Speed Flow Density Models Prediction for Urban Roadway in Falluja City

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Abstract.

This research focuses on studying the speed flow density relationships which are considered the fundamental traffic flow relationships. The objective of the present study is to predict statistical models represent these relationships depending on a field survey data collected from Al-Thirthar road in Falluja city.

Data were collected by using video-recording technique. The required data were abstracted, analyzed, grouped, and processed using computer programs developed for this purpose. Standard statistical analysis techniques were used to examine and analyze the observed data.

FWASIM simulation traffic software program was used to verify the predicted traffic stream models, while the obtained results were presented in this research. To test the validity and reliability of the model, the output results of the predicated model were compared with the output data obtained from **FWASIM** model using similar input data and segment geometry. The comparison leads to consider that the developed regression model may be used to evaluate the performance of urban streets in Falluja city.

Keywords: Speed-Flow-Density, Predicted Model, Traffic Simulation.

1. Introduction.

In the recent years, transportation problems have been attracting a lot of attention. Recent growth in urban areas has resulted in increasing demand for travel on the urban street. As a result, the traffic operations in Falluja city reflect lowest level of service (LOS) in the urban streets. In many areas in Falluja city, urban streets are operating in congested conditions throughout the work day.

Improvement of the quality service of highway traffic movement would contribute to reduce the congestion. Evaluating quality of service and fundamental traffic flow relationships through development regression model are the important issues that are discussed in transportation analysis.

Three descriptors are significance for considering the flow of traffic along a highway. These factors are the speed and the density, which describe the quality of service experienced by the stream and the flow or volume, which measures the quantity of the stream and the demand on the facility.

A comprehensive statistical analysis of macroscopic parameters at a highway segments are essential requirements in planning, design, and operation of transportation systems. This study obtained values for speed, flow, density and predicted regression model to explain the traffic fundamental relationship between them.

2. Research Objective.

The objective of this research is to predict statistical models to represent the fundamental traffic flow relationships between speed, flow and density in the urban roads in Falluja city.

3. Review of Literature.

Based on the relationship between the three parameters(speed, flow and density), many observations have been carried out to determine the relationship between any two of these parameters for, with one relationship established, the relationship between the three parameters is determined as mentioned by R.J., Salter [1]. Usually the experimenters have been interested in the relationship between speed and flow because of a desire to estimate the optimum speed for maximum flow.

Obeid [2] developed mathematical models that deal with the three main characteristics of traffic: speed, flow, and density, in order to describe the intersection between these key variables for different types of facilities on selected arterial streets in Baghdad city.

Nicholas J. Garber, et al. [3] noted that the development of mathematical relationships among the primary elements of a traffic stream: flow, density and speed; help the traffic engineer in planning, designing, and evaluating the effectiveness of implementing traffic engineering measures on a highway system.

4. Speed-Density Models.

It is an observable fact that drivers reduce their speeds as the number of vehicles increases as stated in Highway Research Board [4]. Because of the close interaction between density and speed, and knowing density and speed, from which flow can be computed, early investigators explored relationships between speed and density.

C. Jotin Khisty, et al. [5] discussed so far the general model connecting speed and density which is a linear model proposed by Greenshields (1935). **Fig. (1)** illustrates this linear relationship. The statistical quality of this model may be poor because of the low coefficient of determination and high standard errors. The form of the model is:

$$V_s = V_f - \left(\frac{V_f}{D_j}\right) D \tag{1}$$

Where:

V_s = the space mean speed.

V_f = the space mean speed for free flow conditions.

D = the density.

D_j = the jam density.

However a linear relationship does not always exist over the entire range of observations. Greenberg, as mentioned by R.J., Salter [1]observed traffic flow in the north tube of the Lincoln Tunnel at New York City. He assumed that high density traffic behaved in a similar manner to the movement of continuous fluid. He found the developed speed–density model was of the form:

$$V_s = C \ln\left(\frac{D_j}{D}\right) \tag{2}$$

Where:

C is constant and the remaining symbols are as previously defined. This model shows good agreement with field data for congested flow condition.

D.R. Drew [6] has described a family of models of which Greenshields'model is a special case. The other families result from car following analysis. He proposed a family of models of the form:

$$V_s = V_f \{1 - (\frac{D}{D_j})^{(n+1)/2}\} \text{ …… for } n > -1 \tag{3}$$

Where: n is a real number.
When n=1 equation can be solved to yield Greenshield's model.

