (Table 4.5)				
FFS = BFFS - f_{LW} – f_{LC} – f_A - f_{LD} (km/h)				
Traffic composition				
Total cars, q_c (veh/h)				
Total lorries, q_l (veh/h)				
Total trailers, q_t (veh/h)				
Total buses, q_b (veh/h)				
Total motorcycles, q_m (veh/h)				
Demand volume for the full peak hour, V_i (veh/h) $V_i = q_c + q_l + q_t + q_b + q_m$				
Traffic composition factor, f_c $f_c = \frac{q_c + 1.58q_l + 1.76q_t + 1.65q_b + 0.84q_m}{V_i}$				
Peak Hour Factor				
Peak hour factor, PHF (Table 4.6)				
Level of Service				
Flow rate, v_i (pc/h/ln) $v_i = \frac{V_i \times f_c}{PHF}$				
Average travel speed, S (km/h)				
Density, D $D = \frac{v_i}{S}$				
LOS (choose the worse LOS for each direction)				

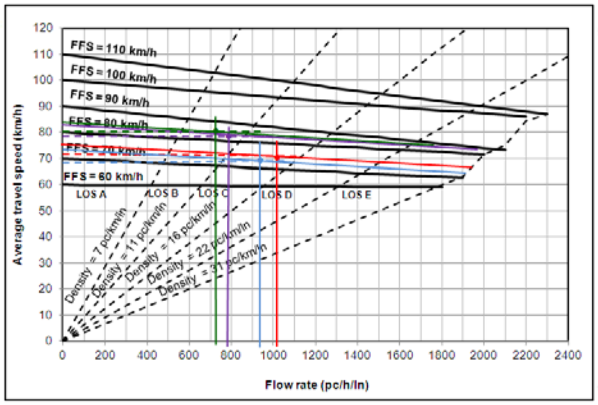
4.5 SAMPLE CALCULATION

MULTILANE HIGHWAYS (UNDIVIDED) WORKSHEET

General Information

Analyst	DEF	Highway	K9
Agency or Company	USM	From/To	Bandar Baru to Serdang
Date Performed	21/11/2011	Jurisdiction	
Analysis Time Period	AM	Analysis Year	2011



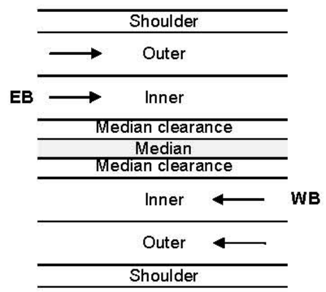


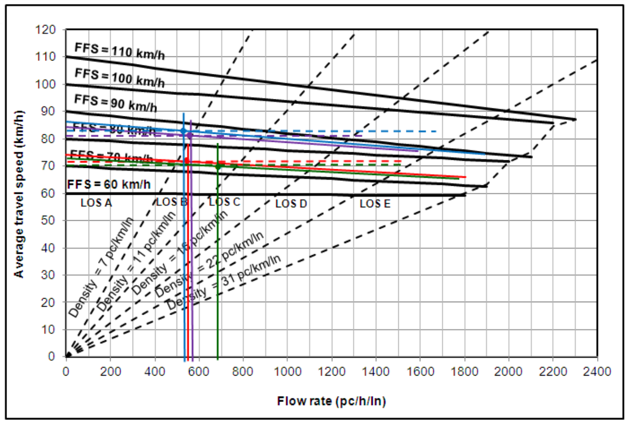
Geometric Input	East Bound		West Bound	
	Outer	**Inner**	**Outer**	**Inner**
Lane width, m	3.70	3.50	3.70	3.60
Shoulder width, m	2.00		1.60	
Median clearance, m		0.00		0.00
Access points density (per km)	1.00		2.00	
Free-Flow Speed				
Base free-flow speed, BFFS (km/h)	100		100	
Adjustment for lane width, f_{LW} (km/h) (Table 4.2)	0.00	6.30	0.00	2.10
Adjustment for lateral clearance, f_{LC} (km/h) (Table 4.3)	0.00	7.50	0.80	7.50
Adjustment for access point, f_A (km/h) (Table 4.4)	3.40		6.90	
Adjustment for lane position, f_{LD} (km/h) (Table 4.5)	20.30		20.30	
FFS = BFFS - $f_{LW} - f_{LC} - f_A - f_{LD}$ (km/h)	76.30	82.80	72.00	83.50
Traffic composition				
Total cars, q_c (veh/h)	586	543	552	508
Total lorries, q_l (veh/h)	105	56	85	45
Total trailers, q_t (veh/h)	92	56	53	40
Total buses, q_b (veh/h)	16	12	11	8
Total motorcycles, q_m (veh/h)	36	8	118	21
Demand volume for the full peak hour, V_i (veh/h) $V_i = q_c + q_l + q_t + q_b + q_m$	835	675	819	622
Traffic composition factor, f_c $f_c = \frac{q_c + 1.58q_l + 1.76q_t + 1.65q_b + 0.84q_m}{V_i}$	1.162	1.121	1.095	1.094
Peak Hour Factor				
Peak hour factor, PHF (Table 4.6)	0.968	0.951	0.967	0.944
Level of Service				
Flow rate, v_i (pc/h/ln) $v_i = \frac{V_i \times f_c}{PHF}$	1002	795	928	721
Average travel speed, S (km/h)	71.00	79.00	69.00	80.00
Density, D $D = \frac{v_i}{S}$	14.12	10.07	13.44	9.01
LOS (choose the worse LOS for each direction)	C	B	C	B

MULTILANE HIGHWAYS (DIVIDED) WORKSHEET

General Information

Analyst	DEF	Highway	K9
Agency or Company	USM	From/To	Bandar Baru to Serdang
Date Performed	21/11/2011	Jurisdiction	
Analysis Time Period	AM	Analysis Year	2011





Geometric Input		East Bound		West Bound	
		Outer	**Inner**	**Outer**	**Inner**
Lane width, m		3.70	3.50	3.70	3.60
Shoulder width, m		2.00		1.60	
Median clearance, m			0.80		0.90
Access points density (per km)		1.00		2.00	
Free-Flow Speed					
Base free-flow speed, BFFS (km/h)		100		100	
Adjustment for lane width, f_{LW} (km/h)	(Table 4.2)	0.00	6.30	0.00	2.10
Adjustment for lateral clearance, f_{LC} (km/h)	(Table 4.3)	0.00	4.10	0.80	3.70
Adjustment for access point, f_A (km/h)	(Table 4.4)	3.40		6.90	
Adjustment for lane position, f_{LD} (km/h)	(Table 4.5)	20.30		20.30	
FFS = BFFS - f_{LW} – f_{LC} – f_A - f_{LD} (km/h)		76.30	86.20	72.00	87.30
Traffic composition					
Total cars, q_c (veh/h)		190	328	277	312
Total lorries, q_l (veh/h)		86	71	102	55
Total trailers, q_t (veh/h)		30	28	39	41
Total buses, q_b (veh/h)		6	8	4	8
Total motorcycles, q_m (veh/h)		141	13	162	5
Demand volume for the full peak hour, V_i (veh/h)	$V_i = q_c + q_l + q_t + q_b + q_m$	453	448	584	421
Traffic composition factor, f_c	$f_c = \frac{q_c + 1.58q_l + 1.76q_t + 1.65q_b + 0.84q_m}{V_i}$	1.119	1.146	1.112	1.160
Peak Hour Factor					
Peak hour factor, PHF	(Table 4.6)	0.912	0.911	0.938	0.905
Level of Service					
Flow rate, v_i (pc/h/ln)	$v_i = \frac{V_i \times f_c}{PHF}$	556	564	693	540
Average travel speed, S (km/h)		71.00	81.00	70.00	85.00
Density, D	$D = \frac{v_i}{S}$	7.83	6.96	9.89	6.35
LOS (choose the worse LOS for each direction)		**B**	**A**	**B**	**A**

4.6 CALCULATION STEPS

MULTILANE HIGHWAYS (UNDIVIDED) STEP CALCULATION	
For East Bound direction	
1. All input parameters are known and insert into the worksheet.	
2. Compute free-flow speed (use Table 4.2, 4.3, 4.4 and 4.5)	$FFS = BFFS - f_{LW} - f_{LC} - f_{A} - f_{LD}$ **Outer** FFS = 100-0.0-0.0-3.4-20.3 = 76.3 km/h **Inner** FFS = 100-6.3-7.5-3.4 = 82.8 km/h
3. Determine demand volume for the full peak hour	$V_i = q_c + q_l + q_t + q_b + q_m$ **Outer** V_i = 586+105+92+16+36 = 835 veh/h **Inner** V_i = 543+56+56+12+8 = 675 veh/h
4. Determine traffic composition	$f_c = \frac{q_c + 1.58q_l + 1.76q_t + 1.65q_b + 0.84q_m}{V_i}$ **Outer** $f_c = \frac{586 + 1.58(105) + 1.76(92) + 1.65(16) + 0.84(36)}{835} = 1.162$ **Inner** $f_c = \frac{543 + 1.58(56) + 1.76(56) + 1.65(12) + 0.84(8)}{675} = 1.121$
5. Find the peak hour factor (use Table 4.6)	**Outer** PHF = 0.968 **Inner** PHF = 0.951
6. Compute flow rate	$v_i = \frac{Vi \times f_c}{PHF}$ **Outer** $v_i = \frac{835 \times 1.162}{0.968}$ = 1002 pcu/h/ln **Inner** $v_i = \frac{675 \times 1.121}{0.951}$ = 795 pcu/h/ln
7. Find the average travel speed, S (use speed-flow graph given in worksheet)	**Outer** S = 71 km/h **Inner** S = 79 km/h
8. Compute density	$D = \frac{v_i}{S}$ **Outer** $D = \frac{1002}{71}$ = 14.12 pc/km/ln **Inner** $D = \frac{795}{79}$ = 10.07 pc/km/ln
9. Determine LOS (use speed-flow graph given in worksheet)	**Outer** v_i = 1002 pcu/h/ln , S = 71.0 km/h , D = 14.12 pc/km/ln , **LOS C** **Inner** v_i = 795 pcu/h/ln , S = 79.0 km/h , D = 10.07 pc/km/ln **LOS B**
10.The similar step calculation is use for West Bound direction	

MULTILANE HIGHWAYS (DIVIDED) STEP CALCULATION	
For East Bound direction	
1. All input parameters are known and insert into the worksheet.	
2. Compute free-flow speed (use Table 4.2, 4.3, 4.4 and 4.5)	$FFS = BFFS - f_{LW} - f_{LC} - f_{A} - f_{LD}$ **Outer** FFS = 100-0.0-0.0-3.4-20.3 = 76.3 km/h **Inner** FFS = 100-6.3-4.1-3.4 = 86.2 km/h
3. Determine demand volume for the full peak hour	$V_i = q_c + q_l + q_t + q_b + q_m$ **Outer** V_i = 190+86+30+6+141 = 453 veh/h **Inner** V_i = 328+71+28+8+13 = 448 veh/h
4. Determine traffic composition	$f_c = \frac{q_c + 1.58q_l + 1.76q_t + 1.65q_b + 0.84q_m}{V_i}$ **Outer** $f_c = \frac{190 + 1.58(86) + 1.76(30) + 1.65(6) + 0.84(141)}{453} = 1.119$ **Inner** $f_c = \frac{328 + 1.58(71) + 1.76(28) + 1.65(8) + 0.84(13)}{448} = 1.146$
5. Find the peak hour factor (use Table 4.6)	**Outer** PHF = 0.912 **Inner** PHF = 0.911
6. Compute flow rate	$v_i = \frac{Vi \times f_c}{PHF}$ **Outer** $v_i = \frac{453 \times 1.119}{0.912} = 556$ pc/h/ln **Inner** $v_i = \frac{448 \times 1.146}{0.911} = 564$ pc/h/ln
7. Find the average travel speed, S (use speed-flow graph given in worksheet)	**Outer** S = 71 km/h **Inner** S = 81.000
8. Compute density	$D = \frac{v_i}{S}$ **Outer** $D = \frac{556}{71} = 7.83$ pc/km/ln **Inner** $D = \frac{564}{81} = 6.96$ pc/km/ln
9. Determine LOS (use speed-flow graph given in worksheet)	**Outer** v_i = 556 pc/h/ln , S = 71.0 km/h , D = 7.83 pc/km/ln , **LOS B** **Inner** v_i = 564 pc/h/ln , S = 81.0 km/h , D = 6.96 pc/km/ln **LOS A**
10.The similar step calculation is use for West Bound direction	

CHAPTER 5

BASIC SEGMENT EXPRESSWAY

CHAPTER 5

5.0 BASIC SEGMENT EXPRESSWAYS

CONTENTS

FIGURES

TABLES

5.1 INTRODUCTION

Expressway is defined as a divided highway with full control of access and two or more lane for the exclusive use of traffic in each direction. An expressway provides uninterrupted flow. There are no signalized or stop-controlled at-grade intersection and direct access to and from adjacent property is not permitted. Access to and from the expressway is limited to ramp locations. Opposing directions of flow are continuously separated by a raised barrier, an at-grade median or a continuous raised median.

Basic segment is defined as one of facility types under the expressways categories in which it is outside of the influence area of ramp or weaving areas of the expressways. Figure 5.1 shows a typical of four-lane basic segment expressways in Malaysia and Figure 5.2 shows a typical of six-lane basic segment expressways in Malaysia.

Figure 5.1: Typical four-lane basic segment expressways in Malaysia

Figure 5.2: Typical six-lane basic segment expressways in Malaysia

The base conditions for basic segment expressways adopted in this manual are based on "Guideline for Malaysia Toll Expressway System – Design Standard" which was published by Malaysian Highway Authority (2008). These conditions are as follows:

- Lane width greater than or equal to 3.75 m
- Shoulder width greater than or equal to 3.0 m
- Median clearance wider than or equal to 1.0 m
- Minimum interchange spacing of 5 km (in rural areas)
- Level terrain

5.2 CONCEPTS AND DEFINITIONS

5.2.1 FREE-FLOW SPEED

Free-flow speed is a speed that the drivers can drive their vehicle without obstruction and can speed with their own desired speed and not be influenced by other road users but influenced by characteristics of the vehicle, the driver, the physical characteristics of the road and external conditions such as weather and traffic rules such as speed limits. To measure free-flow speed at sites, speeds for unobstructed vehicles with headway to the nearest vehicle in front of more than 8 s were considered as free-flow speed. Factors affecting free-flow speed are lane width, lateral clearance and interchange density.

5.2.1.1 Lane Width

Drivers are forced to travel closer to one another than they would normally desire if lane widths are less than 3.75 m and thus reducing their travel speed. In Malaysia, there are four-lane expressways and six-lane expressways. Typical driving behaviour at expressways, traffic tends to be distributed across lanes according to speed. Traffic in the outer lane typically moves slower than in the centre lane and inner lane.

Lane is defined as either outer, centre (only applies for six-lane expressways) or inner lane based on the position of the lane itself. Figure 5.3 illustrates the lane definition for four-lane expressways while Figure 5.4 shows the illustration of lane definition for six-lane expressways.

Figure 5.3: Illustration of lane positions for four-lane expressways

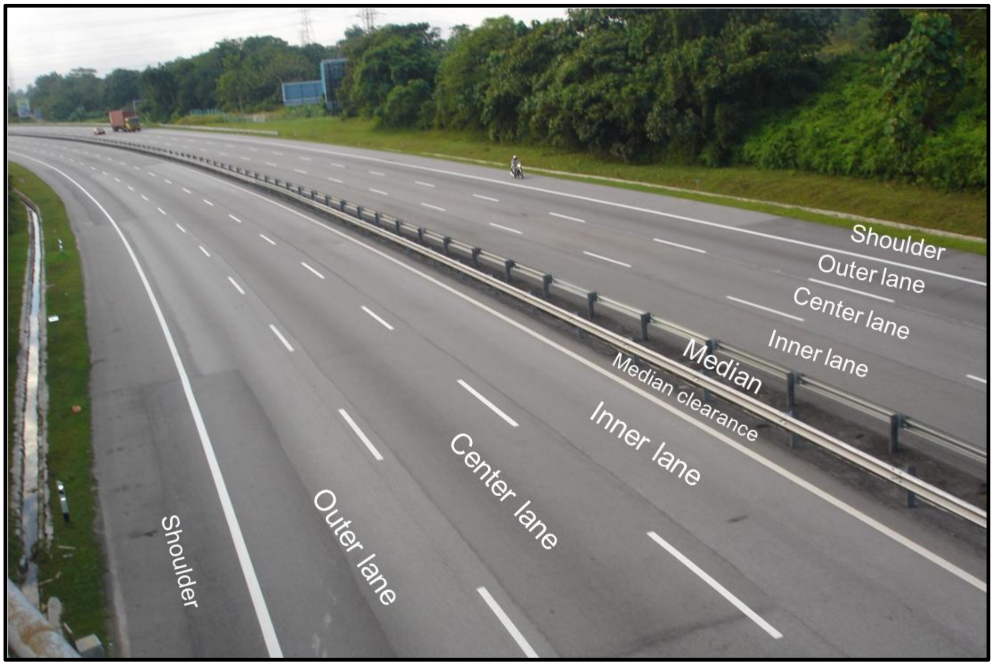


Figure 5.4: Illustration of lane positions for six-lane expressways

5.2.1.2 Lateral Clearance

Similar effect of restricted lane width applies for restricted lateral clearance, when the objects are located too close to the edge of the median and roadside lanes, drivers in these lanes will shy away from them and positioning themselves further from the lane edge.

The closeness of objects has a greater effect on drivers in the outer lane (slow lane) than on those in the inner lane (fast lane). Drivers in the inner lanes are affected when median clearance is less than 1.0 m, whereas drivers in the outer lanes are affected when shoulder width is less than 3.0 m.

5.2.1.3 Interchange Density

Basic segment expressways with closely spaced interchanges will operate at lower free-flow speed. The merging and weaving associated with interchanges also affect the speed of traffic. Speeds generally decrease with increasing frequency of interchanges. The minimum interchange spacing for expressways in Malaysia is 5 km. Interchange density is determined over a 10 km segment of expressway (5 km upstream and 5 km downstream) in which the expressway segment is located.

