Eng. & Tech. Journal, Vol.29, No.3, 2011

Improving a Model for Speed / Density Relationship on Arterial Roads in Baghdad City

Abeer Khudher Jameel*
Received on: 18/9/2010
Accepted on: 3/3/2011

Abstract

This paper was undertaken to investigate the relationships between speed and density on urban arterial roads of Baghdad City. This research work was based on the traffic survey data (PC volume and average speed) collected in Palestine Street in 3 sections at two directions through 12 hours within 3 weekdays. The density is computed using fundamental formula of traffic flow. Eight theoretical Speed-Density models (5 are single Regime Models and 3 are Multi-Regime models) are validated by the field data by two statistical test methods (CHISQ test and Paired T-test). The results show that no one of the theoretical models is good in fit with the real data. Then a Multi-Regime Model is improved under two ranges of density (<70 and >70) at south approach and (<60 and >60) at north appraoch . This model is tested using regression analysis, CHISQ test, and Paired T-test. This analysis shows that the model has good fit with the field data.

Keywords: Speed-Density relationship, arterial, regression analysis, CHISQ, paired T-test

تطوير نموذج رياضي للعلاقة بين سرعة وكثافة المرور على الطرق الشريانية في مدينة بغداد

الخلاصة

يهدف البحث إلى تطوير نموذج رياضي للعلاقة بين سرعة وكثافة المرور على بعض الوصلات للطرق الهامة بمدينة بغداد. أعتمد البحث على مسح البيانات المرورية (الحجم المروري للمركبات الصغيرة ومعدل السرعة) والتي جمعت من موقع شارع فلسطين من خلال ثلاث مقاطع وبالاتجاهين وخلال مدة مسح 12 ساعة لثلاث ايام. قيم الكثافة المرورية حسبت باستخدام معادلات الجريان المروري الاساسية. تم تدقيق صحة النتائج المستحصلة من ثمانية موديلات نظرية تربط بين سرعة المرور والكثافة المرورية (خمسة منها ذات نظام مفرد وثلاثة ذات نظام متعدد) باستخدام طريقتان للفحص الاحصائي (CHISQ و Paired T-test). بينت النتائج أن الموديلات الثمانية لاتطابق في نتائجها البيانات الحقلية. لذا تم تطوير نموذج رياضي باعتماد النظام المتعدد ضمن مديين من قيم الكثافة المرورية (<70و>70) في الاتجاه الجنوبي و (<60و>60) في الاتجاه الشمالي . تم فحص هذا الموديل باستخدام (regression analysis, CHISQ test, وPaired T-test). بينت نتائج التحليل أن الموديل المستنبط يتطابق الى حد ما مع البيانات الحقلية.

* College of Engineering,University of Al-**Mustansiriy / Baghdad**

https://doi.org/10.30684/etj.29.3.17
2412-0758/University of Technology-Iraq, Baghdad, Iraq

Introduction

Traffic studies form a major part of the traffic engineer's work, as most control and design problems demand a detailed knowledge of the operating characteristics of the traffic concerned [1].

There are at least eight basic variables or measures used in describing traffic flow, and several other stream characteristics are derived from these. The three primary variables are speed (*v*), volume (*q*), and density (*k*). Three other variables used in truffle flow analysis are headway (h), spacing (s), and occupancy (R) [2].

Traffic flow theory involves the development of mathematical relationships among the primary elements of a traffic stream. These relationships help the traffic engineer in planning, designing, and evaluating the effectiveness of implementing traffic engineering measures on a highway system [3].

With more vehicles on the roads the interest in enhancing knowledge of microscopic simulation of traffic streams has become more important [4]. Nowadays, traffic flow models are needed for practical traffic control systems as well as for the investigation of characteristics of traffic flow. Traffic flow models developed until now can not be satisfactorily applied to practical traffic control systems because of difficulties in calibrating the parameters of the models. The parameters of traffic flow models have dominant effects on the simulation results of the models and should be calibrated depending on traffic data sets. These properties of traffic flow models are crucial for the online application of the models [5].

Traffic theory models

There are several traffic flow models, which can be mostly divided in 4 categories: macroscopic, mesoscopic, microscopic and submicroscopic. Speed, flow, and density are the most important macroscopic traffic flow parameters. The unique relation between the three macroscopic traffic flow parameters form the fundamental relationship:

$$q = k \times v \quad \ldots\ldots\ldots\ldots(1)$$

Beside the fundamental relation, there are also experimental relations between the traffic flow parameters. Traffic can have different regimes (characterized by variables related to the traffic state):

- Free-flow traffic is characterized by a low density (high speed), which results in a free-flow speed vf. Mostly vf is the maximum allowed speed.
- Capacity-flow traffic is characterized by a maximum flow which is called the capacity flow qc.
- Jammed traffic is characterized by a maximum density (low or no speed) called the jam density kj [6].

The role of traffic models in transportation engineering is two-fold. First, they provide better understanding of traffic dynamics, in particular the formation and propagation of traffic congestion. Hence, traffic researchers can use traffic models to identify possible bottlenecks. Second, they can serve as a simulation platform, on which different strategies for improving mobility can be developed and evaluated. For example, in the plan for expanding a road network, traffic models can be used to simulate proposed expanded networks and help chose the most cost-effective strategy. For another example, they are also helpful in determining the best location of tolling booths, which are designed to divert traffic away from busy roads by charging fees. Finally, traffic models can be used to evaluate previously implemented strategies [7].

