EXTENT OF TRAFFIC SHOCKWAVE PROPAGATION INDUCED BY MIDBLOCK U-TURN FACILITIES

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ABSTRACT

The aim of study is to determine the extent of traffic shockwave propagations induced by midblock U-turn facilities. Based on the hypothesis that shockwave would result from U-turning at midblock facility, 24 hour data were collected which is volume and speed at two sites in FT005 Skudai – Pontian highway, Malaysia. The two sites are denoted as site A and site B. The study of highway capacity is the most important part in the identification of road performance. Any change made at the roadway for example installing a midblock U-turn facilities would result in highway capacity loss.There are mainly three causes of capacity loss which are due to the road condition itself, due to ambient and due to the traffic operation. When capacity loss happen, it would lead to traffic shockwaves. Traffic shockwave is a motion of propagation of a change in density and flow.When shockwaves happen, it would lead to reduction of roadway level of service. Speed, fow and density for with and without midblock U-turn facility are estimated using Greenshields Model. All data was collected using Automatic Traffic Counters (ATC). Shockwave velocity propagation with and without midblock U-turn facility were estimated by determining and comparing the capacity and density of roadway. Direct empirical capacity estimation methods are use to estimate capacity of roadway. Results shows that there is significant shockwave velocity propagation happen on the exit of the U-turn midblock facility which is about -35.1 km/hr. While a minor shockwave happens at the approaching of the U-turn. This study concluded that midblock U-turn facilities will induce traffic shockwave that may lead to road accidents.

ABSTRAK

Tujuan kajian adalah untuk menentukan tahap gelombang kejutan trafik berlaku disebabkan oleh blok kemudahan pusingan-U. Berdasarkan pada hipotesis bahawa gelombang kejutan trafik akan berlaku disebabkan blok kemudahan pusingan-U, 24 jam data telah dikumpul iaitu isipadu dan kelajuan pada dua tapak di FT005 lebuhraya Skudai – Pontian, Malaysia. Tapak ditandakan sebagai tapak A dan tapak B. Kajian kapasiti lebuh raya adalah bahagian yang paling penting dalam pengenalpastian prestasi jalan raya. Sebarang perubahan yang dibuat di jalan, contohnya memasang satu blok kemudahan pusingan-U, akan mengakibatkan kehilangan kapasiti. Terdapat tiga punca kehilangan kapasiti iaitu disebabkan oleh keadaan jalan raya itu sendiri, persekitaran dan operasi trafik. Apabila kehilangan kapasiti berlaku, ia akan membawa kepada gelombang kejutan trafik. Gelombang kejutan trafik adalah perubahan dalam ketumpatan dan aliran. Apabila gelombang kejutan trafik berlaku, ia akan membawa kepada pengurangan tahap perkhidmatan jalan. Kelajuan, aliran, dan ketumpatan untuk dengan adanya kemudahan pusingan-U dan tanpanya dianggarkan menggunakan Model Greenshields. Semua data telah diambil menggunakan cerapan traffic automatik (ATC).

Halaju gelombang kejutan trafik dengan dan tanpa kemudahan pusingan-U dianggarkan dengan menentukan dan membandingkan kapasiti dan ketumpatan jalan. Empirikal langsung adalah kaedah penganggaran kapasiti yang digunakan untuk menganggar kapasiti jalan. Keputusan menunjukkan bahawa terdapat halaju gelombang kejutan trafik yang ketara berlaku pada laluan keluar kemudahan pusingan-U iaitu -35.1km/jam. Manakala, kelajuan gelombang kejutan trafik yang kecil berlaku di laluan menghampiri kemudahan pusingan-U. Kesimpulanya, blok kemudahan pusingan-U akan mendorong gelombang kejutan trafik yang membawa kepada kemalangan jalan raya.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS/ ABBREVIATIONS

AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
ATC	Automatic Traffic Count
HCM	Highway Capacity Manual
HGV	Heavy Good Vehicle
hr	Hour
JKR	Jabatan Kerja Raya / Public Work Department
k	Density
k_c	Critical Density
k_j	Jam Density
km	Kilometer
p.c.u	Passenger Car Unit
Q	Capacity
q	Flow
q_{max}	Maximum Flow
R^2	Regression
SSD	Stopping Sight Distance

u	Speed
u_f	Free Flow Speed
u_c	Optimum Speed
veh	Vehicle

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Traffic congestion problem and excessive traffic delays that is happening all around the world on urban and suburban multilane highways may due to the ineffective installation of traffic signal control system. In recent years, there has been major interest in "access management" as a new reaction to this situation. Based on TRB (2003), access management refers to the design, implementation, and management of entry and exit points between roadways and adjacent properties. Access management calls for improvements in access control, spacing, and design to preserve the functional integrity of the road system (Koepke & Levinson, 1992). One of the access management strategies is to prohibit the left turn movements at unsignalized driveways and the deterred traffic will be forced to make a U-Turn.

