

## DETERMINATION OF PREDICTIVE MODELS FOR TRAFFIC CONGESTION IN LAGOS METROPOLIS

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### ABSTRACT

*Traffic congestion always have negative effects on lives and environment. To quantify these negative effects is complex and multivaried. For congestion to be mitigated or eliminated, gathering of information on traffic incidents such as state of the road, congestion spots, and volume of traffic on each road cannot be overemphasized. Outright elimination of traffic congestion may not be a realistic goal, but traffic management that is based on available traffic information that will reduce the intensity of congestion may be achievable.*

*This work was directed at identifying causes of congestion on some selected routes in Lagos Metropolis. Questionnaires were administered. Results revealed that bad access road is the highest cause of traffic congestion, and that cars are the highest mode of transportation. For Recurrent Congestion, data on traffic volume were used to develop a generalized polynomial of  $n$  order. From the generalized model, a response (dependent) variable  $y$  for any route can be determined for any predictor (independent) variable  $x$ . Spatial queries of the various volume of traffic on these roads revealed more routes are congested between 7.00 – 8.00hrs in the morning peak period and between 16.00 – 17.00hrs and 18.00 – 19.00hrs in the evening peak period.*

**Keywords:** *Traffic Congestion, Geographic Information Systems (GIS), Passenger Car Equivalents (PCE), Generalized Polynomial, Volume of Traffic.*

### 1. INTRODUCTION

Traffic congestion is a condition on road networks that occurs when the number of vehicles on the roads exceeds the capacity of the roads, and is indicated by deceleration, delay in travel time, and long queues. Traffic congestion is a regular occurrence on road networks in major cities of the world, the frequency of its occurrence is a concern to all road users. This situation has prompted transport researchers to carry out research on traffic congestion and thereby develop models to help reduce congestion on road networks (Victoria Transport Policy Institute, 2010; The United Kingdom House of Commons Library, 1998).

According to traffic engineers, congestion comes in two major forms: (i) Recurrent Congestion- this occurs regularly on a daily, weekly or annual cycle. It is the consequence of factors such as commuting, shopping or weekend trips, that cause regular demand surges on the transportation system. Recurrent

congestion can have unforeseen impacts in terms of its duration and severity. Mandatory trips are mainly responsible for the peaks in circulation flows, implying that about half the congestion in urban areas are recurring at specific times of the day and on specific segments of the transport system; and (ii) Non-Recurrent Congestion- this occurs as a result of accidents, road construction, road closures or special events. It is caused by random events such as accidents and unusual weather conditions (rain, snowstorms, and so on), which are unexpected and unplanned. Non-recurrent congestion is linked to the presence and effectiveness of incident response strategies. As far as accidents are concerned, their randomness is influenced by the level of traffic as the higher the traffic on specific road segments the higher the probability of accidents (Rodrigue, Comtois and Slack, 2009).

Congestion is prevalent in cities across Nigeria. Lagos – one of the highly industrialized and well developed cities in Africa is confronted with this menace. Every morning, afternoon and evening, the streets of Lagos, are crowded with cars, taxis, buses

and trucks. Traffic congestion in Lagos occurs as a result of several factors which include disregard of traffic rules by motorists, narrow road networks, bad access roads, indiscriminate parking of vehicles on roads, and so on.

Ogunbodede (2009) examined traffic problems in Akure (Nigeria) using a GIS application. A Traffic Information System (TIS) was developed. TIS is to provide solutions to traffic congestion in the study area in two ways: (i) by providing traffic information and (ii) by determining queries which could be used to tackle traffic congestion in the study area; Aworemi, Abdul-Azeez, Oyedokun, and Adewoye (2009) investigated the following variables as factors causing congestion in Lagos State: poor road condition, accident, inadequate road infrastructure, absence of integrated transport system, inadequate traffic planning and driver's behavior and came up with this multiple regression estimation. The results obtained from the statistical analysis of the research indicated that poor road condition, accident, inadequate road infrastructure, absence of integrated transport system, inadequate traffic planning and driver's behavior made a joint significant contribution of about 70.7% to the traffic congestion in Lagos State; Lindsey and Verhoef (2009) on congestion modelling, postulated that there is no single best way to model traffic flow and congestion but that the level of detail at which driver's behaviour should be modelled depends on the objectives of the analysis. Non-stationary traffic phenomena, such as the rush hour, hyper congestion and passing, are more complex and may call for a microscopic rather than macroscopic approach. As is true of most scientific endeavours, there is a trade-off in modelling between realism and tractability. With today's computers it is possible to simulate the minute-by-minute progress of many thousands of vehicles on a large-scale network; and (Olusina, 2013) described Intelligent Transportation Systems (ITS) as another technology that holds promise for alleviating congestion. Intelligent Transportation Systems include Advanced Traffic Management Systems that optimize traffic signals and freeway ramp controls, Advanced Vehicle Control Systems that allow closely-spaced platoons of vehicles to operate at high speeds, and Motorist Information Systems that provide real-time information and advice to individuals about travel conditions. Congestion pricing may be a complement to ITS, rather than substitute for, information technology

Therefore, to provide traffic information that will assist in congestion mitigation, a generalized predictive model for traffic congestion in Lagos Metropolis using Geographic Information Systems (GIS) was developed. Traffic congestion routes and causes of traffic congestion were identified, database was created, traffic flow on some selected roads in Lagos Metropolis was modelled using the volumes of traffic, and suggestions were proffered on improving traffic flow in Lagos Metropolis.

