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Study of Traffic Stream Characteristics on Highways in Egypt using Digital Video Camera

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ملخص البحث

من خلال الدراسات السابقة يتبين أنه لا يوجد نماذج دقيقة لوصف خصائص وعناصر تدفق المرور على الطرق السريعة داخل مصر وبناءً عليه فإن الهدف من هذا البحث إيجاد أنسب علاقة لهذه العناصر لوصف دقيق لتدفق المرور على هذه الطرق السريعة والتي تستخدم في التخطيط والتصميم وتشغيل الطريق.
وسوف يتم تجميع البيانات مثل تدفق المرور، السرعة، الكثافة من خلال دراسة كلاً من طريق القاهرة-الفيوم، والطريق الدائري لمحافظة الفيوم وذلك باستخدام كاميرات رصد الحركة المرورية (the traficam x-stream camera)، وسيتم عمل زيارة موقعيه للطريقين لتحديد القطاعات الحرجة على الطرق المختارة وتحديد أنسب الأماكن لوضع أنابيب المطاط الهوائي وسيراعي أخذ البيانات من على الطريقين خلال الأيام التي بها ازدحام على الطريقين وهي الايام التي تسبق العُطل والأيام التي تلي العُطل من الاثنين الى الخميس. وسيتم من جانب آخر أخذ أيام العُطل والتي بها حركة مرور نتيجة للرحلات السياحية.
وسيتم أخذ هذه البيانات وتحليلها وعمل النماذج المطلوبة والمقترحة للحصول على أنسب علاقة والتي تمثل خصائص تدفق المرور على الطرق السريعة داخل جمهورية مصر العربية.

Abstract

Although there are many studied that describe the relation between the traffic stream parameters (i.e., Speed, Density and Traffic Volume), there are no accurate models that describe the relationship between traffic steam parameters on highway in Egypt. Therefore, the main objective of this research is to develop relationships between the main characteristics that describe the traffic stream on multi-lane divided highways in Egypt. These relationships are used in planning, designing and operation of transportation facilities.
Traffic data such as flow rate, speed, and density would be collected using Digital video camera -based measurement technique on sections of two selected roads: Fayoum-Cairo desert road and Fayoum ring road. An investigation would be perform to select critical sections on the selected roads. The selected segments should have different demand levels and speed limits in order to provide adequate data for better describe the speed-density and flow relation. Thus, Digital video camera (the traficam x-stream camera) would be placed at the selected locations where, Traffic data would be collected during typical weekdays and weekends On the other hand, weekends would be consider to take tourism trips. Samples would be record in different times of the day to represent all conditions of traffic flow on the selected roads sections.

Keywords: Traffic Stream Parameters; Digital video camera; Flow; Speed

1. Introduction

Rural multi-lane highways are an important type of un-interrupted flow facilities. In such facilities, there is no obstruction to the movement of vehicles along the roadway. These facilities represent the majority of the highway system in Egypt. Traffic analysts are required to be familiar with different traffic characteristics on multi-lane highways. These characteristics are important in the evaluation of traffic performance, examination of highway safety, setting appropriate traffic control devices and speed limits, and development of simulation programs Traffic stream models provide relationships among the three basic traffic variables namely speed, flow and density under steady-state conditions. Since reported stream models are mainly developed for homogeneous traffic conditions, they may not be directly suitable for Egyptian traffic condition, which is heterogeneous and lacks lane discipline. Only very limited studies have been reported from Egypt in this respect and the present study develops an optimal speed–density relation and from that derive theoretically the speed-flow and flow density relations that are suitable for the study stretch under consideration. The results indicate that the developed model is able to represent the steady-state macroscopic behavior of the traffic stream with reasonable accuracy.

2. Literature Review

To figure out the exact relationship between the traffic parameters, a great deal of research

Has been done over the past several decades. The results of these researches yielded many

Mathematical models. Some important models among them will be discussed in this research.

