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ASSESSMENT OF TRAFFIC FLOW ON ENUGU HIGHWAYS USING SPEED DENSITY REGRESSION COEFFICIENT

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ABSTRACT
In an attempt to estimate the operating speeds and volume of traffic on highway lanes as a function of predicted demands, speed-density models were estimated using data from highway sites. Speed, flow and volume are the most important elements of the traffic flow. In this study, the speed-density regression models are compared using five highways in relation to their correlation coefficient based on the daily traffic flow data obtained from the roads. The traffic flow data were collected by hourly traffic count on each road. The coefficient of correlation (R) proved to have the best fit with a higher confidence and less variation for a two-lane highway than a one-lane highway. The space-mean speed (u) and density (k) relationship for the two-lane highways are; $u = 39.57 - 0.0025k$, $u = 58.67 - 0.01k$, ***and*** $u = 33.15 - 0.002k$, ***whereas the space-mean speed (u) and density (k) relationship for the one-lane highways are;*** $u = 53.84 - 0.0016k$, $u = 29.76 - 0.003k$ ***respectively. This research provides practical application for speed estimation, construction, maintenance and optimization of the highways using the speed-density models which will enhance traffic monitoring, traffic control management, traffic forecasting and model calibration.***

Keywords: *speed, density, flow, traffic count, correlation coefficient.*

1. INTRODUCTION
Annual Average Daily Traffic, (AADT), is a measure used primarily in transportation planning and transportation engineering. Traditionally, it is the total volume of vehicle traffic of a highway or road for a year divided by 365 days. In 1992, American Association of State Highways and Transport Officials (AASHTO) released the AASHTO Guidelines for Traffic Data Programs which identified a way to produce an AADT without seasonal or day-of-week biases by creating an "average of averages" [1]. AADT is a useful and simple measurement of how busy the road is. Newer advances from traffic data providers are now providing AADT by side of the road, by day of week and by time of day. The presence of several hourly-congested highways forces researchers to better understand freeway operations under congested condition. The intelligent vehicle-highway system (like speed enforcement) programs will be able to function effectively if traffic behaviours under all conditions are modeled accurately [2].

Traffic flow in engineering is the study of interaction between vehicles, commuters and infrastructure (including the highways, signage and traffic control devices) with the aim of understanding and developing an optimal road network with efficient movement of traffic and minimal traffic congestion problems. The existing transportation facility which was originally designed and constructed to be adequate for the past traffic volume becomes practically inadequate to handle the present day traffic demand, resulting to an inevitable tremendous traffic congestion along the highway [3]. Most highways in Nigeria were designed without taking into consideration the daily traffic volume of the highway and the speed limits at necessary points along the highway. The tendency of the drivers to exceed the road design speed limits become prevalent leading to traffic accidents and conflicts. Thus, there is the need for road/highway designers to use a valid model equation to help calibrate the speed limits in relation to the traffic density obtained at the section of the road.

The term traffic flow and volume are used interchangeably to define the number of vehicles that ply a particular road network at a given period of time. Queuing and delay occur in all congested situations; therefore a study on flow, speed and density on the roads would be relevant and necessitates a proper design of their intersection.

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The common approach proposed by most traffic flow researchers was using the density and speed data to calibrate the mathematical models and then convert them into speed flow model using Eq. (1):

$$q = uk. \quad (1)$$

In (1), q is the traffic flow (veh/hr), which is the number of vehicles, *n*, passing some designated highway point in a time interval of duration, *t, u* is the space-mean speed (Km/hr), which is the time necessary for a vehicle to traverse some known length of highway, L, and k is the traffic density (veh/Km), which is the number of vehicles per unit length of roadway [4]. In this model, the density and speed data are obtained by using a special model vehicle (made for the purpose) that traverses the stated distance on the highway. The speed of the vehicle is recorded as it travels from one point of the highway to the other point under investigation.

The most intuitive starting point for developing a consistent, generalized traffic model is to focus on the relationship between speed and density [5]. To begin, consider a section of highway with only a single vehicle on it. Under these conditions, the density will be very low (veh/km) and the driver will be able to travel freely at a speed close to the design speed of the highway. This speed is referred to as the free-flow speed (denoted here as u_f) because vehicle speed is not inhibited by the presence of other vehicles. As more and more vehicles begin to use a section of the highway, the traffic density will increase and the average operating speed of vehicles will decline from the free-flow value as drivers slow to allow for the maneuvers of others vehicles. Eventually, the highway section will become so congested (i.e. will have such a high density) that the traffic condition is referred to as 'come to a stop' ($u = 0$) and the density will be determined by the length of the vehicles and the spaces that drivers leave between them. This high-density condition is referred to as the jam density, k_j.

