EVALUATION OF TRAFFIC WEAVING BEHAVIOR AND PERFORMANCE AT MALAYSIAN URBAN HIGHWAY WEAVING SEGMENTS

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by

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LIST OF SYMBOLS

L_s	Short length, the distance in feet between the endpoints of any barrier markings (solid white lines) that prohibit or discourages lane changing.
L_B	Base length, the distance in feet between points in the respective gore areas, where the left edge or the ramp-traveled way and the right edge of the freeway-traveled way meet.
L_W	Weaving length

LIST OF ABBREVIATIONS

ARTEMiS	Advance Real-Time Electro-Mechanical Transient Simulator
C-D	Collector-Distributor
CORSIM	Corridor Simulation
DS	Degree of saturation
FOSIM	Freeway Operation Simulation
FFS	Free flow speed
FLC	Frequency Of Lane Changes
GPL	General purposed lane
HCM	Highway Capacity Manual
ITS	Intelligent Transport System
LOS	Level of Service
MLs	Managed Lane
NCHRP	National Cooperative Highway Research Program
NHSA	National Highway Traffic Safety Administration
OD	Origin destination
PCE	Passenger Car Equivalent
PCU	Passenger Car Unit
Q	Flow
REAM	Road Engineering Association Malaysia
RV	Recreational vehicle
V	Speed
VISSIM	Microscopic multi-modal traffic flow simulation
VR	Volume ratio

PENILAIAN TINGKAH LAKU DAN PRESTASI TRAFIK MENJALIN DI BAHAGIAN MENJALIN LEBUH RAYA BANDAR DI MALAYSIA

ABSTRAK

Bahagian menjalin ditakrifkan apabila terdapat jalan bercantum dan jalan mencapah yang tersusun bersama. Konflik di lorong pertukaran lalu lintas, di mana lintasan ke titik masuk / keluar yang hendak dituju, akan mengakibatkan penurunan kelajuan di seksyen tersebut dan menyebabkan cerutan trafik. Aliran di lebuh raya bandar akan terganggu jika halangan terjadi di sepanjang hiliran lebuhraya kerana jumlah lalu lintas yang tinggi. Akibatnya, lebuh raya itu tidak dapat mengekalkan tahap perkhidmatan yang dikehendaki untuk bahagian tertentu lebuh raya itu. Fenomena ini adalah acara harian di lebuh raya bandar raya Malaysia. Objektif kajian ini termasuk memahami tingkah laku trafik menjalin, menilai prestasi bahagian menjalin, menilai mitigasi yang dilaksanakan dan mengesyorkan pindaan garis panduan sedia ada pada bahagian menjalin di lebuh raya bandar di Malaysia. Data yang dikumpulkan di empat lokasi di lebuh raya bandar yang setiap hari mengalami masalah kesesakan yang disebabkan oleh aktiviti trafik menjalin. Dalam kajian ini, kaedah analisis trafik menjalin yang diubahsuai digunakan untuk menilai aras perkhidmatan (LOS) bahagian menjalin untuk disesuaikan dengan keadaan lalu lintas Malaysia. Hasil tersebut kemudiannya dibandingkan dengan kaedah analisis trafik menjalin HCM 2010. Adalah didapati bahawa nilai keputusan LOS menggunakan kaedah analisis yang diubahsuai adalah lebih tinggi daripada HCM 2010. Daripada data, didapati bahawa motosikal adalah lalu lintas tertinggi kedua dan ia juga diambil kira dalam kaedah analisis trafik menjlain yang diubah suai. Pelaksanaan mitigasi di

bahagian menjalin dengan menambah lorong tambahan kemudian dianalisis untuk menilai keberkesanannya. Adalah didapati bahawa menambah bilangan lorong di bahagian trafik menjalin akan meningkatkan keupayaan segmen dan mengurangkan kadar pertukaran lorong. Akhir sekali, pindaan *Guideline Of Toll Road System – Design And Standard* dicadangkan untuk dikemaskini mengikut data sebenar di tapak.

EVALUATION OF TRAFFIC WEAVING BEHAVIOR AND PERFORMANCE AT MALAYSIAN URBAN HIGHWAY WEAVING SEGMENTS

ABSTRACT

A weaving section is defined when there is a merging and a diverging road formed together. The conflict at the traffic changing lane, where crossing to the desired exit or entry point happens will consequently reduce the speed of the section and creating bottlenecks at the highway facilities. The flow on an urban highway will be interrupted if an obstruction happens along the downstream highway because of the high traffic volume. As a result, the highway will be unable to maintain the desired level of service for that particular section of the highway. This phenomenon is a daily event on Malaysian urban highways. The objective of this study includes understanding the weaving behaviour, evaluating the performance of the weaving section, evaluating the mitigation measure implemented and recommending a further study to amend the current guideline on the weaving of the Malaysia urban highway. The data were collected at four locations at urban highways which is daily having problem of bottleneck caused by the weaving activities. In this research, a weaving analysis method which included the small lorry and motorcycles, is used to evaluate the LOS of the weaving segment to suit the Malaysian traffic condition. The result is then compared with the HCM 2010 weaving analysis method. It is found that the result of LOS by this modified analysis method is higher than the HCM 2010. From the data, it is found that the motorcycle is the second highest traffic and it is also taken into account in the modified weaving analysis method. An implementation of mitigation at the weaving segment by adding an additional lane was then analysed to evaluate the effectiveness. It is found that adding an additional lane at the weaving segment will increase the capacity of the segment and reduce the lane changing rate. Finally, recommendation for an amendment of the Guideline of Toll Road System – Design Standard were proposed to update according to real data at site.

