

Analysis and Assessment of Freeway Weaving Segments in Mosul City, Iraq

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Abstract

The purpose of this work is to compare and assess the accuracy and effectiveness of weaving segment analysis methodologies offered in the last three current editions of the Highway Capacity Manual (HCM). The study area consists of three major weaving segments on the main urban freeway in Mosul City. Traffic data for this work were collected using video recordings. Two stages were created, with six weekdays of 12 hours of daily traffic operations videotaped at each location to cover a wide range of traffic flow characteristics. The GoodVision Software was used to assess if the HCM methodology can effectively predict the behavior of weaving sections. The results, comparing estimated values from three methodologies with observed values for weaving and non-weaving speed and density under peak-hour normal daily traffic conditions, show the relative validity of HCM 2000. The work revealed that traffic congestion and problems on the freeway section downstream of the weaving segment had a noticeable influence on non-weaving speed and density, as well as the level of service and weaving performance. As a result, the work recommended future research to incorporate this influence into the HCM methodology.

Keywords: Freeway Weaving Analysis, Highway Capacity Manual, Lane-Changing Rate, Level of Service, Mosul, Traffic Density, Traffic Speed

1. Introduction

A freeway is a facility with continuous flow; interactions between vehicles inherent to the traffic stream disrupt the flow [1]. When two streams move across a significant section of a freeway in the same direction without the use of traffic control devices, it is referred to as weaving [2], [3]. As a result, traffic turbulence in a weaving area is greater than on basic freeway sections [4]. Congestion may exist when traffic demands exceed capacity at these sites, affecting the functioning of the entire freeway portion. Congestion may develop when traffic demands at any site exceed available capacity, which impacts how well the overall freeway segment functions [5].

Drivers must access lanes corresponding to their planned exit point in weaving zones, which necessitates significant lane-changing maneuvers. Because lane change is a crucial component of weaving areas, one of the important geometric aspects to consider is configuration (number of entrance and exit lanes and their relative placement). Other considerations include speed, level of service, volume distribution, and so on. Turbulence caused by vehicle "weaving" frequently causes operational issues and requires specific design criteria [6].

The Highway Capacity Manual (HCM), which is a catalog of theories and procedures to aid analysts, is the primary reference

for traffic operational analysis in this work [7]. The HCM approach summarizes the analysis and estimation of study-section capacity and level of service using the HCM methods and suggests ways to make improvements [8]. Weaving is regarded as an essential component of the HCM's freeway capacity and Level of Service (LOS) study [9]. Traditional weaving methodologies in the HCM model use traffic conditions and freeway geometry as inputs for weaving-section analysis and estimate speeds as an output. This calculated speed is also utilized to determine the weaving location's Level of Service [10].

In the network of Mosul City highways, freeway weaving segments represent a key operational and design challenge, requiring special criteria for traffic problem resolution, performance analysis, and design. As a result, the purpose of this work is first to collect and then analyze (for the existing conditions and projections for 2030) the necessary traffic data. Its objective is to evaluate the traffic operation characteristics of selected freeway weaving problem areas in Mosul City using the HCM 2016 methods and the latest two editions of the HCM. Secondly, the work intends to compare the analysis results of the sixth edition with those of the other two latest manual publications to choose the best model for analyzing and

assessing the different freeway segments in Mosul City using statistical techniques.

1.1. Problem Statement and Purposes

The number of motorists traveling on and through Mosul City's major freeway has grown since 2018. Additionally, while there haven't been many noticeable modifications to the roadway system and network that might lower service levels and lead to difficulties with unacceptably hazardous traffic situations, the convenience offered by personal automobiles has increased. This rise in car ownership has occurred due to the city community's increased monthly income. Personal vehicles offer door-to-door service, the highest degree of comfort and convenience, significant flexibility, and the ability to adjust travel plans.

The purpose of this work is to assess the current and future traffic flow elements and conditions on selected freeway weaving segments. Its objective is to observe, analyze, and propose more acceptable solutions with recommendations based on these issues to enhance traffic safety and mobility efficiency in these areas. The work employs three versions of the Highway Capacity Manual methodology (2000 [11], 2010 [12], and 2016 [13]) to examine and discuss the data collection findings and determine the characteristics of current traffic conditions. To achieve this objective effectively, statistical techniques have been applied to compare and evaluate the accuracy and effectiveness of the procedures for weaving segment analysis proposed in the three most recent versions of the HCM. This case necessitates a brief review of each HCM process edition.

1.2. HCM Literature Review

The HCM 1950 was the first to propose a system for weaving design and analysis [9]. The basis for it was field data obtained in 1947 from six weaving locations in Arlington, Virginia, and Washington, D.C. Since then, a variety of methods for assessing weaving sections have been developed. Much of this work is based on data gathered during the late 1960s and early 1970s. This section provides a historical overview of weaving investigations, modeling and simulation techniques, and safety studies [14].

Additional works significantly expanded the weaving section chapter in the HCM's next iteration (1965) [9]. The HCM 1950 chart, used to determine the operational parameters of weaving sections, traffic loads, and operating speeds, was presented graphically. To assess a weaving segment, the chart was combined with a relevant formula. A table was created to determine the number of lanes necessary for a weaving segment under high flow conditions, showing the relationship between maximum lane service volumes and flow quality. The HCM 1965 observed that the length and width of the weaving section have a significant impact on weaving performance. According to the HCM 1965, a weaving segment becomes severely congested when the number of weaving vehicles reaches the capacity of two lanes of traffic, regardless of the segment's length or the number of lanes. Researchers found that methodologies from the HCM 1965 were inaccurate in predicting the level of service (LOS), and these inaccuracies

were linked to ambiguities in service standard definitions [9]. The authors investigated the impacts of various designs and discovered that lane arrangement sometimes resulted in weaving vehicles using only a specific area of the highway. They demonstrated that merely having the exact total number of lanes was insufficient to provide the projected operational characteristics outlined by the HCM 1965 [15].