5. Flow-Density Models.

Hight F.A.[7] mentioned that the relationship between flow and density illustrated in **Fig. (2)** has been referred to as the fundamental diagram of traffic.

From **Fig. (2)** it can be clarified that as density increases, the flow increases to a maximum flow. This corresponds to the optimum density D_0. Beyond the optimum density, the flow decreases with increasing density. The optimum density is the cut-off point between free-flowing and congested traffic conditions.

There are two models of flow-density relationship as mentioned by Matthew J. Huber[8]:

1) The Parabolic Model

This model is directly derived from Greenshield's model of speed-density. The final form is:

$$q_m = V_f * (D_j / 2) - (V_f / Dj) * (Dj / 2)^2 = V_f * Dj / 4 \tag{4}$$

2) The Logarithmic Model

The logarithmic model of flow-density follows directly from Greenberg's model of speed-density. Substituting equation for V in above equation it will result:

$$Q = D*C \ \ln(\frac{D_j}{D}) \tag{5}$$

Some important features of the flow-density diagram may be summarized as follows as mentioned by R.J., Salter [1] :

1- The flow is obviously zero when the density is zero and at the jam density the flow may also be assumed to be zero.

2- Between these limits the flow must rise to at least one maximum, often referred to as maximum capacity.

3- At any point on this curve, the slope of the line joining that point to the origin is the space mean speed, the slope is obviously greatest at origin and decreases to zero at the jam density.

6. Speed-Flow Relationship.

Al-kubaisy [9] stated that speed-flow model can be determined, as the speed-density model has been determined. The free flow speed V_f at zero density is the maximum obtainable speed. There will be a second point of zero flow, corresponding to zero speed at maximum density D_j. Between zero and maximum speeds, the diagram will form some type of loop toward maximum flow. The final model of this relationship is as below:

$$Q = D_j \left(V - \frac{V^2}{V_f}\right) \qquad (6)$$

The general form of speed-flow relationship may be illustrated in **Fig. (3)**.It is clear from **Fig. (3)** that in low flow (free-flow) conditions, speed decreases as the flow increases up to a maximum flow point (q_m) . Furthermore, speed decreases with flow reductions because of the increase of traffic density beyond the maximum flow. This occurs because maximum flow can be reached in congested traffic conditions, and in these conditions the traffic flow is not stable.

7. Data Collection.

Based on the initial surveys, Al–Thirthar highway section, that starts from Baghdad main road and ends to the roundabout facility which leads to Al-Saqlawia direction was selected since it is found to be satisfied with the objectives and specifications of the data collection. The selected section consists of two segments separated by Al-Hadra Mosque intersection. A brief description of each segment is presented below:

Segment one represents the beginning of highway section which starts from the main highway that leads to Baghdad and ends at Al- Hadra Mosque. This segment has two directions; North Bound (NB) and South Bound (SB), they are divided by a concrete median with height of (50) cm and above width of (36) cm. Each direction has two lanes with 3.5 m width and wide sidewalk more than 10 m for both directions.

Segment two represents the second part of the highway section starts from Al-Hadra Mosque and ends at Al-Saqlawia roundabout direction. This segment also has the same above mentioned two directions; which are divided also by the same dimensions of concrete median. Each direction has two lanes with 3.5 m width and wide sidewalk more than 10 m for both directions.

This research contains highway section layout located on Falluja city map as illustrates in **Fig. (7)**.

8. Method of Data Collection

The method of measurement should be suitable for the various activities of traffic movements through providing data about a number of vehicles (traffic volume), types of vehicles (traffic composition), speed, density, direction and the distance that vehicle travels.

According to the currently available methods of traffic data collection, the video recording is the most suitable method due to the following factors:

1. Shortening time and cost.

2. Size of required activities and traffic behaviors which may be achieved.
3. The manual and automatic methods allow only for partial information about traffic movements to be collected during an observation period.
4. Because of the capability of replaying the video film many times to check any suspicious event, so there is a possibility to recover any human error and manipulate any incident occurred during the recording session.

So, the researcher uses video recording technique to collect the data, this technique has the following advantages, Al-kubaisy [9]:

- Allowing for a large number of events to be recorded at one time.
- Recording any incident that may occur during the recorded session which may result in abnormalities in the observed data, that can be abstracted in a later stage.

