Assessment of level of service (LOS) for entrance ramp merging by using HCM US 2000 and HCM US 2010

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Abstract. Congestion is a normal occurrence on the urban Malaysian expressway system, usually associated with areas having entrance ramp, exit ramp and weaving section. A good practice for expressway system can be determined by the efficiency of the traffic operation itself. Thus, this research paper provides the assessment of level of service for entrance ramp merging using US HCM 2000; US HCM 2010 and empirical data as the indicator. Study was conducted at KM 12, Grand Sepadu Expressway, Selangor and the data were collected by using TRAX Apollyon Automatic Traffic Counter. An analysis was conducted and the RSME result shows that the plotted data are successfully developed and validated in these studies.

1. Introduction

Roads are primary mean of transportation. It provides human access to different places and contributes to economic development and growth of social benefits. Over the past 10 years a tremendous amount of continues research and the best practice has been done to improve road design to ensure the efficiency and mostly the safety of the end user. Since this research paper is focusing on the performance measures and operational quality; Level of Service (LOS) of entrance ramp segment, merging area issues will be the central of discussion. Merging usually occurs when two separate traffic streams join to form a single stream. The subject of merging control has been studied extensively by many traffic engineers in 1960s, [1]. Empirical models were established to predict and evaluate the performance for these highway facilities with specific measure of effectiveness (MOE) using both HCM 2000 and 2010 respectively.

Entrance ramp junctions have been the subject of interest to many traffic engineers [2]. On expressways, all entering maneuvers take place on ramps are designed to facilitate smooth merging of on-ramp vehicles into the adjacent traffic stream with minimal disruption and provide minimum safety to the drivers. Interactions are dynamics in expressway merge areas, and so the operating conditions on the mainstream can affect the operating conditions on the ramp, and vice versa [3]. The turbulence created by these interactions often causes congestion, and can lead to break-down when the combined volume from the ramp, and the mainline exceed the capacity of the downstream expressway segment [4]. As to date, only few empirical investigations have been reported on the effect of merging vehicles on expressway operation in Malaysia. Even though the HCM 2000 and 2010 presents the estimated capacity of entrance ramp areas, they were calibrated based on US expressway and traffic condition. Therefore, this research is an attempt to develop model based on the local traffic empirical data that...
will be used to evaluate the measure of effectiveness (MOE) of entrance ramp junctions with the development of Level of Service (LOS) chart and adoption of both HCM 2000 and 2010 merging density models.

The objectives of this study are, firstly, to obtain and analyze local field data; vehicle classification, density and flow rates for determine the operational performance of the merging areas based on Grand Sepadu expressway traffic condition. Secondly, to develop scatter plot graph based on 45-degree linear line and to provide comparative evaluation of the empirical data. Thirdly, to assess and verify the accuracy of developed empirical models against HCM 2000 and HCM 2010.

2. Literature Review

Expressways were build in order to serve the movement of traffic providing high level of service to the road users. Therefore, control of access is an important characteristic in expressway design. Our expressway system mainly consists of main highway, frontage roads, entrance and exit ramps, weaving sections and interchanges. When it is related to the congestion in urban areas, the problems may lead to the associated with areas having entrance ramp, exit ramp and weaving section that connected to the expressway mainstreams. This research paper is mainly focusing on entrance ramp merging as the central of discussion.

Merging can be defined as the absorption of one traffic stream by another stream. Their effects on expressway operation have become increasingly important to the traffic engineers [5]. Figure 1 below shows an illustration of merging facility involves an entrance ramp merging, where it can be referred as ramp-expressway junction.

![Figure 1. Illustration of Entrance Ramp Merging (US HCM, 2010).](image)

An acceleration lane is designed in order to allow vehicles to merge smoothly and without causing interference to the traffic streams. A proper design is a must to guarantee the road safety and their effectiveness.

The prediction of capacity and operational quality for expressway is important in planning, design and maintaining the road efficiency. Both capacity and Level of Service are in related, which capacity is defined as in how much the traffic a given transportation facility can accommodate, and how good the present traffic situation on a given facility can be measured in Level of Service [6]. The term capacity may be described as the maximum number of vehicles can be accommodated at given time and conditions and it is closely related to Level of Service. When capacity provides a quantitative measure of traffic, level of service or LOS will give a qualitative measure. For example, on a given road or facility, capacity can be constant but actual flow might be different depending on the days and times itself. The LOS designates a range of operating conditions on a particular type of facility.

