UNIVERSITI PUTRA MALAYSIA

DETERMINATION OF CRITICAL GAP FOR MOTORCYCLE AT MERGING POINTS OF EXCLUSIVE MOTORCYCLE LANE IN MALAYSIA

NORFAIZAH MOHAMAD KHAIDIR

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By

NORFAIZAH MOHAMAD KHAIDIR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, In Fulfilment of the Requirements for the Degree of Master of Science

February 2018

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TO

My parents and teachers

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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February 2018

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Although definitely not the worst in the region, Malaysia is facing a similar worrying situation as the countries in Southeast Asia which is a high number of motorcyclist fatalities. Various efforts have been implemented to improve this mortality rate and among the efforts that have contributed a large positive impact is the construction of exclusive motorcycle lanes (EMCL) aimed at segregating motorcycles from other motorised vehicles. Despite the huge growth in the EMCL demand, to date, the total length of EMCL constructed on primary roads in Malaysia are not more than 1% from the overall road length. One of the reason for the slow implementation of EMCL is the high construction cost. Therefore, an optimal design with sufficient capacity to cater for the traffic demand and at the same time cost effective must be developed.

Capacity is one of the main parameters for optimal design of EMCL. Under-estimation of capacity at the design stage may result in a detrimental degree of congestion and over-estimation of capacity may cause the over-design of infrastructure that would in turn cause excessive investment. The capacity for the entire road network is also highly dependent on the estimated capacity value at access points where significant volumes of vehicle joining or leaving at access will cause interruption and capacity reduction to the overall traffic flow on the road network. On EMCL, access points are provided through egress (section to exit from the EMCL) and ingress (section for entering into EMCL). For accurate capacity estimation at interruption facilities like egress and ingress, the critical gap parameter is of high interest. Despite the suggested value of critical gap in international road design manuals, the critical gap value for motorcycle facilities remains as the missing link. As motorcycles are small in size compared with other motorised vehicles, the critical gap value for motorcycles is predicted to be smaller. Hence, the determination of critical gap for motorcycles at egress and ingress of EMCL forms the main interest of this study.

Field data collection was conducted involving mainly videotaping the accepted and rejected gaps size and gap acceptance decision based on the oncoming vehicle type on the major road traffic by a single motorcycle from the minor road. The critical gap values obtained at egress are 2.28 seconds and 2.42 seconds when the oncoming vehicle is a passenger car and a heavy vehicle respectively and the critical gap value obtained at ingress where the traffic is made up of motorcycles only is 2.43 seconds. Findings from this study suggested that the critical gap for motorcyclists at egress and ingress is starkly lower than the recommended threshold value (6.2 seconds) used for other motorised vehicles at stop-controlled intersection. Applying a motorcycle's critical gap for the estimation of capacity at the design stage of EMCL will directly affect the amount of space required to build EMCL, translating into more effective construction cost. This in turn, provides positive evidence to encourage the construction of more EMCL and in long term can possibly contribute for better road safety level in Malaysia.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Sarjana Sains

PENENTUAN JURANG KRITIKAL UNTUK MOTOSIKAL DI TITIK PENGGABUNGAN LALUAN MOTOSIKAL EKSLUSIF DI MALAYSIA

Oleh

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Walaupun bukan paling teruk, Malaysia juga menghadapi situasi membimbangkan sama seperti negara-negara di Asia Tenggara yang lain iaitu jumlah kematian yang tinggi dikalangan pengguna motosikal. Pelbagai usaha dilakukan untuk mengurangkan kadar kematian ini dan antara inisiatif yang memberi kesan positif yang besar adalah pembinaan lorong motosikal eksklusif (EMCL) yang bertujuan untuk mengasingkan motosikal dari kenderaan bermotor yang lain. Walaupun terdapat permintaan yang tinggi terhadap EMCL, sehingga kini jumlah panjang EMCL yang terbina adalah kurang daripada 1% dari jumlah keseluruhan panjang jalan di Malaysia. Salah satu punca perlaksanaan EMCL yang perlahan adalah kos pembinaan yang tinggi. Oleh itu, reka bentuk EMCL yang optimum iaitu kapasiti yang mencukupi untuk menampung permintaan trafik dan kos pembinaan yang efektif mesti dibangunkan.

