Assessing the Magnitude of Traffic Congestion Towards Planning for Building Smart City in Nigeria

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Abstract- As the economy grows and real income of household increases, vehicle population surges up, contributing to traffic congestion, particularly within cities. Given the critical importance of productivity on the Gross Domestic Product (GDP) growth, it is economically worthwhile, and of policy importance to recognize causes of congestion and their harmful effect. This study investigates the causes of traffic congestion, focusing on a selected road link (Karu-Keffi, Mararaba in Nasarawa State, Nigeria). Physical manual traffic survey was used to gather the data and Descriptive Statistics employed to analyze the data. The average traffic volume on the road was observed to be 4346veh/hr as compared to 2595 veh/hr (Model Road State (MRS) HCM 2000), signifying almost 170% increase. The average travel speed found to be 11kmph and the FFS of 45kmph, giving level of service (LOS) classification of F (signifying breakdown in the flow of traffic). The findings and recommendations herein will help to curb possible traffic congestion and ensure proper traffic management and control consistent with specifications for the smart city.

Indexed Terms- Traffic Congestion, Smart City, Level of Service, Traffic Volume, Traffic Survey.

I. INTRODUCTION

The department of Transport U.S. (2005), Defined traffic congestion as essentially a relative phenomenon that is linked with the different road way system performance that road users expect and how the system actually performs. Furthermore, European conference of ministers of transport (ECMT) (1999) Defined congestion as long queues of vehicles which are constantly stopping and starting passengers cannot move in a desirable manner under the serious conditions. This is a condition of traffic delays whereby traffic flow is slowed below reasonable speeds because the number of vehicles to use exceeds the design capacity of the traffic to handle it.

Traffic Congestion continues to remain major problem in most cities all over the world, most especially developing regions resulting in massive delays, monetary losses, fuel wastage, and accidents that sometimes result into death. Due to poorly planned road networks, and poor traffic management, that results into elongated traffic congestion.

Road transport (land) is major dominant mode of transport in Nigeria, with over 90% of (Users) passengers and freight traffic. Latest report from the Nigeria Bureau of statistics NBA, (2023) has estimated, the total vehicle population in Nigeria is about 11.8 million, with commercial vehicle holding about 58.08% ; private are 4,739,939 (40.67%) while diplomatic vehicles

Karu Local Government Area of Nasarawa State is located between latitudes 8° 5' N and 10° 42' N and longitudes 9°25'E and 7° 54'E. Karu is an unplanned area covering a spatial extent of about 800sqkm. It extends from the eastern boundary of the Federal Capital Territory Abuja (Old Nyanya) to Gora about 15 kilometers to Keffi. The area has an estimated population of 10,000 in 1991, and is believed to have grown rapidly to an estimated population of 50,000 and 130,000 by 2001 and 2010 respectively; due to continuous migration of people from other parts of the country to this area. Its current population is estimated at 205, 477.

Nasarawa as whole is sometimes faced with the challenge of traffic congestion. Congestion prevents us from moving freely and it slows and otherwise disrupts the conduct of business within urban areas. However, it is important to note that unfettered movement is not the primary benefit we derive from living in urban areas.

Nasarawa provides access to a wide range of activities, people, services, goods, markets, opportunities, ideas and networks. These benefits can be delivered either through speed or through greater proximity. Congestion may affect travel speed but, in some circumstances such as dense urban cores, congestion may both be expected and, to some degree accepted. In these cases, the Nasarawa has come to accept a degree of congestion and continue to get along relatively well as long as overall accessibility is high.
The research helps to understand the magnitude of congestion along Keffi-Karu(Mararaba) road in Nasarawa State thus coming up with possible and valid management control measures. It provides valid traffic control measures so as to reduce travel time and other effects of congestion. This would increase gross domestic product that would boost the economy since there would be reduced delays, comfortability in transport systems and efficiency. It will have an important implication for policymakers to understand that since congestion takes place on the roads, it is not only a traffic engineering problem, but sustainability issue in general.