The clear advantage of prohibiting right turns at midblock driveways is an immediate increase in safety by the reduction in crashes. A study in California, United States which is applying right-hand traffic stated that by simplifying driving tasks could significantly reduce the crash rate (Vargas & Gautam, 1989). Other than can reduce the number of conflict points between road users it also provide smoother, more reliable, and potentially higher travel speeds for arterial traffic.

As for Malaysia which has left-hand traffic, the approach is to prohibit the right turn movements by allowing the left turning movements only. This approach often coupled with provision of midblock U-turns in the downstream to accommodate the right turning traffic. This system is called the left turn U-turn (LTUT) system. The most common factors that influence the decision of this approach are the volume on the roadway and crash rates involving fatality at the site is high.

A quantitative assessment of traffic stream which is roadway capacity is based on the relationship of flow, speed and density. According to TRB (2000), the capacity of a facility is defined as the maximum hourly flow rate at which vehicles can reasonably be expected to traverse a point or section of a roadway under prevailing roadway, traffic and control conditions. By knowing the capacity of the roadway, we can do improvements to the roadway design and also traffic management.

Due to the midblock U-turn on downstream, it would create the phenomenon of backups and queuing on a highway due to a sudden reduction of the capacity of the highway which is known as a bottleneck condition. The sudden reduction in capacity could be due to a crash, reduction in the number of lanes, restricted bridge sizes, work zones, a signal turning red and so forth (Nicholas J. Garber & Hoel, 2009). Any change made on the roadway for example installing midblock U-turn facilities would result in highway capacity loss. Not only changes of roadway geometry is the only factor of highway capacity loss, the traffic conditions and also the ambient condition like dry and wet condition also contribute to highway capacity loss. When capacity loss happens, it would lead to traffic shockwaves.

Traffic Shockwave is a motion of propagation of a change in density and flow. Where traffic stream is moving at a speed in close proximity and lead vehicle driver step on the brake, if the follow up driver lose their nerves on sighting the brake lights, abrupt braking will trigger shockwaves (Johnnie Ben-Edigbe & Mashros, 2011). A driver is influenced mostly by motion of vehicles downstream of him or her. The shockwave speed is conventionally represented by the rate of change in volume and density (Lighthill & Whitham, 1955; Richards, 1956). When shockwaves happen, it would lead to reduction of roadway level of service.

1.2 Problem of Statement

Over the past few decades, there have begun considering the use of U-turn as an alternatives to direct left turn for the right-hand traffic and direct right turn for the left-hand traffic. The driving side depends on the country itself. Past studies have indicate that direct left turn maneuvers increase delay, conflicts, and crashes, and they reduce capacity and mobility in the major traffic stream and stated that the access management which providing a right turn followed by U-turns (RTUT) system gives many advantages like reducing the conflict points at the intersections.

Somehow, there are also arguments have been raised by some opponents of median modification projects, that the increase number of U-turning vehicles may result in safety and operational problems on multilane highways. Presently, there is a lack of information especially on the extant of traffic shockwave propagation induced by highway midblock U-turn facilities based on empirical research for Malaysia multilane highway condition.

1.3 Aim and Objectives

The aim of this study is to determine the extent of traffic shock wave propagations induced by highway midblock U-Turn facilities, and the objectives of this are:

i. Estimate flow and density for road section.
ii. Estimate and compare traffic flow for road section with and without midblock U-turn facility.
iii. Estimate and compare density for road section with and without midblock U-turn facility.
iv. Determine shockwave speed for road section.

1.4 Scope of Study

This study is focused on the determining the shockwave propagations of highway midblock U-turn facilities at FT005, Skudai – Pontian highway as shown in Figure 1.1. In achieving the capacity and shockwaves associated with midblock U-turn, the method covered in this study are direct empirical methods which are directed at estimation of capacity values at a specific site with traffic observations from site. The study relied on fundamental diagrams of traffic stream where flow is a function of speed multiply by density. The data collection is taken 24 hours per day for 3 weeks.

