

Capacity Estimation of Multi-lane Rural Highway: A Comparative Study



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Abstract The highway capacity manual (HCM) of the United States of America provides techniques for evaluating the capacity and the quality of service of any facility. The present study is an attempt to determine the adequacy of the techniques in US HCM to predict the traffic performance of highways in Al-Anbar, Iraq. Capacity of the multi-lane rural highway that connects two cities in Al-Anbar Governorate, Iraq was estimated. Twenty sections of the multi-lane rural highway were selected and observed for this purpose. Data were collected using the video recording technique. Data were abstracted, processed and then analyzed using computer programs developed for this purpose. Three methods for estimating capacity were applied, which are, the enveloping curve technique, the best-fit technique, and the US HCM methodology. Results showed that the capacity estimation methodology using US HCM has limited application for the heterogeneous traffic situation prevailing in the studied sites. This finding is consistent with that obtained by previous studies in developing countries, such as India, Thailand, and Indonesia. The capacity estimate showed that the US HCM methodology tends to underestimate capacity unlike other techniques because the adjustment factor for the traffic composition is not applicable for all vehicle types in the traffic stream that has different equivalency units. Further, the underestimation is attributed partly by differences in driver behavior, vehicle characteristics, and roadside activities.

Keywords Capacity estimation • Multi-lane highway • Free flow speed • Passenger car unit • Highway capacity manual

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© Springer Nature Switzerland AG 2020
F. Mohamed Nazri (ed.), *Proceedings of AICCE'19*, Lecture Notes in Civil Engineering 53, https://doi.org/10.1007/978-3-030-32816-0_12

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1 Introduction

A highway is a public road that connects two or more destinations. A multi-lane highway has at least two lanes for the exclusive use of traffic in each direction, with each having an uninterrupted flow. However, periodic interruptions to traffic flow may be present at intersections with signal lights, which are spaced more than two miles in multi-lane highways. Rural multi-lane highways are typically “located along high-volume rural corridors that connect two cities or important activity centers”, thus generating numbers of trips daily. The concept of capacity is a considerable operational characteristic of the facilities in multi-lane highways. The capacity estimation of any roadway facility is fundamental in the traffic operation, geometric design, and planning of the roadway network. Capacity is significantly influenced by traffic, roadways, and driver and ambient conditions. The highway capacity manual [9] defines vehicle capacity as “the maximum number of vehicles that can pass a given point during a specified period under the prevailing roadway, traffic, and control conditions” [9]. In designing or improving roads, methods are necessary for the evaluation of traffic performance. Exploring the relationship between the capacity and the traffic interaction and the roadway geometry is considered as the most important factor to evaluate the system [6]. A widely important tool, US HCM, has been developed internationally to meet road requirements and to predict traffic performance measures such as capacity, density, and level of service (LOS). This research aims to estimate the capacity of the multi-lane rural highway that connects two cities in Al-Anbar Governorate, Iraq. Twenty sections were selected and observed for this purpose. Three methods, namely, the enveloping curve technique, the best-fit technique, and the US HCM methodology, were conducted to estimate capacity. The contribution of this study to literature is determining whether traffic performance can be adequately predicted in Iraq using the US HCM methodology.

2 Review of Literature

Determination of multi-lane highway capacity is the main function of any traffic network performance [4]. Some previous theories and empirical researches focused on the interrelationships among the contemporaneous influences of capacity, traffic features, geometric elements, environmental conditions and temporal weather factors on the interrupted highway [11].

Research in developed countries had led to the emergence of methodologies in roadway capacity analysis. For example, the US produced HCM, which explains highway capacity under typical conditions and then estimates practical capacities under prevailing conditions [4]. The finalized US HCM (2010) suggests that the capacity of a segment of a multi-lane highway under base conditions varies with the free-flow speed (FFS). The capacity of 2200 pcph for 100 km/h FFS decreases as

FFS decreases. These values represent national norms. Capacity varies stochastically, depending on prevailing conditions. In addition, capacity is the average flow rate across all lanes. Thus, a two-lane (in one direction) multi-lane highway segment with 100 km/h FFS would have an expected capacity of $2 \times 2200 = 4400$ pcph [9].