The MAIN OBJECTIVEs incuced the following

- To carry out traffic count
- To determine traffic stream characteristics
- To determine level of service
- To find out the traffic flow rate and peak hour factors
- To determine the capacity of road section
- To investigate the magnitude of traffic congestion along Keffi-Karu(Mararaba) road in Nasarawa State.
- To provide mitigation measures to traffic congestion in light of sustainability approach.

II. METHODOLOGY

The methodology covered the research design, sources of data, study area, method of data collection, data collection instrument, and procedures which were adopted in order to achieve the objectives.

2.1 SOURCES OF DATA

Basically, the information needed for this project was obtained from the following sources .The data was obtained from both primary and secondary sources Primary sources include; direct acquisition of information by conducting traffic counting, This helped to gather exact information to assess the magnitude of congestion Secondary sources include; using records from journals, libraries, magazines or using internet from visiting websites, Research from lecture notes and handbooks

2.2 DATA COLLECTION

METHOD OF DATA COLLECTION

Traffic assessment was conducted to provide traffic flow data, this included traffic counting and projection.
It also helped to determine traffic stream parameters that enabled assessing the magnitude of traffic congestion along Keffi-Karu(Mararaba) Road.
It was carried out manually through daily traffic counting and recording traffic volumes per 15 minutes (AADT Veh/15min) Using A Test vehicle to determine free flow speed (high way capacity manual)

PROCEDURES OF DATA COLLECTION

TRAVEL SPEED

For determining the average speed of the vehicles the License Plate method is used, the observers were positioned in the two stations. In this method the observer is required to take the last four digits of some of the vehicles passing the road at the first station, as well as the time of passing this station is also recorded using stopwatch. The time of arrival to the second station is also recorded with the last four digits of the vehicle. It’s not possible to do this process for all vehicles, only some vehicles can be recorded in both stations. The difference between two recorded times is the travel time of this vehicle. The average of travel time can be calculated as a mean of observed travel time of all vehicles, equation below was used for determining the average travel speed.

$$S = \frac{nL}{\sum_{i=1}^{n} t_i} = \frac{L}{\frac{1}{n}\sum_{i=1}^{n} t_i} = \frac{L}{t_a}$$

Where: S - The average travel speed in (kph), n is number of matched plates, L - The length of the test section (m), in this case L= 100 m, t - The recorded Time in (sec.).

TRAVEL VOLUME

The rate of flow was measured throughout one week to take in consideration all different days of the week including the weekend from 06:00 to 06:00. Late night hours were neglected because traffic flow is reduced too much. The Counting intervals were 15 minutes.

DENSITY

Density, k

Density was calculated from dividing a number of vehicles occupying a given length of the selected section of the road by length and is generally expressed as vehicles per km.

Density, k = $\frac{n}{x}$

Where: k – Density, n - Number of vehicles per the given length,

x - Length of the selected section.

FLOW RATE

This represents the number of vehicles that were observed passed a point during a time interval less one hour but expressed as an equivalent hourly rate.

Flow rate is the number of vehicles observed in a sub hourly period, divided by the time (in hours) of the observation since vehicles were observed in 15minutes interval, thus

Flow rate = $\frac{number\ of\ vehicle}{0.25}$

PEAK HOUR FACTOR

Peak flow rates and hourly volumes produce the peak hour factor (PHF), the ratio of total hourly volume to the peak flow rate (within the hour)

PHF = $\frac{V}{4\ x\ V15}$

Where:

PHF - Peak Hour Factor

V - Hourly volume (veh/hr)

V15 - volume during the peak 15min of the peak hour (veh/15min)

CAPACITY

Design capacity was obtained from the AASHTO pavement design manual However, possible capacity or the capacity of the road based on the existing conditions was obtained by guidelines of HCM 2010

FREE FLOW SPEED

Free flow Speed (FFS) is the average speed of a vehicle in a specific road, it was observed during very low traffic volume conditions or late night hours while drivers were not constrained by other vehicles or by traffic signals, FFS is measured using test car.