There have been significant researches on the study of the speed-density and speed-flow models. In most models, the relationship of speed-flow or speed-density is dependent only on road type and a free flow speed. Researchers in many countries have investigated the relationship of the traffic flow, speed and density since 1934. In [6], the flow-density relationship of Canada using an extensive data set collected on the Queen Elizabeth Way in Ontario was studied. In [7] the regression model for the three variable relationships for Japanese cities was developed. Olszewski, *et al* [8] developed an area-wide traffic speed-flow model for the Singapore CBD to get an analytical framework for traffic management measures and evaluation. Lum, *et al* [9] analyzed the speed-flow relationship of the arterial road using the traffic volume and travel time data at a number of arterial roads in Singapore. Macroscopic stream models represent how the behaviour of one parameter of traffic flow changes with respect to another. Most traffic flows obeys the Poisson Model. The assumption of Poisson vehicle arrival also implies a distribution of the time interval between the arrivals of successive vehicle. Empirical observations have shown that the assumption of Poisson-distributed traffic arrivals is most realistic in highly congested traffic conditions [10].

A number of mathematical models between the traffic speed and density were proposed and calibrated by fitting curves to empirical traffic data. The results of these researches yielded many mathematical models.

The first traffic flow model was proposed by [11]. It suggested a linear relationship between the density and speed Eq. (2) expresses the relationship called the Green shield's model.

$$u = uf - \left[\frac{u_f}{k_j}\right]k \quad (2)$$

Here, u,k, u_f, and k_j maintain their usual meaning. It indicates that when density becomes zero, speed approaches free flow speed (i.e. $u = u_f$, when$K \to O$). In Greenshield's model, there exists an assumption of the relationship between speed and density which is difficult (if not impossible) to be obtained in the field. Hence, the validity of Green shield's model becomes questionable as it cannot be applied practically to field event.

Greenberg [12] proposed of a model using a fluid flow analogy and data from the Lincoln Tunnel in New York to establish a logarithmic relation between speed and density. This is called Greenberg's model as expressed by Eq. (3);

$$u = u_c \ln\frac{k_j}{k} \quad (3)$$

Where; u_c is the speed at full traffic capacity, k_j and k are previously defined. This model has gained very good popularity because this model can be derived analytically (the derivation is out of the scope of this study). However, the main drawback 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.

Underwood [13] hypothesized an exponential relationship between density and speed. The model is observed to generally have a better fit than the Greenshields and Greenberg models [12] for the uncongested traffic conditions, but does not present a good fit to the data for congested conditions. This model is called the Underwood model [13] as expressed by Eq. (4):

$$u = u_f e^{-\frac{k}{ko}} \quad (4)$$

Where, u_f is the free flow speed and k_o is the optimum density, i.e. the density corresponding to the maximum flow. In this model, speed becomes zero only when

density reaches infinity which is the drawback of this model. Hence this cannot be used for predicting speeds at high densities.

Drake, *et al* [14] studied the various macroscopic traffic models postulated at that time and did not find any of them statistically significant. In developing his model, he estimated the density from speed and flow data, fitted the speed versus density function and transformed the speed versus density function to a speed versus flow function. The formulation of the [14] model is expressed by Eq. (5) and is called the Drake model:

$$u = u_f \exp\left[-\frac{1}{2\left(\frac{k}{kc}\right)^2}\right] \quad (5)$$

Where, k_c is the density at capacity. His model generally yields a better fit than the above three models for uncongested conditions.

From the review above, it is obvious that most researchers focused on the character of the network roads, using traffic data generated by electronic counting machines without actually taking physical field traffic record, and lacking of comparisons of different road configurations. The researches were carried out mostly in the western world where road failures are rare and observation of traffic laws is held esteem, unlike in Nigeria that has a lot of the failed section of the highways and little or no observation to traffic laws. Hence, the postulated models above may be non-functional to Nigerian highways. In addition, many of the models were calibrated by using assumed and estimated values of the traffic data which is non-practical to field phenomenon. Some of them applied unattainable values to the traffic data, thus invalidating the postulated model.

This research paper is to compare the speed-density classical linear model to calibrate functional relationship based on the field recorded daily traffic data by a manual traffic count obtained from five (5) highways (with distinct number of lanes) in Enugu, Enugu State. So they represent two different kinds of roads being assessed by various traffic compositions.