Critical for modeling traffic dynamics are speed-density functions that play an important role in both mesoscopic and macroscopic traffic simulation models. Speed-density functions are particularly challenging, as they must encapsulate a variety of effects including traffic dynamics, lane speed distributions, vehicle and driver mix, and weather conditions. Many of these aspects vary with location within the network,and require careful calibration against real-world sensor data [8].

Speed-Density Relationship

Traffic flow models, particularly speed-density relations, lie at the core of a wide range of applications in almost all areas of traffic engineering and control [9].

The speed-density relationship serves as the basis to understand system dynamics in various disciplines. It can be used to model moving objects (or particles) in many scientific areas: pedestrians, conveyors, network information packages, crowd dynamics, molecular motors, and biological systems. In a live transportation system, a totally deterministic model is unlikely to include various dynamical randomness effects (or uncertainties). The stochastic behavior of real-world traffic systems is often difficult to describe or predict exactly when the influence of unknown randomness is sizable. However, it is quite possible to capture the chance that a particular value will be observed during a certain time interval in a probabilistic sense. In particular, speed-density (or concentration) models in a deterministic sense, whether single or multi-regimes, have a ‘pairwise’ relationship; that is, given a density there exists a corresponding speed from a deterministic formula [10].

The Highway Capacity Manual [11] provides the recent understanding of the empirical speed-flow relationship, which indicates that tin's relation has a more gradual slope with constant speed for higher volume of flow, therefore emphasizes on the transportation professionals to concentrate their research efforts on developing analytical speed-flow models that can describe speed-flow relationship and match the real behavior [11].

The shape of the speed-flow-density relationship of a highway facility has traditionally had a significant impact on the highway design and planning process, as the relationship would provide quantitative estimates of the change in speed as a function of anticipated or projected changes in traffic demand [12]. The decreasing relationship between speed and density is evident from physical observations. As the traffic on a roadway becomes more dense, the overall speed will decline [13]. Those model or simulate highways have also experienced a similar dependence of their models on a curve that describes the sensitivity of speed or travel time to the level of traffic flow. More recently, those who desire to subject a highway to various forms of real-time control or incident detection have once again revisited the topic of calibrating speed-flow-density relationships. Current real-time applications of speed-flow-density relationships involve a greater dependence on the accuracy of the estimates and have a need to autocalibrate these relationships on-line, rather than being granted the luxury to explore alternative fits off-line [12]

Speed-Density Relationships Models

Since Greenshield's (1935) seminal paper, various models have been proposed to analyze the speed–density relationship. Much effort has been devoted to improving the oversimplified relationship specified by Greenshield. Attaching empirically derived curves to a fitted linear model of the speed-density relationship started a new era of transportation science and engineering. Due to its strong empirical nature, the efforts to find a perfect theory to explain these particular shapes mathematically never cease, but they always achieve limited success. There is a fairly large amount of effort devoted to revising or improving such an over-simplified relationship. These efforts are shown in Table 1.There are also multiregime models which include the models that shown in Table 2 [10] and [14]. Traffic researchers have long been interested in functionally specifying and estimating these relations (*e.g.*, Greenshield 1935 and Drake *et al.* 1967), but without much behavioral and/or statistical sophistication. Greenshield's (1935) data suggested a linear speed-density relation, him to propose a parabolic function as an approximation to the flow-density relation. Other functional forms, based on notions like fluid dynamics and car following leading decisions, give rise to a variety of forms. For example, Greenberg (1959) proposed a logarithmic form for speed versus density, Underwood (1961) used an exponential form, and Edie (1961) combined these two to accommodate a clear discontinuity in data near critical densities. Segmentation of congested and uncongested data points is performed exogenously, and estimation relies on ordinary least squares methods [15].

The Objectives

The objectives of this study are

- Validating eight speed-density Models that are shown in Tables 1 and 2 with the actual speed and density values that collected from the field.
- Improving a Speed-Density Model and tested it by statistical testing tools.

Methodology

The following methodology has been adopted through the research undertaken:

1- Selection of the suitable sites along some arterial streets in Baghdad City
2- Comprehensive survey to determine the peak and off- peak hours to collect the necessary field data during the selected observation intervals.
3- Analysis and reduction of the collected data.
4- Selection of the proper statistical techniques for test the theoretical models and utilization of the reduced data in the development of the regression models using appropriate computer software.

Site Selection

Palestine Street is the site that has been chosen to meet the requirements of an interrupted flow facility. Three sections with length of 50m are selected to collect data, the first is between Mustansiriyah square and Palestine Intersection1, the second section is between Palestine Intersection1 and Palestine Intersection2 and the third between

Palestine Intersection2 and Beirut Square. This road has the following characteristics:

1. It is located in level terrain.
2. It carries a composite traffic volume of passenger car, microbuses, minibuses , and truck
3. It carries a large proportion of the daily traffic volume.
4. It is two-way, divided signalized urban arterial.

All surveys were achieved during daytime only in dry and clear conditions. Adverse weather conditions may cause variation in the usual traffic flow patterns.

Volume Conducting

Traffic volume was observed manually at the selected sections. The traffic counts used in this survey were collected of each segment at the midblock in 5-minute intervals for four and three arbitrary hours of observations in order to determine morning and afternoon peak and off-peak periods. A total of 12 observation hours within three days were earned out on the selected roads.

One observer with stop watch and field sheet was needed for each direction for the purpose of this survey.

Urban routes show very little variation in peak-hour traffic. In many urban areas, both the A.M. and P.M. peak periods extend for more than one hour. Figures 1 and 2 present the graphic representation of volume data sample at two directions of the section1.

PCE Values for Traffic Volumes

Vehicles of different types require different amounts of road space because of variations in size and performance. To allow for this in capacity measurements for roads, traffic volumes are expressed in passenger car unit.