In this project, the FFS was obtained by marking runs with a test car during periods of late night hours. The FFS can be determined as the average of several speed reading of the car in different five nights according to the equation below

$$FFS = \sum_{i=1}^{n} s_i \ /n$$

Where:

FFS - The free flow speed (Kph),

n - number of samples in this case is 5, and

S - The vehicle speed reading in each time (Kph)

LEVEL OF SERVICE

Level of service (LOS) is a measure used to determine the effectiveness of elements of transportation infrastructure. LOS is most commonly used to analyze highways by categorizing traffic flow with corresponding safe driving conditions. According to Highway Capacity Manual (HCM) and AASHTO Geometric Design of Highways and Streets, the levels of service for any highway or street is ranked using letters A through F, with A being the best and F being the worst. The LOS was determined based on FFS and average travel speed

III. RESULTS AND DISCUSSIONS

3.1 TRAFFIC VOLUME

Figure 1: The Pictorial View of The Traffic Flow At The Point Of Counting

The rate of flow was measured throughout one week to take into consideration all different days of the week including the weekend from 06:00 to 20:00. Late night hours were neglected because traffic flow is reduced too much. The Counting intervals were 15 minutes (HCM 2000). The table below shows results for hourly volumes of the week.

Table 1: Results for hourly volumes of the week.

TIME (HRS)	TRAFFIC VOLUME (VEH/HR)
06:00 - 07:00	1918
07:00 - 08:00	2199
08:00 - 09:00	1917
09:00 - 10:00	2628
10:00 - 11:00	3132
11:00 - 12:00	3149
12:00 - 13:00	2784
13:00 - 14:00	2592
14:00 - 15:00	2423
15:00 - 16:00	2607
16:00 - 17:00	2669
17:00 - 18:00	2640
18:00 - 19:00	2595
19:00 - 20:00	2164

- Passenger Car Equivalent

Passenger Car Equivalent (PCE) is a metric used to assess traffic-flow rate on highways. A Passenger Car Equivalent is the impact that a mode of transport has on traffic variables such as speed or volume of traffic if compared to a single car. The equivalent values for each kind of vehicles are shown in table below

Table 2: Passenger Car Equivalent

Passenger car (including private cars, taxi, and pickups) 1 Bus, tractor, truck 3.5 Motorcycle 0.5 Bicycle 0.2 Horse-drawn vehicles 4

In this study, most of the vehicles were private cars, taxies, pickups, buses, and tractors. Some Motorcycles and Bicycles were not recorded because of their little effect and horse-drawn vehicles did not exist. We directly multiplied the number of vehicles by their equivalent values to get the PCE/ 15 mins, and then PCE/ h.

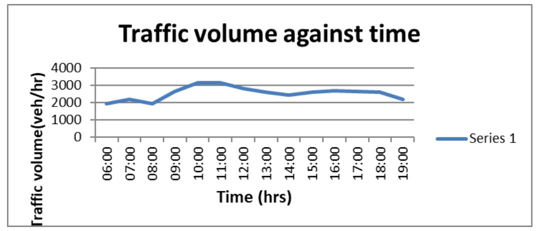

Figure 1: The traffic flow graph shown in the graph above

Every day two peak hours occur one at 11:00 and the second one at 16:00. The noticeable thing here is that, peak hours occur at the same time in both directions. The first rush hour is occurring at the beginning of the working day which is normal in all routes around the city. The second rush hour occurs on evenings when people are returning back to their homes. Another cause of the evening rush hour is a parallel parking, and also because of access roads.