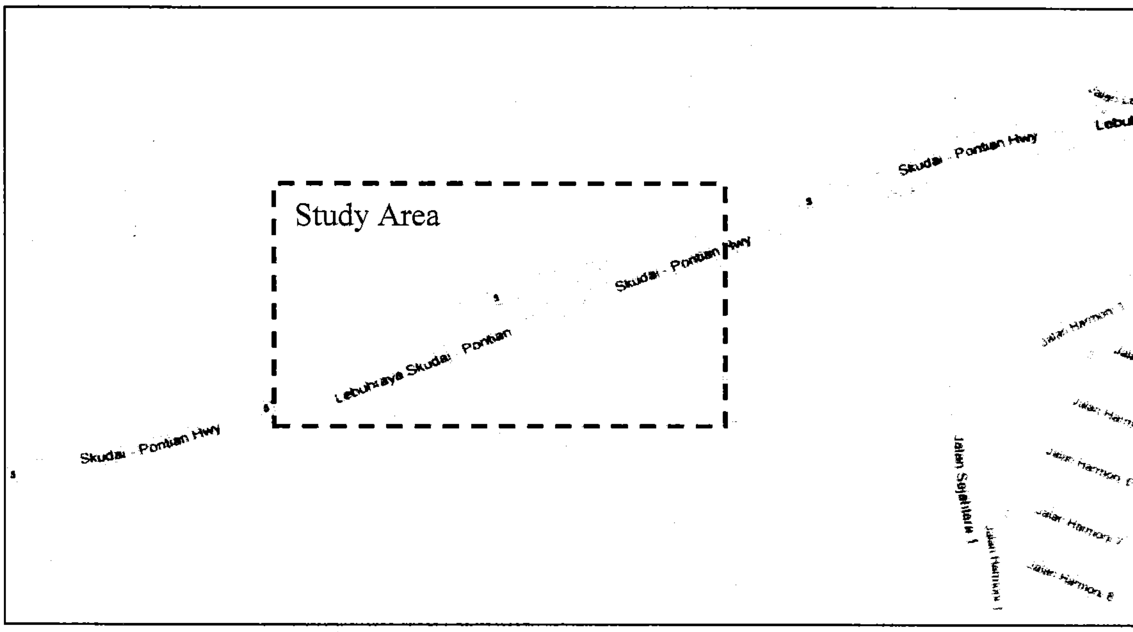

Figure 1.1: Midblock U-turn facilities at FT005

(Source: http://maps.goole.com)

1.5 Significance of Study

The shockwave propagation at any point along a road has a major implication in traffic flow analysis, modelling, traffic engineering design and also traffic management. Shockwaves would affect the level of service of the roadway. Data obtained from this study can be used as a reference for future traffic improvements and developments on the site location. It also can be used as a basis for traffic design and timing of traffic signals if need to implement for the future. By all the improvements, it helps to ease traffic flow and to decrease the travel time therefore minimizing the travel cost.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter will cover various facts and previous studies with reference to the topic and objectives of the study which is the extant of traffic shockwave propagation induced by highway midblock U-turn facilities. Traffic and highway in Malaysia, highway facilities, U-turn facilities, flow, speed, density, passenger car equivalent,.highway capacity, and traffic shockwave propagation are the topics that will be explained.

2.2 Traffic and Highway in Malaysia

Malaysia has a total landmass of 329,847 square kilometres that is consist of thirteen states and three federal territories. Peninsular Malaysia and Malaysian Borneo regions are separated by the South China Sea. Kuala Lumpur is the capital city of Malaysia while Putrajaya is the seat of the federal government. The population in Malaysia exceeded 27.5 million in 2010, with over 20 million of them are living on the Peninsula.

Malaysia's road network covers 98,721 kilometres (61,342 mi) and includes 1,821 kilometres (1,132 mi) of expressways. There were 27 highways in the country. The North – South Expressway is the longest highway of the country. It extends over 800 kilometres (497 mi) between Thai border and Singapore. Ministry of Work Malaysia had divided roads into two groups by area which is rural and urban roads. Generally it is classified as expressway, federal, state, municipal highways and others. An expressway is divided highway for through traffic control of access and always with grade separations at all intersections (Arahan Teknik (Jalan) 8/86). It is a high speed roadway with the design speed limit of 120 km/h and allowing the speed limit is 110 km/h (70 mph).

As for federal highway, it is a Malaysian highway connecting the capital city of Kuala Lumpur, Klang and Selangor. The features on a federal highway are often built with two carriageway lanes in each direction, but now are upgrading to three carriageway lanes because it is the busiest highway. Moreover, another feature of federal highway is that there are buildings along the highway. The operating speed of a federal highway is 90 km/h.

State highways are the secondary highways in Malaysia. Malaysian Public Work Department (JKR) of each state gives funding to the construction of state highways in Malaysia. State highways connect district headquarters. They normally single carriageway road. Municipal highways are connecting residential and commercial roads. It is maintained by the responsible local authority. In Malaysia, midblock U-turn facilities are commonly found along federal highways. The installation of midblock U-turn facilities along the roadway segment has been national debated about their advantages and disadvantages.

2.3 Highway facilities

Uninterrupted flow facilities and interrupted flow facilities are the two categories of flow. Highway facilities can be classified based on these two categories. It will be discussed in the following sub chapter. Several major types of transportation facilities are described in the TRB (2000). Uninterrupted flow facilities are freeways, multilane highways and two-lane highways. For interrupted flow facilities are signalized intersections, unsignalized intersections and also urban streets.

2.3.1 Uninterrupted Flow Facilities

According to TRB (2000), volume and traffic flow is a parameter common to both uninterrupted and interrupted flow facilities, but speed and density apply primarily to uninterrupted flow. Uninterrupted flow facilities will have no fixed elements on the roadway such as traffic signals that might interrupt the traffic flow. Traffic flow conditions are from the interaction among vehicles in traffic stream and between vehicles and the geometric characteristics of roadway. An uninterrupted flow is flow that not being interrupt by any means or facilities on the roadway. One important characteristic of uninterrupted flow facilities is the formation of platoons of moving vehicles.