The observed traffic volumes consist of five classes of vehicles namely the Passenger cars, bus, minibus (Coaster), microbus (Kia) and truck.

To convert the traffic volume to passenger car, passenger car equivalents (PCE) values were taken as (2.0) for buses and trucks and 1.8 for condition of level terrain.

Speed Conducting

Average through-vehicle travel speed (space mean speed) for the segment is the speed measure in Highway Capacity Manual [11], It is the most common method of collecting speed data and computed by the measurement of the time required for a vehicle to traverse a measured course. This method requires a stopwatch and a meters tape.

The following equation is used to determine the speed for any chosen length of study course:

$$SpotSpeed(kph) = \frac{CourseLength(km)}{ElapsedTime(hr)}$$

Spot speed data manually recorded, generally appears in the form of numbers of observations in defined speed ranges.

Figures 3 and 4 present the graphic representation of speed data sample at two directions of the section 1.

This data are reduced to standard statistics. Table 3 presents the Descriptive Statistics of field Spot Speed for the Selected Arterial at two directions.

Density

Density or concentration is defined as the number of vehicles in a one-mile segment of one lane of traffic. Ideally, free-flow speed is the speed that occurs when density and flow are zero over time [3].

The approximate of vehicles in a traffic stream is given by density, which is a critical parameter in describing freedom of maneuverability. The vehicle density (represented by the number of vehicles per kilometer per lane) used forthe exploratory analysis and the predictive models was computed with the methodologyproposed in the HCM 2000 [11].

Direct measurement of density in the field is difficult, requiring a vantage point from which significant lengths of highway can be photographed, videotaped, or observed, but commonly it is calculated from eq. (1) when the space mean speed and corresponding volume are known [3].

Density = flow / speed…….. (1)

Sample of the density results for one of the selected sections are shown in Figures 4 and 5.

Validating of the Theoretical Speed-Density Models

The collected density data were used as input to the eight Speed-Density Models that are shown in Tables 1 and 2, the graphic representation of the results with the field data are presented in Figure 7. Theoretical speed values are validated with the field speed data using CHISQ test and paired t-test. The results of this validating are presented in Table4.

From Figure 7 it is shown that the eight theoretical models give different values of speed at the same density point. Drake's Model and Greenberg Model Single-Regime Models give high values of speed that have high difference percent from the other models. On the other when the field density is less than 60 PC/km/lane, Northwestern Single-Regime Model give speed value that the nearest to the field speed values with average difference of (15 km/hr). When the field Density is greater than 60 PC/km/lane, Drake's Single-Regime Model give speed value that the nearest to the field speed values but with average difference of (18 km/hr).

From Table 4, it is shown that all the theoretical models have a CHISQ test with relative standard values less than 5%. This means that the deviation of the observed from that expected is not due to chance alone (other forces acting). So the predicted values are rejected.

The paired t-test results, as shown in Table 4, showed the mean of differences with a P-value. The p-value associated with t is low (< 0.05), there is evidence to reject the null hypothesis. Thus, we would have evidence that there is a difference in means across the paired observations and A null hypothesis of no difference between the means is clearly rejected; the confidence interval is a long way from including zero.

Improving of Speed-Density Model

Regression analysis method is used to build a Speed-Density Model for the selected arterial at two directions. The field Speed and Density data are used as input data in the Excel package to select the most appropriate model with highest coefficient of correlation (R^2). Figures 8a and 9a show the graphical representation of actual Speed-Density relationship for the selected arterial at the two Directions. From these figures it is shown that this relationship takes two shapes at two density ranges (less and greater than 60 PC/km/lane for north direction and less and greater than 70 PC/km/lane for south direction). Then two models are Improving for the two ranges as shown in Tables 5 and 6 and Figures 8b,8c, 9b, and 9c.

Validating of the Estimated Models

The estimated Speed-Density Model is validated with the field speed data using CHISQ test and paired t-test. The results of this validating are presented in Table 7.

From Table 7, it is shown that the estimated model have a CHISQ test with relative standard values g than 5%. This means that the deviation of the observed from that expected is due to chance alone (no other forces acting). So the predicted values are accepted.

The paired t-test results, as shown in Table 7, showed the mean of differences with a P-value. The p-value associated with t is greater than 0.05. Thus, we would have evidence that there is no difference in means across the paired observations and A null hypothesis is clearly accepted.

Conclusions and Recommendations

1-The results of the theoretical Speed-Density Models validating showed that:

- All of the Models give an estimated Speed value lower than the actual field value with high difference value except Drake's Model and Greenberg Model.
- All the theoretical models are rejected by statistical tests.

2- The most appropriate Model for the actual Speed-Density relationship is the 2nd order Polynomial model which was best fitting the speed-density relationships for arterial traffic flow in Baghdad City.

3- For more accurate model, it is recommended to investigate the speed-density model for more selected arterials within Baghdad city.

References

[1]El-Shourbagy M "Speed / Flow Relationship on Some Important Urban Arterial Roads: Fayoum City as a Study Case", http://www.mans.edu.eg/faceng/Journal/Abstract/2002/dec2002_Civ1.pdf, 2002

[2]Khisty, C., J. and Lall, B., K."Transportation Engineering, An Introduction", The United States of America: Prentice-Hall, Inc., 1998.

[3]Garber, N.J.,and Hoel, L.A ."Traffic and Highway Engineering." 2nd Edition, 1997.

[4] Erlingsson S, Jonsdottir A M, and Thorsteinsson T, "Traffic Stream Modelling of Road Facilities", Transport Research Arena Europe, 2006.