In 1975, the National Cooperative Highway Research Program (NCHRP) released Report 159, which introduced a new methodology for weaving section analysis. This methodology considered additional factors such as geometric features, traffic composition, mainline vehicle volumes, and weaving vehicle volumes. Leisch provided the Highway Capacity and Quality of Service Committee with a nomograph-based process to evaluate all solutions developed using information from previous studies. The HCM 1985 presentation [4] included comprehensive explanations and definitions of the configuration types for weaving sections, detailing the number of lane changes required to complete each weaving maneuver [9].

According to the JHK & Associates investigation, neither of the two methods outlined in Circular 212 accurately defined weaving area activities [16]. The study proposed a more streamlined approach with two equations: one to predict the average speed of weaving vehicles and another to predict the average speed of non-weaving vehicles. Formulas were developed to determine whether the weaving section would experience constrained or unconstrained operations based on the number of available lanes. Cassidy et al. [17] demonstrated that the functioning of motorway weaving areas can be significantly affected by conditions within individual lanes, as congestion in these areas often arises from a breakdown in just one lane. Cassidy and May [18] found that the capacity of a weaving section is 2,200 passenger cars per hour (pcph) at any point in the weaving area, with lane-changing capacity ranging from 1,100 to 1,200 pcph per lane over a 250-foot section within the weaving area. Because previous methods were found to underestimate the average operating speeds of weaving and non-weaving vehicles in several areas where data were available for verification, Roess, McShane, and Prassas (1998) developed improvements to the HCM 1985 techniques, as reviewed by Glad [19].

Since the HCM's release in 1985, various transportation scholars and professionals have expressed reservations about it [20]. As a result, this model has been revised twice. In the fourth edition of the HCM, a model for analyzing weaving sections was introduced, which drew heavily on previous research and advances. Its construction was based on: (a) the speed prediction algorithm in Reilly's model; (b) configuration and operating principles in the NCHRP 3-15 model (1975) and its late 1970s update; (c) the updated model of the HCM 1985 (1997); and (d) both Leisch and Fazio's investigations in the late 1980s [11]. This methodology attempted to address the drawbacks of prior techniques. These changes include: (a) a new calibration of the constants reflecting additional changes in other freeway analyses in the Manual; and (b) determining the LOS in the weaving area based on density and removing the practice of assigning separate levels of service to weaving and

non-weaving vehicles [20]. Another significant change in the HCM 2000 is the inclusion of a multi-page table for determining weaving segment capacity [11].

Following the HCM 2000, the NCHRP 3-75 [21] project was initiated to develop a redesigned technique to simplify model calibration and ensure compatibility with other highway segment types. The work was based on Fazio's speed estimation methodology. Fazio recalibrated Reilly's model by adding lane change factors to eliminate the need to determine the configuration type [22]. The NCHRP 3-75 methodology was incorporated into the HCM 2010. The HCM 2010 calculated the speed of weaving and non-weaving vehicles based on expected lane changes [12].

The most recent weave analysis approach, developed by Project NCHRP 3-75, is included in the HCM 6th Edition (HCM 2016) [13]. The work assessed different weave section layouts by predicting speeds, capacities, and levels of service using real-world data and analytical models. The model was implemented in the HCM 2010 and remains in use in the HCM 2016. The HCM 2016 includes methodologies for evaluating basic freeway segments, weaving areas, merge and diverging segments [23], freeway facilities [24], and freeway travel time reliability. Weaving segments are often critical components of freeway infrastructure because they can act as bottlenecks [22], [25].

The Mixed Flow Model (MFM) was developed to predict trip rates for cars and trucks independently under varied freeway operating conditions and was used in the HCM 2016. Yang [26] reports results from efforts to validate the MFM's predictions. The development of performance measurements for individual lanes on freeway segments was described in a paper by Sasahara et al. [27].

A key limitation of the HCM is the assumption that all lanes perform equally, which does not align with field conditions and can lead to inaccurate performance estimates. Sasahara et al. [28] aim to develop a series of models to estimate flow and speed by lane for various types of highway segments.

The HCM 2016 edition adds guidance for using the weaving analysis process for segments that provide access to or from controlled lanes adjacent to general-purpose lanes. It also explains how to apply the weaving analysis process to controlled lane weaving sections. This version emphasizes the use of CAFs and SAFs for calibration [13]. Xu [29] aims to demonstrate consistency with previous freeway segment assessments in HCM 2016 and provides a simplified approach for ramp weave sections.

Mohajeri and Akbarzadeh [30] assess and compare the accuracy and effectiveness of models presented in the four most recent editions of the HCM. According to the HCM 2016, if the segment length exceeds the maximum weaving length (L_{wmax}), it is classified as a merging and diverging segment; otherwise, it is considered a weaving segment. Kashani and Shirgir [31] focus on cases where L_{wmax} in merging/diverging segments equals the segment length or the total sum of acceleration and deceleration.

Among the most notable changes introduced by these updates are the adoption of a speed prediction model that accounts for the effects of both constrained and unconstrained flow, as well as section configuration, between 1965 and 1985; the introduction of Type A, B, and C weaves between 1985 and 2000; further changes to the identification of ramp and major weaves in 2010; and the inclusion of lane change rate calculations to forecast speed [32]. Van Beinum et al. [33] found that lane changes near freeway ramps and weaving segments are major contributors to traffic instability. It has also been suggested that the frequency of lane changes at the beginning of a weaving segment reduces the bottleneck's maximum capacity [34].

2. Method of Research

2.1. Study Area

The study area consists of three major weaving segments on a 6-lane urban freeway located in northern Mosul, as shown in Fig. 1. This freeway provides both economic benefits and serves as a practical and essential feature. It is situated south of the University of Mosul's main campus and the educational zone, extending from Baghdad Main Street to the Mosul Al-Jadida Interchange and the Al-Yarmouk Interchange to the west. The freeway crosses the Tigris River via the third bridge, connecting to the University Interchange and the Al-Massarf Bridge, which leads to Al-Massarf Main Street to the east.



