EXPLORATION ON TRAFFIC CHARACTERISTICS AND GAP ASSESSMENT ON MIDBLOCK U-TURN FACILITIES

MOHAMAD HILMI BIN HAMIZAN

B. ENG(HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's Full Name : MOHAMAD HILMI BIN HAMIZAN

Date of Birth : 12 APRIL 1994

Title : EXPLORATION ON TRAFFIC CHARACTERISTICS AND GAP ASSESSMENT ON MIDBLOCK U-TURN FACILITIES

Academic Session : SEMESTER 2 2017/2018

I declare that this thesis is classified as:

- ☐ CONFIDENTIAL (Contains confidential information under the Official Secret Act 1997)*
- ☐ RESTRICTED (Contains restricted information as specified by the organization where research was done)*
- ☑ OPEN ACCESS I agree that my thesis to be published as online open access (Full Text)

I acknowledge that Universiti Malaysia Pahang reserves the following rights:

1. The Thesis is the Property of Universiti Malaysia Pahang
2. The Library of Universiti Malaysia Pahang has the right to make copies of the thesis for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

_______________________	_______________________
(Student's Signature)	(Supervisor's Signature)
_______________________	_______________________
New IC/Passport Number	Name of Supervisor
Date:	Date:

NOTE : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach a thesis declaration letter.

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Civil Engineering.

(Supervisor's Signature)

Full Name :

Position :

Date :

(Co-supervisor's Signature)

Full Name :

Position :

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

____

(Student's Signature)

Full Name : MOHAMAD HILMI BIN HAMIZAN

ID Number : AA15258

Date : 20 Jun 2018

EXPLORATION ON TRAFFIC CHARACTERISTICS AND GAP ASSESSMENT ON MIDBLOCK U-TURN FACILITIES

MOHAMAD HILMI BIN HAMIZAN

Thesis submitted in fulfillment of the requirements
for the award of the
Bachelor Degree in Civil Engineering

Faculty of Civil Engineering and Earth Resources

UNIVERSITI MALAYSIA PAHANG

JUNE 2018

ACKNOWLEDGEMENTS

Foremost, I would like to thank my family and friends who have supported me while I have been completing my research. Especially my parents, Hamizan Bin Baharum and Rozitah Binti Mahmod, who have always convinced me in my study and to my partner Nusaibatul As-Syahidah Binti Ishak who always give me a motivation, inspiration and accompany me when I am doing video recording for gap assessment study.

I would like to express my sincere gratitude to my supervisor, Puan Azlina Binti Haji Ismail for the continuous support of my research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my research.

And last, but not least, thank you to everyone at UMP especially Staff in Highway and Traffic Lab that always helping me on lab and on site to complete these research.

ABSTRACT

The idea of a Midblock U-turn Opening installation is to eliminate direct right turns. Midblock U-turning facilities are median openings on multi-lane highways. U-turning facilities aimed at easing traffic conflicts and pressures at highway intersections. This study is to identify the influence of midblock U-turn facilities towards traffic parameters of speed, flow and density relationship and to determine the safe merging gap for the midblock U-turn facilities. This study is referring to unsignalized junction, that is the midblock U-turn facilities located at Jalan Tanah Putih, heading to Kuantan, Pahang. The traffic characteristics of this study is to define the speed, flow and density when the vehicle at free flow speed and when reaching the conflict point near the midblock U-turn facilities. Raff's Method is the method used to analysed the critical gap for the passenger car that want to make a U-turn. By using Raff Method, the gap acceptance and gap rejected will be observe and from these data, it can produce a linear graph which can determined the critical gap. The result obtained showed the traffic characteristics relationship which is speed, flow and density that the data relationship was similar to Greenshield Model and critical gap of the U-turn was 5.0 second. The critical gap was comply with the standard of Malaysia Public Work Department and Transportation Research Board. The result show from the speed, flow and density relationship, the road was in a good condition and the drivers behavior that desire to merge into major road from the U-turn.

ABSTRAK

Idea pemasangan persimpangan pusingan U adalah untuk menghapuskan pergerakan ke arah kanan yang tidak terurut. Kemudahan persimpangan pusingan U adalah memberi ruang bukaan di jalan raya yang mempunyai berbilang lorong bagi menukar arah laluan dan bertujuan untuk mengurangkan konflik lalu lintas di persimpangan jalan raya. Kajian ini adalah untuk mengenal pasti pengaruh persimpangan U terhadap parameter lalu lintas berhubung dengan kelajuan, aliran dan ketumpatan dan untuk menentukan jurang penggabungan yang selamat di fasiliti persimpangan U. Kajian ini merujuk kepada persimpangan U yang terletak di Jalan Tanah Putih, menuju ke Kuantan, Pahang. Ciri-ciri lalu lintas kajian ini adalah untuk menentukan kelajuan, aliran dan kepadatan ketika kenderaan pada kecepatan aliran bebas dan ketika mencapai titik konflik berdekatan fasiliti persimpangan U. Kaedah Raff adalah kaedah yang digunakan untuk menganalisis jurang kritikal bagi pemamdu kereta yang ingin membuat pusingan U. Dengan menggunakan kaedah Raff, jurang yang diterima dan jurang yang ditolak akan diperhatikan dan dari data ini, ia boleh menghasilkan graf yang boleh menentukan jurang kritikal. Hasil yang diperoleh menunjukkan hubungan ciri-ciri lalu lintas yang merupakan kelajuan, aliran dan ketumpatan bahawa hubungan data tersebut serupa dengan model Greenshield dan jurang kritikal bagi pusingan U tersebut ialah 5.0 saat. Jurang kritikal adalah mematuhi piawaian Jabatan Kerja Raya Malaysia dan Lembaga Penyelidikan Pengangkutan Awam. Hasil kajian menunjukkan bahawa hubungan kelajuan, aliran dan ketumpatan jalan berada dalam keadaan yang baik dan tingkah laku pemandu yang ingin bergabung ke jalan utama dari giliran U.

TABLE OF CONTENT

DECLARATION		
TITLE PAGE		
ACKNOWLEDGEMENTS		**ii**
ABSTRAK		**iii**
ABSTRACT		**iv**
TABLE OF CONTENT		**v**
LIST OF TABLES		**viii**
LIST OF FIGURES		**ix**
LIST OF SYMBOLS		**x**
LIST OF ABBREVIATIONS		**xi**
CHAPTER 1 INTRODUCTION		**1**
1.2	Background	1
1.2	Problem Statement	1
1.3	Research Objective	2
1.4	Scope of Work	3
1.5	Research Methodology	4
1.6	Significant of Research	5
CHAPTER 2 LITERATURE REVIEW		**6**
2.1	Introduction	6
2.2	Midblock U-turn Opening	6
	2.2.1 General Consideration	8

2.3 Merging 9

2.4 Type of Conflict Point 9

2.4.1 The Pattern of Weaving at U-turn 10

2.5 Term Definition 11

2.6 Speed, Flow and Density Relationship 12

2.6.1 Speed 12

2.6.2 Flow 13

2.6.3 Density 13

2.7 Free Flow Speed 14

2.8 Gap 15

2.8.1 Gap Acceptance 16

2.8.2 Critical Gap 17

2.9 The Raff's Method 17

2.10 Greenshield's Model 19

2.10.1 Relationship between Speed and Density 20

2.10.2 Relationship between Speed and Flow 21

2.10.3 Relationship between Flow and Density 22

CHAPTER 3 METHODOLOGY 24

3.1 Introduction 24

3.2 Chart Review Methodology 24

3,3 Site Location 26

3.4 Description of the Study Area 26

3.5 Study Location 27

3.6 Data Collection 27

3.6.1 Traffic Characteristics 28

3.6.2 Critical Gap Assessment 28

3.7 Research Equipment 29

CHAPTER 4 RESULTS AND DISCUSSION 30

4.1 Introduction 30

4.2 Traffic Characteristics 31

4.2.1 Traffic Composition 32

4.2.2 Characteristics of Speed, Flow and Density 33

4.3 Critical Gap Assessment 36

4.3.1 Critical Gap 36

CHAPTER 5 CONCLUSION 41

5.1 Introduction 41

5.2 Conclusion 41

5.3 Recommendation 42

REFERENCES 43

APPENDIX 47

LIST OF TABLES

Table 4.1	Type of Vehicle Classes	32
Table 4.2	Average Traffic Flow for 3 days	33
Table 4.3	Speed, Flow and Density at Point A and Point B	33
Table 4.4	Cummulative Accepted Gap and Rejected Gap	39

LIST OF FIGURES

Figure 1.1	Illustration of merging at Midblock U-turn Opening	2
Figure 1.2	Research Methodology Flow Chart	4
Figure 1.3	Typical Midblock Median U-turn Opening Facilities	5
Figure 2.1	Types of Traffic Conflict	10
Figure 2.2	Illustration of Traffic Conflict	10
Figure 2.3	Flow Density Relationship Graph	14
Figure 2.4	Illustration of gap and headway definition	15
Figure 2.5	Example of Raff's Method Graph	19
Figure 2.6	Relationship between Speed and Density	20
Figure 2.7	Relationship between Speed and Flow	21
Figure 2.8	Relationship between Flow and Density	22
Figure 3.1	Flow Chart Methodology	25
Figure 3.2	Selected Midblock U-turn Opening	27
Figure 3.3	The condition of metrocount placed	28
Figure 3.4	List of Equipment Used forResearch Purposes	29
Figure 4.1	Illustration for Free Flow Speed	32
Figure 4.2	The Traffic Speed versus Traffic Density	34
Figure 4.3	The Traffic Speed versus Traffic Flow	35
Figure 4.4	The Traffic Flow versus Traffic Density	35
Figure 4.5	Position of Video Recorder	36
Figure 4.6	Video Recorder Placed On Site	36
Figure 4.7	Situation of Accepted Gap by Passenger Car	37
Figure 4.8	Situation of Rejected Gap by Passenger Car	38
Figure 4.9	Average Critical Gap	40
Figure 5.1	Reported Critical Gap	42

LIST OF SYMBOLS

q	Flow (veh/h)
k	Density (veh/km)
v	Speed (km/h)
t	perception / reaction time, sec, typically 2.5 sec
f	coefficient friction
g	percent grade (% / 100)

LIST OF ABBREVIATIONS

SSD	Stopping Sight Distance
PWD	Public Work Department
FFS	Free Flow Speed
BFFS	Base Free Flow Speed
AASHTO	American Association of State Highway Transportation Organization

CHAPTER 1

INTRODUCTION

1.0 Background

Heavy traffic volumes at signalizad at-grade intersections on urban and suburban multilane divided highways may cause the traffic signal control system installed failed to function efficiently which in turn may lead to congestions and excessive traffic delays. According to Liu Pan (2008), the idea of a U-turn facility installation is to eliminate direct right turns. There are many problems are appeared at the intersection such as congestion, queues, delay and also accident. Brilon (1999) said that the evaluation of capacity at unsignalized intersection is practically measured using the gap acceptance approach and used for unsignalized intersection procedure. In this study, the gap acceptance approach was used for unsignalized intersection procedure. The critical gap is a major parameters need to be considered to analysis the unsignalized intersection. In Malaysia, the critical gap for an unsignalized intersection is proposed by Highway Capacity Manual (2011). Therefore, the critical gap is difference between each intersection based on the geometry of the road, numbers of lane, and surrounding area located near the intersection. According to Ban (2009) the efficiency of the performance at unsignalized intersection is become worst if the problem such as delay, queue is always occurred. Therefore, this research should be evaluated by taking the data traffic volume and relate with time which is during peak hour. In addition, this research also important to assess the road situation which shows the maximum level of usage.

1.2 Problem Statement

The idea of a Midblock U-turn Opening installation is to eliminate direct right turns. Traffic operation at a midblock U-turn opening is illustrated in Figure 1.1. Considering a U-turning vehicle A in figure 1, arrived at the U-turn opening from major road of opposite direction, will enter the accerleration lane and reach merging arrival point. At this point, the vehicle will move slowly while searching for suitable gaps until it departs at the merging departure point. The departure point varies for each vehicle. During the merging activities, vehicle in acceleration lane will have conflict points with the vehicles from near-side and far-side of major road. A particular concern about a midblock U-turn is that it may result in safety and operational problems. A precise analysis or design of U-turn is a very important task because undesirable incident at any U-turn opening can affect the operational of traffic on the entire highway. This study is to analyse the result carried out to evaluate speed, flow and density relationship, driver critical gap for merging maneuvers at midblock U-turn opening. To date, limited reported studies that address such a facility were only focused on the merging gap acceptance behaviour.