Kapasiti adalah salah satu parameter utama untuk memastikan reka bentuk EMCL yang optimum. Anggaran nilai kapasiti yang rendah di peringkat rekabentuk boleh mengakibatkan kemudahan yang dibina mudah mengalami kesesakan manakala anggaran kapasiti yang tinggi, boleh meningkatkan nilai pelaburan kewangan. Kapasiti bagi rangkaian jalan juga sangat bergantung kepada kapasiti di persimpangan dimana jumlah kenderaan keluar atau masuk yang tinggi boleh mengganggu aliran trafik dan mengurangkan kapasiti rangkaian jalan tersebut. Di EMCL, akses disediakan melalui laluan keluar dari EMCL (*egress*) dan laluan masuk ke EMCL (*ingress*). Untuk menganggar kapasiti bagi sistem lalu lintas yang terganggu seperti di akses, jurang kritikal memainkan peranan penting. Walaupun jurang kritikal ada dicadangkan dalam manual reka bentuk antarabangsa, nilai untuk motosikal masih tiada. Oleh kerana saiz motosikal kecil berbanding kenderaan bermotor lain, motosikal dijangkakan mempunyai jurang kritikal yang lebih rendah. Oleh itu, penentuan jurang kritikal untuk motosikal di akses EMCL menjadi tujuan utama kajian ini.

Pengumpulan data adalah menggunakan kaedah rakaman video bagi merekodkan saiz jurang dan keputusan penerimaan jurang berdasarkan jenis kenderaan yang terdapat di laluan utama. Nilai jurang kritikal yang diperolehi di laluan keluar adalah 2.28 saat dan 2.42 saat apabila kenderaan di laluan utama masing-masing ialah kenderaan penumpang dan kenderaan berat dan nilai jurang kritikal di laluan masuk di mana jenis kenderaan adalah motosikal sahaja ialah 2.43 saat. Penemuan mencadangkan jurang kritikal bagi motosikal di akses EMCL adalah lebih rendah daripada jurang kritikal (6.2 saat) yang disyorkan untuk kenderaan bermotor lain di persimpangan dengan kawalan tanda berhenti. Penggunaan jurang kritikal bagi motosikal dalam menganggarkan kapasiti di peringkat reka bentuk akan memberi kesan kepada jumlah ruang yang diperlukan untuk membina EMCL dan diterjemahkan kepada pengurangan kos pembinaan. Ini seterusnya dapat menggalakkan pembinaan EMCL dan dalam jangka masa panjang dapat menyumbang kepada peningkatkan mutu keselamatan jalan raya di Malaysia.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Organization

WHO	World Health Organization
RMP	Royal Malaysia Police
RTDM	Road Transport Department Malaysia
NHTSA	National Highway Traffic Safety Administration
AASHTO	American Association of State Highway and Transportation Officials
TRB	Transportation Research Board
MIROS	Malaysian Institute of Road Safety Research
PLUS	Projek Lebuhraya Utara Selatan
KESAS	Shah Alam Expressway
REAM	Road Engineering Association of Malaysia

Other Terms

EMCL	exclusive motorcycle lane
NEMCL	non-exclusive motorcycle lane
F02	Federal Road 2
HCM	Highway Capacity Manual
ITS	intelligent transportation system
BCR	Benefit to Cost Ratio
E1, I1	Egress or Ingress with entry angle of 90 degree or more
E2, I2	Egress or Ingress with presence of auxiliary lane
E3, I3	Egress or Ingress with entry angle less than 90 degrees and length less than 15 m
E4, I4	Egress or Ingress with entry angle less than 90 degrees, length more than 15 m
E5, I5	Egress or Ingress with skewed access
E1-01	Location KESAS – Subang Jaya
E1-02	Location KESAS – Taman OUG
E3-01	Location Padang Jawa
E3-02	Location Subang Airport
E4-01	Location Amcorp Mall
E4-02	Location ke Bulatan Kayangan
I1-01	Location susur Batu Tiga
I1-02	Location Petronas Shah Alam
I3-01	Location Seksyen 7
I3-02	Location Setia Jaya
I4-01	Location susur NPE
I4-02	Location dari Bulatan Kayangan
MC	main carriageway
MCL	motorcycle
HV	heavy vehicle