An interchange is defined as having at least one on-ramp. Therefore, interchanges that has only off-ramps would not be considered in determining interchange density. Interchanges considered should include typical interchanges with arterials or highways and major expressway-to-expressway interchanges. Figure 5.5 show how interchange density is taken into consideration in the analysis of basic segment expressways.

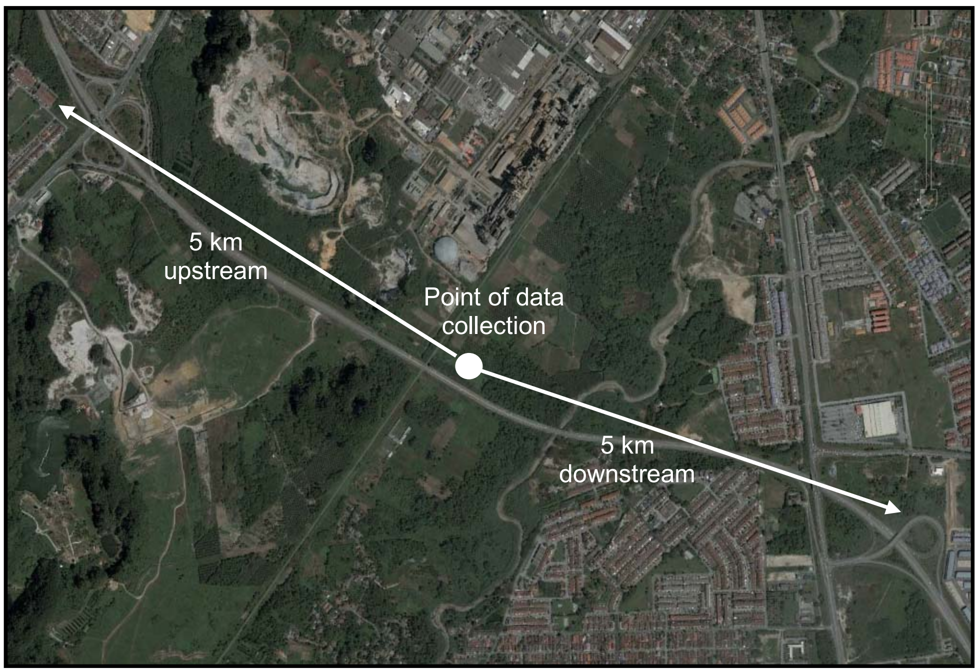


Figure 5.5: Interchange density for basic segment expressways

5.2.2 PEAK HOUR FACTOR

The peak hour factor represents the variation in traffic flow within an hour. Analysis of level of service is based on peak rates of flow occurring within the peak hour because substantial short-term fluctuations typically occur during an hour. Common practice is to use a peak 15-minutes rate of flow. However, flow rates are usually expressed in vehicles per hour, not vehicles per 15-minutes. The relationship between the peak 15-minutes flow rate and the full hourly volume is given by the peak hour factor as shown in the equation below:

$$PHF = \frac{v}{4 \times v_{15-minutes\ peak}} \tag{5.1}$$

Where

PHF	=	Peak hour factor
v	=	Hourly volume
$v_{15-minutes\ peak}$	=	Peak fifteen-minutes volume

5.2.3 TRAFFIC COMPOSITION FACTOR

Traffic composition factor was a weighted average determined by the proportions of various vehicle types. The traffic composition factor, f_c was calculated using equation (5.2).

$$f_c = \frac{\sum e_i q_i}{q} \tag{5.2}$$

Where

q_i	=	Flow in vehicles for vehicle type *i*
q	=	Total flow ($\sum q_i$)
e_i	=	Passenger car equivalent of vehicle type *i*

Therefore, passenger car equivalents derived in this manual were used to calculate the traffic composition factor in equation (5.2). In this manual, vehicles are categorizes into five types of classifications as shown in Table 5.1.

Table 5.1: Vehicle classifications

Vehicle class	Vehicle type
Class 1	Cars/Small Vans/ Utilities
Class 2	Lorries (with 2 axles)/ Large Vans
Class 3	Large lorry, trailers, heavy vehicles with 3 axles and more
Class 4	Buses
Class 5	Motorcycles

5.2.4 SPEED-FLOW AND DENSITY-FLOW RELATIONSHIPS

The speed-flow and density-flow relationships for typical basic segment expressways are as shown in Figure 5.6 and Figure 5.7 respectively.

In order to assess the speed-flow and density-flow relationships, speed, flow and density data were segregated based on various range of free-flow speeds, which are 70 – 79 km/h, 80 – 89 km/h, 90 – 99 km/h, 100 – 109 km/h, 110 – 119 km/h and 120 – 129 km/h. Regression analyses were conducted and trend lines for free-flow speed of 70, 80, 90, 100, 110 and 120 km/h were plotted in Figure 5.6.

Based on the empirical data collected at expressways in Malaysia, the speed-flow relationship shown in Figure 5.6 indicates that the average travel speed decreased with increasing flow rate and reductions in speeds are quite consistent throughout the range of free-flow speed except for free-flow speed of 70 km/h.

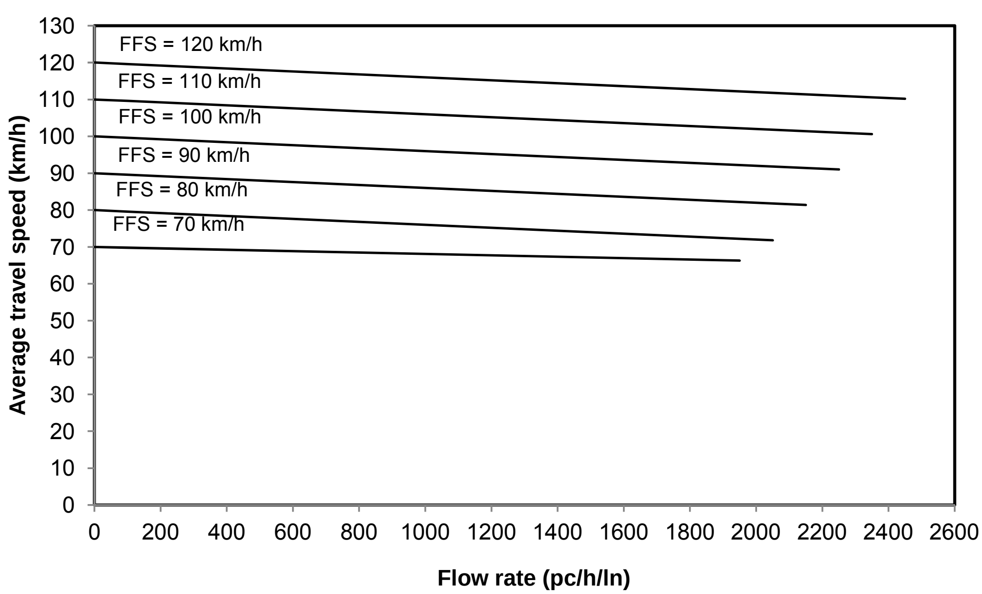


Figure 5.6: Speed-flow relationship on basic segment expressways

Figure 5.7 shows the density-flow relationship obtained for basic segment expressways. Regression analyses were conducted and trend lines were plotted for each free-flow speed value. The regression lines plotted in Figure 5.7 indicates that as free-flow speed increased the slope of the regression lines decreased and density increased as flow rate increased.

The LOS criteria for basic segment expressways established were based on the speed-flow and density-flow relationships.

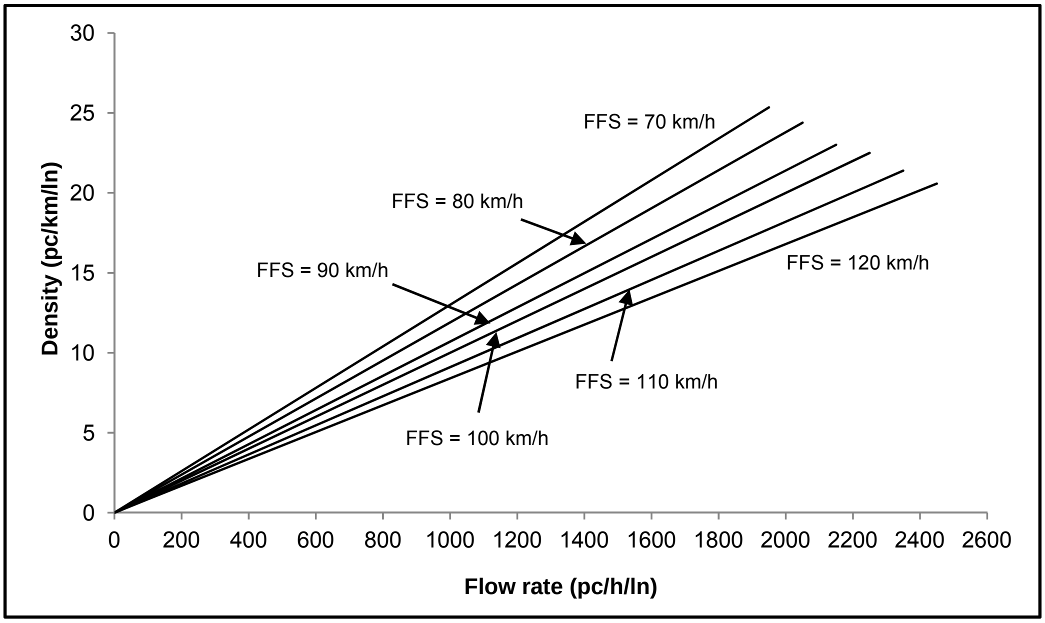


Figure 5.7: Density-flow relationship on basic segment expressways

5.2.5 LEVEL OF SERVICE (LOS)

Level of service are defined to represent reasonable ranges in the three critical flow variables; speed, density and flow rate. LOS A describes free-flow operations while LOS B represents reasonably free-flow conditions and free-flow speed is maintained. LOS C provides for flow with speeds at or near the free-flow speed of the expressway. LOS D is the level at which speeds begin to decline slightly with increasing flows and density begins to increase somewhat more quickly. LOS E describes operation at capacity at highest density value. LOS F describes conditions at the point of the breakdown or bottleneck and the queue discharge flow that occurs at speeds lower than the lowest speed for LOS E, as well as the operations within the queue that forms upstream.

5.3 METHODOLOGY

The methodology to determine level of service or to carry out analysis involving the basic segment expressways is as shown in Figure 5.8. Each parameter in Figure 5.8 was investigated thoroughly based on empirical data and the equations obtained are discussed in subsequent sections of this manual.

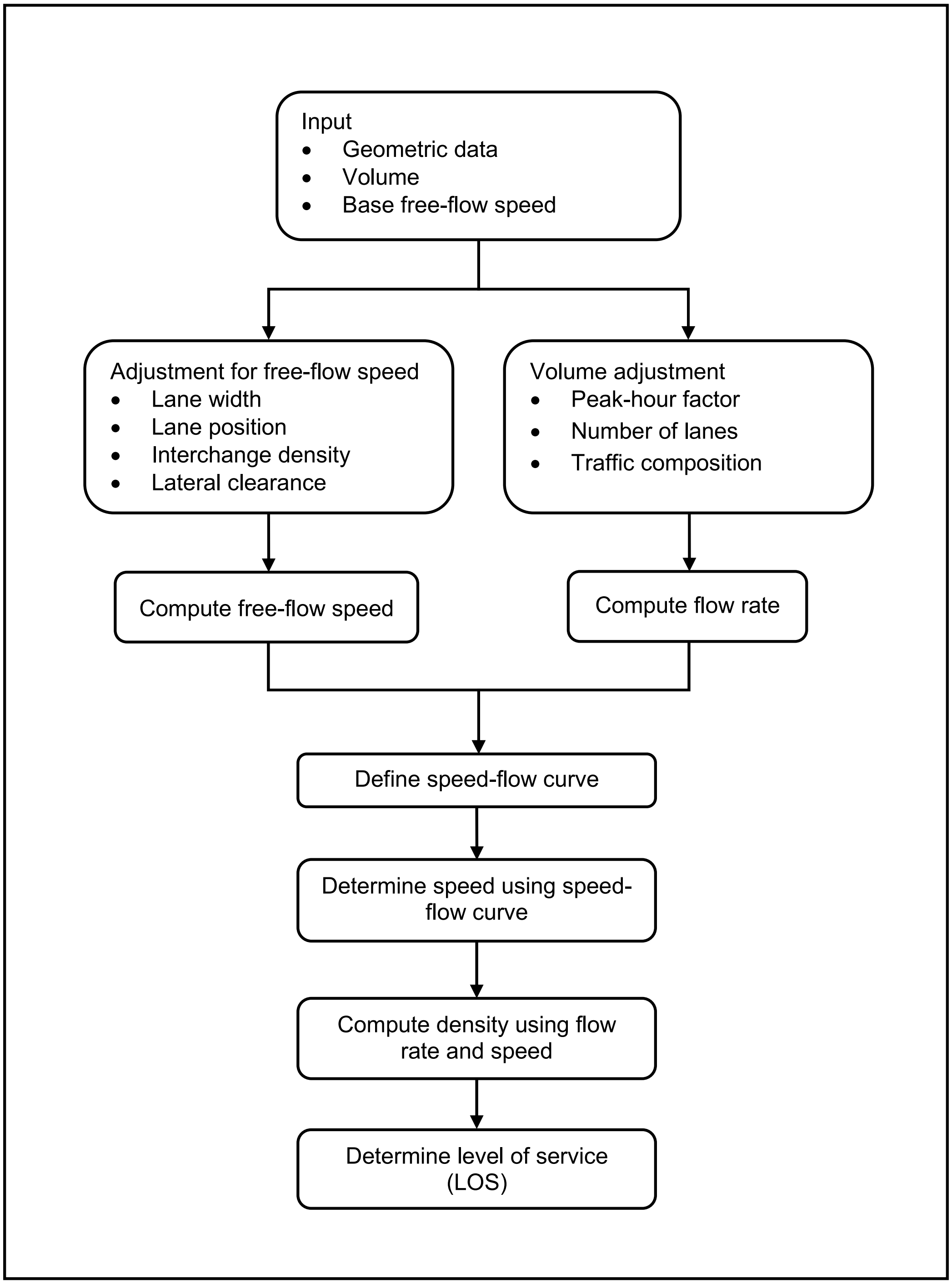


Figure 5.8: Basic segment expressway methodology

5.3.1 DETERMINING FREE-FLOW SPEED

Free-flow speed is the term used to describe the average speed that a motorist would travel if there were no congestion or other adverse conditions (such as bad weather). At sites, free-flow speed is measured based on space mean speed with headway more than 8 seconds. However, in the absence of measured data, free-flow speed can be estimated directly using equation (5.3). Factors affecting free-flow speed are lane width, lateral clearance, interchange density and lane position.

$$FFS = BFFS - f_{LW} - f_{LC} - f_{ID} - f_{LP} \qquad (5.3)$$

Where

FFS	=	Free-flow speed (km/h)
$BFFS$	=	Base free-flow speed
f_{LW}	=	Adjustment for lane width from Table 5.2 (km/h)
f_{LC}	=	Adjustment for shoulder width, f_{SH} (for outer lane) from Table 5.3 (km/h) or adjustment for median clearance, f_{MC} (for inner lane) Table 5.4
f_{ID}	=	Adjustment for interchange density from Table 5.5 (km/h)
f_{LP}	=	Adjustment for lane position from Table 5.6 (km/h)

Based on equation (5.3), estimation of free-flow speed for an existing or future expressway segment is accomplished by adjusting a base free-flow speed to reflect the influence of four factors which are lane width, lateral clearance, interchange density and lane position. Thus, the analyst is required to select an appropriate base free-flow speed as a starting point. Based on the empirical data, the recommended value for base free-flow speed is 120 km/h.

The base condition for lane width is 3.75 m or greater. When the lane width is less than 3.75 m, the base free-flow speed (e.g., 120 km/h) is reduced. Adjustments to reflect the effect of narrower lane width are given in Table 5.2.

Table 5.2: Free-flow speed reduction for lane width

Lane width (m)	Reduction in free-flow speed (km/h)
3.60	12.2
3.65	8.1
3.70	4.1
≥ 3.75	0.0

Base condition for lateral clearance is 3.0 m or greater of shoulder width for outer lane and 1.0 m or greater of median clearance for inner lane. Adjustments to reflect the effect of narrower shoulder width (for outer lane) are given in Table 5.3.

Table 5.3: Free-flow speed reduction for shoulder width (for outer lane)

Shoulder width (m)	Reduction in free-flow speed (km/h)
2.6	16.8
2.7	12.6
2.8	8.4
2.9	4.2
≥ 3.0	0.0

No adjustments are made for median clearance greater than 1.0 m, however when the median clearance is less than 1.0 m, the base free-flow speed is reduced. Adjustments to reflect the effect of narrower median clearance (for inner lane) are given in Table 5.4.

Table 5.4: Free-flow speed reduction for median clearance (for inner lane)

Median clearance (m)	Reduction in free-flow speed (km/h)
0.7	12.6
0.8	8.4
0.9	4.2
≥ 1.0	0.0

The base condition for interchange density is zero interchanges per kilometre, or 5 km of interchange spacing. Base free-flow speed is reduced when interchange density becomes greater. Adjustments to reflect the effect of interchange density are provided in Table 5.5.

Table 5.5: Free-flow speed reduction for interchange density

Interchange points/km	Reduction in free-flow speed (km/h)
0.0	0.0
0.1	8.9
0.2	17.7

The effect of lane position needs to be considered for expressway segments with two or three lanes (in one direction). When the outer lane and centre lane are present, base free-flow speed is reduced. Table 5.6 provides adjustments to reflect the effect of lane position on base free-flow speed. Table 5.6 indicates that base free-flow speed is to be reduced by 19.2 km/h if it is an outer lane and 13.6 km if it is a centre lane.