Highway Capacity Manual (HCM) is developed by the organization of the transportation research board of USA that provides several procedures in determine the Level of Service (LOS). The LOS in merge influence area is determined by the density of all stable operation cases; assuming that there will be no breakdowns within the merge influence area, represented by LOS A through E. While LOS F will exist only when the total flow departing from the merges area exceeds the capacity of downstream mainstream segment. LOS A represents the absolute free flow conditions, where every
vehicle able to travel without any influence by other vehicles, whereas the worst LOS should represent absolute congestion [7].

![Figure 2. Level of Service A to F.](image)

There are three macroscopic traffic parameter variables represent in LOS: speed, density and flow rate. The Measure of Effectiveness (MOE) used to define in level of service is the density in merge influence area, denoted as DR (pc/km/ln). The terms density can be described as the number of vehicles occupying a given length of a lane or roadway at particular instant [8], which becoming the principle influence in freedom to maneuver in merging influence area. The operating condition for the level of service best describe as follows:

| Level of Service (LOS) | Description |
|------------------------|-------------|
| **LOS A** | The operation of traffic is a free flow and unrestricted where the density is low, thus the operation of each vehicle may not be influenced by the presence of other vehicles that create little turbulence in the traffic stream. |
| **LOS B** | Mainly the drivers will begin to notice the existence of other vehicles in the traffic stream and minimal turbulence occurs. |
| **LOS C** | Speed may decline within ramp influence area thus the turbulence become more noticeable, and it allows the driver to adjust their speeds to accomplish smooth transitions. |
| **LOS D** | Speed decline to an average while the flow increasing, all vehicles will virtually slowdown in order to accommodate merging or diverging manoeuvres. Some queues may be formed, but the freeway operation remains stable. |
| **LOS E** | Represent that the operation is approaching the capacity in merge influence area and the smallest changes in demand or interruption within the traffic stream may cause an extensive queuing. |
| **LOS F** | The operation conditions within the queue that form when the ramp demand exceeds the capacity of the acceleration lane and main-lane stream where it might lead deterioration in the flow drastically. |

3. Methodology
This research was conducted in order to assess the performance measure on entrance ramp merging segment, with respect to macroscopic analysis; speed-flow-density. More than 100 survey data were collected where a single selected data on the preferred day is taken for analysis at every 15 minutes
interval time at selected study area. The computational methodologies applied to the analysis of ramp-
freeway junction are illustrated in Figure 3 as a guide used for this research.

![Flowchart for analysis of ramp-freeway junctions.](image)

**Figure 3.** Flowchart for analysis of ramp-freeway junctions.

### 3.1. Collection Data at Located Study Area
This study was conducted at KM 12, Grand Sepadu Expressway, Selangor where the traffic flows from Shah Alam towards Port Klang. It is known as intra-urban expressway (R5/U5) where it serves intermediate to long trip length with high operational speed at 80kmh to 100kmh, where the posted limit recognise at this location is 90kmh. The test was conducted for 4 days from 26th March 2017, at 11.38 AM until 29th March 2017, at 7.15 PM. The location of the study area is shown in Figure 4 and 4 where the condition of the road can be described as four lanes expressway that serves two lanes for each direction together with one lane on-ramp from Meru towards Port Klang.

**Table 2.** Geometric Properties & Site Condition

| Geometric Properties       | Measurement (Ramp) | Measurement (Intra-Urban Expressway) |
|----------------------------|--------------------|--------------------------------------|
| Lane Width                 | 3.5 meter          | 3.65 meter                           |
| Shoulder Width             | -                  | 2.5 meter                            |
| Speed Limit                | 80 km/hr           | 90 km/hr                             |
| Apollyon’s Layout          | L5                 | L11                                  |
Figure 4. Location of study area from Google Maps.

Figure 5. Location of study area, KM 12 Grand Sepadu Expressway.

3.2. TRAX Apollyon Automatic Traffic Counter
The technique employed to obtain empirical data was done by using TRAX Apollyon Automatic Traffic Counter. It is one of the best instruments developed by JAMAR Technologies where it provides systematic and easy interpreted data, also it is user-friendly. Before the device is installed, site investigation has been conducted in order to obtain the visual situation beforehand. Three types of road tubes were chosen; namely as mini-tube, round tube and paired mini-tube. The selection of layouts for the tube’s installation at the site is shown in Figure 6.
Two types of layout involve in this tube installation. They are Layout L11 for the main road and Layout L5 for the ramp segment as shown in Figure 7 and 7 respectively. At the main road, tube B and D (round tube) were installed for traffic counting on Lane 1 while tube A and C (mini-tube), responsible in collecting the traffic count on Lane 2. While on the ramp segment tube A and B (paired mini-tube) were installed for traffic count through it. Both layouts will be carried out the data on vehicle classification, speed, gap, and volume of traffic. Basically, Layout L5 will be used when it involves two lanes two carriageways, where both tubes are extended across the lane studied area, and the data will be recorded in TRAX record. Practically, Layout L11 is same as Layout L5 except that there are two additional half tubes to be installed to provide lane separation.

