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Traffic Performance Assessment and Modeling Microscopic Characteristics on Urban Multilane Highways in Mosul City

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ABSTRACT

As the multilane highway system is a fundamental part of the urban highway network, it is essential for traffic engineers, planners, and policymakers to understand and evaluate the quality of service these facilities provide. The evaluation process was conducted using the US Highway Capacity Manual, employing Level of Service (LOS) concept. Additionally, traffic flow is significantly influenced by microscopic characteristics, making it crucial to model these characteristics for each highway lane. This modeling impacts both vehicular and driver behavior. This research aims to assess the (LOS) for five segments of multilane highways using (HCM) 2022 methodology. Additionally, modeling the relationships between speed, headway, and spacing. The results indicate a failure in the level of service in two of the studied segments, especially for projections seven years into the future. For speed-headway-spacing models, the coefficient of determination (R-square) and the chi-square test were used to evaluate the goodness of fit for the models, using SPSS. The findings showed no significant differences between the predicted and observed data, highlighting traffic characteristics of flow, speed, and density. These models can be utilized to identify various traffic parameters in future studies on the examined highways.

Keywords:

Multilane highway; LOS; HCM2022; Traffic speed; Headway; Spacing.

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1. INTRODUCTION

In the context of current transportation, multi-lane highways are crucial, they serve as vital mobility for the movement of people and goods [1]. To guarantee effective and secure mobility, it becomes essential to evaluate the performance of these routes and model a relationship for essential parameters on studied routs of transportation. Traffic performance assessment provides valuable insights into the operational characteristics, capacity, and level of service of multilane highways, enabling transportation engineers and policymakers to make informed decisions regarding design, operation, and management. Multilane highways generally have posted speed limits between 60 km/h and 90 km/h. They usually have four or six lanes, often with physical medians, although they may also be undivided [2].

Regression models are highly effective tools commonly utilized to forecast a dependent variable based on various predictors. Their applications span across numerous fields and contexts [3]. Linear and nonlinear models are frequently employed in traffic flow analysis due to their accuracy and simplicity [4]. These models graphically depict the relationship between flow, speed, and density. The time headway parameter can be obtained by the inverse of flow, and spacing distance by the inverse of density. So, it is crucial to understand the relationship between speed and time headway or spacing distance, or between headway and spacing, which represents vehicular traffic behavior [5]. (LOS) is a term used to qualitatively define and measure the operating conditions of a roadway segment based on various performance measures. These measures include traffic flow rates, density, speed, travel time, delay, freedom to maneuver, traffic interruptions, driver comfort, operating cost, and v/c ratio [6]. The Highway Capacity Manual (HCM) and Highway Capacity Software (HCS) are intended to provide a systematic and consistent basis for assessing the capacity and level of service for elements of the multilane highways. The vehicle time headway and space distance are fundamental for analyzing traffic stream characteristics on a microscopic level. Vehicle time headway (h) refers to the time interval between the front ends of two consecutive vehicles passing a point. Vehicle space distance (s) is the distance between the front ends of two consecutive vehicles [7]. Since headway can be the inverse of traffic flow and spacing can be the inverse of traffic density, modeling these parameters in relation to traffic speed is essential for understanding traffic stream behavior and its impact on driver behavior.

2. RESEARCH OBJECTIVE

In this research, the LOS will be assessed on five segments of multilane highways in Mosul city. This research also aims to model the relationship between traffic characteristics depending on lane position on a six-lane divided highway. Microscopic and mesoscopic models will be developed to analyze speed-spacing, speed-headway, and headway-spacing relationships on each lane, using linear and nonlinear approaches by SSPS software and Microsoft EXCEL.

3. LITERATURE REVIEW

There is a critical analysis and synthesis of existing research on traffic performance assessment for multilane highways. In Ramadi city, a study analyzed and evaluated the LOS on a multilane highway segment [8], using HCS 2000. As a result, the highway segment (Sejarea-Hesaba) in both directions operates under high LOS (A or B). In 2015, a research intended to examine and enhance the level of service (LOS) of Jordan's multi-lane highways[9]. HCS-2000 and HCS-2010 software were used to assess LOS for current, short-term (2020), and medium-term (2025) situations. A comparison of output results between HCM-2000 and revised HCM-2010 reveals no major differences. The suggested enhancement plan recommends expanding lane width and improving geometric conditions, particularly for portions operating at LOS-E or LOS-F. Due to the significance of FFS for predicting LOS, a study conducted in Malaysia [10] intended to evaluate and compare various types of FFS measuring techniques that are appropriate for Malaysia's multilane highways. The study examined three methods for estimating FFS: calculating the average speed during low to moderate traffic, using speed-density graphs, and applying the HCM 2010 approach, which bases FFS on the average speed of vehicles with headways over eight seconds. A striking similarity may be seen when comparing the free-flow rates derived from these three methods using graphical analysis. Further statistical analysis, including the application of one-way ANOVA test, Levene test, and post hoc test, indicates that there is no significant difference between the three methods.