1. Greenshields's (1934) macroscopic stream model

Macroscopic stream models represent how the behavior of one parameter of traffic flow changes with respect to another. Most important among them is the relation between speed and density. Greenshield (1934) proposes the first and most simple relation between them. Greenshield assumed a linear speed-density relationship to derive the model. The equation for this relationship is shown below.

$$Ui = Uf\ (1 - \frac{Ki}{Kj}) \qquad (1)$$

where Ui is the mean speed at density K, Uf is the free speed and Kj is the jam density. This equation (1) is often referred to as the Greenshields's model. It indicates that when density becomes zero, speed approaches free flow speed (i.e. U → Uf when k → 0). Once the relation between speed and flow is established, the relation with flow can be derived. This relation between flow and density is parabolic in shape. In addition, we know that

Q = Ki. Ui (2)

Now substituting equation 5.1 in equation 5.2, we get

Q = Uf. Ki – Uf. Ki/Kj (3)

2. Greenberg's (1959) logarithmic model

Greenberg (1959) assumed a logarithmic relation between speed and density. He proposed,

$$Ui = Um\ .Ln\frac{Kj}{Ki} \qquad (4)$$

This model has gained very good popularity because this model can be derived analytically. (This derivation is beyond the scope of these notes). However, main drawbacks of this model is that as density tends to zero, speed tends to infinity. This shows the inability of the model to predict the speeds at lower densities.

3. Underwood's (1961) exponential model

Trying to overcome the limitation of Greenberg's model, Underwood (1961) put forward an exponential model as shown below.

$$Ui = Uf \, . e^{\frac{Ki}{Km}} \qquad (5)$$

where Uf is the free flow speed and Km is the optimum density, i.e. the density corresponding to the maximum flow. In this model, speed becomes zero only when density reaches infinity that is the drawback of this model. Hence, this cannot be used for predicting speeds at high densities.

4. Pipes' (1967) generalized model

Further developments were made with the introduction of a new parameter (n) to provide for

A more generalized modeling approach. Pipes (1967) proposed a model shown by the following equation.

$$Ui = Uf \left[1 - \left(\frac{Ki}{Kj}\right)^n\right] \qquad (6)$$

When n is set to one, Pipe's model resembles Greenshields's model. Thus by varying the values of n, a family of models can be developed.

5. Drew's (1968) model

Drew (1968) proposed formulation based on Greenshield model but with the introduction of an additional parameter n as shown in the equation below:

$$U = Uf \left[1 - \left(\frac{K}{Kj}\right)^{\left(\frac{n+1}{2}\right)}\right] \qquad (7)$$

Where the parameter n is in the range of (-1 to +1) which makes the speed- density relationship to be linear when the value of n is +1, a parabolic relationship if the value is 0, and an exponential relationship if the value is -1.

6. Multi-regime (1961) – (1967) models

All the above models are based on the assumption that the same speed-density relation is valid for the entire range of densities seen in traffic streams. Therefore, these models are called single-regime models. However, human behavior will be different at different densities. This is corroborated with field observations that shows different relations at different range of densities. Therefore, the speed-density relation will also be different in different zones of densities. Based on this concept, many models were proposed generally called multi-regime Models. The simplest one is called a two-regime model, where separate equations are used to represent the speed-density relation at congested and uncongested traffic.

3. Methodology

The fundamental steps of the research is shown in Figure1. As shown in the figure, nine steps were applied; selection of case study, data collection, data processing, data analysis, Developing VISSIM model, comparison between developed models field data, model application and recommendation adjustment to Egyptian code.