Table 5.6: Free-flow speed reduction for lane position

Lane position	Reduction in free-flow speed (km/h)
Inner	0.0
Centre	13.6
Outer	19.2

5.3.2 DETERMINING DEMAND FLOW RATE

Adjustments must be made to hourly demand volumes, whether based on traffic counts or estimates to arrive at the equivalent passenger car flow rate used in the level of service analysis. The adjustments are the peak hour factor and the traffic composition factor. For basic segment expressways, the equation to estimate 15-minutes flow rate is as follows:

$$v_i = \frac{V_i \times PHF}{f_C} \tag{5.4}$$

Where

v_i = 15-minutes passenger-car equivalent flow rate (pc/h/ln)

V_i = Hourly volume (veh/h)

PHF = Peak hour factor

f_C = Traffic composition

5.3.2.1 Peak Hour Factor

The peak hour factor represents the variation in traffic flow within an hour. The model for estimating peak hour factor is as show in equation (5.5) and the recommended peak hour factor values for basic segment expressways are as shown in Table 5.7.

$$PHF = \frac{2}{1 + e^{-2(0.001042V+0.9098)}} - 1 \qquad (5.5)$$

Where

PHF = Peak hour factor

V = Traffic flow (pc/h)

Table 5.7: Recommended peak hour factor values based on flow rate for basic segment expressways

Flow (veh/h)	PHF
≤200	0.8070
300	0.8404
400	0.8685
500	0.8919
600	0.9113
700	0.9274
800	0.9407
900	0.9516
1000	0.9605
1100	0.9678
1200	0.9738
1300	0.9787
1400	0.9826
1500	0.9859
1600	0.9885
1700	0.9907
1800	0.9924
1900	0.9938
2000	0.9950
2100	0.9959
2200	0.9967
2300	0.9973
≥ 2400	0.9978

5.3.2.2 Traffic Composition Factor

Traffic composition factor is a weighted average determined by the proportions of various vehicle types. Passenger car equivalents are used to represent varying effects of mixed vehicle types by converting a traffic stream comprising of various vehicle types into an equivalent traffic stream comprising entirely of passenger cars. Table 5.8 shows the passenger car equivalents obtained for basic segment expressways based on Malaysian road condition.

Table 5.8: Passenger car equivalents for basic segment expressways

Vehicle class	Vehicle type	Passenger car equivalents
Class 1	Cars/Small Vans/ Utilities	1.00
Class 2	Lorries (with 2 axles)/ Large Vans	1.47
Class 3	Large lorry, trailers, heavy vehicles with 3 axles and more	1.95
Class 4	Buses	1.66
Class 5	Motorcycles	0.63

As such, traffic composition factor can be calculated based on the passenger car equivalent values shown in Table 5.8 by using equation (5.6).

$$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.63q_m}{V_i} \quad (5.6)$$

Where

q_c = Flow in vehicles for car

q_l = Flow in vehicles for lorry

q_t = Flow in vehicles for trailer

q_b = Flow in vehicles for bus

q_m = Flow in vehicles for motor

V_i = Total flow ($\sum q_i$)

5.3.3 DETERMINING LEVEL OF SERVICES (LOS)

The criteria of level of service for basic segment expressways are based on the values of free-flow speed and flow rate for each individual lane. The level of service criteria for six levels of free-flow speed which are 70, 80, 90, 100, 110 and 120 km/h are as shown in Table 5.9. The capacity values determined in this manual for free-flow speed of 70, 80, 90, 100, 110 and 120 km/h are 1950, 2050, 2150, 2250, 2350 and 2450 pc/h/ln respectively. These values were adopted with slight modifications from the values used in U.S. HCM 2000. In addtion, the level of service criteria in a graphical format can be found in Figure 5.9.

Table 5.9: LOS criteria for basic segment expressways

Base free-flow speed (km/h)	Criteria	LOS				
		A	B	C	D	E
120	Maximum density (pc/km/ln)	7	11	16	19	22
	Average speed (km/h)	117.1	114.5	113.1	112.0	110.2
	Maximum volume to capacity ratio (v/c)	0.33	0.51	0.74	0.89	1.00
	Maximum service flow rate (pc/h/ln)	820	1260	1810	2180	2450
110	Maximum density (pc/km/ln)	7	11	16	20	23
	Average speed (km/h)	107.1	104.5	103.1	102.0	100.6
	Maximum volume to capacity ratio (v/c)	0.32	0.49	0.70	0.87	1.00
	Maximum service flow rate (pc/h/ln)	750	1150	1650	2040	2350
100	Maximum density (pc/km/ln)	7	11	16	20	25
	Average speed (km/h)	97.1	95.5	93.8	92.5	91.0
	Maximum volume to capacity ratio (v/c)	0.30	0.47	0.67	0.84	1.00
	Maximum service flow rate (pc/h/ln)	680	1050	1500	1890	2250
90	Maximum density (pc/km/ln)	7	11	16	21	26
	Average speed (km/h)	88.6	86.4	84.4	83.3	81.4
	Maximum volume to capacity ratio (v/c)	0.29	0.44	0.63	0.81	1.00
	Maximum service flow rate (pc/h/ln)	620	950	1350	1750	2150
80	Maximum density (pc/km/ln)	7	11	16	22	29
	Average speed (km/h)	78.6	76.4	75.0	72.7	71.8
	Maximum volume to capacity ratio (v/c)	0.27	0.41	0.59	0.78	1.00
	Maximum service flow rate (pc/h/ln)	550	840	1200	1600	2050
70	Maximum density (pc/km/ln)	7	11	16	22	29
	Average speed (km/h)	69.3	68.2	68.1	67.7	66.3
	Maximum volume to capacity ratio (v/c)	0.25	0.38	0.56	0.76	1.00
	Maximum service flow rate (pc/h/ln)	485	750	1090	1490	1950

Level of service for a basic segment expressway can also be determined directly from Figure 5.9 based on free-flow speed and flow rate. The procedure involved is as follows:

- Based on either measured or estimated free-flow speed, construct an appropriate speed-flow curve of the same shape as the typical curves shown in Figure 5.9. The curve should intercept the y–axis at the free-flow speed.
- Based on the flow rate $v_{i,}$ read up to the free-flow speed curve indentified previously and determine the average passenger-car speed and LOS corresponding to that point.

- Also, based on speed and flow, density can be determined according to equation (5.7).

$$D = \frac{v_i}{S} \tag{5.7}$$

Where

D = Density (pc/km/ln)

v_i = Flow rate (pc/h/ln)

S = Average passenger car travel speed (km/h)

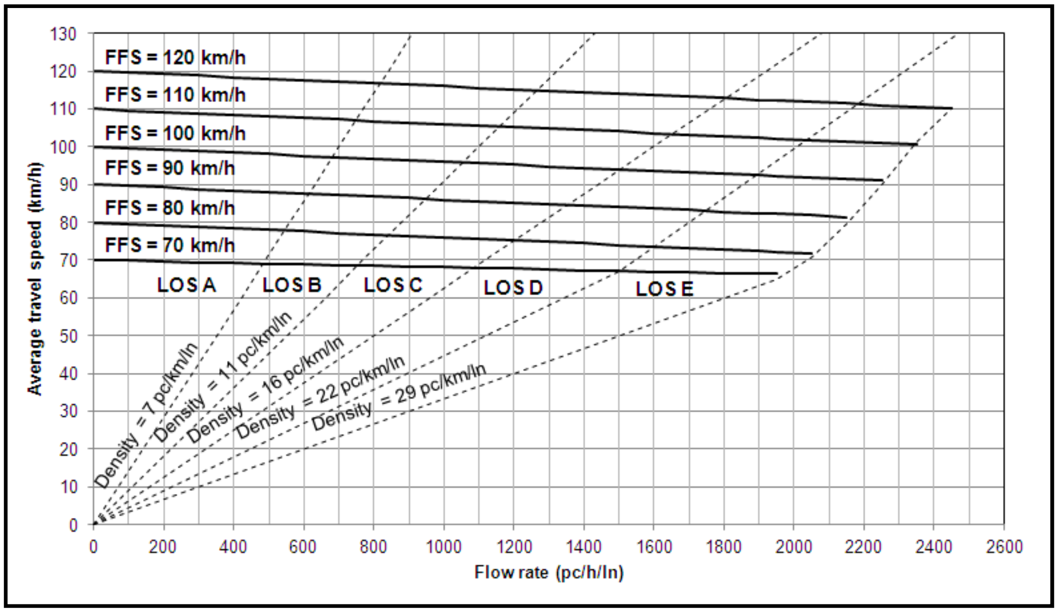


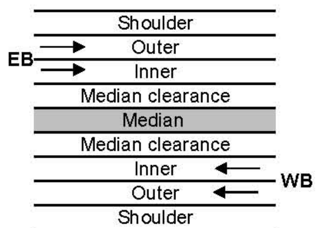
Figure 5.9: LOS criteria for basic segment expressways

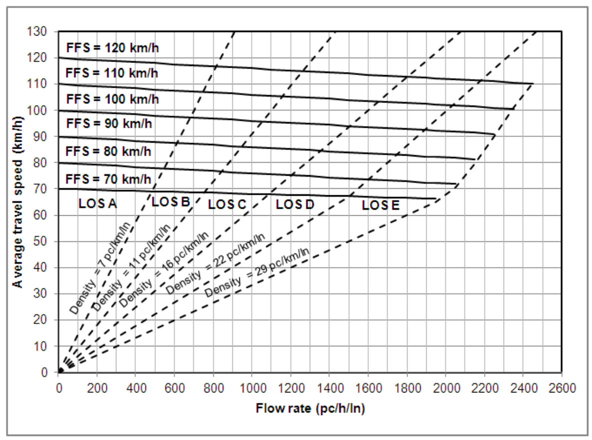
5.4 WORKSHEETS

BASIC SEGMENT EXPRESSWAYS (FOUR-LANE EXPRESSWAYS) WORKSHEET

General Information

Analyst	______	Highway	______
Agency or Company	______	From/To	______
Date Performed	______	Jurisdiction	______
Analysis Time Period	______	Analysis Year	______



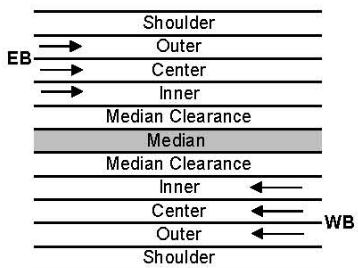


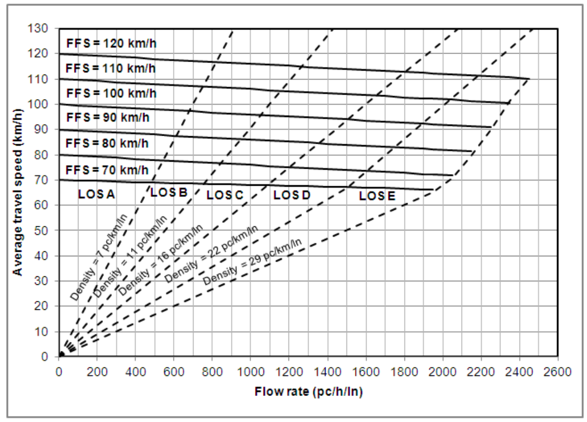
Geometric Input	EB		WB	
	Outer	Inner	Outer	Inner
Lane width, (m)				
Shoulder width, (m)				
Median clearance, (m)				
Interchange density, (I/km)				
Free-Flow Speed				
Base free-flow speed, BFFS (km/h)				
Adjustment for lane width, f_{LW} (km/h) (Table 5.2)				
Adjustment for shoulder width, f_{SH} (km/h) (Table 5.3)				
Adjustment for median clearance, f_{MC} (km/h) (Table 5.4)				
Adjustment for interchange density, f_{ID} (km/h) (Table 5.5)				
Adjustment for lane position, f_{LP} (km/h) (Table 5.6)				
Free-flow speed, FFS (km/h) $FFS = BFFS - f_{LW} - f_{SH}$ or $f_{MC} - f_{ID} - f_{LP}$				
Traffic Composition				
Total cars, q_c(veh/h)				
Total lorries, q_l (veh/h)				
Total trailers, q_t (veh/h)				
Total buses, q_b (veh/h)				
Total motorcycles, q_m (veh/h)				
Demand volume for the full peak hour, V_i (veh/h) $V_i = q_c + q_l + q_t + q_b + q_m$				
Traffic composition, f_c $f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{V_i}$				
Peak-hour factor, PHF (Table 5.7)				
Level of Service				
Flow rate, v_i (pc/h/ln) $v_i = \frac{V_i \times f_c}{PHF}$				
Average travel speed, S (km/h)				
Density, D (pc/km/ln) $D = \frac{v_i}{S}$				
LOS (choose the worse LOS for each direction)				

BASIC SEGMENT EXPRESSWAYS (SIX-LANE EXPRESSWAYS) WORKSHEET

General Information

Analyst	__________	Highway	__________
Agency or Company	__________	From/To	__________
Date Performed	__________	Jurisdiction	__________
Analysis Time Period	__________	Analysis Year	__________





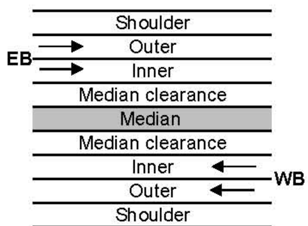
Geometric Input	EB			WB		
	Outer	Center	Inner	Outer	Center	Inner
Lane width, (m)						
Shoulder width, (m)						
Median clearance, (m)						
Interchange density, (I/km)						
Free-Flow Speed						
Base free-flow speed, BFFS (km/h)						
Adjustment for lane width, f_{LW} (km/h) (Table 5.2)						
Adjustment for shoulder width, f_{SH} (km/h) (Table 5.3)						
Adjustment for median clearance, f_{MC} (km/h) (Table 5.4)						
Adjustment for interchange density, f_{ID} (km/h) (Table 5.5)						
Adjustment for lane position, f_{LP} (km/h) (Table 5.6)						
Free-flow speed, FFS (km/h) $FFS = BFFS - f_{LW} - f_{SH}$ or $f_{MC} - f_{ID} - f_{LP}$						
Traffic Composition						
Total cars, q_c(veh/h)						
Total lorries, q_l (veh/h)						
Total trailers, q_t (veh/h)						
Total buses, q_b (veh/h)						
Total motorcycles, q_m (veh/h)						
Demand volume for the full peak hour, V_i (veh/h) $V_i = q_c + q_l + q_t + q_b + q_m$						
Traffic composition, f_c $f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{V_i}$						
Peak-hour factor, PHF (Table 5.7)						
Level of Service						
Flow rate, v_i (pc/h/ln) $v_i = \frac{V_i \times f_c}{PHF}$						
Average travel speed, S (km/h)						
Density, D (pc/km/ln) $D = \frac{v_i}{S}$						
LOS (choose the worse LOS for each direction)						

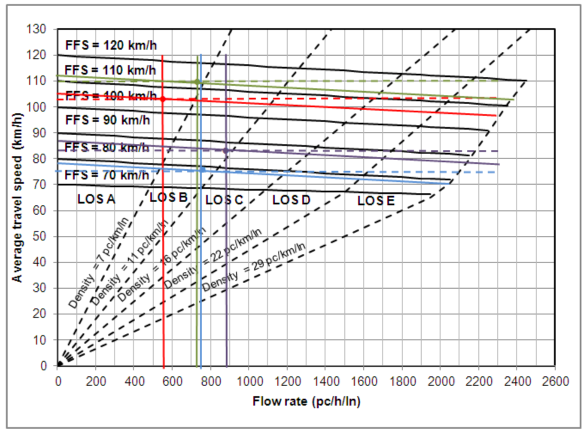
5.5 SAMPLE CALCULATION

BASIC SEGMENT EXPRESSWAYS (FOUR-LANE EXPRESSWAYS) WORKSHEET

General Information

Analyst	GHI	Highway	E1
Agency or Company	USM	From/To	Tapah to Bidor
Date Performed	13/12/2011	Jurisdiction	
Analysis Time Period	AM	Analysis Year	2011



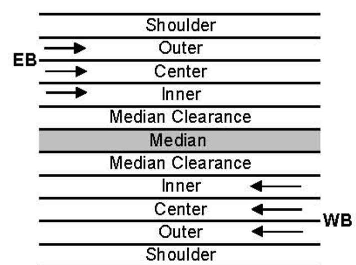


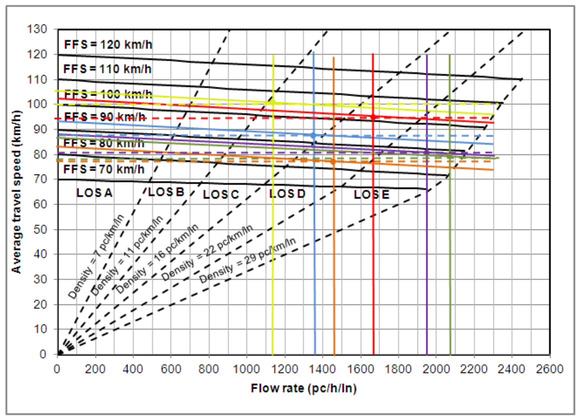
		EB Outer	EB Inner	WB Outer	WB Inner
Geometric Input					
Lane width, (m)		3.7	3.8	3.8	3.9
Shoulder width, (m)		2.8		2.9	
Median clearance, (m)		0.9		1.0	
Interchange density, (I/km)		0.1		0.1	
Free-Flow Speed					
Base free-flow speed, BFFS (km/h)		120	120	120	120
Adjustment for lane width, f_{LW} (km/h)	(Table 5.2)	4.1	0	0	0
Adjustment for shoulder width, f_{SH} (km/h)	(Table 5.3)	8.4		4.2	
Adjustment for median clearance, f_{MC} (km/h)	(Table 5.4)		4.2		0
Adjustment for interchange density, f_{ID} (km/h)	(Table 5.5)	8.9		8.9	
Adjustment for lane position, f_{LP} (km/h)	(Table 5.6)	19.2		19.2	
Free-flow speed, FFS (km/h)	$FFS = BFFS - f_{LW} - f_{SH}$ or $f_{MC} - f_{ID} - f_{LP}$	79.4	106.9	87.7	111.1
Traffic Composition					
Total cars, q_c(veh/h)		410	466	530	610
Total lorries, q_l (veh/h)		85	17	94	26
Total trailers, q_t (veh/h)		55	4	45	4
Total buses, q_b (veh/h)		8	2	18	7
Total motorcycles, q_m (veh/h)		48	4	83	5
Demand volume for the full peak hour, V_i (veh/h)	$V_i = q_c + q_l + q_t + q_b + q_m$	606	493	770	652
Traffic composition, f_c	$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{V_i}$	1.134	1.024	1.092	1.029
Peak-hour factor, PHF	(Table 5.7)	0.912	0.890	0.937	0.92
Level of Service					
Flow rate, v_i (pc/h/ln)	$v_i = \frac{V_i \times f_c}{PHF}$	753	567	897	729
Average travel speed, S (km/h)		75.0	103.5	83.0	110.0
Density, D (pc/km/ln)	$D = \frac{v_i}{S}$	10.05	5.48	10.81	6.63
LOS (choose the worse LOS for each direction)		**B**	**A**	**B**	**A**

