Performance Assessment of the 2010 HCM and Its Calibrated Model in Estimation of Weaving and Non-Weaving Speed

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Received: 11. 06. 2017   *Accepted: 10. 03. 2018*

Abstract

Calibration is a conventional method which is utilized to adapt traffic models based on local situations in order to achieve best results. One of the issues regarding the efficiency of this method is whether traffic models should be calibrated only in one or two major cities of a country or calibrated based upon a comprehensive selection of cities. Therefore, this study, which has used the actual speeds, attempts to evaluate the performance of the weaving model that was proposed in the fifth edition of Highway Capacity Manual (HCM 2010) and its calibrated model, which was calibrated in Tehran highways. In this regard, adequate field-data were collected on a ramp-weaving segment in Isfahan. The procedure was of 9 fifteen-minute time steps of recording at different hours of a working day. The analysis results indicated poor and app.ropriate performances by the HCM 2010 model in estimating speeds of non-weaving and weaving vehicles, respectively, for which the RMSE (Root Mean Square Error) values were obtained as 16.34 km/h and 2.11 km/h, respectively. Moreover, not only was the calibrated model unable to improve the performance of the original model, but also it affected the original model negatively and caused a larger difference in the model output compared to the actual values. Hence, calibrated models based on metropolises such as Tehran may not necessarily be app.lied to other cities and may lead to unrealistic results. This reflect the fact that traffic patterns in two cities of one country may be highly dissimilar.

Keywords: Weaving speed; non-weaving speed; weaving segment; calibration; Highway capacity manual.

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1. Introduction

The U.S. Highway Capacity Manual is the main reference for traffic operational analysis in the United States and many other countries around the world. The HCM is comprised of concepts and methods to guide analysts [Findley et al. 2016]. Weaving is considered as one of the most important elements in the freeway capacity and the Level of Service (LOS) analysis in the HCM [Liu et al. 2012]. A typical weaving segment forms where two one-way traffic streams intersect by merging and diverging maneuvers [AASHTO, 2011]; these segments are widespread design components on freeway facilities near ramps and freeway-to-freeway connectors [Skabardonis and Mauch, 2015]. Weaving segments on urban freeways are some critical elements in the traffic system and they should be evaluated closely [Pande and Wolshon, 2016].

The geometry and configuration of weaving segments are in the way that leads to conflict between entering and exiting drivers along these segments. This increases the risk of crashes [AASHTO, 2010] and reduces the discharging flow. Therefore, lane-changing maneuvers in weaving segments create bottlenecks in freeways and cause flow breakdown under heavy traffic conditions [Moridpour, Sarvi and Rose, 2010].

It is realized that many features and characteristics of the present procedures related to weaving segments, to some extent, are based on individual judgement and discernment because, in most cases, collecting comprehensive and efficient data on weaving segment operations has been difficult and costly, and studies show that the functioning of a traffic system is affected by various aspects of human behavior. Therefore, human behavior is considered as a crucial factor in traffic safety [Tavakoli Kashani, Sokouni Ravasani and Ayazi, 2016]. Moreover, it is a self-evident truth that no two traffic streams will behave in exactly the same way, even in similar circumstances. Because driver behavior varies with local characteristics and driving habits [Roess, Prassas and McShane, 2011; NCHRP Report 600, 2012]. Thus, directly employing the manuals specifically developed based on the conditions of the U.S. may lead to unrealistic results [Sohrabi, Ovaici and Ghanbarikarekani, 2016].

As one of the most common app.roaches to this problem, traffic models can be calibrated based on the respective conditions and characteristics of every region. Calibration is a process by which the analyst adapts model parameters so that the model estimates best reproduce field-measured local conditions [TRB, 2010]. Thereby, the present study attempts to employ Isfahan-field-data in order to assess the performance of the HCM 2010 model in estimation of weaving and non-weaving speed alongside its calibrated model which was calibrated by Ghavidel Abraghan and Afandizadeh Zargari (2016) in Tehran highways.

