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# Analysis of Maximum Weaving Length and Lane-Changing Rate for Two-Sided Weaving Section for Federal Road FT050 Based on HCM 2010

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**Abstract:** Weaving is defined as a movement of vehicles that crossing over the direct traffic from on-ramp to off-ramp. Apparently, weaving maneuver lead to collision risk and weaving turbulence especially at two-sided weaving section. In order to analyze the operational of two-sided weaving segment on Federal Route 50 (FT050), the following study recognize the maximum weaving length and lane-changing rate. Video recording technique was used at two different locations that are Site A (KM15) and Site B (KM16). The volume data was extracted by playback the video using computer. Analysis was made using Microsoft Excel spreadsheet and applied the methodology in the Highway Capacity Manual 2010. The study found that Site A has more tendencies to encounter longer weaving turbulence with maximum weaving length ranging from (1952 m – 2120 m) compared to site B that is 1866 m - 1882 m. Site A with a longer distance of weaving section 358 m has higher intense of total lane-changing rate that is 1142 lc/h compared to Site B with a distance of weaving section 316 m has total lane-changing rate of 812 lc/h. Shorter weaving distance cause less lane-changing activity because drivers does not prefer to perform weaving at shorter weaving section as it is forced the drivers to perform weaving drastically in more crammed situation and risk to dealing with accident is huge. The findings shall help to understand more about causes of weaving turbulence at weaving section by using HCM 2010.

**Keywords:** maximum weaving length, lane-changing rate, weaving turbulence, two-sided weaving.

## 1. Introduction

Weaving is an action that performed by merging traffic to cross the through lane over diverging movements [1]. Basically, weaving is types of conflict that occurred in daily traffic and traffic streams conflicts are common at any of weaving sections/intersections [2]. A weaving maneuver performed by drivers is normally depending on their own purpose. However, inefficiencies of driver when perform weaving will finally lead to risk of accident and also confusing maneuver/conflict [3] and speed is considered to be one of the main cause [4]. Normally, a weaving maneuver could be detected by the driver on direct traffic when the weaving's driver gives signal to change lane. Effect of the lane-changing of the weaving vehicles along a weaving segment could create weaving turbulence.

Since collision risk at weaving section is large, human error could be one of the biggest factors. Somehow, by prevention this error, there might be a high probability to reduce the accident risk [5]. In traffic engineering view, the collision risk at weaving section might be influenced by the length of the weaving segment itself. Previous study [6] proved that longer distance of weaving cause less collision risk because its influence the driver decision to change lane safely. If longer weaving section is more preferred by most of driver to perform weaving, then activity of lane changing is become higher as the volume of vehicles is increase. Affected by this is weaving turbulence that will be created by the increasing volume of vehicles and this could be measured by analyze the maximum weaving length of the section. Therefore, this study is carried out to investigate the maximum weaving length and lane-changing rate which is affected by volume ratio and weaving length at different sites. Methodology of Chapter 12 in Highway Capacity Manual 2010 is applied to assist the analysis.

## 2. Review on Weaving Behavior

A study on weaving section was conducted as early in 1965 by HCM which the length of weaving section was used as approach. Since that, a lot of studies were conducted to analyze a weaving section in order to

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investigate the length, flow, lane-changing rate, capacity and speed. Basic purpose of investigating these is due to a problem regarding to weaving turbulence. This problem is often formed within the weaving section [7]. However, there is a lack of method used in HCM 1965 which is the volume and flows of non-weaving was not taken into consideration to analyze the rate of lane-changing. Year by year, HCM was upgraded to provide the best methodology of weaving analysis and finally the latest version of HCM was published in 2010. The methodology of freeway weaving analysis in HCM was adapted by the report of NCHRP which a study was conducted to develop a new model or methodology for maximum weaving length and lane-changing rate [8]. New version of HCM used one-sided and two-sided instead of using 'Type' to classify the weaving's configuration. Two-sided weaving section is classic and special as it is frequently occurred on multilane highways and ramp to ramp flow is a main subject of analysis [9].

Due to weaving maneuver, lane-changing activity is become more aggressive in purpose of avoiding weaving vehicles. There were a lot of studies regarding to lane-changing in traffic which is more complex compared to other situation especially in the developing cities where traffic is heterogeneous (large and small vehicles mixed) [10]. Gap acceptance is a very famous approach in order to analyze lane-changing activity and it also used to analyze for conflicting pedestrians movements [11]. Lane-changing at a roundabout also complex as a lot of confusing and weaving maneuver which was studied mostly by using gap acceptance approach [12]. Speed adjustment is also one of approach used and studied by Uno as a speed adjustment model was developed to analyze speed adjustment processes of a lane-changing vehicle at weaving section. However, both approaches could not be applied as it does not measure a weaving turbulence impact. Approach of HCM 2010 is the best to use in order to analyze lane-changing rate at weaving section so that the impact of weaving turbulence could be known.