The data were collected using a digital video camera with direct display. The camera was put in front of the segments to collect the data associated with vehicle traffic flow parameters. A good vantage point was selected by researcher to give the best view to record the two segments. The camera was connected to spatial apparatus to transfer video recording from videotaped to the personal computer to abstract and process the observed data.

9. Data abstraction and processing.

9. 1 Data abstraction.

The recorded data were abstracted from video films with the aid of computer program called "EVENT" program. This program was developed by Ali-H-Al-Neami [10]. The program produces time accuracy values of the recorded data. The accuracy is up to 0.01 second. The procedure of how this program works was explained by Al-Neami, H. K., [10].

Another program wrote by Visual Basic language was developed to group the data in a form of intervals to simplify the statistical analysis of the data. Video films were played back a number of times to get the required information.

The abstracted data included the following:

1. Vehicular traffic flow and traffic composition.
2. Sufficient speed data measured for individual vehicles and should be statistically meaningful.

9. 2 Data processing.

9. 2. 1 Traffic Flow.

The total traffic flow for the two segments in morning and evening periods from (7:30 to 9:00) A.M and (3:30 to 5:00) P.M and their combinations are presented in **Table (1)**.

9. 2. 2 Traffic Composition.

The traffic composition for the two segments in both directions and in morning and evening periods are presented in **Table (2)**.

In **Table (2)**, the percentage of bicycles in south bound of segment two is reasonably high. The reason is the periods of video recording which were done in peak hours from (7:30 to 9:00) A.M and (3:30 to 5:00) P.M and during the time that the pupils using bicycles go to or leave their schools, in addition people use bicycles to avoid passing through the check points.

10. Development of Regression Model.

Data survey was made to develop a regression model. The model which needs to be built for this study represents speed-density relationship. This relationship is well known in the traffic engineering community as the fundamental relation of traffic flow. This means that if two parameters are known, the third can be estimated easily.

Set of data were collected from the two segments of the highway section. Speed data were collected by taking two reference points with known distances, and different durations of time which vary between (90, 60, 30, 15 and 10) minutes for the whole of 12 hours from video recording for both segments in the two directions, through morning and evening periods from (7:30 to 9:00) A.M and (3:30 to 5:00) P.M. The speed of each vehicle passing between these two points was calculated through dividing the distance over time that the vehicle spent to pass these known distances. Several values of an average speed were obtained; also the traffic flow was computed in the same time of each duration. The surveyed data are presented in **Table (3)**. The density can be calculated from the fundamental relationship, which is [Q=V*D].Their values are also shown in **Table (3)**.

To test the adequacy of the sample size, Nicholas J. Garber, et al. [3] mentioned that the duration of the study should be such that the minimum number of vehicle speeds required for statistical analysis is recorded, typically, the duration is at least (1) hour and the sample size is at least 30 vehicles. The duration of this study is 12 hours and the sample size is 65 different periods of many measured vehicles in each period which resulted in 65 average speed points. The minimum number of speed collected that satisfies the requirement of this case is less than the actual sample size that collected in the field which is greater than 30 vehicles.

The speed and density values were analyzed statistically using regression analysis. The main objective is to develop a statistical model which represents the speed-density relationship. The regression technique results in an equation which is described as in following:

$$Y = 57.065 - 0.9024 * X \qquad (7)$$

It is important to mention that this model is applicable for free flow speed equal to (57.065) or less.

The determination coefficient (R^2) for this model is equal to (0.804). This value suggests that the obtained regression model explains about 80 % of the observed scattered data. The remaining 20% is not explained due to the random nature of other variables which were drawn from statistical distribution. **Fig. (4)** shows the scattered plot and the developed regression model for the relationship between average speed and density.