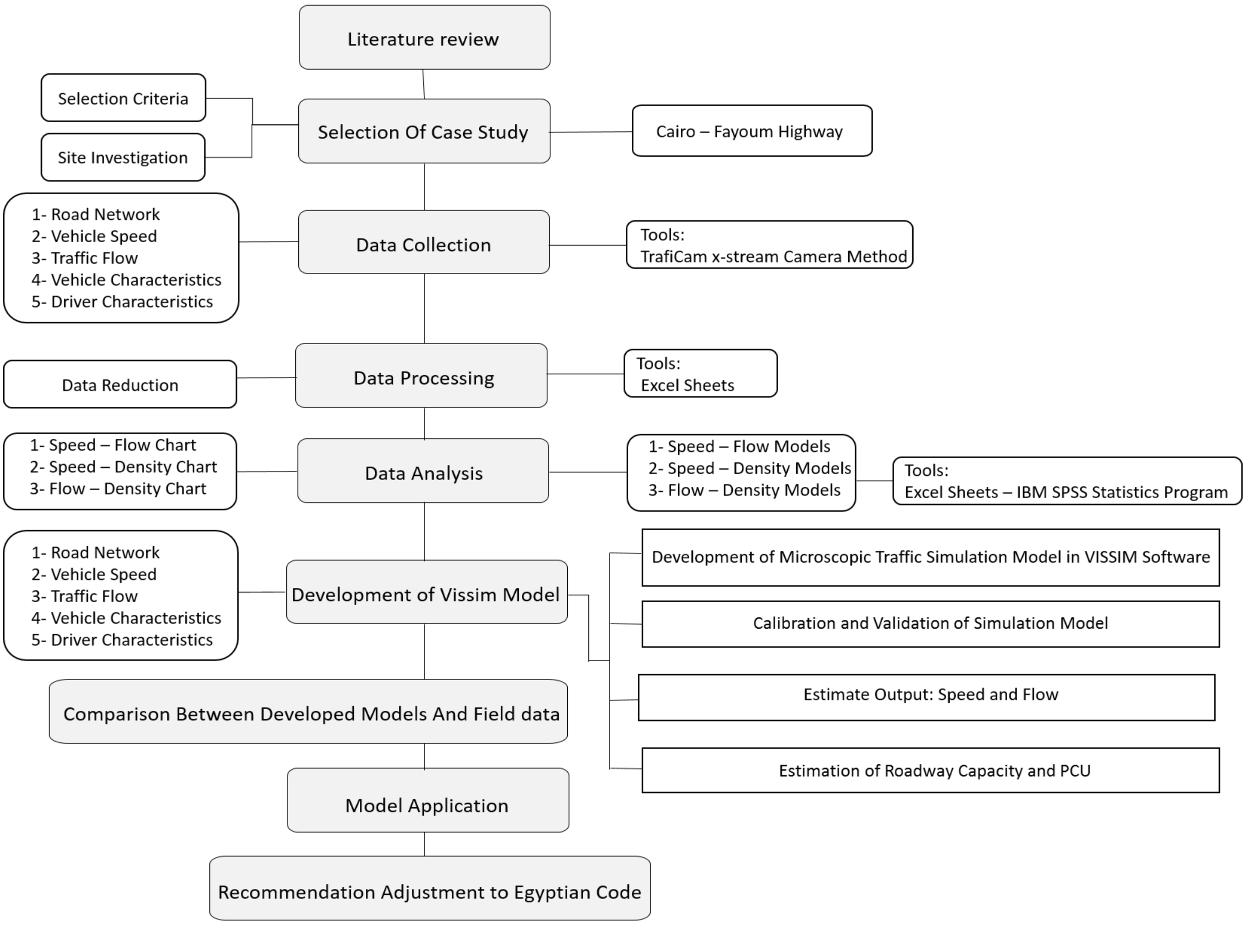

Fig 1: General Framework of the Research

4. Study Section

Egypt has many highways with different characteristics in terms of number of lanes, length and width, side and longitudinal slope, side shoulder width, different speed and different traffic volume. When determining the site selection criteria for this study, all the above factors should be considered. More than one site should be chosen so that this study covers all factors affecting on the traffic stream characteristics, but it was difficult to obtain security approvals for most of this roads. Only Cairo Fayoum desert road.

Prior to obtaining the necessary security approvals to study the traffic stream characteristics on the road under study, many highways were investigated to select the best road to represent the other highways. The chosen roads were the Cairo Fayoum

Desert Road, the Ismailia Desert Road, the Agricultural Alexandria Road and the Desert Road. After sending the security letters to approve the development of traffic cameras to monitor the traffic on one of these roads, was approved only on the Cairo Fayoum road, and the number of lanes, the variety of cars, the security and safety factors distinguishes this road, the leveling of all sectors of the road.

Before actual field data collection, there was an investigation for the best location to view the study section and the best way to collect data.

As resulted from site investigation for Cairo Fayoum road, the best location to mount the traficam x-stream camera is from a high communication tower has a clear view to the study section. The study sites were located on a major highway that runs north/south (Cairo-Fayoum highway). This highway is a three-lane divided highway, with a posted speed limit of 90 km/h. The chosen sites are located on straight sections with level terrain to avoid the effect of the longitudinal gradient and to minimize the influence of geometric features of the highway, and far from the influence of intersections, driveways and horizontal curves. The sites were also selected at least 3.56 km away from any traffic toll and at least 1.59 km away from any U-turn. In addition, the chosen sites have relatively similar geometry characteristics (pavement and shoulders widths). The average pavement width for each direction is about 15 m.