2. METHODOLOGY AND DATA COLLECTION

2.1. The Study Area.

The data in this study were obtained from five (5) highways in Enugu, Enugu Sate. The roads include:

1. Enugu – 9TH Mile Expressway (E9E)
2. Enugu – Abakaliki Expressway (EAE)
3. Enugu – Port Harcourt Expressway (EPE)
4. 9th Mile – Onitsha Expressway (9OE)
5. 9th Mile – Oji-River Expressway (9ORE)

The locations of the two roads to be used for the full analysis are shown in the Figures 1 and 2 with a highlighter. These two roads are the representatives of the rest of the highways. Figure 1 is an aerial map of the communities close to the Enugu-9th Mile Expressway, with the road shown with a highlighter. The arrows pointing in both directions indicate that the road is a 2-way highway. E9E has 2 lanes with the carriage width of 10m average. It originated from New Market junction and goes through Gulf estate and continued its course to Onitsha. This highway is notorious for skidding away of heavy lorries and trailers/tanker, also head-on vehicular collision.

Figure 2 shows the aerial map of the towns surrounding Enugu-Abakaliki Expressway, with the road under study shown with dark highlighter indicating a two-way direction movement.

EAE has one lane of average width of 9.8m. It originated from Airport Road junction, goes through PRODA Headquarters and continued to Abakaliki.

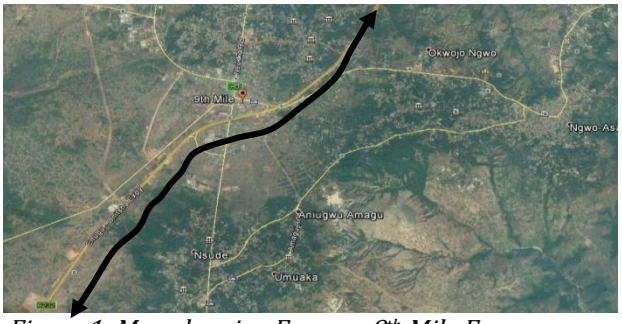

Figure 1: Map showing Enugu – 9th Mile Expressway

Figure 2: Map showing Enugu – Abakaliki Expressway

2.2. Method of Data Collection

Regression analysis was conducted based on the collected data by the road manual hourly traffic counters on the two highways. Fourteen (14) human recorders (counters) were stationed at Point A and Point B of 1km distance of separation, seven (7) counters at one point on the road side, each counter recording one type of traffic composition. Each of the recorders was replaced by other recorders to avoid over-labour and fatigue. Then at the end of every hourly traffic record, the average of the volume of traffic composition at Points A and B is taken as the hourly traffic volume. The traffic

count can be diagrammatically and mathematically expressed in the Figure 3.

Hourly daily traffic, H_d is expressed by Eq. (6) as follows:

$$H_d = \frac{traffic\ Point\ A + traffic\ Point\ B}{2} \quad (6)$$

The time of record transition is taken to be one minutes of average lagging. We have seven traffic composition in consideration; 1. Motorcycle, 2. Tricycle, 3. Pickup/cars, 4. Mini buses, 5. Luxurious buses, 6. Lorry/trucks, 7. Tankers/trailers.

The hourly traffic count was done for seven consecutive days after which the summary of the count was recorded. Table 1 and 2 show the summary of the hourly traffic count collected from 07:00hrs – 19:00hrs (from Enugu – 9th Mile Expressway and Enugu – Abakaliki Expressway respectively) for a period of seven consecutive days using Eq. (6) [15].

2.3. Model Formulation and Calibration

Using a linear relationship between space-mean speed and density, the model equation can be formulated as stated in Eqs. (7 – 10) respectively. Let

$$y = a + bx \quad (7)$$

Where: y is the speed (u), x is the density (k), R is the correlation coefficient, a, b is the constants to be determined.,

$$R = \frac{n\sum_{i=1}^{n} xy - (\sum_{i=1}^{n} x)(\sum_{i=1}^{n} y)}{[\sqrt{[n(\sum_{i=1}^{n} x^2) - (\sum_{i=1}^{n} x)^2]} \cdot [\sqrt{[n(\sum_{i=1}^{n} y^2) - (\sum_{i=1}^{n} y)^2]}} \quad (8)$$

$$b = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i - (\sum_{i=1}^{n} x_i)^2} \quad (9)$$

$$a = \overline{y} - b\overline{x} \quad (10)$$

Where: $\overline{y}$ and $\overline{x}$ are the average values of y and x respectively