Figure 1. Study area Location in Mosul city

The first weaving segment (No. 1) is located at the Al-Baladiyat Interchange, as shown in Fig. 2, while the second and third segments (No. 2 and No. 3) are situated at the Third Bridge Interchange, as shown in Fig. 3. This freeway is considered one of the most important urban arterial streets in the city's road network, connecting various sections and large areas in different directions of the city, while also providing access to all the suburban communities it passes through. The freeway's basic segments are designed with parallel frontage roads, 8 meters wide, to provide direct access and parking for adjacent areas.

The current design used at the site conforms to the HCM standards. The freeway section is designed according to HCM guidelines and has a speed limit of 55 miles per hour (90 kilometers per hour). The current traffic volume aligns with the traffic volumes proposed in the HCM, as the road is designed based on engineering standards outlined in the Traffic Engineering Studies ITE Manual (AASHTO design).



Figure 2. Al-Baladiyat Interchange Layout



Figure 3. Third Bridge Interchange Layout

The weaving sections consist of four lanes, one of which is an auxiliary lane. In the first segment (No. 1), the lane width is 3.6 meters (12 ft), and the section length is 660 ft. In the second and third segments (No. 2 and No. 3), there are also four lanes, but the auxiliary lane is narrower than the adjacent lanes, with a width of 3.3 meters (11 ft). The length of the second section is 650 ft, while the length of the third section is 675 ft.

The geometric criteria for weaving section analysis include weaving length, configuration (to define the weave type and the stable values to apply), and weaving width (the number of lanes in the segment). As illustrated in Fig. 4, the configuration of each freeway weaving section includes four traffic movements: freeway-to-freeway, ramp-to-ramp (non-weaving movements), freeway-to-ramp, and ramp-to-freeway (weaving movements).

2.2. Data Collection and Analysis

The work selected typical weekdays to conduct the field surveys to ensure satisfactory and unbiased results. Monday, Tuesday, and Wednesday were chosen as representative workdays, and the surveys were conducted over two weeks in October 2021 and two weeks in March 2022. A radar speed gun was used to collect speed data. As shown in Fig. 5, appropriate locations were selected for camera installation. The camera placement was done by the requirements of the GoodVision program to gather the necessary traffic data. Traffic data was collected at each study area at 5-minute intervals over 12 hours (7:00 a.m.–7:00 p.m.). To avoid unusual events, all field survey measurements were taken during times that reflected typical daily conditions in the study area locations, under normal traffic and weather conditions.

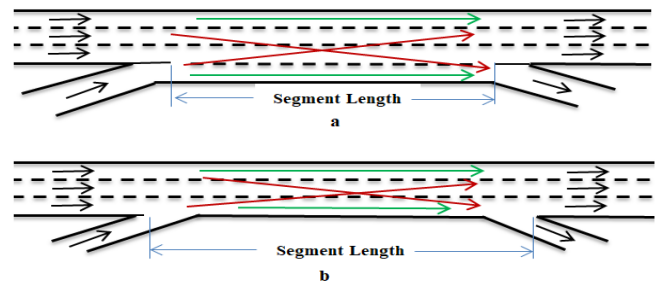


Figure 4. Configuration of the selected weaving segments
a. Segment No.1, b. Segment No.2 and 3



Figure 5. Traffic data collection using video imaging methods in the study area, 2021

The study of data collection, organization, analysis, and interpretation is known as statistical analysis. This encompasses both the technology of deriving information from data and the science of dealing with uncertainty. When working with a large population, a representative sample is used to conclude the entire population, as it is often impractical or too costly to collect data from everyone. Common sampling techniques include simple random sampling, stratified sampling, systematic sampling, cluster sampling, and convenience sampling [35].

According to the Traffic Engineering Handbook [35], the sample size must be determined by accounting for errors in the data collection technique and the subsequent travel prediction process, where rough estimates of travel demand are necessary. The likelihood that there is no significant difference between the estimated and true means increases with larger sample sizes. Therefore, it is essential to choose a sample size that will produce an estimated mean within acceptable error bounds. This minimum sample size is determined using statistical methods. In traffic engineering research, sample sizes are calculated using probability theory. The required level of precision determines the minimum sample size. The degree of confidence that the sampling error of an estimate will fall inside a specific fixed range is known as the accuracy level. Typically, the confidence level is expressed as the significance level, where $S = (100 - \text{confidence level})$.

The minimum sample size for an acceptable error E is then determined using the properties of the normal distribution. An equation linking the sample size to the number of standard deviations corresponding to a specific confidence level, the limits of allowable error, and the standard deviation has been

developed based on the characteristics of the normal distribution. The following equation (1) is used to calculate the required sample size:

$$N = (S \cdot K / E)^2 \quad (1)$$

Where N is the minimum sample size, K is the constant depending on the desired confidence level (K= 1.96 for a 95% confidence level), S is the expected sample standard deviation, and E is the allowable error. Section 3 (Results and Discussion) explains the sample size. To offer a good idea of the performance of the study areas, the primary elements of traffic flow are applied, which include traffic volume, speed, and density. Traffic density (Traffic volume is calculated by dividing the rate of flow by the traffic speed) is an important aspect in analyzing traffic jams and assessing the performance of weaving locations. Since all input parameters have been given, no default settings are required. Under current

conditions, demand volumes are expressed in vehicles per hour. For the methodology's calculations, these volumes must be converted to passenger cars per hour under ideal conditions. To determine the applicability of the weaving methods described in each HCM edition, the segment length must be compared to the maximum allowable length for weaving analysis. The capacity of the weaving segment is then assessed and compared to the total demand flow to evaluate whether LOS F occurs. Lane change rates are estimated to allow speed predictions for both weaving and non-weaving flows. To determine the level of service (LOS), the average overall speed (including both weaving and non-weaving speeds) and traffic density are calculated and compared to the HCM criteria. Tables 1 and 2 provide a comparison of the methodology design of freeway weaving segments from 2000 to 2016.