5. Traffic Data

Data were collected from Cairo - Fayoum highway using elevated observer technique by using digital video camera (Traficam X-Stream Camera Method). The collected data were reduced and processed to be in the suitable form to be analyzed statistically. Statistical analysis was performed on the processed data to select the most mathematical model to represent the data based on the value of the correlation coefficient R^2. Many solutions were then proposed and analyzed, and then, the best one was selected using the VISSIM simulation model.

Digital video camera (Traficam X-Stream Camera Method) was used to collect the traffic and speed data used in this paper. Data collection was carried out in working days, during daylight hours. During all data collection periods, the weather was clear and the pavement was dry and in a good condition, List of Periods of the Collected Data are shown in the blow table (1).

Table(1): *List of Periods of the Collected Data*

Day of the week	Record time (hh:mm)	Starting time	Weather condition
Saturday 08/10/2016	10:13	7:10 AM	Weather Clear
Sunday 09/10/2016	11:00	6:00 AM	Weather Clear
Monday 10/10/2016	10:20	7:00 AM	Weather Clear
Tuesday 11/10/2016	9:40	7:15 AM	Weather Clear
Wednesday 12/10/2016	10:35	6:35 AM	Weather Clear
Thursday 13/10/2016	10:00	7:00 AM	Weather Clear

The collected data from the Traficam X-Stream Camera was direct exported to Excel sheets, and then processed in order to obtain the three macroscopic traffic parameters; flow, speed, density, and PCU values. A sample of exported data is shown in the below table (2).

Table (2): Exported data

Time	Lane	HeadWay (m)	Concentration (vehicles/km)	Class	#vehicles	Speed (km/h)	Gap (s/10)
08/10/2016 07:10	1	918	1	1	4	128	240
08/10/2016 07:10	1	918	1	2	1	112	218
08/10/2016 07:10	1	918	1	3	3	108	218
08/10/2016 07:10	1	918	1	4	8	98	382
08/10/2016 07:10	1	918	1	5	1	106	407
08/10/2016 07:10	2	634	2	1	1	128	131
08/10/2016 07:10	2	634	2	2	1	129	107
08/10/2016 07:10	2	634	2	3	9	143	176
08/10/2016 07:10	2	634	2	4	23	137	155
08/10/2016 07:10	2	634	2	5	2	129	260
08/10/2016 07:10	3	1033	1	1	0	0	0
08/10/2016 07:10	3	1033	1	2	1	133	291
08/10/2016 07:10	3	1033	1	3	2	140	127
08/10/2016 07:10	3	1033	1	4	17	141	293
08/10/2016 07:10	3	1033	1	5	3	119	164
08/10/2016 07:20	1	772	1	1	7	132	164
08/10/2016 07:20	1	772	1	2	3	127	201
08/10/2016 07:20	1	772	1	3	8	118	167
08/10/2016 07:20	1	772	1	4	9	108	324
08/10/2016 07:20	1	772	1	5	1	103	790
08/10/2016 07:20	2	525	2	1	2	138	71
08/10/2016 07:20	2	525	2	2	3	139	51
08/10/2016 07:20	2	525	2	3	20	142	136
08/10/2016 07:20	2	525	2	4	18	142	151
08/10/2016 07:20	2	525	2	5	2	137	181
08/10/2016 07:20	3	1304	1	1	0	0	0
08/10/2016 07:20	3	1304	1	2	1	170	556
08/10/2016 07:20	3	1304	1	3	1	158	258
08/10/2016 07:20	3	1304	1	4	13	146	283

6. Results and Discussion

6.1 Modeling relationship between Speed, density and Flow

The relationship between space mean speed, density and flow was plotted using IBM SPSS Statistics software. It was plotted using all data points, and has the following figures:

Where:

q	:	Expected values of Flow (pc/hr/lane)
U	:	Space mean speed (km/hr)
K	:	Density (pc/km/lane)