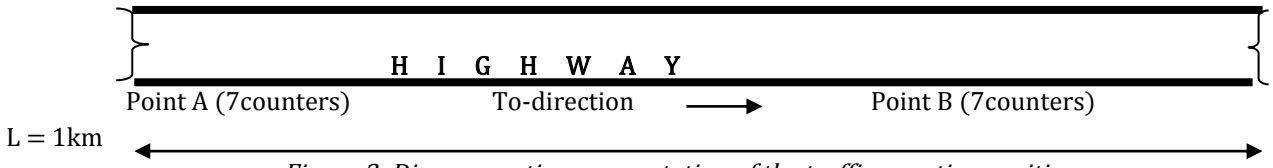

Figure 3: Diagrammatic representation of the traffic counting positions

Table 1: Traffic count done along Enugu – 9th Mile Highway in accordance with the Road Safety Standard by the Federal Road Safety Corps, Enugu State Command, 2015.

TRAFFIC COUNT TEMPLATE (SUMMARY SHEET)								
COMMAND- RS9.1 ENUGU SECTOR COMMAND								
DIRECTION INDICATORS: TO ROUTE:ENU-9THMILE								
TIME INTERVAL	DAY ONE 21/09/2015	DAY TWO 22/09/2015	DAY THREE 23/09/2015	DAY FOUR 24/09/2015	DAY FIVE 25/09/2015	DAY SIX 26/09/2015	DAY SEVEN 27/09/15	TOTAL
0700-0800HRS	459	297	291	252	297	320	162	2078
0801-0900HRS	540	556	353	290	336	365	189	2629
0901-1000HRS	358	424	455	312	370	380	189	2488
1001-1100HRS	302	286	513	345	448	408	194	2496
1101-1200HRS	272	251	453	339	459	527	179	2480
1201-1300HRS	224	285	449	351	476	508	259	2520
1301-1400HRS	259	334	451	414	495	450	297	2700
1401-1500HRS	292	321	424	472	525	508	281	2823
1501-1600HRS	304	332	436	493	534	544	302	2945
1601-1700HRS	362	367	533	496	549	560	337	3204
1701-1800HRS	382	385	593	513	396	532	351	3152
1801-1900HRS	354	328	473	524	351	380	235	2645
TOTAL	4108	4166	5424	4801	5236	5482	2975	32160

Table 2: Traffic count done along Enugu – Abakaliki Highway in accordance with the Road Safety Standard by the Federal Road Safety Corps, Enugu State Command, 2015.

TRAFFIC COUNT TEMPLATE (SUMMARY SHEET)								
COMMAND- RS9.1 ENUGU SECTOR COMMAND								
DIRECTION INDICATORS: TO-DIRECTION ROUTE: ENUGU - ABAKALIKI								
TIME INTERVAL	DAY ONE 23/12/2015	DAY TWO 24/12/2015	DAY THREE 25/12/2015	DAY FOUR 26/12/2015	DAY FIVE 27/12/2015	DAY SIX 28/12/2015	DAY SEVEN 29/12/2015	TOTAL
0700-0800HRS	338	439	187	197	161	244	188	1754
0801-0900HRS	367	519	272	228	184	258	202	2030
0901-1000HRS	418	546	310	173	203	260	253	2163
1001-1100HRS	447	577	252	227	235	277	206	2221
1101-1200HRS	490	624	253	228	246	301	200	2342
1201-1300HRS	552	714	253	204	272	307	208	2510
1301-1400HRS	627	681	331	225	267	261	237	2629
1401-1500HRS	628	693	419	222	271	235	240	2708
1501-1600HRS	524	692	451	228	286	218	271	2670
1601-1700HRS	661	699	448	243	286	213	287	2837
1701-1800HRS	588	814	431	254	246	220	231	2784
1801-1900HRS	553	681	349	194	234	130	189	2330
TOTAL	6193	7679	3956	2623	2891	2924	2712	22785

2.4 Calculation of the Flow, Speed and Density.

Traffic Flow, *q*, is simply defined as the number of vehicles, *n*, passing some designated highway point in a time interval of duration, *t*, as expressed by Eq. (11) as:

$$q = \frac{n}{t} \tag{11}$$

Here q is the traffic flow (veh/hr), n is the number of vehicles, t is the time interval (hr). Space – Mean Speed, u, is the time necessary for a vehicle to traverse some known length of highway, L. If all vehicle speeds are measured over the same length of highway ($L = L_1 = L_2 = \ldots L_n$), then u is expressed as:

$$u = \left(\left(\frac{1}{n}\right) \sum_{i=1}^{n} \frac{1}{(L/t_i)} \right)^{-1} \tag{12}$$

where, L = length of highway under study (Km), t_i = time interval of i^{th} vehicle (hr).