## 2. STUDY AREA



Figure 1: Map of Lagos Metropolis (Wikipedia, 2010).

The study area is Lagos Metropolis (Fig. 1) Lagos State was created in 1967 and served as the capital of Nigeria up till December 12th, 1991. The State comprises twenty (20) Local Government areas. The capital of Lagos is Ikeja.

The Metropolitan Lagos refers to the urban areas of Lagos and also includes semi-rural areas of the State. 88% of the population of Lagos resides in the Metropolitan Area of Lagos – the largest and most complex urban area in Nigeria. The Area has the highest concentration of economic activities in the country and provides employment to the work force of the country (Wikipedia, 2010).

## 3. CONGESTION AND ITS CAUSES

There is no universally acceptable definition for traffic congestion; different schools of thought have different definition for it. In a study carried out by the Joint Transport Research Centre (2007), the following definitions were adopted for traffic congestion:

1. Congestion is a situation in which demand for road space exceeds supply;

2. Congestion is the impedance vehicles impose on each other, due to the speed-flow relationship, in conditions where the use of a transport system approaches capacity.

Several factors are responsible for traffic congestion on road networks. As in the cities of developing nations including Lagos, findings from transport researchers revealed the following factors to be responsible for traffic congestion on roads:

- (1) Indiscriminate parking of vehicles on the road;
- (2) Potholes;
- (3) Absence of traffic light and traffic wardens;
- (4) Narrow road network;
- (5) Attitude of road users;
- (6) Bad access roads;
- (7) Use of road for social functions, religious activities and commerce;
- (8) Presence of too many vehicles on the road;
- (9) Bad weather;
- (10) Crashes/disabled vehicles;
- (11) Urbanization;
- (12) Economic/Population Growth;
- and (13) Abuses by Law Enforcement Agents. (Olusina, 2013; Transportation Research Board, 2000).

These factors have caused traffic congestions resulting to physical, emotional and economic problems such as: fatigue and stress, increase in cost of travel, environmental pollution, delay in travel time leading to loss of man-hours and missed appointments, highway robbery, street trading and street begging (especially in developing countries), slow response time to emergencies, and deterioration of vehicles (Olusina, 2013).

#### 4. RELATIONSHIP BETWEEN SPEED, FLOW AND DENSITY

Some traffic flow parameters are describe below:

- (i) Speed (v)- The speed of a vehicle is defined as the distance it travels per unit of time.
- (ii) Flow (q)- Flow is the number of vehicles that pass a given point on the road per unit of time.
- (iii) Density (k)- Density is the number of vehicles present on a given length of roadway.

The relationships between these traffic parameters are shown in Table 1.0.

Table 1.0 Traffic Flow Parameters (Drew, 1970).

	Vehicles per hour (Veh/h)		Seconds per vehicle (s/veh)
<b>Flow</b>		<b>Headway</b>	
<b>Speed</b>	Kilometers	<b>Travel</b>	Seconds

	per hour (Km/h)	<b>time</b>	per km (s/km)
	Vehicles per lane-km (veh/lane-km)		Meters per vehicle (m/veh)
<b>Density</b>		<b>Spacing</b>	

The relationship between speed, flow and density is given in Eq. (1):

$$q = k v \tag{1}$$

where:  $q$  = Flow (vehicles/hour),  
 $v$  = Speed (miles/hour, kilometers/hour), and  
 $k$  = Density (vehicles/mile, vehicles/kilometer) (Drew, 1970).

### 5. METHODOLOGY

#### 5.1 Data Acquisition

Administration of Questionnaires- a survey was carried out to obtain information on traffic congestion from the road users within the study area. In carrying out the survey, consideration was given to the population of the local government areas within Lagos Metropolis. For the survey, the following was carried out: (1) identification of the congestion hot spots within the considered 16-Local Government Areas; (2) identification and classification of the roads into twelve broad classes –with at least one of the classes of the roads in the study area selected; and (3): random selection of respondents (not < 16 years) for the survey and not more than one respondent was selected in an area. The sample population size for the survey was two hundred and fifty (250). The survey spanned a period of thirty (30) working days. Questions addressed include: identifying congestion hot spots, the causes of congestion in their areas, and the effects of congestion. Thirty-two (32) roads (To and Fro) were considered for the study.

Traffic Count Data- The traffic count data for some selected roads within Lagos Metropolis was obtained from Lagos Metropolitan Area Transport Authority (LAMATA).

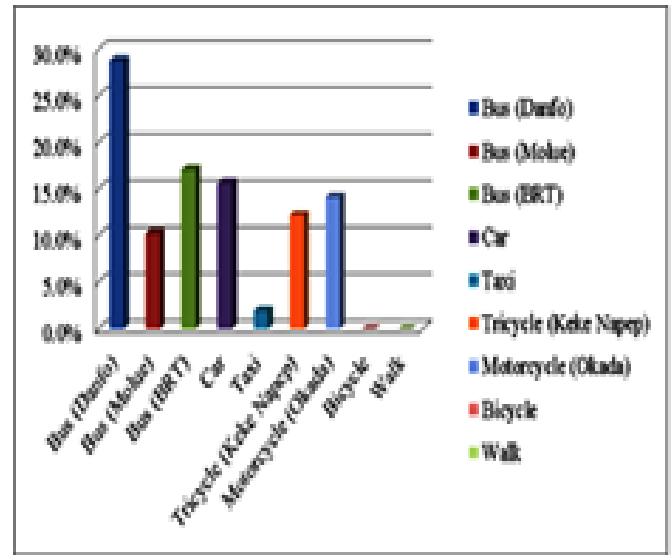
Road Network Map- Lagos Metropolitan road network map was obtained from Lagos Metropolitan Area Transport Authority (LAMATA).