## 3. Method

It was earlier explained that data analysis was made using methodology in Chapter 12: Freeway weaving segment of the HCM 2010. Early stage of analysis is to find the short length LS which will be as weaving length and also base length LB. LS is measured between the end point of any barrier marking that prohibit lane-changing while LB is measured between right edge and left edge of the ramp meet. If there is no barrier found, so LS is equal to LB. Otherwise, if there is any presence of barrier, Eq. (1) is used.

$$L_s = 0.77 \times L_B \quad (1)$$

In order to determine at which distance the weaving section no longer has an impact of turbulence, maximum weaving length will be calculated using Eq.(2). The equation shows that the length of maximum weaving at certain weaving section is sensitive to volume ratio VR and number of weaving lanes NWL. As stated in HCM 2010, NWL is defined as zero for two-sided weaving. Therefore, only VR used as function and determination of VR are using volume adjustment from volume data that calculated as in Eq. (3) through Eq. (7). Finding of LMAX will be compared with value of LS in order to specify if the section studied should be analyzed as weaving section or isolated merging and diverging. HCM 2010 specifies that a studied section only could be analyzed as weaving section if the value of LMAX is greater than value of LS.

$$L_{MAX} = [5{,}728(1+VR)1.6] - [1{,}566\ NWL] \quad (2)$$

$$R = \frac{V_W}{v} \quad (3)$$

where,
VW = total weaving flow (pc/h)
V = total demand flow fractions.

$$V_p = V_{NW} + V_W \quad (4)$$

$$V_p = \frac{V}{PHF\ x\ f_{hv}\ x\ f_p} \quad (5)$$

where,
PHF = peak hour factor
$f_p$ = 1.00 (assume drivers are familiar with the site)
$f_{HV}$ = heavy-vehicle factor

$$PHF = \frac{V}{4\ x\ V_{15}} \quad (6)$$

where,
$V$ = peak hourly volume
$V_{15}$ = highest 15-minute volume

$$f_{HV} = \frac{1}{1+P_T\left(E_T-1\right)} \quad (7)$$

Where,
$P_T$ = percentage of trucks and buses
$E_T$ = passenger car equivalent for trucks and buses as in (Table 1)

Table 1. Passenger Car Equivalents for Extended General Highways

| | Type of Terrain | | |
|---|---|---|---|
| Factor | Level | Rolling | Mountainous |
| $E_T$ (truck and buses) | 1.5 | 2.5 | 4.5 |
| $E_R$ (RVs) | 1.2 | 2.0 | 4.0 |

Since lane-changing at weaving section consist of weaving and nonweaving maneuver, then analysis of lane-changing rate for both maneuver could be analyze. This could be done by using Eq. (8) through Eq. (13). Calculation of nonweaving lane-changing rate requires index number in order to specify which formula between Eq. (11) to Eq. (13) should be use. To specify which equation should be use, the index number should fulfill the condition as stated below:

If $I_{NW} \leq 1{,}300$ : $LC_{NW} = LC_{NW1}$
If $I_{NW} \geq 1{,}950$ : $LC_{NW} = LC_{NW2}$
If $1{,}300 < I_{NW} < 1{,}300$ : $LC_{NW} = LC_{NW3}$
If $LC_{NW1} \geq LC_{NW2}$ : $LC_{NW} = LC_{NW2}$

$$LC_W = LC_{MIN} + 0.39\left[\left(L_S - 300\right)^{0.5} N^2 \left(1 + ID\right)^{0.8}\right] \quad (8)$$

where,`

$LC_w$ = Equivalent hourly rate at which weaving vehicles make lane changes within the weaving segment (lc/h)

$LC_{min}$ = Minimum equivalent hourly rate at which weaving vehicles must make lane changes within the weaving segment to successfully complete all weaving maneuvers (lc/h)

$L_s$ = Length of the weaving segment using the short length definition (ft) 300 ft is the minimum value

N = Number of lanes within the weaving segment;

ID = Interchange Density (int/mi)

$$LC_{MIN} = LC_{RR}\ x\ V_{RR} \text{ (for two sided)} \quad (9)$$

$$I_{NW} = \frac{L_S\ x\ ID\ x\ V_{NW}}{10000} \quad (10)$$

$$LC_{NW1} = \left(0.206 V_{NW}\right) + \left(0.542 L_S - 192.6N\right) \quad (11)$$

$$LC_{NW2} = 2135 + 0.223\left(V_{NW} - 2000\right) \quad (12)$$

$$LC_{NW3} = LC_{NW1} + (LC_{NW2} - LC_{NW1})\frac{I_{NW} - 1200}{650} \quad (13)$$

Both equation of lane-changing rate are consisting of LS function. This explained weaving length could influence the lane-changing rate. In turn, total lane changing rate could be determine by using Eq. (14) to find out the intensity of lane-changing activity at each site.

$$LC_{ALL} = LC_W + LC_{NW} \quad (14)$$

## 4. Results

Measurement of short length $L_S$ at both sites found that there is no barrier presence to prohibit the vehicles to weave at on-ramp. Therefore, $L_S$ was assumed as equal to LB. Measurement shows that weaving segment at Site A is longer than Site B. Table 2 shows the result of $L_S$ at both sites. The following Figure 1 and Figure 2 show the current geometric and situations along the Federal Road FT050-Jalan Kluang.