[5]Kim Y., "Online traffic flow model applying dynamic flow-density relation", Master degree thesis submitted to Fachgebiet Verkehrstechnik and Verkehrsplanung, Munich University of Technology, Germany, 2002.

[6] Ceulemans W, Magd A. W, Kurt De P ,and Geert W. "Modelling Traffic Flow with Constant Speed using the Galerkin Finite Element Method", Proceedings of the World Congress on Engineering London, U.K., Vol II, 2009.

[7] Wenlong J, "Kinematic Wave Models of Network Vehicular Traffic", doctoral thesis submitted to Office Of Graduate Studies of the University of California Davis, 2003.

[8] Balakrishna R, Antoniou C, Haris N. K, Yang W, and Ben-Akiva M, "Calibrating Speed-Density Functions for Mesoscopic Traffic

Simulation”, Symposium on the Fundamental Diagram: 75 Years (Greenshields 75 Symposium), Transportation Research Board, 2008.

[9] Tavana, H. , Mahmassani, H S, “Estimation and Application of Dynamic Speed-Density Relations by Using Transfer Function Models”, Transportation Research Record No. 1710, ISSN: 0361-1981, p. 47-57, 2000.

[10]Wang H., Jia LI, Chen Q Y, Daiheng N, “Speed-Density Relationship: From Deterministic to Stochastic”, TRB 88th Annual Meeting at Washington D. C. Jan. 2009.

[11]Transportation Research Board, “Highway Capacity Manual”, National Research Council. Washington, D.C. ,2000.

[12]Aerde M. V. and Rakha H., “Multivariate Calibration of Single Regime Speed-Flow-Density Relationships”, Vehicle Navigation and Information Systems Conference,. Proceedings. In conjunction with the Pacific Rim Trans Tech Conference. 6th International VNIS. 1995.

[13] Richters P, “Effects of Speed-Density Relationship on the lighthill-whitham-richards traffic model”, Master Thesis submitted to the faculty of the department of mathematics, Jacksonville University, College of Arts and Sciences, 2009.

[14]Karato K., SATO N., HATTA T., “The Speed–Density Relationship :Road Traffic Flow Analysis with Spatial Panel Data”, a study supported by KAKENHI: a Grant-in-Aid for Young Scientists (B) (#21730190) of the Japanese Ministry of Education, Culture, Sports, Science and Technology. 2009.

[15]Kockelman K. M., “Modeling Traffic’s Flow-Density Relation: Accommodation of Multiple Flow Regimes and Traveler Types’, *Transportation*, 2000.

Table 1 Deterministic Single-Regime Speed-Density Models*

Deterministic Models	Function	Parameters
Greenshields’ Model	$V=V_f (1-k/k_j)$	V_f, k_j
Greenberg Model	$V=V_m\text{-ln} (k_j/k)$	V_m, k_j
Underwood Model	$V=V_f e^{-(k/ko)}$	Vf, ko
Northwestern Model	$V=V_f e^{-1/2(k/ko)2}$	Vf, ko
Drake’s Model	$V=V_f e^{-1/2(k/kj)2}$	V_f, k_j

*Source [10]. and [14].

Table 2 Deterministic Multi-Regime Speed-Density Models*

Multi-regime Model	Free-flow Regime	Congested Regime
Edie Model	$V = 54.9e^{-k/163.9}$ $(k \le 50)$	$V = 26.8\text{In}(162.5/k)(k \ge 50)$
Two-regime Model	$V = 60.9 - 0.515k(k\le 65)$	$V = 40 - 0.265k(k \ge 65)$
Modified Greenberg Model	$V = 48(k \le 35)$	$V = 32\text{In}(145.5/k)(k \ge 35)$

*Source [10]. and [14].

Table 3 Descriptive Statistics of Field Spot Speed for the Selected Arterial

Direction	Sample Size	Min. Speed (km/hr)	Max. Speed (km/hr)	Mean Speed (km/hr)	Std. Deviation
South Direction	180	26.96	46.79	38.0484	5.32865
North Direction	180	26.96	50.96	38.1149	5.39430

Table 4 Statistical Test Results of the Theoretical Models

Model	CHISQ Test	Paired T-test
Greenshields' Model	0	0.000835098
Greenberg Model	0.000359	0.000359026
Underwood Model	0	4.4258E-09
Northwestern Model	0	0.221090179
Drake's Model	0	2.03488E-17
Edie Model	0.4901391	5.2327E-12
Two-regime Model	0	1.01181E-11
Modified Greenberg Model	0	7.69271E-13

Table 5 Estimated Speed-Density Model for the Selected Arterial (North Direction) with its Coefficient of Correlation

Density Range (PC/km/lane)	Estimated Model	R2
<60	$V^*=-1.0217K^*+93.354$	0.8238
>60	$V^*=0.0042K^{*2} -1.3067K^* +128.28$	0.9679

*V=Averae Speed (km/hr), K=Density (PC/km/lane)

Table 6 Estimated Speed-Density Model for the Selected Arterial (South) Direction)with Its Coefficient of Correlation

Density Range (PC/km/lane)	Estimated Model	R2
<70	$V^*=0.0219K^{*2} - 3.2365K^* - 148.72$	0.8682
>70	$V^*=0.0064K^{*2} - 1.8517K^* - 158.39$	0.9409

*V=Averae Speed (km/hr), K=Density (PC/km/lane)

Table 7 Statistical Test results of the Estimate Models

Model	CHISQ Test	Paired T-test
North Direction	1	0.829123582
South Direction	1	0.807432521