Traffic Density (*k*) in veh/km is defined by Eq. (13) as:

$$k = \frac{n}{L} \tag{13}$$

As usual, *n* and *L* maintain their usual meanings and units. In this paper, the Microsoft Excel Worksheet from Microsoft Office 2007® was employed in the calculation to aid in handling of large data and eliminates computation errors for computation of space-mean speed, u, length, L of highway under study = 1km, Time interval, (t) = 1hr for the first sample record of traffic and 0.9833hr for the rest of the sample.

3. RESULTS AND DISCUSSION

3.1. Enugu – 9th Mile Expressway (E9E).

Using Day 6 (26-9-2015) for the computation, because it has the highest volume of daily traffic, n = 5482 vehicles Computing in tabular form by using Microsoft Excel spread sheet from Table 1from Eqs.11, 12 and 13 respectively the traffic flow, q, speed, u and density, k can be calculated on hourly basis as can be seen in Table 3 (for Enugu – 9th Mile) and Table 4 (for Enugu – Abakaliki).

3.2 Computation of Coefficient of Regression, (r or R).

Denoting speed (u) = *y*, density (k) = *x*, *n* = number of hourly sample (n = 12). From Table 4, the values of the space-mean speed and density are imported from Table 3 above. Using statistical equation to create another table for the coefficient of correlation in an Excel Worksheet, the value of coefficient of correlation, R can be found.

Table 3: Computation of Flow, Speed, and Density using Microsoft Excel Worksheet for E9E

Time interval	Volume, n	1/n	t(hrs)	L(km)	Flow, q=n/t (veh/km)	L/t (km/hr)	1/(L/t)	A= 1/n x ∑(1/(L/T))	Space-mean Speed, U = L/A	Density, k = n/L
0700-0800HRS	320	0.0031	1.0000	1	320	1.0000	1.0000	0.0369	27.0803	320
0801-0900HRS	365	0.0027	0.9833	1	371	1.0169	0.9833	0.0324	30.8885	365
0901-1000HRS	380	0.0026	0.9833	1	386	1.0169	0.9833	0.0311	32.1579	380
1001-1100HRS	408	0.0025	0.9833	1	415	1.0169	0.9833	0.0290	34.5274	408
1101-1200HRS	527	0.0019	0.9833	1	536	1.0169	0.9833	0.0224	44.5979	527
1201-1300HRS	508	0.0020	0.9833	1	517	1.0169	0.9833	0.0233	42.9900	508
1301-1400HRS	450	0.0022	0.9833	1	458	1.0169	0.9833	0.0263	38.0817	450
1401-1500HRS	508	0.0020	0.9833	1	517	1.0169	0.9833	0.0233	42.9900	508
1501-1600HRS	544	0.0018	0.9833	1	553	1.0169	0.9833	0.0217	46.0365	544
1601-1700HRS	560	0.0018	0.9833	1	569	1.0169	0.9833	0.0211	47.3906	560
1701-1800HRS	532	0.0019	0.9833	1	541	1.0169	0.9833	0.0222	45.0210	532
1801-1900HRS	380	0.0026	0.9833	1	386	1.0169	0.9833	0.0311	32.1579	380
SUM	**5482**						**11.8167**			

Table 4: Computation of correlation coefficient using Microsoft Excel Spreadsheet

n	Density (k) x	Speed (u) y	x^2	y^2	xy
1	320	27.0803	102400	733.3426	8665.696
2	365	30.8885	133225	954.0994	11274.3025
3	380	32.1579	144400	1034.1305	12220.002
4	408	34.5274	166464	1192.1414	14087.1792
5	527	44.5979	277729	1988.9727	23503.0933
6	508	40.2820	258064	1622.6395	20463.256
7	450	38.0817	202500	1450.2159	17136.765
8	508	42.9900	258064	1848.1401	21838.92
9	544	46.0365	295936	2119.3593	25043.856
10	560	47.3906	313600	2245.8690	26538.736
11	532	45.0210	283024	2026.8904	23951.172
12	380	32.1579	144400	1034.1305	12220.002
SUM	5482	461.2117	2579806	18249.9314	216942.98
AVERAGE	456.8333	38.43430833			
	n∑x2	=	30957672		
	n∑y2	=	218999.177		
	n∑xy	=	2603315.76		
	∑x∑y	=	2528362.539		