Spatial Data- The coordinates of the congestion spots obtained from the field was based on Universal Transverse Mercator (UTM) coordinate system, Zone 31N: Eastings and Northings.

5.2 Data Processing

The responded questionnaires were edited and analyzed. The traffic data were reduced to hourly interval and the Passenger Car Equivalent (PCE) for the each vehicle type was determined for different time periods (Saha, Hossain, Mahmud and Islam, 2009). The base map used for this study is the Lagos Street in ArcGIS 9.2 environment. Attribute and spatial data were integrated together in the GIS environment (Burrough, and McDonnell, 1998). The roads in the study areas were spatially classified based on the PCE (Vehicles). Finally, various queries were generated and analyzed.

The processed traffic data were imported into MATLAB R2008b, plotted and polynomial models of varying degrees were used to fit the plotted observed data (Eq. 2 – 6) (Aworemi, Abdul-Azeez, Oyedokun, and Adewoye, 2009).



6. RESULT AND ANALYSIS

6.1 Results

Results obtained include:

6.1.1 Results for the questionnaires

Various results were generated from the responses of the questionnaire. These include: Local Government Areas of the Respondents (Fig.2.1); Travel Modes of Respondents (Fig.2.2); and so on:

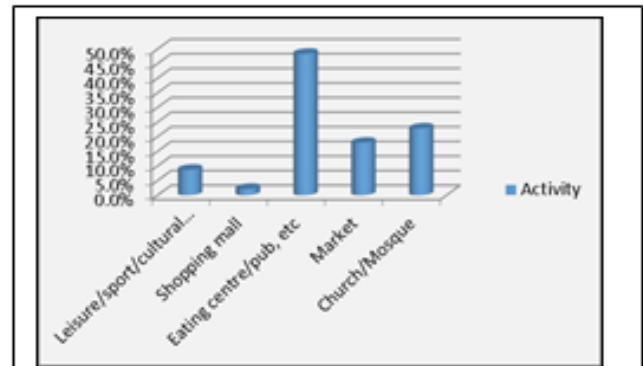


Figure 2.3: Other Places Visited by Respondents before getting Home from Work/School.

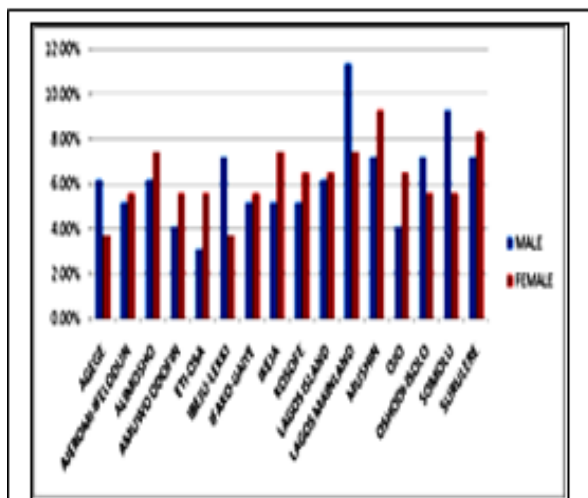


Figure 2.1: Local Government Areas of the Respondents.

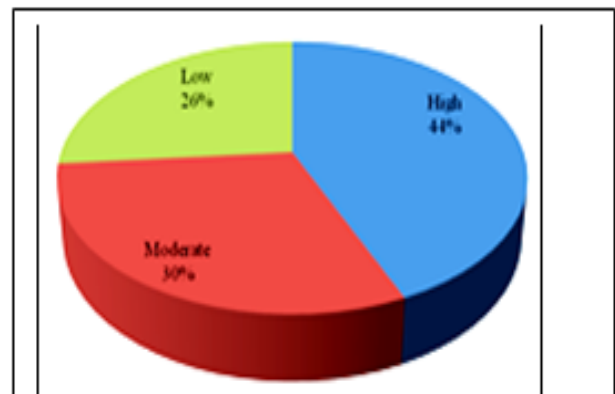


Figure 2.4: Volume of Traffic along Respondents' Route to Work/School.

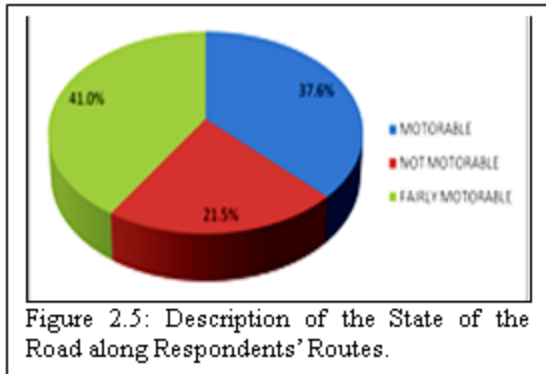


Figure 2.5: Description of the State of the Road along Respondents' Routes.