Roman Letters

G	percent grade divided by 100
L	crosswalk length (m)
N_c	total number of pedestrians in the crossing platoon (p)
N_p	spatial distribution of pedestrians (p)
P_{HV}	proportion of heavy vehicles for minor movement
P_i	the probability that the target motorcycle *i* accepts the available gap
S_p	average pedestrian walking speed (m/s)
t_c	critical gap for a single pedestrian (s)
$t_{c,base}$	base critical gap from Table 2.3 (s)
$t_{c,G}$	adjustment factor for grade (s)
$t_{c,HV}$	adjustment factor for heavy vehicles (s)
$t_{c,T}$	adjustment factor for each part of two-stage gap acceptance process (s)
$t_{c,x}$	critical gap for movement x (s)
t_g	gap time (t_2 - t_1)
t_G	group critical gap (s)
t_s	pedestrian start-up time and end clearance time (s)
t_1	time of vehicle arrival at point t_1
t_2	time of vehicle arrival at point t_2
$t_{3,LT}$	adjustment factor for intersection geometry (s)
v	vehicular flow rate (veh/s)
v_p	pedestrian flow rate (p/s)
W_E	effective crosswalk width (m)
x_i	a vector of control factors which impact the decision of motorcycle *i*
1- P_i	the probability that the target motorcycle *i* rejects the available gap

Greek Letters

α	intercept parameter
β	vector of the coefficients of the corresponding control factors

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter outlines the background of the study, research problem, research gap, as well as the aim and objectives of the study. In addition, this chapter also includes the reason why this study is important and what are the scope in conducting the study effectively.

1.2 Background of the study

Motorcycle or powered two-wheeler vehicle is commonly acknowledged as the cheapest form of motorised vehicle, fastest mode of transport in congested cities, cost-effective in petrol consumption and required less space on the road as well as at parking spaces, thus, making it a favourable choice of transportation in low and middle income countries in Asian (Industry Research Department, 2015; Law, Hamid, & Goh, 2015; Leong & Sadullah, 2007). World Health Organization (WHO) reported the five (5) Asian countries with high population of motorcycles are Viet Nam (95%), Myanmar (86%), Cambodia (84%), Indonesia (83%) and Lao People's Democratic Republic (78%). However, the population of motorcycle is still low in high income Asian countries such as Korea (9%), Japan (13%) and Singapore (15%) (WHO, 2015). There is a stark difference in the main purpose of motorcycle commuting where the main use of motorcycle in developed countries are for hobbies and leisure but for low-to middle-income and developing countries, motorcycle is a key transportation for daily usage. Based on the above-mentioned favourable features, the volume of motorcycles within the region rapidly grows each year, as does the number of fatalities involving motorcyclists. Viet Nam, Lao People's Democratic Republic and Thailand reported that the high proportion of motorcycles in the countries resulted in approximately more than 70% of road deaths involving motorcycle users (WHO, 2015). In Cambodia, the number of motorcycles increased by 50.7% from year 2010 to year 2013, resulting with a 1.7% increase in number of road deaths involving motorcycles within that period. Motorcycle fatalities account for nearly 25% of the world's road traffic fatalities and was reported as a global issue by WHO (WHO, 2015).

As a Southeast Asian country, Malaysia is facing a similar worrying situation on high fatalities involving motorcycle users. The motorcycle safety status in Malaysia based on the statistics for the period between 2001 to 2016 (Royal Malaysia Police (RMP), 2016) is depicted in Figure 1.1. Even though it is not among the worst in Southeast Asia, crash records have shown that motorcycle fatality carves a large portion of the total road fatalities in Malaysia with an average of 3,892 (59%) fatalities each year. For the last decade, approximately a 21% increase was observed in motorcycle fatalities; from 3,693 fatalities in year 2006 to 4,485 fatalities in year 2016 (RMP,

2016). In the corresponding period, the number of motorisation ownership represented more than half of all registered vehicle in Malaysia and has also shown an increment average rate of 5.6% per year (Ministry of Transport (MOT) Malaysia, 2017).