Table 1. Comparison of speeds for weaving and non-weaving; find N_w and N_{wMAX} , and limitations for freeway weaving segments

HCM	Speed for Weaving and Non Weaving	Find N_w and N_{wMAX}	Limitations
2000	a-It was decided to adjust the high speed in the speed formulae from 100 km/h (65 mph) to the free-flow speed (FFS) + 8 km/h (or 5 mph). Then new equations for speed prediction in this HCM have the following form: $S_i = 24 + \frac{S_{FF} - 16}{1 + W_i}$	Equations that enabled the estimation of how many lanes weaving vehicles would require for an unconstrained operation were calibrated so that they could be used (N_w). After this, a comparison might be made to the maximum values (N_{wMAX}) that have been determined for each of the configuration kinds. Then, the operation was unconstrained if the value of N_w was less than or equal to N_{wMAX} , and it was constrained if the value of N_w was greater than N_{wMAX} . In the second method, the speeds were recalculated using the equations with constraints.	Set of tables in HCM 2000 to find capacity for various weaving segments.
	b-To find out the weaving intensity factor, Exhibit 24-6 in HCM 2000 presents the calibration constants that were used. This HCM offers regression-based equations for forecasting the speed of vehicles that are weaving as well as those that are not weaving: $S_w = 15 + \left[\frac{FFS - 15}{1 + W_w} \right] \quad W_w = 0.226 \left(\frac{LC_{ML}}{L_s} \right)^{0.789}$	Found in different methods, not like the N_w and N_{wMAX} .	The capacity of a weaving section is evaluated using the following equations: $c_{NWL} = c_{NWL} - [438.2(1 + VR)^{1.6}] + [0.0765L_s] + [119.8N_{WL}]$ $c_w = c_{NWL} N f_{HV} f_p$
2010	While the average speed of vehicles that are not weaving in a weaving section was estimated as follows: $S_{NW} = FFS - (0.0072 * LC_{MIN}) - (0.0048 * v/N)$		If the volume ratio, VR, is regarded as a fundamental demand feature, the capacity of a weaving segment based on required maximal weaving flow rates would be calculated as follows: $C_{1W} = 2400/VR$ (for $N_{WL}=2$) and $C_{1W} = 3500/VR$ (for $N_{WL}=3$)
	The lowest expected speed is 15 miles per hour, and the highest expected speed is the FFS, which may be adjusted to account for the effects of adverse weather. There are currently no established processes for modifying the FFS to account for accidents; with the addition of SAF (speed adjustment factor, unitless), the average speed of vehicles in the weaving segment is calculated as: $S_w = 15 + \left(\frac{FFS * SAF - 15}{1 + W} \right)$ Weather and work zone influences can be represented by the SAF.	Found in different methods, not like N_w and N_{wMAX} .	For calibration, there is a strong focus on using CAFs. Adjustments can be made to the weaving segment's capacity to accommodate severe weather, driver population, the occurrence of traffic incidents, or a mix of these variables. Adjusting the capacity of a weaving section according to: $c_{wa} = c_w * CAF$

Table 2. Comparisons of finding LOS, determining lane change, and finding L_{MAX} for freeway weaving segments

HCM	Find LOS	Determination Lane Change	Find L_{MAX}	Notes
2000	<p>1- The adjustment of level of service requirement from speed to density was one of the most significant changes to this manual weaving process. To get an average density for the weaving section, which included both weaving and non-weaving flows, a spatial mean speed for all vehicles had to be estimated using the values of S_{NW} and S_W obtained from the speed equations. Then density was calculated using the average speed as follows:</p> $S = \frac{v}{\left(\frac{v_w}{S_w}\right) + \left(\frac{v_{nw}}{S_{nw}}\right)} \quad D = \frac{\left(\frac{v}{N}\right)}{S}$ <p>2- Exhibit 24-2 in HCM 2000 shows the density-based level of service standards for weaving segments.</p>	No method was found to find it.	No method was found to find it.	A series of modifications that were implemented in the HCM 2000.
2010	<p>In this edition, the same procedures of HCM 2000 are done to get an LOS based upon density standards. The only minor adjustment that made was to specify that LOS F exists whenever the demand flow rate was higher than the capacity of the weaving section.</p>	<p>1- The analysis method in this edition begins by determining three lane-changing variables that are easily observable based on the geometry of the weaving segment.</p> <p>2- Lane-changing values may be calculated:</p> $LC_{MIN} = (LC_{FR} * V_{FR}) + (LC_{RF} * V_{RF})$ <p>3- The total number of lane changes done by weaving vehicles is predicted to be:</p> $LC_W = LC_{MIN} + 0.39[(L_s - 300) N^2 (1 + ID)^{0.8}]$ <p>4- Based on "a non-weaving vehicle index," a set of equations is used to figure out the "equivalent hourly lane-changing rate of non-weaving vehicles" (LC_{NW}, in lane changes per hour). The equations below are used to find out how often the vehicles that don't weave between lanes change lanes.</p> $L_s * ID * V_{NW} / 10000$ <p>If $INW \leq 1300$ then</p> $LC_{NW} = LC_{NW1} = (0.206 V_{NW}) + (0.542 L_s) - (192.6 N)$ <p>If $INW \geq 1950$ then</p> $LC_{NW} = LC_{NW2} = 2,135 + 0.223(V_{NW} - 2000)$ <p>If $1300 < INW < 1950$ then</p> $LC_{NW} = LC_{NW3} = LC_{NW1} + (LC_{NW2} - LC_{NW1})(INW - 1300 / 650)$ <p>If $LC_{NW1} \geq LC_{NW2}$ then</p> $LC_{NW} = LC_{NW2}$ <p>5- The total rate at which all vehicles change lanes in an hour (LC_{ALL}) is then:</p> $LC_{ALL} = LC_W + LC_{NW}$	<p>The construction of a calibrated equation for a weaving section's capacity allows for the consideration of a new way to establish a weaving segment's maximum length L_{MAX}, which is calculated (in feet) as:</p> $L_{MAX} = [5728(1 + VR)^{1.6}] - [1566 N_{WL}]$ <p>When the length of the "weaving section" exceeds this value, it is divided into an on-ramp section at one end, an off-ramp section at the other, and a basic freeway section in between.</p>	A series of changes that were implemented in HCM 2010.