In Finland and Norway, the methodology for estimating the capacity of multi-lane highways is based on the US HCM 2000 version, with some modifications to be suitable with the local conditions. The Finnish and Norwegian methods determined capacity of 2000 pcph for multi-lane highways [10]. In Australia, the method is similar to that of the US HCM, but with unique approaches for specific problems. The Australian method considered an average minimum headway of 1.8 s under ideal conditions and assumed a maximum flow of 2000 pcph [4].

Bang et al. [2] in their study indicated that the application of US HCM methodology in Indonesia is unsuitable due to the major differences in driver behavior, vehicle types, and roadside activities. The authors also observed that in two-lane roads in the country, FFS of vehicles was less than that of vehicles in developed countries because of narrow road widths and side friction [2]. These findings led the authors to conduct an investigation involving several traffic facilities to develop Indonesian HCMs. The study concluded that HCMs for developed countries, such as the US, have misleading results when implemented in Indonesia because of differences in driver behavior, vehicle types, and roadside activities [6].

A study was carried out in Thailand, where the speed-volume relationship was used for capacity estimation. It was found that the capacity of four-lane urban roads in Thailand is mainly affected by the traffic composition especially the percentage of the motorcycle. It increases with the increase in the percentage of motorcycle in the traffic stream. However, though the estimate of capacity was very close to that recommended by the Indonesian highway capacity manual [8].

Based on the above literatures, it can be concluded that the application of US HCM methodology has misleading results due to the differences in traffic type, driver behavior, and some road features.

This study aims to estimate the capacity of multi-lane rural highway in Iraq with different methods applied around the world. One of these methods is The US HCM 2010 methodology. The purpose is to see how well this method can be applied to prevailing local conditions of the road geometry and traffic features.

3 Data Collection

Traffic data were collected during peak and off-peak periods at selected sections of the highway. The collected data at peak periods represented traffic flow conditions, while those collected at off-peak periods represented the free-flow conditions. Traffic composition includes passenger cars, pickups, minibuses, and trucks. The collected data were then abstracted using computer programs developed for the

purpose of the study. The data collected from selected sites had geometric features, ambience, and traffic conditions that are analogous to the base conditions recommended by US HCM and that are manipulated to implement an acceptable comparison study.

3.1 Selection of Suitable Sites

Selecting sites with traffic flow, speed, and section geometry that yield realistic results is necessary to satisfy the research requirements. The following criteria were used during the selection of suitable sites [1]:

- Existence of an accessible vantage point for data collection without affecting the observed traffic behavior.
- Vehicle flow varies in relation to the times of the day and the days of the week.
- The percentages of vehicle movement types and traffic compositions are considered in ranges.

3.2 Selected Site Description

The selected site is a rural multi-lane highway connecting two big cities, namely Al-Ramadi and Al-Fallujah in Al-Anbar Governorate, Iraq. The highway consists of four lanes, with two lanes for each traffic direction. The carriageway width for both sides is 7.5 m. The earth median (5 m wide) divides the two directions. The highway is 45 km long and has unpaved shoulders. For this study, 20 levelled sections on the northbound direction were selected, seven of which were horizontal curved sections while the remaining 13 were tangent sections. “Figure 1 shows the highway location based on satellite imaging”.

The observations were conducted under good weather with good visibility in zones without work activities and pavement defects that can affect traffic operations. The definition, location, and geometric properties of the studied sections are described in the succeeding sections.

3.3 Data Abstraction, Processing, and Analysis

Data collection used the video recording technique to save time and to allow a one-time documentation of a large number of events. Any incident occurring during the recording session that may result in abnormalities in the observed data can be abstracted [5]. A vantage location was chosen for each section for setting the video camera and then obtaining an accurate recording for proper calculation. Data were



