Comparative Evaluation of Malaysian HCM 2011 and US HCM 2010: Ramp Merging Expressway

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Abstract. It is important for traffic engineers in Malaysia to comply with the relevant and appropriate standards and manuals to determine the performance of highway facilities that will provide accurate result reflecting the existing operation of highways. This paper provides the comparative study in performance evaluation of ramp segment between Malaysia Highway Capacity Manual 2011 (MHCM 2011) and US Highway Capacity Manual 2010 (USHCM 2010). The study was conducted by analyzing data collected, obtained by using Trax Apollyon Automatic Traffic Counter at Km 12, Grand Sepadu Expressway, Selangor. The evaluation of performance for ramp segment was measured by density. Both densities measured using MHCM 2011 and USHCM 2010 were statistically compared with empirical data provided and the accuracy of both manual was calculated by using the root mean square error (RMSE) for each manual. Correspondingly, RMSE for MHCM 2011 showed lower value which was at 2.44 compared to 2.70 for USHCM 2010. Results showed that MHCM 2011 was more accurate in measuring the density for the ramp section as it has lower value.

Keywords – MHCM 2011, US HCM 2010, Ramp Segment, Density

1. Introduction

Since the 19th century, world’s road and highway system has undergone a lot of major development and improvements. However, error and shortcomings in designing the system and during construction still occur which contributes to traffic congestion and accidents. According to Larson (2016), road design on banking, barriers and guard rails, entry and exit ramps, road markings, road surface, shoulder design, signage, traffic control devices, traffic flow patterns and visibility are among the factors that might contribute to the likelihood of an accident. In the case where merging and diverging section are focused, a good design of entry and exit ramps on a highway can lessen traffic congestion as it will provide adequate space for vehicles to merge or diverge into or out of the mainstream therefore reducing the risk of accidents.

Since traffic and mobility is an integral part of our daily life, transportation demand has increased dramatically. Following this increase, we additionally have to cater for the increase in the desire for mobility efficiency with the societal concerns regarding traffic problems. Today’s traffic demand is predominantly served by individual motorized vehicles, which is one of the primary means of transportation.

Road maintenance and preservation is very crucial as it contributes to safe, smooth and sustainable transportation system. The duty and necessity to maintain highway infrastructures is typically the longest phase
of a highway life cycle. Well planned maintenance schedule is highly recommended as it involves ongoing investments where a more cost-effective option is available compared to delayed or postponed maintenance (Yurek et al., 2012).

Once designed, roads are analyzed to quantify their performance with respect to traffic volumes (Che Puan et al., 2014). One of the performance measures that is commonly used on roadways is capacity. Highway capacity is defined as “the highest traffic flow rate that the roadway is capable of accommodating or more accurately the maximum number of vehicles that can pass over a given section of a lane or a roadway during a given time period under prevailing roadway and traffic conditions” (Fred & Scott, 2013; PWD, 2014). In every traffic analysis, a guideline or manual is essential to ensure uniformity and consistency. Therefore, United States Highway Capacity Manual (HCM) becomes the most cited and referred capacity manual with some adjustment factors modification (Ravinder et al., 2013).

United States HCM was first published by Transportation Research Board (TRB) of the National Academies of Science in the 1950 (TRB, 2000). Since then, Finland, Norway and South Asian countries like Malaysia, Indonesia, China etc., have also developed their own highway capacity manuals to adapt to their local conditions (Ravinder et al., 2013). For instance, Malaysia is using Malaysian Highway Capacity Manual (MHCM) for road performance measurement where it is basically an improvised version of HCM (Che Puan et al., 2014). This somehow raised the doubt on its reliability to be implemented in Malaysian roadways.

2. Methodology

This study was conducted at KM 12, Grand Sepadu Expressway, Selangor where traffic is flowing from Shah Alam towards Klang. It is an intra-urban expressway (R5/U5) where it serves long to intermediate trip length with high operational speed of 80kmh and may go up to 90-100kmh. However, at this particular location, the posted speed limit is 90kmh. Figure 2.1 below shows the condition of the study area where selected location is made up of a one lane on-ramp and a four lanes expressway (two lanes each way) with 122m length of acceleration lane.

![Figure 2.1: Location of study at KM12 Grand Sepadu Expressway](image)

2.1 TRAX Apollyon Automatic Traffic Counter

Trax Apollyon is an automatic traffic counter or classifier device developed by JAMAR Technologies, Inc that adapts pneumatic system in its operation. Before the device is installed, site measurement was conducted to obtain lane widths and to study the site condition in order to ensure right tube length and selection are made. For this study, three types of tubes were used namely mini-tube, round tube and paired mini-tube.