2016

The boundary between stable and unstable flow, also known as the boundary between LOS E and F, occurs in the weaving segment of the freeway when the demand flow rate is higher than the capacity of the segment and when the density on the weaving segment of the freeway is higher than 43pc/mi/ln.

As in the HCM 2010

As in the HCM 2010

Required data and sources as summarized in Exhibit 13-7 in HCM 2016, where the default values are recommended when segment-specific data is unavailable.

Applications for video analytics reduce the effort required to obtain traffic data from typical field sources, such as conducting traffic counts and primary traffic assessments. GoodVision is a program used to extract traffic data from recorded videos and collect traffic data through image recognition, as applied in recent traffic studies [36]-[38]. GoodVision automates all stages of traffic operations, from camera data collection to traffic analysis. The software captures all traffic events in a single instance, allowing for the computation of various traffic behavior evaluations, such as speed and saturation flow calculations, to calibrate and test traffic models without the extensive manual effort required by traditional methods. In this software, artificial intelligence automatically collects traffic data from videos, making it easy to count and report traffic volumes, speeds, lane-changing rates, and other traffic behaviors (version 26 was used in this work).

Once videos have been recorded, they must be uploaded into the GoodVision application to begin the image recognition process and extract traffic data. To do this, follow these steps:

- 1- Identify the Camera: The first step after opening the software is to select a folder where the video will be uploaded, as shown in Fig. 6.
- 2- Once the video has been uploaded, processing takes approximately one hour for every hour of video. After processing is complete, clicking on the video image allows for the analysis and definition of movements and events to begin.
- 3- To define the movements, lines must be drawn to represent the desired movement. Once the lines are drawn, the movement can be added and saved by clicking the "New" button, as illustrated in Fig. 7.

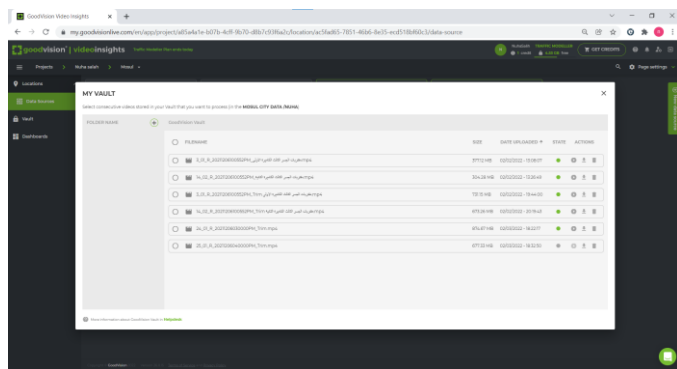


Figure 6. Upload the video in GoodVision.

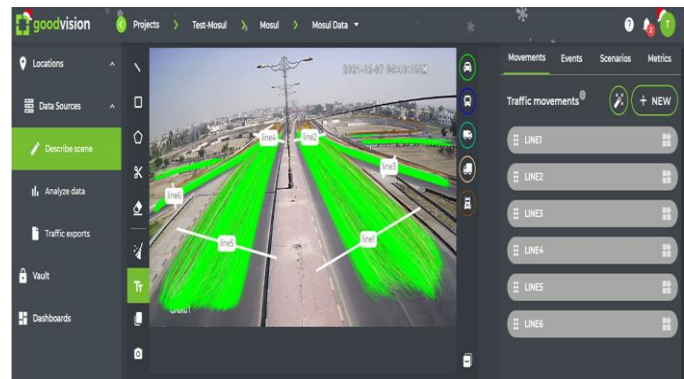


Figure 7. Define the movement in GoodVision.

4- After sketching the movements, the kinds of vehicles for which the data will be calculated are selected from the list of vehicle types.

5- Next, the data can be obtained by using the "Analyze Data" tab, as shown in Fig. 8. To collect the desired data, follow these steps:

1. Define the widget.
2. Select the vehicle class to include.
3. Press "Next" to choose the movements, as shown in Fig. 9.
4. Press "Next" again to select the specific data you need, such as volume or vehicle trajectory, as illustrated in Fig. 10.

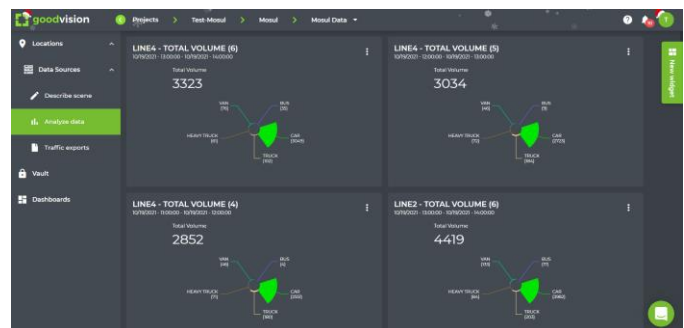


Figure 8. Selecting GoodVision's data analysis option

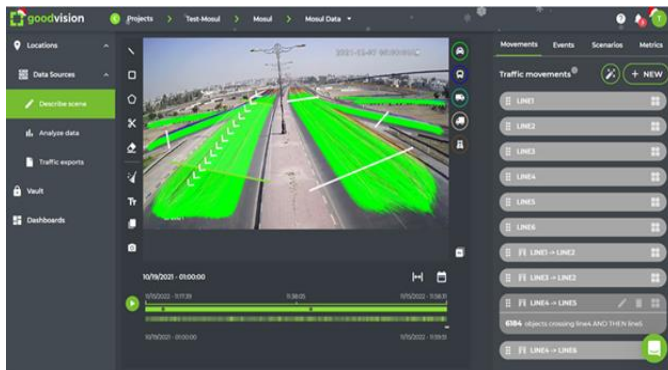


Figure 9. Selecting the movement for GoodVision's data collection

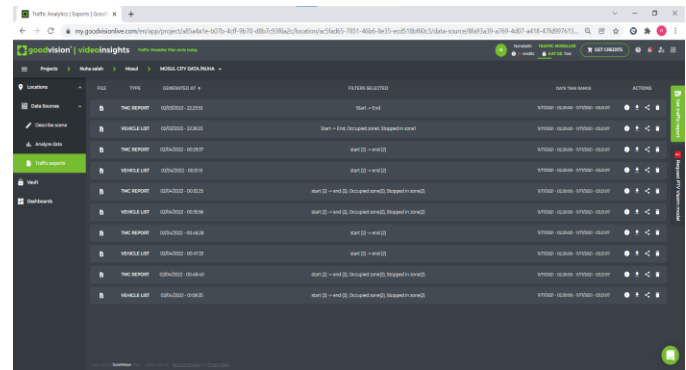


Figure 12. Exporting the data file to GoodVision's Traffic Analysis.