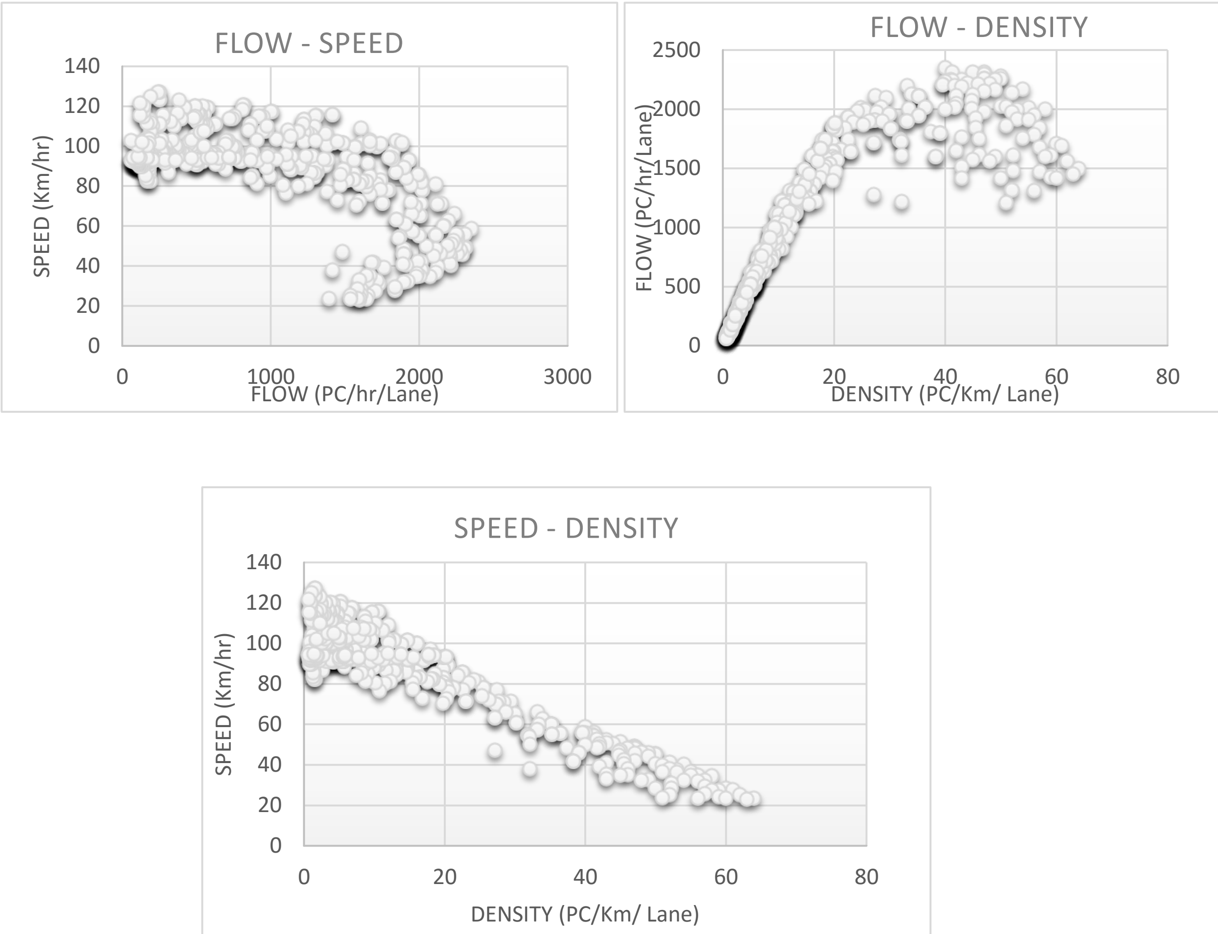

Fig 2: Speed, Flow, and Density Collected Data

6.2 Modeling relationship between Flow and Speed

The relationship between space mean speed and flow was developed using regression analysis. The relationship was developed using IBM SPSS Statistics software. It was derived using all data points, and has the following formula:

$$q = \beta_0 + \beta_1 U + \beta_2 U^2$$

Where:

q	:	Expected values of Flow (pc/hr/lane)
U	:	Space mean speed (km/hr)
$\beta_0, \beta_1, \beta_2$	:	Regression coefficient to be estimated