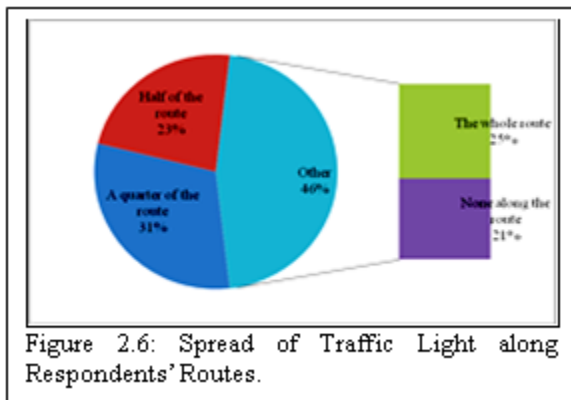


Figure 2.6: Spread of Traffic Light along Respondents' Routes.

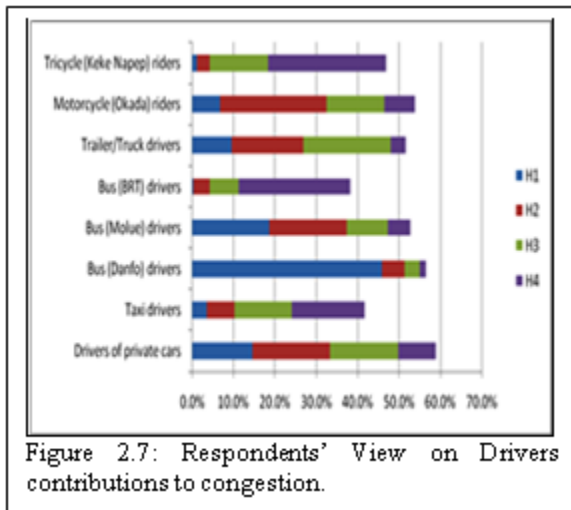
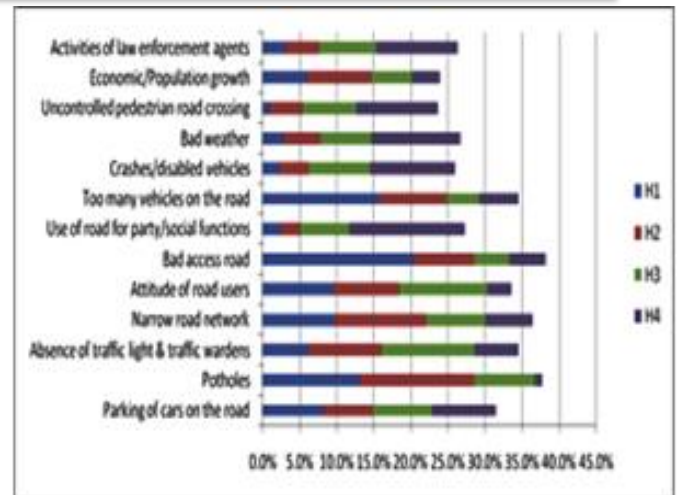


Figure 2.7: Respondents' View on Drivers' contributions to congestion.



For Figures 2.8 and 2.9:  
 H1 = Highest cause of traffic congestion  
 H2 = Next highest cause of traffic congestion  
 H3 = Average cause of traffic congestion  
 H4 = Below average cause of traffic congestion

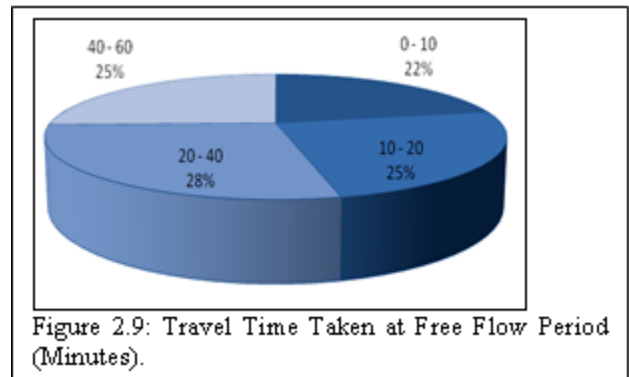


Figure 2.9: Travel Time Taken at Free Flow Period (Minutes).

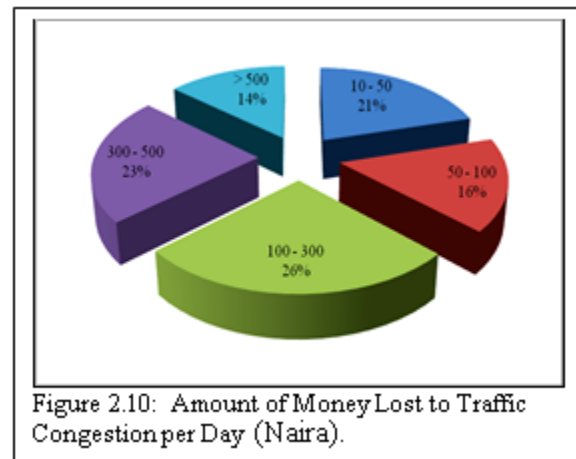


Figure 2.10: Amount of Money Lost to Traffic Congestion per Day (Naira).

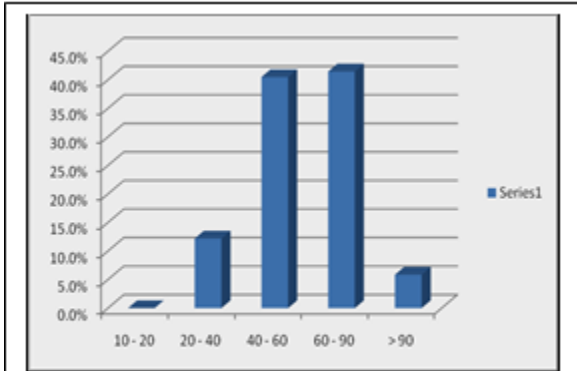


Figure 2.11: Travel Time Taken at Peak Period (Minutes).