CHAPTER 1

INTRODUCTION

1.1 Research Background

In the 2010 Highway Capacity Manual (HCM 2010), weaving is defined as the crossing of two or more traffic streams moving in the same common path along a significant distance measurement of highway without the help of traffic control devices (with the exception of guide signs). Weaving sections are formed when a merge area is thoroughly followed by a diverging area, or when a one-lane on-ramp is closely followed by a one-lane off-ramp and the two are linked by an auxiliary lane. A normal highway system is composed of three basic components, comprising basic freeway sections, ramp sections, and weaving sections.

Weaving is an undesirable situation in which traffic has to dodge right and left, must cross paths within a restricted distance, to merge with traffic on the through lane. It is also a consequence of having too many grade-separated junctions on a road in a short distance, where traffic intending to leave the grade-separated road at the next junction has to compete to occupy the lane with traffic which has just entered from the previous merging lane. Weaving activity is described as Figure 1-1 :

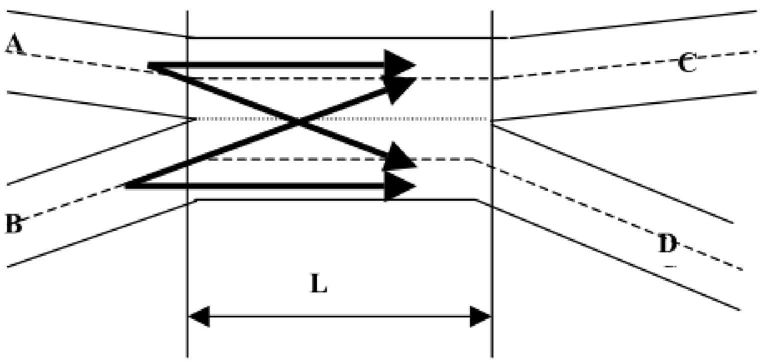

Figure 1.1 Weaving manoeuvre

This situation is either where the junction has on-slip road before the off-slip road at a junction (for example, the cloverleaf interchanges), or in urban areas with lots of short distance between interchanges or junctions. The driver changing lane from its original lane to the target lane on weaving section using limited time and area given. The driver of the lane - changing vehicle must estimate the conflict with surrounding vehicles to change its traveling lane safely. It is assumed that the lane-changing vehicle chooses acceleration or deceleration after encounter with the surrounding cars. The compulsory lane-changing behaviour is assumed to consist of the following two steps. Firstly, a driver of lane-changing vehicle is assumed to decide whether he / she should make acceleration or deceleration to prevent a collision with the other vehicles based on the driver subjective evaluation on the traffic conflict. Secondly, it is assumed that the driver fine-tunes acceleration or deceleration rate based on the severity of vehicle interaction's conflicts.

Controlling the traffic in highway weaving sections is a complex issue since there are a lot of vehicles movement activities in the segment such as crossing paths, changing lanes, or merging with through traffic as the vehicle enter or exit an expressway. There are two types of weaving sections: (a) single weaving sections which have one entry at upstream and one exit point at downstream; and (b) multiple weaving sections which have more than one point of entry followed by more than one point of exit.

The third edition of the Highway Capacity Manual (1985) reflected the extensive research on weaving areas since the publication of the 1965 HCM. "Weaving areas are formed when a merge area is closely followed by a diverging area, or when an on-ramp is closely followed by an off-ramp and the two are joined by an auxiliary lane."

Weaving areas are defined in terms of three principal geometric characteristics: weaving length (defined as in the 1965 HCM), the configuration of lane (relative placement and number of entry and exit lanes, generalized to three types), and width (number of lanes).