Using equation (8):

$$R = \frac{n\sum_{i=1}^{n} xy - (\sum_{i=1}^{n} x)(\sum_{i=1}^{n} y)}{[\sqrt{[n(\sum_{i=1}^{n} x^2) - (\sum_{i=1}^{n} x)^2)]} \,.\, [\sqrt{[n(\sum_{i=1}^{n} y^2) - (\sum_{i=1}^{n} y)^2)]}}$$

$$\mathrm{R} = \frac{2603315.76 - 2528362.539}{\sqrt{[(30957672 - (5482)^2)]} \,.\, [\sqrt{[(218999.177 - (461.2117)^2)]}\,]} = \frac{74953.221}{75420.5005} = 0.9938$$

To find the values of *a* and *b*, using Microsoft Excel Worksheet for the computation;

Substitute in the equation (9) above;

$$b = \frac{\mathrm{n}\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x_i y_i} - \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x_i} \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{y_i}}{\mathrm{n}\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x_i} - (\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{x_i})^2}$$

$$\mathrm{b} = \frac{2587847.742 - 2513603.765}{65400 - 29702500} = -0.0025$$

$$\mathrm{a} = \overline{y} - b\overline{x} = 38.4343 - (-0.0025 \times 454.1667) = 39.57$$

Therefore the model equation (from equation 10);

$$u = a + bk = = 39.57 - 0.0025k \qquad (14)$$

This value of R = 0.9938shows a best fit of the data analysis and thus has a very high confidence and less variation of the traffic data. The Figure 4.1 shows the graph of space-mean speed against density for Enugu – 9th Mile Expressway. From the graph, as the density increases, the speed decreases because drivers slow down to allow for maneuvers of other vehicles. Consequently, when where there are very few vehicles along the highway, the density becomes very low and the drivers will be able to travel freely to a maximum speed. This maximum speed is referred to as free flow speed, u_f. From Figure 4.1 u_f = 39.57km/hr when k = 0. This maximum value of speed is the design speed at that particular highway section.

3.2. Enugu – Abakaliki Expressway.

Using Day 2 (24-12-2015) for the computation, because it has the highest volume of daily traffic. As explained in section 3.1, the flow, space-mean speed and density can be calculated using the formulae in equations 11, 12 and 13 respectively. Table 5 shows the values of the traffic parameters as computed using Microsoft Excel Worksheet® 2007.

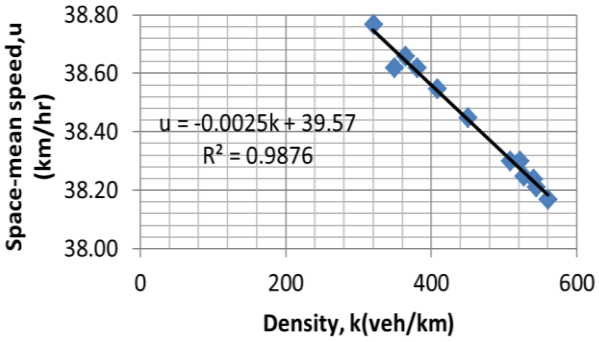

Fig. 4: Plot of Space-mean Speed versus Traffic Density for E9E

3.3 Computation of Coefficient of correlation, (r or R).

Denoting speed (u) = *y*, density (k) = *x*, *n* = number of hourly sample (n = 12). Table 6 shows the statistical values of the computation for calculation of coefficient of correlation, R. Using equation (8) to calculate R.

Table 5: Analysis of Flow, Speed, Density using Microsoft Excel Worksheet for EAE

Time interval	Volume, n	1/n	t(hrs)	L(km)	Flow, q=n/t	L/t	1/(L/t)	A= 1/n x ∑(1/(L/T))	Speed, U = L/A	Density, k = n/L
0700-0800HRS	439	0.0023	1.0000	1	439	1.0000	1.0000	0.0269	37.1508	439
0801-0900HRS	519	0.0019	0.9833	1	528	1.0169	0.9833	0.0228	43.9209	519
0901-1000HRS	546	0.0018	0.9833	1	555	1.0169	0.9833	0.0216	46.2058	546
1001-1100HRS	577	0.0017	0.9833	1	587	1.0169	0.9833	0.0205	48.8292	577
1101-1200HRS	624	0.0016	0.9833	1	635	1.0169	0.9833	0.0189	52.8066	624
1201-1300HRS	654	0.0015	0.9833	1	665	1.0169	0.9833	0.0181	55.3454	654
1301-1400HRS	681	0.0015	0.9833	1	693	1.0169	0.9833	0.0174	57.6303	681
1401-1500HRS	693	0.0014	0.9833	1	705	1.0169	0.9833	0.0171	58.6458	693
1501-1600HRS	692	0.0014	0.9833	1	704	1.0169	0.9833	0.0171	58.5612	692
1601-1700HRS	699	0.0014	0.9833	1	711	1.0169	0.9833	0.0169	59.1536	699
1701-1800HRS	685	0.0015	0.9833	1	697	1.0169	0.9833	0.0173	57.9688	685
1801-1900HRS	870	0.0011	0.9833	1	885	1.0169	0.9833	0.0136	73.6246	870
SUM	7679						11.8167			