The HCM2016 technique was applied in research conducted in Suleimani[11], to assess the capacity and LOS of an urban multi-lane highway with non-uniform traffic composition. Consequently, the segments' capacity and LOS were identified. Most segments have LOS that fall between C and D. The segments have a base capacity of 1850–1900 pc/h/ln. A study conducted in Hillah[12] sought to evaluate and enhance the traffic performance of two sites inside Al-Hillah's urban multilane roadways. HCS 2010 was used to calculate the LOS to evaluate the congestion. The study results demonstrated that the selected highway segments, with low LOS and high congestion costs, were insufficient to handle the heavy traffic demand. As a result, many enhancements are needed to modernize the LOS and reduce the quantity of fuel and time wasted on such traffic facilities. A study was developed in India to use a micro-simulation model to analyze mixed traffic conditions with different drivers' behavior parameters. A multi-modal time increment oriented and behavior-based simulation tool VISSIM6 has been utilized to simulate the variety the traffic of the multilane highways of India [13]. This study compared the capacity gained by simulation to the traditional procedure. The two simulation models for estimation capacity produced accurate results within a ± 5% range of data. Several recent studies have also demonstrated that some significant traffic flow phenomena are related to mesoscopic headway distributions. In traffic engineering, vehicle headway distribution models are extensively employed due to their ability to capture the inherent uncertainty in drivers' car-following behaviors. These models offer a precise description of the stochastic characteristics of traffic flows, making them invaluable tools for theoretical analysis and practical applications[14, 15]. A study conducted in India [16] established LOS parameters for multilane highways based on traffic density and lane arrangement. The technique was used by analyzing data from two locations on 4- and 6-lane highways. The study found that LOS differed across roadway segments and lanes under diverse traffic situations. In China[17], a study investigated the best-fitted distribution model for specific headway types under lane management on a multi-lane highway, considering car-truck interactions. The study collected traffic data, including traffic flow rates, percentages of trucks, speeds, and headways. Statistical tests revealed that traffic flow rates, the percentage of trucks, and lane position significantly influences vehicle headways. Another survey study conducted in China focused on explaining headway distributions, [15] demonstrating that both the dispersion of points on density-flow plots and the shape of traffic flow breakdown curves implicitly rely on vehicular headway distributions. The findings highlighted that headway distribution models fill the gap between macroscopic and microscopic traffic models, combining the strengths of both approaches.

In Chen, et al. [18] study, the empirical headway and spacing distributions were analyzed as outcomes of stochastic car-following behaviors, reflections of the unconscious and imprecise perceptions of space and time intervals by drivers. Headway, or time headway, is the time interval, measure in seconds, between two successive vehicles as they pass a specific point on the roadway, with the measurement taken from the same reference point on each vehicle. Spacing, or space gap, is the distance between two successive vehicles in a traffic lane, also measured from the same reference point on each vehicle.

A research study in Sri Lanka aimed to address the gap in capacity values [19], which vary with the nature of the road and traffic stream, by developing indigenous capacity models. This was achieved by creating a speed-flow model for urban four-lane roads. Headway data were also recorded for the surveyed sections to examine their relationship with capacity. The findings revealed that the traffic stream struggled to sustain capacity flow for extended periods, especially at low speeds.

A study conducted in Baghdad city, Iraq [20], simulated the characteristics of urban multilane highways intending to estimate road capacity based on headway time, considering road user behavior as a crucial element in microsystem traffic analysis. The study also incorporated lane position to develop a capacity headway model that reflects driver behavior in lane usage. It indicated that lane position significantly influences driver decisions in lane selection and notably impacts capacity values, particularly in the right lane position.

4. THE METHODOLOGY

4.1 Study area

The traffic performance assessment focused on five segments of multilane highways in Mosul city, labeled as segments 1, 2, 3, 4, and 5, as shown in Figures (1) & (2). All roads are located on the left coast of Mosul city. The first two consist of six lanes, three in each direction, in Al-Baladiyat and Al-Muthanna regions, and serve as arterials connecting Mosul with Dohuk city. These routes pass by several key facilities, including a private hospital, a university entrance, schools, restaurants, and various commercial offices. The other three segments are four-lane divided highways with two lanes in each direction. They pass through diverse main areas with high land use and are considered important routes on the left bank of Mosul city, around Al-Zuhour and Qadisiya regions. Each segment has two directions (northbound N & southbound S).