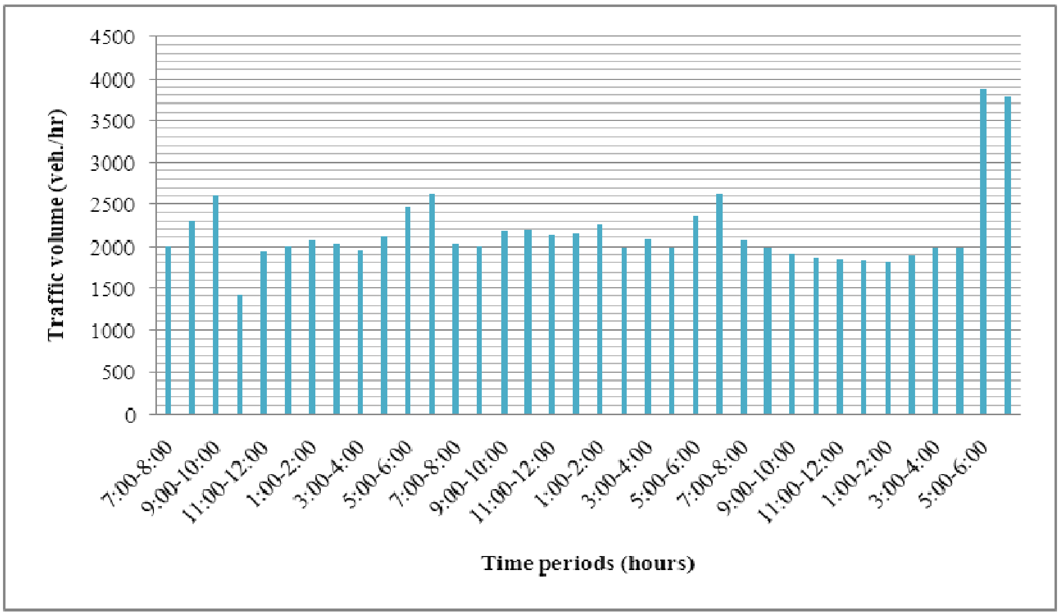


Figure 1 Graphic Presentation of the Field Traffic Volume of the Selected Arterial (Section 1/North Direction)

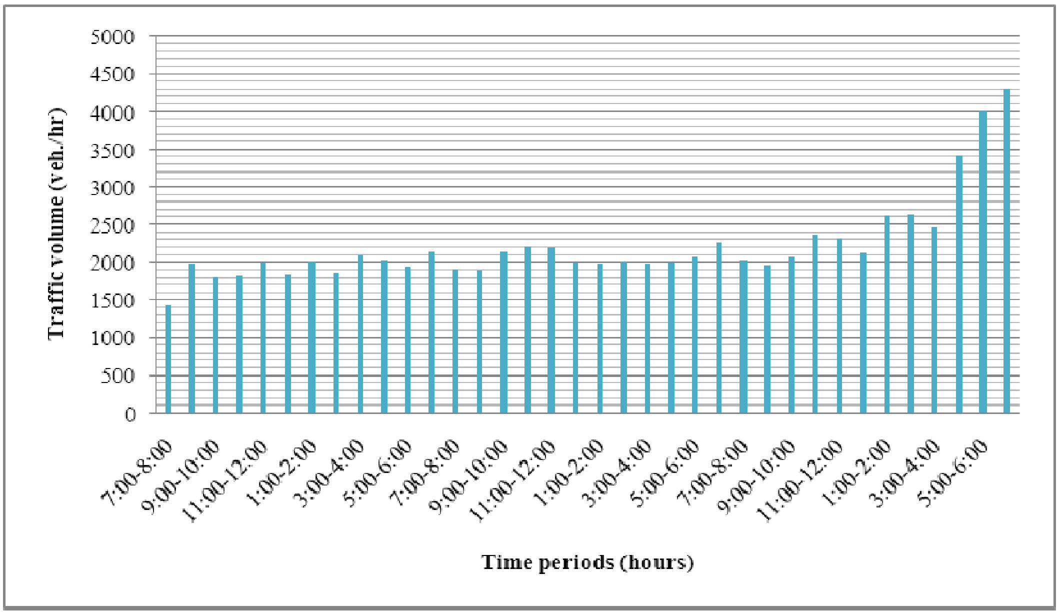


Figure 2 Graphic Presentation of the Field Traffic Volume of the Selected Arterial (Section 1/South Direction)