Figure 10. Selecting the GoodVision traffic data

6- The duration of the video you want to analyze can be entered. Additionally, a traffic report can be generated by exporting the data to Excel. To do this, select the desired data to export by tapping the "Get Traffic Report" tab, as illustrated in Fig. 11.

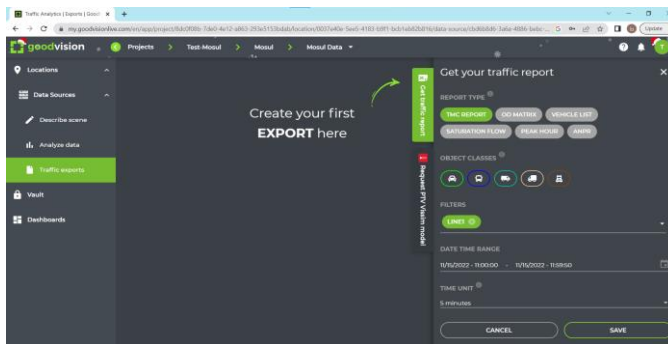


Figure 11. Selecting GoodVision's "Get Traffic Report" option.

7- The period for the traffic data analysis can also be selected. Next, as shown in Fig. 12, click the "Traffic Exports" option to download the exported data as an XML file.

The work objectives are to identify the most suitable estimation technique for assessing traffic weaving characteristics across the last three HCM versions. Three statistical metrics were used for this purpose: the t-test, coefficient of variation (CV), and root mean square error (RMSE).

A t-test is a statistical test used in this work to compare the means of predicted (by HCM) and observed (actual) values to determine whether there are significant differences between the two groups at a 95% confidence level. The standard deviation (SD) measures the degree of variation or dispersion within a set of values. The coefficient of variation (CV) is calculated as the ratio of the standard deviation to the arithmetic mean. The root mean square error (RMSE) is a commonly used metric to assess the variations between values predicted by a model or estimator and the observed values.

3. Results and Discussion

The measurements of traffic flow and analysis conducted at the three freeway weaving segments, according to the HCM methodology, provided the following results:

1. Traffic flows for every weaving section fluctuate during the day due to variations in distribution, speed, and stream composition. In the HCM weaving section capacity and speed calculations, significant criteria are the volume ratio (the ratio of weaving traffic volume to overall traffic volume), the weaving segment's short length, and the number of weaving lanes.

Along with traffic flow rate parameters, such as peak hour factor (PHF), peak and off-peak hourly volume (V), and the percentage of different traffic compositions (passenger cars (P%), trucks (T%), buses (B%), and recreational vehicles (RVs%)), Table 3 explains the traffic speed parameters for each segment. These include time mean speed (TMS), space mean speed (SMS), and the 85th percentile speed (SP₈₅). According to UNDP estimates and forecasts, as well as statistics from the World Bank Report [39], Iraq's growth rate for the years 2021-2030 is projected to be 2.2%. The work intended to employ a 2.2% growth rate to estimate future traffic volumes in the study areas.

Table 3. Findings from the study's weaving sections' analysis of traffic flow parameters and service level, 2021

Weaving Segment No.	Traffic Speed mile/h			PHF	Off-peak hour				Peak hour			
	TMS	SMS	SP ₈₅		Time a.m.	Volume veh/h	T+B %	RV's %	Time a.m.	Volume veh/h	T+B %	RV's %
W1	42	40	55	0.90	9:45-10:45	2863	3.1	1.6	8:10-9:10	4294	4.2	2.0
W2	45	42	58	0.90	10:00-11:00	2018	5.3	1.5	7:55-8:55	3007	7.9	3.3
W3	45	42	57	0.90	10:15-11:15	2791	4.4	1.2	8:05-9:05	4318	6.5	2.0

2. The work analyzed the weaving locations to assess the operation and characteristics of the traffic flow. Current traffic conditions indicate that all selected weaving segments experience unacceptable levels of excessive congestion during peak hours in the morning and evening.

As shown in Table 4, the current level of service (LOS) during peak hours is E, while the projected future LOS (in 2030) is F due to increased traffic density. These freeway segments were created for a 15-minute peak period and operated at a much lower capacity for the remainder of the day.

Table 4. Findings from the study's weaving sections' analysis of traffic flow parameters and service level, 2021

Weaving Segment No.	Number of Lane	Segment Length ft	HCM	Off-peak hour				Peak hour					
				Speed mile/h		Density pc/mi/l	LOS	Speed mile/h		Existing 2021		Expected 2030	
				SNW	Sw			SNW	Sw	Density pc/mi/l	LOS	Density pc/mi/l	LOS
W1	4	660	2000	46	44	15.7	C	43	24	25.5	E	29.6	F
			2010	49	43	26.2	C	34	39	34.2	D	*	F
			2016	50	46	27.33	C	33	39	35.6	E	*	F
W2	3.5	650	2000	55	52	12.25	C	45	44	21.05	D	27.17	F
			2010	52	50	22.67	C	47	45	34.5	D	39.11	E
			2016	54	53	24.00	C	48	46	34.95	D	41.33	E
W3	3.5	675	2000	49	46	14.92	C	39	38	26.1	E	30.4	F
			2010	48	46	25.77	C	40	42	38.33	E	*	F
			2016	50	48	26.85	C	40	43	40.11	E	*	F

* Traffic demand exceeds capacity

The average speed of non-weaving vehicles is indicated as a function of the free-flow speed, the minimum number of lane changes, the flow rate of the weaving segment, and the number of lanes. The weaving segment capacity, which is determined based on density for the three segments taken for the work and under the current conditions, is always greater than that computed based on weaving demand flows from HCM 2010 and HCM 2016, with the lowest value adopted as the final capacity.