The three typical geometric elements of weaving sections that have an impact on the operational characteristics (US HCM 2010) are :

i. Length
ii. Width
iii. Configuration

Weaving length was defined as only one type of length in the previous study. However in the US HCM 2010, the weaving length defined as two types as illustrated in Figure 1.2 :

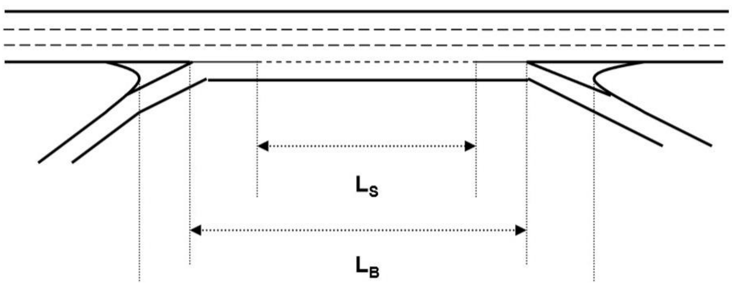

Figure 1.2 Weaving length

L_S = short length, the distance in feet between the endpoints of any barrier markings (solid white lines) that prohibit or discourages lane changing.

L_B = base length, the distance in feet between points in the respective gore areas, where the left edge or the ramp-traveled way and the right edge of the freeway-traveled way meet.

The US Highway Capacity Manual 2000 categorized weaving configuration to 3 types which are as Type A, Type B, and Type C as described in figures below :

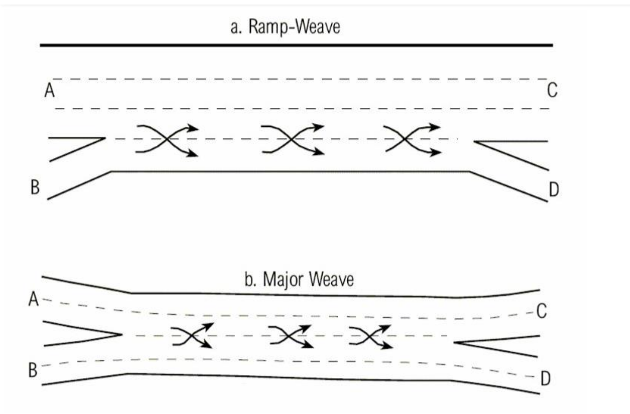

Figure 1.3 Type A weaving

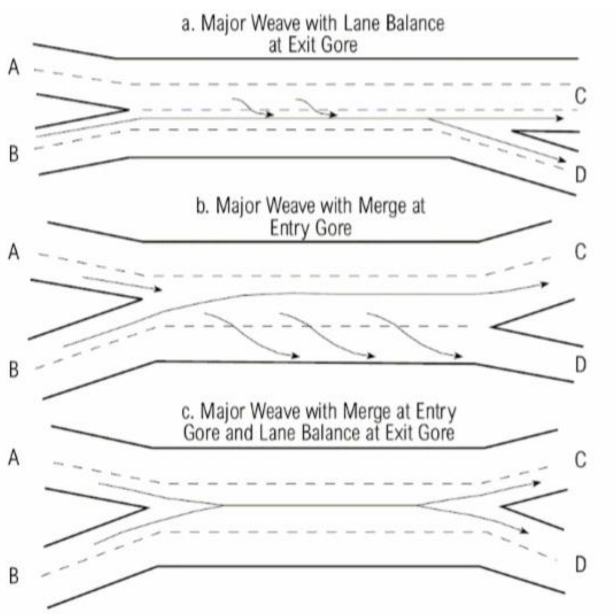

Figure 1.4 Type B weaving

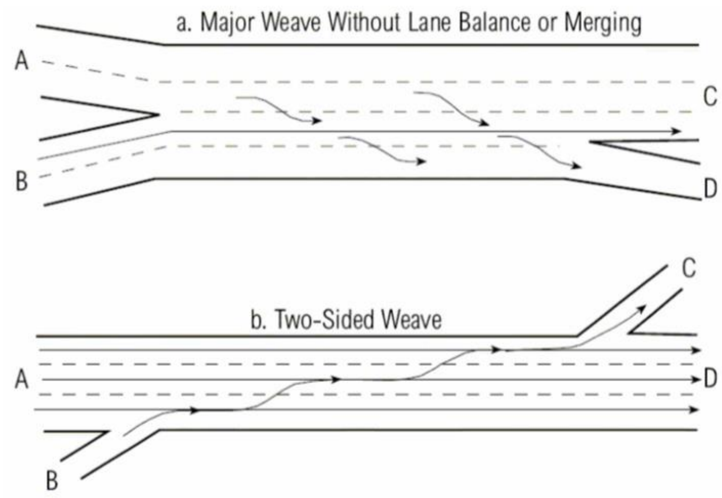

Figure 1.5 Type C weaving

Traffic weaving and road safety are closely related as the traffic weaving activities effect to the safety of the driver because it’s involved conflicts at the traveling lane such as lane crossing, merging and diverging. A survey conducted by the National Highway Traffic Safety Administration (NHSA) US found that 24% of the people typically encountered cars weaving in and out of traffic when they are on the roads. The survey also found that people also tend to change lanes unsafely. Thus the traffic weaving activities should be a concern in ensuring road safety.

A research on the relationship of weaving length and safety found that as the weaving length increase, the capacity and the total number of conflicts also increase relatively (Xu, et al., 2008). The research also found that the measure of conflicts decreases relatively with the increases in the severity of conflicts as demonstrated through the average speed.

