STUDY OF GAP ACCEPTANCE FOR YIELD-CONTROLLED LEFT-TURNING LANE AT SIGNALISED INTERSECTIONS

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UNIVERSITI SAINS MALAYSIA
2017

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By

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This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering,
Universiti Sains Malaysia

June 2017

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2014/2015

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title: STUDY OF GAP ACCEPTANCE FOR YIELD-CONTROLLED LEFT-TURNING LANE AT SIGNALISED INTERSECTIONS

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I hereby declare that all corrections and comments made by the supervisor(s) and examiner have been taken into consideration and rectified accordingly.

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Approved by:

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(Signature of Examiner)

Name of Examiner :

Date :

ACKNOWLEDGEMENT

Immeasurable appreciation and deepest gratitude for the help and support are extended to the following persons who in one way or another have contributed in making this study possible.

Assc. Prof. Ir. Dr. Leong Lee Vien, supervisor and lecturer, for all the consistent guidance, encouragements, suggestions and advices she has provided throughout my final year for the final year project. Sharing her knowledge and helped in the analysis of data and valuable comments that benefited in the completion and success of this study.

Mr. Shamsul Ishak and Mr. Rasidi Razak, assistant engineers of the Traffic Lab, for the cooperations in providing all the equipments and materials needed for the study.

To staff members of School of Civil Engineering, for helping in providing all the informations and official letters needed for the research study.

To my family, especially my parents, for their love and, continuous moral and financial support over the years in making this study possible.

To my friends, especially Asyraf, Norazilah and Nadhira, for always listening, giving words of encouragement and being there when things get rough along the way in order to keep me going for the research study.

To my classmates, for all the assistance, time, worthy supports and lifting comments regarding the research study.

To the people who, directly or indirectly, have lent their helping hand in completing this study and making it a success.

ABSTRAK

Proses penerimaan ruang adalah satu proses di mana kenderaan menerima ruang yang tersedia untuk bergerak masuk ke dalam aliran trafik utama. Seseorang pemandu mesti menilai ruang antara kenderaan yang berpotensi untuk bercanggah di aliran trafik utama dan perlu membuat keputusan sama ada untuk memasuki aliran trafik utama atau tidak dengan menggunakan ruang yang ada.

Kekurangan kajian lepas yang mencukupi berkaitan penerimaan ruang bagi lorong belok kiri dengan tanda beri laluan di persimpangan berlampu isyarat di Malaysia telah memberi motivasi untuk membuat kajian lanjut. Kajian ini dilakukan untuk mengkaji ruang kritikal dan susualan masa di lorong belok kiri dengan tanda beri laluan di persimpangan berlampu isyarat dan juga melihat kepentingan kesan ruang kritikal terhadap tempoh masa dan masa menunggu.

Kaedah Raff digunakan untuk menganggar ruang kritikal di persimpangan yang telah dipilih untuk kajian ini. Kaedah Raff sering digunakan pada kajian lepas disebabkan kaedah ini memudahkan untuk mendapatkan ruang kritikal dan kaedah ini juga digunakan bagi kajian ini untuk mendapatkan ruang kritikal. Kaedah Raff menggunakan ruang yang ditawarkan kepada pemandu di mana ruang ialah masa antara ketibaan kenderaan yang dipandu oleh pemandu di garisan beri laluan dan ketibaan kenderaan seterusnya di aliran trafik utama. Seseorang pemandu ditawarkan satu ruang dan mereka perlu membuat keputusan sama ada ingin menerima atau menolak ruang yang ditawarkan.

Nilai ruang kritikal yang diperolehi untuk motosikal ialah 1.25 saat. Nilai jurang kritikal diperolehi untuk lorong belok kiri dengan lorong nyahpecutan ialah 1.25 saat dan dengan lorong belok kiri tanpa nyahpecutan ialah 1.20 saat.

ABSTRACT

Gap acceptance is a process where a vehicle accepts an available gap to manoeuvre in to the major traffic stream. A driver entering in to a major traffic stream must evaluate the space between potentially conflicting vehicles and have to decide whether to enter the lanes or not using the space available.

Lack of adequate past study on gap acceptance for yield controlled left-turning lanes at signalised intersections in Malaysia has provided motivation for the research study. Main study of this research is to study the critical gap and follow up time at the yield controlled left-turning lanes at signalised intersection and to observe the significance of the effect of the critical gap on the queue length and delay time.

Raff's method is used to estimate the critical gap at the intersection. Raff's method is frequently used because of its simplicity and also been used in the study. Raff's method used gaps offered to the drivers which is the time between the arrivals of minor stream vehicle at a give-way line to the arrival of the next vehicle in the major stream. Each driver is offered one gap and they can then decide to accept or reject the gap. The critical gap is assumed to have the same value as critical lag.