Fig. 1 Satellite image highway location

collected in sessions of 8 h/day during both peak and off-peak traffic periods. Data collection were continued for four consecutive days lying at the mid of a week. The recorded data were reduced into sessions of 30 min. The 30-min sessions are considered statistically meaningful samples that ensure the absence of large fluctuations in the traffic flow. The traffic data set at each session was divided into 15-min intervals for the purpose of capacity estimation. Traffic volumes and traffic composition for the observed sections were abstracted during the peak periods from the video films using a computer program called EVENT. The program produces time accuracy values of the recorded data. The accuracy is about up to 0.01 s. It may be important here to describe the procedure of how this program works. The method is as follows: The program starts displaying a message that press ESC key to start and press ESC key again to finish. Following the pressing of the ESC key, the program starts counting time for successive events. The observer allocates a specified key from (F1 to F12) to be pressed for each vehicle type and its maneuver. Then a tag character is appeared for each pressed key to gather with the recorded time of the successive events. This method would simplify the process of vehicle classification and movement in a later stage. Data finally can be stored for further use. Trap length technique was adopted to calculate the average speed and FFS of the passenger car vehicles, that is the speed was determined by the time required to travel a known distance. The average speed was measured during the on-peak period while the FFS was measured during the off-peak period. In this study, the trap length was assigned as a distance of (60 m) between two solid lines posted on the pavement of the section prior to the video recording process. For the curved sections, the center of the curve lies in the mid-distance between the two solid lines. FFS was measured for all sections at the center of the curves for the curved sections. The time required to travel the trap length was then measured by repeating the video tape many times to record the entry and exit times of that length. Table 1 provides the traffic and speed data during the survey duration for each section, while Table 2 indicates the average traffic composition for the observed sections.

Table 1 Traffic data for the studied sections

S. no.	Alignment	Av. peak traffic flow (v/h)	Av. peak flow rate (pcph)	Av. speed (km/h)	FFS (km/h)
1	Straight	1470	1892	72	80
2	Straight	1011	1314	79	85
3	Straight	1180	1540	72	75
4	Curve	917	1195	67	70
5	Straight	1128	1445	80	88
6	Curve	946	1155	73	78
7	Curve	1064	1347	73	80
8	Straight	1372	1685	73	78
9	Straight	1360	1722	67	74
10	Straight	1147	1490	64	76
11	Curve	1045	1321	78	80
12	Straight	980	1246	73	78
13	Straight	966	1132	83	95
14	Curve	920	1125	81	98
15	Curve	1055	1320	81	94
16	Straight	815	1015	69	80
17	Straight	805	1000	80	90
18	Straight	967	1175	69	72
19	Curve	866	1080	80	82
20	Straight	980	1210	68	70

Table 2 Average traffic composition for the observed sections

Vehicle type	Pc	Pick-up	Mini-bus	Truck
% at traffic	66.6	10.5	17.45	5.45

4 PCU Estimation

Passenger Car Equivalent (PCE) or Passenger Car Unit (PCU) value is very important for any traffic studies. (PCE) is a universally adopted unit used to analysis capacity of any transportation system with heterogeneous traffic condition [7]. Heterogeneity of the traffic is the main problem in predicting the speed-flow relationship for estimating the capacity of a system. The impedance of traffic caused by the different static and dynamic characteristics of vehicles is not consistent with the concept that by considering the maximum sum of the vehicle numbers, highway capacity will be measured. To address this non-uniformity, all vehicles were converted into a common unit for a standard type of vehicle. The passenger car was considered as the common unit or the reference vehicle, for this reason, the factor is known as PCU. The PCU value for a vehicle is not constant, it varies with the traffic

Table 3 Observed vehicle dimension with their PCU values

Category	Av. dimension (m)		Av. speed (km/h)	PCU
	Length	Width		
Pc	4.40	1.65	82	1.00
Pick-up	5.15	1.75	80	1.27
Mini-bus	4.80	1.70	73	1.26
Truck	9.40	2.50	68	3.90

and roadway conditions. Accordingly, many procedures have been developed to estimate the PCU value.

In the present study, the Satish Chandra method was adopted to calculate PCU [3]. This method considers PCU as directly proportional to the ratio of clearing speed and inversely proportional to the space occupancy ratio, concerning the standard design vehicle, that is, a car. The adopted equation is:

$$PCU_i = \frac{V_c/V_i}{A_c/A_i} \quad (1)$$

where PCU_i = passenger car unit value of the i th type vehicle. V_c, V_i = speed of the car and the i th type vehicle (km/h). A_c, A_i = projected rectangular area of a car and the i th type vehicle (m^2).

