A NEW CAPACITY MODEL FOR MALAYSIAN URBAN ROADS USING MACROSCOPIC FUNDAMENTAL DIAGRAM AND MULTIPLE LINEAR REGRESSION APPROACH

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Abstract

The existing manuals used to estimate urban road capacity have limitations. Adapting these manuals to compute the road capacity at urban roads reduces estimation accuracy. This study attempts to develop a capacity model to characterise urban road capacity. Twenty-two sites consisting of the collector/distributor roads and local roads in the Cheras-Kajang area in Klang Valley are selected for traffic data collection during the morning peak hour from 8 a.m. to 9 a.m. Site video camera recording is carried out, and the traffic data is extracted from the video footage. The speed-density and flow-density curves of the macroscopic fundamental diagram are fitted with the traffic data extracted. The capacity value is then derived from these curves. The urban road capacity model, termed the UrbanCap model, is developed in this study using the multiple linear regression approach. The results show that the urban road capacity depends on the type of road and carriageway and speed limit. The comparison of the capacity values produced from the UrbanCap model with other manuals justifies that it has a better estimate than the existing manuals used in Malaysia. The results also signify a need to develop a manual/guideline to quantify the urban road capacity in Malaysia for road design and analysis.

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1.0 INTRODUCTION

Road capacity is the maximum hourly rate at which persons or vehicles reasonably can be expected to traverse a point or a uniform section of a lane or roadway during a given period under prevailing roadway, traffic, and control conditions (TRB, n.d.). Understanding the road capacity is crucial as it facilitates road design, planning, and performance assessment. The road capacity is well established with a handful of research studies and technical manuals/guidelines that define the values. The Highway Capacity Manuals (HCM 2000 and HCM 2010) (TRB, n.d.) provide details on estimating the capacity for basic freeway segments, multi-lane highways, and two-lane highways. However, most of these manuals focus on deriving the capacity value for expressways and highways. There are limited studies on urban roads, i.e., arterial roads, collector/distributor roads, and local roads, especially in Malaysia.

Nevertheless, the traffic impact assessment (TIA) requires the road performance assessment that needs the road capacity value. Most of the time, the types of roads investigated in the TIA are not expressways and highways where the capacity values can be estimated from the manual. Adopting the capacity charts shown in HCM 2000, HCM 2010, or Malaysia Highway Capacity Manual (MHCM 2011) (HPU, 2011) to assess the urban road has the following limitations: (1) the free flow speed of the highway starts from 60 km/hr on the speed-volume relationship, while most of the collector/local roads have a free flow speed below 60 km/hr, extrapolation is performed to derive the capacity value. This extrapolation approach requires further engineering judgment; (2) there are no or limited theoretical findings to support that the multi-lane highway's speed-volume chart could be extrapolated to the speed below 60 km/hr; (3) the driver behavior on highway/expressway and urban roads tend to be different due to different road geometry and environment. Urban roads tend to be narrower with roadside parking or/and bus stops; hence, the capacity value derived might not be appropriate; (4) the existence of median/divider might have impact on the urban road capacity.

The objectives of this study come in twofold, i.e. (1) to develop a new capacity model for urban roads, termed the UrbanCap model, and (2) to determine the factors that influence the urban road capacity. Traffic data is collected from the sites selected before extracting the traffic parameters required for the model development. The speed-density and flow-density curves are estimated from the data. Then, the capacity value is calculated with the macroscopic fundamental diagram (MFD) approach. The UrbanCap model is then developed by relating the capacity value obtained with several independent variables that classify the urban road, i.e., the type of carriageway and road and speed limit using the regression analysis. A comparison of the capacity values derived from the model with those extracted from the guidelines/manuals is carried out. The results show that the UrbanCap model is reliable and appropriate for capacity estimation for urban roads.

The paper's organisation is as follows: the introduction section provides the background and objectives of the study, followed by the literature review section highlighting the existing studies. Then, the methodology adopted to conduct this study is presented, which includes data collection, extraction, processing, and model development. An analysis follows it by comparing the capacity values obtained from the UrbanCap model and those used in practice and some other guidelines in abroad countries. Lastly, the findings are concluded, and recommendations are made.