BASIC SEGMENT EXPRESSWAYS (SIX-LANE EXPRESSWAYS) WORKSHEET

General Information

Analyst	GHI	Highway	E1
Agency or Company	USM	From/To	Tapah to Bidor
Date Performed	13/12/2011	Jurisdiction	
Analysis Time Period	AM	Analysis Year	2011





Geometric Input

	EB			WB		
	Outer	Center	Inner	Outer	Center	Inner
Lane width, (m)	3.9	3.7	3.9	3.9	3.65	3.9
Shoulder width, (m)		2.8			2.9	
Median clearance, (m)		0.9			0.8	
Interchange density, (I/km)		0.1			0.1	
Free-Flow Speed						
Base free-flow speed, BFFS (km/h)	120	120	120	120	120	120
Adjustment for lane width, f_{LW} (km/h) (Table 5.2)	0	4.1	0	0	8.1	0
Adjustment for shoulder width, f_{SH} (km/h) (Table 5.3)	8.4			4.2		
Adjustment for median clearance, f_{MC} (km/h) (Table 5.4)			4.2			8.4
Adjustment for interchange density, f_{ID} (km/h) (Table 5.5)		8.9			8.9	
Adjustment for lane position, f_{LP} (km/h) (Table 5.6)	19.2	13.6		19.2	13.6	
Free-flow speed, FFS (km/h) $FFS = BFFS - f_{LW} - f_{SH}$ or $f_{MC} - f_{ID} - f_{LP}$	83.5	93.4	106.9	87.7	89.4	102.7
Traffic Composition						
Total cars, q_c(veh/h)	1253	1254	1055	1791	1879	1612
Total lorries, q_l (veh/h)	40	18	10	63	10	6
Total trailers, q_t (veh/h)	53	10	6	72	9	4
Total buses, q_b (veh/h)	5	11	5	18	10	7
Total motorcycles, q_m (veh/h)	9	10	5	26	8	9
Demand volume for the full peak hour, V_i (veh/h) $V_i = q_c + q_l + q_t + q_b + q_m$	1360	1303	1081	1970	1916	1638
Traffic composition, f_c $f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{V_i}$	1.051	1.017	1.011	1.051	1.009	1.005
Peak-hour factor, PHF (Table 5.7)	0.981	0.979	0.967	0.995	0.994	0.989
Level of Service						
Flow rate, v_i (pc/h/ln) $v_i = \frac{V_i \times f_c}{PHF}$	1457	1353	1130	2081	1945	1664
Average travel speed, S (km/h)	78.5	88.5	100.0	79.5	81.0	94.5
Density, D (pc/km/ln) $D = \frac{v_i}{S}$	18.56	15.29	11.30	26.18	24.01	17.61
LOS (choose the worse LOS for each direction)	**D**	**C**	**C**	**E**	**E**	**D**

5.6 CALCULATION STEPS

BASIC SEGMENT EXPRESSWAYS (FOUR-LANE EXPRESSWAYS) WORKSHEET	
For EB direction	
1. All input parameters are known and insert into the worksheet.	
2. Compute free-flow speed (use Table 5.2, 5.3, 5.4, 5.5 and 5.6).	$FFS = BFFS - f_{LW} - f_{SH}$ or $f_{MC} - f_{ID} - f_{LP}$ **Outer** FFS = 120-4.1-8.4-8.9-19.2 = 79.4 km/h **Inner** FFS = 120-0-4.2-8.9 = 106.9 km/h
3. Determine demand volume for the full peak hour	$Vi = q_c + q_l + q_t + q_b + q_m$ **Outer** V_i = 410+85+55+8+48 = 606 veh/h **Inner** V_i = 466+17+4+2+4 = 493 veh/h
4. Determine traffic composition.	$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{V_i}$ **Outer** $f_c = \frac{410 + 1.47(85) + 1.95(55) + 1.66(8) + 0.66(48)}{606} = 1.134$ **Inner** $f_c = \frac{466 + 1.47(17) + 1.95(4) + 1.66(2) + 0.66(4)}{493} = 1.024$
5. Find the peak hour factor (use Table 5.7).	**Outer** PHF = 0.912 **Inner** PHF = 0.890
6. Compute flow rate	$v_i = \frac{V_i \times f_c}{PHF}$ **Outer** $v_i = \frac{606 \times 1.134}{0.912} = 753$ pc/h/ln **Inner** $v_i = \frac{493 \times 1.024}{0.890} = 567$ pc/h/ln
7. Determine S (use speed-flow graph given in worksheet)	**Outer** S = 75.0 km/h **Inner** S = 103.5 km/h
8. Compute density	$D = \frac{v_i}{S}$ **Outer** $D = \frac{753}{75.0} = 10.1$ pc/km/ln **Inner** $D = \frac{567}{103.5} = 5.5$ pc/km/ln
9. Determine LOS (use speed-flow graph given in worksheet)	**Outer** v_i = 753 pc/h/ln , S = 75.0 km/h , D = 10.1 pc/km/ln , **LOS B** **Inner** v_i = 567 pc/h/ln , S = 103.5 km/h , D = 5.5 pc/km/ln **LOS A**
10. The similar step calculation is use for WB direction	

BASIC SEGMENT EXPRESSWAYS (SIX-LANE EXPRESSWAYS) WORKSHEET	
For EB direction	
1. All input parameters are known and insert into the worksheet.	
2. Compute free-flow speed (use Table 5.2, 5.3, 5.4, 5.5 and 5.6).	FFS = BFFS - f_{LW} – f_{SH} or f_{MC} – f_{ID} - f_{LP} **Outer** FFS = 120-0-8.4-8.9-19.2 = 83.5 km/h **Center** FFS = 120-4.1-8.9-13.6 = 93.4 km/h **Inner** FFS = 120-0-4.2-8.9 = 106.9 km/h
3. Determine demand volume for the full peak hour	$V_i = q_c + q_l + q_t + q_b + q_m$ **Outer** V_i = 1253+40+53+5+9 = 1360 veh/h **Center** V_i = 1254+18+10+11+10 = 1303 veh/h **Inner** V_i = 1055+10+6+5+5 = 1081 veh/h
4. Determine traffic composition.	$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{V_i}$ **Outer** $f_c = \frac{1253 + 1.47(40) + 1.95(53) + 1.66(5) + 0.66(9)}{1560} = 1.051$ **Center** $f_c = \frac{1254 + 1.47(18) + 1.95(10) + 1.66(11) + 0.66(10)}{1303} = 1.017$ **Inner** $f_c = \frac{1055 + 1.47(10) + 1.95(6) + 1.66(5) + 0.66(5)}{1081} = 1.011$
5. Find the peak hour factor (use Table 5.7).	**Outer** PHF = 0.981 , **Center** PHF = 0.979 , **Inner** PHF = 0.967
6. Compute flow rate	$v_i = \frac{V_i \times f_c}{PHF}$ **Outer** $v_i = \frac{1360 \times 1.051}{0.981}$ = 1457 pc/h/ln **Center** $v_i = \frac{1303 \times 1.017}{0.979}$ = 1353 pc/h/ln **Inner** $v_i = \frac{1081 \times 1.011}{0.967}$ = 1130 pc/h/ln
7. Determine S (use speed-flow graph given in worksheet)	**Outer** S = 78.5 km/h; **Center** S = 88.5 km/h; **Inner** S = 100.0 km/h
8. Compute density	$D = \frac{v_i}{S}$ **Outer** $D = \frac{1457}{78.5}$ = 18.56 pc/km/ln **Center** $D = \frac{1353}{88.5}$ = 15.29 pc/km/ln **Inner** $D = \frac{1130}{100.0}$ = 11.30 pc/km/ln
9. Determine LOS (use speed-flow graph given in worksheet)	**Outer** v_i = 1457 pc/h/ln , S = 78.5 km/h , D = 18.56 pc/km/ln **LOS D** **Center** v_i = 1353 pc/h/ln , S = 88.5 km/h , D = 15.29 pc/km/ln **LOS C** **Inner** v_i = 1130 pc/h/ln , S = 100.0 km/h , D = 11.30 pc/km/ln **LOS C**
10.The similar step calculation is use for WB direction	

CHAPTER 6

RAMPS EXPRESSWAY

CHAPTER 6

6.0 RAMPS

CONTENTS

FIGURES

TABLES

6.1 INTRODUCTION

Expressway has become an integral part of the transportation system in Malaysia. According to U.S. HCM 2000, expressway is defined as a divided highway with full control access and two or more lanes for the exclusive use of traffic in each direction in which it provides uninterrupted flow with no signalized intersection. Access through and from expressway is limited to ramp locations. Opposing direction of flows is continuously separated by a raised barrier, at-grade median or a continuous raised median.

The expressway network in Malaysia comprises of many different expressways such as the North-South Expressways (NSE), Kuala Lumpur-Seremban Expressway, Shah Alam Expressway (KESAS) and many more. In Malaysia, expressways are defined as high-speed routes with at least four lanes (two in each direction) and may be either with limited or partial access.

According to U.S. HCM 2000, ramp is a length of roadway providing an exclusive access between two highway facilities (expressway, multilane highways, two-lane highways, suburban streets and urban streets). Entrance ramp has become the major concern of many traffic engineers because if the design of entrance ramp does not comply with the available standards, it will cause serious congestion in the particular area and hence, it will affect the operational performance of the expressway. As such, the performance of expressway is affected by the ramp junctions and it is very important to incorporate the analysis procedure based on Malaysian traffic conditions for the ramp junctions.

A ramp-expressway junction is typically designed to allow high-speed merging or diverging with minimum disruption to the adjacent expressway traffic. The geometric characteristics of ramp-expressway junctions vary where the length and type (taper, parallel) of acceleration or deceleration lanes, free-flow speed of the ramp in the immediate vicinity of the junction, sight distances and other elements all influence ramp operations. As such, this manual only provides operation analyses for on-ramp and off-ramp junctions. Utilisation for design must conform to design guidelines used in Malaysia such as the “Guideline for Malaysia Toll Expressway System – Design Standard” published by Malaysian Highway Authority (2008) or Arahan Teknik (Jalan) 12/87 on “A Guide to the Design of Interchanges,” published by Public Works Department, Ministry of Works Malaysia (1987). Figure 6.1 shows a typical on-ramp junction and Figure 6.2 shows a typical off-ramp junction in Malaysia.

Figure 6.1: Typical on-ramp junction in Malaysia

Figure 6.2: Typical off-ramp junction in Malaysia

6.2 CONCEPTS AND DEFINITIONS

6.2.1 LENGTH OF ACCELERATION LANE OR DECELERATION LANE

Length of the acceleration lane, L_A or deceleration lane, L_D is a critical geometric parameter influencing the operation at merge or diverge areas. This length is measured from the point at which the right edge of the ramp lane or lanes and the left edge of the freeway lanes converge to the end of the taper segment connecting the ramp to the freeway. The point of convergence can be defined by painted markings or physical barriers and both taper area and parallel ramps are measured in the same way. Figure 6.3 shows the illustration of length of one-lane acceleration lane and one-lane deceleration lane. Figure 6.4 shows the illustration of length of two-lane acceleration lane and two-lane deceleration lane.

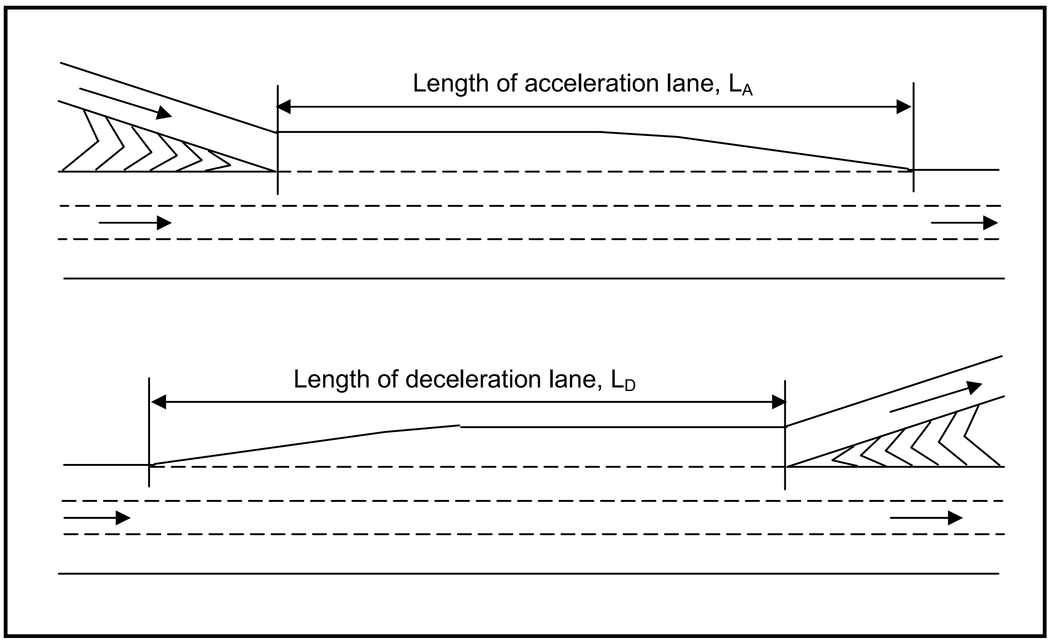


Figure 6.3: Illustration of length of one-lane acceleration lane and one-lane deceleration lane

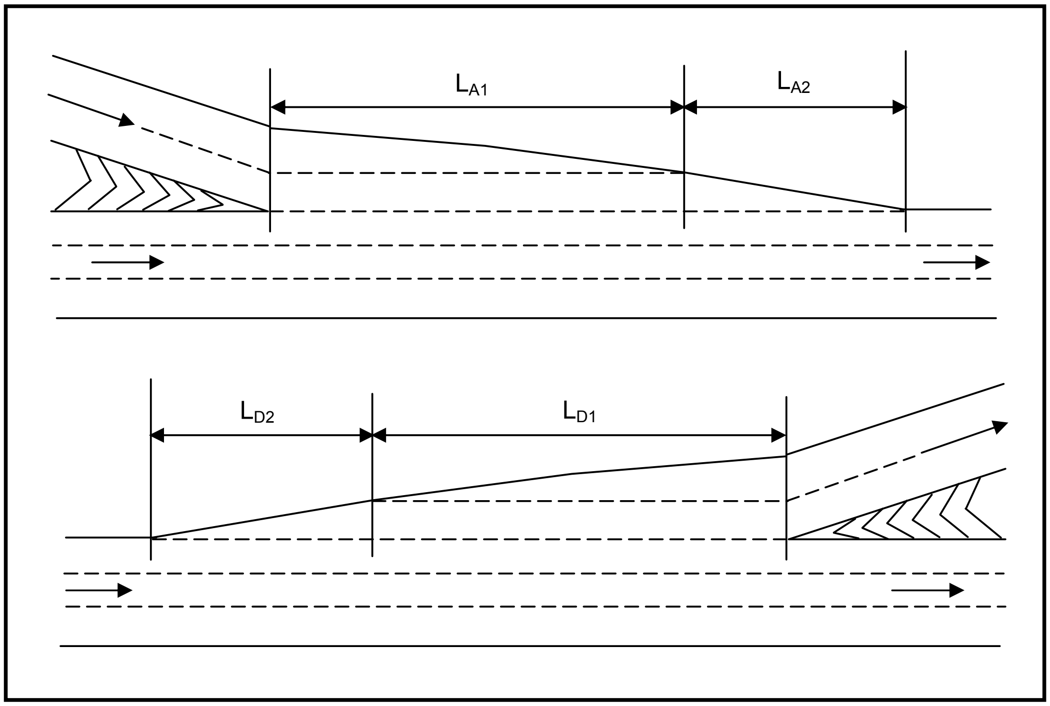


Figure 6.4: Illustration of length of two-lane acceleration lane and two-lane deceleration lane

For two-lane acceleration lane, length of acceleration lane, L_A is replaced by the effective length of the acceleration lane, L_{Aeff} as shown in equation (6.1).

$$L_{Aefff} = 2L_{A1} + L_{A2} \qquad (6.1)$$

Similarly for two-lane deceleration lane, length of deceleration lane, L_D is replaced by the effective length of the deceleration lane, L_{Deff} as shown in equation (6.2).

$$L_{Defff} = 2L_{D1} + L_{D2} \qquad (6.2)$$

6.2.2 OPERATIONAL CHARACTERISTICS

Ramp-expressway junction is regarded as an area of competing traffic demand for space and in truth the vehicle from the merging lane is competing for space with vehicle from the mainline and thus this creates conflicts in the merging area. In a merge area, individual on-ramp vehicles attempts to find gaps in the adjacent expressway lane traffic stream. Because most ramps are on the left side of the expressway, the expressway lane in which on-ramp vehicles seek gaps is designated as Lane 1. By convention, expressway lanes are numbered from 1 to N, from the left shoulder to the median. The action of individual merging vehicles entering the Lane 1 traffic stream creates turbulence in the vicinity of the ramp. Approaching expressway vehicles move toward the right to avoid this turbulence.

At off-ramps, the basic manoeuvre is a diverge, that is a single traffic stream separating into two streams. Exiting vehicles must occupy the lane adjacent to the off-ramp (Lane 1 for a left-hand off-ramp). Thus, as the off-ramp is approached, diverge vehicles move left. These effects a redistribution of other expressway vehicles, as they move right to avoid the turbulence of the immediate diverge area.

U.S. HCM 2000 defines that the basic approach in modelling the merge and diverge area is by focusing on the influence area of 450 m including the acceleration lane, Lane 1 and Lane 2 on the expressway. Although other expressway lanes may experienced some congestion due to merging or diverging operation, but U.S. HCM 2000 only considered the most critical part of the expressway merging activities to occur in the influence area of within 450 m, which will directly affect the level of service of the ramp. Flows entering ramp junctions on expressways, both at on-ramps and off-ramps cause turbulence to traffic from mainline.