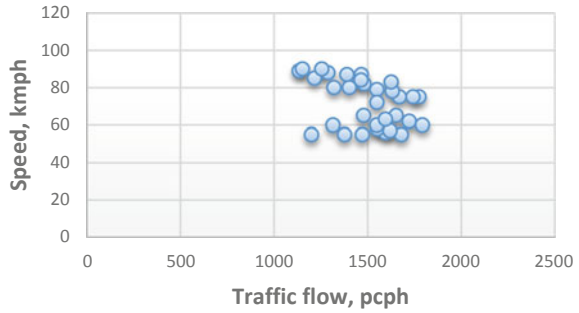
Table 3 explains the computed PCU value for each vehicle type and shows the static characteristics for different categories of vehicles at the studied sections in which PCU was calculated. Based on the estimated PCU for the traffic flow composition, the traffic flow rates for the studied sections represented by the unified PCU are shown in Table 3.

5 Capacity Estimation

5.1 Field Capacity Estimation

Capacity was estimated using the fundamental relationship (speed-flow diagram) based on the actual observed peak traffic flow rate data for each section. The maximum number of vehicles passing a screen line using the EVENT program were computed for the peak hours at each section. The peak hourly flow was computed as four times the peak 15 min during each peak hour and then averaged for all recorded hours to be considered as the capacity for that section. Speed for that peak 15 min was computed as well. “Figure 2 illustrates the speed-flow relationship for Section 3” as an example. Figure 2 demonstrates the scatter plots that may not indicate any specific trend owing to the limited duration of the field observations for all sections and the low range of collected data.

Fig. 2 Speed-flow relationship



The following procedures are subsequently conducted to estimate the capacity.

5.2 The Enveloping Curve Technique

This method is based on the basic concept that capacity is always larger than the actual flow observed on-site and, therefore, speed flow curve must envelop all the data points [8]. “Figure 3 shows the speed-flow diagram for Section 3”, which is drawn using the enveloping curve technique. In actual conditions, the capacity of a facility is always larger than any observed traffic flow value. The diagram is drawn as a tangent with the highest traffic flow value points and starts from the origin. Therefore, the diagram encompasses all points. In the same manner, the speed-volume relationships are obtained for all sections of the rural multi-lane highway and used to estimate the capacity and FFS that are summarized in Table 4.

Fig. 3 Capacity estimation based on the enveloping curve technique

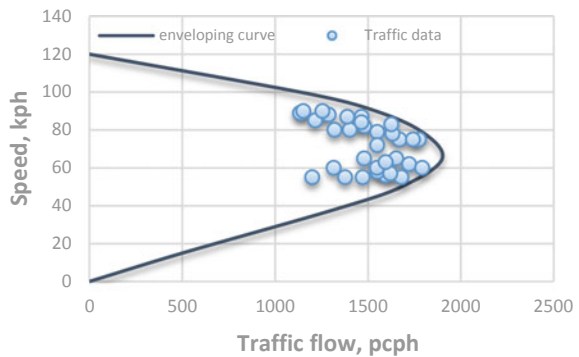


Table 4 Estimated capacity with different techniques

Method	Enveloping curve	Intersecting best fits	US HCM
S. no.	Capacity (pcph)	Capacity (pcph)	Capacity (pcph)
1	2250	2540	1950
2	1503	1728	1388
3	1860	2083	1550
4	1334	1465	1235
5	1650	1922	1544
6	1460	1675	1236
7	1545	1745	1488
8	2050	2295	1925
9	1935	2261	1812
10	1706	1960	1577
11	1570	1720	1406
12	1488	1610	1312
13	1444	1602	1288
14	1416	1600	1267
15	1605	1830	1478
16	1178	1390	1104
17	1199	1260	1120
18	1500	1620	1367
19	1278	1406	1200
20	1395	1574	1345

5.3 Intersecting Best-Fit Technique

This method is based on the basic concept that the traffic flow data can be analyzed by dividing the traffic volume into two segments, as shown in Fig. 4 [10]. The upper part represents the uncongested traffic flow and queue discharge states, while the lower part reflects the congested traffic related to the queuing state. The method