### 6.1.2 Modelling the Traffic along the Selected Roads

Some of the graphical plots and the derived mathematical models for all the roads covered by this study are shown below:

1a. Agege Motor Road (South-Eastbound), Agege:

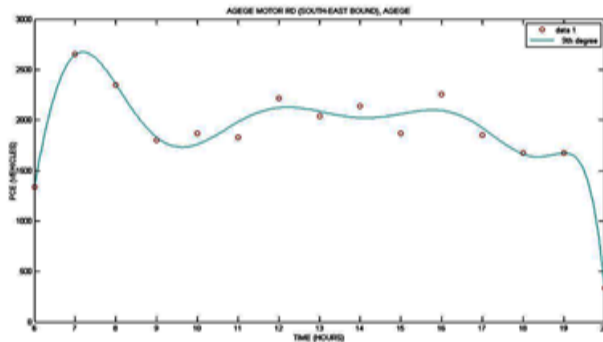


Figure 3.1: The Best Fit Polynomial for the Volume of Traffic (PCE) vs. Time [hr.].

A 9th degree polynomial gave the best fit:

$$y = p_1 * z^9 + p_2 * z^8 + p_3 * z^7 + p_4 * z^6 + p_5 * z^5 + p_6 * z^4 + p_7 * z^3 + p_8 * z^2 + p_9 * z + p_{10} \quad (2)$$

where:  $y$  = predicted volume of vehicles;  
 $z$  = the  $z$  value of the time  $x$  (centered and scaled) i.e.  
 $z = (x - \mu) / \sigma$  i.e.  $(\mu / \sigma)$ ,  $\mu = 13$ ,  $\sigma = 4.4721$ ;

Coefficients:  $p_1 = -543.89$ ,  $p_2 = -363.64$ ,  $p_3 = 3080.9$ ,  
 $p_4 = 1138.8$ ,  $p_5 = -5644.8$ ,  $p_6 = -723.04$ ,  $p_7 = 3359.3$ ,  
 $p_8 = -226.76$ ,  $p_9 = -378.31$ ,  $p_{10} = 2086.6$ ;  
 Norm of residuals = 358.13.

1b. Agege Motor Road (North-Westbound), Agege:

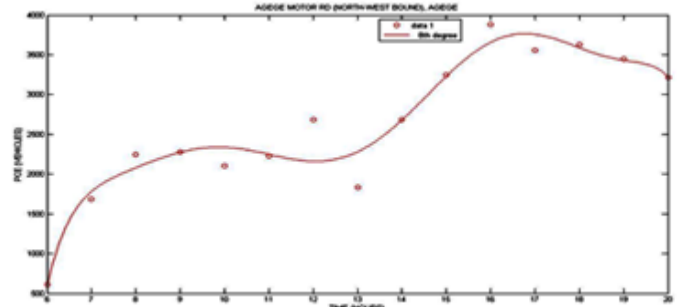


Figure 3.2: The Best Fit Polynomial for the Volume of Traffic (PCE) vs. Time [hr.].

An 8th degree polynomial gave the best fit:

$$y = p_1 * z^8 + p_2 * z^7 + p_3 * z^6 + p_4 * z^5 + p_5 * z^4 + p_6 * z^3 + p_7 * z^2 + p_8 * z + p_9 \quad (3)$$

Where  $z$  is centered and scaled:  $z = (x - \mu) / \sigma$ ,  $\mu = 13$ ,  
 $\sigma = 4.4721$ . Coefficients:  $p_1 = -370.55$ ,  $p_2 = 87.324$ ,  
 $p_3 = 2008$ ,  $p_4 = -100.97$ ,  $p_5 = -3987.6$ ,  $p_6 = -417.24$ ,  
 $p_7 = 3014.1$ ,  
 $p_8 = 1183.4$ ,  $p_9 = 2280.7$ . Norm of residuals = 816.08

The best fit polynomials for the other roads were determined.

### 6.1.3 Deriving Generalized Model

From all the equations, a generalized polynomial equation for all the roads was derived:

$$y = p_1 * z^n + p_2 * z^{n-1} + p_3 * z^{n-2} + p_4 * z^{n-3} + p_4 * z^{n-4} + \dots + p_n * z + p_{(n+1)}, \quad (4)$$

Equation 4 is an  $n^{th}$  degree polynomial with coefficients  $p_1, p_2, p_3,$

$p_4, \dots,$

$p_n$  and  $p_{(n+1)}$

To predict the volume of traffic  $y$  for a given time  $x$  on any of the selected roads in the study area, the  $z$  value of the time  $x$ , was entered into the generalized polynomial Equation 4, and the results are shown in Table 2.

6.1.4 Predicting and Validating the Generalized Model

Along Agege Motor Road (South-Eastbound), Agege: plugging the coefficients of  $p_1, p_2, p_3, p_4, \dots, p_n$  and  $p_{(n+1)}$  of the route (where  $n = 9$ ) into Equation 4, the Volume of Traffic on Agege Motor Road (South-Eastbound) at different time were predicted. The result was compared with the observed data to validate the predicted model (Tables 2 and Figure 4.1).