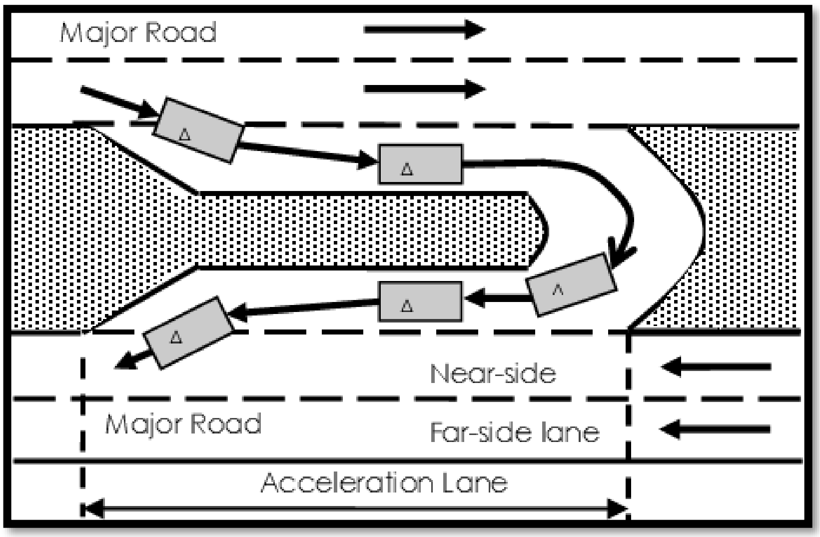


Figure 1.1: Illustration of merging at midblock U-turn opening

1.3 Research Objective

The aim and objective of this case study is to analyse the effectiveness of Midblock U-turn Opening movement along Jalan Tanah Putih. To achieve the aim of this study, the following objectives have been set as:

i. to identify the influence of midblock U-turn facilities towards traffic parameters of speed, flow and density relationship
ii. to determine the safe merging gap for the midblock U-turn facilities

1.4 Scope of work

The scope of this research is to focus on the effectiveness of speed, flow and density relationship, and critical gap for U-turn movement at Jalan Tanah Putih. The authorities involved in this study are Public Work Department (JKR).

This study focuses on the free flow speed of vehicle that desire to travel on the major stream and wants to do U-turning at the midblock U-turn opening and to analyse the critical gap at U-turn area to merge major stream. The time to collect data is on weekdays during peak hours from 7.00am until 11.00am. The data will collected three days in a week (tuesday, wednesday and thursday).

1.5 Research Methodology

To make this study work, several research methodologies were used. There is initial discussion, proposal, literatures review, collecting data, analysis data and conclusion. The figure below showed the flow chart of research methodology in this study.

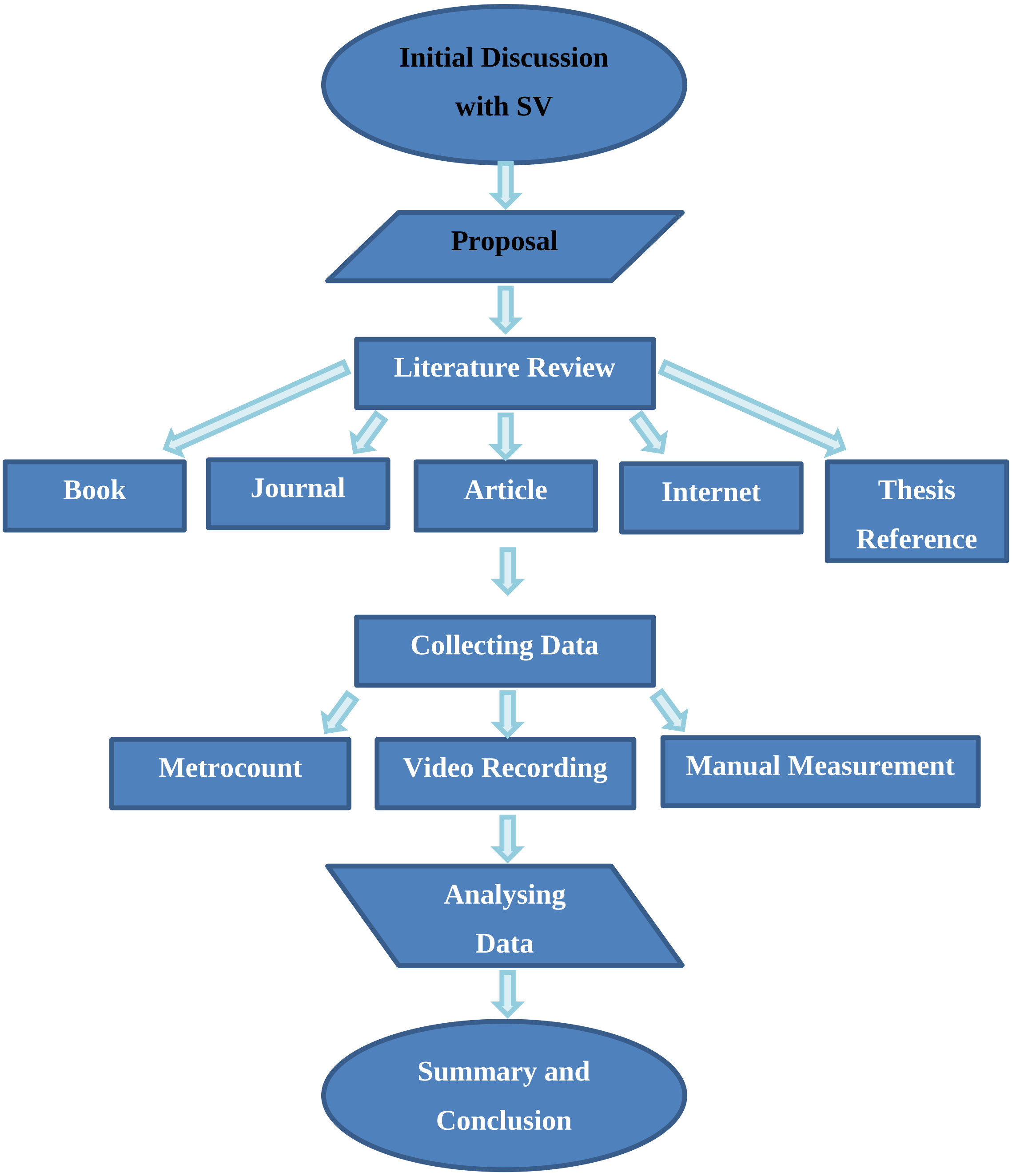


Figure 1.2: Research Methodology Flow Chart

1.6 Significant Of Research

In many countries (Malaysia, Nigeria, and South Africa), directional midblock median U-turn openings are exclusive facilities at road segments meant for U-turn movement only (Liu Pan, 2008). They are meant to ease traffic pressure at intersections located some distance away from the facilities. These facilities are not to be confused with median opening at highway intersections. Typical midblock median U-turn opening has three sections, entry, middle curvature, and exit. According Chevion, D. S (2011), vehicles entering the facilities decelerate gradually on approach and continue at lower speed until it is safe at the exit to merge with priority traffic stream. As shown in Figure 1.3, midblock median U-turn opening is a non-uniform structure. Since the midblock median opening facilities have three sections (entry, middle curvature, and exit), capacity estimation method is dependent on the section of interest. After all, capacity represents the maximum sustainable hourly flow rate at which vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given time period under prevailing roadway, environmental, traffic, and control conditions (Akçelik, 2008).

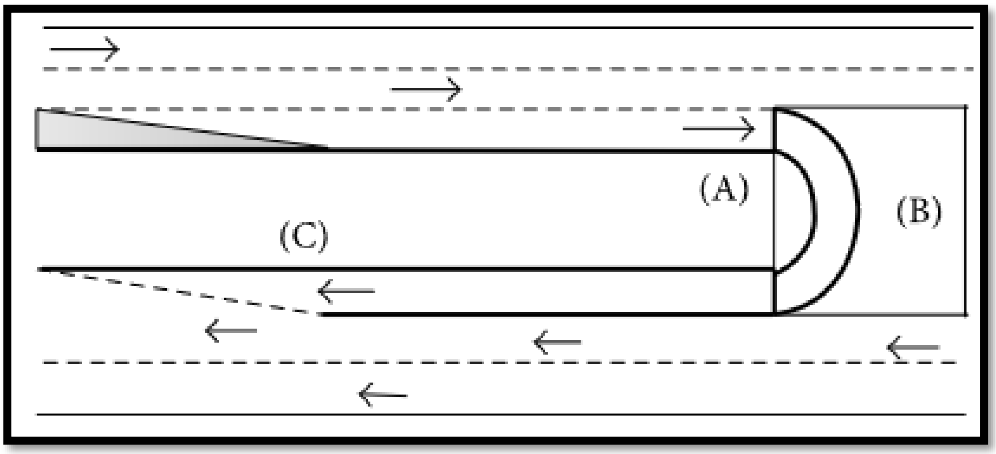


Figure 1.3: Typical midblock median U-turn openings facilities.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Movement is the backbone system to human activities. It is very important network to carry out the activities with various location and to bring people and goods through the growing network at the same time in line with the growth of an increasing complex society. The movement depends on the existence of adequate transport and transport requires road networking such as smooth, good and systematic. According to Chen (2002), a good network system not only can accommodate volume of traffic capacity flow in one time, but can give a minimum delay to driver. The driver is more concerned with faster journey times than other things. Delay is the main thing is always avoided by the driver. Changes in road management systems mostly done to minimize the delay which must be received by the driver, but there is also a preferred system change over delay in road capacity, particularly in urban areas to accommodate the traffic volume is high. Changes in system should be reviewed to avoid wastage effectiveness not only on time but also on the cost of fuel and travel distance to be passed by the driver. Papageorgiou (2003) said that traffic management required to control road users for get in maximum from the road network system existing in place for the benefit of all users. Maximum use will lead to higher traffic volumes without delay and to be safe for use.

2.2 Midblock U-turn Opening

According to Rahman (2015), a U-tum in driving refers to performing a 180 degree rotation to reverse the direction of travel. It is called a "U-turn" because the maneuverer looks like the letter U. In some areas, the maneuverer is illegal, while in others it is treated as a more ordinary tum, merely extended. Consequently, vehicles making U turns may have. Slower turning speeds. At median openings, drivers usually need larger gaps in the major street traffic stream to make U turns. Based on previous research, Liu Pan (2008) said the arguments have been advanced by some opponents of median modification projects that median openings may not be able to handle large numbers of U-tuming vehicles due to the limited capacity of U-turn movement, and the increased number of U turns may result in traffic congestion at median openings. There has been little documentation on the operational effects of U-turns, which contains procedures and models for estimating capacity and delay for different movements at unsignalized intersections, does not provide specific guidelines for estimating capacity and delay of U-turns at median openings. Traffic operations at U-turn median openings have not yet been formally addressed (HCM, 2000). According to Pirdavani (2011), developed regression equations to estimate the delay and capacity of U-turns by field experiment. According to Hashem Al Masaeid (1999), the empirical formulas indicate that there are strong correlations among the delay, capacity and total conflicting traffic flow. U-turns at median openings can only be made in the gaps between platoons during peak traffic periods. Nothing occurs while the platoons pass side streets and U-turn median openings. It was found that delays of U-tum vehicles making a right tum from upstream side streets have a strong correlation with the offset of upstream and downstream signal timing, weaving length, the length between the side street and upstream signal, and signal spacing (Hashem Al-Masaeid, 1999) .

Midblock U-turning facilities are median openings on multi-lane highways. U-turning facilities aimed at easing traffic conflicts and pressures at highway intersections. While some are built as complimentary facilities to existing road geometric designs, others are built as a complete replacement to existing facilities on the premises that they will reduce conflicts and ease traffic congestions at adjoining intersections. In Malaysia, where the right hand driving rule is in place, drivers decelerate when diverging, accelerate when converging at the midblock facilities. Therefore, it is not surprising that the issue of midblock U-turning facilities has provoked fierce national debates. Proponents of midblock facilities argue that their installation has brought some help to motorists plagued with conflicts and congestions at adjoining intersections. According to (Forward. S) in claimed that to reduce the number of accident, the skill and knowledge of the drivers need to be increased. So, this research will identify the safe distance of entry vehicle to enter the main lane and the safe distance of fast lane vehicle with the slow lane vehicle before make decision to change the lane at this U-turn facility road segment. Other than that, this study will focus on develop a lane changing model in order to determine the relationship between the reaction time (RT), speed (V) and distance from behind vehicle to the front vehicle due to changing lane at U-turn facility road segment. Finally, the model can be used to estimate the safe distance for road user to slow down their rate of speed while approaching the U-turn facility road segment and can be used to estimate the speed, safe distance in lane changing process. The result can be put into driver's guideline in daily driving process and can be used in the real scenario.

2.2.1 General Considerations

According to Arahan Teknik (Jalan) 8/86 by the Public Works Department (PWD, 1986), the divided highways require median openings to accommodate vehicles making U-turns in addition to right truning and cross traffic. Separate U-turn median openings may be required at the following locations:-

i. Locations beyond intersections to accommodate minor turning movements not otherwise provided in the intersection or interchange area. The major intersection area is kept free for the important turning movements, in some cases obviating expensive ramps or additional structures.

ii. Locations just ahead of an intersection to accommodate U-turn movements that would interfere with through and other turning movements at the intersection. Where a fairly wide median on the approach roadway has few openings, U-turning is necessary to reach roadside areas. Advance separate openings to accommodate them outside the intersection proper will reduce interference.

iii. Locations occurring in conjunction with minor crossroads where traffic is not permitted to cross the major road but instead is required to turn left, enter the through traffic stream, weave to the right U-turn, then return. On high-speed or high-volume roads, the difficulty and long lengths required for weaving with safety usually make this design pattern undesirable unless the volumes intercepted are light and the median is of adequate width. This condition may occur where a crossroad with high volume traffic, a shopping area, or other traffic generator that requires a median opening nearby and additional median openings would not be practical.

iv. Locations occurring where requlary spaced openings facilitate maintenance operations, policing, repair service of stalled vehicles, or other highway-related activities. Openings for this purpose may be needed on controlled-access roads and on divided roads through undeveloped areas.

v. Locations occurring on roads without control of access where median openings at optimum spacing are provided to serve existing frontage developments and at the same time minimize pressure for future median openings.