2.0 RELATED EXISTING STUDIES

The most important reference of road capacity in traffic engineering studies is the Highway Capacity Manual (2000, 2010) published by the Transportation Research Board, USA. The manual is a vital reference in estimating the level of service and the capacity for basic freeway segments, multi-lane highways, and two-lane highways. Charts and tables are provided to assist the users in referring to the manual. The Malaysian Highway Capacity 2011 version adapted the HCM 2000 to the Malaysian local condition. Sets of procedures, charts, and tables are provided to estimate the level of service and capacity for the three facilities mentioned above. The significant difference between MHCM and HCM is the consideration of motorcycle traffic in the estimation procedure. The road capacity estimation using MHCM 2011 could be referred for roadway with free flow speed higher than 60 km/hr. Besides, the Road Traffic Volume Malaysia (RTVM) (Ministry of Works Malaysia, 2020) has indicated a formula to estimate the capacity for single and dual carriageways. It indicates the ideal capacity for a multi-lane carriageway (per lane per direction) and a two-lane single carriageway (both directions), and the model considers the roadway and traffic reduction factor in the capacity estimation.

Internationally, there are published guideline for urban roadway capacity estimation. The UK TA79/99 Guideline (The Highway Agency, 1999), the Indian Guideline IRC: 106-1990 (Indian Roads Congress, 1990), and the Austroads Guideline (Austroads, 2017) are established guidelines that provide references for urban road capacity. The UK TA 79/99 Guideline (The Highway Agency, 1999) classified urban roads into five types, i.e., urban motorways (UM) and urban all-purpose (UAP1, UAP2, UAP3, and UAP4), based on their features that distinguish the roads, which include speed limit, the existence of side roads, the access to roadside development, parking and loading facility availability, pedestrian crossings, and bus stop availability. The urban motorways have the highest hierarchy in the urban roads with the highest speed limit and lowest accessibility, and UAP4 is vice versa. Besides the road classification, the carriageway type, the number of lanes, and the carriageway width are considered in determining the capacity. The Indian Guideline IRC:106-1990 (Indian Roads Congress, 1990) defined eight carriageway types: one-way and two-way, divided and undivided carriageway. These carriageways are classified into three categories, i.e., arterial, sub-arterial, and collector. The Australian Guidelines (Austroads, 2017) defined the urban road capacity based on lane type (i.e., inner lane, middle lane, and kerb lane) and single/dual carriageway (i.e., divided/undivided). The capacity recommended is within the range of 600 pc/hr/lane to 1000 pc/hr/lane. It is mentioned that the capacity may increase from 1200 pc/hr/lane to 1400 pc/hr/lane under specific conditions such as controlled or no roadside parking, signalised and unsignalised intersection flow conditions, and others.

Regarding the methodology in capacity model development, most of these studies are empirical studies where traffic data (i.e., volume, speed, density, traffic composition) is collected and analysed to produce charts/tables. Some other models adopted include Van Aerde model (Modi *et al.,* 2014), product limit method (Shao, 2011), sustained flow index (Shojaat *et al.,* 2016), headway method (Suresh and Umadevi, 2014), and macroscopic fundamental diagram method (Chandra and Kumar, 2003). Li and Laurence (2015) and Modi *et al.* (2014) applied the Van Aerde Model to estimate highway capacity. While Van Aerde Model is the most commonly used method for capacity estimation, the model's downside is that the estimated capacity value is significantly lower than those estimated with other methods. The estimated capacity value is deterministic and does not consider breakdown flow distribution or breakdown events. The product limit method (PLM) depends on lifetime statistics and was initially researched to assess the variation in capacity values. Shao (2011) and Ben-Edigbe *et al.* (2013) adopted the PLM method to estimate the freeway's capacity. The results show that PLM can capture the capacity stochasticity, but it produces inconsistent results due to arbitrary selection of the capacity value from the cumulative distribution function. The sustained flow index (SFI), the breakdown probability method, is adopted to predict the possibility that traffic flow will continue at a specific value. The volume with the highest probability of sustain is defined as the capacity. Shojaat *et al.* (2016) and Uswaththa *et al.* (2021) adopted the SFI approach to estimate the highway capacity. The headway method considers road user behavior as the primary component of the microsystem of traffic analysis in road capacity estimation. Sohrabi *et al.* (2016), Suresh and Umadevi (2014), and Qasim *et al.* (2020) estimated the road capacity using the headway method. Some of the studies adopted the fundamental diagram approach to evaluate the capacity. The macroscopic fundamental diagram describes the relationship of the three parameters, i.e., speed, density, and volume in a traffic flow stream. Chandra and Kumar (2003) and Jain *et al.* (2019) applied the fundamental diagram method to estimate road capacity. Ashish *et al.* (2022) determined the capacity model for six-lane divided urban arterials by developing speed models. The simultaneous equations are used to develop the speed-flow plot to estimate the midblock road capacity.