2.3.2 Interrupted Flow Facilities

Time dimension involved in allocating space to conflicting traffic streams are the factor interrupted flow is more complex than uninterrupted flow. Interrupted flow facilities have controlled and uncontrolled access points that can interrupt the flow. The flow is usually dominated by points of fixed operation, such as traffic signals and stop signs (TRB, 2000). Some parameters related to flow rate such as spacing and headway are used for both type of facilities. But other parameter such as saturation flow and gap are only to interrupted flow.

The most important aspect on interrupted flow facilities occur at the points of interruption. The most common interrupted facilities are the signalized intersections, but signs on the roadway such as stop and yield signs are also one of the example. Based on Roger P. Rosess (2004), the dynamic of continually starting and stopping a traffic stream which is green and red signals, radically changes the flow regimen from that experienced under uninterrupted flow.

A flow on a link will be uninterrupted normally, but it can be interrupted flow for example a link with signalize zebra crossing. At any given time uninterrupted and interrupted flows describe the type of facility, not the quality of the traffic flow. The analysis for interrupted flow facilities must consider the impact of fixed interruptions. Capacity is constrain not only by the physical space but by the time available for the movement also. For example, a traffic signal limits the time available to various movements in an intersection.

2.4 U-turn Facilities

U-turn in driving refers to performing a 180 degree rotation to reverse the direction of travel. It is called a U-turn because the maneuver looks like the letter U. As contained in many literatures, midblock U-turn facilities are effective to reduce the conflict points in intersections. Based on Newell (1993), an intersection without treatment has 32 conflict points (16 crossing, 8 diverge, 8 merge), but at treated intersection conflict points are reduced to 8 (1 crossing, 3 diverge, 3 merge). Figure 2.1 compares the number of conflict points before and after left turn prohibition treatments at a midblock driveway. The installation of non-traversable medians and directional median opening are the potential treatment to solve congestion and safety problems at intersections. It has produced an increased number of midblock U-turn facilities on multilane roadway.

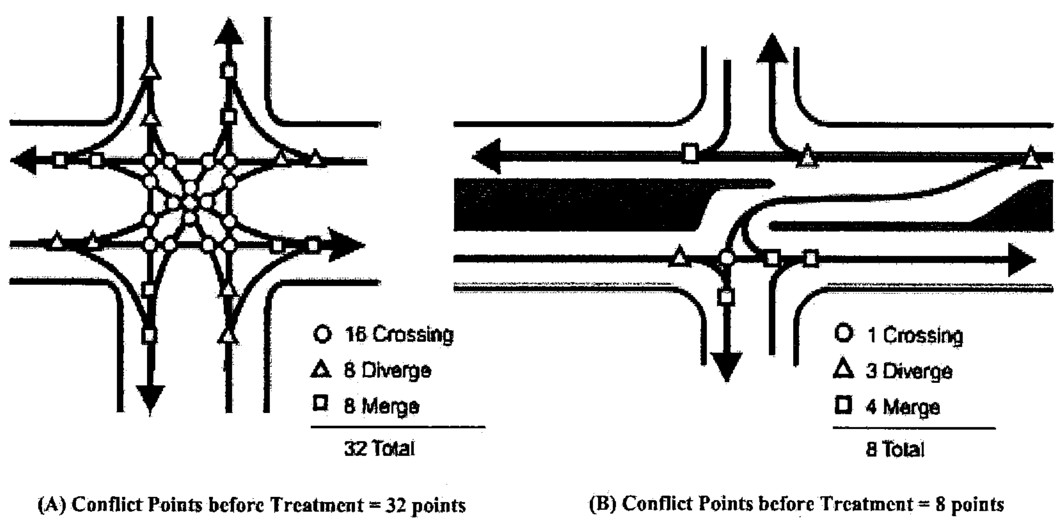

Figure 2.1: Conflict points before and after left-turn prohibition

(Source: TRB, 2003)

On some major arterials in the state of Florida, directional median openings and restrictive medians are installed to prohibit direct left turn access from driveways onto major arterials. This make, drivers that wants to make direct left turns would instead make right turn followed by U-turns (RTUT). As for Malaysia which is using left-hand traffic, the direct right turn is prohibited and a left turn followed by U-turn (LTUT) is applied. LTUT and RTUT are the same concept. The difference is only based on the hand traffic used by each country.

A typical RTUT procedure requires five steps (Liu, Lu, & Chen, 2008): (1) Drivers stop and wait at a driveway; (2) Make a right-turn onto the major road when a suitable gap is available from left-side through traffic; (3) Accelerate to the operating speed of the major road, weave to the inside lane, and decelerate to a stop at the exclusive left-turn/U-turn bay; (4) Wait until the signal turns green (if U-turns are accommodated at a signalized intersection) or when there are suitable gaps in the major road traffic stream (if U-turns are accommodated at a median opening) to make U-turns; (5) Accelerate to the operating speed of the major street through traffic. By using this system, the conflict points of an intersection will be reduced and same goes with the accidents rate.