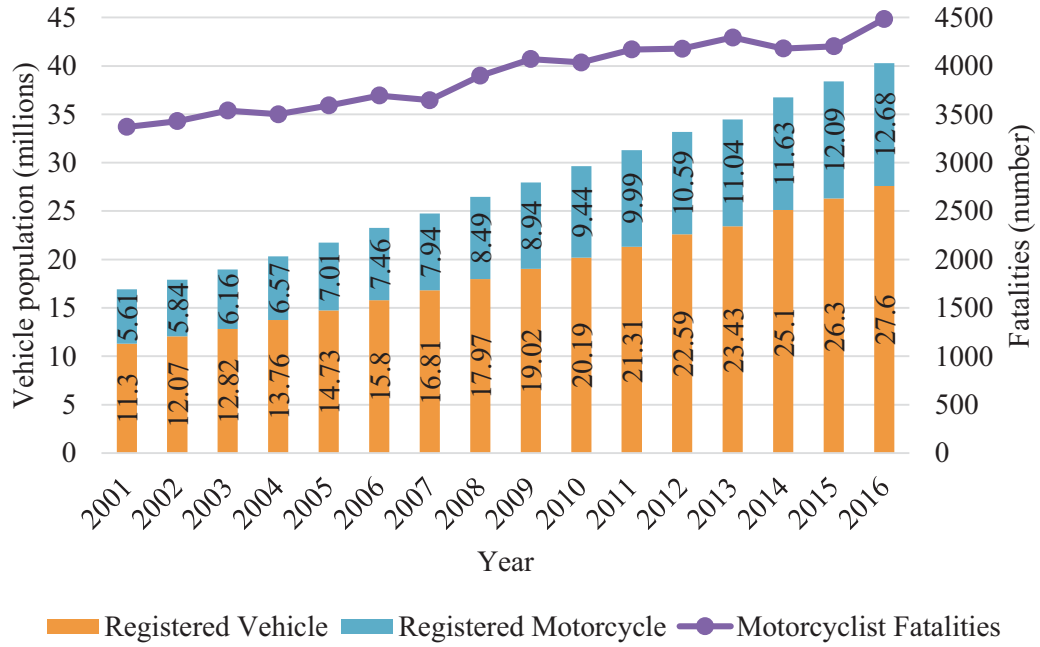

Figure 1.1: Comparison of Fatality Data of Motorcyclists and Other Road Users from Year 2001 To 2016
(Source: Ministry of Transport (MOT) Malaysia, 2017; RMP, 2016)

Motorcyclists, with their lack of protection gear, have low tolerance to severe injuries in the occurrence of a traffic crash (Vlahogianni, Yannis, & Golias, 2012). Per vehicle mile travelled, motorcyclists are exposed up to 20 times more chance of getting injured (Sohadi, Mackay, & Hills, 1995b) and 27 times more chance of being killed (National Highway Traffic Safety Administration (NHTSA), 2016) compared to four-wheel vehicle occupants in traffic crashes. Focusing on the facts of increasing popularity of motorcycles and the associated high risk of injury and fatality that comes with it, Malaysia is expected to lose more human resources if nothing is done to improve this scenario. In 2016, Malaysia lost more than RM5 billion due to the 4,485 motorcycle fatalities in that year, the highest fatality in a 10-year period. This was estimated based on a study by Nor, Yusoff and Sohadi (2001), which suggests the statistical value of life for motorcyclists to be RM1.2 million, which may have grossly increased in the recent years since the study was initially conducted.

Motorcycles in Malaysia share the road space with other larger vehicles. This mixed traffic system leads to complex manoeuvres and interactions between road users (Kanagaraj, Srinivasan, Sivanandan, & Asaithambi, 2015) and results in different cruising speed of vehicles affecting the likelihood of crashes (Hauer, 1971). Acknowledging the fact that the risk can be managed efficiently when motorcycles are segregated from other larger vehicles, in the early of seventies, the Government of Malaysia with the support from the World Bank has started an effort to build Exclusive

Motorcycle Lane (EMCL). The EMCL is a dedicated lane for motorcyclists that was built separately from the traffic carriageway and functions to segregates motorcycle from other motorized vehicles. The lane was built along the Federal Road 2 (F02), one of the most congested roads in Malaysia, with the aim to curb the high motorcycle fatality issues in Malaysia. The lane was then further extended for another 15 km in 1992. Following the opening of EMCL to the public in November 1993, numerous research has been conducted to value the effectiveness of the facility. Upon the introduction of EMCL, a significant reduction of approximately 25% was observed in number of motorcycle crashes (Sohadi, Mackay, & Hills, 1995a). In 2000, they added that the construction of 30 km long (per direction) of EMCL has significantly reduced motorcycle crash by 39% per year (Sohadi, Mackay, & Hills, 2000). Though no study was found on the direct reduction of motorcycle fatality benefiting from the constructed EMCL, there is evidence that collisions with bigger size vehicles (i.e. higher mass ratio) commonly result in severe injury to the motorcyclists (Pang et al., 2000).