It could be observed that there is a lack of research work in quantifying the urban road capacity values, which is essential in urban road design and analysis. The MHCM or RTVM could only be used under certain circumstances. A specific and detailed guideline/manual is required to facilitate a more accurate capacity value estimation for urban roads.

3.0 METHODOLOGY

Since this is an empirical study, traffic data collected from the roads are used in model development and analysis. Twenty-two sites that consist of collector/distributor roads and local roads in Cheras-Kajang, Klang Valley, are selected for data collection. The traffic data is collected during the morning peak hour (8 a.m. – 9 a.m.) from January 2023 to March 2023. The traffic data, i.e., traffic flow, density, and speed, are extracted from the video footage playback in the laboratory. Then, the road capacity is estimated based on the speed-density and the flow-density curve fitted with the traffic data. The regression of coefficient is adopted to justify the data fitting quality. Lastly, the urban road capacity model, i.e., the UrbanCap model, is estimated using the multiple linear regression approach by establishing the regression relationship between the dependent variable, capacity, with the independent variables, i.e., number of lanes, type of carriageway, type of road, and speed limit. With the adoption of the multiple linear regression analysis, we assume the underlying data distribution is normally distributed. Figure 1 shows the flowchart of the research framework.

3.1 Site Selection and Data Collection

The type of roads of interest in this study is collector/distributor roads and local roads in urban area. The factors affecting road capacity, such as the type of carriageway and road and speed limit, are considered during site selection. The sites selected are at the mid-block of the roads, away from roadside parking, bus stops, and intersections. After looking into the possible areas to conduct this research, three locations in Klang Valley were selected: Bandar Sungai Long, Bandar Mahkota Cheras, and Maluri in Cheras-Kajang district. Twenty-two sites were selected. Table 1 lists the sites chosen for this study, the locations, the type of carriageway and road, and their speed limit.

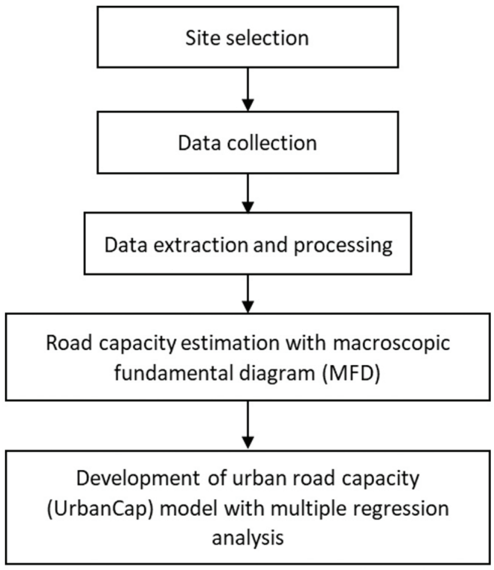

Figure 1: Research framework

Table 1: Sites selected for data collection

Site	Area	Carriageway Type	Road Type	Speed Limit (km/hr)
Persiaran Sungai Long 1	Bandar Sungai Long	2-lane Single	Local	60
Persiaran Sungai Long 2	Bandar Sungai Long	Dual 2	Collector Distributor	60
Jalan Sungai Long (near Green Acre Park)	Bandar Sungai Long	Dual 2	Collector/Distributor	70
Persiaran Bukit Sungai Long 2	Bandar Sungai Long	3-lane Single	Local	60
Jalan Sungai Long (near Forest Green Condominium)	Bandar Sungai Long	Dual 2	Collector/Distributor	70
Jalan Sungai Long (near Sungai Long Residence)	Bandar Sungai Long	Dual 2	Collector/Distributor	70
Persiaran SL 1	Bandar Sungai Long	2-lane Single	Local	30
Jalan Bendahara	Bandar Mahkota Cheras	4-lane Single	Collector/Distributor	70
Jalan Laksamana	Bandar Mahkota Cheras	4-lane Single	Local	60
Persiaran Mahkota Cheras 1	Bandar Mahkota Cheras	Dual 3	Collector/Distributor	60
Jalan Shahbandar	Bandar Mahkota Cheras	4-lane Single	Local	70
Jalan Permaisuri	Bandar Mahkota Cheras	4-lane Single	Local	70
Jalan Dayang	Bandar Mahkota Cheras	2-lane Single	Local	60
Jalan Putera	Bandar Mahkota Cheras	2-lane Single	Local	60
Jalan Inang	Bandar Mahkota Cheras	2-lane Single	Local	60
Jalan Cochrane	Maluri	Dual 3	Collector/ Distributor	60
Jalan Perkasa	Maluri	Dual 3	Collector/ Distributor	60
Lorong Shahbandar	Maluri	2-lane Single	Local	30
Lorong Peel	Maluri	2-lane Single	Local	30
Jalan Perkasa 1	Maluri	2-lane Single	Local	60
Jalan Shelley	Maluri	3-lane Single	Local	60
Jalan Menteri	Maluri	2-lane Single	Local	30