Figure 2.2 shows the layout for the tubes installation at site. At the mainstream, tube B and D were made up of round tube responsible for traffic counting on lane one while tube A and C were made up of mini-tube responsible for lane two. On the other hand, tube A and B on the ramp section were paired mini-tube. These installations involved two types of layout which is layout L5 for the ramp and layout L11 for the mainstreams as shown in Figure 2.3 and 2.4 respectively. Both layouts allow Trax to record vehicle classification, speed, gap and volume of traffic. Layout L5 is used when there are two lanes two carriageways involved. Both tubes (A and B) were extended with two feet spacing across the lane to be studied and channel A and channel B record were dependent on each other. Layout L11 is basically the same as layout L5 except that two additional half tubes (A and C) were installed to provide lane separation which are Lane 1 and Lane 2.
Figure 2.2: Traffic counting layout

Figure 2.3: Road tubes layout L5 at ramp (JAMAR Technologies)

Figure 2.4: Road tubes layout L11 at mainlines (JAMAR Technologies)

2.2 Ramp Performance Measurements

2.2.1 Malaysia Highway Capacity Manual 2011

MHCM 2011 basically uses density as the primary measure to obtain level of service (LOS) for ramp-expressway. There are four formulas in MHCM used to determine the density of ramp depending on the ramp condition. For this case, the equation for one-lane on-ramp was used to determine the density at the study area.

\[ D_R = 3.389 + 0.003369v_{12} + 0.005860v_R - 0.006397L_A \]

where \( v_{12} \) is the flow rate in lanes 1 and 2 of expressway immediately upstream of merge (pc/h), \( v_R \) is flow rate on the ramp (pc/h) and \( L_A \) is the length of acceleration lane (m).

Before obtaining density, capacity within the merge influence area and existing or forecasted demand flows should be determined to establish the likelihood of congestion at the particular area. Two possible conditions may occur in the analysis. Firstly is the total departing expressway flow may exceed the capacity of the downstream expressway segment that indicates LOS F, in which traffic will form queues on the upstream of the merge segment. Secondly is that the total flow entering the ramp influence area exceeds its maximum desirable level but the total expressway flow does not exceed the capacity of the downstream expressway segment.

If the result falls into the second case, calculation of the density can be proceeded in order to determine the LOS. Table 2.1 below shows the LOS criteria for merge and diverge ramp for MHCM 2011.

| LOS | Density (pc/km/ln) |
|-----|---------------------|
| A   | ≤ 6                 |
| B   | > 6-12              |
| C   | > 12-17             |
| D   | > 17-22             |
| E   | > 22                |

Table 2.1: Level of Service criteria for merge and diverge ramps
2.2.2 US Highway Capacity Manual 2010

Apart from the difference in formula and LOS values from MHCM 2011, US HCM 2010 also measures the ramp performance by mean of density. The flow process to determine density for ramp expressway in US HCM 2010 is basically almost the same as in MHCM 2011. There are two formulas in US HCM used to determine the density of ramp depending on the ramp condition. For this case, the equation for on-ramp (merge) influence areas was used to determine the density at the study area.

\[ D_R = 5.475 + 0.00734v_R + 0.0078v_{12} - 0.00627L_A \]

Where \( v_R \) is flow rate on the ramp (pc/h), \( v_{12} \) is the flow rate in lanes 1 and 2 of expressway immediately upstream of merge (pc/h) and \( L_A \) is the length of acceleration lane (m).

In the capacity estimation, there are three major checkpoints that have to be estimated which are the capacity of the freeway immediately downstream of the on-ramp, the capacity of the ramp roadway and the maximum flow rate entering the ramp influence area. Failure of any of those three capacity checks will result in LOS F. Otherwise, calculation of the density can be proceeded in order to determine the LOS at the study area. Table 2.2 below shows the LOS criteria for freeway merge and diverge segments for US HCM 2010.

| LOS | Density (pc/mi/ln) | Comments |
|-----|--------------------|----------|
| A   | \( \leq 10 \)      | Unrestricted operations |
| B   | > 10-20            | Merging and diverging manoeuvres noticeable to drivers |
| C   | > 20-28            | Influence area speeds begin to decline |
| D   | > 28-35            | Influence area turbulence becomes intrusive |
| E   | > 35               | Turbulence felt by virtually all drivers |
| F   | Demand exceeds capacity | Ramp and freeway queues form |