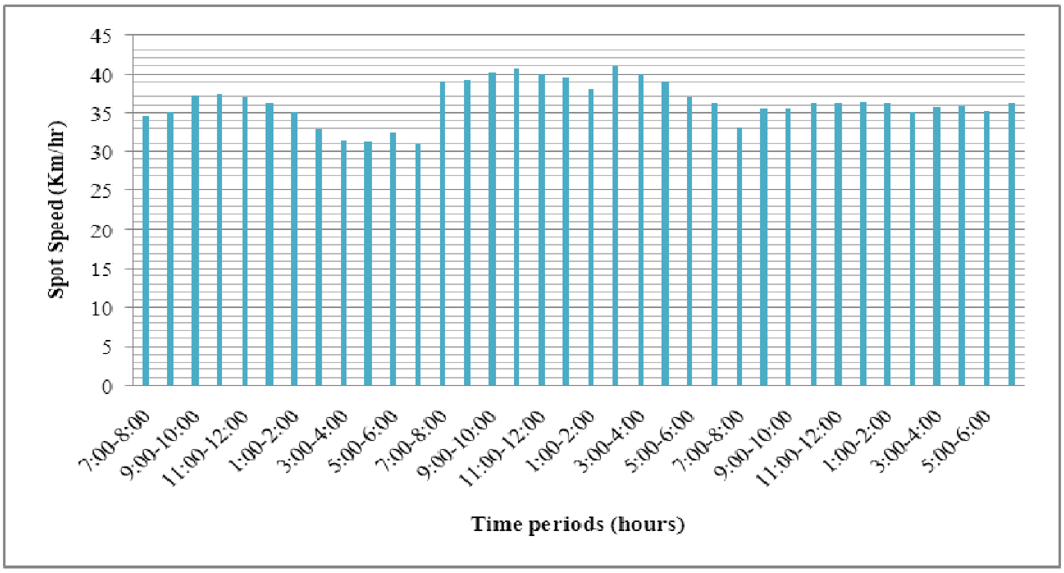


Figure 3 Graphic Presentation of the Field Traffic Speed at the Selected Arterial (Section 1/North Direction)

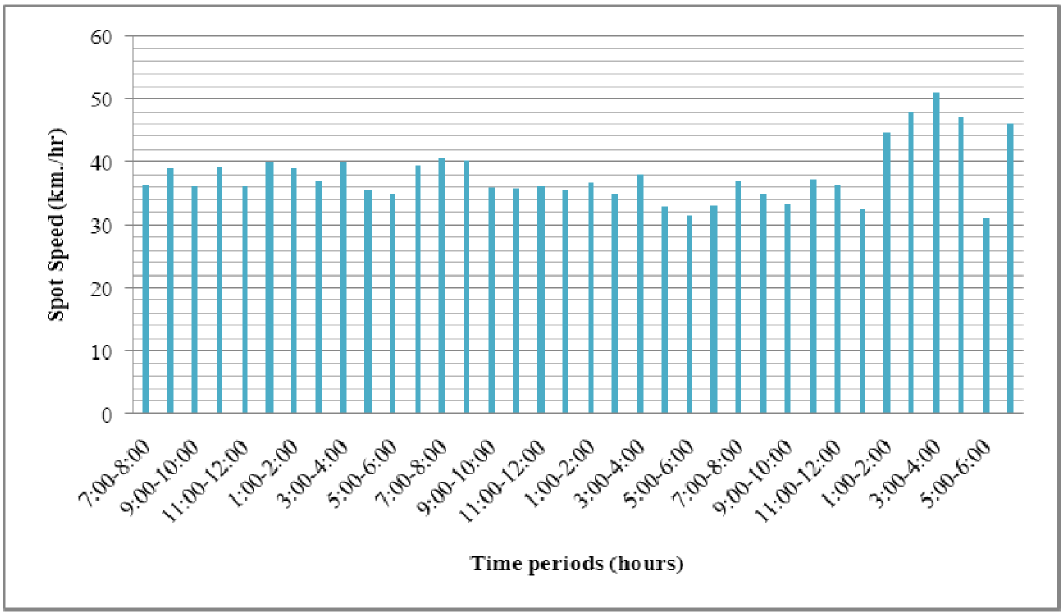


Figure 4 Graphic Presentation of the Field Traffic Speed at the Selected Arterial (Section 1/South Direction)

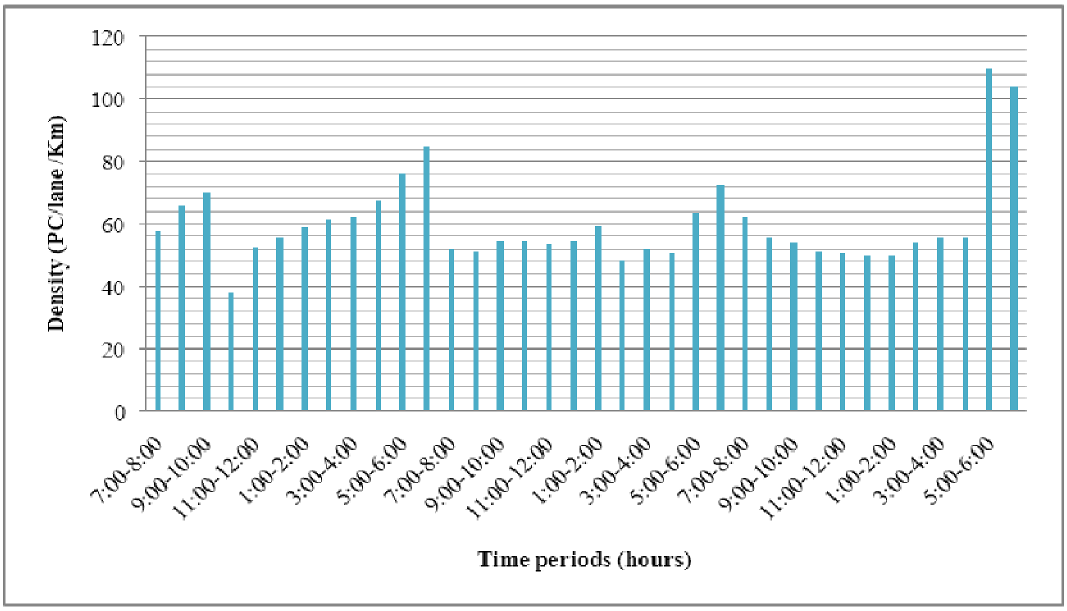


Figure 5 Graphic Presentation of the Traffic Density at the Selected Arterial (Section 1/North Direction)

