Assessment of Level-of-Service for On-Ramp Expressway using MHCM 2011 and Microsimulation Vissim

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Abstract The traffic congestion during peak hour in Malaysia is becoming worst from year to year due to the increase of traffic demand volume. At the year 2018, the total accumulated vehicles in Malaysia are 14,415,978 vehicles in 2018 based on 16-hours traffic volume [4]. Based on this figure, the normal growth of the vehicle has increased by 0.74% per year. It is crucial for traffic engineer in Malaysia to follow an appropriate standard and manual to determine the performance of highway facilities that will provide accurate result reflecting the existing operation of the highway. Thus, this paper provides the comparative study in evaluating the performance of the on-ramp segment between Malaysia Highway Capacity Manual 2011 (MHCM 2011) and microsimulation Vissim. The evaluation of performance measure for on-ramp expressway is based on the traffic density at merge influence area. Both performances measured using MHCM 2011 and Vissim was statistically compared with collected empirical data and the difference in the level of service (LOS) is also compared. The result from this study will determine which tools will be able to replicate the empirical data and the difference of grade of LOS between MHCM 2011 and Vissim.

1. Introduction
Ramp is a part of the expressway which served to connect between two highway facilities. A ramp can also be functioning as access to specific development. There are two important types of ramp known as on-ramp (merging ramp) and off-ramp (diverging ramp). On-ramp has caught attention from many traffic engineers as a faulty design of this type of ramp may lead to the severe congestion on the mainline expressway. Thus, it is essential for the traffic engineer to incorporate a proper procedure based on the Malaysian traffic condition [6,7]. It will ensure the result of the traffic analysis reflects the actual situation on the on-ramp.

There are various tools available for on-ramp performance analysis. Malaysia highway planning unit itself has released its standard and guideline known as Malaysia Highway Capacity Manual, 2011 to assist traffic engineer in obtaining the performance of on-ramp and other highway facilities [3]. Alternatively, the microscopic simulation program for modelling the traffic network has become a popular tool among the traffic engineer. This tool has become an alternative way to conduct highway performance analysis more efficiently. Therefore, the validation of vissim output and MHCM 2011 output with empirical data is required to ensure the reliability of both tools. This study will provide an
in-depth view of the difference between vissim and MHCM 2011 output for on-ramp performance analysis.

2. Literature Review
Previous literature has provided the comparison study between HCM and various highway capacity analysis tools. Jolovic, Stevanovic, Sajjadi, & Martin, 2016 develop a comparison between observed data, FREEVAL and Vissim for on-ramp segment, basic segment and weaving segment [5]. FREEVAL is a macroscopic freeway analysis tool based on U.S Highway Capacity Manual 2010 [2]. The study reveals that the density at on-ramp segment, basic segment and weaving segment obtained from FREEVAL is generally higher than Vissim and empirical density while Vissim result can closely match with empirical density.

The previous study also provides the effect of calibration from the microsimulation model. Skabardonis and Kim, 2010 showed that lane changing parameter, car following parameter and percentage of through vehicle that yields to merging traffic had impacted the result of microsimulation [8]. Researchers found that the program mostly underpredicts the average speeds when adopting the default settings in the software. The calibrated model was successfully replicate the field conditions of the weaving area. However, the study is not considering lane changing behaviour.

Dowling et al., 2004 developed guidelines for calibration of microsimulation models [1]. The test bed consisted of a freeway section with two diamond interchanges and a parallel arterial with a signalised intersection. Authors divided calibration procedure into three steps, calibration for capacity at bottlenecks, route choice calibration and overall system performance calibration against field measurements such as travel time and delay, respectively. In case that one facility is calibrated, the second step in the procedure should be neglected. Parameters were classified into two groups: parameters chosen to be adjusted and ones left the default. Global and local parameters were classified based on how they affect the simulation process. Once global parameters were adequate, the adjustment of local parameters was deployed through the correct tuning process. Researchers gave an example of 13 mean headway as the main calibration parameter. Authors indicated that model satisfied calibration criteria.