Interactions are dynamic in ramp influence areas. Approaching expressway vehicles will move right as long as there is capacity to do so. Whereas the intensity of ramp flow influences the behaviour of expressway vehicles, general expressway congestion can also act to limit ramp flow, causing diversion to other interchanges or routes.

Figure 6.5 shows this influence area for on-ramp and off-ramp junctions.

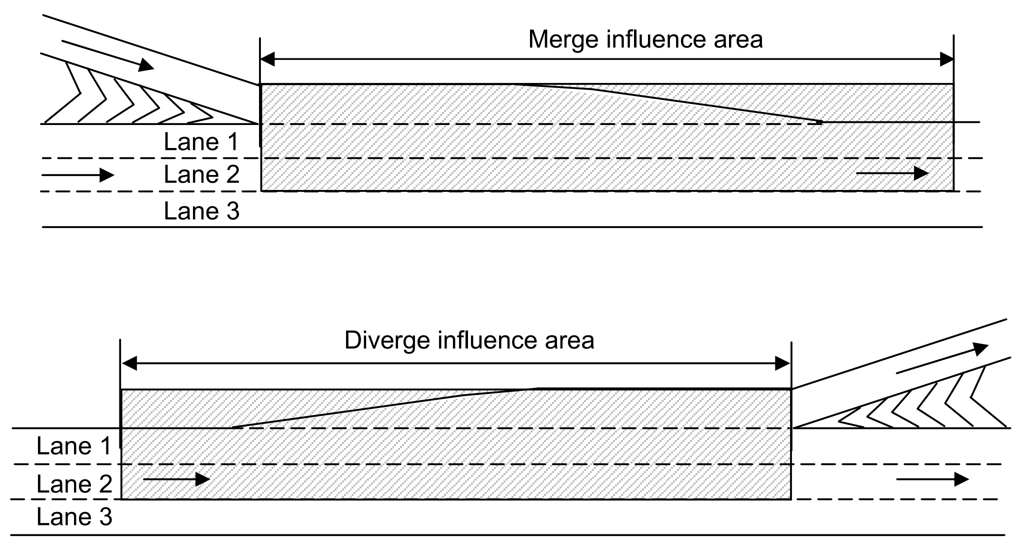
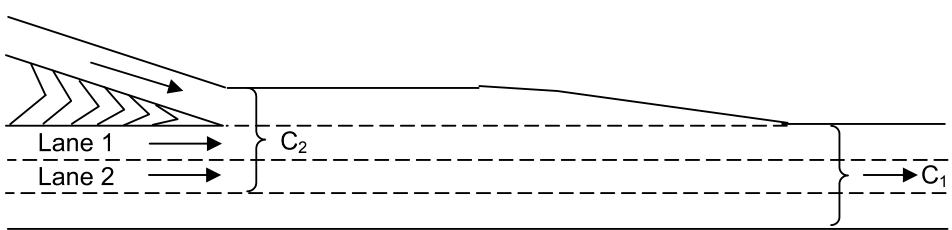


Figure 6.5: Influence areas for on-ramp and off-ramp junctions

6.2.3 CAPACITIES OF RAMP-EXPRESSWAY

For on-ramp, vehicles enter the expressway at a merge area, the total number of ramp and approaching expressway vehicles that can be accommodated is the capacity of the downstream basic expressway segment as shown in Figure 6.6.

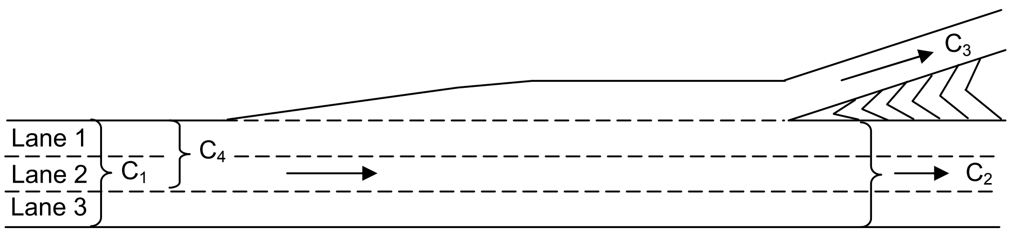


C_1 = Capacity of merge area, controlled by the capacity of the downstream basic segment expressway

C_2 = Maximum flow into the merge influence area

Figure 6.6: Capacity of merge areas

The total capacity that can be handled by the diverge junction is limited either by the capacity of the approaching (upstream) basic expressway segment or by the capacity of the downstream basic expressway segment and the ramp itself as shown in Figure 6.7.



C_1 = Upstream basic expressway capacity

C_2 = Total downstream capacity of the basic expressway

C_3 = Ramp flow rate

C_4 = Maximum expressway flow in Lanes 1 and 2 that may enter the diverge influence area

Total diverge capacity cannot be more than the upstream basic segment expressway capacity (C_1) or the total downstream capacity of the basic segment expressway (C_2) plus the ramp (C_3).

Figure 6.7: Capacity of diverge areas

As such, capacity value that affects the operation of ramp-expressway junction is the effective maximum number of expressway vehicles that can enter the ramp junction influence area without causing local congestion and local queuing. For on-ramps, the total entering flow in Lanes 1 and 2 of the expressway plus the on-ramp flow cannot exceed 4,600 pc/h. For off-ramps, the total entering flow in Lanes 1 and 2 of the expressway (which includes the off-ramp flow) cannot exceed 4,400 pc/h. Demands exceeding these values will cause local congestion and queuing. However, as long as demand does not exceed the capacity of the upstream or downstream expressway sections or the off-ramp, breakdown will normally not occur. Thus, this condition is not labelled as level of service (LOS) F, but rather at an appropriate level of service based on density in the section.

6.2.4 LEVEL OF SERVICE (LOS)

Levels of service in merge and diverge influence areas are defined in terms of density for all cases of stable operation, LOS A through E.

- LOS A represents unrestricted operations. Density is low enough to permit smooth merging and diverging with virtually no turbulence in the traffic stream.
- At LOS B, merging and diverging manoeuvres become noticeable to through drivers and minimal turbulence occurs. Merging drivers must adjust speeds to accomplish smooth transitions from the acceleration lane to the expressway.
- At LOS C, speed within the influence area begins to decline as turbulence levels become noticeable. Both ramp and expressway vehicles begin to adjust their speeds to accomplish smooth transitions.
- At LOS D, turbulence levels in the influence area become intrusive and virtually all vehicles slow to accommodate merging and diverging. Some ramp queues may form at heavily used on-ramps but expressway operation remains stable.
- LOS E represents conditions approaching capacity. Speeds reduce significantly and virtually all drivers feel turbulence. Flow levels approach capacity, small changes in demand or disruptions within the traffic stream can cause both ramp and expressway queues to form.
- LOS F exists when the demand exceeds the capacity of upstream or downstream expressway sections or the capacity of an off-ramp.

6.3 METHODOLOGY

The methodology to determine level of service or to carry out analysis involving the ramp-expressway is as shown in Figure 6.8.

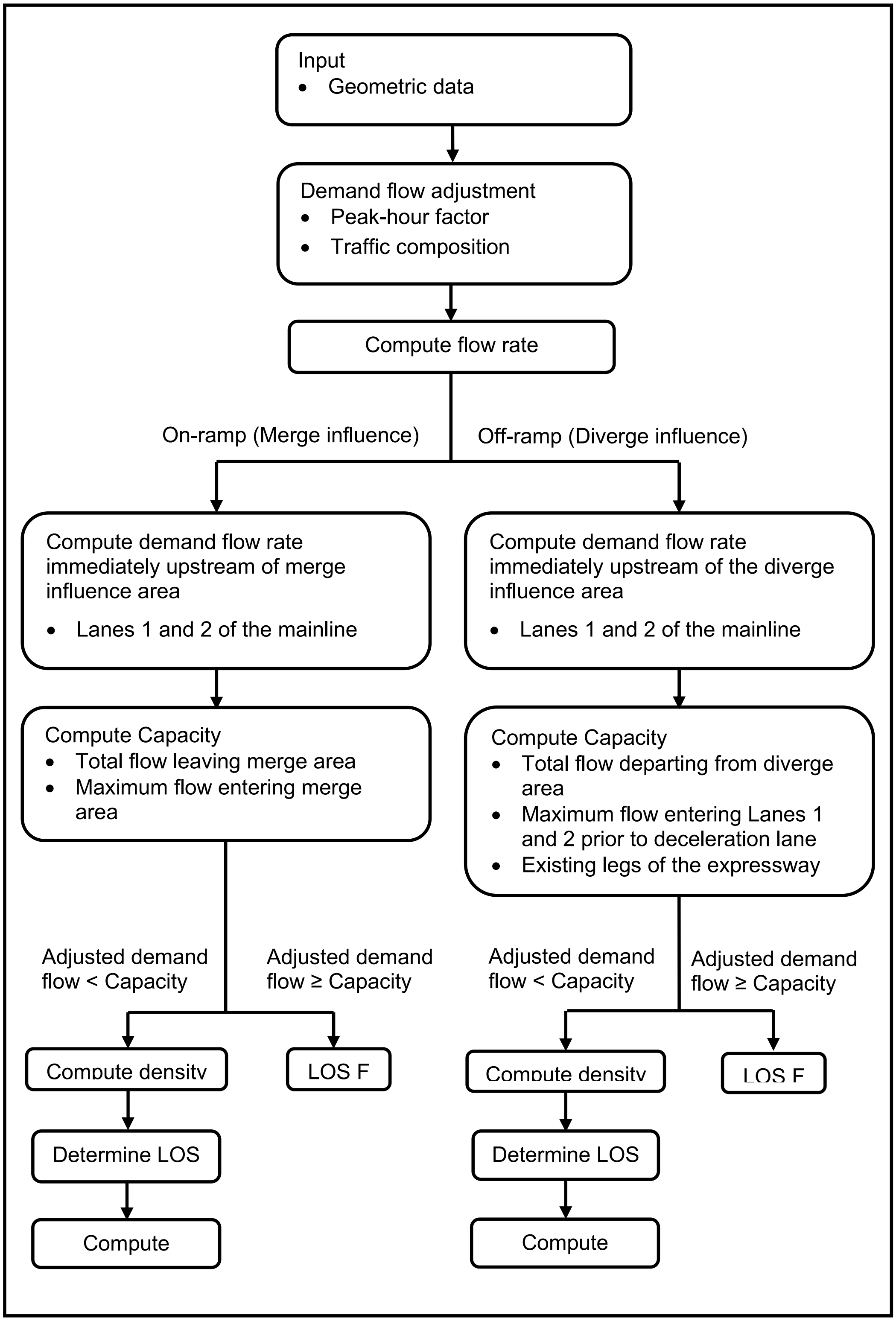


Figure 6.8: Ramp-expressway methodology

6.3.1 DETERMINING FLOW RATE

All equations in the analyses of ramp-expressway and LOS criteria are expressed in terms of equivalent maximum flow rates in passenger cars per hour during the peak 15-minutes of the hour of interest. Therefore, before any of these procedures are applied, all relevant expressway and ramp flows must be converted to equivalent pc/h during the peak 15-minutes of the hour.

For ramp-expressway, adjustment factors for demand flow rate are the same as those used for analysis of basic segment expressway. The adjustments are the peak hour factor and the traffic composition factor. The equation to estimate flow rate in passenger cars per hour during the peak 15-minutes of the hour of interest is as shown in equation (6.3).

$$v_i = \frac{V_i \times PHF}{f_C} \qquad (6.3)$$

Where

v_i	=	15-minutes passenger-car equivalent flow rate (pc/h/ln)
V_i	=	Hourly volume (veh/h)
PHF	=	Peak hour factor
f_C	=	Traffic composition

The equation to estimate peak hour factor for ramp-expressway is as shown in equation (6.4) and the recommended values for peak hour factor based on flow rate are as shown in Table 6.1.

$$PHF = \frac{2}{1 + e^{-2(0.001042V + 0.9098)}} - 1 \qquad (6.4)$$

Where

PHF	=	Peak hour factor
V	=	Traffic flow (pc/h)

Table 6.1: Recommended peak hour factor values based on flow rate for ramp-expressway

Flow (veh/h)	Peak hour factor
≤ 200	0.8070
300	0.8404
400	0.8685
500	0.8919
600	0.9113
700	0.9274
800	0.9407
900	0.9516
1000	0.9605
1100	0.9678
1200	0.9738
1300	0.9787
1400	0.9826
1500	0.9859
1600	0.9885
1700	0.9907
1800	0.9924
1900	0.9938
2000	0.9950
2100	0.9959
2200	0.9967
2300	0.9973
≥ 2400	0.9978

Table 6.2 shows the passenger car equivalents used for ramp-expressway based on Malaysian road conditions.

Table 6.2: Passenger car equivalents for ramp-expressway

Vehicle class	Vehicle type	Passenger car equivalents
Class 1	Cars/Small Vans/ Utilities	1.00
Class 2	Lorries (with 2 axles)/ Large Vans	1.47
Class 3	Large lorry, trailers, heavy vehicles with 3 axles and more	1.95
Class 4	Buses	1.66
Class 5	Motorcycles	0.63

Traffic composition factor can be calculated based on the passenger car equivalents shown in Table 6.8 by using equation (6.5).

$$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.63q_m}{q} \qquad (6.5)$$

Where

q_c	=	Flow in vehicles for car
q_l	=	Flow in vehicles for lorry
q_t	=	Flow in vehicles for trailer
q_b	=	Flow in vehicles for bus
q_m	=	Flow in vehicles for motor
q	=	Total flow ($\sum q_i$)

6.3.2 ON-RAMP

Critical variables for on-ramp junction are as shown in Figure 6.9.

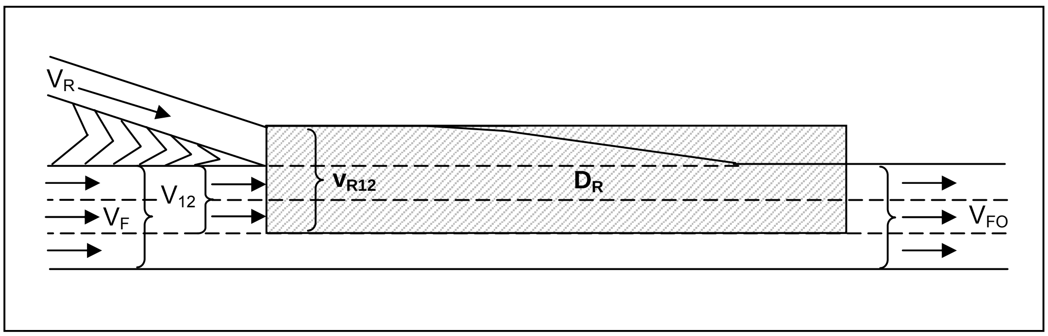


Figure 6.9: Critical variables for on-ramp junction

There are 3 major steps in determining the level of service of merge area of on-ramp-expressway which comprises of:

a) Determining v_{12} (flow rate in Lanes 1 and 2 of expressway immediately upstream of merge (pcu/h))

b) Determine the capacity within the merge influence area and compared with existing or forecast demand flows to determine the likelihood of congestion. Several capacity values are evaluated:

- Maximum total flow approaching a merge or diverge area on the expressway (v_F).
- Maximum total flow departing from a merge or diverge area on the expressway (v_{FO}).
- Maximum total flow entering the ramp influence area (v_{R12} for merge areas and v_{12} for diverge areas).
- Maximum flow on a ramp (v_R).

c) Determine the density of flow within the ramp influence area, D_R

For an on-ramp, the flow into the ramp influence area includes v_{12} and v_R. Thus, the total flow entering the ramp influence area is given in equation (6.6):

$$v_{R12} = v_{12} + v_R \quad (6.6)$$

While the total flows from merge area is determined by the equation (6.7):

$$v_{FO} = v_F + v_R \quad (6.7)$$

There will be two conditions which may occur in an analysis. First is the total departing expressway flow, v_{FO} may exceed the capacity of the downstream expressway segment which will be indicated by LOS F in which queues will form upstream of the merge segment.

The second condition is when the total flow entering the ramp influence area, v_{R12} exceeds its maximum desirable level but the total expressway flow does not exceed the capacity of the downstream expressway segment, v_{FO}. In this case, locally high densities are expected, but no queuing is expected on the expressway and LOS F is not expected to occur.

As such, when the downstream freeway capacity is exceeded, LOS F exists regardless of whether the flow rate entering the ramp influence area exceeds its capacity.

Table 6.3 shows the lists capacity flow rates for the total downstream expressway flow ($v_{FO} = v_F + v_R$) and maximum desirable values for the total flow entering the ramp influence area, v_{R12}.

Table 6.3: Capacity values for merge areas

Expressway free – flow speed (km/h)	Maximum downstream expressway flow, v_{FO} (pcu/h)				Maximum desirable flow entering influence area, v_{R12} (pcu/h)
	Number of lanes in one direction				
	2	3	4	>4	
120	4900	7350	9800	2450/ln	4600
110	4700	7050	9400	2350/ln	4600
100	4500	6750	9000	2250/ln	4600
90	4300	6450	8600	2150/ln	4600
80	4100	6150	8200	2050/ln	4600
70	3900	5850	7800	1950/ln	4600

The criteria use to determine level of service for an on-ramp junction is based on density within the ramp influence area. As such, the equations to estimate density within the merge influence area for one-lane on-ramp and two-lane on-ramp are provided in this manual. Equation (6.8) and equation (6.9) show the equations to estimate density for undersaturated flow conditions for one-lane on-ramp and two-lane on-ramp respectively.

One-lane on-ramp:

$$D_R = 3.389 + 0.003369\ v_{12} + 0.005860\ v_R - 0.006397\ L_A \quad (6.8)$$

Where

D_R = Density of flow within the ramp influence area (pc/km/ln)

v_{12} = Flow rate in Lanes 1 and 2 of expressway immediately upstream of merge (pcu/h). For four-lane expressways (two lanes in each direction), only Lanes 1 and 2 exist, and v_{12}= v_F by definition.

L_A = Length of acceleration lane (m)

Two-lane on-ramp:

$$D_R = 11.785 + 0.001396\ v_{12} + 0.0001687\ v_R - 0.01536\ L_{Aeff} \quad (6.9)$$

Where

D_R = Density of flow within the ramp influence area (pc/km/ln)

v_{12} = Flow rate in Lanes 1 and 2 of expressway immediately upstream of merge (pcu/h).