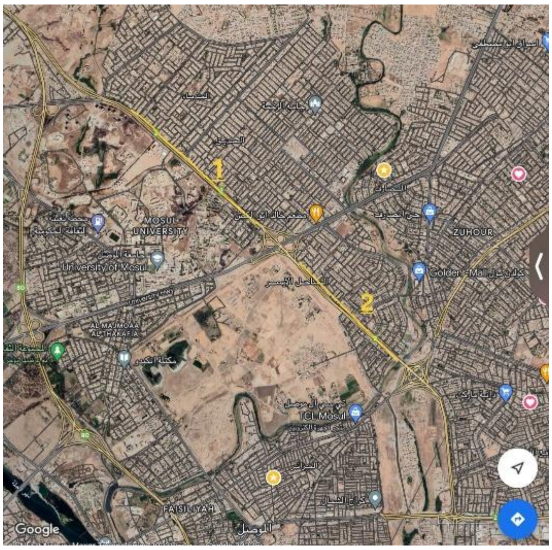

Fig. 1 Segments No.1 and No.2 of the study area. (Google map)

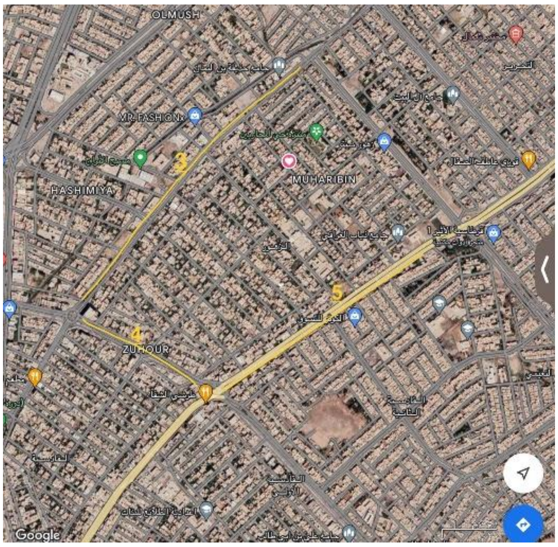

Fig. 2 segments No. 3, 4, and 5 of the study area. (google map)

The modeling examined relationships between three traffic characteristics for each segment lane, focusing on one specific segment of the study area, segment 1.

4.2 Data collection methods

4.2.1 Geometric data collection

The length of each segment was measured in the field and verified using Google Maps. Lane width and lateral clearance were determined using a measuring tape, while the grade was assessed with Kapro Level devise. Access points were identified through a field survey. The details for each segment are provided in Table (1).

Table 1: Geometric data of the study areas.

Road section no.	Number of lanes	Length (km)	Lane width (m)	lateral clearance (m)	Grade (%)	Access points	
						N	S
1	6	1.620	3.4	1.22	0	5	5
2	6	1.710	3.4	1.22	±4	5	6
3	4	1.115	3.6	1.4	0	4	5
4	4	0.5	3.6	1.4	±3.7	6	6
5	4	0.66	3.4	1.4	0	8	5

4.2.2 Volume data collection

Traffic volume data will be collected using video recordings from fixed cameras mounted on electricity poles in the median of each highway, as shown in Figure (3), these cameras will record traffic flow in both directions, capturing the number of vehicles over a twelve-hours period each day, from 7 a.m. to 7 p.m., to fully capture the impact of peak hours. This data will be used to determine peak and off-peak hours.

The traffic volume for Segment No. 1 will be calculated for each lane in 15-minute intervals to model a lane-based relationship between traffic characteristics.

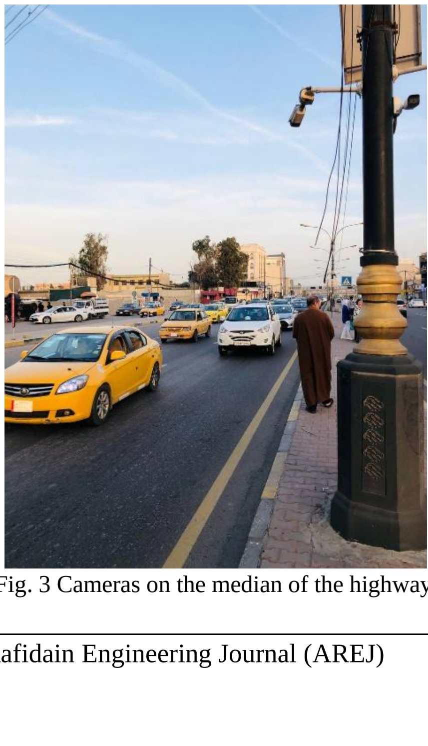

Fig. 3 Cameras on the median of the highway.