Each of the dual carriageway roads selected in data collection contributes to two sets of data since both carriageways in dual carriageways do not interfere with one another in terms of traffic flow. From Table 1, seven of the roads selected for data collection are dual carriageways, and the other fifteen are single carriageways. Among the selected sites, eight are collector or distributor roads, while fourteen are local roads. These roads were chosen to ensure that sufficient traffic data could be collected for the model development. All of the roads selected are within the residential and commercial areas. The data was collected from January 2023 to March 2023 on Tuesdays – Thursdays during morning peak hours, 8 a.m. – 9 a.m., taking a turn for each site by one surveyor only.

The traffic data is collected through video recording. The camera is set up at the mid-block section of the road selected. It is positioned at a vantage location around the site to ensure the equipment can collect the traffic data over the full stretch of the studied road. The markings are done on the road to indicate the length of a road section. It is to facilitate the speed and density computation later.

3.2 Data Extraction and Processing

The video footage is played back in the laboratory to extract the traffic data, i.e., traffic volume, density, and travel speed for the traffic stream recorded for 1 hour. The number of vehicles for each direction and lane for the dual carriageway and the total volume for the single carriageway (both directions) are counted for each 15-minute interval and sum to 1-hour volume. The traffic volume is converted from the unit of vehicle per hour to passenger-car unit (pcu) per hour using the conversion factor stated in Arahan Teknik (Jalan) 8/86 - A Guide on Geometric Design of Roads (Traffic Signal Design) conversion factor (Public Work Department Malaysia, 2015). The mean travel speed is a weighted mean speed considering the vehicle classification, which is computed by the following equation:

$$V_m = \frac{\sum_{i=1}^{N} n_i v_i}{\sum_{i=1}^{N} n_i} \tag{1}$$

where
V_m = mean stream speed, km/h
N = total number of vehicle categories
v_i = average speed of vehicle of category i, km/h
n_i = number of vehicles of category i (veh)

The parameter required to compute the traffic density is the distance headway or spacing, which is the distance between successive vehicles. Since the distance of a specific stretch of road at the site, which is displayed on the screen of the video recorder, was being measured and marked with visible objects, the distance between the successive vehicles could be captured, and by reviewing the full length of the video recorded, the average distance headway was obtained. Eqn. (2) shows the computation of traffic density with the average distance headway.

$$k = \frac{1000}{\bar{s}} \tag{2}$$

where
k = traffic density, pcu/km
$\bar{s}$ = average distance headway, meter/pcu

3.3 Road Capacity Estimation Using Macroscopic Fundamental Diagram (MFD)

The development of the macroscopic fundamental diagram is essential in determining the relationship between traffic speed, flow, and density of the road. The flow-density and speed-density relationship is developed in this study to assess the capacity of urban roads. The flow-density relationship is characterized by a parabolic curve with a maximum vertex shown by eqn. (3) as follows.

$$q = \beta_1 k^2 + \beta_2 k + c \tag{3}$$

where
q = traffic flow, pcu/h
k = traffic density, pcu/km
β = coefficient
c = y-intercept

The maximum vertex represents the maximum flow, which is the capacity of a roadway. Hence, the road capacity value is determined from the curve by differentiating eqn. (3) and equating it to zero as shown below:

$$\frac{dq}{dk} = 0 \tag{4}$$

where
q = traffic flow, pcu/h
k = traffic density, pcu/km

3.4 Development of Road Capacity Model Using Multiple Regression Approach

Six capacity values are computed for each road based on three categories of classification (type of carriageway, type of road, and speed limit) and two curves (speed-density and flow-density curves). The highest value is adopted as the road capacity based on the computed values. This road capacity value is used as the dependent variable in the UrbanCap model. In contrast, the independent variables chosen are the type of road, type of carriageway, and speed limit of the road. Multiple regression analysis is conducted to find the relationship between the capacity values and the independent variables. Analysis of Variance (ANOVA) is used to justify the statistical significance of the model developed. The F-statistic is referred to verify the significance of the UrbanCap model. The significance of the independent variables to the UrbanCap model is studied with the p-value. The R^2 value is referred to justify the overall model fitting. Eqn. (5) shows the general form of a multiple regression model.