Fig. 4 Traffic flow segment

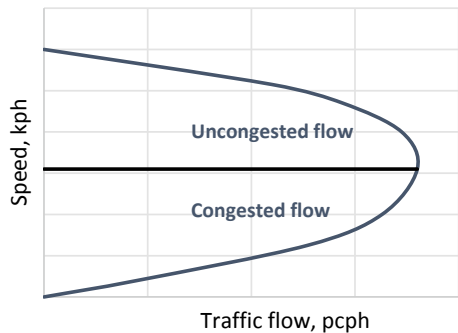
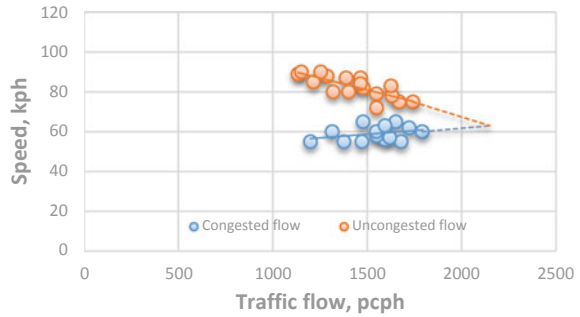


Fig. 5 Capacity estimation based on the intersecting best fit technique



proposes a separate analysis of the two parts, with the speed-flow relationship likewise determined separately.

Different models are available for representing speed-flow relationships. In the present study, linear models were adopted for both parts owing to their simplicity. Highway capacity was considered as the intersecting point of best speed-flow models developed for the upper and lower parts. Figure 5 indicates the best models for both parts and their intersecting point which represents the estimated section capacity. The estimated capacity for all sections according to this technique is also listed in Table 4.

5.4 US HCM, Capacity Estimation Technique

The US HCM 2010 defines vehicle capacity as “the maximum number of vehicles that can pass a given point during a specified period under the prevailing roadway, traffic, and control conditions” [9]. However, the HCM states that “these conditions should be reasonably uniform for any section of the analyzed facility”. Therefore, the capacity of the facility will be affected by any changes in the prevailing field conditions. The stated capacity for a given facility is a flow rate that can be achieved repeatedly for the peak periods of sufficient demand.

Hourly volume counts should be adjusted to reach the passenger car equivalent (PCE) flow rate. This is necessary for determining the capacity of the facility. These adjustments are the peak hour factor (PHF) and heavy vehicle adjustment factor (FHV).

Peak hourly flow was computed by dividing the hourly volume by the calculated PHF. The result was then divided by FHV and then resulted in capacity estimates.

PHF’s field data was used to represent the local conditions. “Equation (2), explains PHF computation”. However their values are within the range (0.75–0.95) as recommends by US HCM 2010 for multilane highways [9].

$$PHF = \text{Peak Hour Volume} / 4 * \text{Peak 15 – min Volume} \tag{2}$$

The US HCM method considers the heavy vehicle as any vehicle with more than four wheels. Therefore, trucks, buses and recreational vehicles should be adjusted stipulates values of the adjustment factor for the presence of trucks depending on the segment topography. “Equation (3) represents the FHV adjustment calculation”.

$$FHV = \frac{1}{1 + PT(ET - 1)} \tag{3}$$

where ET = passenger-car equivalents for trucks (equals 1.5 for terrain segments, Exhibit 14-12, HCM 2010). PT = proportion of trucks.

PT for each section is utilized in Eq. (3) to compute the FHV for each section. The peak hourly flow (the hourly flow divided by the PHF) for each section is then divided by the FHV value to estimate the section capacity. The predicted capacity for all selected sections is presented in Table 4.

6 Results and Discussion

Three methods for estimating capacity under mixed traffic conditions were presented and tested on 20 sections of a multi-lane rural highway. The primary contribution of this paper, therefore, is to evaluate the applicability of the US HCM methodology in estimating highway capacity at developing countries such as Iraq. Field data were collected and speed-flow relationships were predicted to achieve the main research objectives. Their results are shown in Table 4 and they are graphically represented by Figs. 6 and 7 for curved and straight sections, respectively.