4.2.3 Speed data collection

A speed radar gun is used for measuring speed data, it can measure the speed of a vehicle by pressing the specific button on the device [21]

As shown in Figure (4), this gun is used to obtain 100 values of individual car speeds in each direction of all segments, on the side of road with no access point or u-tern through off-peak hours, then using a statistical table to calculate space mean speed SMS.

Fig. 4 Radar speed gun.

According to the ITE Guide for Traffic Engineering Studies [22], the sample size should be determined by calculating the allowable error in the data collection technique and the method of future trip estimation based on the approximate trip requirements. The following equation is used to calculate the required sample size[23].

$$N = \left(SD * \frac{K}{E}\right)^2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

where N represents the minimum required number of samples, K is the constant of the normal distribution corresponding to a specific confidence level (with K = 1.96 for a 95% confidence level or 5% significance level), E is the allowable error in the speed estimation, which depends on the measurement method. For example, with a speed measuring device, the error value ranges between ± 1.609 km/h, according to the company's guide, and SD is the standard deviation of the estimated sample [21]. In this research, the sample size is 100 values of harmonic means for speed data, and 90 harmonic means of 12-hours in five work days for other parameters.

4.2.4 Headway and spacing data

Headway, or time headway, is the time interval, measure in seconds, between two successive vehicles as they pass a specific point on the roadway, from the same reference point on each vehicle. Spacing, or space gap, defined as the distance between two successive vehicles in a traffic lane, also measure from the same reference point on each vehicle. The research requires time headway and spacing distance data for modeling purposes, specifically with speed parameters. The average time headway between consecutive through vehicles was measured on each lane in the road section, during the same hours as the traffic volume data collected.

The most common method for collecting time headway data involves measuring the time interval between two vehicles crossing a given point. For this study, time headway was measured using video records of the selected section. A narrow black tape was placed on the screen to serve as a reference point that vehicles would cross. The video recorded the time each vehicle passed this reference point in each lane. The time headway for each lane was then calculated by determining the time difference between successive vehicles passing the reference point [20].

The spacing distance (m) will be computerized calculated by multiplying the speed (m/sec) by the time headway (sec) at the time of measurement, as direct field measurement is challenging. Similarly, traffic density will be calculated using speed and flow data.

4.3 Traffic performance assessment method.

This research will follow the methodology outlined in (HCM) 2022 [24], 7th edition, to calculate the density and determine (LOS) for each direction of the five segments in the study area. The methodology is illustrated in Figure (5). Base free flow speed (BFFS) is measured in the field as the 85th percentile speed, which is defined as the speed at or below which 85 percent of vehicles travel. This measurement typically indicates the speed characteristics of the road. BFFS is used with adjustment of speed by lane width, lateral clearance, access points, and type of median, to calculate free flow speed FFS.

Future analysis will be conducted to determine the level of service in 2030, seven years after the data collection period, using an annual growth factor of 4%, with traffic flow adjusted using the following equation:

$$Vf = Ve * (1 + GF)^{y} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Where Vf is the future demand traffic volume, Ve is the existing demand traffic volume, GF is the growth factor, and y is the number of years, equal to 7 in this study.

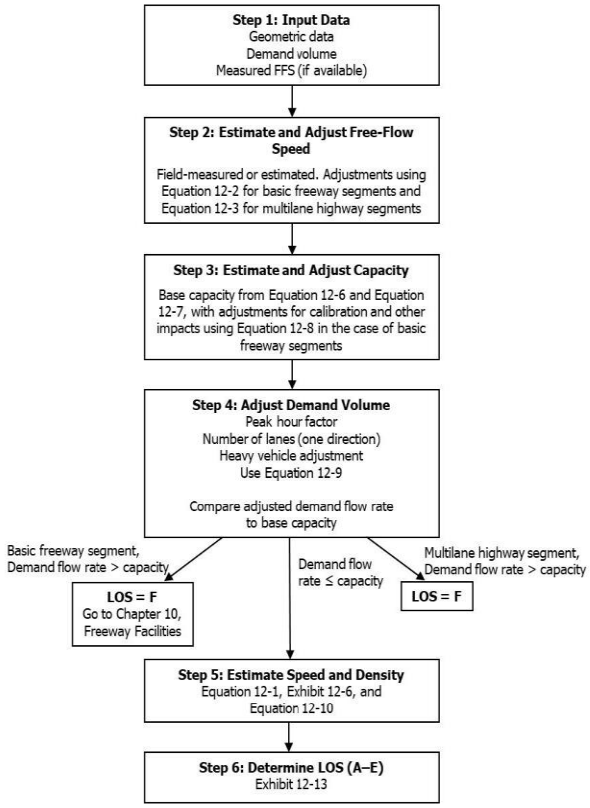

Fig. 5 Methodology of traffic performance assessment (HCM2022) [24].