$$q_{cap} = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 \ldots + \beta_n x_n \tag{5}$$

where
q_{cap} = road capacity value (pcu/hr)
x = independent variables
β = coefficient

4.0 RESULTS

This section presents the results obtained.

4.1 The Flow-Density Curve Developed

Figure 2 (left) shows an example of the flow-density curve fitted using the data for a dual carriageway. The vertex of the curve is obtained as the capacity value. Table 2 shows the flow-density curve developed for each category. It is observed from the table that the flow-density curve has a good fitting that has R^2 value that is more than 0.70. The vertex of the flow-density curve (as stated in Eqn. (4)) is derived as the capacity value.

Table 2: Flow-density curve estimation

Model Type		Model	R^2
Type of Road	Collector/ Distributor Road	$q = 97.96 + 31.71k - 0.09k^2$	0.955
	Local Road	$q = 67.96k - 0.4k^2 - 306$	0.995
Type of Carriageway	Dual Carriageway	$q = 93.21 + 34.19k - 0.1k^2$	0.988
	Single Carriageway	$q = 56.73k - 0.48k^2 - 181$	0.761
Speed Limit	60 km/h	$q = 50.32k - 0.36k^2 - 109$	0.704
	70 km/h	$q = 35.03k - 0.1k^2 - 64.01$	0.984

4.2 The Speed-Density Curve Developed

The fitting of the speed-density curve is shown in Figure 2 (right). The curve estimated for each category is shown in Table 3. It is observed that most of the models (such as: the collector/ distributor and dual carriageway models) are estimated to be at a satisfactory level. However, the local road model exhibits a low R^2 value. The models for speed limit categories could not be presented as the models developed are insignificant.

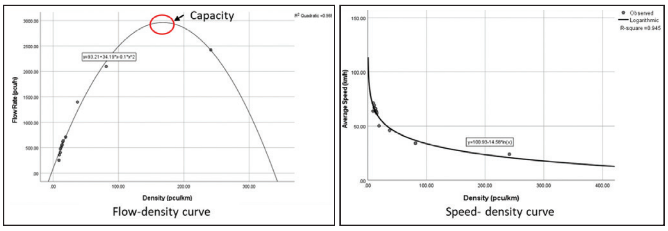

Figure 2: The macroscopic fundamental diagram estimated for dual carriageway

The speed-density curve is fitted into Eqn. (3). Then, Eqn. (4) is adopted to derive the vertex is of the flow-density curve which represents the capacity value.

Table 3: Speed-density curve estimation

Model Type		Model	R^2
Type of Road	Collector/ Distributor Road	$u = 99.83 - 14.49 \ln(k)$	0.919
	Local Road	$u = 80.66 - 6.65 \ln(k)$	0.273
Type of Carriageway	Dual Carriageway	$u = 100.93 - 14.58 \ln(k)$	0.945
	Single Carriageway	$u = 88.66 - 10.3 \ln(k)$	0.462
Speed Limit	60 km/h	Not available	Not available
	70 km/h	Not available	Not available

4.3 The New Capacity Model for Urban Road in Malaysia

The highest value of the capacity estimated from the models shown in Table 2 and Table 3 is adopted as the road capacity value for the specified road. The capacity value (per direction for dual carriageway, both directions for single carriageway) is the dependent variable, while the number of lanes, type of carriageway, type of road, and speed limit are the independent variables. The UrbanCap model is expressed in Eqn. (6) as follows:

$$C = 204.329a + 1358.338b + 6.032S + 1146.334 \qquad (6)$$

where
C = capacity, pcu/h (per direction for dual carriageway, both directions for single carriageway)
a = type of road; 0: local road; 1: collector/distributor road
b = type of carriageway; 0: single carriageway; 1: dual carriageway
S = speed limit, km/h
R^2: 0.99

The ANOVA results in Table 4 indicate that the model presented is statistically significant at 95% confidence level, as evidenced by the F statistic and p-value. Table 4 also shows the significance of the variables in the model. It can be