The value of critical gap obtained for motorcycles that used the yield controlled left-turning lanes at signalised intersection is 1.25 seconds. The value of critical gap obtained for left-turn lane with deceleration lane is 1.25 seconds and without deceleration lane is 1.20 seconds.

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LIST OF ABBREVIATION

AASHTO **A**merican **A**ssociation of **S**tate **H**ighway and **T**ransportation **O**fficials

HCM **H**ighway **C**apacity **M**anual

CHAPTER 1

INTRODUCTION

1.1 Background

In Malaysia, there is lack of adequate past study on gap acceptance for yield controlled left-turning lane at signalised intersection. There is not enough information in order to identify the effect of the gap acceptance of the yield controlled left-turning lane at signalised intersection on the queue length and delay time. Therefore, the purpose of this study is to also identify the significance of the gap acceptance on the queue length and delay time. The process to study the gap acceptance of a vehicle for yield controlled left-turning lane at signalised intersection can be affected by the factors surrounding the area selected for the study. The best method of observing the gap acceptance is through field study. Gap acceptance can be defined as a process by which a vehicle from a minor traffic stream accepts an available gap to manoeuvre in to the major traffic stream. Gap acceptance can also be defined as the minimum gap required for a vehicle from a minor traffic lane to merge into the major traffic lane. The gap refers to the time interval between successive vehicles that have the right-of-way and conflict with the driver’s desired movement. A driver entering in to a major traffic stream must evaluate the space between a potentially conflicting vehicle and have to decide whether to enter the lanes or not. Gap acceptance is the main parameters of intersection capacity and safety research. It is found out that a long-queue waiting time may reduce the driver’s critical gap and that drivers accept smaller gaps during peak periods than during off-peak hours.

The critical gap is the minimum time interval in the major-street traffic stream that allows intersection entry for one-minor-street vehicle. The critical gap is the minimum gap that would be acceptable. A particular driver would reject any gaps less than the critical gap and would accept gaps greater than or equal to the critical gap. The critical gap can also be defined as the minimum major-stream headway during which a minor-street vehicle can make a manoeuvre. The follow-up time is the time between the departure of one vehicle from a minor lanes and the departure of the next vehicle using the same gap under a condition of continuous queuing. Yield sign-controlled intersection is a type of unsignalised intersection which the entrance into the intersection is controlled by a yield sign. Drivers on an approach controlled by a yield sign are required to reduce the speed of the vehicle to concede the right-of-way to vehicles in the intersection.

The study was performed at different selected locations. It is assumed that each driver has some “critical gap.” A driver would accept a gap in the traffic stream if its duration is longer than his critical gap. The critical gap for a certain manoeuvre would vary across drivers. The most important characteristic of the gap is its length which is the duration. If a driver merges or crosses in a particular gap, he will be described as having “accepted” the gap and such a gap will be an “accepted gap.” Similarly, if a driver decides not to cross in a particular gap he will be said to have “rejected” the gap and such a gap will be a “rejected gap.” The critical gap is the smallest gap that a driver is willing to accept to merge with the traffic and mainly determines the gap acceptance behavior of the driver. The critical gaps are not directly observable. Only gaps that drivers have accepted or rejected are observed.

1.2 Problem Statement

The importance of gap acceptance in terms of capacity analysis is to increase the level of service to traffic facilities under different traffic conditions. Not having accurate gap acceptance values can affect capacity analysis at a signalised intersection as it can increase the delay time and queue length at the intersection. In Malaysia, there is very few past study about gap acceptance and there is no exact value for the gap acceptance for the yield controlled left-turning lane at signalised intersection. The study is conducted to obtain the value of gap acceptance for the yield controlled left-turning lane at signalised intersection.

1.3 Objectives

i. To study the critical gap at the yield controlled left-turning lane with deceleration lane at signalised intersections.
ii. To study the critical gap at the yield controlled left-turning lane without deceleration lane at signalised intersections.
iii. To study the critical gap for motorcycles at the yield controlled left-turning lane at signalised intersections.

1.4 Scope of Work

A few yield control left-turning lanes at signalised intersection around Seberang Perai, Pulau Pinang were selected for the study. Equipments such as high-definition video camera and walking measure will be used to collect the data required for the study.

The vehicles movement will be recorded using the high-definition video camera and the width of the yield controlled left-turning lanes will be measured using the walking measure. The recording from the video camera will be played back to extract the data needed for the study. The data will be extracted manually from the video.

1.5 Justification of Research

The insufficiency of study and research of the gap acceptance for yield controlled left-turning lanes at signalised intersection in Malaysia has provided a motivation to conduct the study. Most existing studies evaluate gap acceptance in developed countries and less deal with developing countries. The study was conducted to understand how and when drivers decide that a gap is safe for the vehicle to cross and merge into the major traffic stream. Different drivers will have different critical gaps due to several factors such as the drivers' behaviour and the surrounding environment.