Table 6: Computation of regression coefficient using Microsoft Excel Spreadsheet

n	DENSITY(k) x	SPEED(u) y	x^2	y^2	xy
1	439	37.1508	192721	1380.1819	16309.2012
2	519	43.9209	269361	1929.0455	22794.9471
3	546	46.2058	298116	2134.9760	25228.3668
4	577	48.8292	332929	2384.2908	28174.4484
5	624	52.8066	389376	2788.5370	32951.3184
6	654	55.3454	427716	3063.1133	36195.8916
7	681	57.6303	463761	3321.2515	39246.2343
8	693	58.6458	480249	3439.3299	40641.5394
9	692	58.5612	478864	3429.4141	40524.3504
10	699	59.1536	488601	3499.1484	41348.3664
11	685	57.9688	469225	3360.3818	39708.628
12	870	57.6303	756900	3321.2515	50138.361
SUM	7679	633.8487	5047819	34050.9216	413261.653
AVERAGE	639.9167	52.820725			

$$R = \frac{12(413261.653) - (7679\ x\ 633.8487)}{\left[\sqrt{[12(5047819) - 7679)^2]}\right] \times \left[\sqrt{[12(34050.9216) - (633.8487)^2]}\right]} = \frac{91815.6687}{104887.9638} = 0.8753$$

To find a and b using equations (8) and (9), substitute in equation (9),

$$b = \frac{4959139.836 - 4867324.167}{92148 - 58967041} = -0.0016.$$

$a = \overline{y} - b\overline{x} = 52.8207 - (-0.0016 \text{ x } 639.9167) = 53.84$

Therefore the model equation is;

$$u = 53.84 - 0.0016k \quad (15)$$

Figure 5 shows the graph of space-mean speed against density for Enugu – Abakaliki Expressway. From the graph, it can be observed that the there is a little variation in the traffic data. As the density increases, the speed decreases because the drivers allow for the safe maneuver of other speeding vehicles. The free flow speed when the density is zero is $u_f = 47.13$Km/hr. this is the design speed of the highway which must not be exceeded at the section of the highway. At a certain point in the graph, the speed drops drastically due to the influx of vehicles trying to pass the highway section at the same time.

From the calibrated equation (14), u = 38.38 – 0.0025k for E9E, and equation (15), u = 53.84 − 0.0016k for EAE, as the traffic density increases, the space-mean speed decreases, and vice versa. It shows that when there are few vehicles on a highway, the vehicles tend to maximize the design speed of the road which is limited to a certain value. This is in contrast to the findings of other researchers which asserted that at a very low density, the speed tends to infinity which is not realistic in the field. The limitation of speed level to a maximum value rather than infinity is as a result of the effect of field phenomena like merging/diverging traffic, breakdown of vehicle that suddenly comes to a stop, traffic joining the highway from a minor road, commercial vehicles/tricycles braking to pick or drop passengers and so on. Table 7 shows traffic data differences of the two roads under study, indicating the jam density (k_j) and the free flow speed (u_f)

The quantity R, called the *linear correlation coefficient*, measures the strength and the direction of the linear relationship between space-mean speed and traffic density. Since the correlation is greater than 0.8, it is generally described as *strong*. The *coefficient of determination, R^2*, gives the proportion of the variance (fluctuation) of space-mean speed that is predictable from the density. The coefficient of determination represents the percent of the data that is the closest to the line of best fit. For E9E, $R^2 = 0.9876$, means that 98.76% of the total variation in speed can be explained by the linear relationship between density and speed (as described by the regression equation). The other 1.24% of the total variation in speed indicates the diverted/merged traffic after/before being counted at one point of traffic counting position. For EAE, $R^2 = 0.7662$, means that 76.62% of the total variation in speed can be explained by the linear relationship between density and speed. The other 23.38% of the total variation in speed indicates the diverted/merged traffic after/before being counted at one point of traffic counting position. This is an indication that more vehicles diverge to or merge from other service roads than on the E9E.