The most significant rush hours are seen at 11:00 and 16:00 .this is due to the people going to and returning back from work, Market, and residential areas of Kuru and FCT

3.2 FLOW RATE

Flow rate is the number of vehicles observed in a sub hourly period, divided by the time (in hours) of the observation since vehicles were observed in 15minutes interval (HCM 2000), thus

Flow rate = $\frac{number\ of\ vehicles}{0.25}$

TIME	VOLUME (A-B)	VOLUME (B-A)	SUM	TIME (HRS)	FLOW RATE (VEH/HR)	HOURLY VOLUME
6:00 - 6:15	322	134	456	0.25	1824	1918
6:15 -	347	101	448	0.25	1792	

6:30						
6:15 - 6:45	310	150	460	0.25	1840	
6:45 - 7:00	374	180	554	0.25	2216	
7:00 - 7:15	337	210	547	0.25	2188	
7:15 - 7:30	356	220	576	0.25	2304	2199
7:30 - 7:45	321	238	559	0.25	2236	
7:45 - 8:00	322	195	517	0.25	2068	
8:00 - 8:15	300	140	440	0.25	1760	
8:15 - 8:30	303	160	463	0.25	1852	1917
8:30 - 8:45	233	190	423	0.25	1692	
8:45 - 9:00	379	212	591	0.25	2364	
9:00 - 9:15	346	252	597	0.25	2392	2628
9:15 -	384	274	658	0.25	2632	

9:30						
9:30 - 9:45	425	265	690	0.25	2760	
9:45 - 10:00	389	293	682	0.25	2728	
10:00 - 10:15	430	302	732	0.25	2928	
10:15 - 10:30	450	299	749	0.25	2996	3132
10:30 - 10:45	522	320	842	0.25	3368	
10:45 - 11:00	499	310	809	0.25	3236	
11:00 - 11:15	530	315	845	0.25	3380	
11:15 - 11:30	488	274	762	0.25	3048	3149
11:30 - 11:45	485	277	762	0.25	3048	
11:45 -	480	300	780	0.25	3120	

12:00						
12:00 - 12:15	477	298	775	0.25	3100	2784
12:15 - 12:30	465	277	742	0.25	2968	
12:30 - 12:45	389	255	644	0.25	2576	
12:45 - 13:00	378	245	623	0.25	2492	
13:00 - 13:15	368	275	643	0.25	2572	2592
13:15 - 13:30	350	300	650	0.25	2600	
13:30 - 13:45	355	298	653	0.25	2612	
13:45 - 14:00	345	301	646	0.25	2584	
14:00 - 14:15	330	310	640	0.25	2560	2423
14:15 - 14:30	299	288	587	0.25	2348	
14:30 - 14:45	288	310	598	0.25	2392	
14:45 - 15:00	278	320	598	0.25	2392	
15:00 - 15:15	277	324	601	0.25	2404	2607
15:15 - 15:30	313	412	725	0.25	2900	
15:30 - 15:45	323	406	729	0.25	2916	
15:45 - 16:00	217	335	552	0.25	2208	
16:00 - 16:15	276	401	677	0.25	2708	2669
16:15 - 16:30	281	412	693	0.25	2772	
16:30 -	301	395	696	0.25	2784	

16:45						
16:45 - 17:00	258	403	603	0.25	2412	
17:00 - 17:15	240	457	697	0.25	2788	2640
17:15 - 17:30	213	448	661	0.25	2644	
17:30 - 17:45	201	446	647	0.25	2588	
17:45 - 18:00	202	433	635	0.25	2540	
18:00 - 18:15	199	441	640	0.25	2560	2595
18:15 - 18:30	211	452	663	0.25	2652	
18:30 - 18:45	212	459	671	0.25	2684	
18:45 - 19:00	200	421	621	0.25	2484	
19:00 - 19:15	188	393	581	0.25	2324	2164
19:15 - 19:30	192	401	593	0.25	2372	
19:30 - 19:45	166	345	511	0.25	2044	
19:45 - 20:00	149	330	479	0.25	1916	

Traffic volume in PCEs is 4346

3.3 PEAK HOUR FACTOR

Peak flow rates and hourly volumes produce the peak hour factor (PHF), the ratio of total hourly volume to the peak flow rate (within the hour) ,(HCM 2000)

$$PHF = \frac{V}{4 \, x \, V_{15}}$$

$$PHF = \frac{3149}{4 \, x 845} = 0.93$$

According to HCM (2000), PHFs in urban generally range between 0.8 to 0.98. Lower values signify greater variability of flow within the subject hour and high values signify less flow variation .PHFs over 0.95 are often indicative of high traffic volumes sometimes with capacity constraints during the peak hour