= $369.914 + 0.627\ v_F - 0.140\ L_A$

v_F = Flow rate on a ramp (pc/h)

L_{Aeff} = Effective length of acceleration lane (m)

6.3.3 OFF-RAMP

The analysis procedures for diverge areas follow the same general approach as that for merge areas. The same three fundamental steps are as follows:

1. Determining the approaching expressway flow in Lanes 1 and 2 of the expressway, v_{12} (pcu/h)
2. Determine the capacity of the segment (v_F and v_{12})
3. Determine the density of flow within the ramp influence area, D_R

The general model specifies that v_{12} consists of the off-ramp flow, v_R plus a proportion of the approaching expressway flow, v_F. For four-lane expressway, this is a trivial relationship since all approaching flow is in Lanes 1 and 2. Figure 6.10 shows the critical variables for off-ramp junction.

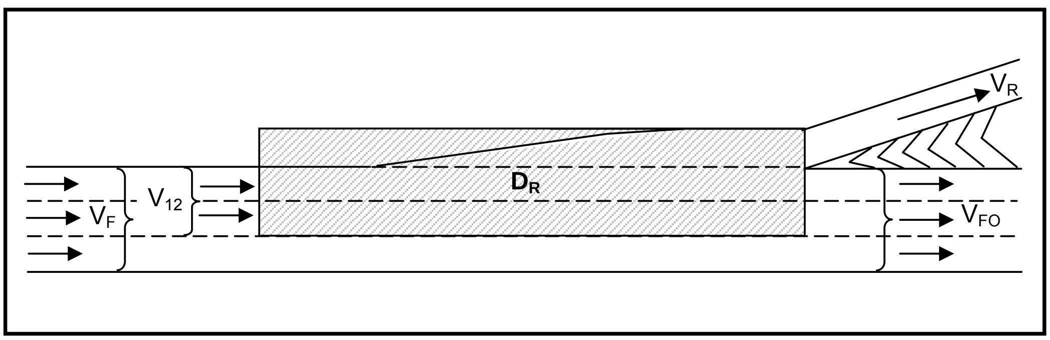


Figure 6.10: Critical variables for off-ramp junction

The three limiting values that should be checked in a diverge area are the total flow that can depart from the diverge, the capacities of the departing expressway leg or legs or ramp or both and the maximum flow that can enter on Lanes 1 and 2 just prior to the deceleration lane. In a diverge area, the total flow that can depart is generally limited by the capacity of the expressway lanes approaching the diverge. Table 6.3 lists the capacity values for this flow.

The second limit is the most important, since it is the primary reason that diverge areas fail. Failure at a diverge is often related to the capacity of one the exit legs, most often the ramp. The capacity of each exit leg must be checked against expected flow. For a downstream expressway leg (at a major diverge area, there may two of these), capacity values may be obtained from Table 6.4 for the appropriate number of expressway lanes. For off-ramp roadways, capacity values are provided in Table 6.5.

Table 6.4: Capacity values for diverge areas

Expressway free – flow speed (km/h)	Maximum upstream, V_{FI} or downstream expressway flow, V (pcu/h)				Maximum flow entering influence area, v_{12} (pcu/h)
	Number of lanes in one direction				
	2	3	4	>4	
120	4900	7350	9800	2450/ln	4400
110	4700	7050	9400	2350/ln	4400
100	4500	6750	9000	2250/ln	4400
90	4300	6450	8600	2150/ln	4400
80	4100	6150	8200	2050/ln	4400
70	3900	5850	7800	1950/ln	4400

Table 6.5: Approximate capacity of ramp roadways

Free-flow speed of ramp (km/h)	Capacity (pc/h)	
	One-lane ramps	Two-lane ramps
> 80	2200	4400
> 65 – 80	2100	4100
> 50 – 65	2000	3800
> 30 – 50	1900	3500
< 30	1800	3200

However, when the total flow approaching the diverge influence area, v_{12} exceeds its maximum desirable level but total demand flows are within all other capacity values, some locally high densities would be expected but stable flow is maintained. Failure of the diverge segment (LOS F) is expected if any of the following conditions is found:

- Capacity of the upstream expressway segment is exceeded by total arriving demand flow
- Capacity of the downstream expressway segment is exceeded by the demand flow proceeding on the downstream expressway
- Capacity of the off-ramp is exceeded by the off-ramp demand flow

The same criteria of density are used to determine the level of service for off-ramp junctions. Equation to estimate density within the diverge influence for undersaturated flow conditions for one-lane off-ramp is provided equation (6.10) and equation (6.11) show the equations to estimate density for two-lane off-ramp for undersaturated flow conditions.

One-lane off-ramp:

$$D_R = 21.977 + 0.006901\, v_{12} - 0.1007\, L_D \tag{6.10}$$

Where

D_R = Density of flow within the diverge influence area (pc/km/ln)

v_{12} = Approaching expressway flow in Lanes 1 and 2 of the expressway (pcu/h). For four-lane expressways (two lanes in each direction), only Lanes 1 and 2 exist, and v_{12}= v_F by definition.

L_D = Length of deceleration lane (m)

Two-lane off-ramp:

$$D_R = 6.924 + 0.001513\, v_{12} - 0.005531\, L_{Deff} \tag{6.11}$$

Where

D_R = Density of flow within the diverge influence area (pc/km/ln)

v_{12} = Approaching expressway flow in Lanes 1 and 2 of the expressway (pcu/h)

= $248.276 + 0.6483\, v_F - 0.01082\, v_R$

v_F = Maximum total flow approaching the diverge area on the expressway (pc/h)

v_R = Flow rate on the ramp (pc/h)

L_{Deff} = Effective length of deceleration lane (m

6.3.4 DETERMINING LEVEL OF SERVICE (LOS)

The measure of effectiveness for ramp-expressways is density of flow within the influence area. Density is computed only when demand flows are within the specified capacity values. Density is not calculated when capacity is exceeded. Thus, when demand flows exceed the specified capacity values, LOS F is automatically applied. The LOS criteria for merge and diverge ramps are as shown in Table 6.6.

Table 6.6: Level of service criteria for merge and diverge ramps

LOS	Density (pc/km/ln)
A	≤ 6
B	> 6 – 12
C	> 12 – 17
D	> 17 – 22
E	> 22
F	Demand exceeds capacity

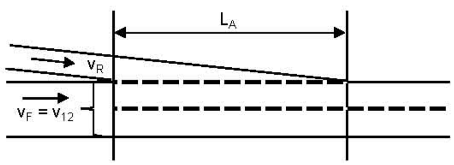
6.3 WORKSHEETS

RAMPS (FOUR-LANE EXPRESSWAYS) WORKSHEET

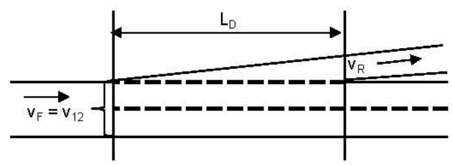
General Information

Analyst	________	Highway	________
Agency or Company	________	From/To	________
Date Performed	________	Jurisdiction	________
Analysis Time Period	________	Analysis Year	________

☐ On-ramp ☐ Off-ramp



FFS expressway = ______ km/h
FFS ramp = ______ km/h
L_A = ______ m



FFS expressway = ______ km/h
FFS ramp = ______ km/h
L_D = ______ m

Traffic composition

Expressway volume		Ramp volume	
Total cars, q_c(veh/h)		Total cars, q_c(veh/h)	
Total lorries, q_l (veh/h)		Total lorries, q_l (veh/h)	
Total trailers, q_t (veh/h)		Total trailers, q_t (veh/h)	
Total buses, q_b (veh/h)		Total buses, q_b (veh/h)	
Total motorcycles, q_m (veh/h)		Total motorcycles, q_m (veh/h)	
Total volume, V_F (veh/h)		Total volume, V_R (veh/h)	

Conversion to pc/h under base condition

	Flow (veh/h)	$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{V}$	PHF (Table 6.1)	$v_i = \frac{V_i \times f_c}{PHF}$
v_F				
v_R				

Merge Areas

Estimation of V_{12}

$v_{12} = v_F$

v_{12} = ____________ pc/h

Capacity checks

	Actual	Maximum	LOS F?
$v_{FO} = v_F + v_R$		(Table 6.3)	
$v_{R12} = v_R + v_{12}$		4600: All	

Level of services determination (if not F)

$D_R = 3.389 + 0.003369\, v_{12} + 0.005860\, v_R - 0.006397\, L_A$

D_R = ____________ pc/km/ln
LOS = ____________

Diverge Areas

Estimation of V_{12}

$v_{12} = v_F$

v_{12} = ____________ pc/h

Capacity checks

	Actual	Maximum	LOS F?
$v_{FI} = v_F$		(Table 6.4)	
v_{12}		4400: All	
$v_{FO} = v_F - v_R$		(Table 6.4)	
v_R		(Table 6.5)	

Level of services determination (if not F)

$D_R = 21.977 + 0.006901\, v_{12} - 0.1007\, L_D$

D_R = ____________ pc/km/ln
LOS = ____________

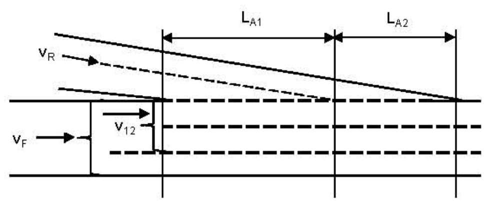
LOS	Density (pc/km/ln)
A	≤ 6
B	> 6 — 12
C	> 12 – 17
D	> 17 – 22
E	> 22
F	Demand exceeds capacity

RAMPS (SIX-LANE EXPRESSWAYS) WORKSHEET

General Information

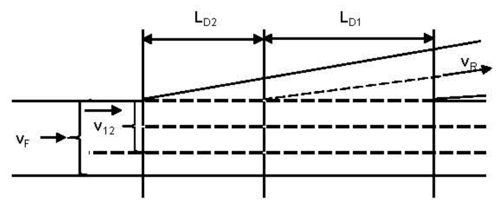
Analyst		Highway (Exit No.)	
Agency or Company		From/To	
Date Performed		Jurisdiction	
Analysis Time Period		Analysis Year	

☐ On-ramp



L_{A1} = ______ m FFS expressway = ______ km/h
L_{A2} = ______ m FFS ramp = ______ km/h
$L_{Aeff} = 2\ L_{A1} + L_{A2}$ = ______ m

☐ Off-ramp



L_{D1} = ______ m FFS expressway = ______ km/h
L_{D2} = ______ m FFS ramp = ______ km/h
$L_{Deff} = 2\ L_{D1} + L_{D2}$ = ______ m

Traffic composition

Expressway volume		Ramp volume	
Total cars, q_c(veh/h)		Total cars, q_c(veh/h)	
Total lorries, q_l (veh/h)		Total lorries, q_l (veh/h)	
Total trailers, q_t (veh/h)		Total trailers, q_t (veh/h)	
Total buses, q_b (veh/h)		Total buses, q_b (veh/h)	
Total motorcycles, q_m (veh/h)		Total motorcycles, q_m (veh/h)	
Total volume, V_F (veh/h)		Total volume, V_R (veh/h)	

Conversion to pc/h under base condition

	Flow (veh/h)	$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{V}$	PHF (Table 6.1)	$v_i = \frac{V_i \times f_c}{PHF}$
v_F				
v_R				

Merge Areas

Estimation of V_{12}

$$v_{12} = 369.914 + 0.627\ v_F - 0.140\ L_{Aeff}$$

v_{12} = ______ pc/h

Capacity checks

	Actual	Maximum	LOS F?
$v_{FO} = v_F + v_R$		(Table 6.3)	
$v_{R12} = v_R + v_{12}$		4600: All	

Level of services determination (if not F)

$$D_R = 11.785 + 0.001396\ v_{12} + 0.0001687\ v_R - 0.01536\ L_{Aeff}$$

D_R = ______ pc/km/ln
LOS = ______

Diverge Areas

Estimation of V_{12}

$$v_{12} = 248.276 + 0.6483\ v_F - 0.01082\ v_R$$

v_{12} = ______ pc/h

Capacity checks

	Actual	Maximum	LOS F?
$v_{FI} = v_F$		(Table 6.4)	
v_{12}		4400: All	
$v_{FO} = v_F - v_R$		(Table 6.4)	
v_R		(Table 6.5)	

Level of services determination (if not F)

$$D_R = 6.924 + 0.001513\ v_{12} - 0.005531\ L_{Deff}$$

D_R = ______ pc/km/ln
LOS = ______

LOS	Density (pc/km/ln)
A	≤ 6
B	> 6 –– 12
C	> 12 – 17
D	> 17 – 22
E	> 22
F	Demand exceeds capacity

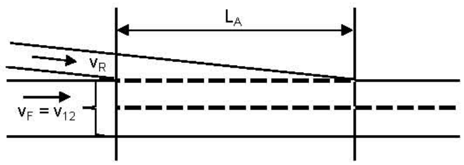
6.4 SAMPLE CALCULATION

RAMPS (FOUR-LANE EXPRESSWAYS) WORKSHEET

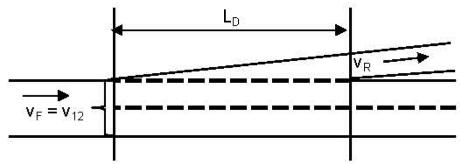
General Information

Analyst	JKL	Highway (Exit No.)	E1 (Exit 128)
Agency or Company	USM	From/To	Sungkai to Bidor
Date Performed	13/12/2011	Jurisdiction	
Analysis Time Period	AM	Analysis Year	2011

[/] On-ramp | [ ] Off-ramp



FFS expressway = 120 km/h
FFS ramp = 65 km/h
L_A = 225 m



FFS expressway = ______ km/h
FFS ramp = ______ km/h
L_D = ______ m

Traffic composition

Expressway volume		Ramp volume	
Total cars, q_c(veh/h)	1100	Total cars, q_c(veh/h)	313
Total lorries, q_l (veh/h)	600	Total lorries, q_l (veh/h)	112
Total trailers, q_t (veh/h)	400	Total trailers, q_t (veh/h)	80
Total buses, q_b (veh/h)	90	Total buses, q_b (veh/h)	17
Total motorcycles, q_m (veh/h)	310	Total motorcycles, q_m (veh/h)	28
Total volume, V_F (veh/h)	2500	Total volume, V_R (veh/h)	550

Conversion to pc/h under base condition

	Flow (veh/h)	$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{V}$	PHF (Table 6.1)	$v_i = \frac{V_i \times f_c}{PHF}$
v_F	2500	1.2464	0.999	3119
v_R	550	1.2370	0.902	754

Merge Areas

Estimation of V_{12}

$v_{12} = v_F$

v_{12} = 3119 pc/h

Capacity checks

	Actual	Maximum	LOS F?
$v_{FO} = v_F + v_R$	3873	(Table 6.3)	No
$v_{R12} = v_R + v_{12}$	3873	4600: All	No

Level of services determination (if not F)

$D_R = 3.389 + 0.003369\ v_{12} + 0.005860\ v_R - 0.006397\ L_A$

D_R = 16.9 pc/km/ln
LOS = **C**

Diverge Areas

Estimation of V_{12}

$v_{12} = v_F$

v_{12} = ______ pc/h

Capacity checks

	Actual	Maximum	LOS F?
$v_{FI} = v_F$		(Table 6.4)	
v_{12}		4400: All	
$v_{FO} = v_F - v_R$		(Table 6.4)	
v_R		(Table 6.5)	

Level of services determination (if not F)

$D_R = 21.977 + 0.006901\ v_{12} - 0.1007\ L_D$

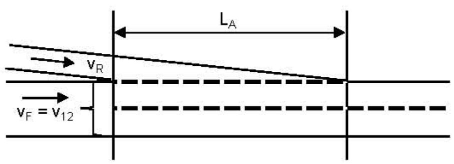
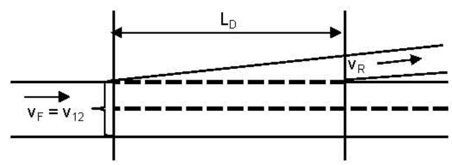
D_R = ______ pc/km/ln
LOS = ______

LOS	Density (pc/km/ln)
A	≤ 6
B	> 6 — 12
C	> 12 – 17
D	> 17 – 22
E	> 22
F	Demand exceeds capacity

RAMPS (FOUR-LANE EXPRESSWAYS) WORKSHEET

General Information

Analyst	JKL	Highway (Exit No.)	E1 (Exit 128)
Agency or Company	USM	From/To	Sungkai to Slim River
Date Performed	13/12/2011	Jurisdiction	
Analysis Time Period	AM	Analysis Year	2011

☐ On-ramp	☑ Off-ramp
	
FFS expressway = ____ km/h FFS ramp = ____ km/h L_A = ____ m	FFS expressway = 120 km/h FFS ramp = 60 km/h L_D = 300 m

Traffic composition

Expressway volume		Ramp volume	
Total cars, q_c(veh/h)	2000	Total cars, q_c(veh/h)	210
Total lorries, q_l (veh/h)	750	Total lorries, q_l (veh/h)	100
Total trailers, q_t (veh/h)	400	Total trailers, q_t (veh/h)	45
Total buses, q_b (veh/h)	50	Total buses, q_b (veh/h)	10
Total motorcycles, q_m (veh/h)	300	Total motorcycles, q_m (veh/h)	35
Total volume, V_F (veh/h)	3500	Total volume, V_R (veh/h)	400

Conversion to pc/h under base condition

	Flow (veh/h)	$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{V}$	PHF (Table 6.1)	$v_i = \frac{V_i \times f_c}{PHF}$
v_F	3500	1.1896	0.999	4168
v_R	400	1.2111	0.869	557

Merge Areas	Diverge Areas
Estimation of V_{12}	**Estimation of V_{12}**
$v_{12} = v_F$ v_{12} = ____ pc/h	$v_{12} = v_F$ v_{12} = 4168 pc/h

Capacity checks (Merge)

	Actual	Maximum	LOS F?
$v_{FO} = v_F + v_R$		(Table 6.3)	
$v_{R12} = v_R + v_{12}$		4600: All	