4.4 Lane-based microscopic modeling

Regression models are powerful tools frequently used to predict a dependent variable from a set of predictors, and they are widely applied in various contexts [25].

This study will employ linear and nonlinear regression models using Microsoft Excel and SPSS ver.26 software to examine the relationships between speed, headway, and spacing distance for each lane (left, center, and right) on highway segment No.1.

Without subsequent performance analysis, modeling techniques can yield poorly fitting results that inaccurately predict outcomes on new data [26].

To validate the models, data will be collected from a different highway segment (Segment No. 2), and the observed data will be compared with the calculated values generated by the developed models. Calibration, which measures how close the predicted probabilities are to the observed rates for given configurations of the independent variables, will be assessed using the Hosmer and Lemeshow chi-squared test. This test provides a reliable measure of calibration through a statistical test. Additionally, R-squared values will be used to evaluate the models' performance [3].

5. RESULTS AND DISCUSSIONS

5.1 Traffic performance assessment results

The analysis of traffic performance was conducted using the HCM 2022 methodology. The results for each calculations included input current data, adjustments, demand traffic flow, base capacity, and traffic density. These factors were utilized to determine (LOS) based on the density values for each segment.

The traffic density calculated using Equation 12-11 of the HCM2022 is compared with the values in Exhibit 12-15 to determine the expected prevailing (LOS). The summary of current and forecast LOS is shown in the Table (2).

Table 2: Summary of Level of Service LOS results.

LOS	Highway segment number and direction									
	1 N	1 S	2 N	2 S	3 N	3 S	4 N	4 S	5 N	5 S
Current	E	E	D	D	E	E	C	E	D	D
Future 2030	F	F	E	F	F	F	D	F	E	E

The results indicate three Levels of Service (LOS): C, D, and E for current, LOS D,E and F for future. LOS C occurs when drivers are more constrained in choosing their speeds and lanes. At LOS D, average speeds drop as traffic flow increases, making maneuvering difficult and causing minor incidents to result in congestion. LOS E represents operations at capacity, where the traffic stream is at its maximum density. Maneuvering becomes exceedingly difficult, and even slight disruptions can quickly lead to queues.

The traffic on segment No. 1 (Al-Baladiyat) and segment No. 3 (from Al-Abadi roundabout to Al-Muharibeen region) is challenging, with operations currently at capacity in both directions. By 2030, it is projected that these segments will reach LOS F, indicating conditions where traffic queues form behind breakdown points. At LOS F, vehicles may progress very slowly or come to a complete stop, leading to low speeds and system failure. To address this issue, it is recommended to implement solutions promptly, such as enforcing strict no-parking laws on the right lane or increasing the number of lanes. Further study is recommended to determine the optimal solution[27, 28]

Segment No. 2 (Al-Muthanna) in the southbound direction and segment No. 4 (between Al-Abadi roundabout and Al-Mahrouq intersection) in the westbound direction (leading to Al-Abadi) are projected to reach LOS F by 2030. This should be taken into consideration when addressing the traffic problems in these areas. Additionally, the traffic stream on segment No. 5 (from Al-Mahrouq intersection to Al-Muharibeen region) is currently challenging in each direction and is expected to reach capacity by 2030.

5.2 Lane-based microscopic modeling results

Regression models are powerful tools commonly used to predict a dependent variable based on a set of predictors. In microscopic traffic analysis, headway time and spacing distance are crucial for assessing traffic performance [29], as they represent vehicular behavior in the traffic stream [30]. Specifically, spacing distance is the inverse of traffic density, and time headway is the inverse of flow. Therefore, regression models were developed to explore the relationships between speed and spacing, speed and headway, and headway and spacing. Figure (6) illustrates the speed-spacing model for each lane within the study area.

The space distance between successive vehicles increases as speed increases, demonstrating a relationship opposite to that of speed-density, as spacing can be represented as the inverse of density. Additionally, the speed values in the left and center lanes are higher than those in the right lane.