The National Cooperative Highway Research Program Report 3-55(5) reported that the two major components of the weaving analysis procedure which were a model to calculate the speed of weaving and non-weaving vehicles for a specified weaving length, width and volume conditions, and a model to determine if the weaving traffic in a particular weaving area is constrained by its geometry features (Denney, 2005). The speed estimation equation was developed through regression techniques for weaving and non-weaving traffic, configuration, and unconstrained and constrained operation.

1.2 Objectives

The objectives of this research are:

i. To analyse the behaviour of the road user at weaving segments on Malaysian highways.
ii. To evaluate the corresponding Level Of Service (LOS) at weaving section at Malaysian urban highways.
iii. To confirm on the necessity of a review or an amendment to the existing guidelines in Malaysia.

1.2.1 Research Question

Traffic in a different country might behave differently according to their local condition. The road facilities, technology, and regulation also might be different and contribute to the behaviour of the driver. Weaving section is an interesting part of the highway to study because it has a lot of activities consisting of merging, diverging and lane changing. The urban highway usually has a higher traffic volume than the interurban highway. How is the traffic behaving or interacting at the weaving section of Malaysian urban highway should be studied for a better understanding in order to design the highway accordingly. This can future benefit to plan for a better design. Furthermore, by understanding the driver’s weaving behaviour, the road authority can suggest suitable mitigation to reduce the problem at the weaving segment.

The Guideline For Malaysia Toll Expressway System – Design Standard stated that the highway should be designed for targeted LOS C for interurban highway, intra-urban highways and urban highways, 20 year after the opening of the highways. But the traffic volume would be expected to increase every year. While in the latest highway concession agreement, it is stated that the highway operator must maintain the highway at LOS D at all-time.

The volume of of Malaysian Tolled Highway increase every years as shown in table 1.1. A study done by Malaysian Highway Authority in year 2009 on traffic congestions for urban highway in Klang Valley, have identified 58 of 'hot spot' locations (MHA, 2009). This hot spot is the most congested area in the highway. Another same study in year 2016 have identified additional 8 more locations. This numbers of hot spot locations were the points at the highway network that causing delay in the traffic stream at Klang Valley.

Table 1.1 The volume of Malaysian Tolled Highway

Year	**Traffic Volume (million vehicles)**
2012	1,567.35
2013	1,641.37
2014	1,718.59
2015	1,808.54
2016	1,828.20
2017	1,844.39
2018	1,726.57

Source : Malaysian Highway Authority Annual Report Year 2012 to 2018

However, problem probably occurred at some weaving segment of the highway, which affect the performance of the highway. The performance of this particular segment of the highway should be evaluated to determine whether the urban highway maintained LOS D at the whole stretch of the highway as required by the Highway Authority and to ensure providing the free flow travelling for the highway user. Weaving activities happened at some interchanges at the highway and cause congestion. What is the problem at the weaving section of Malaysian urban highway that can create the bottleneck phenomena?

This problem needs to be assessed and evaluated to propose suitable mitigation. How to assess the weaving behaviour and the quality of service at the Malaysian Urban Highway with the local traffic condition? Is the current referred method to analyse the LOS is practically the most suitable method to evaluate the LOS at Malaysian urban highway? A study should be carried out to answer all those questions and benefit for the better future design of the highway.

1.3 The Need Of The Research

The capacity and level of service of weaving sections are the issues frequently discussed in traffic analysis subject matters. The efficiency of traffic operation in highway weaving sections is a key factor to the capacity of the whole highway system, hence highway planners, designers and engineers are concerned mostly on the design, analysis or operation management of weaving sections. The Malaysian Highway Capacity Manual 2011 have not yet developed a chapter for freeway weaving. This study could be an effort as a step to develop an analysis of highway weaving sections in Malaysia. However, the complex and stressed lane-change manoeuver in the Malaysia highway weaving section causes the traffic operation to behave differently from other components of the highway system. Thus, the characteristics of the operation must be studied first to analyse or solving the problems of highway weaving sections. This research will identify the problems of the weaving section, determining the capacity and analyzing the operation management of the weaving section, so that similar traffic problem will not be repeated in future road design.

Research on issues of weaving sections is important either to traffic administrator or to facilitate during the design and plan phase, especially to enhancing the effectiveness and the safety of the road system. Analysis on operational characteristics of facilities is the crucial procedure for treatment determination. A research study on mainline and ramp lane arrangement shown that type B weaving has the highest number of total crashes and severe crashes. Meanwhile, the crash data analysis results show that the Type C arrangement reported the lowest average crash frequency and crash rate. Even though using Type A arrangement may result in higher total number of crashes as compared to the Type C arrangement, it still deliberated since most of the crashes associated with the Type A arrangement are rear-ended crashes which usually do not result in severe effects. Freeway segments with Type B arrangements reported the highest average crash frequency, average crash rate, and average percentage of fatal plus severe injury crashes (Liu, et.al, 2010).