Capacity checks (Diverge)

	Actual	Maximum	LOS F?
$v_{FI} = v_F$	4168	(Table 6.4)	No
v_{12}	4168	4400: All	No
$v_{FO} = v_F - v_R$	3610	(Table 6.4)	No
v_R	557	(Table 6.5)	No

Level of services determination (if not F)

Merge	Diverge
$D_R = 3.389 + 0.003369\, v_{12} + 0.005860\, v_R - 0.006397\, L_A$	$D_R = 21.977 + 0.006901\, v_{12} - 0.1007\, L_D$
D_R = ____ pc/km/ln	D_R = 20.5 pc/km/ln
LOS = ____	LOS = **D**

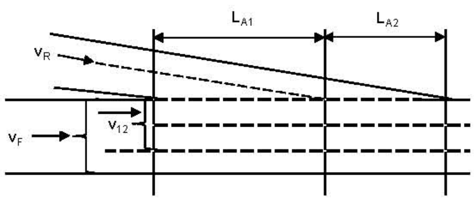
LOS	Density (pc/km/ln)
A	≤ 6
B	> 6 — 12
C	> 12 – 17
D	> 17 – 22
E	> 22
F	Demand exceeds capacity

RAMPS (SIX-LANE EXPRESSWAYS) WORKSHEET

General Information

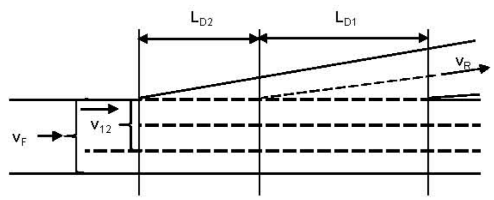
Analyst	JKL	Highway (Exit No.)	E1 (Exit 102)
Agency or Company	USM	From/To	Setia Alam to Bukit Raja)
Date Performed	13/12/2011	Jurisdiction	
Analysis Time Period	AM	Analysis Year	2011

[/] On-ramp



L_{A1} = 150 m FFS expressway = 120 km/h
L_{A2} = 120 m FFS ramp = 70 km/h
$L_{Aeff} = 2 L_{A1} + L_{A2}$ = 420 m

[ ] Off-ramp



L_{D1} = ____ m FFS expressway = ____ km/h
L_{D2} = ____ m FFS ramp = ____ km/h
$L_{Deff} = 2 L_{D1} + L_{D2}$ = ____ m

Traffic composition

Expressway volume		Ramp volume	
Total cars, q_c(veh/h)	2500	Total cars, q_c(veh/h)	420
Total lorries, q_l (veh/h)	700	Total lorries, q_l (veh/h)	260
Total trailers, q_t (veh/h)	350	Total trailers, q_t (veh/h)	125
Total buses, q_b (veh/h)	100	Total buses, q_b (veh/h)	25
Total motorcycles, q_m (veh/h)	300	Total motorcycles, q_m (veh/h)	120
Total volume, V_F (veh/h)	3950	Total volume, V_R (veh/h)	950

Conversion to pc/h under base condition

	Flow (veh/h)	$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{V}$	PHF (Table 6.1)	$v_i = \frac{V_i \times f_c}{PHF}$
v_F	3950	1.1584	0.999	4580
v_R	950	1.2281	0.956	1220

Merge Areas

Estimation of V_{12}

$$v_{12} = 369.914 + 0.627\, v_F - 0.140\, L_{Aeff}$$

v_{12} = 3183 pc/h

Capacity checks

	Actual	Maximum	LOS F?
$v_{FO} = v_F + v_R$	5800	(Table 6.3)	No
$v_{R12} = v_R + v_{12}$	4403	4600: All	No

Level of services determination (if not F)

$$D_R = 11.785 + 0.001396\, v_{12} + 0.0001687\, v_R - 0.01536\, L_{Aeff}$$

D_R = 10.0 pc/km/ln
LOS = **B**

Diverge Areas

Estimation of V_{12}

$$v_{12} = 248.276 + 0.6483\, v_F - 0.01082\, v_R$$

v_{12} = ____ pc/h

Capacity checks

	Actual	Maximum	LOS F?
$v_{FI} = v_F$		(Table 6.4)	
v_{12}		4400: All	
$v_{FO} = v_F - v_R$		(Table 6.4)	
v_R		(Table 6.5)	

Level of services determination (if not F)

$$D_R = 6.924 + 0.001513\, v_{12} - 0.005531\, L_{Deff}$$

D_R = ____ pc/km/ln
LOS = ____

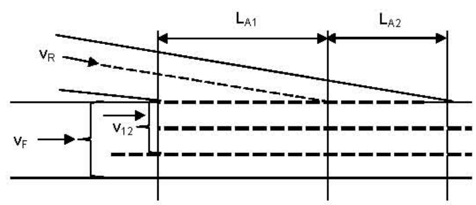
LOS	Density (pc/km/ln)
A	≤ 6
B	> 6 -– 12
C	> 12 – 17
D	> 17 – 22
E	> 22
F	Demand exceeds capacity

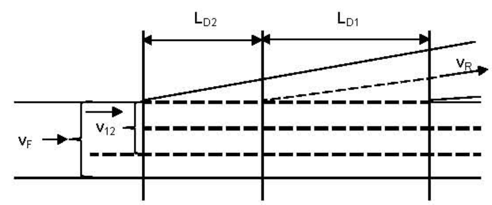
RAMPS (SIX-LANE EXPRESSWAYS) WORKSHEET

General Information

Analyst	JKL	Highway (Exit No.)	E1 (Exit 102)
Agency or Company	USM	From/To	Bukit Raja to Setia Alam
Date Performed	13/12/2011	Jurisdiction	
Analysis Time Period	AM	Analysis Year	2011

☐ On-ramp ☑ Off-ramp





On-ramp		Off-ramp	
L_{A1} = ____ m	FFS expressway = ____ km/h	L_{D1} = 120 m	FFS expressway = 120 km/h
L_{A2} = ____ m	FFS ramp = ____ km/h	L_{D2} = 60 m	FFS ramp = 70 km/h
$L_{Aeff} = 2 L_{A1} + L_{A2}$ = ____ m		$L_{Deff} = 2 L_{D1} + L_{D2}$ = 300 m	

Traffic composition

Expressway volume		Ramp volume	
Total cars, q_c(veh/h)	3600	Total cars, q_c(veh/h)	250
Total lorries, q_l (veh/h)	850	Total lorries, q_l (veh/h)	70
Total trailers, q_t (veh/h)	545	Total trailers, q_t (veh/h)	45
Total buses, q_b (veh/h)	100	Total buses, q_b (veh/h)	10
Total motorcycles, q_m (veh/h)	450	Total motorcycles, q_m (veh/h)	35
Total volume, V_F (veh/h)	5545	Total volume, V_R (veh/h)	410

Conversion to pc/h under base condition

	Flow (veh/h)	$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{V}$	PHF (Table 6.1)	$v_i = \frac{V_i \times f_c}{PHF}$
v_F	5545	1.1497	0.999	6382
v_R	410	1.1716	0.871	551

Merge Areas	Diverge Areas
Estimation of V_{12}	**Estimation of V_{12}**
$v_{12} = 369.914 + 0.627\ v_F - 0.140\ L_{Aeff}$	$v_{12} = 248.276 + 0.6483\ v_F - 0.01082\ v_R$
v_{12} = ____ pc/h	v_{12} = 4380 pc/h

Capacity checks (Merge Areas)

	Actual	Maximum	LOS F?
$v_{FO} = v_F + v_R$		(Table 6.3)	
$v_{R12} = v_R + v_{12}$		4600: All	

Capacity checks (Diverge Areas)

	Actual	Maximum	LOS F?
$v_{FI} = v_F$	6382	(Table 6.4)	No
v_{12}	4380	4400: All	No
$v_{FO} = v_F - v_R$	5830	(Table 6.4)	No
v_R	551	(Table 6.5)	No

Level of services determination (if not F)	Level of services determination (if not F)
$D_R = 11.785 + 0.001396\ v_{12} + 0.0001687\ v_R - 0.01536\ L_{Aeff}$	$D_R = 6.924 + 0.001513\ v_{12} - 0.005531\ L_{Deff}$
D_R = ____ pc/km/ln	D_R = 11.9 pc/km/ln
LOS = ____	LOS = **B**

LOS	Density (pc/km/ln)
A	≤ 6
B	> 6 –– 12
C	> 12 – 17
D	> 17 – 22
E	> 22
F	Demand exceeds capacity

6.4 CALCULATION STPES

RAMP EXPRESSWAYS (FOUR-LANE ON-RAMP EXPRESSWAYS) STEP CALCULATION	
1. All input parameters are known and insert into the worksheet.	
2. Compute traffic composition.	$Vi = q_c + q_l + q_t + q_b + q_m$ **Expressway** V_F = 1100+600+400+90+310 = 2500 veh/h **Ramp** V_R = 313+112+80+17+28 = 550 veh/h
3. Determine traffic composition.	$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{Vi}$ **Expressway** $f_c = \frac{1100 + 1.47(600) + 1.95(400) + 1.66(90) + 0.66(310)}{2500} = 1.2464$ **Ramp** $f_c = \frac{313 + 1.47(112) + 1.95(80) + 1.66(17) + 0.66(28)}{550} = 1.2370$
4. Find the peak hour factor (use Table 6.1).	**Expressway** PHF = 0.999 **Ramp** PHF = 0.902
5. Compute flow rate.	$v_i = \frac{Vi \times f_c}{PHF}$ **Expressway** $v_F = \frac{2500 \times 1.2464}{0.999} = 3119$ pc/h **Ramp** $v_R = \frac{550 \times 1.2370}{0.924} = 754$ pc/h
6. Compute v_{12}.	$v_{12} = v_F$ v_{12} = 3119 pc/h
7. Check capacity of downstream segment (Table 6.3 shows 4900 pc/h).	$v_{FO} = v_F + v_R$ v_{FO} = 3119 + 736 = 3873 pc/h
8. Check maximum flow entering influence area (Table 6.3 shows 4600 pc/h).	$v_{R12} = v_R + v_{12}$ v_{R12} = 736 + 3119 = 3873 pc/h
9. Compute density.	$D_R = 3.389 + 0.003369v_{12} + 0.005860v_R - 0.006397L_A$ D_R = 3.389 + 0.003369(3119) + 0.005860(736) - 0.006397(225) = 16.9 pc/km/ln
10. Determine LOS (use table LOS given in worksheet).	**LOS C**

RAMP EXPRESSWAYS (FOUR-LANE OFF-RAMP EXPRESSWAYS) STEP CALCULATION	
1. All input parameters are known and insert into the worksheet.	
2. Compute traffic composition .	$Vi = q_c + q_l + q_t + q_b + q_m$ **Expressway** V_F = 2000+750+400+50+300 = 3500 veh/h **Ramp** V_R = 210+100+45+10+35 = 400 veh/h
3. Determine traffic composition.	$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{Vi}$ **Expressway** $f_c = \frac{2000 + 1.47(750) + 1.95(400) + 1.66(50) + 0.66(300)}{3500} = 1.1896$ **Ramp** $f_c = \frac{210 + 1.47(100) + 1.95(45) + 1.66(10) + 0.66(35)}{400} = 1.2111$
4. Find the peak hour factor (use Table 6.1).	**Expressway** PHF = 0.999 **Ramp** PHF = 0.869
5. Compute flow rate.	$v_i = \frac{Vi \times f_c}{PHF}$ **Expressway** $v_F = \frac{3500 \times 1.1896}{0.999}$ = 4168 pc/h **Ramp** $v_R = \frac{400 \times 1.2111}{0.888}$ = 557 pc/h
6. Compute v_{12} .	$v_{12} = v_F$ v_{12} = 4168 pc/h
7. Check capacity of upstream segment (Table 6.4 shows 4900 pc/h).	v_F = 4168 pc/h
8. Check maximum flow entering diverge influence area (Table 6.4 shows 4400 pc/h).	v_{12} = 4168 pc/h
9. Check capacity of downstream segment (Table 6.4 shows 4900 pc/h).	$v_{FO} = v_F - v_R$ v_{FO} = 4168 - 546 = 3610 pc/h
10. Check capacity of off-ramp (Table 6.5 shows 2000 pc/h).	v_R = 557 pc/h
11. Compute density.	$D_R = 21.977 + 0.006901v_{12} - 0.1007L_D$ D_R = 21.977 + 0.006901(4168) - 0.1007(300) = 20.5 pc/km/ln
12. Determine LOS (use table LOS given in worksheet).	**LOS D**

RAMP EXPRESSWAYS (SIX-LANE ON-RAMP EXPRESSWAYS) STEP CALCULATION	
1. All input parameters are known and insert into the worksheet.	
2. Compute traffic composition.	$Vi = q_c + q_l + q_t + q_b + q_m$ **Expressway** V_F = 2500+700+350+100+300 = 3950 veh/h **Ramp** V_R = 420+260+125+25+120 = 950 veh/h
3. Determine traffic composition.	$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{Vi}$ **Expressway** $f_c = \frac{2500 + 1.47(700) + 1.95(350) + 1.66(100) + 0.66(300)}{3950} = 1.1584$ **Ramp** $f_c = \frac{420 + 1.47(260) + 1.95(125) + 1.66(25) + 0.66(120)}{950} = 1.2281$
4. Find the peak hour factor (use Table 6.1).	**Expressway** PHF = 0.999 **Ramp** PHF = 0.956
5. Compute flow rate.	$v_i = \frac{Vi \times f_c}{PHF}$ **Expressway** $v_F = \frac{3950 \times 1.1584}{0.999} = 4580$ pc/h **Ramp** $v_R = \frac{950 \times 1.2281}{0.956} = 1220$ pc/h
6. Compute v_{12} .	$v_{12} = 369.914 + 0.627v_F - 0.140L_A$ v_{12} = 369.914 + 0.627(4580) - 0.140(420) = 3183 pc/h
7. Check capacity of downstream segment (Table 6.3 shows 7350 pc/h).	$v_{FO} = v_F + v_R$ v_{FO} = 4580 + 1220 = 5800 pc/h
8. Check maximum flow entering influence area (Table 6.3 shows 4600 pc/h).	$v_{R12} = v_R + v_{12}$ v_{R12} = 1220 + 3183 = 4403 pc/h
9. Compute density.	$D_R = 11.785 + 0.001396v_{12} + 0.0001687v_R - 0.01536L_A$ D_R = 11.785 + 0.001396(3183) + 0.0001687(1220) - 0.01536(420) = 10.0 pc/km/ln
10. Determine LOS (use table LOS given in worksheet).	**LOS B**

RAMP EXPRESSWAYS (FOUR-LANE OFF-RAMP EXPRESSWAYS) STEP CALCULATION	
1. All input parameters are known and insert into the worksheet.	
2. Compute traffic composition .	$Vi = q_c + q_l + q_t + q_b + q_m$ **Expressway** V_F = 3600+850+545+100+450 = 5545 veh/h **Ramp** V_R = 250+70+45+10+35 = 410 veh/h
3. Determine traffic composition.	$f_c = \frac{q_c + 1.47q_l + 1.95q_t + 1.66q_b + 0.66q_m}{Vi}$ **Expressway** $f_c = \frac{3600 + 1.47(850) + 1.95(545) + 1.66(100) + 0.66(450)}{5545} = 1.1497$ **Ramp** $f_c = \frac{250 + 1.47(70) + 1.95(45) + 1.66(10) + 0.66(35)}{410} = 1.1716$
4. Find the peak hour factor (use Table 6.1).	**Expressway** PHF = 0.999 **Ramp** PHF = 0.871
5. Compute flow rate.	$v_i = \frac{Vi \times f_c}{PHF}$ **Expressway** $v_F = \frac{5545 \times 1.1497}{0.999}$ = 6382 pc/h **Ramp** $v_R = \frac{410 \times 1.1716}{0.871}$ = 551 pc/h
6. Compute v_{12} .	$v_{12} = 248.276 + 0.6483_{VF} - 0.01082_{VR}$ v_{12} = 248.276 + 0.6483(6382) - 0.01082(551) = 4380 pc/h
7. Check capacity of upstream segment (Table 6.4 shows 7350 pc/h).	v_F = 6382 pc/h
8. Check maximum flow entering diverge influence area (Table 6.4 shows 4400 pc/h).	v_{12} = 4380 pc/h
9. Check capacity of downstream segment (Table 6.4 shows 7350 pc/h).	$v_{FO} = v_F - v_R$ v_{FO} = 6382 - 551 = 5830 pc/h
10. Check capacity of off-ramp (Table 6.5 shows 4100 pc/h).	v_R = 551 pc/h
11. Compute density.	$D_R = 6.924 + 0.001513v_{12} - 0.005531L_D$ D_R = 6.924 + 0.001513(4380) - 0.005531(300) = 11.9 pc/km/ln
12. Determine LOS (use table LOS given in worksheet).	**LOS B**

REFERENCES

REFERENCES

Ahmed, U. (2010). Passenger car equivalent factors for level freeway segments operating under moderate and congested condition. Unpublished master's thesis, Faculty of the Graduate School, Marquette University.

Akcelik, R. (1981). Traffic signals: capacity and timing analysis. *Research Report ARRB, 123*, Australian Road Research Board, Melbourne, Australia, 12–22.

Albanese, M., Camus, R., & Longo, G. (2003). Capacity and queue modeling for on-ramp-freeway junctions. *Transportation Research Record, 185,* 256-264.

Al-Kaisy, A., & Durbin, C. (2008). Evaluating new methodologies for estimating performance on two-lane highways. *Canadian Journal of Civil Engineering, 35*, 777-785.

Al-Kaisy, A., & Karjala, S. (2008). Indicators of performance on two-lane rural highway. *Journal of the Transportation Research Board*, *2088*, 87-97.

Bang, K. L., Carlsson, A., & Palgunadi. (1996). Development of speed-flow relationships for Indonesian rural roads using empirical data and simulation. *Transportation Research Record, 1484*, 24-32.

Botma, H. (1986). Traffic operation on busy two-lane rural roads in the Netherlands. *Transportation Research Record, 1091,* TRB, National Research Council, Washington, D.C., 126-131.

Burris, M., & Patil, S. (2008). Measuring the marginal cost of congestion. Texas: University System College Station.

Daganzo, C. (2000). Fundamentals of transportation and traffic operations. *Elsevier Science*.