**Figure 6.** Layout for tubes installation at site.

**Figure 7.** Selection of layout L11 for main road.
3.3 Analysis of ramp performance measures using HCM 2000 and 2010 procedures

It is identified that both HCM 2000 and 2010 are using density in merge influence area as measure of effectiveness (MOE).

3.3.1 Traffic Density in US Highway Capacity Manual 2000 and 2010. For the past years, numerous of traffic analysis and research has been done as a guide to traffic engineer, above of all United States Highway Capacity Manual (US HCM) becomes the most cited and referred capacity manual, even though with some adjustment factors modification [2]. However, the adaptation of US HCM to Malaysian Guideline, MHCM must be improvised and suit to its road design conditions.

The traffic density as per defined in US HCM should be assessed in relation to road users as well as planner’s perspective. On the early 1960s, density was estimated using the traditional aerial photographic technique. Thereafter, different types of techniques were used globally all around the world. The continuity equation involving traffic flow expressing the relationship between density, flow, and speed can be made valid under a non-homogenous traffic conditions by introducing certain adjustments in equation [9]

As in HCM 2000, LOS criteria for merge areas are based on density in the merge influence area, and it can be estimated by using equation (1). However, it is noted that the equation for density will only apply to the under saturated flow conditions.

\[
D_R = 3.402 + 0.00456V_R + 0.0048V_{12} - 0.01278L_A
\]

(1)

Where,
- \(D_R\) = density of merge influence area (pc/km/ln),
- \(V_R\) = on ramp peak 15-min flow rate (pc/h),
- \(V_{12}\) = flow rate entering ramp influence area (pc/h), and
- \(L_A\) = length of acceleration lane (m)

Density can be determined only if; the flows entering Lane 1 and 2 are considered at merge influence area, the capacity values are calculated, and to compare with the existing or forecast demand flows to identify the condition of the congestion at that particular area. It is important to take note that the length of acceleration, \(L_A\) is considered as the critical geometric parameter in influencing operations at merge or diverge area. Table 3 below shows the LOS criteria for merge and diverge areas for HCM 2000.
Table 3. Level of Service (LOS) Criteria for Merge and Diverge Areas for HCM 2000.

| Level of Service (LOS) | HCM 2010 Density (pc/mi/ln) | HCM 2000 Density (pc/km/ln) |
|------------------------|-----------------------------|-----------------------------|
| A                      | ≤ 10                        | ≤ 6                         |
| B                      | > 10-20                     | > 6-12                      |
| C                      | > 20-28                     | > 12-17                     |
| D                      | > 28-35                     | > 17-22                     |
| E                      | > 35                        | > 22                        |
| F                      | Demand exceeds capacity     | Demand exceeds capacity     |

The procedures to determine the density for ramp expressway as stated in US HCM 2010 are basically similar with US HCM 2000. The geometric characteristics usually vary for this design, the length and type (parallel, taper) of acceleration, the free-flow speed and other elements contribute to affect the merging operation. The density can be determined using equation (2) shows below.

\[ D_R = 5.475 + 0.00734V_R + 0.0078V_{12} - 0.00627L_A \]  

(2)

where \( D_R \) is the density in the ramp influence area (pc/mi/ln), and all other variables are same as in HCM 2000.

4. Results and discussion

As can be seen in illustration Figure 9, a scatter graph plot between empirical data on the density of HCM 2000 respectively shows that the HCM density overestimates the empirical data result.

Based on both plotted graphs it can be summarized that both HCM density data are over estimate, the empirical data where they are scattered much further than the reference 45-degree line. In other words, it describes that the HCM 2000 and HCM 2010 are over design the empirical data.

Paired T-Test was conducted to define statistically the significance different between the mean of HCM 2000; HCM 2010 and Empirical Data. The test was conducted separately for HCM 2000 and HCM 2010 to compare the different mean with Empirical Data.
Table 4. Paired T-Test analysis between HCM 2000 and empirical.

| Group     | Mean  | Standard Deviation | Standard Error Means | p-value |
|-----------|-------|--------------------|----------------------|---------|
| Empirical | 4.378 | 2.720              | 0.278                | 0.00    |
| HCM 2000  | 6.703 | 3.086              | 0.315                |         |
| Different | 2.3253| 0.7277             | 0.0743               |         |

Table 5. Paired T-Test analysis between HCM 2010 and empirical.

| Group     | Mean  | Standard Deviation | Standard Error Means | p-value |
|-----------|-------|--------------------|----------------------|---------|
| Empirical | 4.378 | 2.720              | 0.278                | 0.00    |
| HCM 2010  | 12.579| 5.015              | 0.512                |         |
| Different | 8.200 | 2.431              | 0.248                |         |

Paired T-Test analysis was conducted for HCM 2010 and the results are tabulated in Table 5, observed that the mean density for empirical is 4.378, lesser than the mean density of HCM 2010 which is 12.579 giving the different to 8.200. The difference of standard deviation between HCM 2010 to empirical is 0.2431, and the standard error means for HCM 2010 is 0.248 higher than the empirical data. P-value for this T-test also shows that the result is equal to zero or less than 0.05.