Table 4: The statistical significance test and ANOVA test for UrbanCap model

Statistical Significance						
Variables	Coefficient	Standard error	t-value	Significant level	95% Confidence level	
					Lower bound	Upper bound
Constant	1146.33	76.43	14.99	<0.001	984.30	1308.36
Type of road	204.33	65.07	3.14	0.006	66.39	342.26
Type of carriageway	1358.34	63.12	21.52	<0.001	1224.52	1492.15
Speed limit	6.03	1.47	4.12	<0.001	2.92	9.13
Number of lane	1.89	41.39	0.046	0.964	-85.8	89.62
Anova						
	Sum of squares	df	Mean square	F	Sig.	
Regression	12463214.57	4	311903.64	540.89	<0.001	
Residual	92170.1	16	5760.63			
Total	12555784.67	20				
R^2	0.99					

Note: Dependent variable is road capacity observed that all independent variables tested are significant at 95% confidence level (by referring to the p-value), except the number of lanes variable. The R^2 values estimated for the model is 0.99. Statistically, R^2 describes how the model explains the data variability. Although a higher R^2 value that suggests a better fit is preferred, it doesn't necessarily mean the model is a good predictor in an absolute sense. The R^2 value obtained in this study indicates that the equation/model explains the data variability to a satisfactory level.

The capacity value computed from the UrbanCap model is per carriageway. It considers both direction for single carriageway while it considers one direction only for dual carriageway. Three independent variables define the capacity for urban roads, namely type of carriageway, type of road and speed limit. Unfortunately, the number of lane variable is not included in the UrbanCap model since it is statistically insignificant. It is crucial to mention that the exclusion of the number of lane from the UrbanCap model does not mean that the number of lane variable does not affect the urban road capacity. It only means that the statistical analysis does not support the existence of the relationship. This could be due to insufficient data to support such relationship.

5.0 DISCUSSION

The capacity values computed from the UrbanCap model is compared to the capacity values obtained from the manuals and guidelines locally or globally. These manuals/guidelines include the Malaysian Highway Capacity Manual 2011 (MHCM) (HPU, 2011), Road Traffic Volume Malaysia (RTVM) (Ministry of Works Malaysia, 2020), The UK TA79/99 Guideline (The Highway Agency, 1999), and the Austroads Guideline (Austroads, 2017).

Chapter 4 of MHCM 2011 shows the procedures used to determine the capacity of the multi-lane highways. It is important to note that the types of facilities are focused on highways/expressways in urban/rural areas but not on urban roads (arterial, collector/distributor, and local). The manual used the free flow speed to determine the roadway's capacity (per lane). Figure 4.9 of MHCM 2011 is referred. The flow value for the level of service (LOS) E defines the road capacity. Based on the speed limit (free-flow speed) of 60km/hr and 70km/hr, the road capacity is 1800 pcu/hr/lane and 1900 pcu/hr/lane, respectively. The chart is extrapolated for the 30 km/hr roadway to determine the capacity, i.e., 900 pcu/hr/lane.

The RTVM 2020 gives a capacity model, which is shown in Eqn. (7) as follows:

$$C = I \; x \; R \; x \; T \qquad (7)$$

where
C = the maximum one-way hourly capacity (pcu/hr)
I = the ideal hourly capacity (pcu/hr)
R = the roadways reduction factor referring to RTVM 2020 (Ministry of Works Malaysia, 2020)
T = traffic reduction factor referring to RTVM 2020 (Ministry of Works Malaysia, 2020)

The guideline suggested that the ideal capacity for a multi-lane road is 2000 pcu/hr/lane while for a two-lane roadway is 2800 pcu/hr for both ways or 1400 pcu/hr/lane). The roadway reduction factor takes into account the carriageway and shoulder width. A lookup table is used to identify the value of the reduction factor for the carriage width ranges from 5 m to 7.5 m and shoulder width from 1 m to 2 m. The traffic reduction factor considers the terrain type, i.e., flat, rolling, and mountainous, and the percentage of commercial vehicles. In this study, no correction to the roadway reduction factor is carried out for carriage width that is out of the range. In contrast, an extrapolation is carried out for roadways with no shoulder to identify the value.