The comparison between the capacity results shown in Table 4 and presented in Figs. 6 and 7 indicates the followings:

- Estimated capacities differed across the three methods for all observed sections.

Fig. 6 Estimated capacity for the observed curved sections

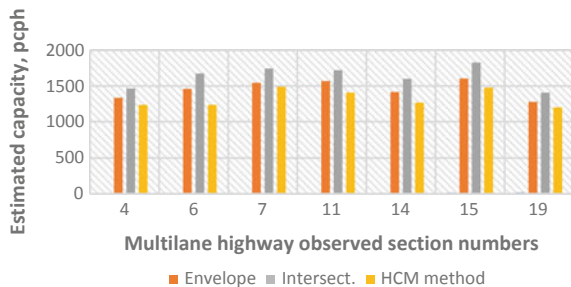
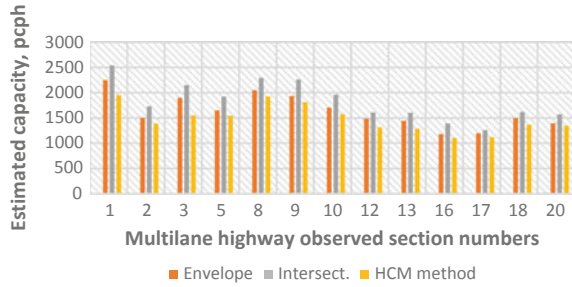


Fig. 7 Estimated capacity for the observed straight section



- The US HCM methodology had the tendency to underestimate capacity and resulted in lower estimates than those obtained by the enveloping curve and the intersection regression techniques.

The above results can be attributed to the following factors:

- (1) The US HCM methodology implemented to estimate the capacity related to traffic composition. In this method, the hourly volume must undergo two adjustments to arrive at the equivalent passenger car flow rate. One of the adjustments is FHV. The US HCM applies an adjustment for heavy vehicles in the traffic stream to the trucks, buses, and recreationally vehicles (RVs) [9]. Table 3, indicates that neither buses nor RVs were observed in the studied sections. Therefore, the proportion for the heavy vehicles applied by Eq. (3) in US HCM method will be represented by the percentage of trucks, which adopts fixed ET value, that is 1.5 for terrain section level (exhibit 14–12). While the average observed ET value as listed in Table 3 is 3.9. Besides, the US HCM methodology does not consider adjustment factors for other vehicle types aside from trucks (in this study, pick-ups and mini-buses), which having an approximately equal PCU values of 1.27 as listed in Table 3.
- (2) Great divergence in driver behavior and the difference in vehicle characteristics. Driver decisions play a central role in the position and the speed of each vehicle that also influenced by external factors relating to the roadway geometry and traffic interaction. All these considerations lead to the difference in capacity estimation for the same prevailing conditions.
- (3) Level of roadside activities, especially the lateral clearances for both sides of the carriageway which could not be observed in this research because of the existence of earth median and shoulders. By contrast, the US HCM methodology considers the lateral clearance adjustment.

7 Conclusions and Recommendations

7.1 Conclusions

The presented research estimates the capacity of a multi-lane rural highway connecting two big cities in Al-Anbar governorate, Iraq. Twenty sections of the highway curved and tangents were selected to test the three methods for estimating capacity. The primary contribution of this research is testing the applicability of the US HCM methodology for estimating capacity in developing countries such as Iraq. Results showed that the US HCM methodology tends to underestimate capacity, unlike the other two methods. The underestimation is mainly attributed to the traffic composition adjustment factors, which was not applied to all vehicle types in the traffic stream that has different equivalency unit and which also partly affected by the followings:

1. Differences in driver behavior and vehicle characteristics.
2. Roadside activities, especially the lateral clearances.

7.2 Recommendations

To apply the US HCM methodology in Iraq for estimating the capacity of multi-lane rural highways, it is recommended to;

- (a) Refining the equation used by US HCM for the calculation of FHV, covering all vehicle types with PCU not equal to (1) to reduce the distinction between the estimated capacity value compared by other methods which depends on observed equivalent values.
- (b) In the developing countries, it is preferable to apply the observed PCU values to estimate a highway capacity instead of depending on the default values recommended by the US HCM.

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