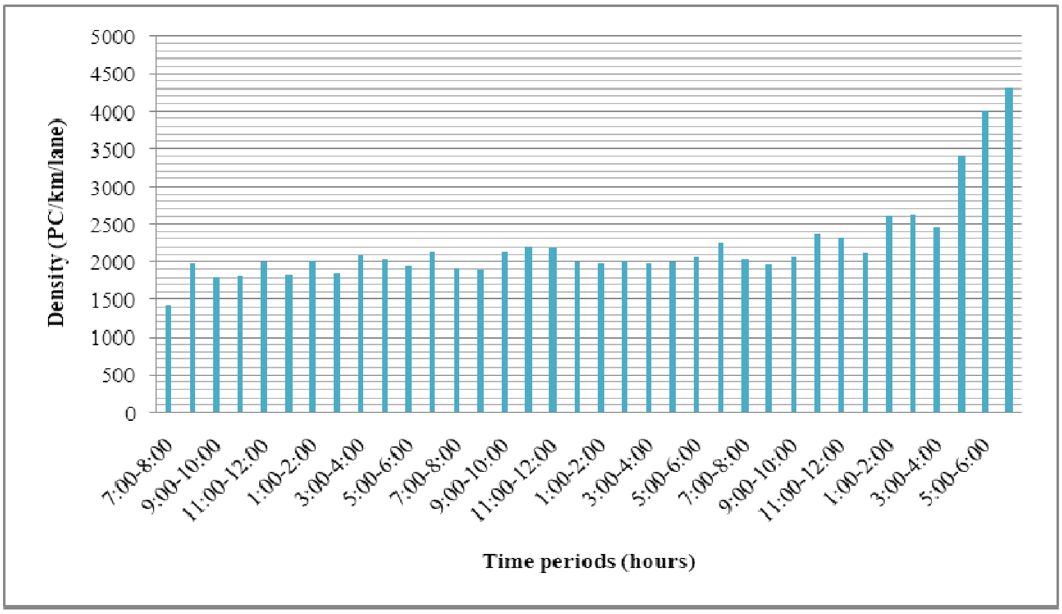


Figure 6 Graphic Presentation of the Traffic Density at the Selected Arterial (Section 1/South Direction)

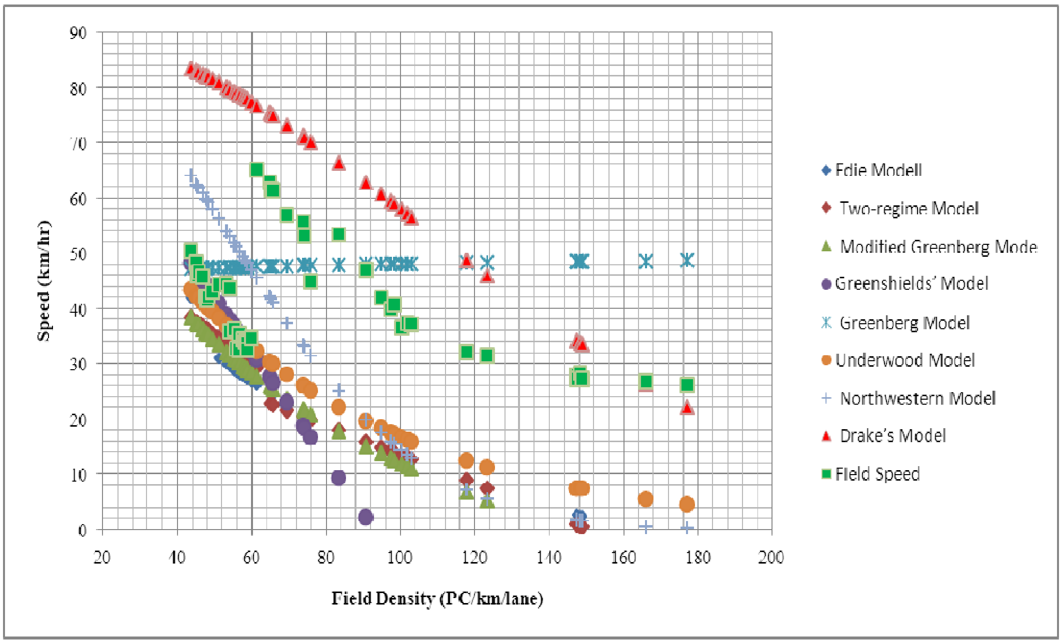
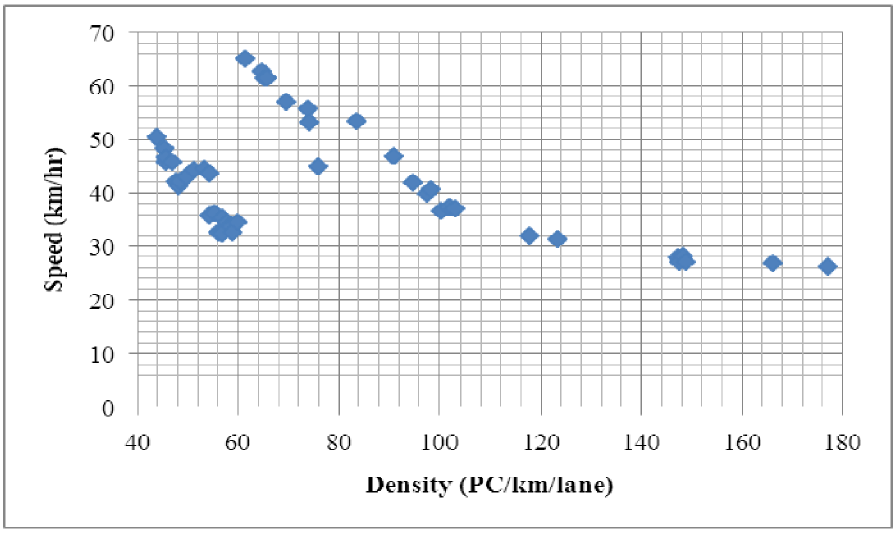
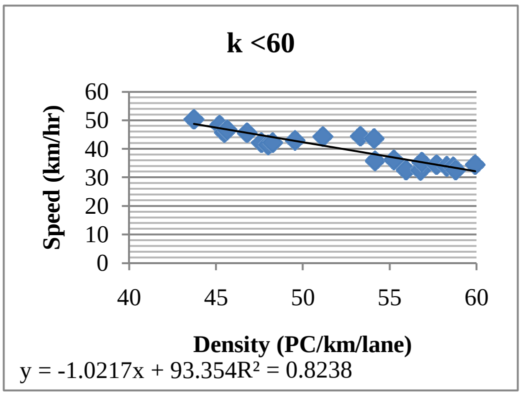
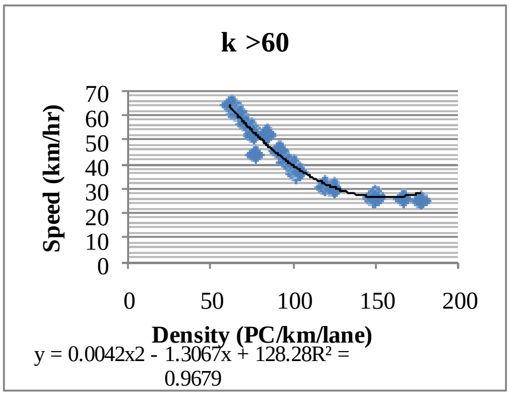