The most current reference in analyzing the weaving section is the US Highway Capacity Manual 2010. However, Malaysia's vehicle composition and the type of vehicle is slightly differenced from the US. This matters should be adjusted to suit the local traffic condition to show more accurate weaving capacity prediction. The Malaysian Highway Capacity Manual 2011 currently does not have a method to analyse the weaving segment. As Malaysia traffic condition and traffic composition are different from the US, this research proposed a modified method which included a different traffic composition that is considering the small lorries and the motorcycles.

This research tries to understand the traffic behaviour at weaving sections, thus assisting to take counter-measures to improve the operation of weaving sections and help designers to design enhanced new conveniences freeway. By achieving the research objectives, this research will benefit in different ways for Malaysian urban highway. In summary, by investigating the driver behaviour and traffic factors that influence highway weaving operation and thus developing the more accurate capacity for weaving sections will beneficial to highway design, traffic operation and management, and road safety.

The finding from the research can be used to develop highway operational design strategies that are more effective and safe. Also, the finding of this research will benefits the Malaysian Highway Authority as a base guideline to revised the current Guideline for Toll Expressway Design. The current guideline stated the reference for the design of interchange weaving length and number of the lane, and it will be better if it can include the traffic parameter in the guideline. It can also be a base guideline for road authority in decision making or setting related policy regarding operational of the highway especially when upgrading the highway is being considered. A better traffic service and a good traffic management will be achieved by a better understanding about the weaving segment. This research will also come out with a proposed Malaysian method for weaving segment analysis.

1.4 Scope And Limitation Of Study

This research focused on selected areas of urban highway in Malaysia. The location were determined based on data and site availability within the control of the Malaysian Highway Authority. The research focused on the behaviour of the vehicle at the weaving section, its effect to the capacity of the weaving segment and the effect of adding additional lane as mitigation to improve the performance of weaving segment. Traffic composition included in the studies are lorries, small lorries, buses, cars and motorcycles

1.5 Dissertation layout

The dissertation consist of six chapters, which will be described as follows:

Chapter 1 is the introduction of the research, in which an overview of the research topic, research objectives, research question, and potential research contribution. Chapter 2 is devoted to reviewing previous studies related to freeway weaving sections, in which the researcher describes and critically reviews international literature on the analysis of freeway weaving sections.

In Chapter 3 the researcher explained the methodology on how the research been carried out. This chapter consist of how the data been collected, the observation data, the method of analysis been done to evaluate the Level of Service (LOS) of the studied location and the evaluation method for the effectiveness of the mitigation. The impact of the performance of the freeway weaving sections is investigated by using the data gained after the implementation of the mitigation at the studied location of weaving segment.

The results and observation finding demonstrated in Chapter 4 by the plotted graph of the behaviour of the highway user.

In Chapter 5, the researcher demonstrated and discussed the result of the LOS analysis and made a comparison of the result from two different analysis methods, which include the HCM 2010 procedure and a modified method. The studied factors include the length of the weaving section, weaving ratio, vehicle composition, and weaving speed differential compared for the four locations and also were discussed in this chapter. A sensitivity test results for the chosen variables using the real data were presented and discussed for further recommendation.

In Chapter 6 the researcher concluded and recommended from the research finding. Recommendations for further research on weaving sections are also written in this chapter. The researcher also highlights the limitation of this research which could be better for future research to consider.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the relevant studies which can help in understanding matters on traffic weaving segment. Initially, this chapter reviews previous studies related to highway weaving segments. Not much literature focusing on weaving analysis was available compare to literature on merging and diverging where weaving is a combination of both. However, available literature regarding factors influencing weaving capacity, weaving modelling, weaving bottleneck and alternative modeling approach to weaving, subsequently gave a good understanding on the weaving segment. Apart from that, there are some literature on traffic safety at weaving segment which is relevant to relate the importance to carry this research. Not many countries have developed their own Highway Capacity Manual. Hence, it is good to introduce new chapter about weaving in addition on to the Malaysian Highway Capacity Manual 2011.

2.2 Factors Influencing Weaving Capacity

The performance of a road section is usually measured by the quality of traffic movement along the route, which is based on the parameters of the degree of saturation (DS), flow (Q) and speed (V). These parameters are interrelated and greatly influenced by traffic conditions, environment and time. In addition, road performance also can be seen from the level of traffic system effectiveness and efficiency of the current level of operations. The effectiveness level of traffic system is usually measured from the time mean speed and speed-time spot. The efficiency rate of flow measured by the space mean speed.

A study by using a simulation on the weaving section found that the weaving ratio does not have an impact on the capacity of the weaving section (Zhang, 2005). The study also found that the weaving capacity decreased as the weaving length increased while the HCM 2000 procedure is adequate in capturing the impact of the heavy vehicle. This proved that a longer weaving length provide a comfortable sufficient space for the vehicle to weave at the section thus reduce the capacity.