Table 2. Prediction of the Volume of Traffic along Agege Motor Road (South-Eastbound), Agege and Validation of the Generalized Model.

Time (x) (Hours)	Z = z-score (x)	Observed Vol. of Traffic (O.V.T)	Modelled/ Predicted Vol. of Traffic (M.V.T)	Model Validation (O.V.T - M.V.T)
6.00	1.56524 758	1336	1336	0
7.00	1.34164 079	2654	2646	-8
8.00	1.11803 399	2347	2356	-9
9.00	0.89442 719	1804	1831	-27
10.00	0.67082 039	1868	1760	108
11.00	0.44721 36	1831	1980	-149
12.00	0.22360 68	2218	2124	94
13.00	0.00	2037	2087	-50
14.00	0.22360 6798	2139	2023	116

15.00	0.44721 3595	1868	2062	-194
16.00	0.67082 0393	2257	2094	163
17.00	0.89442 7191	1854	1922	-68
18.00	1.11803 3989	1673	1664	9
19.00	1.34164 0786	1676	1674	2
20.00	1.56524 7584	336	337	-1

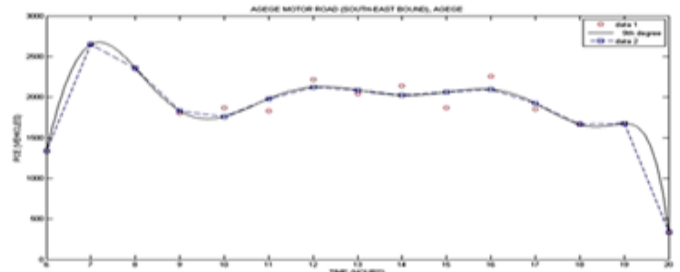


Figure 4: The Best Fit Polynomial for the Observed and Predicted Volume of Traffic (PCE) vs. Time [hr.].

The predictions of the volume of traffic along other routes were carried out and the generalized model also was validated. In all the Legends (e.g. Figure 4.0), the following applies: “data 1” - the raw/observed data (traffic count data); “nth degree” - the best fit polynomial for “data 1”; and “data 2” - the modelled/predicted volume of traffic (where applicable).

6.1.5 Query Results

The observed volumes of traffic on these roads were queried and are graphically shown below:

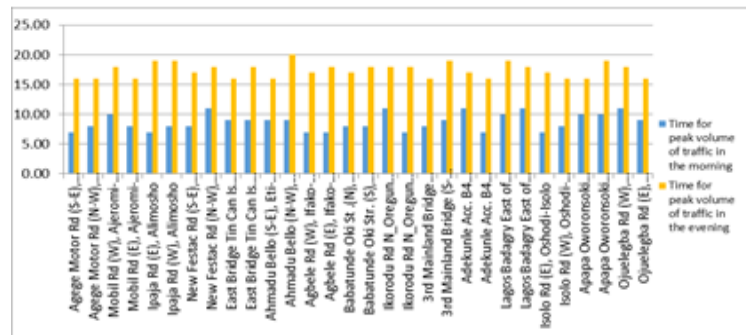


Figure 5.1: Periods of Peak Volume of Traffic on the Roads.

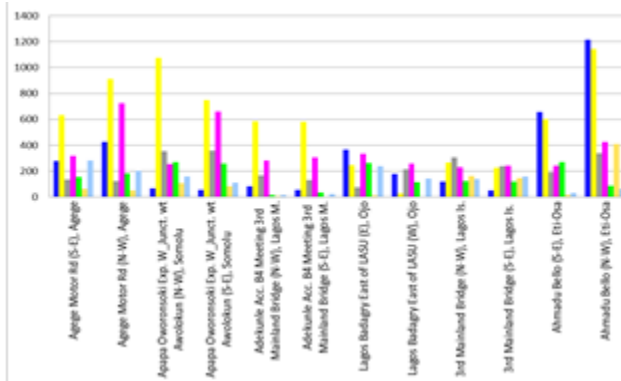


Figure 5.2: Average Volume of Different Types of Vehicles/Day on 16 Routes.

The Average Volume of Different Types of Vehicles/Day for the remaining 16 Routes were also plotted.

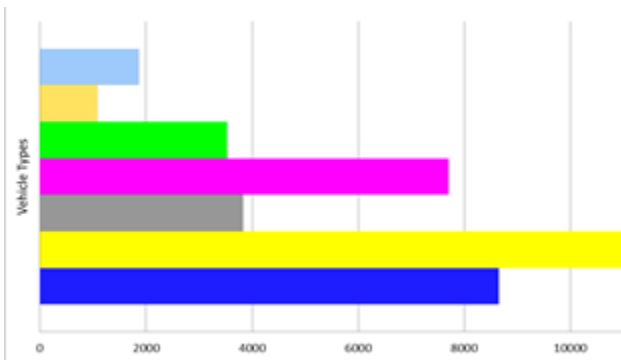


Figure 5.3: Total Average Volume of Different Types of Vehicles/Day for All Routes.

Similarly, the traffic incidents data and the Lagos Street Map were integrated together in the GIS Environment. The various roads in the study area were symbolised with unique colours based on their volumes of traffic (Pine, 1998). The query results showed the description of congested roads at different peak periods within Lagos Metropolis (Downs, 2002.).