The findings from the study can improve operational analysis of yield control left turns at signalised intersections by using different critical gaps for different traffic and geometric conditions. The study can also provide ideas for the development of new technology in the future to lower the risk of crashes between merging vehicles and major traffic stream vehicles such as installing speed bumps in the major traffic lane with the intention of slowing down the upcoming vehicles from the major traffic lane and thus, improving safety and giving ample time for the vehicles from the left-turning lane to merge into the major traffic lane.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

According to HCM 2000, capacity analysis at signalised intersection is dependent on a clear understanding between the driver in the major traffic lane and the driver from the minor traffic lane. While conducting analytical work to study the gap acceptance for yield controlled left-turning lane at signalised intersection, two important parameters are the critical gap and the follow up time.

The task of estimating the critical gap by observation and field study can be considered as a difficult task in traffic engineering. This is because critical gap cannot be estimated directly from observation at the site and can be only obtained from the data of accepted gaps and rejected gaps.

In order to understand more about the objectives and scope of work for the study, literature reviews on several procedures, adopted by similar studies and relevant parameters were discussed in this chapter.

2.2 Parameters

Capacity analysis at yield controlled left-turning lane at signalised intersection will involves many important parameters such as the critical gap and the follow up time. Therefore, understanding of these parameters is very important for the study.

2.2.1 **Gap**

The term gap refers to the elapsed-time interval between arrivals of successive vehicles in the opposing flow at a specified reference point in the intersection area based on Rakha et al (2007). Gap can also be defined as the measure of time between two consecutive vehicles moving in the same direction on the same road. In the HCM 2000, gap is defined as the time, in seconds for the front bumper of the second of two successive vehicles to reach the starting point of the front bumper of the first.

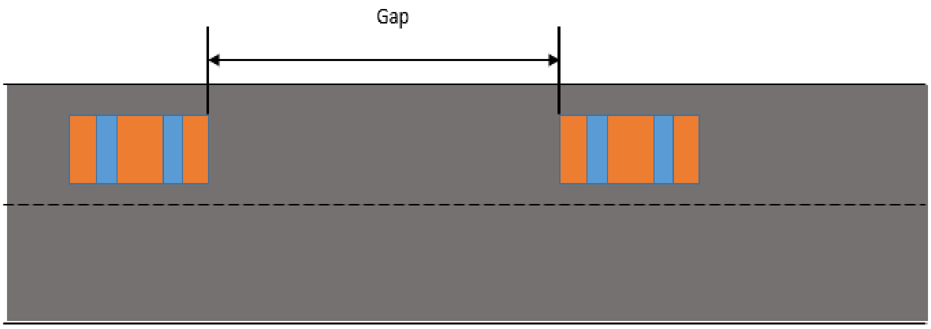

Figure 2.1: Gap between Two Consecutive Vehicles

2.2.2 **Lag**

The term lag refers to the residual part of the first gap that faces the crossing driver. Lag can also be defined as the time interval between the arrival of a yielding vehicle and the passage of the next priority stream vehicle which is forward waiting time.