2. Background

The HCM 2010 is the central core of this study, thus this section is assigned to provide a general overview on this manual.

The fifth edition of the HCM provided a methodology for the analysis of weaving segment developed by Roess et al. in an extensive study. This study started in 2006 by the NCHRP's sponsorship. The bases of this methodology are the effective geometry characteristics (length, width, and configuration), free-flow speed (FFS), and the demand flow rates [Roess and Prassas, 2014; TRB, 2010].

In comparison with the HCM 2000, this methodology has significantly changed: a) the two-fold and tri-classification (based on operation and configuration) weaving segments elimination, b) the redefinition of the algorithm for determination of weaving segment length, c) the modification of speed algorithm estimation, d) an introduction of a new model for capacity prediction, and e) the provision of a mathematical method to determine the maximum weaving length (L_{MAX}) that is based on the volume ratio (VR) and configuration.

This study has intended to provide a model for the lane-changing rates estimation, so it has used the data that could observe the lane changes made by flows moving in a weaving segment. The data were collected from seven cities in six states in the United States. The types of configurations included; the lengths varied from 540 ft to 2,820 ft, and the widths varied from 3 to 6 lanes [Roess and Prassas, 2014].

In the HCM 2000, a model was presented to analyze the weaving segment which took an important role from the prior studies and their developments. Actually, its assembly was based on:

a) Speed prediction algorithm in Reilly's model;
b) Configuration and operation concepts in the NCHRP 3-15 model (1975) and its update in the late 70s;
c) Revised model of the 1985 HCM (1997);
d) Both Leisch and Fazio studies in the late 80s [TRB, 2000].

This model has tried to eliminate the shortcomings of the previous methods. These modifications include:

- Recalibration of the constants to reflect further changes in other freeway analyses related to chapters of the Manual.
- Determination of the LOS based on the density in the weaving section and removing the assignment of separate levels of services to weaving and non-weaving vehicles [Skabardonis and Kim, 2010].
- A multi-page table for determination of the weaving segment capacity [Roess and Ulerio, 2009].

Despite these beneficial changes, the HCM 2000 has limitations. It retains the tri-classification of weaving configurations, and is still based on a relatively small data base which consists of 10 weaving segments, using hourly data.

Weaving became a significant challenge on urban freeways by mid 1960s. Therefore, weaving proved as a good start point for the development of a third-edition of the HCM. Concurrent with this procedure, new app.roaches to weaving segment analysis began to be developed [Roess and Prassas, 2014].

Thus, in 1984, the Highway Capacity and Quality of Service Committee had different options to write the weaving chapter of the 1985 HCM:

a) A procedure developed by PINY in 1979 which was a revision to NCHRP 3-15;
b) A procedure developed by Leisch in 1984;
c) Reilly procedure in 1984.

Eventually, the committee opted to go with the form of the algorithm developed by Reilly with some modifications and recalibrations to reflect the impact of configuration types (included in the PINY and Leisch methodologies), and the issue of types of operation (included in the PINY methodology) by Roess [TRI and Kittelson, 2008; Skabardonis and Kim, 2010].

This led to six equations for the prediction of weaving speed, and six for non-weaving speed. These equations were used for speed estimation of tri-configuration types (A, B and C) and constrained vs. unconstrained operations [TRB, 1985]. The initial calibration tried to adopt regression app.roach but the results were not satisfactory. Because the data base was statistically inadequate to supp.ort such development [Zhang, 2005; TRI and Kittelson, 2008], to achieve better result and an acceptable level of sensitivity, the model was modified by a trial-and-error app.roach [TRI and Kittelson, 2008].

Since the publication of the HCM in 1985, multitude of concerns were expressed by researchers and professionals regarding this model [Skabardonis and Kim, 2010]. Thereby, this model was revised twice.