3.4 CAPACITY

$$Capacity = \frac{\text{hourly capacity}}{\text{Capacity factor in \%}}$$

Where:

Hourly Capacity = hourly capacity in PCE/hr by MRS

Capacity Factor% = proportion of daily traffic in the peak periods (MRS)

Capacity = 2575 X 100

12.5
= 20,600

3.5 VOLUME CAPACITY RATIO, (VCR)

VCR is calculated using the volume and capacity calculations

The VCR is a measure of the level of congestion on a road given the traffic volume and road capacity. When the VCR reaches 1, this indicates that the road is operating at 100% capacity.

The maximum VCR in CBA6 is 1.25.

$$= \frac{4346}{20,600}$$

$$VCR = 0.2$$

3.6 TRAVEL SPEED

LICENSE	LENGTH (M)	AV. TRAVEL TIME(S)
CLASS A	100	15
CLASS B	100	30
CLASS C	100	40
CLASS D	100	45
	AVERAGE	33

$$\text{Travel speed} = \frac{0.1}{(0.009)}$$

$$= 11\text{kph}$$

NOTE:

Class A - Motor cycle

Class B - Motor vehicle of less than 3 tonnes gross weight, other than motor cycle, buses, taxi, stage carriage, or omnibus

Class C - Motor vehicle of less than 3 tonnes gross weight, other than motor cycle

Class D - motor vehicle other than motor cycle, taxi, stage carriage, an articulated vehicle or vehicle drawing a trailer

3.7 FREE FLOW SPEED

In this project, the FFS was obtained by marking runs with a test car during periods of late night hours. The FFS was determined as the average of several speed reading of the car in different five nights

$$\text{FFS} = \sum_{i-1}^{n} s_i \,/n$$

Table 3: Table showing FFS

DAY	FFS(kph)
Monday	50
Tuesday	47
Wednesday	43
Thursday	45
Friday	40
Average	45

3.8 LEVEL OF SERVICE

According to Highway Capacity Manual (HCM) and AASHTO Geometric Design of Highways and Streets, the levels of service for any highway or street is ranked using letters A through F, with A being the best and F being the worst. The LOS was determined based on FFS and average travel speed.

Table below shows the level of service for roads classified according to the FFS and average travel speeds.

Street class	I	II	III	IV
FFS	89 to 72 kph	72 to 56 kph	56 to 48 kph	56 to 40 kph
Typical FFS	80 kph	64 kph	56 kph	48 kph
LOS	Average travel speed (kph)			
A	> 68	> 56	> 48	> 40
B	> 55-68	> 45-56	> 39-48	> 31-40
C	> 43-55	> 35-45	> 29-39	> 21-31
D	> 34-43	> 27-35	> 23-29	> 14-21
E	> 26-34	> 21-27	> 16-23	> 11-14
F	≤ 26	≤ 21	≤ 16	≤ 11

Table 4: Level of service (LOS) according to free flow traffic Street class

The road is considered class IV because the value of 45kph for the FFS falls within the normal range (56 to 40kph) for a class IV arterial road, the average vehicle speed is 11 kph, therefore the LOS of the street is F. Level of service F is most congested.

$$\text{Density} = \frac{\text{Flow Rate}}{\text{Travel Speed}}$$

$$= \frac{4346}{11}$$

$$= 395 \text{ veh/km}$$

Flow rate = 3600/headway
4346 = 3600/headway
Headway =0.8s/veh

$$\text{Density} = \frac{1000}{\text{spacing (m/veh)}}$$

$$395 = \frac{1000}{\text{Spacing}}$$

Spacing = 3m/veh

CONCLUSION

1. The traffic volume (PCE/hr) was found to be about 170% more than the hourly capacity (PCE/hr) for the road width description.
2. The congestion of vehicle along Keffi-Mararaba (Karu) Road at Mararaba Pedestrian bridge axis was found to be extremely high with LOS of class F.
3. Very low flow variation was recorded due to the PHF being high.