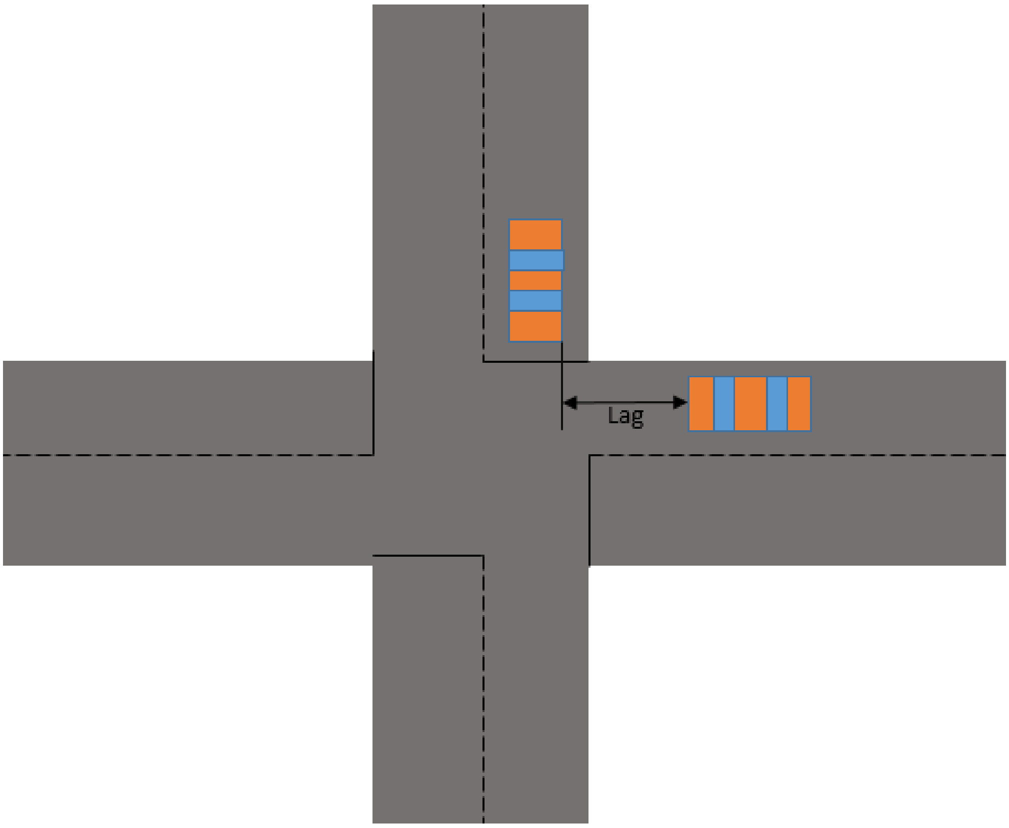

Figure 2.2: Lag between Two Vehicles

2.2.3 **Critical Gap**

Serag (2015) has stated that the critical gap is the minimum gap that a driver is willing to accept which is used to estimate the opposed saturation flow rate. Critical gap is the minimum time needed for a vehicle in the minor road to enter safely into the major road stream. Critical gap can also be defined as the gap size that is equally or likely to be accepted or rejected by the driver, in other words, the gap size corresponding to 50^{th} percentile of the accepting gap probability distribution as stated by Rakha (2007) in his journal. Critical gap is estimated by measuring gap acceptances and rejections of the vehicle from the minor road which wants to enter the major stream road. Several models have been developed specifically to estimate the critical gap values at intersections.

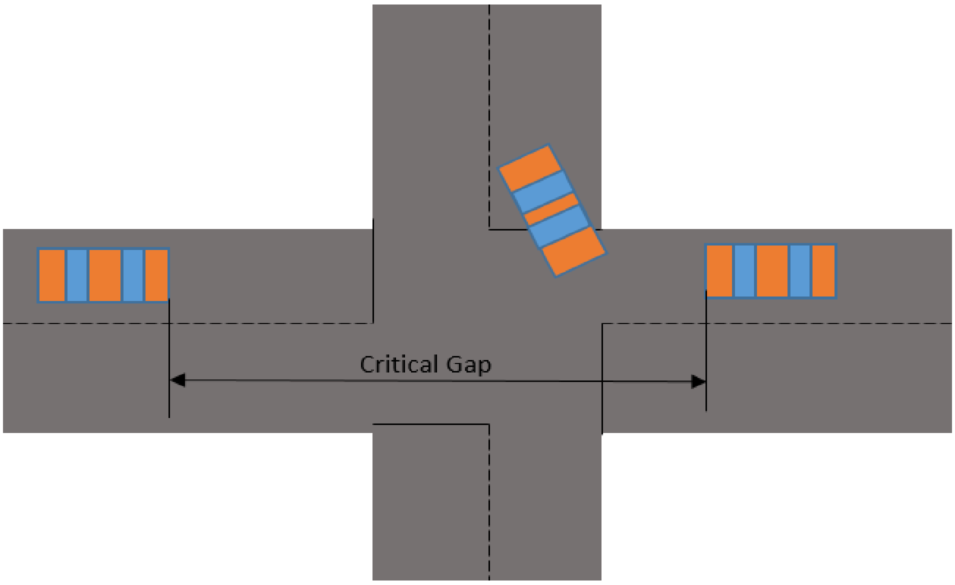

Figure 2.3: Critical Gap

2.2.4 **Follow-up Time**

The follow-up time is the time between the departure of one vehicle from a minor lanes and the departure of the next vehicle using the same gap under a condition of continuous queuing. Troutbeck and Brilon (1999) stated that follow-up time is the minor stream vehicles enter in the long gaps at headways.