There are many past researches proving that the safety impacts of using U-turns as an alternative to direct right turns. For example, Carter (2005) had examined that U-turn crash history at 78 signalizes intersections and found that 65 sites did not have any collisions involving U-turn in 3 year study period. Another study analyzed crash data at 481 conventional full median openings and 187 directional median openings by Potts (2004) found that the crashes related to U-turn and left-turn maneuvers at median openings occurred very infrequently. There are also studies on the conflicts at the intersection that can be reduced by using the LTUT or RTUT system. On average, vehicles making RTUT at a median opening generate 47 percent fewer conflict than those making direct left turns from the driveway (Dissanayake, 2002).

To accommodate vehicles making U-turns, right turning and cross the traffic at intersections, divided highways require median openings. The types and location of the U-turns should be considered very carefully. This is because drivers will have to keep to the right lane for decelerate when diverging and accelerate when converging. There are two types of U-turn: direct U-turn and indirect U-turn. According to Arahan Teknik (Jalan) 8/86, for direct U-turns, the width of the highway, including the median should be sufficient to allow the turn to be made without going beyond the outer of the pavements. Figure 2.2 shows the suggested layout for direct U-turn. When direct U-turn cannot be used due to median restrictions or due to space, indirect U-turns can be used. Indirect U-turns allow traffic to use existing local streets or to go around the block for their turning movements. It is used where medians are narrow and Figure 2.3 shows indirect U-turn that can be used.

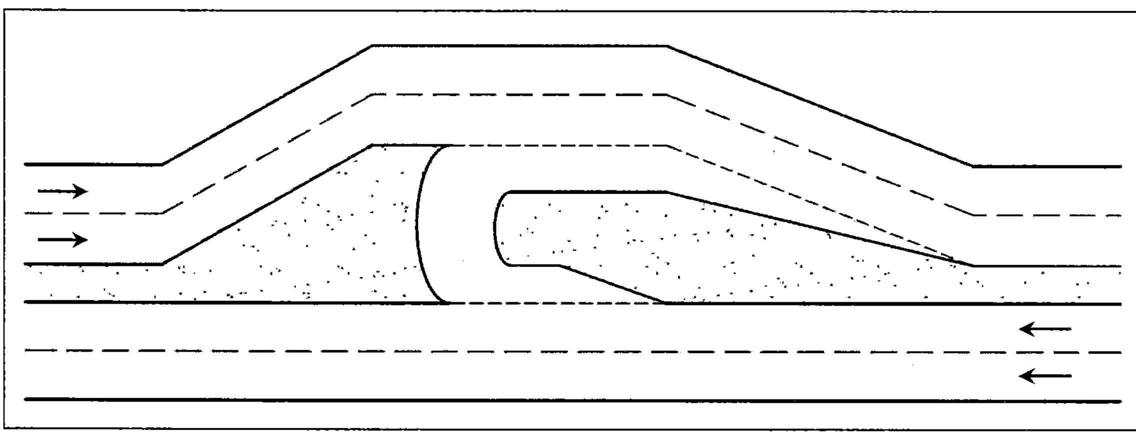

Figure 2.2: Recommended Layout for Direct U-turn

(Source: Arahan Teknik (Jalan) 8/86)

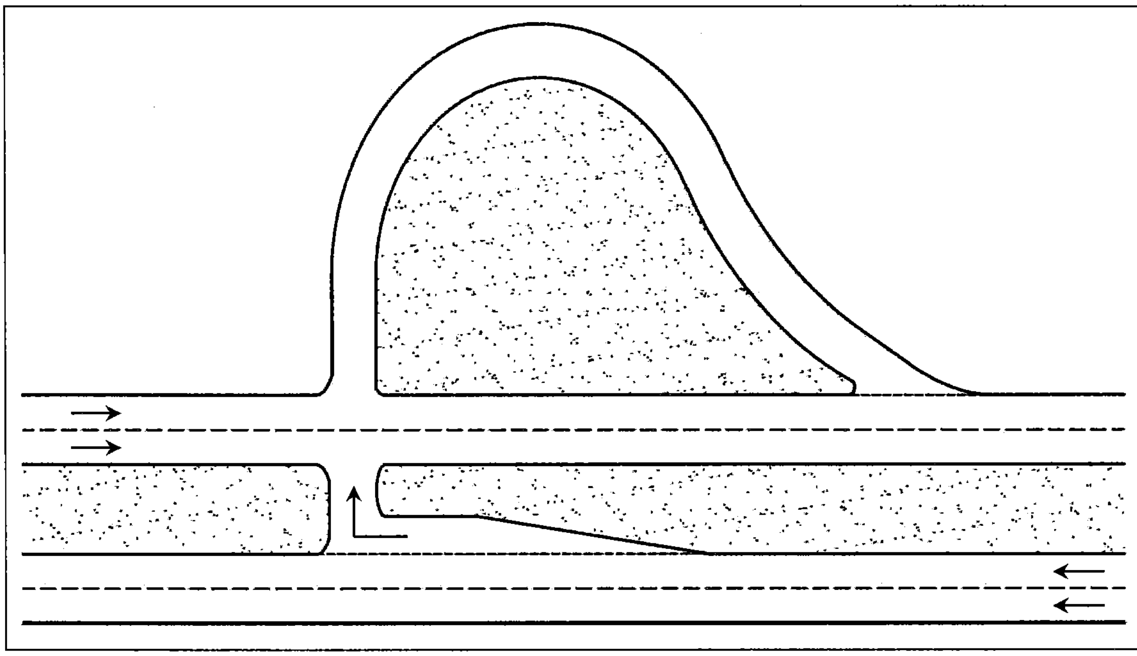

Figure 2.3: Special Indirect U-turn

(Source: Arahan Teknik (Jalan) 8/86)