However, HCM 2010 defined maximum weaving length as the length of a segment that has no longer impacted on the operation by the weaving turbulence. Various equations have been adopted to determine the capacity of such weaving sections. Some of these include factors such as weaving ratio (R), volume ratio (VR) and weaving configuration, all of which influence the weaving capacity. For this research, drivers' behaviours at weaving sections were studied to assess the effect on the capacity of such sections and to aid in the development of an analysis method to evaluate the performance of these sections for various configurations. Factors such as VR, R, the upstream traffic characteristics, the Frequency Of Lane Changes (FLC), the percentage of the pre-segregation for the upstream traffic of weaving section, the length of weaving section and a merging point were investigated. The results of the analysed data indicated that the FLC differed according to the configuration of the weaving section (Al-jameel, 2009). For this purpose, seven weaving sites with different configurations and lengths were selected. This result was found to be much higher than those reported in other studies. In addition, the type of weaving configuration also influenced the effective length that was used by those weaving vehicles. For short weaving sections (i.e. 150 meters or less) the effective length is basically the whole length, whereas, for relatively longer weaving sections (i.e. 300 meters or more), the effective length is found to be equal to 200 meters or less.

The traffic flow characteristic of the weaving area between expressway and at-grade road shows a different distribution (Jiang et al., 2012). The research found that the distribution of vehicle arrival is fluctuates higher in exit ramp during peak hour, and more uniform during the non-peak hour. The situation is similar for the at grade auxiliary road with the exit ramp. While under normal circumstances, the traffic condition affecting the vertical speed in section with gradient, and it gradually reduces from the main line to exit ramp and at-grade connecting section. Horizontal vehicle speed is relatively close with lane function, ramp line trend and traffic demand. This research ran different situations weaving area in traffic simulation software, in a connecting section under the two control modes of alternate discharging and weaving. It is indicated that the length of the connecting section is basically not affecting the alternate discharging, while traffic capacity under weaving mode has close relation with the length of connecting section.

A study was done to analyse the maximum weaving length and lane changing rate for two-sided weaving section by referring HCM 2010. The study found that the site with a longer distance of weaving section tends to encounter longer weaving turbulence with the higher lane-changing rate (Prasetijo et al., 2018). Shorter weaving length causes less lane-changing activities because drivers do not tend to weave at shorter section area as it is forced to perform weaving abruptly and risk themselves with collision.

Heavy vehicles also have influence to the flow rate of the weaving segment. Capacity obtained from Freeway Operation Simulation (FOSIM) has a normal distribution (Vermijs, 1998). Weaving capacity declines when the truck percentage is increases and the weaving flow rate increases. Weaving section length has little influence on capacity when lengths used in practice are considered. Estimated pcu values for trucks are not the same for different weaving section types.

It is common in developing countries that the road carriageway width is not uniform. The number of lanes is one of the factors contributing to the capacity of the weaving segment. Due to change in carriageway width, congestion happens along the segment and effecting the traffic stream speed (Ketankumar et al., 2013). The research also found another important factor that is the composition of traffic. The traffic flow, as well as the speed, reduces as the volume of large size and slow-moving vehicles increases.

The weaving length is also related to the traffic safety at interchanges. The weaving length increases relatively with the increasing of the capacity and incline with the increasing of the total number of conflicts (Xu et al., 2008). It is also found that the number of relative conflicts declines, whereas the severity of conflicts increases.

Crashes can happen at the weaving segment due to lane-changing activities. 29.16% traffic precede one lane changing and prefer to change the lane at the first 50 meters (Kusuma et al., 2014). A vehicle with more than one lane-changings can change the lane into the target lane either straight or staggered. The average passing time between the lane changing is about 4.09 sec. From this study, it shows the important to determine the number of lane at the weaving segment during the design stage to avoid the risk of crashes at the weaving segment.

A study by Wang & Park (2016) about crashes at expressway weaving segments was done by a regression model using crash data, geometric, Microwave Vehicle Detection System (MVDS) and weather data. The crash risk found to be higher at the location where there is no need for on-or off-ramp traffic to change lane because of more interactions of traffic and higher speed variances between weaving and non-weaving traffic. This shows that more interaction happened during lane change will risk more to the driver.

A study of lane-changing behaviour model at the weaving section by Bin & Ph (2003) demonstrated discriminant analysis of the behaviour of choosing between acceleration and deceleration activities. It also modeled the acceleration/deceleration rate of the driver's decision. A framework on how to assess traffic safety and road efficiency using a microscopic simulation developed from this research.