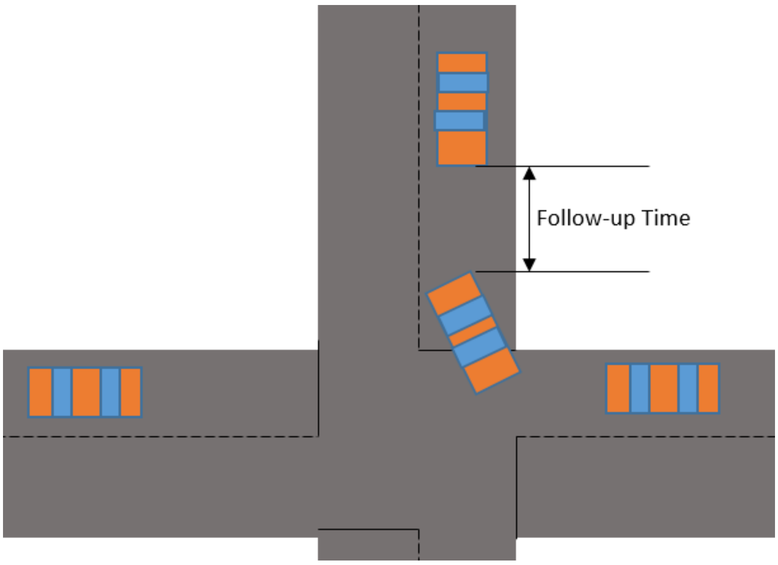

Figure 2.4: Follow-up Time

2.3 Acceleration and Deceleration Lane

Based on Zhou et al (2013), acceleration and deceleration lanes are the critical parts which ensure safety manoeuvre of vehicles from minor traffic lane into major traffic lane. Acceleration lanes or deceleration lanes provide drivers with an opportunity to speed or slow down in a space that is not used by the vehicles in the major traffic lane. Deceleration lane allows traffic exiting a minor lane to slow down to a safer speed to make a left- turn at a signalised intersection without affecting the main flow of traffic. The purpose of acceleration and deceleration lanes are to increase safety by reducing number of conflicts between vehicles.

2.4 Gap Acceptance

Goswami (2007) has stated in his paper that gap acceptance is an integral part of lane change models in microscopic traffic simulation. Offered gap is considered as an accepted gap when it is greater than or equal to a minimum value. The minimum value of accepted gap for the intended lane change manoeuvre is generally defined as the critical gap.

Hwang and Park (2005) has stated that it is a complex process to model the sequence of the decision-making procedures of a driver's lane changing because this procedure is not visible and can only see the final acceptance gap. The past studies on gap acceptance were focused on analysing delay and capacity analysis in an uncontrolled intersection only.

According to Ahmed et al (1996), he has proposed a mandatory lane-changing model and extended the work by developing a new model for heavily congested traffic flow. In heavy congestions, there are very little gaps of acceptable gaps. Hence, a forced merging model is proposed which can capture instances of merging through the creation of gap either by yielding by the lag vehicle in the target lane or by forcing lag vehicle to slow down.

2.4.1 **Concept**

A driver entering into or going across a traffic stream must evaluate the space between a potentially conflicting vehicle and his vehicle and decide whether to cross or enter or not. Hwang (2005) mentioned in his research that gap acceptance is the minimum gap required to finish lane changing safely. The general assumptions is that drivers consider only the adjacent gap that is the headway between lead vehicle and a lag vehicle over the object lane to which it wishes to change to. In the case of a merge into an adjacent lane, if the driver can accept both lead headway and lag headway, the gap is accepted. In the gap acceptance model, the critical gap is an important parameter. Critical gap can also be defined as the accepted gap which is the minimum time interval that a vehicle in the minor lane to merge into the major lane. Rejected gap is the time interval that the subject vehicle from the minor lane fails to enter and merge with the major traffic stream due to the vehicle obstacle flow in the major lane.

2.4.2 **Deterministic Gap Acceptance**

The gap acceptance model is based mainly on capacity analysis, and so it is more focused on capacity analysis than on gap acceptance itself. To estimate deterministic critical gap, there are three representative methods.

The first method is used when vehicles on the ramp accept a gap. The critical gap can be determined through the median or mean observed from the gaps.

The second method is used to determine the intersection of the accumulated curve representing the accepted gap and the accumulated curve representing the rejected gap.

The third method is a regression method introduced by Drew (1968) which uses merge angle and acceleration lane length. An experimental equation is solved to determine critical gap. HCM 2000 provides ramp lane and adjacent lane volume estimation equations by classifications using the deterministic regression analysis method. This method has advantages in that the calculation method is simple through regression analysis and has great practical applications. However, it has a great disadvantages in reflecting a driver's behaviour, hence making it difficult to accurately simulate the real world.

2.4.3 **Stochastic Gap Acceptance**

The critical gap derived a unique value which has the range of the limitation. To overcome the limit, attempts have been made to derive critical gap using gap distribution. Gap distribution uses Logit or Probit probability models partly. The advantage of gap distribution model is that it is very detailed but requires many variables and parameters to be considered and it is also very time-consuming and costly.

Mahmassani and Sheffi (1981) used the Probit Model to estimate the mean and variance of critical gap at an uncontrolled intersection. They explained that the model is affected by the number of gaps judged by the drivers which the value cannot be considered as the critical gap.

Troutbeck (1992) asserted that critical gap distribution assumed the log-normal distribution. According to his model, the best critical gap estimation is the "maximum likelihood" method. The results show that the maximum likelihood method has the smallest value in the difference of population mean and sample mean and deviation to mean measure. That is, the maximum likelihood method has the highest reliance of critical gap estimation methods.

Cassidy et al (1995) used the binary Logit Model to calculate the mean of the single-valued critical gap function to evaluate capacity and delay experientially. With this model, he concluded that the components affecting gap acceptance at intersections are delays caused by gap and first gap indicator which is drivers tend to escape from merging first gap for safety. However, sequences of reject gap are not considered for model formulation or parameter estimation until after the lane-changing is completed.