It was also observed that the Enugu – 9th Mile Expressway has a higher value of R, (best fit) and high confidence but has a lower value of the speed – density relationship than the Enugu – Abakaliki Expressway. This is because of the differences in the structure and the traffic composition of the two highways.

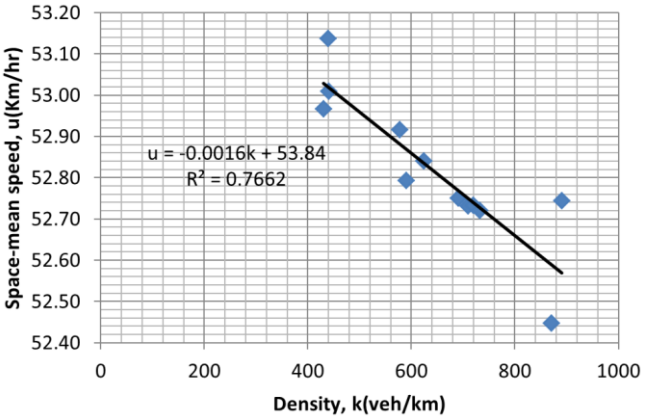

Figure 5: Plot of Space-mean Speed (u) against Traffic Density (k) for EAE

Table 7: Traffic data values for E9E and EAE

Name of Road	Number of Lanes	Correlation Coefficient, R	Coefficient Of Determination, R^2	Model Equation	Jam Density, *(veh/km)* k_j	Free Flow Speed, (Km/hr) u_f
E9E	2	0.9938	0.9878	u = 38.32 - 0.0025k	15,328	38.32
EAE	1	0.8753	0.7662	u= 53.84 - 0.0016k	33,650	53.84

Table 8: Traffic data values for EPE, 9OE, and 9ORE

Name of Road	Number of Lanes	Correlation Coefficient, *R*	Coefficient of Determination,R^2	Model Equation	Jam Density, *(veh/km)* k_j	Free Flow Speed, (Km/hr) u_f
EPE	2	0.9818	0.9757	$u = 58.67 - 0.01k$	5,867	58.67
9OE	2	0.9746	0.9498	$u = 33.15 - 0.002k$	16,575	33.15
9ORE	1	0.8651	0.7483	$u = 29.76 - 0.003k$	9,920	29.76

E9E is a two-lane highway with various dilapidated points and conflicts/accident prone zones, comprising mostly of heavy duty trucks and lorries, which as a result of the nature of the road, travel at a lower speed. This is evidence to the reduced value of the space-mean speed of traffic as many vehicles try to maneuver from one lane to the other. EAE is a one-lane highway with little number of pot holes and conflict zones. The value of R is lower because of frequent stopping, diverging and merging (from other minor roads) of commercial vehicle passing through a section of the highway to serve their passengers. It was also observed that the hourly traffic flow is higher on EAE than on E9E as can be seen in Table 7. This is due to some road users having alternatives to the use of E9E.

Similar work done for Enugu – Port Harcourt Expressway (EPE), 9TH Mile – Onitsha Expressway (9OE), and 9TH Mile – Oji River Expressway (9ORE) yielded the following results as shown in Table 8. It shows that EPE and 9OE have close traffic characteristic as compared to E9E because they are all two-lane highways. Similarly, 9ORE has traffic characteristic very close to EAE because it is also a one-lane highway. In this regard, E9E and EAE become the representatives of the two forms of the highways under study.

4. CONCLUSION

The analysis of the traffic study using the speed-density regression model carried out above revealed that the two-lane highways have a better fit of correlation coefficient than the one-lane highways. The calibrated speed-density model showed that the one-lane highways have higher values of the traffic data for space-mean speed with less variation than the two-lane highways. It can also be observed that the characteristics of the two-lane highway and one-lane highway are different, and the relations of their three traffic flow factors (flow, speed and density) are also different. The decrease of speed in relation to the increase in the traffic density is seen to conform to those in the literature but is contrary to the earlier model that stipulated an infinite speed at a very low density.

This research therefore provides a good approximation necessary for use in the calibration of speed along a highway section in cognizance of diverging/merging traffic from minor service roads. It is also found useful for use in speed control device and law enforcement for over-speeding drivers.

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