In fact, the 1965 HCM provided three different models for the analysis of weaving segments. A model (which was developed by Leisch and Normann) app.lies to all weaving configurations on all types of freeways [Roess and Prassas, 2014]. Two other models are presented in Chapter 8 to analyze the ramp configuration: one to analyze the configuration under free-flow conditions (LOS A to C) which was developed by Hess, and the other to analyze the ramp configuration under heavy traffic conditions (The Level D Method) which was developed by Moskowits and Newman [TRI and Kittelson, 2008].

Although the Leisch/Normann method followed the conceptual framework of the HCM 1950 app.roach, it shows some differences, such as the introduction of LOS criterion to the methodology. Also, it has used much boarder range of lengths and weaving volumes compared to the HCM 1950. Therefore, in this model, the maximum length of weaving segment was extended from 3600 ft to 8000 ft and a total of weaving volume was increased from 3600 veh/h to 4000 veh/h [Roess and Prassas, 2014]. Another unique aspect of this model was the clear definition of “out of the realm of weaving’’ [TRI and Kittelson, 2008].

HCM 1950 presented the first methodology for design and analysis of weaving segments [Yi, Lu and Ma, 2011]. This simple and general method is basically a rational app.roach based upon several judgmental principles, aided by the limited available data on weaving that came from multilane highways and few existing freeways [Roess and Prassas, 2014]. The result was a graphical model which predicted both the capacity and the operating speeds of weaving segments [Zhang, 2005].

To use this model in designs, doubling the traffic volume triples the length of the required weaving segment and doubles the number of lanes required for the weaving vehicles [Yi, Lu and Ma, 2011].

3. Methodology

3.1 HCM 2010

The 2010 HCM methodology is based upon The LOS of weaving segments. In this manual, the weaving analysis procedure begins with determining the operation type in the segment based on the length, after which the values of capacity, lane-changing rates, average speed of vehicles, and ultimately LOS are determined. This procedure is briefly presented in the followings.

Considering the ambiguity in the logic and the base underlying the available definition of weaving length, Roess et al. re-examined it. They presented the base length (L_B) and the short (L_S) as the new definitions. In all cases, the 2010 HCM used L_S in its equations. Even, these lengths were based for segment classification. In the way that the method computed L_{MAX} in the first step (Equation 1) and if $L_S < L_{MAX}$, the area would be a weaving segment, otherwise the segment is treated as separate merge and diverge segments.

$$L_{MAX} = [5{,}728(1+VR)^{1.6}]-[1{,}566N_{WL}] \quad (1)$$

Where N_{WL} is the number of lanes from which a weaving maneuver may be made with one or no lane changes.

The capacity estimation model of the HCM 2010 deliberates two situations; each one of which determines the occurrence of the capacity. The situations are as follows:

- Breakdown of a weaving segment when the average density of all vehicles in the segment reaches 43 pc/mi/hr.
- Breakdown of a weaving segment when the total weaving demand flow rate reaches vW(MAX) (2400 pc/h or 3500 pc/h, according to geometrical characteristics of the segment).

In this model when the capacity is controlled by the weaving flow rate, the operation is highly likely to be what is called "constrained" in the 1985 HCM and the 2000 HCM methodologies. When it is controlled by density, the operation will likely be what is then called "unconstrained" [Roess and Prassas, 2014].

If demand is less than the estimated capacity ($v/c \leq 1$), the 2010 HCM uses a model to determine the lane-changing rates of the weaving and non-weaving vehicles separately. The sum of these two rates is the total lane-changing rate (LC_{ALL}) of all vehicles in the weaving segment.

In the proposed method of the 2010 HCM, the LOS determination is based on density. In the way that after the determination of an average speed of each flow vehicle (Equations 2 to 4) the average speed of all vehicles is computed (Equation 5). Then, the density is computed from the average speed (Equation 6). Ultimately, a table is provided, which shows that the LOS is determined based on the density and the type of facility. It is notable that in this table the LOS F occurs when demand exceeds capacity.