2.5 Capacity Analysis Procedures

Serag's (2015) study shows that of a total of 1496 observations, 509 observations were those for which the left-turning vehicle were presented with a gap and the remaining 987 were those for which the left-turning vehicles were presented with a lag. Nearly, 59% of all lags were accepted by the drivers whereas only 12% of all the gaps were accepted by the drivers. The range of critical gaps were smaller than that of critical lags. The smallest critical gap was found to be 4.18 seconds and the largest was 5.46 seconds. Similarly, the smallest critical lag was found to be 3.46 seconds and the largest was 4.74 seconds.

2.5.1 **Raff's Method**

Based on Gazzarri et al. (2013), Raff defines critical gap as the size of gap whose number of acceptance gaps shorter than it is equal to the number of rejected gaps longer than it. The method used to determine critical gap in the field is similar to the one developed by Raff. Raff used accepted and rejected lags only. Both gaps and lags were used to determine the critical gap. A lag was measured as the unaccepted gap if only the lag was unaccepted or gaps following the lag were not larger.

In order to develop a gap acceptance graph, all the accepted gaps chosen are sorted in ascending order and are grouped in different classes. Gap times from 0 to 0.99 seconds are classified into one group followed by another from 1.0 to 1.99 seconds up until 12 seconds are reached. Kittleson and Vandehey (1991) mentioned that most drivers will accept 12 seconds gap thus, larger gaps do not represent how driver will react to lesser gaps. It is then logical to use gap time that are less or equal to 12 seconds.

The number of observations in each group is counted and recorded on a table as a number of observed gap acceptance. The data is accumulated to produce the graph for the total number of accepted gaps. The same process is done for the rejected gaps with the number of observed rejections is accumulated to produce the graph for the total number of rejected gaps.

2.6 Summary

Raff's method is frequently used because of its simplicity and also one of the easiest method in determining the critical gap. Raff's method used gaps offered to the drivers which is the time between the arrivals of minor stream vehicle at a give-way line to the arrival of the next vehicle in the major stream. Each driver is offered one gap and they can then decide whether to accept or reject the gap.

CHAPTER 3

METHODOLOGY

3.1 Overview

The chapter describes the methodology used to carry out the study. Figure 3.1 shows the flowchart of research methodology of the study.