2.3 Merging

Based on Othman Che Puan (2015), merging is one type of vehicles interaction in a traffic stream. It is defined as the movement of a vehicle from a ramp entering into a main lane traffic stream. In other words, it is a process where vehicles in two streams of traffic moving in the same direction combine to form a single stream of traffic.

2.4 Type of Conflict Point

According to Chang (1982), a conflict point is the point at which a highway user crossing, merging with, or diverging from a road or driveway conflicts with another highway user using the same road or driveway. It is any point where the paths of two through or turning vehicles diverge, merge, or cross as shown in Figure 2.1 and Figure 2.2 below.

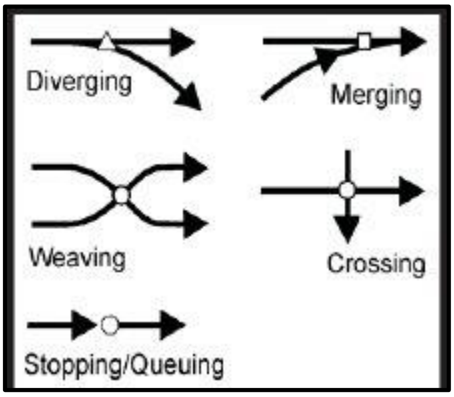


Figure 2.1: Type of Traffic Conflict

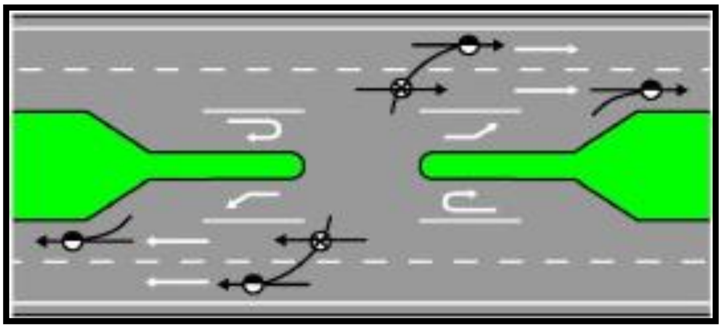


Figure 2.2: Illustration of Traffic Conflict

2.4.1 The Pattern of Weaving at U-turn

According to a study conducted by the National Cooperative Highway Research Program (Zhou, 2013), there are three types of patterns for Weaving:

i. When weaving distance is short (i.e., 75-150 meters (250-500 feet), less than a right turn deceleration lanes on major roads),many drivers will choose the appropriate intervals simultaneously to enter all the streets and make a direct entry into the lane right-tum deceleration.

ii. Weaving is the medium of distance (i.e., 150-305 meters (500 to 1.000 feet), not enough to make changes lane with ease), most drivers will choose intervals appropriate to the simultaneous enter all the streets and make a direct entry into the lane most of.

iii. When Weaving distance is long (i.e.,> 305 meters (1,000 feet)), the driver will choose an appropriate interval, enter the left-side lane, speeding with appropriate speed, and then make a change lanes to right into the lane.

2.5 Term Definition

There are two types of data used in this study, the primary data and secondary data. Primary data is data that are observed in the study area and is the primary data needed to facilitate analysis. In addition, primary and secondary data information is also needed for comparison in this study. Among the data required for this study are:-

i. **Gap** - the time interval between the passage of consecutive vehicles moving in the same stream, measured between the rear of the lead vehicle and the front of the following vehicle.
ii. **Gap Accepted** – is the time gap between two consecutive conflicting vehicles that the u-turning vehicle makes a u-turn
iii. **Critical Gap** – Gap Study is the minimum time interval that allows entry tone vehicle and is acceptable to a driver. From gap study it also can find the follow up time (minimum headway between first vehicle and second vehicle)
iv. **Rejected Gap -** is the time gap between two consecutive conflicting vehicles that the u-turning vehicle declines to make a u-turn
v. **Speed Limit** – Pattern of speed limit of vehicle at study area whether speed at that location is suitable or not.
vi. **Stopping Sight Distance** – distance of the driver needs to be able to see the midblock U-turn opening.
vii. **Free Flow Speed -** the speed that occurs when density and flow are zero.
viii. **Speed -** the time rate of change of distance.
ix. **Flow** – the number of vehicles passing a point per unit of time; often called volume when the time unit is one hour.
x. **Density** – the number of vehicles occupying a road lane per unit length at a given instant.

2.6 Speed, Flow and Density Relationship

Speed, flow, and density are all related to each other. The relationships between speed and density are not difficult to observe in the real world, while the effects of speed and density on flow are not quite as apparent (Hughes, 2002).

Under uninterrupted flow conditions, speed, density, and flow are all related by the following equation:

$$q = k \times v \qquad 2.1$$

Where ;
q = Flow (vehicle/hour)
v = Speed (mile/hour, kilometer/hour)
k = Density (vehicle/mile, vehicle/kilometer)

Because flow is the product of speed and density, the flow is equal to zero when one or both of these terms is zero. It is also possible to deduce that the flow is maximized at some critical combination of speed and density. Two common traffic conditions illustrate these points. The first is the modern traffic jam, where traffic densities are very high and speeds are very low. This combination produces a very low flow. The second condition occurs when traffic densities are very low and drivers can obtain free flow speed without any undue stress caused by other vehicles on the roadway. The extremely low density compensates for the high speeds, and the resulting flow is very low.

2.6.1 Speed

Speed is the distance covered per unit time (Guin, 2006). One cannot track the speed of every vehicle, in practice, average speed is measured by sampling vehicles in a given area over a period of time. Two definitions of average speed are identified as time mean speed and space mean speed.

i. Time mean speed is measured at a reference point on the roadway over a period of time (RT Underwood, 1960). In practice, it is measured by the loop detectors. Loop detectors, when spread over a reference area, can identify each vehicle and can track its speed. However, average speed measurements obtained from this method are not accurate because instantaneous speeds averaged over several vehicles do not account for the difference in travel time for the vehicles that are traveling at different speeds over the same distance.

ii. Space mean speed is measured over the whole roadway segment (H Rakha, W Zhang, 2005). Consecutive pictures or video of a roadway segment track the speed of individual vehicles, and then the average speed is calculated. It is considered more accurate than the time mean speed. The data for space calculating space mean speed may be taken from satellite pictures, a camera, or both.

2.6.2 Flow

Flow is the number of vehicles passing a reference point per unit of time, vehicles per hour. The inverse of flow is headway, which is the time that elapses between the number of vehicle passing a reference point in space and the number of vehicle. In congestion, headway remains constant. As a traffic jam forms, headway approaches infinity. Knowledge of fundamental traffic flow characteristics, namely, speed, volume, and density and the related analytical techniques is an essential requirement in planning, design, and operation of transportation systems. Fundamental traffic flow characteristics have been studied at three levels: microscopic, mesoscopic, and macroscopic. Existing traffic flow models are based on time headway, flow, time-space trajectory, speed, distance headway, and density. These models lead to the development of a range of analytical techniques such as demand-supply analysis, capacity and level-of-service analysis, traffic stream modeling, shock-wave analysis, queuing analysis, and simulation modeling (May 1990).

2.6.3 Density

Traffic density is the third fundamental traffic flow characteristic. It is an important characteristic that engineers can use in assessing traffic performance from the point of view of users and system operators. Engineers also employ it as the central variable in freeway control and surveillance systems. For example, the Highway Capacity Manual (HCM, 1994) uses traffic density as the primary LOS measurement for uninterrupted flow situations (freeways and highways). Traffic density also plays an important role in system-wide traffic performance evaluations and on-line traffic-responsive freeway control systems.

Density is defined as the number of vehicles per unit length of the roadway. In traffic flow, the two most important densities are the critical density and jam density refer Figure 2.3. The maximum density achievable under free flow is critical density, while jam density is the maximum density achieved under congestion. In general, jam density is seven times the critical density. Inverse of density is spacing, which is the center-to-center distance between two vehicles. The density within a length of roadway at a given time is equal to the inverse of the average spacing of the number of vehicles.

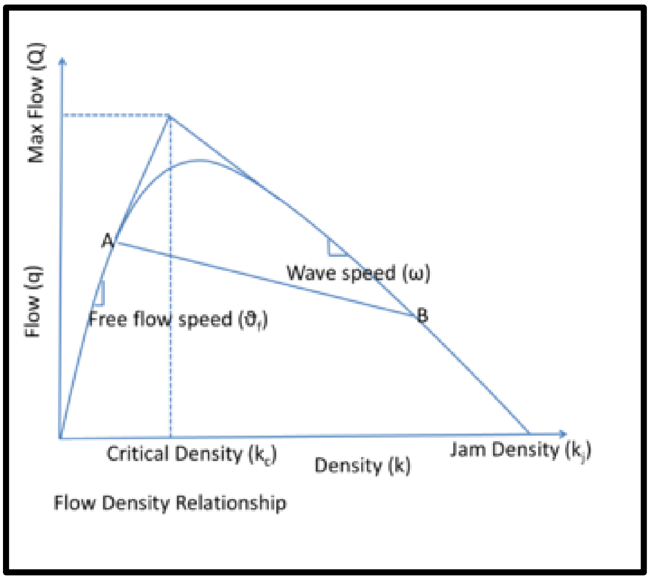


Figure 2.3: Flow Density Relationship Graph

2.7 Free Flow Speed

Free flow speed (FFS) is referred to the vehicles that is desired speed on a road segment at low traffic flow or low traffic density condition and in the absence of traffic control devices (Liao, M. , Li, K., Du, X. and Wang, K , 2007). It is a significant variable used in assessing the expected operating conditions or level of service (LOS) of highways. A key step in the capacity and LOS analyses of two-lane highways in the determination of FFS through which average travel speed (ATS), a key LOS indicator for the subject road class is estimated. The Highway Capacity Manual 2010 (HCM2010) suggests an indirect method for field measurement of FFS based on the operating conditions of the highway in terms of base free flow speed (BFFS) and geometric features regarded as factors influencing FFS. It is however, recommended by the HCM 2010 that direct field measurement of FSS is the most preferred approach. Other sources suggested that FFS be measured as the mean speeds of unimpeded vehicles travelling with headways greater than 8 seconds based on spot observation.

2.8 Gap

Gap is very similar to headway, except that it is a measure of the time that elapses between the departure of the first vehicle and the arrival of the second at the designated test point. Gap is a measure of the time between the rear bumper of the first vehicle and the front bumper of the second vehicle, whereas headway focuses on front-to-front times. Gap is also reported in units of seconds. Figure 2.4 illustrates the difference between gap and headway.

In the context of this study, a gap is defined as the time duration (in seconds), measured at the same point in space, between the rear bumper and the front bumper of two consecutive vehicles. According to Ashlata R. (1966), most researchers define gap as the time interval between two successive vehicles measured at a specific reference point. The critical gap is defined as the minimum time length (in seconds) of a gap in traffic which will permit (on average) a side street vehicle, a single pedestrian, or a group of pedestrians to cross a roadway of specified width without coming into conflict with passing vehicles. In the case of side street traffic, this value may also represent the time length of a gap in traffic permitting side street vehicles to merge into the traffic stream between two vehicles (Manual on Uniform Traffic Studies, 2000).

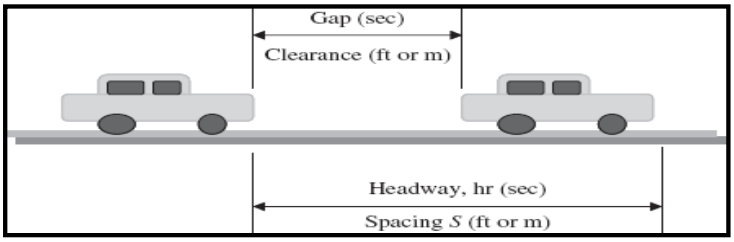


Figure 2.4: Illustration of gap and headway definition.

2.8.1 Gap Acceptance

According to Othman Che Puan (2015), the gap acceptance is a task that drivers perform so regularly that it occurs nearly at a subconscious level. However, being able to successfully complete this task is essential in order to drive safely. Not all drivers display the same gap acceptance behaviour and even same driver can react differently in different locations and under different conditions. Gap acceptance data can be collected and analyzed in a number of different ways. However, the principles of each method are quite similar. The best way to collect data on driver's gap acceptance behaviour is through direct field observations. When traffic is congested, drivers may choose to behave more aggressively and accept smaller gaps than is modelled by standard parameters. Existing condition may therefore be hard to reproduce unless more aggressive parameters are adopted.