3. Methodology
This study involves traffic survey on-site using automated traffic counting known as Trax Apollyon. A pneumatic road tube was installed at the mainline and on-ramp at KM 12, Grand Sepadu Expressway, and Selangor. Figure 1 shows the aerial photo of the location of installation of road tube at mainline and on-ramp segment. The site inventory study is conducted to obtain the geometric properties of on-ramp segment in order to be used as input value during traffic analysis using MHCM 2011 and mirosimulation Vissim. The geometric property of the on-ramp segment is shown in Table 1.

Figure 1. Aerial photo of the location of installation of road tube at mainline and on-ramp segment.
Table 1. The geometric properties of the on-ramp segment.

| Parameter                | Mainline     | On-Ramp      |
|--------------------------|--------------|--------------|
| Lane Width               | 3.7 meter    | 5.0 meter    |
| Shoulder Width           | -            | 1.0 meter    |
| Speed Limit              | 90 km/h      | 50 km/h      |
| Type of Terrain          | Level        | Level        |
| Length of the Acceleration lane | 122 meters |              |

The collected traffic data is sorted, filtered and arranged based on 15 minutes interval from 12.00 am to 12.00 pm. The traffic volume at mainline expressway and on-ramp is converted to the traffic flow rate in passenger cars per hour (pc/h) during the peak 15-minutes by using the rate from MHCM 2011. The empirical density is calculated simply by dividing the traffic flow with speed obtained from Trax Apollyon. Whilst the Eq. (1) is used to calculate the density of flow within the on-ramp influence area based on MHCM 2011:

\[
D_R = 3.389 + 0.003369 \cdot V_{12} + 0.005860 \cdot V_R - 0.006396 \cdot L_A
\]  

(1)

Where \( V_R \) is total flow rate at on-ramp expressway in pc/h, \( L_A \) is the length of acceleration lane in meter and \( V_{12} \) is the flow rate in lane 1 and lane 2 of the mainline expressway at the upstream of merge area. After determine the density of merge influence area, the level of service of on-ramp segment can be determined by referring to the criteria of level of service for on-ramp segment.

The density from Vissim is obtained by developing the microsimulation model using PTV Vissim software version 9.0. The link and connector are used to replicate the actual lane configuration with tapered acceleration lane. In this study, the right-side rule driving behavior with Wiedemann 99 type of car following model and slow lane rule is selected to suit with the existing site condition. With this option selected, vehicles with the higher speed will overtake of other vehicles in the right lane which replicates the driving behaviour at the expressway. The desired speed distribution is also calibrated based on the speed distribution pattern of each vehicle obtained from Trax Apollyon. The summary of the mean, standard deviation, minimum value, median, 85th percentile and maximum value of vehicle speed is shown in Table 2 for mainline and Table 3 for the ramp.

Table 2. Summary of the mean, standard deviation, minimum value, median, 85th percentile and maximum value of vehicle speed at mainline.

| VARIABLE     | MEAN (km/h) | MINIMUM (km/h) | MEDIAN (km/h) | MAXIMUM (km/h) | 85TH PERCENTILE (km/h) |
|--------------|-------------|----------------|---------------|----------------|------------------------|
| Car          | 86.186      | 67.920         | 86.582        | 123.919        | 94.66                  |
| Medium Lorry | 82.422      | 54.718         | 82.076        | 106.216        | 90.67                  |
| Large Lorry  | 76.087      | 61.230         | 76.877        | 87.508         | 81.49                  |
| Buses        | 77.64       | 43.45          | 77.25         | 96.56          | 88.31                  |
| Motocycles   | 76.443      | 58.741         | 76.156        | 101.925        | 84.17                  |
Table 3. Summary of the mean, standard deviation, minimum value, median, 85th percentile and maximum value of vehicle speed at mainline.

| VARIABLE       | MEAN (km/h) | MINIMUM (km/h) | MEDIAN (km/h) | MAXIMUM (km/h) | 85TH PERCENTILE (km/h) |
|----------------|-------------|----------------|---------------|----------------|------------------------|
| Car            | 64.87       | 43.45          | 65.98         | 87.71          | 74.52                  |
| Medium Lorry   | 59.63       | 40.23          | 57.94         | 90.12          | 77.89                  |
| Large Lorry    | 54.40       | 40.23          | 48.28         | 72.42          | 67.81                  |
| Buses          | 59.546      | 59.546         | 59.546        | 59.546         | 59.546                 |
| Motocycles     | 62.49       | 27.36          | 60.89         | 94.95          | 77.75                  |

The simulation process is then run for three times with different random seed to get a different simulation result. The result of three simulation runs was averaged and compared to the empirical values to account for the stochastic nature of Vissim.