The safety impact of different distance for each lane change maneuver on the general purposed lane (GPL) weaving segments close to the ingress and egress of Managed Lane (MLs) were studied by Cai et al. (2018) using two simulation methods: microscopic multi-modal traffic flow *simulation* (VISSIM) and driving simulator. The two simulation results supported each other. Based on the two simulation studies, it is suggested that 1,000 feet be used as the optimum length for per lane change at the GPLs weaving segments with MLs. The research not only investigates on the safety impact of traffic volume, variable speed limit control strategies but also discovering the drivers' gender and age characteristics. This study can comprehend the evaluation of traffic performance of freeway weaving segments with the presence of simultaneous GPLs and MLs in highway safety. It also provides guidelines for prospect adaptation of freeways to include MLs.

Cho & Tsai (2005) studied the traffic flow characteristics of weaving traffic in a separated connecting Collector-Distributor (C-D) roadway on the freeway weaving section and on congested traffic flow conditions. Three basic factors as traffic density, traffic speed, and traffic rate of flow characteristics of weaving vehicles were analysed to understand the behaviour. The study found that the value of traffic variables as well as the traffic speed and rate of flow are identical with the Highway Capacity Manual (HCM) 2000 but HCM is lesser in term of traffic density value.

There are not many countries that develops their own Highway Capacity Manual. A comparative study of selected two capacity values for weaving section types in the HCM 2000 and in the Dutch manual for freeway shows very large differences for weaving segments of Type C from the sensitivity analysis conducted by Minderhoud & Elefteriadou (2003). Both HCM and the Dutch procedures consider a variable defining the overall weaving ratio, but does not deliberate the dependency of the capacity estimate on the distribution of weaving traffic per leg. The research suggested that the presence of asymmetrical weaving volumes should be considered in any weaving analysis procedure.

However, Dijker (2003) did a simulation to estimate capacity values for asymmetrical weaving sections for an update of the Dutch capacity manual for freeways. The weaving section length's influence was limited mainly because it only considered minimum weaving lengths. The more important effect on capacity is the percentage of trucks but not adequately be described with a single pcu value. This study found that capacity decreased with increasing weaving flow rate as expected since it only considered symmetrical OD patterns. Sensitivity analyses showed that the results from this study could not be used when the OD pattern does not correspond rather closely to the symmetrical type used in the simulations. Djiker (2003) suggested additional future research for non-symmetrical OD patterns.

Another model developed to incorporate into the new edition of the German Highway Capacity Manual. The model introduced the consideration for the total segment of freeway merge, diverge, and weaving as an entire object. The volume-to-capacity ratio of the whole segment can be considered as a combination of volume-to-capacity ratios in the different critical areas under consideration according to the probability and queuing theory. With this model, the traffic quality can be obtained directly as a function of the volumes on the freeway and on the on-ramp or off-ramp respectively.

The goal of literature on factors of influencing weaving capacity is to identified the relevant factors that are suitable with this research objective.

2.3 Weaving Modeling

There are several research on the development of model for weaving section analysis. One of them is focusing on the lane-changing activities at weaving area. Lane-changing activities are critical to traffic operations on weaving areas. A study was done to propose a methodology which directly provides the lane-changing models that account for effects of lengths of weaving sections, speeds of traffic streams, and utilization of time headways based on gap acceptance theory (Lertworawanich & Elefteriadou, 2007). This methodology delivers closer capacity estimations for the three study sites than the HCM 2000 weaving methodology. However, the research suggested to enhance research on weaving area capacity analyses as below :

i. evaluate the accuracy of the proposed methodology for configurations other than those considered in this research that can provide information on volume ratios of traffic streams from both the freeway and the ramp to; and

ii. develop capacity models for ramp junction facilities based on the method developed.

A corresponding macroscopic model at the weaving section was derived by D. Ngoduy (2006) to calculate the lane-changing probabilities. The model has also taken into account the give-way effect and the willingness to accept smaller gaps of subject drivers when approaching the end of the weaving area.

National Cooperative Highway Research Program (2008) did a study named NCHRP Project 3-75 sponsored by American Association of State Highway and Transportation and the objective was to calibrate new and/or updated models for prediction of performance in freeway weaving sections and draft a replacement chapter for the HCM 2000. Most traffic models have to be re-evaluated with new databases every ten years or so. Driver and vehicle characteristics and behaviour change rapidly, and models need to keep up with the reality of the actual operations. The report, strongly recommended freeway weaving and ramp junction operations be studied simultaneously, to develop the possibility of more integrated and harmonious models.

Roess & Ulerio (2009) found about the new approach in NCHRP 3-75 was to determine speed and density in order to quantify the impact of configuration and type of operation by predicting the lane-changing activity within the weaving segment. In NCHRP 3-75, the configuration types have been substituted with direct measures of lane-changing activity in the weaving segment. In addition to eliminating configuration types, the lane-changing intensity is also good to be defined by the degree of turbulence in the weaving segment and can be used directly as another performance parameter of interest.

A new model which can be assessed in one step was introduced which considered the total segment of freeway merge, diverge and weaving as an entire object (Wu & Lemke, 2011). The model was intended to be incorporated into the new edition of the German Highway Capacity Manual. Wu & Lemke (2011) defined the LOS of the total segment as a combination of volume-to-capacity ratio. Hence, this was a different way to present the weaving segment performance.