$$S_W = 15+\left[\frac{FFS-15}{1+W}\right] \quad (2)$$

$$W = 0.226\left(\frac{LC_{ALL}}{L_S}\right)^{0.789} \quad (3)$$

$$S_{NW} = FFS+(0.0072LC_{MIN})-\left(0.0048\frac{v}{N}\right) \quad (4)$$

$$S = \frac{v}{\left(\frac{v_W}{S_W}\right)+\left(\frac{v_{NW}}{S_{NW}}\right)} \quad (5)$$

$$D = \frac{\left(\frac{v}{N}\right)}{S} \quad (6)$$

where

S_W = average speed of weaving vehicles within the weaving segment (mi/h),

FFS = free-flow speed (mi/h),

W = weaving intensity factor,

S_{NW} = average speed of non-weaving vehicles within the weaving segment (mi/h),
LC_{MIN} = minimum rate at which weaving vehicles must change lane to complete all weaving maneuvers successfully (lc/h),
v = total demand (pc/h),
N = number of lanes within the weaving segment,
S = space mean speed of all vehicles in the weaving segment (mi/h),
v_W = weaving flow rate in the weaving segment (pc/h),
v_{NW} = non-weaving flow rate in the weaving segment (pc/h), and
D = average density of all vehicles within weaving segments (pc/mi/ln).
FFS is the mean speed of passenger cars measured during periods of low to moderate flow (up to 1,000 pc/h/ln). For a specific freeway segment, average speeds are almost constant in this range of flow rates. In this method the speed study should measure the speeds of all passenger cars or use a systematic sample (e.g., every tenth car in each lane). A sample of at least 100 passenger-car speeds should be obtained [TRB, 2010].
It is also worth noting that the 2016 HCM model for determination of weaving and non-weaving speed is very similar to the HCM 2010 and only a “unitless factor” (SAF: the speed adjustment factor, including weather and work zone effects) is added to Equations 2 and 4 [TRB, 2016].

3.2 Calibrated Model

In order to calibrate the HCM 2010 model, Ghavidel Abraghan and Afandizadeh Zargari (2016) exploited data of 9 weaving segments collected from the urban highways in Tehran. Collected within 5-minute time steps, this database includes different weaving segment configurations (A, B and C) with 3 to 5 lanes. The measured FFS values in this study ranged from 74 to 98 km/h [Ghavidel Abraghan and Afandizadeh Zargari, 2016].
To estimate S_W and S_{NW}, two equations are presented as the final outputs of this study (Equation (7) and Table (1)).

$$S_i = 15 + \left[\frac{FFS-15}{1+W_i}\right] \tag{7}$$

where :
S_i = average speed of weaving (i = w) or non-weaving (i = nw) vehicles (km/h),
W_i = weaving intensity factor for weaving (i = w) and non-weaving (i = nw) flows, Table (1).

Table 1. Constants for computation of weaving intensity factor.

General Form $W = a\left(\frac{LC_{ALL}}{L_B}\right)^b$			
Constants for S_W		Constants For S_{NW}	
a	**b**	**a**	**b**
0.279	0.715	0.054	1.109

In addition to calibrating the constants, the authors made modifications to the equations proposed by the 2010 HCM as follows:

- Instead of using the proposed equation by the HCM 2010 to estimate S_{NW} (Equation 4), the calibrated model employed Reilly’s algorithm as it was used in the HCM 1985 and 2000.
- Incorporating L_B in estimation of weaving intensity factor unlike the case for HCM 2010.
- Reducing the maximum speed of vehicles from 24 km/h to 15 km/h.

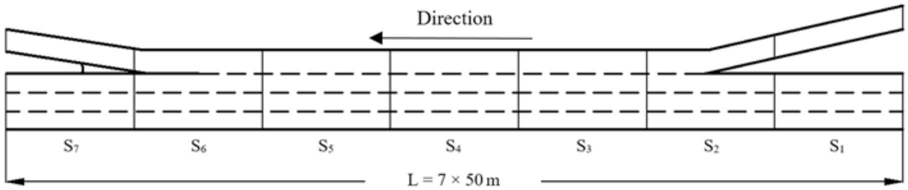


Figure 1. Segment-sectioning of the weaving segment under study

4. Data Collection

Field-data were collected from a ramp-weaving segment of the depressed part of the urban Shahid Aghababaie Freeway in Isfahan, using a closed circuit observation technique. The upstream basic freeway segment of this segment has three 3.6-m lanes and 1.5-m right-shoulders. The regulatory signs of the freeway indicate a 70-km/h Speed Limit, a No-Trucks, and a No-Motorcycles signs. The weaving segments under study were divided into seven 50-m sections to record the lane-changing rate and the speed of all vehicles (Figure 1). This sectioning has tried to consider the significant length of the basic freeway segments in upstream and downstream areas.