4. Result and Discussions

The summary of the mean, minimum value, median, and maximum value of density from Empirical, MHCM 2011 and Vissim is shown in Table 4. The result of traffic density from Vissim is presented in veh/km/ln as to follow the actual output of the software. Even though the unit is in veh/km/ln, the microsimulation models deal with heavy vehicle explicitly by assigning more sluggish characteristics to each of them. The frequency distribution of density for Empirical, MHCM 2011, and Vissim are shown in Figure 2. In short, the mean of density for MHCM 2011 is higher than empirical data while Vissim is closely match with empirical data. This indicates a potential different between the MHCM 2011 and empirical data.

Table 4. Summary of the mean, minimum value, median, and maximum value of density from Empirical, MHCM 2011 and Vissim

| VARIABLE         | MEAN     | MINIMUM | MEDIAN | MAXIMUM | Density (pc/hr/ln) |
|------------------|----------|---------|--------|---------|-------------------|
| Empirical (pc/hr/ln) | 4.294     | 0.228   | 4.973  | 10.041  |                   |
| MHCM 2011 (pc/hr/ln) | 6.101     | 2.821   | 6.582  | 10.173  |                   |
| Vissim (veh/km/ln)  | 4.218     | 0.206   | 4.707  | 10.884  |                   |

Figure 2. Frequency distribution of density for Empirical, MHCM 2011, and Vissim.
The Paired T-Test was conducted to determine if there is a significant difference between the density means of MHCM 2011, Vissim and empirical data. The test was conducted separately for MHCM 2011 and Vissim to compare the different mean with empirical data. The first test is conducted between MHCM 2011 and empirical data. The hypothesis for the first test was conducted as below:

Null Hypothesis, $H_0(1) =$ There is no significance different between the density mean of MHCM 2011 and empirical data.

Alternative Hypothesis, $H_a(1) =$ There is significance different between the density mean of MHCM 2011 and empirical data.

Table 5. Shows the result of paired T-test between MHCM 2011 and empirical data

| SAMPLE     | MEAN | STANDARD DEVIATION | STANDARD ERROR MEAN | P-VALUE |
|------------|------|--------------------|---------------------|---------|
| MHCM 2011  | 6.101| 2.220              | 0.227               | 0.00    |
| EMPIRICAL  | 4.294| 2.801              | 0.286               | 0.00    |
| DIFFERENT  | 1.806| 0.701              | 0.072               | 0.00    |

Table 5 shows the result of paired T-test between MHCM 2011 and empirical data. The p-value is equal to 0.00 which is less than 0.05; it can conclude that the mean of density from MHCM 2011 differs from empirical data at the 95% confidence level. Thus, rejecting the null hypothesis $H_0(1)$.

The second test is conducted between Vissim and empirical data. The hypothesis for the second test was conducted as below:

Null Hypothesis, $H_0(2) =$ There is no significance different between the density mean of Vissim and empirical data.

Alternative Hypothesis, $H_a(2) =$ There is significance different between the density mean of Vissim and empirical data.

Table 6. The result of the paired T-test between Vissim and empirical data

| SAMPLE  | MEAN | STANDARD DEVIATION | STANDARD ERROR MEAN | P-VALUE |
|---------|------|--------------------|---------------------|---------|
| VISSIM  | 4.218| 2.918              | 0.298               | 0.304   |
| EMPIRICAL| 4.294| 2.801              | 0.286               | 0.304   |
| DIFFERENT| -0.076| 0.721            | 0.074               |         |

Table 6 shows the result of the paired T-test between Vissim and empirical data. The p-value is equal to 0.304 which is more than 0.05; it can conclude that there is no significant difference between the mean density of Vissim and empirical data at the 95% confidence level. Thus, accepting the null hypothesis $H_0(2)$.