Based on Guo, R & Lin, B (2011), gap assessment study was conducted to collect the number of accepted and rejected gap. The numbers of accepted and rejected gap was collected using video camera. Currently, the most common way to observe gap acceptance behaviour in the field is to set up video surveillance equipment at the site and then process the data off-site. Processing the data generally involves slowly advancing the recording and capturing time stamps of each vehicle passing through the intersection. This is a very time consuming process, however the results are generally thought to be quite accurate. Once the gap data was collected and analysed, curves representing the frequency of rejection and acceptance of gaps were developed. Based on Noel Kay (2006), the calculated gap acceptance parameters were applied in a micro simulation model and compared with observed travel times. These showed a better level of fit compared to the use than the default value. Hamed & S. M. Easa (1997) was defined gap acceptance is an important factor in evaluating delays, queue lengths, and capacities at unsignalized intersections. Gap acceptance may also be used to predict the relative risk at intersections, where smaller gaps generally imply higher accident risk (Polus, 1985).

2.8.2 Critical Gap

In Malaysia, the critical gap acceptance is still being used as in the existing guideline for unsignalised intersection (Arahan Teknik Jalan, 11/1987). However, the use of the gap acceptance procedure does not take into consideration the mixed traffic flow condition prevalent on Malaysian road. In this study, critical gap acceptances under normal saturation flow condition were estimated for unsignalised. Critical gap is an important parameter for capacity calculation. There are different values of critical gaps for drivers in different geometry and traffic conditions. The problem is the critical gaps cannot be measured directly. For gap acceptance, (TRB, 2000) most researchers agreed that it is difficult to measured critical gap directly in the field. Consequently, some statistical model or procedure for estimating critical gaps at unsignalized intersections is needed. Based on Al-Taie (2010), the critical gap is defined as the minimum time length (in seconds) of a gap in traffic which will permit (on average) a side street vehicle, a single pedestrian, or a group of pedestrians to cross a roadway of specified width without coming into conflict with passing vehicles. In the case of side street traffic, this value may also represent the time length of a gap in traffic permitting side street vehicles to merge into the traffic stream between two vehicles. Values of critical gaps are different for different drivers (some of them are too fast or risky, some of them are slow or careful) and there are dependent on types of movements, geometry parameters of intersections, traffic situation. Due to this variability gap acceptance process is consider as a stochastic process and the critical gaps are random variables. The estimation of critical gaps tries to find out values for the variables and as well as for the parameters of their distributions, which represent typical driver behavior at the investigated intersection. The Californian Department (2012) of motor vehicle advises the the drivers to use minimum gap of 4.0 seconds to merge on a motorway.

2.9 The Raff's Method

This method is based on macroscopic model and it is the earliest method for estimating the critical gap which is used in many countries because of its simplicity. This method involves the empirical distribution functions of accepted gaps and rejected gap. When the sum of cumulative probabilities of accepted gaps and rejected gaps is equal to one then a gap of length is equal to critical gap. It means the number of rejected gaps larger than critical gap is equal to the number of accepted gaps smaller than critical gap. The critical lag is the size lag which has the property that the number of accepted lags shorter than is the same as the number of rejected lags. A similar definition was proposed by Drew (1968) but for gaps rather than lags. So critical gap can be derived from the cross point between the number of curves of accepted gaps and rejected gaps. Raff's method is also called threshold method. The flow rate of major road has a prominent influence on critical gap value. The method is used widely in many countries owing to its simplicity and practicality.

Raff's process was first established to estimate the critical lag. The process only used the lags offered to drivers; that is the time between the arrival of a minor stream vehicle at a stop or give way line to the arrival of the next vehicle in the major stream. Each driver is offered one lag and they can then decide to accept or reject it depending on each driver's critical lag. The critical gap is assumed to have the same value as the critical lag. For Raff's method, the critical lag can be evaluated when the number of accepted lags shorter than the critical lag is equal to the number of rejected lags longer than the critical lag.

Raff's method was used in many countries in earlier times. Because of its simplicity, it is still being used today in some research projects (Wu, 2006). By using raff's method to analyse the data, Figure 2.5 below show the example of raff's method graph. Raff's method can be expressed as shown below:-

$$1 - Fr\ (t) = Fa(t) \qquad 2.2$$

.where *t* is headway of major stream *Fa(t)* is cumulative probability of accepted gap *Fr(t)* is cumulative probability of rejected gap.

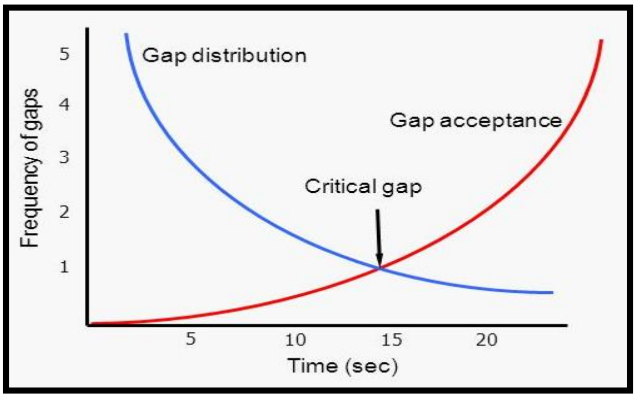


Figure 2.5: Example of Raff's Method Graph

2.10 Greenshield's Model

Greenshield was able to develop a model of uninterrupted traffic flow that predicts and explains the trends that are observed in real traffic flows (Adolf D. May,1990). While Greenshield's model is not perfect, it is faily accurate and relatively simple. From this model, it can give an assumption on under uninterrupted flow conditions, speed and density are linearly related. This relationship is can be expressed mathematically and graphically. Based on Ben-Edigble (2010), to compare with Greenshield's hypothesis of linear relationship model for speed versus density, speed versus flow and flow versus density need to be analyse. There are 3 types of relationship in this model which is:-

i. Relation between Speed and Density

ii. Relation between Speed and Flow

iii. Relation between Flow and Density

From this model, it can give an assumption on under uninterrupted flow conditions, speed and density are linearly related. This relationship is can be expressed mathematically and graphically.

2.10.1 Relationship between Speed and Density

Macroscopic stream models represent how the behaviour of one parameter of traffic flow changes with respect to another. Most important among them is the relation between speed and density. Greenshield assumed a linear speed-density relationship as illustrated in Figure 2.6 to derive the model. The equation for this relationship is shown below.

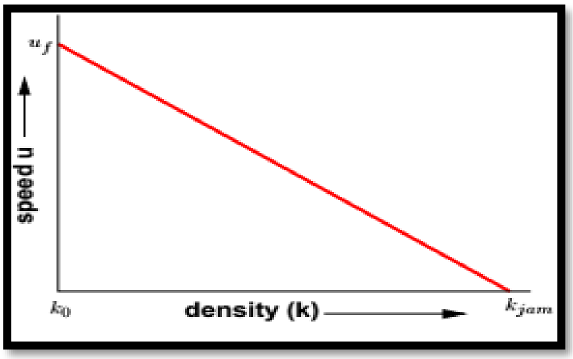


Figure 2.6: Relationship between Speed and Density

$$v = v_f - \left[\frac{v_f}{k_j}\right].k \qquad 2.3$$

where v is the mean speed at density k, vf is the free speed and kj is the jam density. This equation is often referred to as the Greenshields' model. It indicates that when density becomes zero, speed approaches free flow speed.

2.10.2 Relationship between Speed and Flow

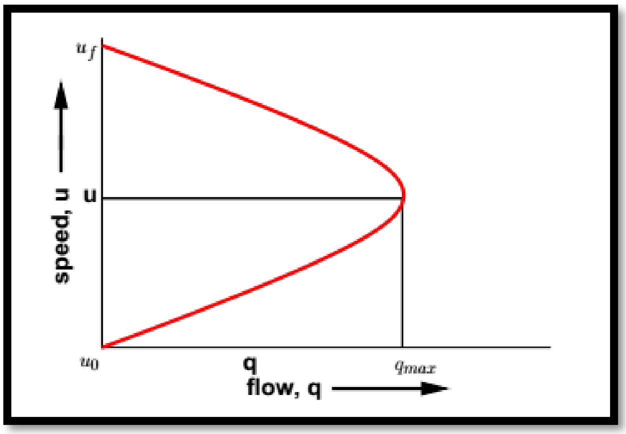


Figure 2.7: Relationship between Speed and Flow

Once the relation between speed and flow is established, the relation with flow can be derived. This relation between flow and density is parabolic in shape and is shown in Figure 2.7. Also, we know that

$$q = k.v \qquad 2.4$$

2.10.3 Relationship between Flow and Density

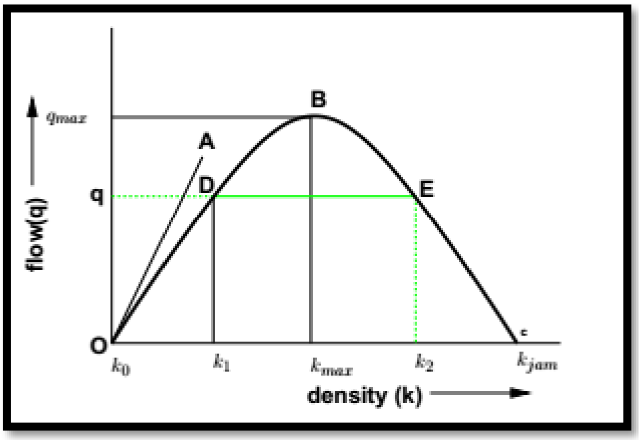


Figure 2.8: Relationship between Flow and Density

Now substituting equation 1 in equation 2, we get

$$q = v_f.k - \left[\frac{v_f}{k_j}\right] k^2 \qquad 2.5$$

$$k = \frac{q}{v} \qquad 2.6$$

Similarly we can find the relation between speed and flow. For this, put in equation 1 and solving, we get

$$q = k_j.v - \left[\frac{k_j}{v_f}\right] v^2 \qquad 2.7$$

This relationship is again parabolic and is shown in Figure 2.8. Once the relationship between the fundamental variables of traffic flow is established, the boundary conditions can be derived. The boundary conditions that are of interest are jam density, free flow speed, and maximum flow. To find density at maximum flow, differentiate *k* equation 3 with respect to and equate it to zero, for example:-

$$
\begin{aligned}
\frac{dq}{dk} &= 0 \\
v_f - \frac{v_f}{k_j}.2k &= 0 \\
k &= \frac{k_j}{2}
\end{aligned}
\qquad 2.8
$$

Denoting the density corresponding to maximum flow as k_o,

$$
k_0 = \frac{k_j}{2} \qquad 2.9
$$

Therefore, density corresponding to maximum flow is half the jam density Once we get, we can derive for maximum flow, *qmaz*. Substituting equation 5 in equation 3

$$
\begin{aligned}
q_{max} &= v_f.\frac{k_j}{2} - \frac{v_f}{k_j}.\left[\frac{k_j}{2}\right]^2 \\
&= v_f.\frac{k_j}{2} - v_f.\frac{k_j}{4} \\
&= \frac{v_f.k_j}{4}
\end{aligned}
\qquad 2.10
$$

Thus the maximum flow is one fourth the product of free flow and jam density. Finally to get the speed at v_o maximum flow, , substitute equation 5 in equation 1 and solving we get,

$$
\begin{aligned}
q_{max} &= v_f.\frac{k_j}{2} - \frac{v_f}{k_j}.\left[\frac{k_j}{2}\right]^2 \\
&= v_f.\frac{k_j}{2} - v_f.\frac{k_j}{4} \\
&= \frac{v_f.k_j}{4}
\end{aligned}
\qquad 2.11
$$

Therefore, speed at maximum flow is half of the free speed.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

In this chapter, the case study will focus on the effective methods to get more detailed information. Through this chapter, it will develop a better. understanding about the research in detail, particularly how research is conducted and the information that will be discussed. In a research, the important thing is a process and how the way to interpret the correct data so that the research will do smoothly and the information provided are true and have their evidence. In general, there are two methods of carrying out the research which is qualitative methods and quantitative methods but there is some research that carries both methods. In this research, the author uses qualitative methods in which the authors work on site by planting the devices to get data. The data is very useful to the study to gain more information. This chapter will discuss briefly about the methodology that has been used in this study. It will also describe the locations of case study data collection, the equipment used, the equations used, the statistical and mathematical analysis and the Highway Standard.

3.2 Chart Review Methodology

In this study, the first step is to provide a flow chart of the study as shown in Fiqure 3.1, to implementation of the study. At the beginning of this study, related research has been studied to find the scope of case study which is relate with this topic. The location of the study determined before doing the next job processes. The next process is a set of data from metrocount that is needed in this study. Then determine the appropriate method of observation and observation of work done on site. Results of observation data gathered and analysed. After analysis, the analyses of the study are discussed and finally conclusions and recommendations made.