Table 2. Finding of Short Length at Both Sites

| Location | Short Length, $L_S$ (m) |
|---|---|
| Site A | 358 |
| Site B | 316 |

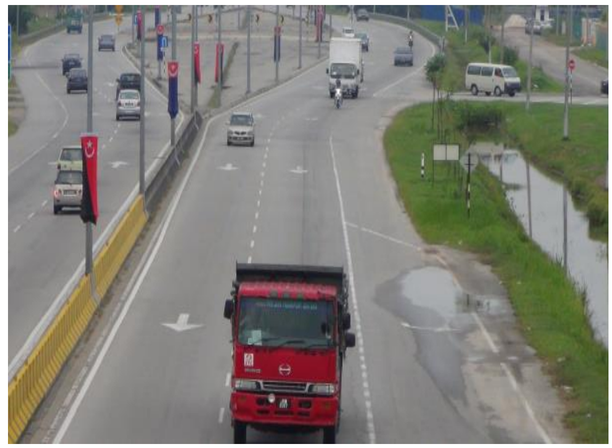

Fig. 1 Site A: Federal Road FT050 KM15

Fig. 2 Site B: Federal Road FT050 KM16.

Besides, investigation of maximum weaving length was made by using Chapter 12 in HCM 2010 since the value of LMAX for both sections was greater than LS. Hence, both sites could be analyzed as weaving section. The analysis found that Site A has more tendencies to encounter weaving turbulence since the value of maximum weaving length is ranging from (1952 m – 2120 m) while Site B is ranging from (1866 m - 1882 m). This means that the impact of weaving turbulence at Site A could be felt as far as 168 m meanwhile impact of weaving turbulence at Site B could be felt as far as only 16 m. In term of operational, Site A is worse than Site B.

Table 3 and Figure 3 summarize this finding for both sites.

In turn, analysis of lane-changing rate found that the most intense lane-changing activity of weaving occurred at Site A with a highest rate 555 lc/h. Meanwhile, a weaving lane-changing with a rate of 254 lc/h was recorded at Site B. These values were adapted during peak hours in order to obtain the

Table 3. Finding of Maximum Weaving Length

| Location | Time Periods | $L_{MAX}$ (m) | Range (m) | Impact of Weaving Turbulence Encountered(m) |
|---|---|---|---|---|
| Site A | 10.00 - 11.00 am | 2018 | (1952 - 2120) | 168 |
| | 11.00 - 12.00 am | 1952 | | |
| | 4.00 - 5.00 pm | 2082 | | |
| | 5.00 - 6.00 pm | 2120 | | |
| Site B | 10.00 - 11.00 am | 1866 | (1866 - 1882) | 16 |
| | 11.00 - 12.00 am | 1867 | | |
| | 4.00 - 5.00 pm | 1882 | | |
| | 5.00 - 6.00 pm | 1875 | | |

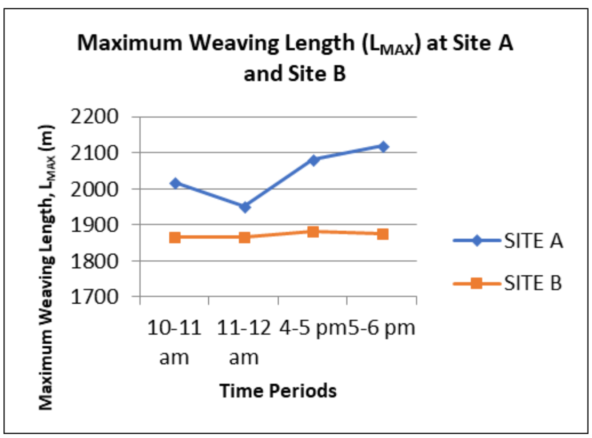


Fig. 3 Graph of Maximum Weaving Length at Sites

absolute value due to highest volume of vehicles but even during off peak hour's period, Site A still encounter a higher value of $LC_W$ compared to Site B. This difference explained that weaving maneuvers frequently happened at Site A with a longer weaving length because drivers more prefer to perform weaving in an unforced circumstance. Shorter length of weaving provides less comfortability to drivers to perform weaving because it happens in crammed situation. Table 4 and Figure 4 illustrate the finding of lane-changing rate of weaving vehicles at both sites.