After that, the locations of U-turns are very important and need proper consideration. Table 2.1 can be used to determine the minimum distances between U-turn. The location is important to be considered because it relates to the safety of road users.

Table 2.1: Distances between U-turns

Rural		Urban	
Design Standard	Distance between U-turns	Design Standard	Distance between U-turns
R6	No U-turns allowed	U6	No U-turns allowed
R5	3 km	U5	2 km
R4	2 km	U4	1 km
		U3	0.5 km

(Source: Arahan Teknik (Jalan) 8/86)

2.5 Traffic Stream Parameters

There are two broad categories for traffic stream parameters. First are macroscopic parameters which characterize the traffic stream as a whole. Second, microscopic parameters which characterize the behaviour of individual vehicles in the traffic stream with respect to each other. The three principal macroscopic parameters that describe traffic stream in any roadway are volume or rate of flow, density and speed (Roger P. Rosess, 2004). These three parameters are described the operational state or the actual condition of the traffic stream of a roadway and had been mentioned in previous studies (Castillo & Benítez, 1995; Greenberg, 1959).

2.5.1 Volume and Flow

Flow is the number of vehicles passing a specific referent point on a road section within a certain period of time. It is denoted by parameter q (veh/h). In practice, the number of vehicles on the road can be determined by standing at the side of the road for a certain period of time denoted as (t) while the number of vehicle count is (n), passing that point in that period in one lane. It is as equation (2.1). It will derive a rate per unit time.

$$q = \frac{n}{t} \tag{2.1}$$

Although the unit volume is often expressed as vehicles per unit time, it is basically "vehicles". The time intervals used are commonly daily and hourly. They are expressed as vehicle per day and vehicle per hour respectively. The variation of volume with time is important in a survey or study because the purpose in each study is different.

The purposes of using daily volumes are for highway planning and general observations of trends. The following volumes are described is vehicles per day (vpd). Daily volumes are not differentiated by the direction or lane, but are totals for an entire facility at the specified location. There are four daily volume parameters that are widely used:

(a) Average annual daily traffic (AADT). It is the average 24-hour traffic volume at a given location over a full 365-day year. Generally, it is the total number of vehicles passing the site in a year divided by 365 days.

(b) Average annual weekday traffic (AAWT). It is the average 24-hour traffic volume occurring on weekdays over a full year. The weekend traffic is light, so it is of considerable. AAWT is computed by dividing the total weekday volume for the year by 260.

(c) Average daily traffic (ADT). It is an average 24-hour volume at a given location for some period of time less than a year. While AADT is for a full year, an ADT can be measured for six months, a season, a month, a week, or as little as two days.

(d) Average weekly traffic (AWT). It is an average 24-hour traffic volume occurring on weekdays for some period less than one year. For example, for a month or a season.

Although daily volume is very useful in highway planning, they cannot be used alone for design or operational analysis purposes. Volume varies in 24-hour day. Normally, periods that have the maximum volume occurs during the morning and evening. This is referred as "peak hour". Peak hour is the most important data to traffic engineers in design or operational analysis. Generally, a directional volume is the peak hour volume. Simply, it is a volume in which the directions of flow are separated. Highways must be design to adequately serve the peak hour volume in the peak direction of flow.

2.5.2 Speed

Speed is the second principle parameter describing the state of a traffic stream. Speed is the distance travelled by a vehicle during a unit of time. It is the inverse of the time taken by a vehicle to traverse a given distance. It can be denoted by parameter u (km/h). Equation (2.2) shows speed is equal to distance over time.

$$S = \frac{d}{t} \tag{2.2}$$

Where,

S = Speed (km/h or mph)

d = Distance traversed (km or mi)

t = Time to traverse distance d (hr)

Each vehicle travels at a different speed in a moving traffic stream. So, the traffic stream does not have a single characteristic speed, but rather having distribution of individual vehicle speed. A number of "average" values may be used to characterize the traffic stream as a whole from a distribution of discrete vehicles speeds. According to Nicholas J. Garber & Hoel (2009) there are two types of mean speed which are time mean speed and space mean speed. Time mean speed ($\overline{u}_t$) is the arithmetic mean of the speed of vehicles passing a point on a highway during an interval time. The time mean speed can be calculated by the following equation.

$$\bar{u}_t = \frac{1}{n}\sum_{i=1}^{n} u_i \tag{2.3}$$

Where:

$\bar{u}_t$ = Time mean speed

n = Number of vehicles passing a point on the highway

u_i = Speed of the ith vehicle

Space mean speed ($\bar{u}_s$) is the harmonic mean of the speeds of vehicles passing a point on a highway during an interval time. This is the speed that is involved in flow-density relationship. The space mean speed can be calculated by the following equation.

$$\bar{u}_s = \frac{n}{\sum_{i=1}^{n}\frac{1}{u_i}} \tag{2.4}$$

$$\bar{u}_s = \frac{nL}{\sum_{i=1}^{n} t_i} \tag{2.5}$$

Where:

$\bar{u}_s$ = Space mean speed

n = Number of vehicles passing a point on the highway

u_i = Speed of the ith vehicle

t_i = Time it takes the ith vehicle to travel across a section of highway

L = Length of section of highway

Average speed which is the arithmetic mean of all observed vehicle speeds. It is given as;

$$\bar{u} = \frac{\sum f_i u_i}{f_i} \quad (2.6)$$

Where,

$\bar{u}$ = arithmetic mean

f_i = number of observations in each speed group

u_i = midvalue for the ith speed group

The formula also can be written as;

$$\bar{u} = \frac{\sum u_i}{N} \quad (2.7)$$

Where,

u_i = speed of the ith vehicle

N = number of observed values

Standard deviation of speeds is a measure of the spread of the individual speed. It is estimated as;

$$S = \sqrt{\frac{\sum (u_j - \bar{u})^2}{N-1}} \quad (2.8)$$

Where,

S = standard deviation

$\bar{u}$ = arithmetic mean

u_j = jth observation

N = number of observation

However, speed data are frequently presented is classes where each class consists of a range of speeds. The standard deviation is computed for such cases as;

$$S = \sqrt{\frac{\sum f_i(u_i-\bar{u})^2}{N-1}} \tag{2.9}$$

Where,

u_i = midvalue of speed class i

$\bar{u}$ = arithmetic mean

f_i = frequency of speed class i

N = number of observation

2.5.3 Density

While density which is sometimes referred to as concentration, is the number of vehicles travelling (n) over a unit length of highway (x) at an instant in time and can be denoted by parameter k (veh/km). Density is difficult to measure directly, as an elevated vantage point is required. Density equation can be shown as equation (2.10):

$$k = \frac{n}{x} \tag{2.10}$$

Density is the most important of the three traffic stream parameters because it is the measure that is most directly related to traffic demand and it shows the quality of a traffic flow. Generated trips by a number of vehicles that are placed on a limited segment of highway will produce a traffic density, which then produces a rate of flow and a speed.

2.5.4 Relationship of Flow, Speed and Density

As mentioned in many literatures, under uninterrupted flow condition, flow, speed and density are related by the following equation (2.11). The flow equal to zero when either speed or density is zero since flow is the product of speed and density.

$$q = uk \quad => \quad u = \frac{q}{k} \quad => \quad k = \frac{q}{u} \tag{2.11}$$

Where,

q = flow (veh/h)

u = speed (km/h)

k = density (veh/km)

2.6 Passenger Car Unit

Passenger car unit is denoted as (pcu). Road capacity usually is in terms of passenger car unit per hour per lane (pcu/hr/ln). Passenger car units (pcu) values are used in highway capacity analysis to convert a mixed vehicle flow into an equivalent passenger car flow. This is because in a road survey, there is more than one type of vehicles that pass the route. Arahan Teknik (Jalan) 8/86 by Public Work Department, Malaysia stated that various classes of vehicles should be converted into passenger car using conversion factors as given in Table 2.2.

Table 2.2: Conversion Factors to pcu

Vehicle Types	Equivalent Values in pcu			
	Rural Standard	Urban Standard	Roundabout	Traffic Signal
Passenger Car	1.00	1.00	1.00	1.00
Motorcycle	1.00	0.75	0.75	0.33
Light Vans	2.00	2.00	2.00	2.00
Medium Lorries	2.50	2.50	2.80	1.75
Heavy Lorries	3.00	3.00	2.80	2.25
Buses	3.00	3.00	2.80	2.25

(Source: Arahan Teknik (Jalan) 8/86)

Vehicles can be classified according to its weight and number of axles. In a study, the types need to be defined property. One scheme that defines the types of vehicles is Scheme F classification. Detail about the classification is attached in Appendix A.