Referring to the UK TA 79/99 Guideline (The Highway Agency, 1999), the collector/distributor roads in the study area are defined as UAP2 roads, while the local roads are defined as UAP3 roads. The 2-lane dual carriageway has a width of 6.75 m, while the single carriageway has a width of 9 m. It is important to note that the capacity estimated using the guideline is per direction. For a single-carriageway, the busiest direction is considered.

Referring to the Austroads Guideline, the value of 1400 pc/hr/lane is used for dual carriageway while 900 pc/hr/lane is used for single carriageway in this study. Only one direction is considered at one time for dual carriageway while both directions are considered for single carriageway.

Figure 3 shows the capacity estimated by the UrbanCap model and compare with the capacity values obtained from the above manual/guidelines for the seven road sections on a dual carriageway (each road has two directions). It is to be noted that the capacity has the same value for both directions except for those values derived from RTVM, as the traffic reduction factor (T) differs for both directions due to a slightly different percentage of commercial vehicles.

It is observed from Figure 3 that the capacity estimation from the UrbanCap model developed in the study is consistent with the capacity value obtained from the UK and Austroads guidelines. The difference between the capacity value obtained from the UrbanCap model and those shown on the dual-2 carriageway (road section 1- 8) of the UK guideline is less than +6%, the difference with Austroads guideline is less than +10%, and the difference with RTVM method is less than +11%. This difference indicates that the UrbanCap model has a higher capacity value estimation than the values computed from both guidelines. Since the difference is not large (within 10%), it could be said that the UrbanCap model can estimate the dual-2 lane carriageway capacity reasonably. When the capacity values are compared to those obtained from MHCM 2011, it is observed that the differences are lesser than -21%. It shows that the MHCM over-estimates the dual-2 carriageway capacities.

The road sections 9-14 are the capacities estimated for a dual-3 carriageway. It can be seen that the UrbanCap model is insensitive to the number of lanes since the number of lanes is not one of the model's variables. Nevertheless, it is observed that the MHCM constantly overestimates the capacities of these roads when compared to the UK and Austroads guidelines. The capacity estimation by RTVM is sensitive to the roadway reduction factor (R) used in the calculation. As such, it is observed that the capacity estimated differs significantly across different types of roads depending on the carriage width.

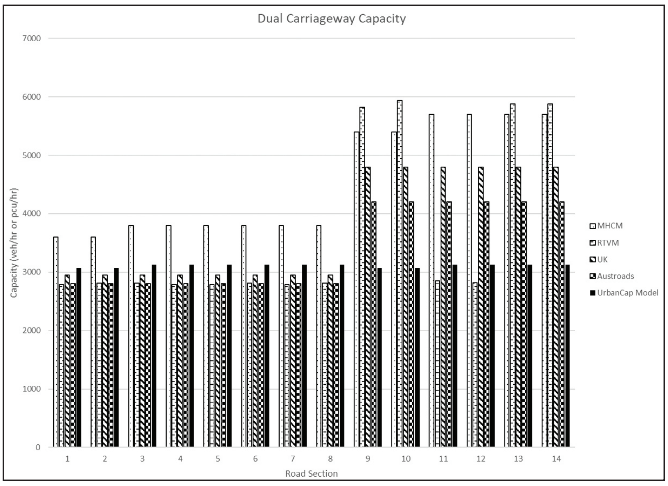

Figure 3: Road capacity estimation with different models for dual carriageway

Note: Legend for road section in Figure 5

Road Section	*Road Name*
1-2	*Persiaran Sungai Long 2 (Northbound, Southbound)*
3-4	*Jalan Sungai Long, Green Acre Park (Northbound, Southbound)*
5-6	*Jalan Sungai Long, Forest Green (Northbound, Southbound)*
7-8	*Jalan Sungai Long, Sungai Long Residence (Northbound, Southbound)*
9-10	*Persiaran Mahkota Cheras 1 (Northbound, Southbound)*
11-12	*Jalan Perkasa (Westbound, Eastbound)*
13-14	*Jalan Cochrane (Eastbound,Westbound)*

For single carriageways, the UrbanCap model considers both directions of the carriageway in the estimation. It is the same approach used in the RTVM method. The UK guideline considers only one direction, i.e., the busiest, while the MHCM and Austroads guideline considers capacity per lane. For consistency and fair comparison, the capacity estimated for the single carriageways account for both directions. The capacity of some road sections is undefined in the UK guideline as quoted in the guideline due to insufficient data. Figure 4 shows the road capacity estimated for single-carriageways. The capacity value estimated using the UrbanCap model is close to the capacity values obtained from the UK guideline, specifically the UAP3 category. The difference in capacity estimation is about less than -1.5% to -15%, except for road section 1, as the UAP2 category is used. The MHCM, RTVM, and Austroads guidelines give a much higher estimation.