11. Determination of Speed-Density Relationship.

The above data obtained in the previous section which is analyzed statistically using linear regression technique is used to develop a statistical model that represents the relationship between speed and density .The general form of the adopted model for linear regression analysis is as below:

$$Y = a + bX$$

The similarity between the adopted model for linear regression analysis and the general form of Greenshield's model which was explained hereinbefore indicates that:

Y is equivalent to the value of V
a the constant, is equivalent to the value of V_f
$b = \frac{V_f}{D_j}$, and X is equivalent to the value of D

So, the final form of predicted speed-density relationship is presented as in following:

$$V = 57.065 - 0.9024 * D \tag{8}$$

12. Determination of Flow-Density Relationship.

The flow-density relationship can be derived as described below:

$$V = V_f - \frac{V_f}{D_j} D \quad \text{and;} \quad Q = VD$$

Where:

$Q =$ The traffic flow, therefore, by substitution

$Q = (V_f - \frac{V_f}{D_j} D)D$ and by simplification

$Q = V_f D - \frac{V_f}{D_j} D^2$

Substituting the constant values of the above developed regression model, results in;

$$Q = 57.065 * D - 0.9024 * D^2 \tag{9}$$

Which represents the predicted flow-density relationship.

13. Determination of Speed-Flow Relationship.

The speed-flow relationship can be derived as described below;

From the predicted above equation which is

$V = 57.065 - 0.9024 * D$, therefore,

$D = (57.065 - V)/0.9024$

By substitution the value of D in the following flow-density predicted equation $Q = 57.065 * D - 0.9024 * D^2$ the resulted equation is as follow:

$$Q = 57.065 * \left[(57.065 - V)/0.9024\right] - 0.9024\left[(57.065 - V)/0.9024\right]^2 \tag{10}$$

The equation represents the predicted relationship between the flow and speed for this highway section.

The developed regression model is applicable for free flow speed equal to (57.065) or less. This result is compared with other similar studies in Baghdad city as shown in **Table (4)**.

The observed data for this study seems to be approximately consistent with the study of Younis Ahmed [11], while it is underestimated as compared with that produced by Al-kubaisi study [9], the reason is attributed to the fact that Al-kubaisi study was conducted on freeways which have higher design speed limits.

14. Verification of the Developed Regression Speed-Density Model.

Verification of the developed regression model output is achieved by selecting a proposed highway section similar to urban street. The following assumptions are considered for this test:

1. Flow varied from 500 to 2500 veh/hr with an interval of 100 veh/hr.
2. Vehicles arrive at highway section at random with Negative exponential distribution of vehicle inter-arrival times.
3. Traffic composition is 95% passenger cars, and 5% heavy goods vehicles (trucks).

The **FWASIM** (**F**reeway **W**eaving **A**rea **SI**mulation **M**odel) is used to calculate the average speed and density, which corresponds to each level of vehicle flow. The density values produced from **FWASIM** are used as an input data for the developed equation to calculate speed expressed by developed equation. The obtained speed values of developed equation are then compared with that predicted by the **FWASIM** model. **Table (5)** shows the data obtained from **FWASIM** program (predicted) and that obtained from developed equation (calculated). These values are also plotted against the density variation as shown in **Fig. (5)**. Comparison of calculated and predicted speed results is presented in **Fig. (6)**.

Fig. (5) illustrates that the trend of both models goes symmetrical, however, there is a lower estimate of the relationship shown by regressed model. This may be attributed to the following:

1- **FAWSIM** is a microscopic model because of its nature of handling the movements of vehicles and resolution and it is a mathematical model that captures the movement of individual vehicles, while the developed regression model is a mathematical model that employs traffic flow rate variables like (flow, speed, density .etc).

2- **FWASIM** model designed for freeways that deals with high speeds, while the developed regression model derived from data collected on un urban highway section.

15. Conclusions and Recommendations.

15. 1 Conclusions.

Based on the findings of this study, the followings can be concluded:

1- The developed regression models may be used to predict the speed- flow-density relationships for urban highways in Falluja city and other similar areas.

2- Segment one and the south bound of segment two have the same average speed and standard deviation which are closely to be (50.1 km/hr) and (10.2) respectively. While the north bound of segment two an average speed of (43.95 km/hr) and standard deviation of (10.814). This reduction in speed value is mainly attributed to the existence of conflicting flow generating from the local roads which meets this segment.

3- The free flow speed that calculated for road section was found to be (57.065 km/hr).

15. 2 Recommendations.

1- Due to the existence of wide width of shoulders along both sides of the road, it is recommended to redesign the road geometry through increasing the number of lanes and making On-Street parking to prevent stopping on the street to enhance its performance.

2- It is recommended to use the developed regression model to evaluate the speed-flow-density relationships for the urban highways in Falluja city.