An analysis carried out by Lertworawanich & Elefteriadou (2007) indicate that the proposed methodology provides a closer capacity estimation for the three study sites than the HCM 2000 weaving methodology. Lane-changing activities are critical to traffic operations on weaving areas, and the proposed methodology directly provides the lane-changing models that account for effects of lengths of weaving sections, speeds of traffic streams, and utilization of time headways based on gap acceptance theory. However, the research recommended :

i. carry out an extensive data collection that can make available information on volume ratios of traffic streams from both the freeway and the ramp to assess the precision of the proposed methodology for configurations other than those deliberated here; and
ii. Develop capacity models for ramp junction facilities based on the method suggested here.

A microscopic simulation model using Integration software was done to estimate the capacity of weaving segment which specifically on lane changing logic. The research found that Integration model offers a vigorous tool for modeling and evaluating of weaving section (Zhang, 2005). Weaving ratio as defined in HCM 2000 is the ratio of the lowest weaving volume to the total weaving volume. Zhang (2005) introduced new weaving ratio. However, the study analysed models by utilized the empirical data at at two sites which were gathered back in 1980s by Cassidy et. al. (1990). It is better if the study gathered the current empirical data in the simulation.

Skabardonis & Kim (2010) developed a simulation model to analyse weaving sections based on the field data of two weaving bottlenecks. HCM 2010 method should be evaluated using the same data used in this study to determine if it's an appropriate analysis tool to be used. This tool can be potentially used in several freeway operations analyses (e.g., auxiliary lane lengths, ramp metering) provided that accurately represents real-world operating conditions. There is a need for a systematic model to evaluate the accuracy of the methods regarding capacity prediction, by selecting weaving sites that are bottlenecks and comparing predicted and observed queue discharge flows.

Yang & Shao (2012) proposed a model to estimated weaving capacity at the urban expressway. The research demonstrated that the capacity estimated by the proposed model is constant with field data while the HCM procedures tend to overestimate the capacity of weaving segments significantly. It also considers capacities of weaving segments short than 150m. The study was done in Beijing, China by VISSIM simulation. The HCM procedure tends to overestimate the capacity of the weaving segment significantly.

The weaving characteristics and traffic variables have a significant effect on crashes. Pulugurtha & Bhatt (2010) found that crashes per total number of required lane changes increase significantly as with the increasing of non-weaving volume because of failure to reduce the speed at weaving sections. They observed that Type A weaving sections comparatively safer to other types of weaving section configurations. Type A-B and Type C sections found to be safer than Type A and Type B weaving sections based on crashes per weaving volume. Instead, analysis based on crashes per total number of required lane changes indicates that lesser crash weaving sections rates are for Type A and Type C than other types of configurations.

2.4 Weaving Bottleneck

An active freeway bottleneck is a location regarded by the existence of queued traffic immediately upstream and freely flowing traffic immediately downstream. The bottleneck happened because of merging and diverging traffic activities. The exact location of the bottlenecks and when they are active must be observed to understand the traffic pattern. Queuing was caused by drivers who had just entered the shoulder lane from the on-ramp and had decelerated to merge (Bertini & Malik, 2004). The vehicles slowing down and spread to both lanes then disseminated upstream. The average discharge flows together with the start of queuing were 4% lower than flows measured at the location before the beginning of the queue. During bottleneck condition, flow reductions happened consecutively in time and space marking the path of the backward-moving shock. However, the traffic data was collected at on-ramps with metered flows.

Not much literature available for weaving bottleneck situation, but it is much similar happened due to the activities of merging and diverging.

2.5 Alternative Modeling Approach To Weaving

HCM 2010 mentioned that weaving segment can be analysed by using variety of simulation tools as the HCM 2010 has limitations. Where situation as below that cannot be analysed by HCM, a simulation tools can be very useful. The limitations listed by HCM 2010 are :

i. Lane management within the weaving segment, for example, regulating the lane with pavement marking, signage, and physical barrier.
ii. Ramp metering.
iii. Specific operating conditions when oversaturated condition exist.
iv. Application of intelligent transportation system technologies on weaving segment operations.
v. Multiple weaving segment.

A microscopic study was done for merging and weaving maneuvers under congested traffic conditions to develop a new lane change model by Hidas (2005). The new model incorporated explicit modeling of vehicle connections by using the ARTEMiS traffic simulator. The model can reproduce the observed behaviour of individual vehicles in all three types of lane change maneuvers, in terms of speed, gap acceptance, and conflict resolution. The macroscopic results are close in terms of speed-flow relationship and the typical, expected results. The model can simulate both freeways and signalized urban arterial networks.

Wei & Wanjing (2013) presented a simulation study of a lane assignment approach to improving the operation of freeway weaving sections. By assigning the vehicles with different destinations into different lanes, the study proposed an effective