3. During peak hours, traffic volumes in the weaving sections approach capacity limits, affecting driver expectancy and judgment. As a result, weaving vehicles can sometimes move faster than non-weaving vehicles, especially in congested areas where non-weaving vehicles often shift to the outer lanes to avoid weaving disruptions. Otherwise, flows in a weaving area tend to utilize the available lanes at approximately the same average speed, with weaving flows moving slightly slower than non-weaving flows.

In reality, the weaving segment's operation is classified as constrained, and non-weaving vehicles generally travel at significantly higher speeds than weaving vehicles. The

majority of non-weaving vehicles are moving from freeway to freeway.

4. Since peak hour traffic volume is the most important for operations and has the greatest capacity requirements, it is the main focus of traffic analyses. The same turbulence that occurs in basic freeway sections downstream of the weaving area affects traffic flow in that region. The spillback effect from the downstream weaving segment impacts overall freeway flow rates, causing delays and potentially posing safety risks when traffic demand exceeds capacity for any reason. As observed in segment No. 1, the effects of a breakdown can persist far longer than the period during which demand exceeds capacity.
5. To determine the appropriate approach for assessing the segments under consideration, a statistical analysis of the last three methods of the HCM based on field data provides crucial information regarding their applicability.

Fig. 13 compares the predicted weaving speed values to the observed values determined by various HCM algorithms.

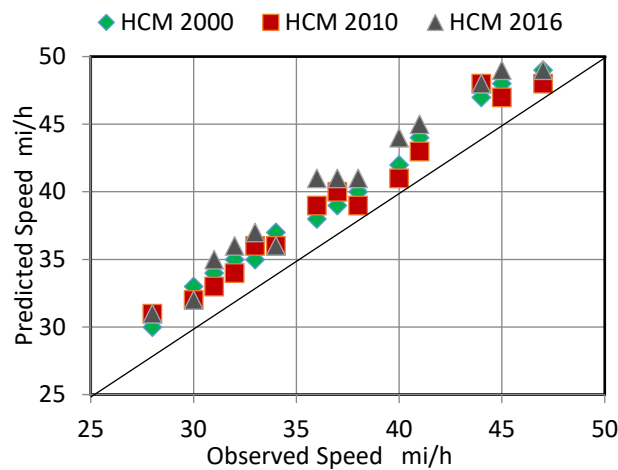


Figure 13. The comparison of predicted weaving speed with actual weaving speed according to HCM editions

In 2000, 2010, and 2016, the predicted values were higher than the observed values because the designated speed does not exceed 55 miles per hour, and vehicles may travel at speeds lower than this. For weaving segments in the study area under typical weekday traffic and roadway conditions, the 2000 edition is preferred, followed by the 2010 edition.

Fig. 14 depicts a comparison of the predicted non-weaving speed values to the observed values across the three HCM editions. The predicted values are higher than the observed values for all three versions, with significant variations due to differences in the calculation equations. The 2010 and 2016 editions rely on flow rate and minimum lane changes, while the 2000 edition depends on the W_{NW} factor. Additionally, because the designated speed does not exceed 55 miles per hour, vehicles may travel at speeds lower than this. This figure indicates that the estimated speed values from the HCM 2000 and HCM 2010 methods are closer to the observed values compared to other editions.

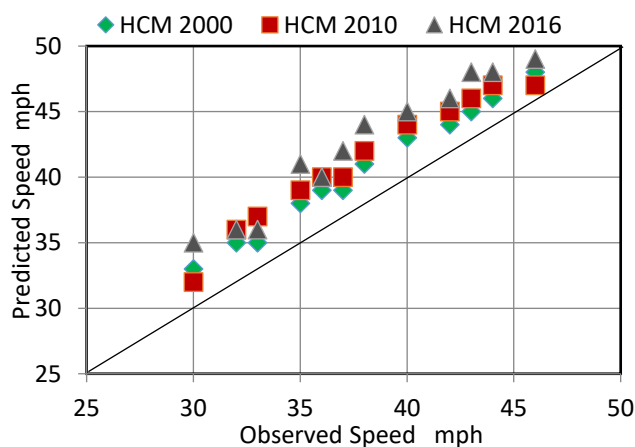


Figure 14. The comparison of predicted non-weaving speed with actual non-weaving speed according to the HCM edition

Fig. 15 presents a comparison of the predicted traffic density values to the observed values across the three HCM editions. In general, the observed values are lower than the predicted

values, as density is calculated based on flow rate and average speed for both weaving and non-weaving traffic. This figure shows that the predicted density values from the HCM 2000 methodologies are more reliable than those from the other editions.

Fig. 16 explains the computed lane change values for the last two HCM editions, as these were the first to develop equations for determining them. No mechanism exists to calculate lane changes in earlier versions. The observed values are generally smaller than the expected values, as lane change calculations depend on multiple parameters, including L_s , N , ID , LC_{MIN} , and V_{NW} for both weaving and non-weaving lane changes. There were no significant differences between the two HCM methodologies, although some results indicate a preference for the HCM 2010 approach.

Only during peak hours and for low-speed travels on usual weekdays do these figures indicate the relative supremacy of the HCM 2000 in forecasting density, weaving speed, and non-weaving speed, while the relative supremacy of the HCM 2010 is evident in other circumstances and in lane-changing rate.