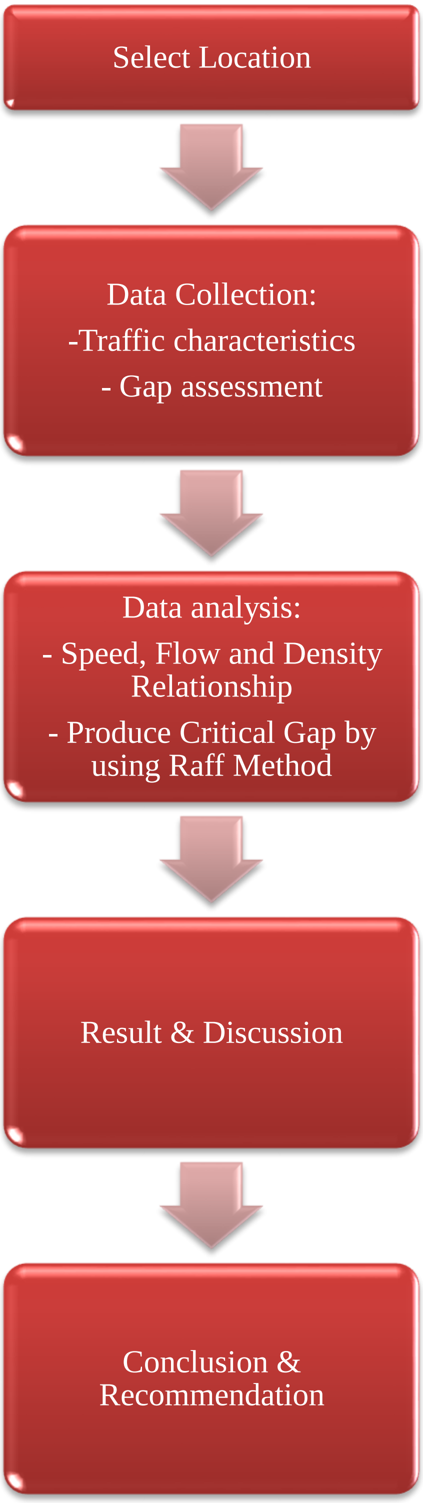


Figure 3.1: Flow Chart Methodology

3.3 Site Location

In this study, the following criteria were applied in the site selection process:

i. This location has been chosen because it is significance as major road that form a backbone of Kuantan road network
ii. The selected site is on a multilane divided highway
iii. The type of road design is JKR (U5) which is Partial Access Control
iv. There should be an exclusive U-turn at the median opening, thus, the vehicle need to queue at the U-turn lane and then wait for a suitable gap to enter the fast lane
v. The U-turn volume at the selected site should not be too small in order to record as many observations as possible during a certain period of time.

3.4 Description of the Study Area

The study area from two places are considered in such a mode that the road networks give the required input data for analyzing critical gap and comparing the same between different modes of transport. Median U-turn openings at four-lane are considered in the present study. In this study, the maximum speed limit for this study area is 80-90 km/h.

3.5 Study Location

In this study, midblock U-turn opening at Jalan Tanah Putih area was selected as study area to collect all data needed for the analysis. The midblock U-turn is selected based on the reasons that were stated in previous chapter. The view of midblock U-turn selected is shown in Figure 3.2

Figure 3.2: Selected Midblock U-turn Opening

3.6 Data Collection

Data collection needed for this study was critical gap and speed, flow and density of traffic stream through the study area. Data observed manually by using video recording and site measurement for stopping sight distance. The observations has be done for about few weeks until all the required data is acquired amd the result was then presented in the table so that the analysis can be done later. The data analysis can be separated in two parts that is traffic characteristics data and gap assessment data from video recording. According to Vien (2008), data for gap assessment is observed manually by using video recording and site measurement for stopping sight distance. The application of a recording method for traffic data collection has many advantages.

3.6.1 Traffic Characteristics

The parameter of data collection for traffic characteristic is speed, traffic composition, headway and volume. The method to get data for free flow speed, speed, flow, headway, volume and density is observed using metrocount. This metrocount is placed in three condition as shown in Figure 3.3 :-

i. Point A and B – To obtain the traffic parameter data which is speed, flow and density by using metrocount

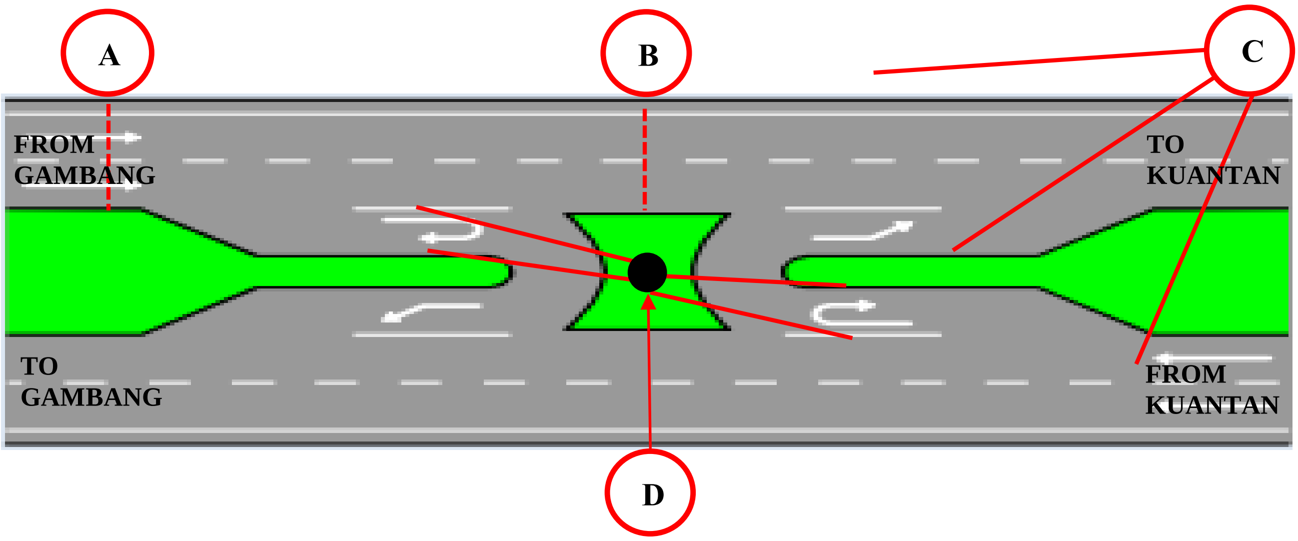


Figure 3.3: The condition of metrocount placed

3.6.2 Critical Gap Assessment

For gap assessment data is observed using a video recorded and radar gun. This video recorded which records vehicles entering the U-turn and through the first and last lines. During observations, it is need to ensure that the vehicle is observed to move from the driveway and make U-turns to enter the major road. For this data collection, the video recorder and radar gun is placed as shown in Figure 3.3 :-

i. Point C – To obtain the gap assessment data by using video recording

ii. Point D – To obtain the passenger car speed by using radar gun

Data observed for four hours, during peak time at 7.00 am – 11.00 am. When the vehicles enter and exit from the midblock U-turn opening which is the vehicle will passing through the U-turn to major road, the video recorded will be analysed to get the crititcal gap. Gap is to determine by the difference of time of vehicle from the storage area to merging with major road.

3.7 Research Equipment

In this study, observations have been using a metrocount, video recorder and measurement apparatus. The list of equipment used for this study show in Figure 3.4 below.

No.	Equipment	Number / Unit
1.	Metrocount	1
2.	Video Recorder	1
3.	Radar Gun	1
4.	Tape measurement	1
5.	Safety Jackets	1
6.	Data sheet gap assessment	1

Figure 3.4: List of Equipment Used for Research Purposes

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter was discussed about the results that had acquired from the observation conducted to get the necessary data. Traffic characteristics was counted automatically during peak hour by using metrocount. The collected data from metrocount will provide the classes of vehicle, speed, flow and volume. For the gap assessment study, the video camera was used to record the accepted and rejected gap. The gap assessment study was performed in four hours and one camera are placed at the site.

The analysis was conducted to view the real situation for the problem that occurs at this midblock U-turn opening. From the early observation that has been done, this intersection was identified as one of the critical midblock U-turn especially during peak hour. The performance of this midblock U-turn was analysed in terms of their gap assessment study and traffic characteristics. From the analysis that has been done, the performance of this midblock U-turn can be identified either it is good or worst. Then, the recommendation was proposed to improve the performance of midblock U-turn opening. Therefore, the congestion and road accident problem that occur at the midblock U-turn can be reduced.

4.2 Traffic Characteristics

In this study, the traffic characteristics along Jalan Tanah Putih was observed such as the number of lane, speed limit, volume, density and flow. The equipment were used in this study are metrocount. The speed limit imposed at this site as stated by JKR is 80 km/h. From the observation, the free flow speed data are taken at 180 meter based on stopping sight distance (SSD) calculation before the conflict point which is the storage lane for midblock U-turn opening. The illustration of the free flow speed for this site shown at Figure 4.1.

$$SSD = 0.278\, Vt + \frac{V^2}{254(f \pm g)} \tag{4.1}$$

where :

SSD = required stopping sight distance, ft or m,

V = speed, km/h

t = perception – reaction time, sec, typically 2.5 sec for design

f = coefficient of friction

g = percent grade(% / 100)

$$\text{SSD} = 0.278\ (80)(2.5) + \frac{80^2}{254(0.30 \pm 0)} \tag{4.2}$$

SSD = 139.59m ≈ 140m

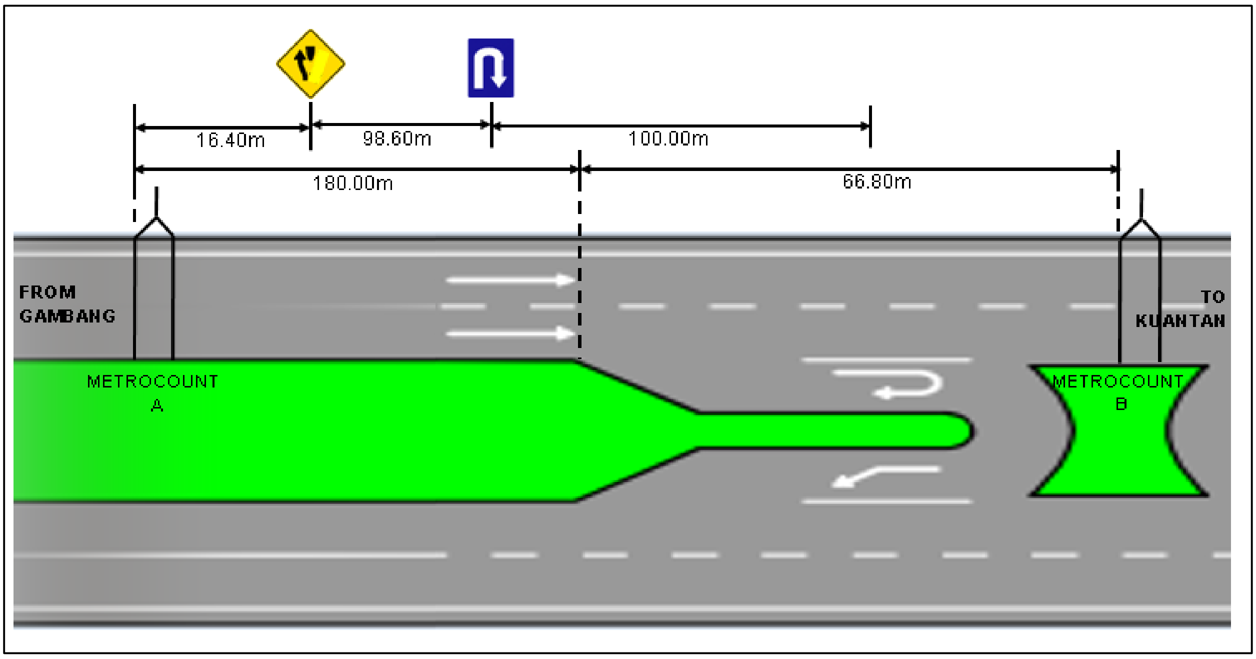


Figure 4.1: Illustration for Free Flow Speed

The primary traffic characteristics data collected were speed, flow and density that acquired from the observation. The data was collected during AM (7.00am – 11.00am). In three consecutive days Tuesday, Wednesday and Thursday.

4.2.1 Traffic Composition

From Table 4.1, there was the type of vehicle classes that has been analyse. Table 4.1 shows the summary results of the traffic composition at Jalan Tanah Putih.

Class	Type of Car
C1	Car, Taxi
C2	Small Van, Medium Lorry
C3	Heavy Lorry
C4	Bus
C5	Motorcycle

Table 4.1: Type of Vehicle Classes

These average traffic composition was divided into two part to observed the differences between major road and at U-turn facilities for four hours in three days The number of vehicles that using major road was slightly higher compare to the U-turn as shown in Table 4.2.

Vehicle Classes	Traffic Flow on Major Road		Traffic Flow at U-turn	
C1	6720	80.1%	2809	81.0%
C2	337	4.0%	104	3.0%
C3	8	0.1%	7	0.2%
C4	83	1.0%	62	1.8%
C5	1238	14.8%	488	14.1%

Table 4.2: Average Traffic Flow for 3 days

As shown from the traffic data obtained, private cars (C1) recorded the highest percentage of traffic followed by motorcycle on major road. The highest percentage of private cars on major road which was 80.1% of the total traffic.

4.2.2 Characteristics of Speed, Flow and Density

The traffic flow, speed and density between point A and Point B was to determined the differences which the point A data was taken at the free flow speed condition and point B was taken at the conflict point at the midblock U-turn facilities. These data was interpret in Table 4.3 below

Time	Point A			Point B		
	Speed (km/h)	Flow (veh/hr)	Density (veh/km)	Speed (km/h)	Flow (veh/hr)	Density (veh/km)
7.00-8.00	63	2638	42	62	2352	38
8.00-9.00	70	2237	32	69	2051	30
9.00-10.00	72	1837	26	70	1658	24
10.00-11.00	73	1674	23	70	1498	21

Table 4.3: Speed, Flow and Density at Point A and Point B

From Table 4.3, these data was taken as an average for three days to determined the speed,flow and density at point A and Point B. Therefore, the data observed shows that there was a differences in speed at point A and point B when the speed at point A slightly higher 63-73 km/h compared to the speed at point B during four hours observation.