Direktorat Jenderal Bina Marga. (1997). Indonesian Highway Capacity Manual (IHCM). Jakarta, Indonesia.

Dixon, K. K., Wu, C. H., Sarasua, W., & Daniel, J. (1999). Posted and free flow speed for rural multilane highways in Georgia. *Journal of Transportation Engineering*, *125*, 487- 494.

Dixon, M. P., Sarepali, S. S. K., & Young, K. A. (2002). Field evaluation of highway capacity manual 2000 analysis procedures for two-lane highways. *Transportation Research Record: Journal of the Transportation Research Board, 1802*, 125-132.

Dowling, R., Kittelson, W., Zegeer, J., & Skabardonis, A. (1997). Planning techniques to estimate speeds and service volumes for planning applications. *Transportation Research Board, 387*.

Drake, J. S., Schofer, J. L., & May, J. A. D. (1967). A statistical analysis of speed density hypotheses. *Transportation Research Board, 154*, 53-87.

Edigbe, J. B. (2009). Application of pce values in capacity and los analysis. Paper presented at the 13th REAAA Conference, 3rd International Road & Traffic EXPO, PIARC Council Meeting, Songdo ConvensiA, Incheon, Korea.

Fan, H. (1990). Passenger car equivalents for vehicles on Singapore expressways. *Transportation Research, 24*(5), 391-396.

Galin, D. (1981). Speeds on two-lane rural roads – a multiple regression analysis. *Traffic Engineering & Control*, 453-460.

Garber, N. J., & Hoel, L. A. (2001). *Traffic and highway engineering (*3rd ed*.),* California: Brooks/Cole.

Ghani, A. R., Ibrahim, W. H., & Sadullah, A. F. (1996). Penentuan hubungan laju-aliran lalu lintas jalan arteri. *Jurnal Kejuruteraan*, 117-133.

Guell, D. L., & Virkler, M. R. (1988). Capacity analysis of two-lane highways. *Transportation Research Record, 1194,* TRB, National Research Council, Washington, D.C., 199-205.

Hablas, H. E. (2007). A study of inclement weather impacts on freeway free-flow speed. Unpublished master's thesis, Faculty of the Virginia Polytechnic Institute and State University.

Harwood, D. W., & Hoban, C. J. (1987). Low-cost methods for improving traffic operations on two-lane roads: informational guide*. Report FHWA-IP-87-2*, FHWA U.S. Department of Transportation.

Harwood, D. W., May, A. D., Anderson, I. B., Leiman, L., & Archilla, A. R. (1999). Capacity and quality of service of two-lane highways. National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Midwest Research Institute, University of California-Berkeley.

Highway Planning Unit (2006). Road Traffic Volume Malaysia (2006). Ministry of Works Malaysia.

Hoban, C. J. (1986). Planning and design of rural roads: observations on a year in America. *Research Report AAR No. 140,* Australian Road Research Board.

Ibrahim, A.T., & F.L. Hall. (1994). Effect of adverse weather conditions on speed-flow-occupancy relationships. *Transportation Research Record, 1457,* Transportation Research Board, Washington, D.C.

Ingle, A. (2004). Development of passenger car equivalents for basic freeway segments. Unpublished master's thesis, Faculty of the Virginia Polytechnic Institute and State University.

Johnson, G. P. (199*5).* Proceedings of the 65th Annual Meeting, Institute of Transportation Engineers: *1985 highway capacity manual misses mark on rural highway capacity.*

Kaisy, A. F. (2006). Passenger car equivalents for heavy vehicles at freeways and multilane highway: some critical issues. Unpublished master's thesis, Faculty of the Virginia Polytechnic Institute and State University.

Kaisy, A. F., Hall, F. L., & Reisman, E. S. (2001). Developing passenger car equivalents for heavy vehicles on freeways during queue discharger flow.

Karjala, S. R. (2008). Estimating quality of traffic flow on two-lane highways. Unpublished master's thesis, Montana State University.

Kittichai. (2006). Development of a model to predict proportion of vehicles entering merge influence areas at freeway ramp junctions. *Thammasat Int. J. Sc. Tech, 11*(3).

Kou, C. C., & Machemehl, R. B. (1997). Modeling vehicle acceleration-deceleration behaviour during merge maneuvers. *Can. J. Civ. Eng., 24*, 350 – 358.

Krammes, R. A., & Crowley, K. W. (1986). Passenger car equivalents for trucks on level freeway segments. *Transportation Research Record*, *1091*, 10-17.

Krumins, I. (1991). Two-lane highway capacity and level of service research project: phase III final report. *Transportation Association of Canada.*

Kyte, M., Khatib, Z., Shannon, P., & Kitchener, F. (2000). Effect of environmental factors on free-flow speed. *Transportation Research Circular E-C018: 4th International Symposium on Highway Capacity*, 108-119.

Lan, C. J., Abia, S. D., & Chimba, D. (2001).Determining peak hour factor for capacity analysis. *Journal of Transportation Engineering,* 520-526.

Lu, H. C. (2003). Estimating the emission source reduction of PM_{10} in central Taiwan*. Journal of Chemosphere, 54*, 805-814.

Luttinen, R. T. (1992). Statistical properties of vehicle time headways. *Transportation Research Record, 1365,* TRB, National Research Council, Washington, D.C*.,* 92-98*.*

Luttinen, R. T. (2000). Level of service on finnish two-lane highways. *Transportation Research Circular E-C018: 4th International Symposium on Highway Capacity, 2000*, TRB, Washington, D.C., 175-187.

Luttinen, R. T. (2001). Percent time-spent-following as performance measure for two-lane highways. *Transportation Research Record: Journal of the Transportation Research Board, 1776***,** 52-59.

Luttinen, R. T. (2002). Uncertainty in operational analysis of two-lane highways. *Transportation Research Board of the National Academies, Highway Operations, Capacity and Traffic Control, 1802,* 105-114.

Mathew, T. V., & Rao, K. V. K. (2007). Traffic stream models. *Introduction to Transportation Engineering, 33*, 33.1-33.5.

Mclean, J. (1998). The effects of width standard on two lane speed – flow capacity. *Road and Transport Research, 7*(3).

Medina, A. M. F., & Tarko, A. P. (2005). Speed factors on two-lane rural highways in free flow conditions. *Transportation Research Record 1912*, 39-46.

Mingjun, L., Keping, L., Xiaohui, D., & Kaiyang, W. (2007). Implementation and validity of the free flow speed model of on freeway. International Conference on Transportation Engineering 2007, 3452-3457.

Ministry of Works Malaysia. (1986). Arahan Teknik (Jalan) 8/86: A guide on geometric design of roads. Kuala Lumpur, Malaysia.

Ministry of Works Malaysia. (1996). Traffic Study for Malaysia

Muhammad Akram Adnan. (2007). Development of entrance ramp merging density model based on urban expressway traffic condition. Unpublished PhD's thesis, Universiti Sains Malaysia.

Nix, S. J. (1994). Urban modelling and transportation. Boca Raton, FL: Lewis Publishers.

Othman Che Puan. (2004). Driver's car following headway on single carriageway roads. *Jurnal Kejuruteraan Awam*, *16*(2), 15-27.

Polus, A., & Cohen, M. (2009). Theoretical and empirical relationships for the quality of flow and for a new level of service on two-lane highways. *Journal of Transportation Engineering, 135*, 380-385.

Pursula, M., & Enberg, A. (1991). Characteristics and level-of-service estimation on two-lane rurals in Finland. *Transportation Research Record, 1320*, 135-143.

Road Engineering Association of Malaysia (2002) REAM – GL 2/2002: A guide on geometric design of roads. Kuala Lumpur.

Robertson, H. D., Hummer, J. E., & Nelson, D. C. (1994). *Manual of transportation engineering studies,* U.S.A: Prentice Hall.

Staplin, L., Gish, K. W., Decina, L. E., Lococo, K. H., Harkey, D. L. & Tarawneh, M. S. (1997). Synthesis of human factors research on older drivers and highway safety. *Human factors and highway safety research synthesis, 2*, retrieved 2 July 2010, from http://ntl.bts.gov/DOCS/97095/ch02/ch02_01.html

Tiwari, G., Fazio, J., & Pavitravas, S. (2000). Passenger car units for heterogeneous traffic using a modified density method. *Transportation Research Circular E-C018,* 246-257.

Transportation Research Board (1985). Highway Capacity Manual: Special Report 209 (1985). National Research Council, Washington, D.C.

Transportation Research Board (1994). Highway Capacity Manual: Special Report 209, (3rd Ed.). National Research Council, Washington, D.C.

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

Tseng, P. Y., Shieh, S. L., & Lin, F.B. (2005). Estimation of free flow speeds for multilane rural and suburban highways. *Journal of the Eastern Asia Society for Transportation Studies, 6,* 1484 – 1495.

Wang, H., Li, J., Chen, Q.Y., & Ni. D. (2009). Speed-density relationship: from deterministic to stochastic. *Transportation Research Board 88th Annual Meeting*, Washington D. C.

Wardrop, J. G. (1952). Some theoretical aspects of road traffic research. *Proceedings of the Institute of Civil Engineers, 1-2*, 325-378.

Washburn, S. S., McLeod, D. S., & Courage, K. G. (2002). Adaptation of highway capacity manual 2000 for planning-level analysis of two-lane and multilane highways in Florida. *Transportation Research Record, 1802*, 62-68.

Werner, A., & Morrall, J.F. (1976). Passenger car equivalencies of trucks, buses and recreational vehicles for two-lane rural highways. *Transportation Research Record, 615*, 10-17.

Yagar, S. M., & Van Aerde (1983). Geometry and environment effects on speeds of two lane highways. *Transportation Research Part A: Policy and Practices, 17A(4)*, 315-325.

Yi, H., & Mulinazzi, T.E. (2007). Urban freeway on-ramps-invasive influence on main-line operations. *California Department of Transportation*, 112-119.

Yu, Q., & Washburn S. S. (2009). Operation performance assessment for two-lane highway facilities. *Journal of Transportation Engineering, 135*(4), 197-205.

GLOSSARY

GLOSSARY

Acceleration lane - A paved auxiliary lane, including tapered areas, allowing vehicles to accelerate when entering the through-traffic lane of the roadway.

Access point - An intersection, driveway or opening on the left-hand side of a roadway. An entry on the opposite side of a roadway or a median opening also can be considered as an access point if it is expected to influence traffic flow significantly in the direction of interest.

Access point density - The total number of access points on a roadway divided by the length of the roadway.

Adjustment - An additive or subtractive quantity that adjusts a parameter for a base condition to represent a prevailing condition.

Adjustment factor - A multiplicative factor that adjusts a parameter for a base condition to represent a prevailing condition.

Average travel speed - The length of the highway segment divided by the average travel time of all vehicles traversing the segment.

Base condition - The best possible characteristic in terms of capacity for a given type of transportation facility; that is, further improvements would not increase capacity; a condition without hindrances or delays.

Basic segment expressway - A length of expressway facility whose operations are unaffected by weaving, diverging, or merging.

Bottleneck - A road element on which demand exceeds capacity.

Breakdown - The onset of a queue development on an expressway facility.

Capacity - The maximum sustainable flow rate at which vehicles are reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period under given roadway, geometric, traffic, environmental, and control conditions; usually expressed as vehicles per hour or passenger cars per hour.

Center lane - The highway or expressway lane adjacent and between outer lane to the left and inner lane to the right.

Congestion - A traffic condition in which the arrival flow rate exceeds capacity.

Deceleration lane - A paved auxiliary lane, including tapered areas, allowing vehicles leaving the through-traffic lane of the roadway to decelerate.

Demand - The number of users desiring service on the highway system, usually expressed as vehicles per hour or passenger cars per hour.

Density - The number of vehicles on a highway segment averaged over space, usually expressed as vehicles per kilometer or vehicles per kilometer per lane.

Design speed - A speed used to design the horizontal and vertical alignments of a highway.

Directional flow rate - The flow rate of a highway in one direction.

Directional segment - A length of two-lane highway in one travel direction, with homogeneous cross sections and relatively constant demand volume and vehicle mix.

Diverge - A movement in which a single lane of traffic separates into two lanes without the aid of traffic control devices.

Downstream - The direction of traffic flow.

Empirical model - A model that describes system performance based on the statistical analysis of field data.

Expressway facility - An aggregation of sections comprising mid section of expressway, ramp segments, and weaving segments.

Facility - A length of highway composed of connected sections, segments, and points.

Fixed obstruction - Obstructions along a roadway, including light poles, signs, trees, abutments, bridge rails, traffic barriers, and retaining walls.

Flow rate - The equivalent hourly rate at which vehicles pass a point on a lane, roadway, or other traffic way; computed as the number of vehicles passing the point, divided by the time interval (usually less than one hour) in which they pass; expressed as vehicles per hour.

Free-flow - Flow of traffic unaffected by upstream or downstream conditions.

Free-flow speed - (1) The theoretical speed of traffic, in kilometers per hour, when density is zero, that is, when no vehicles are present;
(2) The average speed of passenger cars over a basic segment expressway or multilane highway segment under conditions of low volume;
(3) Speed of vehicle when the vehicle movement is not interfered by other vehicle or interrupted by control devices.

General terrain - A classification used for analysis in lieu of a specific grade.

Geometric condition - The spatial characteristics of a facility, including shoulder width, lane width, access point, interchange, median clearance and unpaved width.

Headway - (1) The time, in seconds, between two successive vehicles as they pass a point on the roadway, measured from the same common feature of both vehicles (for example, the front axle or the front bumper);
(2) The time, usually expressed in seconds, between the passing of the front ends of successive vehicle moving along the same lane in the same direction.

Inner lane - The highway or expressway lane adjacent to the median.

Interchange density - The average number of interchanges per kilometer, computed for 10 km of expressway including basic segment expressway.

Inter-urban - The area connecting between two urban areas.

Lane width - The arithmetic mean of the lane widths of a roadway in one direction, expressed in meters.

Lateral clearance - The left- and right-side clearance from the outside edge of travel lanes to fixed obstructions on a highway.

Level of service - A qualitative measure describing operational conditions within a traffic stream, based on service measures such as speed and travel time, freedom to maneuver, traffic interruptions, comfort, and convenience.

Level terrain - A combination of horizontal and vertical alignments that permits heavy vehicles to maintain approximately the same speed as passenger cars; this generally includes short grades of no more than 1 to 2 percent.

Mainline - The primary through roadway as distinct from ramps, auxiliary lanes, and collector-distributor roads.

Median - The area, which separates opposing lanes of traffic and it may contain landscaping, planted trees, a median barrier, or be simply paved.

Merge - Movements in which two separate lanes of traffic combine to form a single lane without the aid of traffic signals or other right-of-way controls.

Multilane highway - A highway with at least two lanes for the exclusive use of traffic in each direction, with no control or partial control of access.

No-passing zone - A segment of a two-lane, two-way highway along which passing is prohibited in one or both directions.

Off- ramp - A ramp for traffic to depart from an expressway.

On- ramp - A ramp that allows traffic to enter an expressway.

Outer lane - The highway or expressway lane adjacent to the shoulder.

Passenger car equivalent - The number of passenger cars displaced by a single heavy vehicle of a particular type under specified roadway, traffic, and control conditions.

Peak hour factor - The hourly volume during the maximum-volume hour of the day divided by the peak 15-minute flow rate within the peak hour; a measure of traffic demand fluctuation within the peak hour.

Percent time-spent-following - The average percent of total travel time that vehicles must travel in platoons behind slower vehicles due to inability to pass on a two-lane highway.

Performance measure - A quantitative or qualitative characteristic describing the quality of service provided by a transportation facility or service.

Platoon - a group of vehicles or pedestrians travelling together as a group, either voluntarily or involuntarily because of signal control, geometrics or other factors.

Prevailing condition - The geometric, traffic, and control conditions during the analysis period.

Queue discharge flow - A traffic flow that has passed through a bottleneck and is accelerating to the free-flow speed of the expressway.

Ramp - A short segment of roadway connecting two traffic facilities.

Ramp junction - A short segment of highway along which vehicles transfer from an on-ramp to the main roadway or from the main roadway to an off-ramp.

Roadway characteristic - A geometric characteristic of a street or highway, including the type of facility, number and width of lanes (by direction), shoulder widths and lateral clearances, design speed, and horizontal and vertical alignments.

Rural - An area with widely scattered development and a low density of housing and employment.

Segment - A portion of a facility on which a capacity analysis is performed; it is the basic unit for the analysis, a one-directional distance. A segment is defined by two endpoints.

Shoulder - A portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles, emergency use, and lateral support of the sub-base, base, and surface courses.

Space mean speed - (1) The harmonic mean of speeds over a length of roadway; (2) An average speed based on the average travel time of vehicles to traverse a segment of roadway; in kilometers per hour.

Specific grade - A single grade of a roadway segment or extended roadway segment expressed in percentage.

Speed - A rate of motion expressed as distance per unit of time.

Suburban - An area with a mixture of densities for housing and employment, where high-density nonresidential development is intended to serve the local community.

Time mean speed - The arithmetic average of individual vehicle speeds passing a point on a roadway or lane, in kilometers per hour.

Traffic condition - A characteristic of traffic flow, including distribution of vehicle types in the traffic stream, directional distribution of traffic, lane use distribution of traffic, and type of driver population on a given facility.

Travel speed - The average speed, in kilometers per hour, of a traffic stream computed as the length of a highway segment divided by the average travel time of the vehicles traversing the segment.

Travel time - The average time spent by vehicles traversing a highway segment, including control delay, in seconds per vehicle or minutes per vehicle.

Two-lane highway - A roadway with a two-lane cross section, one lane for each direction of flow, on which passing maneuvers must be made in the opposing lane.

Uncongestion - A traffic condition in which the arrival flow rate is lower than the capacity or the service flow rate at a point or uniform segment of a lane or roadway.

Uninterrupted flow - A category of facilities that have no fixed causes of delay or interruption external to the traffic stream; examples include expressway and unsignalized sections of multilane and two-lane rural highways.

Upstream - The direction from which traffic is flowing.

Volume - The number of vehicles passing a point on a lane, roadway, or other traffic-way during some time interval, often one hour, expressed in vehicles per hour.

Volume to capacity ratio - The ratio of flow rate to capacity for a transportation facility.