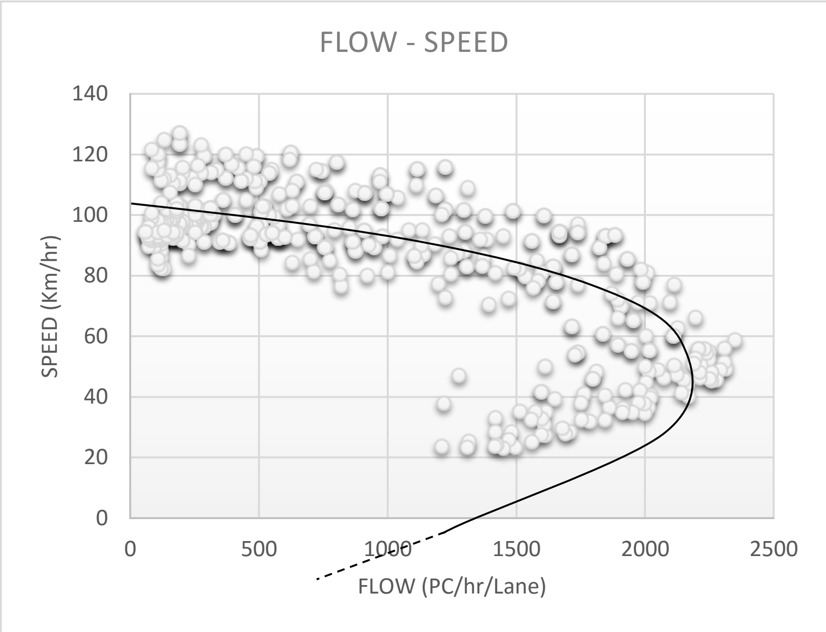

Fig 3: Flow and Speed Relationship

Figure (3) shows the resulted model. The model has the following form:

$$Q = 472.48 + 50.246U - 0.469U^2$$

As shown in the equation, the relationship between flow and speed was derived as a polynomial of the second degree and has a coefficient of correlation R^2 of 51.5 %. The model gives a maximum flow rate of 1818 pc/hr/lane, which is relatively lower than practical values adopted in the HCM of 2200 pc/hr/lane. This could be because of the relatively low R^2 of the model. In addition, HCM deals with ideal conditions in which each vehicle moves in its lane and the lanes are marked on the road, which is not the case in the study section. However, the field data shows a capacity up to 2351 pc/hr/lane, which conforms to the HCM.

6.3 Modeling relationship between Speed and Density

The relationship between space mean speed and density was developed using regression analysis. The relationship was developed using IBM SPSS Statistics software. It was derived using all data points, Three types of relationships were tested as follows:

1. Greenshields's linear model
2. Greenberg's logarithmic model
3. Underwood's exponential model

Table (3): Models for Speed and Density Relationship

Model	Form	Regression Model	R^2
Linear	$U = \beta_0 + \beta_1 K$	$U = 106.86 - 1.3417K$	85.3%
Logarithmic	$U = \beta_0 + \beta_1 \ln(K)$	$U = 117.19 - 14.97 \ln(K)$	58.3%
Exponential	$U = \beta_0 e^{\beta_1 K}$	$U = 112.25e^{-0.021K}$	87.8%

In first type of modeling, a linear relationship was assumed between space mean speed and density. The fitted curve of this relation is shown in Figure 4; this relationship has a correlation coefficient (R^2) of 85.3%, which indicates a good relationship between the two parameters.