It is observed from the above comparison that the UrbanCap model produces a consistent and reasonable estimation of road capacity for urban dual-2 carriageways and single carriageways. The values estimated are close to those estimated by the UK and Austroads guidelines. The capacity values obtained from MHCM are high when compare to the capacity values estimated by UrbanCap model and other guidelines for both single and dual carriageways. The capacity value estimated from RTVM is susceptible to the traffic reduction factor, which is sensitive to the carriage and shoulder width. The capacity value becomes high when the carriageway width is wide. It performs better when the carriageway and shoulder widths are within their ranges. It is important to note that the significant difference between highways/expressways and urban roads is that the capacity of the urban roads is affected by the type of carriageway (dual vs single), the number of lanes, the speed limit, and the roadside development (such as access, bus stop, parking, etc.). Thus, this research study shows that the existing methods adopted in urban road capacity estimation have limitations that warrant further investigation into establishing an urban road capacity model/guideline/manual for Malaysia.

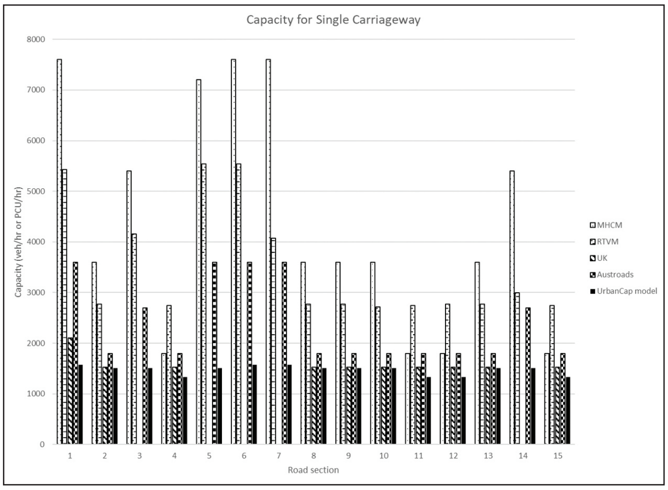

Figure 4: Road capacity estimation with different models for single carriageway

Note: Legend for road section in Figure 5

Road Section	*Road Name*
1	*Jalan Bendahara*
2	*Persiaran Sungai Long 1*
3	*Persiaran Bukit Sungai Long 2*
4	*Persiaran SL 1*
5	*Jalan Laksamana*
6	*Jalan Shahbandar*
7	*Jalan Permaisuri*
8	*Jalan Dayang*
9	*Jalan Putera*
10	*Jalan Inang*
11	*Lorong Shahbandar*
12	*Lorong Peel*
13	*Jalan Perkasa 1*
14	*Jalan Shelley*
15	*Jalan Menteri*

6.0 CONCLUSIONS

This study investigates the capacity for urban roads, i.e., collector/distributor roads and local roads. Twenty-two sites, consisting of seven dual carriageways and fifteen single carriageways in the Cheras-Kajang area in Klang Valley, are visited for data collection. The traffic volume, speed, and density are extracted from the video footage recorded during the site's AM peak hour. The road capacity is determined by fitting the speed-density and flow-density relationship on a chart with the macroscopic fundamental diagram approach. Then, the urban road capacity model is developed using the multiple regression analysis to establish the relationship between the capacity and the independent variables that influenced it, i.e., type of carriageway, type of road, and speed limit. The comparison of the capacity value obtained with the UK and Austroads guidelines shows that the UrbanCap model can produce reasonable estimates. The results also show that MHCM and RTVM have limitations in estimating the urban road capacity.

The limitation of this study is that the number of lanes is not included in the UrbanCap model due to its insignificance. It has reduced the ability of the model to estimate the capacity with three lanes and above. Besides, the model does not consider the side friction factors of the roads (such as parking, side road access, bus stops, and others). These factors could affect the urban road capacity. The speed-density curve estimated for the local road has low R^2 value. It is recommended that more sites and data be collected to improve the model further. It is important to note that the results of the regression analysis is sensitive to the sample size and the sample size selection in the small sample. Last but not least, there is a need for Malaysia to develop an urban road capacity manual or guideline to facilitate the estimation of urban road capacity for road design and analysis.

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