Figure 3 shows the time series plot of density from MHCM 2011, Vissim and empirical data to graphically show the different pattern of density between MHCM 2011, Vissim and empirical data within 24-hours. The density from MHCM 2011 has the highest values at almost every 15-minutes interval evaluated. While, the Vissim density resulted in consistent estimates even though, Vissim estimates were slightly lower than empirical data. However, the Vissim density is observed to be highest during the maximum peak flow where the traffic volume is highest. Nonetheless, still, there is no significant difference between the mean density of Vissim and empirical data at the 95% confidence interval.
Based on the trend shown by the density estimates from the two models, a more reasonable comparison could be drawn by using the scatter plot of density values with the 45-degree diagonal line for result validation. A 45-degree diagonal line plot is generated to see how the data points are scattered around the diagonal line, to examine and validation of the extent of the difference between the density estimates from the two models evaluated. Figure 4a shows the scatter plot graph of density MHCM 2011 vs Empirical and Figure 4b shows the scatter plot graph of density Vissim vs Empirical. In short, the MHCM 2011 density tend to overestimate the empirical data while Vissim is slightly underestimate the empirical data.
Figure 4. Scatter plot graph of density MHCM 2011 vs Empirical and Vissim vs Empirical.

The literature does not recommend the comparison of LOS obtained from the microsimulation model and HCM tools [2]. However, those recommendations do not state the magnitude of the discrepancy between the two methodologies. Understanding that government agencies and consultants use microsimulation and MHCM extensively, it would be beneficial to reveal the discrepancies between these tools.

Figure 5 shows the LOS comparisons between Vissim and MHCM 2011. One can observe that there is no different in LOS grade calculated based on MHCM versus Vissim analysis from 0.00 to 7.45 where the traffic flow during this time frame is considered lowest. The LOS between MHCM and Vissim shows inconsistent during the morning peak flow. At 7:30 to 8:00, the LOS from both tools is similar, and the LOS start to differ at 8:15 and similar again at 8:30. At evening peak, the LOS is consistently matched between both models and start to differ after evening off-peak from 20:00 to 21:00.
5. Conclusion and Recommendation
Based on the results of paired T-test presented in Chapter 4, it was found that the null hypotheses for test 1 are rejected and conclude that the mean of density from MHCM 2011 differs from the empirical data at the 95% confidence level. The test 2 result shows that the null hypothesis is accepted and conclude that there is no significant difference between the mean density of Vissim and empirical data at the 95% confidence level.

The result is further validated with a scatter plot with a 45-degree diagonal line. It is concluded that MHCM 2011 tend to overestimate the density at most every 15-minutes interval within 24-hours of study. While the result of simulated density from Vissim is slightly underestimated and nearly matched with empirical data at most of the study interval although the result from Vissim can also be overestimated during peak flow where the traffic volume is highest.

It can be concluded that the level of service between MHCM 2011 and Vissim providing the same LOS during off-peak where the traffic flow is lowest. However, during the morning and evening peak, the LOS is inconsistently matched between MHCM 2011 and Vissim. After completed this study, several further studies are required in order to improve the comparison of density from both MHCM 2011 and Vissim with empirical data.
Another detail setting in Vissim needs to be further studied and adjust based on empirical data such as driving behaviour parameter and vehicle characteristic in order to consistently match with empirical data.

A traffic study needs to be conducted at the busy on-ramp expressway with a higher flow rate of vehicles. Thus, the result from Vissim and MHCM 2011 can be further evaluated and compared at such condition.

Vissim result will generally match the empirical density at most of the study interval. However, additional adjustments are necessary in order to ‘translate’ Vissim output to MHCM 2011 measurements as MHCM 2011 is using pc/km/lane as density unit which accounts for the passenger car unit factor. While, Vissim density unit is in veh/km/lane with the incorporation of sluggish, heavy vehicle behaviour and light vehicle such as motorcycle into the simulation.

Acknowledgements
This research was funded by the Universiti Teknologi 600-IRMI/MYRA 5/3/MITRA (007/2017)-1. The authors gratefully acknowledge the cooperation of staffs in Faculty of Civil Engineering and Faculty of Health Science 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. Thank you to Endeavour Consult Sdn. Bhd. for providing the licensed PTV Vissim software to accomplish this study.

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