The same analysis was performed to develop a model predicting the relationship between traffic speed and headway for each lane, as illustrated in Figure (7).

The relationship begins with the maximum headway, which decreases as speed increases until it reaches the critical speed, between 40-50 km/h, where the headway is at its minimum. This opposes the speed-flow relationship, as headway can be represented by the inverse of the flow. A regression model was developed to examine the relationship between headway and spacing, as shown in Figure (8). The figure illustrates that headway is unstable on the left side of the line, it decreases until reaches the critical spacing. Beyond this point, the headway becomes increasingly stable as spacing increases. When the headway reaches 3 seconds, the space distance approaches the critical value, typically between 30 and 40 meters at road capacity. Beyond this point, the headway increases, leading to a lower traffic flow, as the road becomes congested. Vehicles maintaining a distance of less than 30 meters from each other are likely to experience unstable flow conditions.

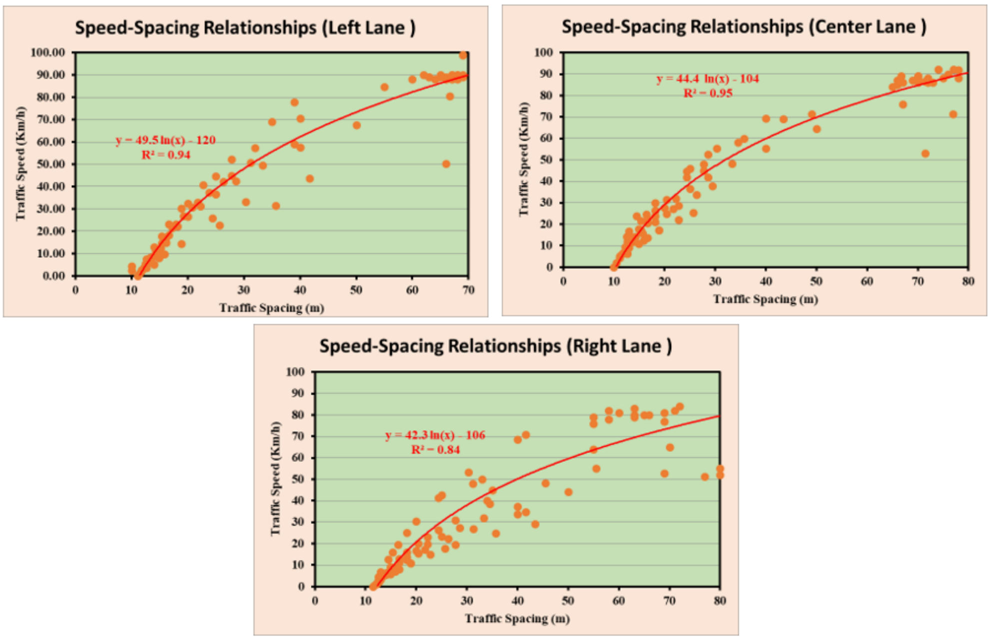

Fig. 6 Logarithm relationship and mesoscopic model between space mean speed and traffic spacing for each lane of segment NO.1, North dir. with R-square values.