The data from table 4.3 were interpreting in the graph to show the speed vs density, speed vs flow and flow vs density relationship between two point. Figure 4.2 below shown the speed vs density relationship for point A and point B.

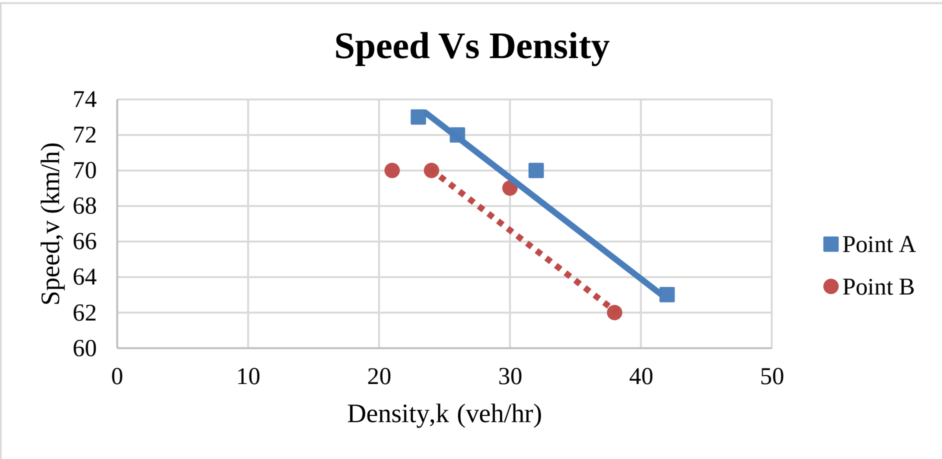


Figure 4.2: The Traffic Speed versus Traffic Density

These graph show the data retribution for the relationship between two point was slightly different and this were because of the conflict at point B, when the speed was higher by 73 km/h the density were lower by 23 veh/km. It shows that when the speed was higher the density were lower that make the vehicle to speed up at this road.

For Figure 4.3, these was the data for the speed vs flow relationship. From the speed vs flow relationship data, it shows that when the speed was increase then the flow will be decrease.

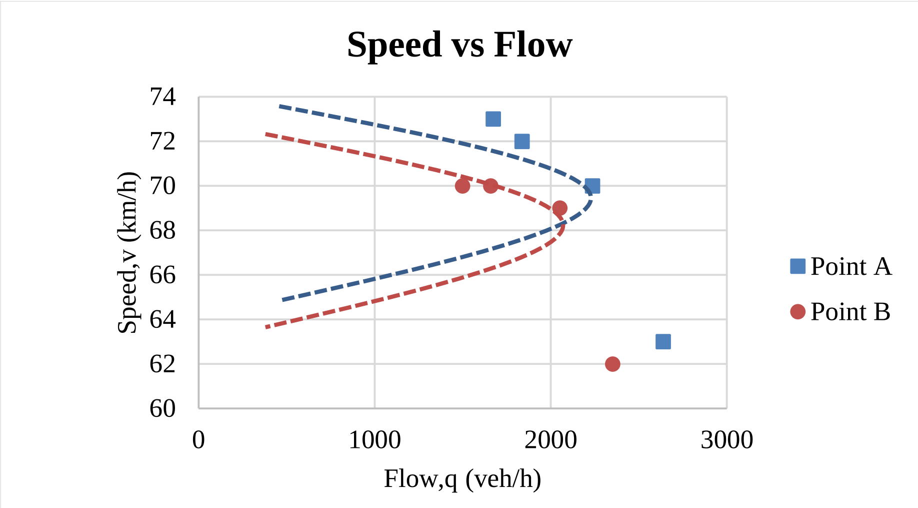


Figure 4.3: The Traffic Speed versus Traffic Flow

Based on observation, when the speed is higher the flow will decrease, it shows that the average vehicle will speed up until 73 km/h when the traffic flow was 1674 veh/h.

From figure 4.4, the flow vs density relationship shows the numbers of traffic flow and traffic density for three days during morning peak hour.

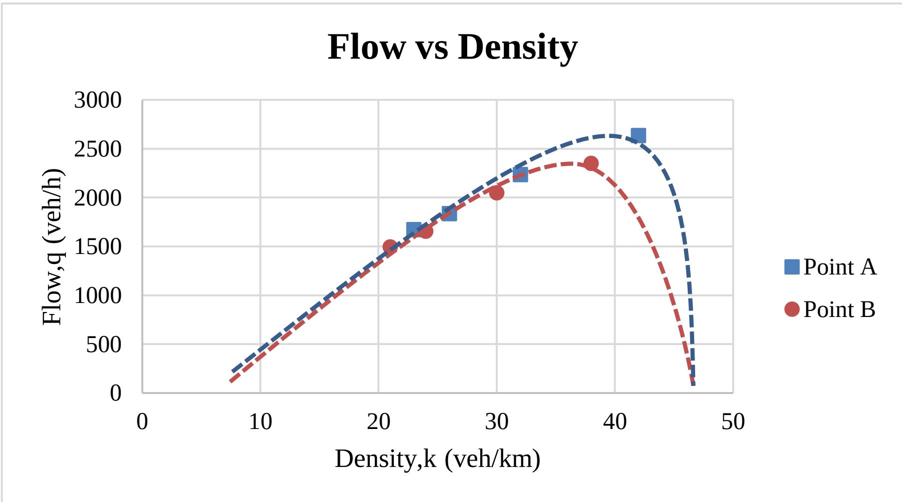


Figure 4.4: The Traffic Flow versus Traffic Density

From the analysis, the flow at point A was slightly higher than point B, this because many of the vehicle desire to used U-turn facilities that makes the traffic flow at point B decreased. The highest traffic flow was 2638 veh/h when the density were 42 veh/h. These analysis shows when the flow was higher the density also will be higher and it can cause congestion.

4.3 Critical Gap Assessment

In this part, gap assessment study was conducted to collect the number of accepted and rejected gap. The numbers of accepted and rejected gap was collected using video camera. The video camera was performed at one point which is the view of the camera was focused on the critical vehicle movement as shown in Figure 4.5 and Figure 4.6 shows the real situation of video recorder is placed.

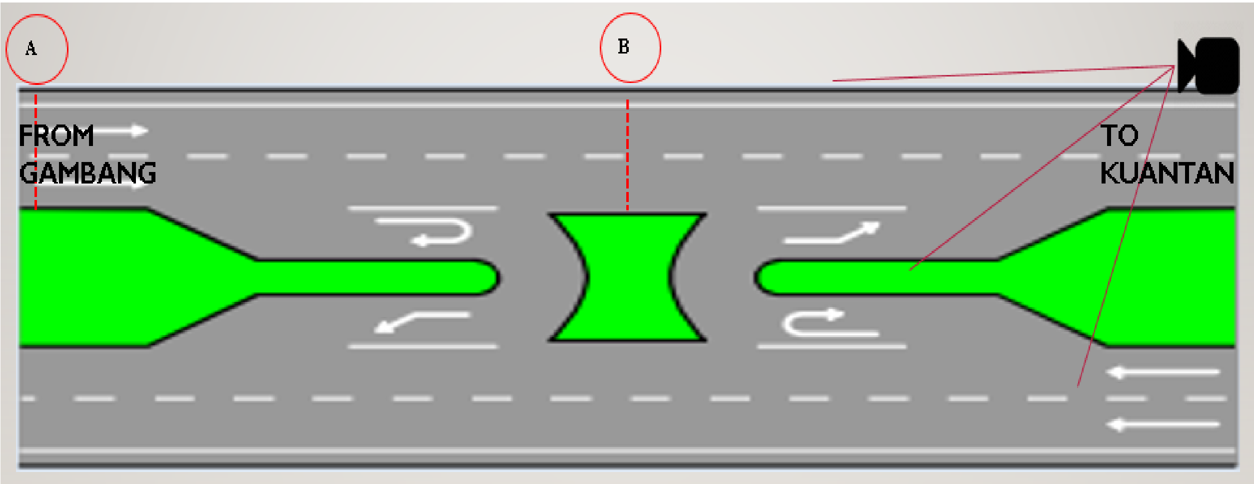


Figure 4.5: Position of Video Recorder

Figure 4.6: Video Recorder Placed On Site

Based on Figure 4.6, the video recorder was only record the vehicle on the storage lane to get the exactly time for accepted gap and rejected gap. The vehicle movement was recorded in four hours at 7.00am – 11.00 am for three days (Tuesday, Wednesday and Thursday). Then, the gap assessment data was analysed in details by using Raff's Method to determine the value of critical gap. From that, the curve representing the frequency of acceptance and rejected gap were developed.

4.3.1 Critical Gap

Critical gap value for each critical passenger car was determined. Gap acceptance describes the driver behaviour, such as the possibility of accepting the gap of a certain time given on the storage lane to merging into main lane. Driver was assumed to have a certain minimum gap to merging in to main road was called critical gap. Based on Figure 4.7, driver from storage lane was successfully merge into main lane. From this situation, it was considered passenger car from storage lane was accepted gap.

Figure 4.7: Situation of Accepted Gap by Passenger Car

Figure 4.8: Situation of Rejected Gap by Passenger Car

Based on Figure 4.8, the driver on the storage lane are waiting to decide a suitable gap from vehicles from main lane to merging. From this situation, it was considered driver on storage lane was a rejected gap.

Second objective in this study is to determine the critical gap results at storage lane of midblock U-turn opening to determine the safe merging gap for the midblock U-turn facilities. Data from video recorder is analysed by using Microsoft Excel to determine the value of critical gap. In this part, Raff's Method was used in determination of critical gap. The potential capacity of U-turn movement at median openings is affected by a number of factors. These factors include:

i. The conflict at the midblock U-turn opening that affect the main lane.
ii. The critical gap of passenger car to merge into the main lane
iii. The follow-up time for U-turn movement

Raff's method includes the distribution data of accepted gap and rejected gap. The sum of cumulative probabilities of accepted gap and rejected gap is one when the headway is equal to critical gap. By the Raff's definition, the percentage of rejected gap is equal to the percentage of accepted gap, it called critical gap. By using the graph, the critical gap can be determined.

The Raff's Method was employed to analyse the data from the field study, by using video recording for four hours (7.00am – 11.00am) during consecutive days, the accepted gap and rejected gap table shows in Table 4.4 below.

Length of Gap, t(s)	Gap Accepted	Cummulative Gap Accepted	Gap Rejected	Cummulative Gap Rejected
0 – 0.99	0	0	0	87
1.00 – 1.99	1	1	1	86
2.00 – 2.99	3	4	5	81
3.00 – 3.99	5	9	14	67
4.00 – 4.99	4	13	13	54
5.00 – 5.99	55	68	6	48
6.00 – 6.99	83	151	7	41
7.00 – 7.99	34	185	7	34
8.00 – 8.99	1	186	3	31
9.00 – 9.99	0	186	4	27
10.00 – 10.99	0	186	3	24
11.00 – 11.99	0	186	5	19
12.00 – 12.99	0	186	4	15
13.00 – 13.99	0	186	0	15
14.00 – 14.99	0	186	1	14
15.00 – 15.99	0	186	14	0

Table 4.4: Cummulative Accepted Gap and Rejected Gap

The graph for the data in Table 4.4 shows in Figure 4.9. The critical gap was taken as an average for three days. From the Table 4.4, the graph has been plotted to determine the critical gap which was the intersection between accepted gap and rejected gap are called critical gap.