The spatial mapping of the various volume of traffic on these roads are shown in figures below:

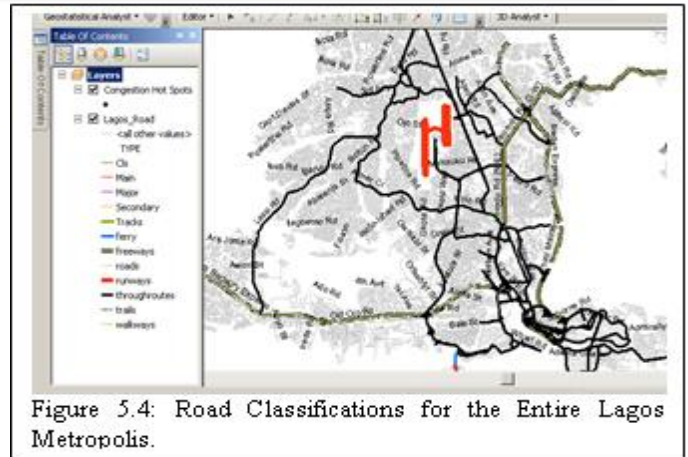


Figure 5.4: Road Classifications for the Entire Lagos Metropolis.

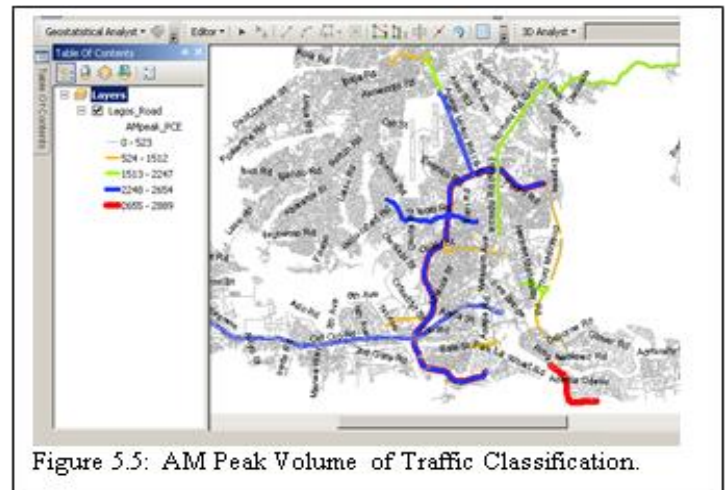


Figure 5.5: AM Peak Volume of Traffic Classification.

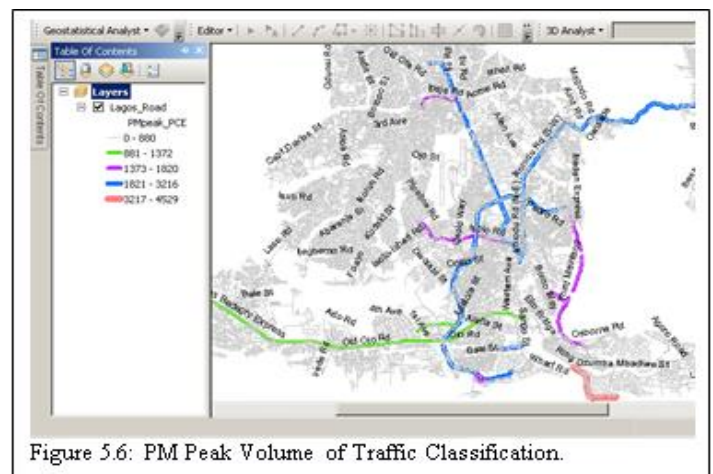


Figure 5.6: PM Peak Volume of Traffic Classification.



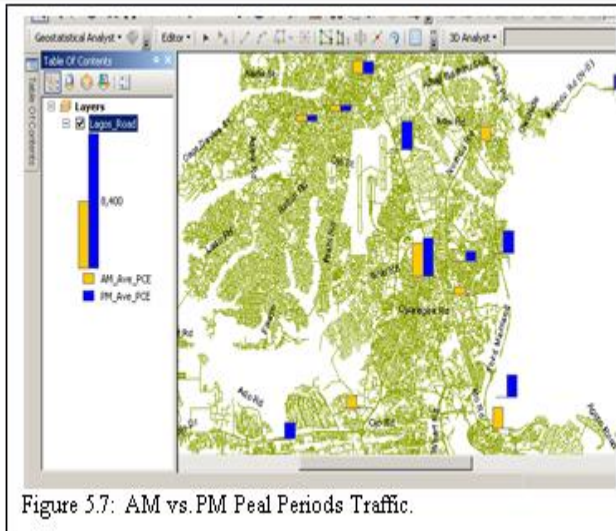


Figure 5.7: AM vs. PM Peak Periods Traffic.

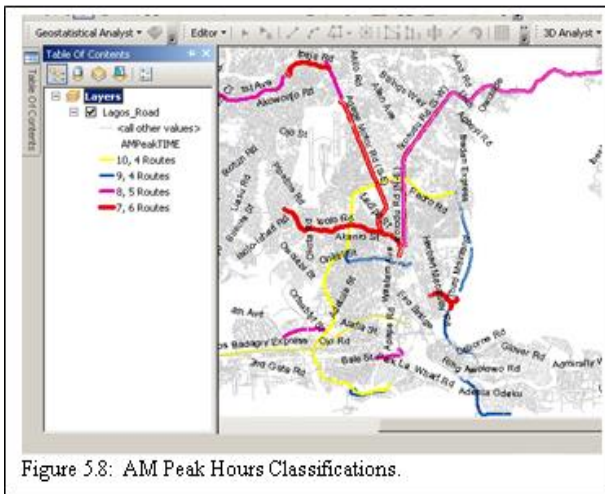


Figure 5.8: AM Peak Hours Classifications.