In 1997, Sohadi and Barton conducted a cost analysis study on the EMCL and concluded that the cost of accidents prevented is at least three times more than the construction cost of EMCL; resulting in a profitable measure to solve motorcycle safety problems in Malaysia (Sohadi & Barton, 1997). However, the high investment costs in constructing the lane is still dampening the effort to build more EMCL in Malaysia. For the last decade, although the demand for EMCL has increased about 1.7 times (Ministry of Transport Malaysia, 2017), the total length of EMCL provided on Malaysian roads is less than 1% of the overall road length (Manan & Várhelyi, 2012). One of the critical factors when considering the construction of additional EMCL is the design of EMCL which directly affects the construction cost, especially when the EMCL is to be built on existing roads. Therefore, optimal design must be provided so that the facility planned may not be over or under-designed.

Optimally designed facility is always associated with sufficient capacity to cater for the traffic demand and growth. Excessive traffic growth may greatly contribute to surpassing the permitted capacity of a road, which may result in an undesirable degree of congestion thus reducing the road efficiency. On the other hand, if capacity is overestimated at the design stage, the road will be over-designed and causing excessive infrastructure investment. Moreover, with the knowledge of the capacity, engineers are able to decide the required number of lanes, the appropriate length of auxiliary lanes, the need for additional of exclusive turning lanes and many more (American Association of State Highway and Transportation Officials (AASHTO), 2010).

Capacity at access point always predominates the overall capacity of the road network (Amin & Maurya, 2015; Prasad, Surisetty, & Kumar, 2014). Significant volumes of joining or leaving traffic at access point will cause interruptions and capacity reduction. Therefore, estimation of the capacity at access point is a critical task at the design stage. On EMCL, access points are provided through egress (road section for exiting from EMCL) and ingress (road section for entering into EMCL). The flow of motorcycle traffic on the EMCL network is interrupted by motorcycles wishing to exit or enter the EMCL. Accurate valuation of capacity for interrupted flow at access point relies on

the critical gap value, the high interest design parameter for road design engineers. Critical gap is a minimum time interval between two consecutive vehicles in the major road traffic that allows entry of one minor road vehicle (Transportation Research Board (TRB), 2000). Therefore, the determination of critical gap for motorcycle form the main interest of this study.

1.3 Problem statement

Road facility can be categorised into uninterrupted-flow and interrupted-flow facility. Uninterrupted-flow facility is the road without the fixed element such as traffic signal that interrupt the traffic flow whilst interrupted-flow facility is the road with controlled and uncontrolled access points that can interrupt the traffic flow (Transportation Research Board, 2000b). For uninterrupted-flow facility, gap appears in the form of a space between two following vehicles to be filled by a passing vehicle. The gap is more prominent for interrupted-flow facilities such as at access point where minor road users must find available gap on the major road traffic to complete the manoeuvre. As previously described, critical gap is the minimum gap time that allows the entry of one (1) minor road user. Longer critical gap value means less minor road vehicle can pass through the access and therefore reduce the capacity of the road network. At the same time, it may create backlog traffic condition on the departure lane. On the other hand, shorter critical gap value may contribute to more vehicles to pass through the access during a stipulated time, thus increasing the capacity of the road network. However, this may increase risk to the road user where they may accept gaps that are smaller than the critical gap (poor gap acceptance decision) thus increase the likelihood of crash to occur. In the light of this, the critical gap is an important parameter for the design of an access. In addition, the information on the critical gap value also forms a basis for road engineers in deciding the intersection sight distance, lane width and number of lanes (AASHTO, 2010).

Despite the crucial parameter in road design, the critical gap value is difficult to be measured directly (McGowen & Stanley, 2012). Typical data collected on-site are the size of available gaps (time interval between two consecutive vehicles) on major road and the minor road motorist's decision whether to accept or reject the gap i.e. gap acceptance. Misjudging the motorist's decision on utilising the available gap may lead to inappropriate design decisions. If over passive gap acceptance behaviour or a large critical gap is assumed, not only will the road be over-designed but it will cause negative value of investment and have adverse effects on the road network. On the other hand, if aggressive behaviour or a small critical gap is assumed, an insufficient capacity of the road network may be perceived and motorists may be forced to make gap acceptance decisions in a dangerous manner. In order to provide safer infrastructure for motorcyclists coupled with optimal design that could offer a high return in investment, accurate estimation of critical gap for motorcyclists is needed.