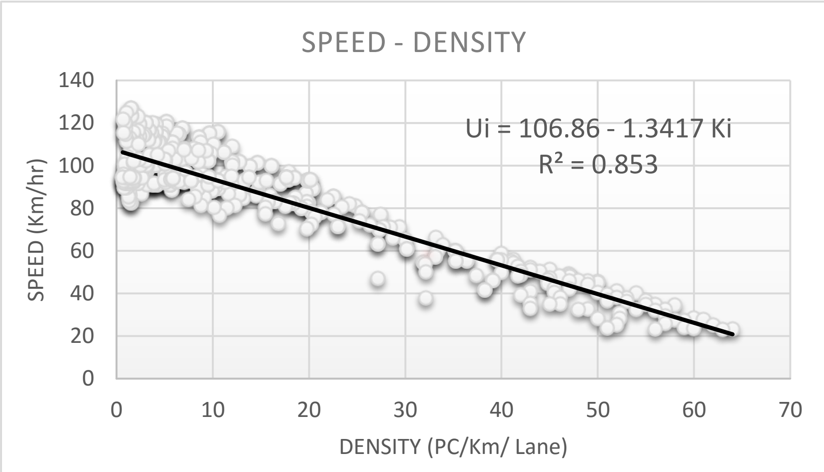

Fig 4: Flow and Speed Linear Relationship

Comparing our model with Greenshield model reveals that the free flow speed (Uf) is about 106.86 km/hr, and the jam density (Kj) is about 80 pc/km/lane. The resulting value of the jam density is relatively less than the practical density observed on the road, typically 64 pc/km/lane. Based on the pattern of data on plot, it seems that the relationship is not the best fit of the data.

In the second type of modeling, a logarithmic relationship was assumed between space mean speed and density. The fitted curve of this relationship is shown in Figure 5. This relationship has a correlation coefficient (R2) of 58.3%, which indicates a fair relationship between the two parameters.

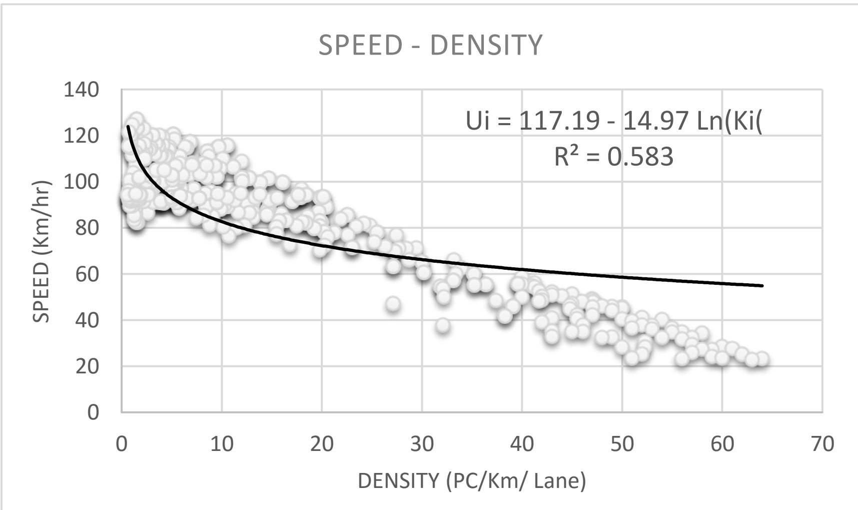

Fig 5: Flow and Speed Logarithmic Relationship

This model is the same as Greenberg model, and comparing our model with it reveals that the jam density is about 2510 pc/km/lane and the free flow speed is not defined. This value for the jam density is not matching with the actual field jam density value of about 64 Pc/km/lane. Comparing this model with that of the linear relationship reveals that the logarithmic model is worse than the linear, otherwise, it is not the best fit of the data as clear from the pattern of data on plot that the relationship.

In the third type of modeling, an exponential relationship was assumed between space mean speed and density. The fitted curve of this relationship is shown in Figure 6. This relationship has a correlation coefficient (R2) of 87.8% which indicates a very good relationship between the two parameters.