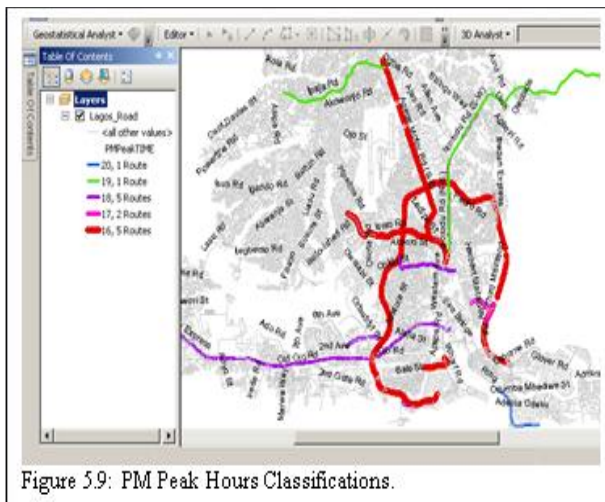


Figure 5.9: PM Peak Hours Classifications.

## 6.2. Analysis of Results

### 6.2.1 Analysis of the Results from the Questionnaires

The analysis of the questionnaires were carried out. Some of the analysis revealed that:

- (1) Buses (Danfos) are the most common public mode of travel (Figure 2.4);
- (2) More than 21% Respondents claimed that traffic lights are not on their routes (Figure 2.6);
- (3) According to the respondents on drivers/motorists, bus (danfo) drivers were Figure rated as the highest cause of traffic congestion while motorcycle (Okada) riders were rated next and Tricycle (Keke Napep) riders as the least (Figure. 2.7);
- (4) For the road conditions: bad access road is the highest cause of traffic congestion; pothole is the next highest cause of traffic congestion; absence of traffic light and traffic officers are on the average cause of traffic congestion; and use of road for party/social functions is below average (Figure 2.8);
- (5) 26% Respondents wastes between =N=100-300 (i.e. \$0.01-2) on traffic congestion (Figure 2.10); and
- (6) More than 80% of the respondents spent between 40-90minutes on the roads at peak periods (Figure 2.11).

### 6.2.1 Aspatial and Spatial Volume of Traffic Analysis

From the volume of traffic plots, it was observed that:

- (1) The peak volume of traffic along the roads in the study areas occurs at different time periods (Figure 5.1); and
- (2) Cars (both Private and Commercial) has the largest number of vehicles on all routes, followed by Motorcycle, Minibuses and the least is BRT/Lagbus (Figure 5.3).

Similarly, the spatial analysis were carried out in the GIS Environment:

- (1) From Figure 5.5, East Bridge Tin Can Is. (N-E), Apapa had the largest volume of traffic with over 2,655Vehs at Morning (AM) Peak Period- been the road that leads to the Major Sea Port (Tin-Can Port), followed by Apapa Oworonsoki Exp. W\_Junct. wt Awolokun (S-E), Somolu between 2,248 – 2,654Vehs.-also been commercial route that leads to the Tin-Can Port and outside Nigeria (i.e. Benin Republic), while the roads with the least has <524 Vehs.;
- (2) From Figure 5.6, East Bridge Tin Can Is. (W), Apapa had the largest volume of traffic with over 3,215Vehs at Evening (PM) Peak Period being

the road from the Major Sea Port (Tin-Can Port), followed by Apapa Oworonsoki Exp. W\_Junct. wt Awolokun (N-W), Somolu between 1,821 – 3,216Vehs. also been commercial route that leads from the Sea Port and from outside Nigeria (i.e. Benin Republic), while the roads with the least has <880 Vehs.; (3) From Figure 5.7, it could be observed that the volume of vehicles at the evening peak period is higher than the morning peak period; (4) Figure 5.8, revealed that at 7.00hrs in the morning, 6 Routes are at their Peak Volume of Traffic; at 8.00hrs, 5 Routes are at their Peak Volume of Traffic; while at both 9.00hrs and 10.00hrs 4 Routes each are at their Peak Volume of Traffic; and (5) Figure 5.9, revealed that at 16.00hrs and 18.00hrs in the evening, 5 Routes each are at their Peak Volume of Traffic; at 17.00hrs, 2 Routes are at their Peak Volume of Traffic; while at both 19.00hrs and 20.00hrs, 1 Route each are at their Peak Volume of Traffic.

## 7.0 CONCLUSIONS

Traffic situation in Lagos Metropolis is worrisome especially during morning and evening peak periods. Adequate traffic data collection, processing and analysis are very crucial to traffic management. In this research, traffic data on some selected roads were collected and analyzed in a Geographic Information Systems (GIS) environment. Models were derived to assist in predicting volume of traffic along the selected roads within Lagos Metropolis at any time. The models were validated, peak periods on the selected roads were mapped and other causes of traffic congestions were identified. When integrated with Intelligent Transport System (ITS), road infrastructure management, up-to-date traffic incident management and traffic redistribution, to reduce congestion, can be achieved through this work and its extension to other roads in Lagos Metropolis. Adequate policies and enforcement must be put in place to curb; indiscriminate parking of vehicles on the roads, use of road for social functions, religious activities and commerce, and monitoring of the Law Enforcement Agents just to mention but a few.

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