Previous studies indicated that there is considerable individual variation in minimum acceptable gap, depending on the risk level that a motorist is willing to take (Alexander, Barham, & Black, 2002; McGowen & Stanley, 2012). Factors influencing gap

acceptance decision includes driver's prediction on the speed of approaching vehicle, the distance of the approaching vehicle from the access point and how quick it may arrive at the access point (Laberge, Creaser, Rakauskas, & Ward, 2006). The vehicle size itself also predicted to be one of the manipulating factor for gap acceptance decision. As motorcycles are small in size compared with four-wheel vehicles, they do not require much space for manoeuvring and can occupy most available lateral position on the road space (Hamid, Sohadi, Sadullah, & Ma'soem, 2005). Moreover, as motorcyclists do not have built body-frame around them to cause visual blind spots, their field of view is minimally restricted. Therefore, it is anticipated that minimum acceptance gap for motorcyclists is smaller than other four-wheel vehicle drivers. In view of this, if critical gaps for four-wheel vehicles is simply adopted for the design of EMCL, there is a possibility for overestimation of critical gap that may lead to the overestimation in space required for EMCL. Consequently, this will decrease the likelihood to build the EMCL on the existing roads.

Highway Capacity Manual (HCM) published by the Transportation Research Board (TRB) in USA is the most referred guideline in transportation business worldwide. The manual has detailed out critical gaps at intersection for passenger cars, bicycles and pedestrian facilities. However, critical gap for motorcycle facilities remain as the missing link. In fact, scientific studies on the motorcycle facilities are limited and considered a non-priority in most developed country. This could be due to the low population of motorcycles in developed countries and when present, most of their motorcycles are high-powered two-wheelers compared to motorcycles in Malaysia and other developing countries in this region.

Substantial studies on safety issues for motorcycle and motorcycle lane is available but very little attention is given on the fundamental engineering of motorcycle traffic such as capacity and critical gap. Nevertheless, this basic engineering concept is vital to ensure that the performance of the facility is maximised at minimal economic cost. Previous study related to motorcycle lane capacity conducted by Hamid, Sohadi, Sadullah, & Ma'soem (2004) highlighted the capacity on a straight and level basic segment of EMCL in Malaysia. Another recent study on fundamental traffic engineering was conducted by Patil and Sangole (2016) which determined the critical gap for motorcyclist at unsignalised intersection in India. Thus, there is a need to establish a study on basic traffic engineering feature for motorcycle at egress and ingress of EMCL so that a more scientific and professional judgement can be applied to achieve the optimal design for motorcycle facility. This will indirectly promote and support additional construction of EMCL on the road.

1.4 Research gap

Motorcycle infrastructure has been an excellent research commodity due to its effectiveness in reducing number of casualties among motorcycle user. However, there are still areas that do lack sufficient information that raises the need for further study. Below are the research gaps raised in the light of the present research:

i. Critical gap is one of the key parameter in road design for interrupted facilities such as at access or stop-control intersection but less significant at straight and basic segment of a road. Although the critical gap value is detailed out in international or local design manuals for intersections, the value is considered significant in representing passenger car. It was anticipated that the critical gap value for motorcycle is smaller than passenger car due to its small size as well as its ability in occupying much of the available lateral space on the road. Currently, critical gap value for motorcycle at access still remains as a loophole requiring further study.
ii. Similar to passenger car, critical gap for motorcycle cannot be obtained directly on-site and the usual data collected are gap size on the major road and motorcyclists' decision from the minor road on the available gap size. This kind of information is required to determine critical gap for motorcyclist.
iii. Motorcyclist's decision on available gap are random and stochastic where they do not always accept or reject gap larger or smaller than the determined critical gap. However only one (1) unique value of critical gap is needed in design works. Therefore, the distribution of gap decision is needed to help determination of critical gap value. This distribution of gap decision for motorcycle access have not been developed previously.

1.5 Research question

Reflecting on previous research findings, research problems and identified research gaps, the research questions for this study are:

i. What is the critical gap value for motorcycle at access of EMCL and how it differs from critical gap value for passenger car at access?
ii. How to determine the critical gap value based on the available data obtained on site?
iii. What is the appropriate model to represent the motorcyclist decision on available gap at access?
iv. How to ensure the developed model is accurate in predicting the critical gap value?

1.6 General objective

Based on the existing research needs and the potential application of the findings in future works related to motorcycle, the general objective of this study is to determine critical gap value for motorcyclists at egress and ingress of EMCL.