2.7 Greenshields Model

In describing the mathematical relationships of traffic flow, there are two ways which are the macroscopic approach and microscopic approach. The macroscopic approach considers flow density relationship. Greenshields B. D. (1935) reported simple relationship between speed and density. He hypothesized that a linear relationship existed between speed and density as illustrated in Figure 2.4 (a). Thus, the equation for this relationship is;

$$u = u_f - \left(\frac{u_f}{k_j}\right) k \tag{2.12}$$

Where:

u = space mean speed

u_f = free flow speed

k = the density

k_j = the density at jam

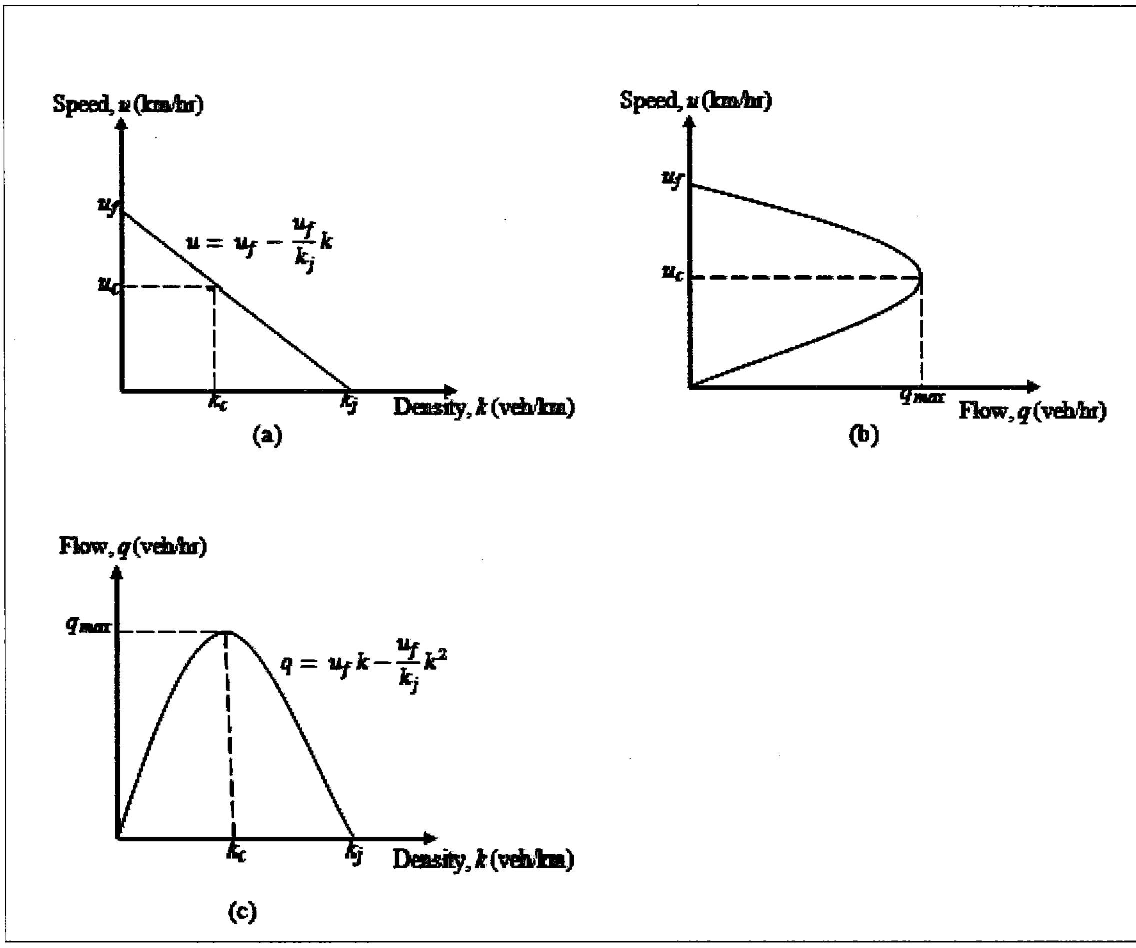

Figure 2.4: The fundamental diagrams according to Greenshields; (a) Speed – Density Model, (b) Speed – Flow Model and (c) Flow – Density Model
(Source: Greenshields, 1934)

Equation (2.13) below tells that when density become zero, speed approaches free flow speed. Usually, u_f is relatively easy to estimate from empirical data and mostly lies between speed limit and highway design speed, but k_j is not easy to observe. However, an approximate value of 185 – 250 veh/mi is a reasonable range (May Adolf D., 1990).

After the relationship of speed and density had been established, corresponding relationships for flow and density can be developed. The relationship between flow and density is parabolic in shape and it is illustrate as Figure 2.4 (c). If equation (2.12) is substituted into equation (2.11), then

$$q = \left[u_f - \left(\frac{u_f}{k_j}\right)k\right] \times k$$

$$q = u_f k - \frac{u_f}{k_j}k^2 \tag{2.13}$$

Where:

q	= flow
u_f	= free flow speed
k	= the density
k_j	= the density at jam

In Greenshields diagrams, the capacity u_c is half of the maximum speed u_f as shown in Figure 2.4 (a). The critical density, k_c in this model as shown in Figure 2.4 (c) is half of jammed density, k_j. Moreover, flow and density relationship have two sections which is the free flow section and congestion section.

To find predicted maximum flow, differentiate equation (2.13) with respect to k and equal to zero. The maximum flow equation is as follows;

$$\frac{\partial q}{\partial k} = u_f - 2\frac{u_f}{k_j}k = 0$$

Hence,

$$k = \frac{k_j}{2}$$

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