Table 4. Finding of Lane-changing Rate of Weaving Vehicles.

| Location | Time Periods | $LC_W$ (lc/h) | Absolute $LC_W$ (lc/h) |
|---|---|---|---|
| Site A | 10.00 - 11.00 am | 391 | 555 |
| | 11.00 - 12.00 am | 319 | |
| | 4.00 - 5.00 pm | 451 | |
| | 5.00 - 6.00 pm | 555 | |
| | 10.00 - 11.00 am | 190 | |
| Site B | 11.00 - 12.00 am | 221 | 254 |
| | 4.00 - 5.00 pm | 254 | |
| | 5.00 - 6.00 pm | 234 | |

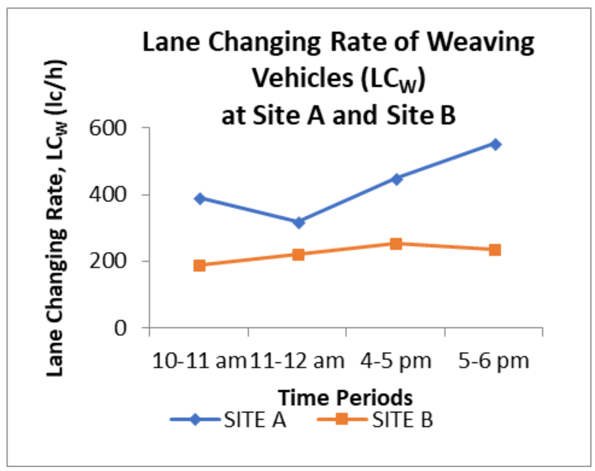


Fig. 4 Graph of Lane-changing Rate of Weaving Vehicles at Sites.

The final finding of this study found that the total lane-changing of both weaving and non-weaving vehicles were absolutely occurred during peak hours and the highest rate recorded at Site A with 1142 lc/h while Site B is 812 lc/h. This number shows in Table 5 and Figure 5. It also explained that Site A has more tendencies to encounter weaving turbulence due to high lane-changing activity. The high total lane-changing activity somehow affected by a lot of weaving vehicles crossing over the direct traffic. In term of operational, Site B is better than Site A because smooth traffic movement occurred at here.

Meanwhile in term of safety, Site B is worse than Site A due to high risk of collision because of shorter weaving length.

Table 5. Finding of Total Lane-Changing rate.:

| Location | Time Periods | $LC_{ALL}$ (lc/h) | Absolute $LC_{ALL}$ (lc/h) |
|---|---|---|---|
| Site A | 10.00 - 11.00 am | 955 | 1142 |
| | 11.00 - 12.00 am | 895 | |
| | 4.00 - 5.00 pm | 999 | |
| | 5.00 - 6.00 pm | 1142 | |
| Site B | 10.00 - 11.00 am | 652 | 812 |
| | 11.00 - 12.00 am | 754 | |
| | 4.00 - 5.00 pm | 812 | |
| | 5.00 - 6.00 pm | 773 | |

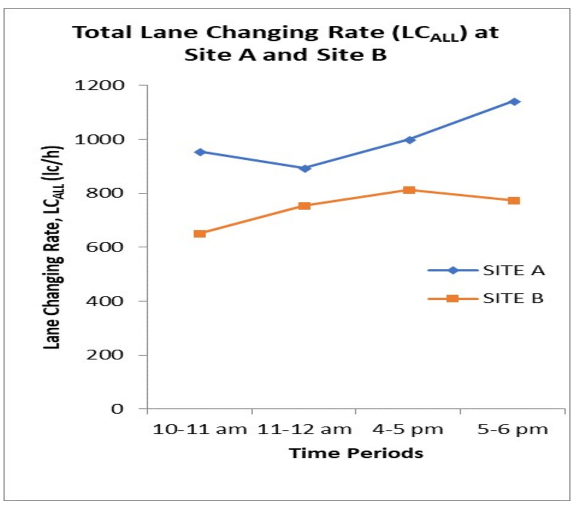


Fig. 5 Graph of Total Lane-changing Rate at Site A and Site B

## 5. Conclusion

Based on the finding, weaving turbulence tend to occur at Site A because of high number of vehicle using the weaving section at this site. In addition, it is also because of the development nearer to the site especially Taman Universiti residential. The drivers that tend to use the weaving section at this site are mostly consisting of the resident of Taman Universiti residential and also consist of students of UTHM. This factor not only leads to high impact of weaving turbulence but also increasing in lane-changing rate especially for weaving vehicles. Development available around the site is a factor that encourages the high intensity of weaving's lane-changing activity other than weaving length factor.

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