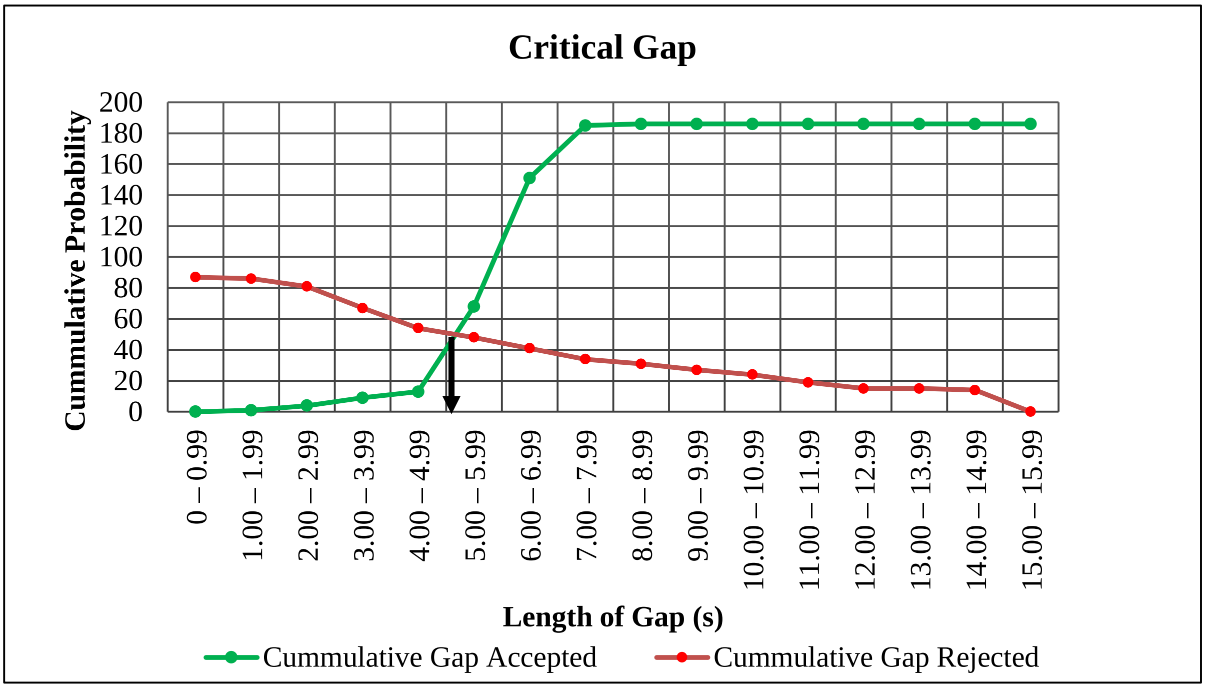


Figure 4.9 : Average Critical Gap

From the graph, the analysis has been done between the accepted gap and rejected gap data and the critical gap that has been analysed using Raff's Method was 5.0 second. These analysis show that the numbers of accepted gap for passenger car was higher compared to rejected gap.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter will summarize the studies that have been conducted and concluded based on the analysis and the results already obtained. Analysis based on traffic characteristics and critical gap assessment at midblock U-turn facilities has been chosen. Each passenger car takes a different gap to merge from storage lane to major road. This happen because there was an influenced by physical factors at surrounding area and driver behaviour. In addition, the problems faced during the study were presented and some suggestions to improve the study of the future will also be made.

5.2 Conclusion

This study was done to explore on traffic characteristics and critical gap assessment using Metrocount and Raff's Method. As stated before in chapter one, the objective of this study were:-

i. to identify the influence of midblock U-turn facilities towards traffic parameters of speed, flow and density relationship
ii. to determine the safe merging gap for the midblock U-turn facilities

It can be conclude that this study was achived all of the objectives. Based on the analysis that was discussed before in chapter four, the speed vs density, flow vs density and speed vs flow is complies with the Greenshield's Model and the value of critical gap was determined using Raff's method. Based on critical gap graph, the critical gap value was 5.0 seconds. According to Malaysia Public Work Department, the critical gap of this study was in range and also Transportation Research Board. Figure 5.1 shows the critical gap of this study.

Source of Information	**Type of Facility**	**Reported Gap (s)**
This Study	U-turn	5.0
Othman Che Puan	U-turn	4.0 - 4.5
Malaysia Public Work Department	U-turn	5.0 – 8.0
Transportation Research Board	U-turn	4.0 – 6.0

Figure 5.1: Reported Critical Gap

5.3 Recommendation

During the analysis, there were some problems that been faced in obtaining the data. Therefore, there were few recommendations for future study purposes that stated below:-

i. The metrocount need to placed far from the study area to get better free flow speed.

ii. The gap assessment observation using video camera need to placed on the right place that can see the overall traffic that might be easier to measure the gap acceptance and gap rejected.

iii. To determine the gap acceptance and rejection gap need a reference and base point on the study area that the process of counting will be easier.

REFERENCES

Liu, P., Lu, J. J., & Chen, H. (2008). Safety effects of the separation distances between driveway exits and downstream U-turn locations. Accident Analysis & Prevention, 40(2), 760-767.

Brilon, W., Koenig, R., & Troutbeck, R. J. (1999). Useful estimation procedures for critical gaps. Transportation Research Part A: Policy and Practice, 33(3-4), 161-186.

Ban, X., Herring, R., Hao, P., & Bayen, A. (2009). Delay pattern estimation for signalized intersections using sampled travel times. Transportation Research Record: Journal of the Transportation Research Board, (2130), 109-119.

Chevion, D. S., Ramm, D., Shimony, Y., & Sivan, R. (2011). U.S. Patent No. 7,969,324. Washington, DC: U.S. Patent and Trademark Office.

Akçelik, R. (2008, May). The relationship between capacity and driver behaviour. In Paper presented at the TRB National Roundabout Conference (Vol. 18, p. 21).

Chen, A., Yang, H., Lo, H. K., & Tang, W. H. (2002). Capacity reliability of a road network: an assessment methodology and numerical results. Transportation Research Part B: Methodological, 36(3), 225-252.

Papageorgiou, M., Diakaki, C., Dinopoulou, V., Kotsialos, A., & Wang, Y. (2003). Review of road traffic control strategies. Proceedings of the IEEE, 91(12), 2043-2067.

Rahman, R., & Johnnie, B. E. (2015). Impact of multilane median openings zone on travel speed. Jurnal Teknologi, 73(4), 15-20.

Liu, P., Lu, J. J., Hu, F., & Sokolow, G. (2008). Capacity of U-turn movement at median openings on multilane highways. Journal of Transportation Engineering, 134(4), 147-154

Chang, M. S. (1982). Conceptual development of exposure measures for evaluating highway safety. Texas Transportation Institute, Texas A & M University.

Pirdavani, A., Brijs, T., Bellemans, T., & Wets, G. (2011). Travel time evaluation of a U-turn facility: comparison with a conventional signalized intersection. Transportation Research Record: Journal of the Transportation Research Board, (2223), 26-33.

Puana, O. C., Ismaila, C. R., Hainina, M. R., Minhansa, A., Norb, N. S. M., & Bahru, U. J. (2015). Midblock U–Turn Facilities On Multilane Divided Highways: An Assessment of Driver's Merging Gap And Stop Delays. Jurnal Teknologi, 76(14).

Sundara, P., Hainin, M. R., Puan, O. C., & Zamli, K. Z. (2015). Influence of Darkness Dry and Darkness Rainfall on Malaysian Expressway for Traffic Characteristics using Greenshield's model.

Puan, O. C., Ibrahim, M. N. I., & Abdurrahman, U. T. (2014). Application of moving car observer method for measuring free flow speed on two-lane highways. Jurnal Teknologi (Sciences & Engineering), 69(6), 15-19

Al-Masaeid, H. R. (1999). Capacity of U-turn at Median Openings. Institute of Transportation Engineers. ITE Journal, 69(6), 28.

Zhou, H., Jalayer, M., Gong, J., Hu, S., & Grinter, M. (2013). Investigation of methods and approaches for collecting and recording highway inventory data.

Guin, A. (2006). Travel time prediction using a seasonal autoregressive integrated moving average time series model. In Intelligent Transportation Systems Conference, 2006. ITSC'06. IEEE (pp. 493-498). IEEE.

Hamed, M. M., Easa, S. M., & Batayneh, R. R. (1997). Disaggregate gap-acceptance model for unsignalized T-intersections. Journal of transportation engineering, 123(1), 36-42.

Ashworth, R. and Green, B.D.(1966). Gap Acceptance at an Uncontrolled Intersection. Traffic Engineering and Control,7(11):676-678

Ashalata R. and Satish Chandra. (2011). Critical Gap through Clearing Behaviour of Drivers at Unsignalized Intersections. KSCE Journal of Civil Engineering.15(8):1427-1434

Abdul Khalik Al-Taei. (2010). Gap Acceptance and Traffic Safety Analysis on U-turn Median Openings of Arterial Roads. Al-Rafidain Engineering Journal.18(6):42-53

Ashworth, R. (1976). A Videotape-Recording System for Traffic Data Collection and Analysis. Traffic Engineering and Control.17(11):468-470.

Vien, L. L., Ibrahim, W. H. W., & Mohd, A. F. (2008, July). Effect of motorcycles travel behaviour on saturation flow rates at signalized intersections in Malaysia. In 23rd ARRB Conference–Research Partnering with Practitioners (pp. 1-11).

Nicholas J. Garber and Lester A. Hoel. (1999). Traffic and Highway Engineering. Washington: PWS Publishing. 201.

Gavulova, A. (2012). Use of statistical techniques for critical gaps estimation. In Twelfth International Conference on Reliability and Statistics in Transportation and Communication(pp. 20-26). Riga, Latvia: Transport and Telecommunication Institute.

Ben-Edigbe. J. (2010). Assessment of Speed-Flow-Density Functions under Adverse Pavement Condition. International Journal of Sustainable Development and Planning. Vol.5, No.3. pp.238-252.

Guo, R. & Lin, B. (2011). Gap Acceptance at Priority-Controlled Intersection, Jounal of Transportation Engineering, Vol.137, Iss.4, pp.269-276.

Greenshield, B.D. (1935). A study of Traffic Capacity. Highway Research Board Proceedings, 14. pp. 448-477

Hughes, R. L. (2002). A continuum theory for the flow of pedestrians. Transportation Research Part B: Methodological, 36(6), 507-535.

Transportation Research Board (2000), Highway Capacity Manual, Specia Report 209. 3rd Edition, National Research Council, Washington, D.C.

HPU. (2011). Malaysia HCM. Unsignalized Intersection. Malaysia: Highway Planning Units, Ministry of Work, Malaysia

Public Works Department Malaysia. (1997). Road Safety Audit – Guidelines for the Safety Audit of Roads and Road Projects in Malaysia. Public Works Department (Malaysia), Kuala Lumpur. 54.

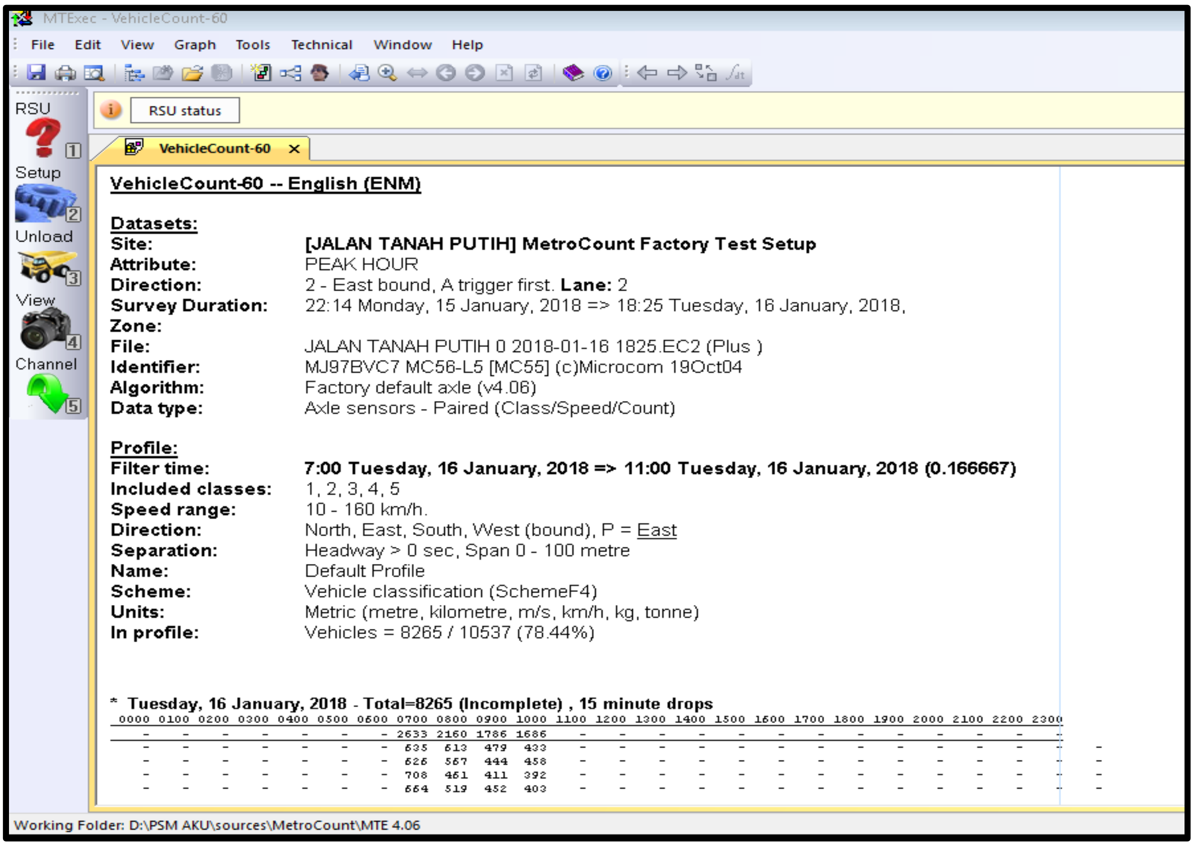
California Department of Motor Vehicles. (2012). California Driver Handbook. State of California. 54.