1.6.1 Specific objectives

The specific objectives have been set as follows:

i. To determine the motorcyclist's gap acceptance time at egress and ingress of EMCL;
ii. To establish the motorcyclist's gap acceptance model at egress and ingress of EMCL; and
iii. To evaluate the model fitness and accuracy in predicting the critical gap value.

1.7 Relevance of the study

This study focused on the access into and out from the EMCL. It was predicted that access is one of the hazardous element on EMCL due to the increase in number of conflict points at access. In addition, multiple tasks are also required at access such as to observe for oncoming traffic, to make decision whether to proceed through the access and at the same time to control motorcycle from falling. These can reduce the motorcyclist's riding attention and thus increase the likelihood of crash. Nevertheless, crash data at these exact locations are scarce due to insufficient details recorded during crash incidents. Recognising the high risk of access, this study is pertinent to be conducted to improve the condition.

By accomplishing the study objective, the expected outcome is gap acceptance models at egress and ingress of EMCL that can be generalised and applied to determine the critical gap for motorcycle. The critical gap value for motorcycle is essential in capacity estimation and contributes largely in deciding the dimensional needs of a road especially at access point of EMCL where scarcity in design can adversely influence the facility performance. It is anticipated that the output serves the objective to build a well-balanced facility able to accommodate traffic demand and at the same time ensure value for investment.

Apart from that, this study is also foreseen as an effort to fill in the gap that exists in the design of motorcycle facility and will contribute to the development of more EMCL on Malaysia's road network. Not only that, the knowledge in critical gap for motorcyclist is also expected to open more opportunity in the future for microscopic simulation study and intelligent transportation system (ITS). This, in the long run, can contribute in reducing the number of motorcycle fatalities due to road crashes.

1.8 Scope of study

This study examined motorcyclist' gap acceptance behaviour in real traffic condition. Careful considerations were given in selection of study locations to reduce the variation in the analysis. Thus, the overall road alignment for all locations were straight and flat terrain, dispelling major sight-distance issues. The effect that nearby intersections or interchanges may have on the traffic exiting or entering the EMCL was excluded in the study. The data collection was limited to egress and ingress along the main arterial road in Klang Valley; Federal Road 2 and Shah Alam Expressway

(KESAS). All observations were conducted during morning peak and off-peak period on normal weekdays (Tuesday, Wednesday and Thursday) and in good daytime weather where no abnormal traffic composition were observed. Even though the difference in volume of oncoming vehicles may affect available gap time, its effect on gap acceptance decision was excluded in this study.

In this study, the critical gap is determined by the type of vehicles on the intended lane. For egress, where motorcycles merge onto the main carriageway consisting of multiple type of vehicles, the emphasis of the study is on passenger cars and heavy vehicles only. The omission of motorcycles from the main carriageway is due to the low motorcycle count on the main carriageway, a result of the Malaysia's Road Traffic Law that prohibits motorcycle use of main carriageway in the presence of EMCL (Attorney General's Chamber of Malaysia, 2013). On the other hand, at ingress, the critical gap was determined between motorcycles, the only form of vehicle within the EMCL.

1.9 Organisation of the thesis

This thesis is divided into five (5) chapters. Chapter One (1) is the introduction to the context of the study. Following that is Chapter Two (2) that provides a review of the significant literatures on the subject, covering the results of high volume of motorcycle on road system performance and safety, the infrastructures provided for motorcycles, the driving behaviour of motorcycles and some fundamental theory of capacity, gap acceptance and critical gap. Chapter Three (3) provides details on methods employed and equipment used in carrying out this research. Further, Chapter Four (4) describes the statistical analysis to establish the critical gap models for motorcycles at egress and ingress of EMCL. Finally, conclusions are drawn and direction for future researches are suggested in Chapter Five (5) based on the present work.

1.10 Chapter Summary

This chapter has described the background of the study focusing on the issue related to motorcycle users. Optimum design for EMCL was formulated to be the main problem that requires solution. From the current state of knowledge, the critical gap value for motorcyclist at access point of EMCL was identified as research gap that needs to be explored. In order to guide the research process and defines the area of interest, research question was developed and research objectives that answer the research question was outlined in this chapter. By accomplishing the research objectives, the expected outcome is critical gap value for motorcycle at access of EMCL and it was believed to be significance to improve the safety of motorcyclist in Malaysia. In addition, this chapter also highlighted the scope of the study and how the thesis was organised to make assist reader's understanding.

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