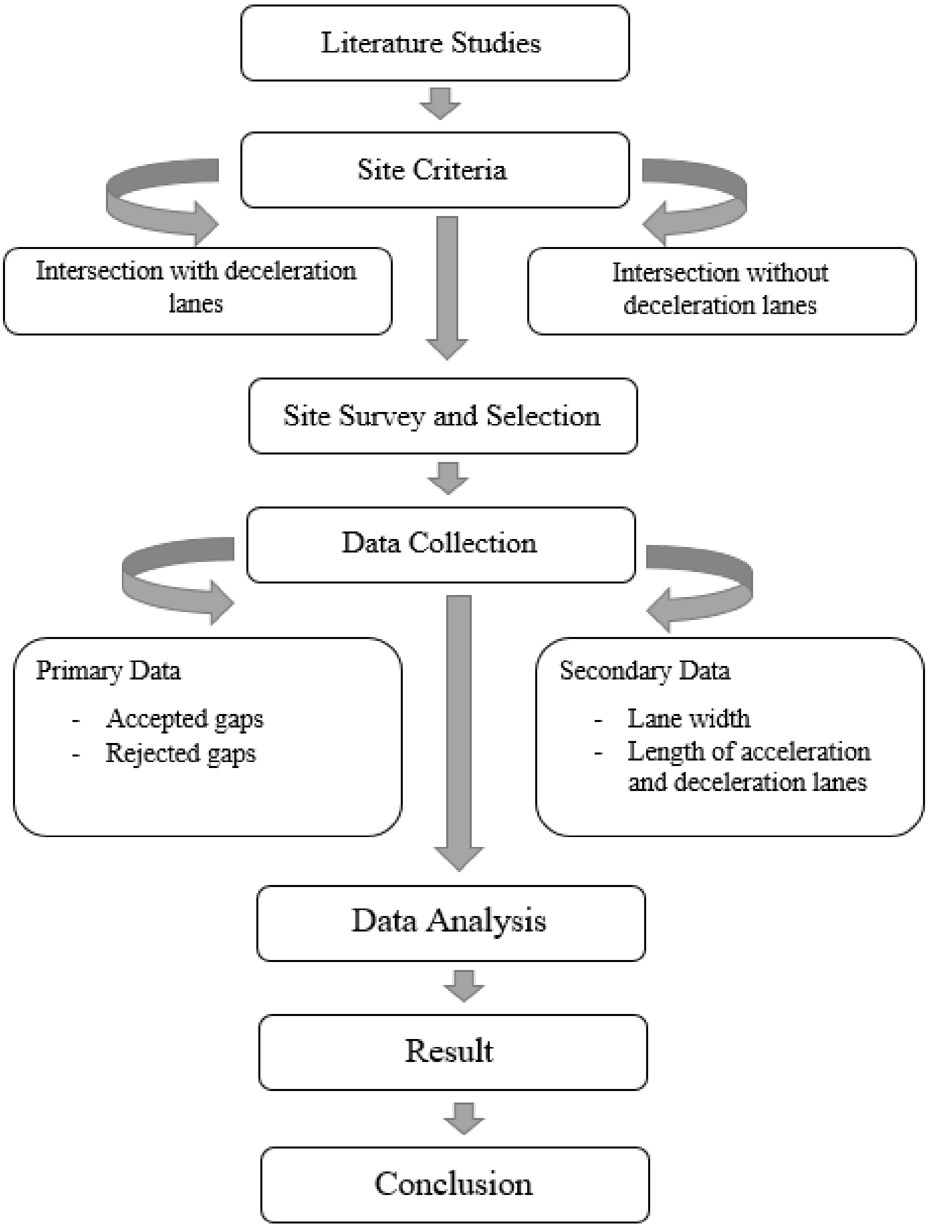

Figure 3.1: Flowchart of Research Methodology

Initially, literature review were conducted to understand more about the scope of work and to determine the data needed for the study. Subsequently, site selection and site survey were carried out at a few intersection in Seberang Perai, Pulau Pinang to find suitable signalised intersections to conduct the study. In order to obtain the data needed for the study, the selected intersections will be monitored using high-definition video camera. The video camera is located at such position so as to capture the movement of minor road vehicle from before leaving the yield line until the end of its manoeuvre when it finally merges with the major road traffic. The video camera was mounted so that it can capture the movement of the vehicles as they complete their manoeuvre from beginning of the entrance in to the major road to the point where they merge with the major traffic stream. The data needed is then extracted manually from the recording from the video camera. The data extracted from the recording were analysed to get the critical gap, gap acceptance and gap rejection times. The result obtained from the analysis is compared and discussed in Chapter 4.

3.2 Site Selection

The study area for the selection of suitable intersections for the study is around Seberang Perai, Pulau Pinang. The criteria for the selection of suitable intersections for the study is that it must be a signalised intersection with a yield-controlled left-turning lane. The intersections must have a sufficient and continuous traffic flow movement to acquire enough data. The volume of vehicles moving along the intersection is also one of the criteria in the selection of the suitable site for the study. Site evaluation is done after a few suitable sites is selected to ensure that the selected intersections will be able to provide all the data required and fulfil all the criteria mentioned before.

For the purpose of the study, six sites has been chosen at five different intersections all around Seberang Perai Selatan, Pulau Pinang. Table 3.1 shows the location of the intersection selected for the data collection and the analysis.

Table 3.1: Location of Intersections

	Intersection
1.	Jalan Bukit Tambun Intersection, SJK (C) Keng Koon
2.	Jalan Bukit Tambun Intersection
3.	Bukit Tambun South Bound Exit Intersection
4.	Jalan Transkrian/Federal Route 1 Intersection
5.	Jawi Exit/Federal Route 1 Intersection
6.	Jalan Transkrian/Bukit Panchor Intersection

The sites chosen are based on a few characteristics such as lane with or without deceleration lane and the volume of traffic at the intersection during the peak hour period.

Figure 3.2: Selected Signalised Intersection in Bukit Tambun South-Bound Exit

3.3 Equipment for Data Collection

Data collection was carried out at the selected intersections using a few types of equipment such as high-definition video camera and walking measure as shown in Figure 3.3 and Figure 3.4 respectively.

Figure 3.3: High-definition Video Camera

Figure 3.4: Walking Measure

Video camera can be considered as one of the universal method for traffic data collection. However, there is a major disadvantage in using video camera which is in finding suitable vantage point with good visibility to acquire all the data needed for the study. Unsuitable vantage point can affect the data needed for the study which can further affect the data analysis.

Figure 3.5: Setting Up of High Definition Video Camera

The high-definition video camera is used to observe the accepted gaps and rejected gaps of the vehicles at the intersection. The high-definition video camera was used to record the vehicles left-turning movement at the intersection. The video camera is positioned at a suitable height to get a clear view of the intersection. The walking measure is used to measure the width of the left-turning lanes and the length of the merging lane.

3.4 Data Collection

The data collection for the study is done by collecting two types of data which are the primary data and the secondary data. The primary data consisted of the accepted gaps and rejected gaps of the vehicles for each selected sites. The secondary data is the lane width of the left-turn lanes and the length of the deceleration lane for selected sites with deceleration lanes.