16. References.

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Table 1: Traffic flow for highway section

Segment Number	Total flow (veh/hr)					
	North bound			South bound		
	Morning	Evening	Aver.	Morning	Evening	Aver.
One	741	939	840	839	700	770
Two	615	736	676	427	376	402

Table 2: Traffic composition for highway section

Veh Type	Seg. no.	% for each type					
		North bound			South bound		
		Morning	Evening	Ave.	Morning	Evening	Ave.
Pcars	One	71.39	73.69	72.74	74.50	74.29	74.42
	Two	76.75	74.86	75.74	70.96	70.75	70.9
Trucks	One	10.26	12.67	11.67	10.85	10.57	10.78
	Two	7.32	8.30	7.84	8.20	9.04	8.71
Buses	One	5.13	1.28	2.97	2.86	1.00	2.08
	Two	3.74	1.90	2.80	3.51	1.86	2.73
Bicycles	One	3.64	1.71	2.5	4.17	5.43	4.67
	Two	5.20	4.21	4.59	8.43	7.71	7.96
Others	One	9.58	10.65	10.12	7.62	8.71	8.05
	Two	6.99	10.73	9.03	8.90	10.64	9.70

Table 3: Surveyed data used for regression model development

Aver. speed Km / hr	Flow Veh / hr	Density Veh / km	Aver. speed Km / hr	Flow Veh / hr	Density Veh / km
47.863	575	12.014	38.284	786	20.531
45.197	658	14.559	41.936	558	13.306
48.497	508	10.475	41.63	519	12.467
45.896	588	12.812	40.962	539	13.159
52.21	460	8.810	43.105	542	12.574
45.8	556	12.141	43.02	604	14.041
45.98	620	13.484	44.732	574	12.832
48.75	664	13.621	43.879	484	11.030
40.38	648	16.048	34.313	464	29.571
53.35	620	6.973	42.604	452	10.610
44.67	582	13.031	20.00	660	33.00
40.22	794	19.741	46.252	425	9.189
47.22	672	14.231	47.284	433	9.157
36.28	916	25.244	50.867	434	8.532
51.21	576	11.247	44.215	410	9.273
37.15	906	24.389	43.002	460	10.697
35.26	1074	30.461	48.808	418	8.564
45.894	804	17.519	52.418	388	7.402
43.077	768	17.829	47.266	444	9.394
42.961	672	15.642	54.129	424	7.833

38.368	792	20.643	44.324	412	9.295
37.416	812	21.702	41.666	522	12.528
39.972	744	18.613	48.521	410	8.449
40.09	716	17.859	46.234	436	9.430
38.402	668	17.395	52.515	381	7.255
37.881	802	21.172	55.13	358	6.494
40.03	730	18.236	47.265	456	9.648
38.596	778	20.157	53.761	378	7.031
39.257	692	17.627	45.826	484	10.562
38.286	834	21.784	49.004	428	8.734
36.462	846	23.202	52.063	380	7.299
39.457	804	20.376	55.593	376	6.763
			54.625	340	6.224

Table 4: Speed results comparison for different studies

Study	2001 Younis Ahmed conducted on arterial road	2004 Al-kubaisi conducted on freeways	This study conducted on collector road
Average free flow speed (km/hr)	55	70.85	57.065

Table 5: Predicted and calculated speed values

Flow veh/h	Predicated speed, km/hr from FWASIM	Predicated density veh/km from FWASIM	Calculated speed from developed equation(km/hr)
500	85.8	3	54.36
600	84.9	3	54.36
700	84.5	4	53.46
800	83	5	52.553
900	82.5	5	52.553
1000	81.8	6	51.651
1100	80.8	7	50.75
1200	80.8	7	50.75
1300	79.5	8	49.85
1400	79.2	9	48.94
1500	78.1	10	48.041
1600	77.7	10	48.041
1700	76.2	11	47.14
1800	76.4	12	46.24
1900	74	13	45.33
2000	74.3	14	44.43

2100	74.2	14	44.43
2200	72.7	15	43.53
2300	72.1	16	42.63
2400	70.8	17	41.724
2500	69.7	18	40.822