The data were collected by digital video recording and the video camera was mounted on the top of a high building adjacent to the freeway. The procedure included 9 fifteen-minute time steps of recording at different hours, and tried to extract the maximum possible data from recorded videos. These data included the lane-changing rate, the demand flow rate of the component flows per vehicle types, the space mean speed by using a systematic app.roach (every tenth vehicle in each lane), and recording the density of segment every one minute in each nine-time steps.

Given L_S=197.7 m and L_B=216.7 m, the process of data extraction was performed from the beginning of the second section to the end of sixth section, such that the movement paths for all vehicles were recorded from the moment of entrance to S_1 and exit from S_6.

The collected data includes recording the flow rate of 10806 vehicles, 7447 lane changes, the space mean speed of 1196 vehicles, and recording the density of the segment under study at 144 moments.

5. Results

After measuring each of the component flows, vehicles were divided, according to the provided definition by the 2010 HCM, into two categories, namely passenger cars and heavy vehicles. The results indicate that 95.95 percent of the observed vehicles were of passenger car type and the remaining were heavy vehicles. Ultimately, the rate of each flow was determined based on passenger-car equivalent, and then S_W and S_{NW} were determined for all time steps using the equations proposed by the two studied models.

A lower-than-1000 pc/h/ln flow rate is only observed under the conditions of a time step among a total of nine. The obtained sample from the observations in this time step includes 136 vehicles, 100 of which are associated with passenger cars in the freeway-to-freeway (FF) flow. The cumulative speed distribution curve for this flow is illustrated in Figure 2. A total of 16 lane change was recorded for this 100-item sample. In other words, 86 percent of the passenger cars in the FF flow did not change their lane (optional lane changes). Hence, the FF flow in the ninth time step is highly similar to the through movement of the basic freeway segments. The average speed of the passenger cars was 86.5 km/h in this time step.

Since the population under study for computation of FFS is similar to the through movement in the basic freeway segments, and considering the obtained speed is within the specified range by The Manual on Uniform Traffic Control Devices (MUTCD) [2009] (only 1 km/h lower than the upp.er limit), it can be inferred that use of this speed in the study does not cause considerable deviations in the analysis process to produce under-predicted values. Thereby, this study utilized the determined FFS in the weaving segment (based on the FF flow) as a roughly acceptable value in the analysis procedure.