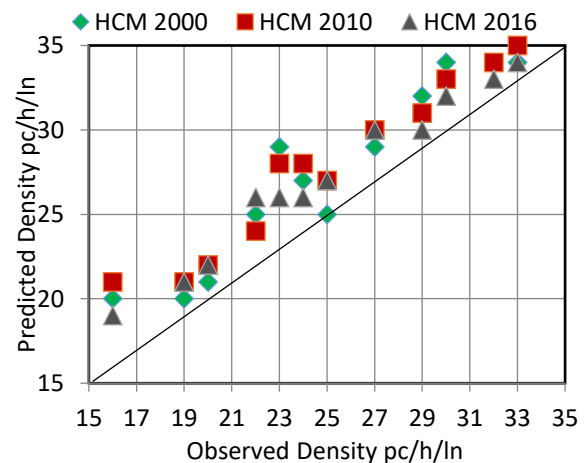


Figure 15. The comparison of predicted density with actual density according to the HCM edition

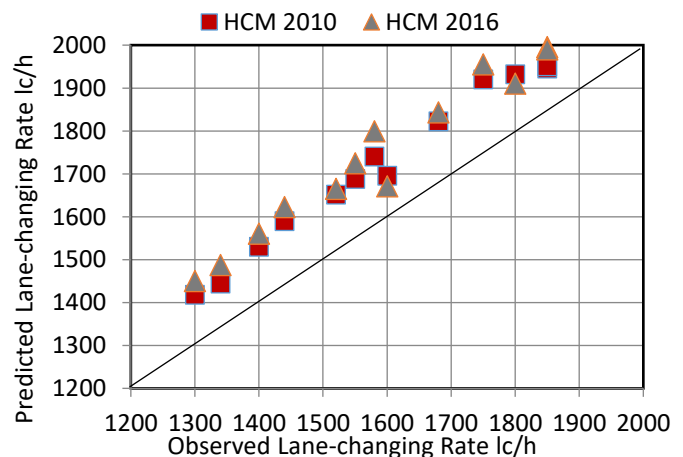


Figure 16. The comparison of predicted lane-changing rate with actual lane-changing rate according to the HCM edition

- As shown in Table 5, three statistical parameters were utilized to increase the validity, reliability, and confidence

of the previous comparison findings of the predicted values of the later three HCM procedures in calculating the traffic density, weaving speed, non-weaving speed, and rate of lane changing with the actual values of the freeway weaving segments.

Under the working conditions, Table 5 shows that HCM 2000 performs best in predicting weaving speed (SW), with an RMSE of 1.15 mi/h, a CV of 12.06 mi/h, and a significant t-test

value of 1.77. Additionally, the table shows that HCM 2010 performs better than HCM 2016 in estimating lane change rate, with an RMSE of 97.2 lc/h, a CV of 11.61 lc/h, and a significant t-test value of 0.99. The HCM 2016, however, has a little competitive advantage in density estimation, with an RMSE of 2.05 pc/mi/ln, a CV of 9.51 pc/mi/ln, and a t-test value of 1.98 at a 95% confidence interval. All statistical results are considered significant.

Table 5. Statistical comparison of predicted traffic weaving parameters with actual values according to HCM edition

Parameter	Sample Size	RMSE			C.V.% **			t-test		
		HCM 2000	HCM 2010	HCM 2016	HCM 2000	HCM 2010	HCM 2016	HCM 2000	HCM 2010	HCM 2016
Non-weaving Speed (mile/h)	25	1.76	1.80	2.15	10.84	11.24	11.95	1.05	1.20	1.40
Weaving Speed (mile/h)	25	1.15	1.44	2.20	12.06	12.92	14.17	1.77	1.54	1.95
Total Speed (mile/h)	25	1.28	1.58	2.22	10.73	11.45	12.70	1.45	1.43	1.85
Lane Change (lc/h)	25	---	97.2	103.9	--	11.61	11.50	--	0.99	1.07
Density (pc/mile/ln)	25	1.65	1.82	2.05	10.69	10.22	9.51	1.43	1.65	1.98

* Not Significant at a 95% confidence interval

**C.V. = (SD / X_{mean})*100

4. Conclusions

This work compares and assesses the accuracy and effectiveness of weaving segment analysis methodologies in the last three editions of the Highway Capacity Manual (HCM). The results highlight that a breakdown in the basic freeway downstream of the weaving influence area significantly impacts the performance of weaving segment No. 1, leading to greater turbulence and the occurrence of LOS F. Similarly, the poor performance (LOS E) in the current state and future breakdown (LOS F) in segments No. 2 and No. 3 are related to insufficient total capacity, where demand exceeds capacity.

To address these traffic-related issues, the work proposes the following alternative solutions for the study area:

For Segment No. 1, the work proposes significant geometric changes and improvements to the parallel frontage road to enhance traffic flow and safety. These improvements include:

- (1) Reducing Freeway Access Points: Limit the number of freeway access points to two—one for entry and one for exit.
- (2) Widening the Street: Increase the street width to 10 meters.
- (3) Enhancing Traffic Operations: Establish a well-designed, safe traffic environment near the gates of the Education Center.
- (4) Prohibiting On-Street Parking: Ban on-street parking and provide designated locations for bus or taxi stops.
- (5) Enforcement Measures: Implement strict enforcement measures to avoid conflicts with vehicles entering or leaving the Education Center.

For Segment No. 2 and Segment No. 3, the work recommends adding a full-width lane to the current weaving segment to serve as an auxiliary lane. This will reduce turbulence caused by lane changes, enhance capacity, and improve the overall traffic flow in these segments.

Because of conceptual variations between the findings of traffic flow characteristics in HCM methods for each edition and real values, direct comparison for weaving segments may be problematic. However, the results revealed a difference in the

analysis technique for the HCM 2000 version versus the HCM 2010 and HCM 2016 versions, as it provides more realistic values under peak hours of a normal weekday for density and weaving or non-weaving speed based on actual data. Under typical situations, the performance of HCM 2010 and 2016 is relatively equivalent.

This work highlights the need for further research to develop a practical traffic and environmental system that can evaluate current roadway conditions and offer recommendations for improvements. Specifically, additional research should focus on other parts of the freeway, such as basic segments and ramp junctions, to address traffic issues comprehensively across the entire freeway network.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Nuha S. Mohammed collected and analyzed data. Mohammed Y. Taha identified the problem statement. Both authors verified the analytical methods, supervised the findings, discussed the results, and contributed to the final manuscript.

Use of LLM and AI

ChatGPT was used to improve language.

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Data Availability

The data used in this study are available from the corresponding author upon reasonable request.

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