Figure 7 Speed-Density Models at actual Density Values with actual field Speed value (North Direction).



a. At all Density Values

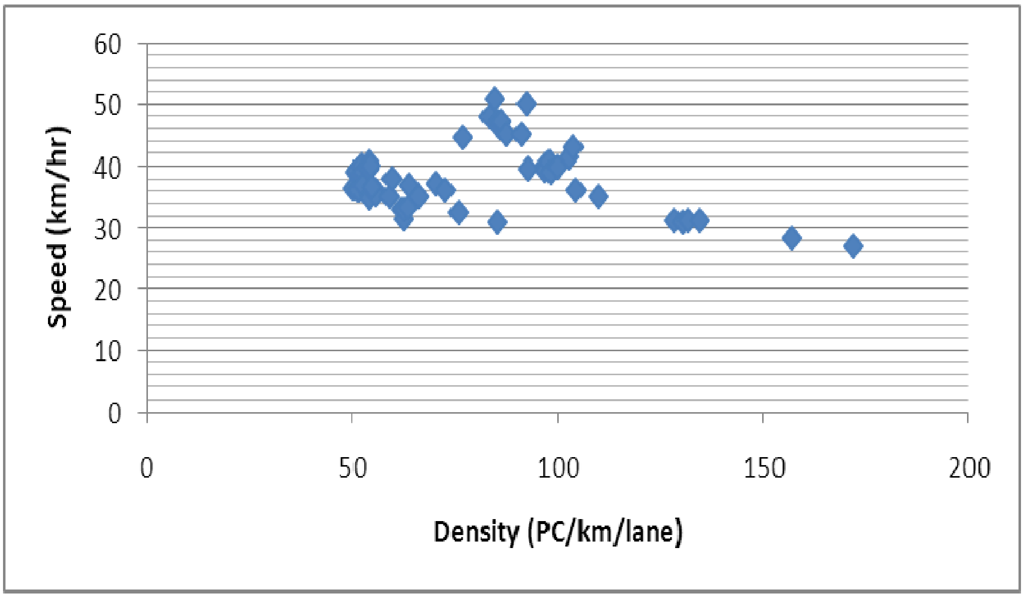




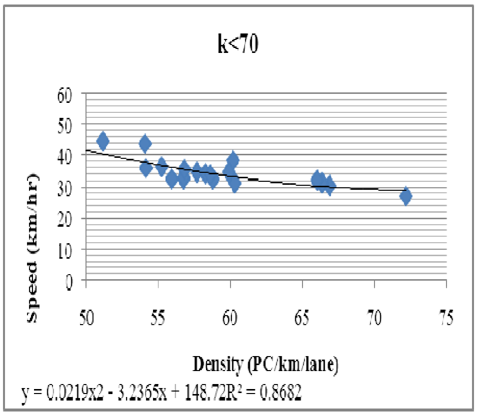
b. At Density Values <60 (PC/km/lane)

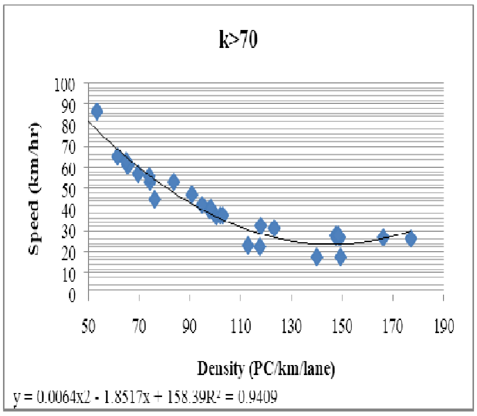
c. At Density Values <60 (PC/km/lane

Figure 8 Speed-Density relationship at the selected arterial (North Direction).



a. At all Density Values





b. At Density Values <60 (PC/km/lane) **c. At Density Values <60 (PC/km/lane**

Figure 9 Speed-Density relationship at the selected arterial (South Direction).