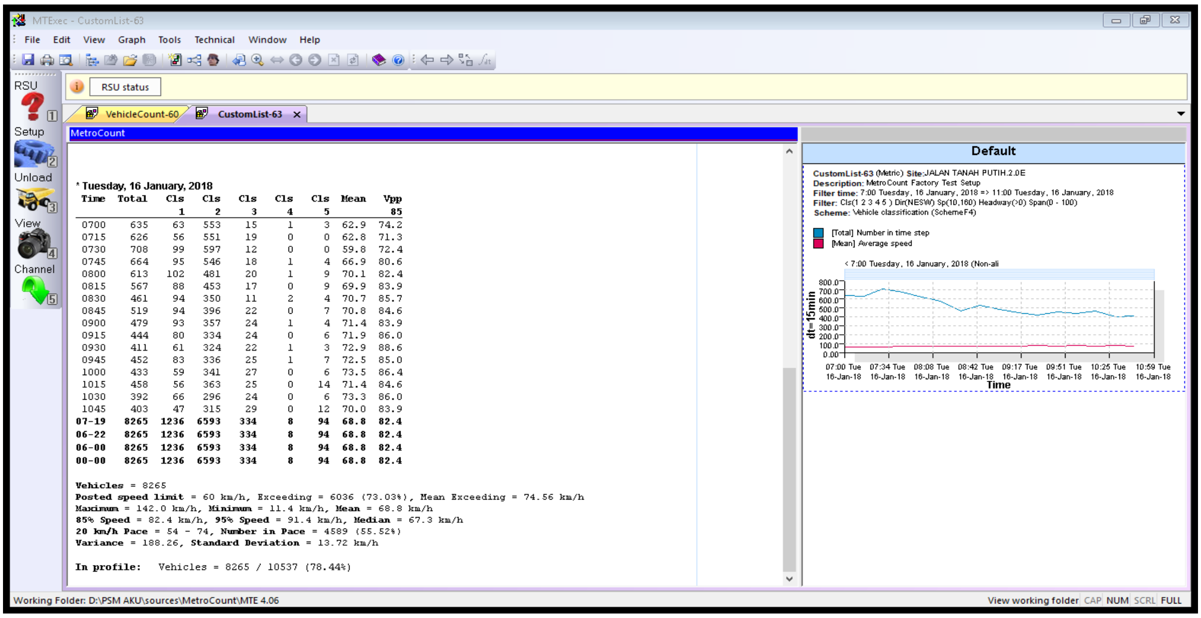
May, Adolf D. (1990). Traffic flow fundamentals.

Drew, D. R. (1968). Traffic flow theory and control (No. 467 pp).

APPENDIX A

SAMPLE DATA FROM METROCOUNT





* Tuesday, 16 January, 2018

Time	Total	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5	Mean	Vpp 85
0700	635	63	553	15	1	3	62.9	74.2
0715	626	56	551	19	0	0	62.8	71.3
0730	708	99	597	12	0	0	59.8	72.4
0745	664	95	546	18	1	4	66.9	80.6
0800	613	102	481	20	1	9	70.1	82.4
0815	567	88	453	17	0	9	69.9	83.9
0830	461	94	350	11	2	4	70.7	85.7
0845	519	94	396	22	0	7	70.8	84.6
0900	479	93	357	24	1	4	71.4	83.9
0915	444	80	334	24	0	6	71.9	86.0
0930	411	61	324	22	1	3	72.9	88.6
0945	452	83	336	25	1	7	72.5	85.0
1000	433	59	341	27	0	6	73.5	86.4
1015	458	56	363	25	0	14	71.4	84.6
1030	392	66	296	24	0	6	73.3	86.0
1045	403	47	315	29	0	12	70.0	83.9
07-19	**8265**	**1236**	**6593**	**334**	**8**	**94**	**68.8**	**82.4**
06-22	**8265**	**1236**	**6593**	**334**	**8**	**94**	**68.8**	**82.4**
06-00	**8265**	**1236**	**6593**	**334**	**8**	**94**	**68.8**	**82.4**
00-00	**8265**	**1236**	**6593**	**334**	**8**	**94**	**68.8**	**82.4**

Vehicles = 8265
Posted speed limit = 60 km/h, **Exceeding** = 6036 (73.03%), **Mean Exceeding** = 74.56 km/h
Maximum = 142.0 km/h, **Minimum** = 11.4 km/h, **Mean** = 68.8 km/h
85% Speed = 82.4 km/h, **95% Speed** = 91.4 km/h, **Median** = 67.3 km/h
20 km/h Pace = 54 - 74, **Number in Pace** = 4589 (55.52%)
Variance = 188.26, **Standard Deviation** = 13.72 km/h

In profile: Vehicles = 8265 / 10537 (78.44%)

APPENDIX B

GAP ASSESSMENT DATA SHEET

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

FACULTY OF CIVIL ENGINEERING & EARTH RESOURCES
UNIVERSITI MALAYSIA PAHANG

GAP ASSESSMENT DATA SHEET

LENGTH OF GAP,t (s)	**GAP ACCEPTED,** *less than t (s)*	**CUMMULATIVE GAP ACCEPTED**	**GAP REJECTED** *greater than t (s)*	**CUMMULATIVE GAP REJECTED**
0 – 0.99				
1.00 – 1.99				
2.00 – 2.99				
3.00 – 3.99				
4.00 – 4.99				
5.00 – 5.99				
6.00 – 6.99				
7.00 – 7.99				
8.00 – 8.99				
9.00 – 9.99				
10.00 – 10.99				
11.00 – 11.99				
12.00 – 12.99				
13.00 – 13.99				
14.00 – 14.99				
15.00 – 15.99				

APPENDIX C

SPOT SPEED DATA FOR U-TURN

FACULTY OF CIVIL ENGINEERING & EARTH RESOURCES
UNIVERSITI MALAYSIA PAHANG
SPOT SPEED STUDY DATA SHEET

Location : JALAN TANAH PUTIH **From :** 7.00 AM **To :** 11.00 AM
Name: MOHAMAD HILMI BIN HAMIZAN **Date/Day :** 23/01/2018 (TUESDAY) **Start Hours :** 7.00 AM
Group: - **Weather :** CLOUDY

No.	Km/h	No.	Km/h	No.	Km/h	No.	Km/h	No.	Km/h	No.	Km/h
1	46	26	45	51	47	76	47	101	47	126	44
2	40	27	48	52	25	77	46	102	42	127	45
3	45	28	40	53	39	78	46	103	43	128	46
4	34	29	46	54	45	79	46	104	46	129	43
5	40	30	52	55	43	80	47	105	45	130	42
6	43	31	40	56	40	81	48	106	46	131	46
7	35	32	48	57	48	82	43	107	41	132	43
8	39	33	43	58	43	83	47	108	38	133	44
9	47	34	46	59	44	84	34	109	35	134	43
10	45	35	40	60	36	85	45	110	42	135	39
11	46	36	47	61	50	86	41	111	47	136	48
12	35	37	40	62	49	87	42	112	46	137	44
13	46	38	40	63	48	88	48	113	44	138	46
14	48	39	35	64	32	89	43	114	45	139	44
15	46	40	43	65	45	90	42	115	43	140	43
16	47	41	43	66	43	91	44	116	49	141	45
17	48	42	49	67	44	92	48	117	41	142	48
18	40	43	38	68	46	93	49	118	44	143	44
19	42	44	35	69	45	94	45	119	43	144	33
20	38	45	39	70	41	95	47	120	46	145	37
21	43	46	45	71	35	96	50	121	46	146	46
22	45	47	25	72	25	97	34	122	44	147	44
23	47	48	48	73	47	98	45	123	32	148	34
24	40	49	49	74	48	99	48	124	46	149	44
25	42	50	40	75	38	100	48	125	46	150	41

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

FACULTY OF CIVIL ENGINEERING & EARTH RESOURCES
UNIVERSITI MALAYSIA PAHANG
SPOT SPEED STUDY DATA SHEET

Location : JALAN TANAH PUTIH **From :** 7.00 AM **To :** 11.00 AM
Name: MOHAMAD HILMI BIN HAMIZAN **Date/Day :** 23/01/2018 (TUESDAY) **Start Hours :** 7.00 AM
Group: - **Weather :** CLOUDY

No.	Km/h	No.	Km/h	No.	Km/h	No.	Km/h	No.	Km/h	No.	Km/h
151	40	176	42	201	44	226	48	251	44	276	45
152	49	177	45	202	47	227	44	252	43	277	49
153	48	178	47	203	40	228	41	253	45	278	51
154	49	179	51	204	42	229	38	254	39	279	42
155	45	180	43	205	46	230	41	255	40	280	48
156	39	181	41	206	48	231	40	256	42	281	45
157	49	182	44	207	49	232	40	257	43	282	46
158	43	183	46	208	44	233	42	258	41	283	46
159	43	184	48	209	40	234	49	259	42	284	41
160	38	185	50	210	41	235	48	260	47	285	40
161	47	186	41	211	40	236	45	261	47	286	38
162	40	187	43	212	42	237	43	262	48	287	35
163	42	188	49	213	44	238	47	263	39	288	41
164	39	189	52	214	43	239	49	264	40	289	42
165	48	190	39	215	38	240	51	265	45	290	45
166	51	191	42	216	35	241	50	266	46	291	44
167	46	192	41	217	39	242	43	267	42	292	44
168	43	193	45	218	41	243	41	268	32	293	43
169	44	194	47	219	34	244	38	269	35	294	41
170	39	195	49	220	41	245	40	270	39	295	42
171	41	196	48	221	47	246	41	271	28	296	43
172	47	197	46	222	50	247	37	272	30	297	42
173	50	198	42	223	48	248	35	273	41	298	41
174	38	199	35	224	47	249	39	274	44	299	37
175	35	200	40	225	44	250	41	275	49	300	39

FACULTY OF CIVIL ENGINEERING & EARTH RESOURCES
UNIVERSITI MALAYSIA PAHANG
SPOT SPEED STUDY DATA SHEET

Location : JALAN TANAH PUTIH **From :** 7.00 AM **To :** 11.00 AM
Name: MOHAMAD HILMI BIN HAMIZAN **Date/Day :** 23/01/2018 (TUESDAY) **Start Hours :** 7.00 AM
Group: - **Weather :** CLOUDY

No.	Km/h	No.	Km/h	No.	Km/h	No.	Km/h	No.	Km/h	No.	Km/h
301	48	326	48	351	46	376	44	401	38	426	35
302	38	327	48	352	46	377	41	402	35	427	40
303	47	328	47	353	44	378	40	403	42	428	44
304	46	329	42	354	45	379	49	404	45	429	47
305	46	330	43	355	46	380	48	405	47	430	40
306	46	331	46	356	43	381	49	406	51	431	42
307	47	332	45	357	42	382	45	407	43	432	46
308	48	333	46	358	46	383	39	408	41	433	48
309	43	334	41	359	43	384	49	409	44	434	49
310	47	335	38	360	44	385	43	410	46	435	44
311	34	336	35	361	43	386	43	411	48	436	40
312	45	337	42	362	39	387	38	412	50	437	41
313	41	338	47	363	48	388	47	413	41	438	40
314	42	339	46	364	44	389	40	414	43	439	42
315	48	340	44	365	46	390	42	415	49	440	44
316	43	341	45	366	44	391	39	416	52	441	43
317	42	342	43	367	43	392	48	417	39	442	38
318	44	343	49	368	45	393	51	418	42	443	35
319	48	344	41	369	48	394	46	419	41	444	39
320	49	345	44	370	44	395	43	420	45	445	41
321	45	346	43	371	33	396	44	421	47	446	34
322	47	347	46	372	37	397	39	422	49	447	41
323	50	348	46	373	46	398	41	423	48	448	47
324	34	349	44	374	44	399	47	424	46	449	50
325	45	350	32	375	34	400	50	425	42	450	48

FACULTY OF CIVIL ENGINEERING & EARTH RESOURCES
UNIVERSITI MALAYSIA PAHANG
SPOT SPEED STUDY DATA SHEET

Location : JALAN TANAH PUTIH **From :** 7.00 AM **To :** 11.00 AM
Name: MOHAMAD HILMI BIN HAMIZAN **Date/Day :** 23/01/2018 (TUESDAY) **Start Hours :** 7.00 AM
Group: - **Weather :** CLOUDY

No.	Km/h	No.	Km/h	No.	Km/h	No.	Km/h	No.	Km/h	No.	Km/h
451	45	476	46	501	44	526	48	551	43	576	41
452	44	477	46	502	45	527	49	552	43	577	40
453	46	478	48	503	47	528	48	553	42	578	46
454	48	479	47	504	47	529	47	554	45	579	40
455	50	480	46	505	48	530	45	555	46	580	45
456	51	481	45	506	51	531	44	556	42	581	34
457	48	482	44	507	52	532	39	557	41	582	40
458	46	483	44	508	50	533	38	558	41	583	43
459	45	484	43	509	48	534	40	559	40	584	35
460	47	485	39	510	49	535	41	560	42	585	39
461	48	486	38	511	46	536	42	561	43	586	47
462	48	487	35	512	45	537	41	562	42	587	45
463	39	488	37	513	45	538	42	563	44	588	46
464	38	489	29	514	46	539	45	564	41	589	35
465	40	490	29	515	47	540	44	565	42	590	46
466	41	491	35	516	44	541	46	566	40	591	48
467	43	492	37	517	42	542	46	567	41	592	46
468	43	493	41	518	38	543	50	568	42	593	47
469	42	494	45	519	39	544	51	569	44	594	48
470	45	495	47	520	41	545	50	570	45	595	40
471	46	496	44	521	43	546	48	571	40	596	42
472	47	497	43	522	44	547	49	572	41	597	38
473	48	498	40	523	45	548	48	573	41	598	43
474	49	499	41	524	44	549	47	574	42	599	45
475	47	500	42	525	44	550	44	575	40	600	47