3. Results and Discussion

3.1 Descriptive Analysis

Table 3.1: Descriptive Analysis of Density for Empirical, MHCM 2011 and USHCM 2010

|          | Mean | Standard Deviation | Median | Minimum | Maximum |
|----------|------|--------------------|--------|---------|---------|
| Empirical| 4.44 | 2.76               | 5.02   | 0.26    | 10.04   |
| MHCM 2011| 3.45 | 0.54               | 3.56   | 2.66    | 4.45    |
| USHCM 2010| 6.64 | 1.23               | 6.89   | 4.83    | 8.93    |

Empirical values were the benchmark for comparison between both MHCM 2011 and USHCM 2010 with mean, standard deviation, median, minimum and maximum were recorded at 4.44, 2.76, 5.02, 0.26 and 10.04 respectively.
Based on Table 3.1, the descriptive values for MHCM 2011 were all lower than the empirical values except the value for minimum which was 2.66 as compared to 0.26 by empirical. Unlike MHCM 2011, USHCM 2010 showed higher values except for its standard deviation and maximum which were 1.23 and 8.93 respectively. From the results obtained, MHCM 2011 seems to be underestimating the density at the ramp influence area while USHCM 2010 was overestimating it.

3.2 Paired T-test

A paired t-test was used to compare two HCM data which were densities obtained by using MHCM 2011 and USHCM 2010 paired with density of the empirical data in order to evaluate the significance difference between both HCM. Hypotheses used in this test are stated below, with an alpha or significance level of 0.05.

I. MHCM 2011 and empirical data,
   \[ H_0 = \text{There is no significance difference between the density of MHCM 2011 and empirical data} \]
   \[ H_a = \text{There is significance difference between the density of MHCM 2011 and empirical data} \]

II. USHCM 2010 and empirical data,
   \[ H_0 = \text{There is no significance difference between the density of USHCM 2010 and empirical data} \]
   \[ H_a = \text{There is significance difference between the density of USHCM 2010 and empirical data} \]

Table 3.2:
Paired T-Test Analysis between Empirical vs MHCM 2011 and Empirical vs USHCM 2010

|                  | Mean | Standard Deviation | Standard Error | p-value |
|------------------|------|--------------------|----------------|---------|
| Empirical        | 4.44 | 2.76               | 0.28           |         |
| MHCM 2011        | 3.45 | 0.54               | 0.05           | 0.00    |
| Difference       | 0.99 | 2.22               | 0.23           |         |
| Empirical        | 4.44 | 2.76               | 0.28           |         |
| USHCM 2010       | 6.64 | 1.23               | 0.13           | 0.00    |
| Difference       | 2.20 | 1.53               | 0.15           |         |

Table 3.2 shows the results tabulation from the t-test conducted, it can be observed that P-values for both tests are equal to zero or less than 0.05 which means that there was a significant difference between the density of empirical data versus MHCM 2011 and density of empirical data versus USHCM 2010. This shows that both MHCM 2011 and USHCM 2010 are yet to be fully reliable to be directly implemented in Malaysian highways.

It is also observed that the difference between standard error of MHCM 2011 to empirical is 0.23, higher than the difference of standard error of USHCM 2010 to the empirical which is 0.15. Standard error refers to the standard deviation of the distribution of sample means taken from a population. The smaller the standard error, the more representative the sample will be of the overall population (Investopedia, 2017). Therefore, USHCM 2010 seems to be more reliable than MHCM 2011.

3.3 Relationship of LOS and Time Series Plot

Figure 3.1 shows the time series for empirical data, MHCM 2011 and USHCM 2010 plotted based on the density calculated against time. Visually, it can be observed that MHCM 2011 overestimated the density at the ramp influence area in the beginning and started to underestimate it at 0700 hour until late night. USHCM 2010 on the contrary was overestimating the density since the 0000 hour until the end of the day with slight fluctuations during evening peak hour.

In addition, the patterns of graphs plotted in Figure 3.1 are basically related to LOS density values showed in Table 3.3 that is ranging from 6 pc/km/ln to more than 22 pc/km/ln for MHCM 2011 and from 10 pc/mi/ln to more than 35 pc/mi/ln for USHCM 2010. The range of density value for USHCM 2010 was slightly bigger than of MHCM 2011. These differences may affect the fluctuations of the graph that led to the over or underestimation.
Additionally, it was also noticed that the density units for both HCM are in kilometre (km) and mile (mi). However, the difference in those units did not seem to affect the graph and the density values. Theoretically, a unit of mile is equivalent to 1.609 km. Conversion of e.g. 6 pc/km/ln into pc/mi/ln eventually resulting to 9.654 pc/mi/ln or equivalent to 10 pc/mi/ln. Thus, a new range of locally influenced density to measure LOS should be produced to decrease the possibility of over and underestimation of the road performance.