Investopedia [10] said that the smaller the standard error, the more representative the sample would be of the overall population. From this phrase, it can be described that HCM 2000 is more reliable compared to HCM 2010, however, based on the analysis to the p-value, it is observed that both HCM 2000 and 2010 are not yet fully reliable to be directly implement for Malaysian Highway design.

4.1. LOS Comparison for HCM 2000 and HCM 2010

Level-of-Service (also called Quality of Service or Service Quality) are widely used to describe how well a transportation facility is operating from a traveller’s perspective. As shown in Figure 10, the maximum density value for HCM 2000 is 12.36 pc/km/ln at hour 1830 and for HCM 2010 is 21.77 pc/km/ln also at hour 1830. From Table 6 it is observed that based on the analysis data, from midnight hour until 7.15 am, the LOS traffic condition shows LOS A where it indicates that the traffic operation is stable, and the individual users are virtually unaffected by the presence of others in the traffic stream. Eventually after 7.15 am until 10 pm the LOS shows LOS B for traffic operation condition due to the increase of vehicle’s presence where freedom to maneuver still stable but with some influence from other users.
### Table 6. Level of Service (LOS) Comparison for HCM 2000 and HCM 2010.

| Level of Service (LOS) | HCM 2000 | HCM 2010 |
|------------------------|----------|----------|
| Density (pc/km/ln)     |          |          |

| A | ≤ 6 |          |          |
| 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 |

### 4.2. Evaluation of RSME of HCM 2000 and HCM 2010

It is known that RSME models are often used in model evaluation studies. The results are then tabulated in Table 7 below. According to [11], the RSME is more appropriate to represent model performance than the MAE when error distribution is expected to be Gaussian. It is observed that the values of HCM 2000 and HCM 2010 are 0.242 and 0.850 respectively. Since the values of HCM 2000 are smaller, thus it indicates that HCM 2000 is more accurate than HCM 2010 in estimating the density for the ramp.
Table 7. Root Mean Square Error for HCM 2000 and HCM 2010.

|                  | HCM 2000 | HCM 2010 |
|------------------|----------|----------|
| Root Mean Square Error (RSME) | 0.242    | 0.850    |

The HCM 2000 and HCM 2010 have been considered and predicted to have the slightly different of attributes when determining the level of service of the existing road. The differences in mean density value when comparing to empirical data shows that there is some factor may contribute to it. For example, the HCM 2000 is using US Customary Unit in estimating the density which is expressed by vehicle per mile while HCM 2010 is adopting Metric Units with the density is in vehicles per km. Apart from that, the empirical data were analyzed by converting the flow which is expressed in passenger car equivalent (PCE) while both HCM 2000 and 2010 are expressed in heavy vehicle adjustment factor ($f_{hv}$) which is not practicable to Malaysian road design. The consideration of an adjustment factors for lane width, lateral clearance, lane position, ramp adjustment shows that the factors are not suitable in evaluating the Level of Service for Malaysia Condition.

5. Conclusion

To conclude, the objectives to be carried out based on HCM 2000 and HCM 2010 have been successfully evaluated in this study. The three objectives are to obtain and analyze local field data for determine the operational performance of the merging areas based on Grand Sepadu expressway traffic condition, to develop scatter plot graph based on 45-degree linear line and to provide comparative evaluation of the empirical data and lastly to assess and verify the accuracy of developed empirical models against HCM 2000 and HCM 2010 towards Malaysia Highway design.

Based on the result discussed in Section 4, it is observed that HCM 2000 is more accurate than HCM 2010 as it generates lower RSME value. From this phrase, it can be described that HCM 2000 is more reliable compared to HCM 2010, but it also proofs that both HCM 2000 and HCM 2010 are not yet fully reliable and practicable to be directly implement for Malaysian Highway design.

Acknowledgement

This research was funded by the Universiti Teknologi MARA 600-IRMI/MYRA 5/3/MITRA (007/2017)-1. The authors gratefully acknowledge the cooperation of staff in Faculty of Civil Engineering, Faculty of Health Science and Faculty of Business Management for giving full support and services as well as handling to set up the tools and equipment for the driving and vision studies in the field.

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