The following recommendations have been made:

1. There should be an expansion of the road to 4 lane, and other features like bicycle path (fitted for even the disabled), green space, walkway and others need to be provided to factor in sustainability requirements for the road. Tramways could also be additional traffic damners through the area.
2. There should be installation of state of the art traffic light and other furniture, to regulate the flow of traffic and the general service of the road.
3. There should be proper and timely maintenance plan of the road pavement and other features to improve serviceability.
4. They should be a taskforce teams set aside to file and arrest people selling directly on the pavement (shoulders) of the road. Hawking should be discouraged by constructing stalls at strategic locations and letting them out to the street hawkers.

REFERENCES

[1] Hodžić, S.; Paleka, H. Fiscal Capacities of Large Cities in Croatia—Financial Support for Smart Cities. *Naše Gospod. /Our Econ.* 2020, *66*, 42–49.

[2] Holden, E.; Banister, D.; Gössling, S.; Gilpin, G.; Linnerud, K. Grand Narratives for Sustainable Mobility: A Conceptual Review. *Energy Res. Soc. Sci.* 2020, *65*, 101454.

[3] Holden, E.; Gilpin, G.; Banister, D. Sustainable Mobility at Thirty. *Sustainability* 2019, *11*, 1965.

[4] Isiaka B.S, (2000). "The effects of street trading on traffic flow within Ilorin Metropolis". HND project report, Civil Engineering Department, Kwara State Polytechnic, Ilorin.

[5] Journal of Geography, Environment and planning vol.4, No.1. Department of Geography and planning science, University of Ado-Ekiti, Nigeria.

[6] Kadiyali L.K(2005): Traffic Engineering and Transportation Planning , Khanna Publishers.

[7] Maldonado Silveira Alonso Munhoz, P.A.; da Costa Dias, F.; Kowal Chinelli, C.; Azevedo Guedes, A.L.; Neves dos Santos, J.A.; da Silveira e Silva, W.; Pereira Soares, C.A. Smart Mobility: The Main Drivers for Increasing the Intelligence of Urban Mobility. *Sustainability* 2020, *12*, 10675.

[8] Masik, G.; Sagan, I.; Scott, J.W. Smart City strategies and new urban development policies in the Polish context. *Cities* 2020, *108*, 102970.

[9] Nadeem, M.; Azam, M.; Asim, M.; Al-Rashid, M.A.; Puan, O.C.; Campisi, T. Does Bus Rapid Transit System (Brts) Meet the Citizens' Mobility Needs? Evaluating Performance for the Case of Multan, Pakistan. *Sustainability* 2021, *13*, 7314.

[10] National cooperative highway research programme report (nschrp) 398 by David N. wormley Pennsylvania state university and Sharon D. banks

[11] Noy, K.; Givoni, M. Is 'Smart Mobility' Sustainable? Examining the Views and Beliefs of Transport's Technological Entrepreneurs. *Sustainability* 2018, *10*, 422.

[12] Okafor, C.; Aigbavboa, C.; Akinradewo, O.; Thwala, W. The future of smart city: A review of the impending smart city technologies in the world. *IOP Conf. Ser. Mater. Sci. Eng.* 2021, *1107*, 012228.

[13] Principles of Highway Engineering and traffic Engineering 5th edition by Fred L. Mannering Purdue University and Scott S. Washburn. University of Florida

[14] Zapolskytė, S.; Burinskienė, M.; Trépanier, M. Evaluation Criteria of Smart City Mobility

System Using MCDM Method. *Balt. J. Road Bridg. Eng.* 2020, *15*, 196–224.

[15] Zhang, K.; Batterman, S. Air Pollution and Health Risks Due to Vehicle Traffic. *Sci. Total Environ.* 2013, *450*, 307–316.

[16] Zhao, Z.; Zhang, Y. Impact of Smart City Planning and Construction on Economic and Social Benefits Based on Big Data Analysis. *Complexity* 2020, *2020*, 8879132.