![Time Series Plot of Density for Empirical, MHCM 2011 and USHCM 2010](Figure 3.1)

**Table 3.3:**

| LOS | MHCM 2011 Density (pc/km/ln) | USHCM 2010 Density (pc/mi/ln) |
|-----|-----------------------------|-----------------------------|
| A   | ≤ 6                         | ≤ 10                        |
| B   | > 6 – 12                    | > 10 – 20                   |
| C   | > 12 – 17                   | > 20 – 28                   |
| D   | > 17 – 22                   | > 28 – 35                   |
| E   | > 22                        | > 35                        |
| F   | Demand exceeds capacity     | Demand exceeds capacity     |

3.4 LOS Comparison for MHCM 2011 and USHCM 2010

LOS is a qualitative measure of a traffic movement. It is to exhibit the relationship of traffic service quality to a given flow rate (Mathew & Krishna Rao, 2007).

Based on Figure 3.2, the maximum density value for MHCM 2011 is 4.45 pc/km/ln and for USHCM 2010 is 8.93 pc/mi/ln, where both were at hour 1845 to 1900. Therefore, the LOS throughout the day for both manuals was the same which was LOS A. According to MHCM 2011 and USHCM 2010, LOS A is when density is less than 6 pc/km/ln and less then 10 pc/mi/ln respectively. Generally, LOS A stands for a free flow operation at average travel speeds where vehicles are completely unimpeded in manoeuvring and minimal control delay.
3.5 Accuracy of MHCM 2011 and USHCM 2010

Accuracy of the manuals can be solely depicted using pictorial evaluation. Due to this, root mean square error (RMSE) was calculated to measure the accuracy for MHCM 2011 and USHCM 2010. The RMSE for both manuals are tabulated in Table 3.4 below.

Table 3.4: Root Mean Square Error for MHCM 2011 and USHCM 2010

| Root Mean Square Error (RMSE) | MHCM 2011 | USHCM 2010 |
|-------------------------------|-----------|------------|
| 2.44                          | 2.70      |

According to Grammelis (2016), RMSE or also called the root mean square deviation (RMSD) is frequently used to measure the difference between values predicted by a model and the values actually observed from the environment that is being modelled or simply to evaluate the accuracy of the developed models. RMSE is always positive and a zero value is ideal. The smaller the value of RMSE, the better the modes performance is.

Based on Table 3.4, the value of MHCM 2011 and USHCM 2010 is 2.44 and 2.70 respectively. Since the value for MHCM 2011 is smaller than of USHCM 2010, thus this indicates that MHCM 2011 is more accurate than USHCM 2010 in estimating the density for the ramp.

4. Conclusion

As a conclusion, the objectives of this study are achieved. The three objectives are to collect and analyse local field data for highway operational performance measurements on merging area at Grand Sepadu Highway (E30), to provide the comparative evaluation of the empirical data of merging section against MHCM 2011 and USHCM 2010 and lastly to verify the accuracy of MHCM 2011 and USHCM 2010 to be implemented in Malaysia’s highway.

The main objective was to verify the accuracy of MHCM 2011 and USHCM 2010 in measuring the local road performance or specifically at Kilometre 12, Grand Sepadu Highway (E30), Klang, Selangor. Based on the results discussed in Section 3, it was discovered that MHCM 2011 was more accurate as it generated lower RMSE value which was at 2.44 compared to 2.70 for USHCM 2010.

In addition, traffic data were also collected and analysed in requirement to fulfil the first objective. Data were collected for four days by using TRAX Apollyon Automatic Traffic Counter. Six individuals from
Faculty of Civil Engineering, UiTM were involved in the process along with three other personnel from Grand Sepadu. Data collected were then tabulated and analysed by using Microsoft Excel and Minitab software.

Moreover, comparative evaluations were also carried out for the data collected by comparing the empirical data against MHCM 2011 and USHCM 2010. Amongst analysis conducted were the descriptive analysis, paired t-test, root mean square error (RMSE) and time series plot which were explained in detail in section 3.

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