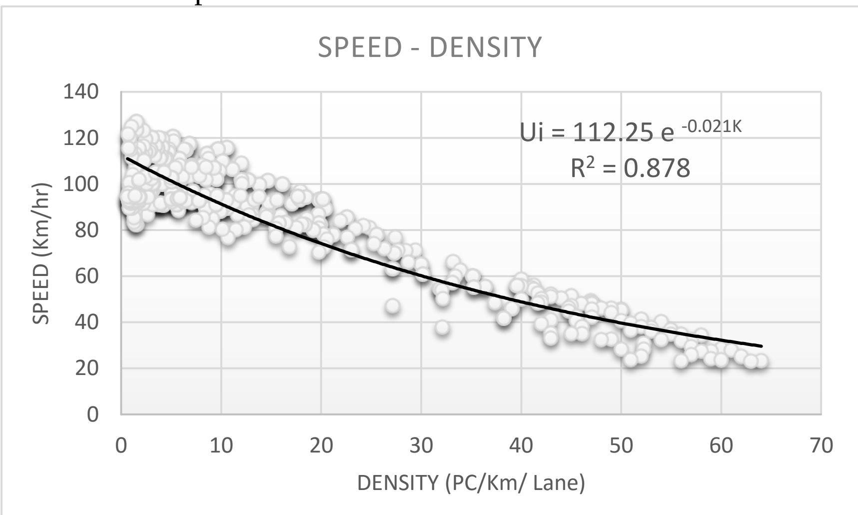

Fig 6: Flow and Speed Exponential Relationship

This model is the same as Underwood model, and comparing our model with it reveals that the free flow speed is about 112.25 km/hr and the jam density is not defined. Comparing this model with both linear and logarithmic relationships reveals that the exponential model is best single regime model.

6.4 Modeling relationship between Flow and Density

The relationship between density and flow was developed using regression analysis. The relationship was developed using IBM SPSS Statistics software. It was derived using all data points, and has the following formula:

$$q = \beta_0 + \beta_1 K + \beta_2 K^2$$

Where:

q : Expected values of Flow (pc/hr/lane)

K : Density (Pc/km/Lane)

β_0 , β_1 , β_2 : Regression coefficient to be estimated

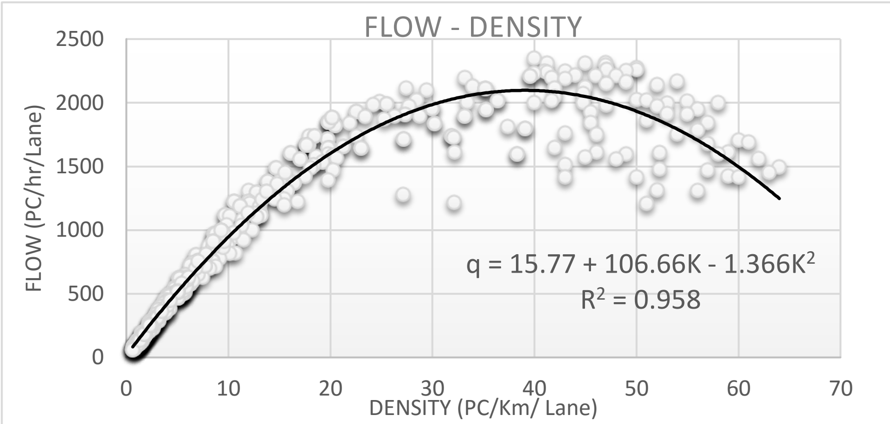

Fig 7: Flow and Density Exponential Relationship

Figure 7 shows the resulted model. The model has the following form:

$q = 15.77 + 106.66K - 1.366K^2$

As shown in the equation, the relationship between flow and density was derived as a polynomial of the second degree and has a coefficient of correlation (R^2) of 0.958%, which indicates a good relationship between density and flow. In addition, the model gives a maximum flow rate of about 2098 pc/hr/lane at a density of about 40 Pc/km/lane, which is similar to practical values adopted in the HCM of 2200 pc/hr/lane. This could be because of the good value of R^2 of the model. The model also gives a jam density of about 79 pc/km/lane, which is near from the practical density observed on the road, typically 64 pc/km/lane.

7. Conclusion and recommendations

Therefore, in light of the previous results and discussions, the study arrived at the following conclusion and recommendation:

7.1 Traficam X-Stream Camera Method used in data collection is accurate and data were approximately the same as those collected using the videotaping technique.

7.2 Regression and correction were used to develop the macroscopic parameters relationships (Speed; Density; Flow).

7.3 According to the best model, the lane capacity was about 2098 pcu/hr/lane which is relatively low if compared with the practical capacity of HCM (2200 pcu/hr/lane). However, the HCM depends on ideal conditions in which each vehicle moves in a single lane, which is not our case in Egypt. In fact, there is no lane marking and the flow on the roads depends on the number of vehicle rows can mode side by side. In addition, the jam density was about 80 pcu/km/lane and the free flow speed was about 106 km/hr.

7.4 The macroscopic simulation model developed in this research was verified, calibrated, and validated.

7.5 The developed models were accorded to data collected from two site. Accordingly, it is recommended that data may be collected from other sites to establish comprehensive validation of the model.

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