The primary data which are the accepted gaps and rejected gaps were collected during the peak hour period which is at 7:00 am to 9:00 am, 12:00 pm to 2:00 pm, and 4:00 pm to 6:00 pm on a Tuesday, Wednesday and Thursday. The data was collected all through the months of February 2017 and March 2017. The days selected for the data collection must be clear and sunny to avoid any other factors that could affect the result of the data analysis. The accepted gaps and rejected gaps of the vehicles was observed using the high-definition video camera which has been mounted at a suitable height and had a good visibility of the intersections.

The secondary data which are the width of the left-turn lane and the length of the deceleration lane was collected during the night time of the data collection days. The secondary data was collected at night time due to there is less vehicles at night time which made it easier for the data to be collected and to avoid any conflicts with the vehicles using the intersections. The data was collected using the walking measure which measure the width of the left-turn lanes for each intersections and the length of the deceleration lanes for intersections with the deceleration lanes. The secondary data was collected to observe the significance of the effect of the width of the left-turn lane and the length of the deceleration lane on the critical gap at each lane.

3.5 Data Extraction and Analysis

The recording from the site were played back to retrieve and extract the relevant data needed. The vehicle classification, accepted and rejected gaps were extracted from the recording. The processes will be repeated until the total numbers of vehicles for sample data were achieved. A point will be plotted on the major road in order to get the arrival time of the vehicle on the major road.

The extracted data will be stored in Excel spreadsheet. The data stored will be analysed to estimate the numbers and length of times accepted and rejected gaps presented to the drivers. The recording were reduced manually by taking the time instant at which the vehicle initiated its movement to make the left-turn manoeuvre. Left turns initiated under conditions where there is no approaching vehicle from the major stream will not be included in the analysis.

3.5.1 Consideration of Accepted and Rejected Gaps

At an intersection, gaps can be classified into two which are the gap acceptance and gap rejection. Gap acceptance or accepted gap is when a driver feels that he will be able to safely complete the manoeuvre and merge with the major traffic stream. Gap rejection or rejected gap is when a driver fails to enter and merge with the major traffic stream due to the obstacle flow of vehicles on the major street. The driver will reject several gap before finally accepting a gap for him to merge into the major traffic stream. A reference point will be set up on the road to measure the accepted and rejected gaps by the drivers from the left-turning lanes.

3.5.2 **Raff's Method**

Raff's method was used to analyse the data collected during the data collection processes due to its simplicity and one of the easiest method to determine the critical gap. Raff's method used accepted and rejected gaps only to obtain the value of critical gap.

Data needed for Raff's Method are gap class, number of observation, number of acceptances, number of rejection, accumulated acceptances and accumulated rejections. The value for critical gap for each categories were obtained from the graph produced.

The number of observations from the video recording was separated into the accepted gaps and rejected gaps for the left-turn lane at each selected signalised intersections. The number of observations for the accepted gaps and rejected gaps are counted and recorded on a table as a number of observed gap acceptance.

In order to develop a gap acceptance graph, all the accepted gaps are sorted into ascending order and are grouped into different classes. Gap times from 0 to 0.99 seconds are classified into one group followed by another from 1.0 to 1.99 seconds and the process continued up until 12 seconds. The data was accumulated in ascending order to produce the graph for the total number of accepted gaps. The same step was used for the rejected gaps and the data was accumulated in descending order to produce the graph for the total number of rejected gaps.

The value obtained from the data accumulated for both accepted gaps and rejected gaps was used to plot the gap acceptance graph. The value of the critical gap can be obtained from the intersection of the two lines of the total number of the accepted gaps and the total number of the rejected gaps on the graph produced.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The chapter discusses the analysis and result of the study of the gap acceptance for yield controlled left-turning lanes at signalised intersection. The critical gap for each intersection is determined using Raff's Method. The critical gap obtained at each intersection was further divided into forced and free flow entry and the critical gap for motorcycles only.

4.2 Data Collection

The data for the analysis was collected at five different intersections with six left-turn lanes around Seberang Perai, Pulau Pinang. Table 4.1 shows the location of the intersection selected for the data collection and the analysis.

Table 4.1: Location of Intersections

	Intersection
1.	Jalan Bukit Tambun Intersection, SJK (C) Keng Koon
2.	Jalan Bukit Tambun Intersection
3.	Bukit Tambun South Bound Exit Intersection
4.	Jalan Transkrian/Federal Route 1 Intersection
5.	Jawi Exit/Federal Route 1 Intersection
6.	Jalan Transkrian/Bukit Panchor Intersection

Figure 4.1(a): Left-turning Lane at SJK (C) Keng Koon, Jalan Bukit Tambun Intersection

Figure 4.1(b): Left-turning Exit Lane at SJK (C) Keng Koon, Jalan Bukit Tambun Intersection

Figure 4.2(a): Left-turning Lane at Jalan Bukit Tambun Intersection

Figure 4.2(b): Left-turning Exit Lane at Jalan Bukit Tambun Intersection