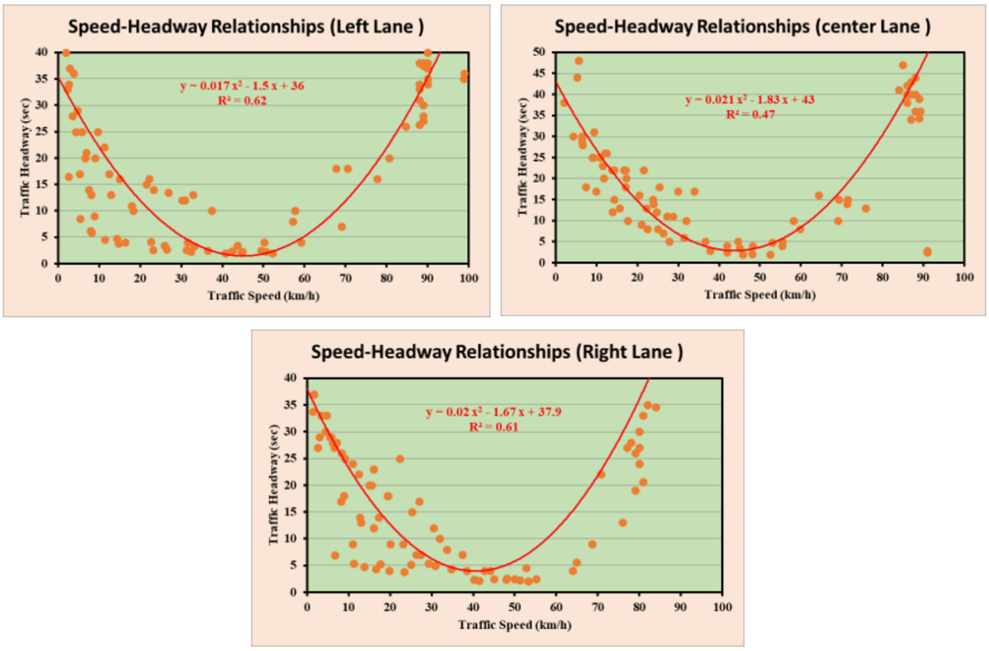

Fig. 7 Quadratic relationship and mesoscopic model between space mean speed and time headway for each lane of segment NO.1, North dir. with R-square values

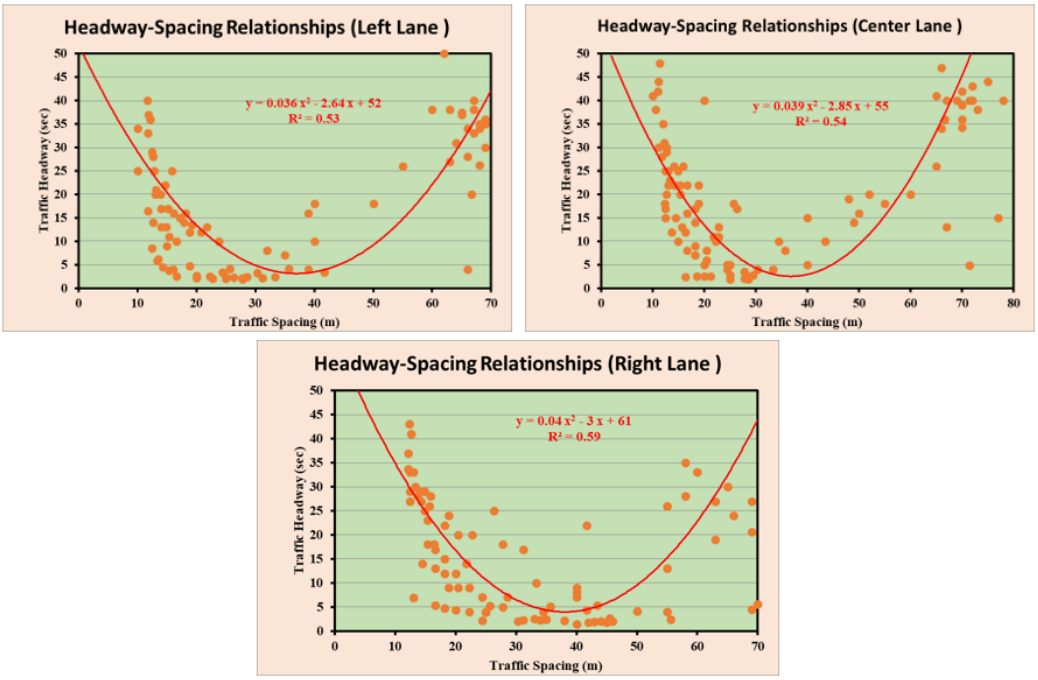

Fig. 8 Quadratic relationship and microscopic model between time headway and spacing for each lane of segment NO.1, North dir. with R-square values.

5.3 Validation of the models

To validate the model, a new dataset was collected from another highway segment and compared with the results of the developed models. The correlation between them was tested using the coefficient of determination and Chi-square methods [20]. In summary, the models are evaluated using R-square as the coefficient of determination and the chi-square test for goodness of fit, as shown in Table (3). The null hypothesis at a 95% confidence interval is H0: there is no significant difference between the observed and expected frequencies.

Table 3 summary of models and statistical calibration.

Traffic Characteristics Y-X	Left lane		Center lane		Rigth lane		Chi-square value
	The model	R-square	The model	R-square	The model	R-square	
Speed-Spacing	Y= 49.5 ln(x) - 120	0.94	Y= 44.4 ln(x) - 104	0.95	Y= 42.3 ln(x) - 106	0.84	90
Headway-Speed	Y= 0.017x^2-1.5x+36	0.62	Y=0.021x^2-1.83x+43	0.47	Y= 0.02x^2-1.67x+37.9	0.61	60
Headway-Spacing	Y= 0.036x^2-2.64x+52	0.53	Y= 0.039x^2-2.85x+55	0.54	Y= 0.04 x^2 - 3x + 61	0.59	60

The models for each lane, as shown in the table, pertain to each lane of the multi-lane highway segment. The coefficient of determination (R-square) indicates the correlation strength of the models, with values close to 1 for speed-spacing model representing a strong correlation and lower values for headway-speed and headway-spacing representing accebtable correlation. Additionally, the goodness of fit test, using chi-square values, shows that all models have chi-square values less than the critical values from the table. This means the null hypothesis (Ho) is accepted. These microscopic variables influence the macroscopic traffic flow parameters that are used in HCM (Highway Capacity Manual) methodology to determine Level of Service (LOS).