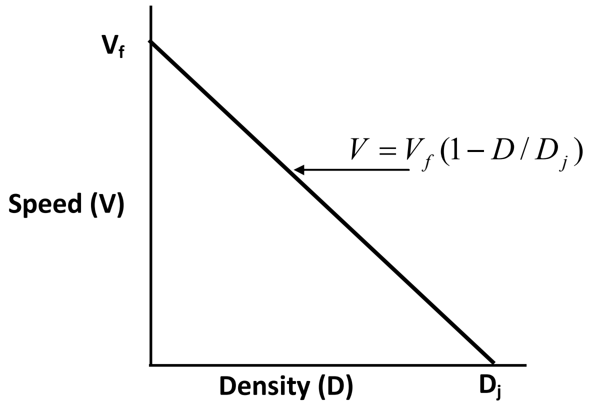

Figure (1): Greenshield's linear speed-density relationship

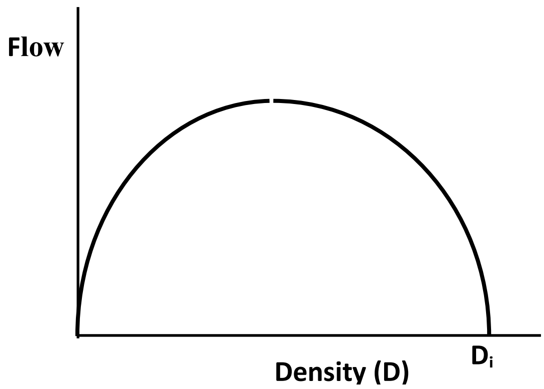

Figure (2): Typical flow-density diagram

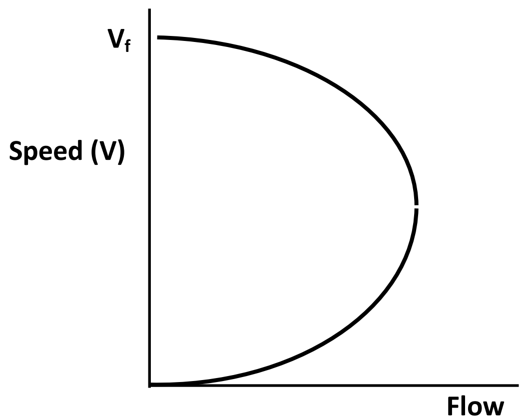

Figure (3): General form of speed-flow relationship

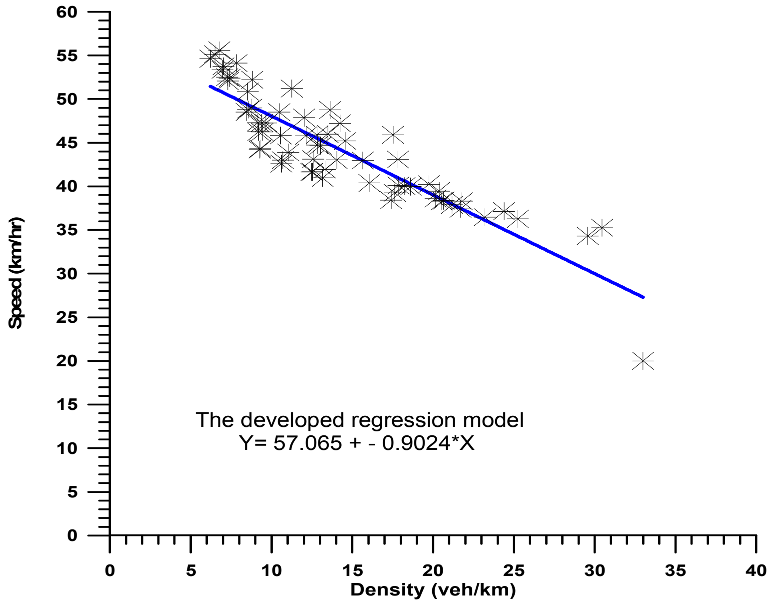

Figure (4): Relationship between the average speed and density value

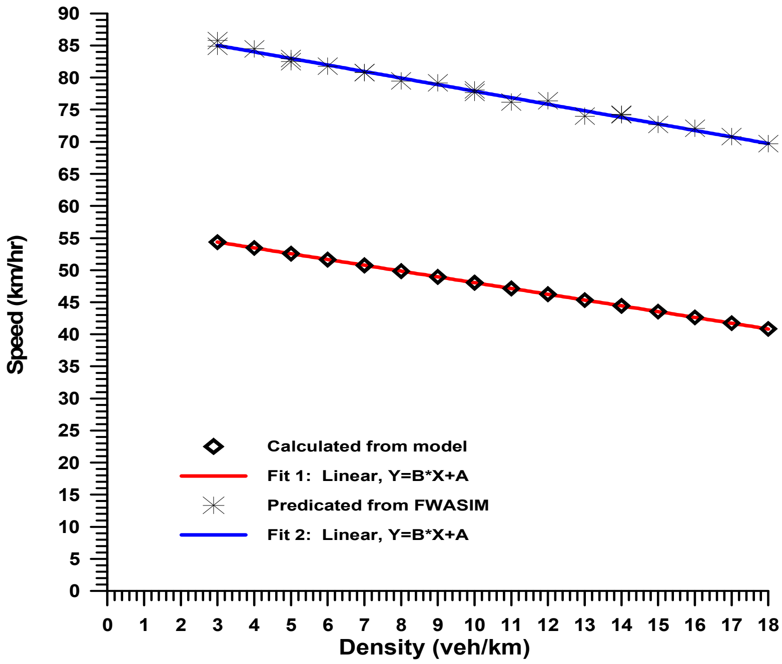

Figure (5): Effect of density variation on average traffic speed

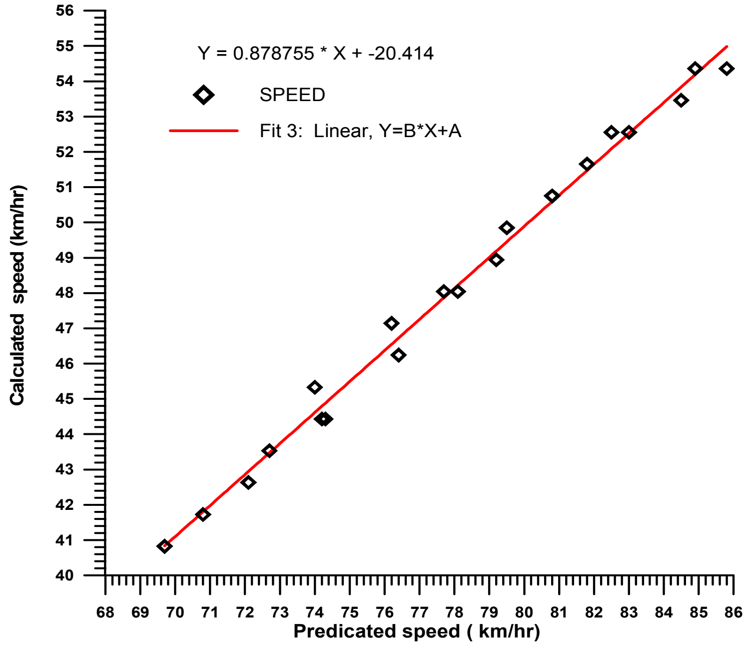

Figure (6): Comparison of the developed equation and FWASIM outputs

Figure (7): Map of the location of Al-Thirthar urban street section in Falluja city

التنبؤ بنماذج السرعة- الحجم- الكثافة لطريق حضري في مدينة الفلوجة

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الخلاصــــة.

البحث يركز على دراسة علاقات السرعة-الحجم-الكثافة والتي تعتبر علاقات أساسية للدراسات المرورية. إن الغرض من الدراسة هو التنبؤ بنماذج إحصائية تمثل هذه العلاقات معتمدة على معلومات حقلية لطريق الثرثار في مدينة الفلوجة. وتم جمع المعلومات بواسطة التصوير الفديوي ولخصت وعولجت وفحصت البيانات بواسطة برامج حاسوبية اعدت لهذا الغرض.

إن (**FWASIM**) هو برنامج محاكاة تم استخدامه للتحقق من صحة ودقة البرامج المستنتجة، بينما تم عرض النتائج المستخلصة في البحث، للقيام بذلك قورنت النتائج المستنتجة من تطبيق النماذج مع مخرجات برنامج ال(**FWASIM**) باستخدام نفس المدخلات للبرنامجين. المقارنة تقود إلى اعتبار إمكانية استخدام النماذج المستنتجة لتقييم أداء الطرق الحضرية في مدينة الفلوجة.