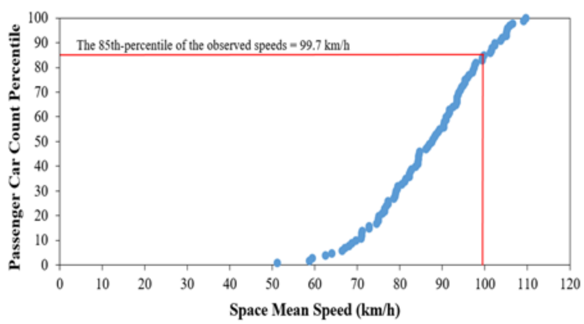


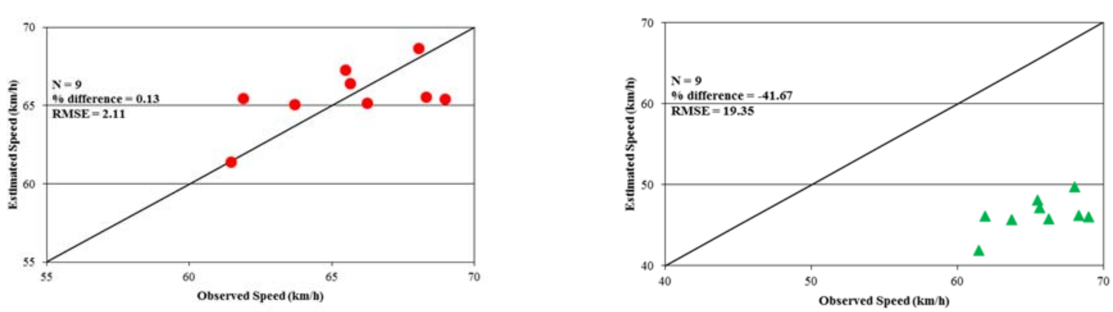
Figure 2. Cumulative speed distribution curve of freeway-to-freeway flow

It should be noted that the measured FFS value should match the standard FFS curves for which no interpolations are recommended to be conducted. Hence, the FFS value was rounded to the closest curve according to the known ranges (55 mi/h).

As the final step, the estimated values were compared to those of observations (Figures (3) and (4)), for the process of which RMSE (Root Mean Square Error) and the average percentage of the difference between estimated and actual values were employed.

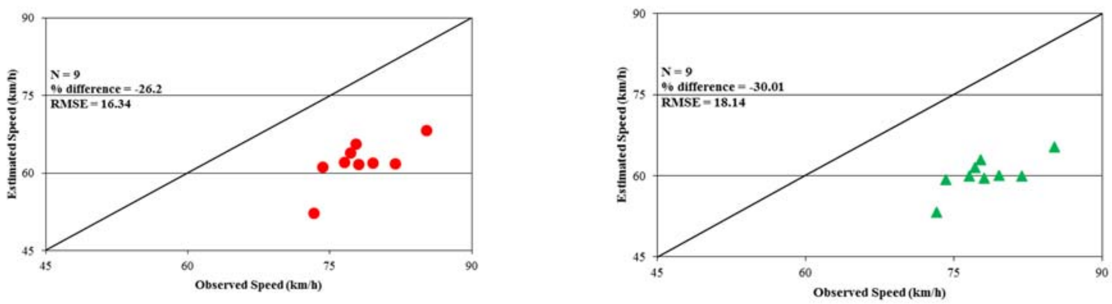
6. Conclusion

The present study investigated the accuracy of the HCM 2010 model as well as the calibrated model in estimating S_W and S_{NW} using field-data. According to the analysis results, both models yielded under-predicted results for the aforementioned speeds. However, despite its under-predicted results, the 2010 HCM managed to achieve relatively accurate results for S_W, and its major weakness was in estimation of S_{NW}. Despite its considerably acceptable results under the conditions of the Tehran highways, the calibrated model demonstrated a poor performance in estimation of both speeds by achieving RMSE values of 19.35 km/h and 18.41 km/h for S_W and S_{NW}, respectively.



(a) HCM 2010 **(b) Calibrated model**

Figure 3. Comparison of estimated S_W with actual S_W



(a) HCM 2010 **(b) Calibrated model**

Figure 4. Comparison of estimated S_{NW} with actual S_{NW}

The difference between the estimated values by the HCM 2010 model and the actual values can be attributed to the differences between the two traffic patterns. In other words, the specifications of the freeways, vehicles, as well as the circumstances of traffic pattern in the U.S. and Iran, i.e. the studied region, have caused a difference in the driving behavior of both traffic patterns. Such a difference can also be observed in the driving behavior in the cities of Isfahan and Tehran in Iran.

From a general perspective, the results of the present study indicate a significant difference between the observed values and those estimated by the HCM 2010 model. This difference still remained in the results of the model calibrated based on Tehran highways, and even the calibration caused a further difference for the considered segment. Thus, developing a traffic methodology based on the cultural-social-economical characteristics of Iran is an inevitable issue, which should be done widely using successful experiences of other countries to present a comprehensive methodology for the analysis of traffic components such as weaving segments.

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