The lane-by-lane analysis provided by microscopic models identifies differences in traffic characteristics across lanes, which are often averaged out in macroscopic models. since spacing is inversely related to density, and headway is inversely related to flow, the analysis with more accurate microscopic data, the flow and density measures used in HCM's LOS calculations can be more reliable. Additionally, lane-specific data address localized issues like congested center lane and closely traffic volume in median and right lane, that can be used to specify the suitable solution and improve overall highway performance.

6. CONCLUSION

The results yielded several conclusions, summarized as follows:

1- Level of Service (LOS) Analysis: Using the HCM 2022 methodology, the LOS results indicated a lower quality of the traffic stream on the five segments of the study area. Currently, many directions show LOS E, with projections indicating LOS F by 2030 on two segments in each direction.

2- Speed-headway-spacing relationships were identified as effective traffic characteristic models for segment No. 1. These models also exhibited high R-square values for speed-spacing model and lower values for headway-speed and headway-spacing models. For all models, there are a low RMSE values, with validation through chi-square values below critical levels at a 95% confidence interval. They accurately represent vehicular and driver behaviors on highways and can be utilized in various traffic engineering studies as a recommendation.

3- By simply knowing the speed data, these models can help obtain microscopic data such as headway and spacing, which will make it easier for future research to collect microscopic data.

4- These microscopic variables influence the macroscopic traffic flow parameters that are used in HCM (Highway Capacity Manual) methodology to determine Level of Service (LOS). Microscopicparameters in this models can be used as measure of effectiveness when analyzing studied multilane highway or similar segments using HCM to determine the precise performance.

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تقييم أداء حركة المرور ونمذجة الخصائص الدقيقة على الطرق السريعة الحضرية متعددة المسارات في مدينة الموصل

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الملخص

نظرًا لأن نظام الطرق السريعة متعددة المسارات يعد جزءًا أساسيًا من شبكة الطرق الحضرية، فمن الضروري للمهندسين المروريين والمخططين وصناع السياسات فهم وتقييم جودة الخدمة التي توفرها هذه الطرق. تم إجراء عملية التقييم باستخدام دليل السعة للطرق السريعة الأمريكي (HCM) من خلال تطبيق مفهوم مستوى الخدمة (LOS). بالإضافة إلى ذلك، فإن تدفق حركة المرور يتأثر بشكل كبير بالخصائص الدقيقة، مما يجعل من الضروري نمذجة هذه الخصائص لكل مسار من مسارات الطريق السريع. تؤثر هذه النمذجة على سلوك كل من المركبات والسائقين.
يهدف هذا البحث إلى تقييم مستوى الخدمة (LOS) لخمسة مقاطع من الطرق السريعة متعددة المسارات باستخدام منهجية دليل السعة للطرق السريعة لعام 2022 (HCM). بالإضافة إلى نمذجة العلاقات بين السرعة، والتباعد الزمني، والمسافة الفاصلة بين المركبات. تشير النتائج إلى فشل في مستوى الخدمة في اثنين من المقاطع المدروسة، خاصة في التوقعات التي تمتد إلى سبع سنوات في المستقبل. بالنسبة لنماذج السرعة-التباعد الزمني-المسافة الفاصلة، تم استخدام معامل التحديد (R-square) واختبار مربع كاي لتقييم مدى ملاءمة النماذج، باستخدام برنامج SPSS. وأظهرت النتائج عدم وجود فروق ذات دلالة إحصائية بين البيانات المتوقعة والبيانات الملاحظة، مما يبرز خصائص المرور مثل التدفق، والسرعة، والكثافة. يمكن استخدام هذه النماذج لتحديد مختلف معايير المرور في الدراسات المستقبلية المتعلقة بالطرق السريعة التي تم فحصها.

الكلمات الدالة:

الطريق السريع متعدد المسارات، مستوى الخدمة، HCM2022، سرعة المرور، المسافة الزمنية بين السيارات، التباعد.