Mathematical Modeling of the Traffic Stream Following the Safety Measures Included Along G.U. Ake Road Eliozu, Port Harcourt

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Abstract – Vehicle traffic flow has become a challenge in this modern world of automobiles due to constantly accelerated influx of vehicles on the road network. The challenge of traffic flow has motivated many researchers to model traffic flow at both the macroscopic and microscopic levels. The study investigates the macroscopic model of traffic flow characteristics and its accompanied continuity equation of vehicles on a road segment. The research presents a mathematical model of car traffic flow using the analogy between vehicles in traffic flow and particles in fluid flows which is based on the conservation laws. Using regression analysis the flow density curve was found to be quadratic of the form q = 30.34$\rho - 0.5441\rho^2$ this verifying the Lighthill – Whitham – Richard (LWR) models.

Index Terms: **Traffic stream models, moving observer method, speed, flow, density.**

1. INTRODUCTION

Speed-flow-density relationships are the most useful tools in highway design and planning process. They are useful in predicting the road capacity, in determining the adequate level of service of the traffic flow and in determining travel time for a given roadway [1]. Improving the level of service of Highway facilities contributes positively to socio-economic development especially in a developing country like Nigeria where the major means of transportation is by road. Traffic flow can generally be described in terms of three parameters: mean-speed (V), traffic flow rate (ρ) and the traffic density (K) [2]. The three (3) parameters are related to each other by the equilibrium relationship

$$q = VK \qquad (1.1)$$

In recent years, transportation system is suffering from challenges due to three modes of transporting goods, equipment and people over land, air, and sea. Many of the challenges encountered in the sea and air modes of transportation are localized to the terminals (air ports and seaports). On the other hand, the problems of congestion is surface mode of transportation are distributed over the highways and local streets along the urban and sub-urban areas of the nation. Congestion or jam concentration, which is also known as jam density is the most serious challenge facing the surface transportation network [3].

Transportation modelling and simulation as interface in the planning process plays an important role in enabling spatial development. The development of simplified models in transportation planning is a representation of real-life occurrences which can be used to explore the consequences of particular polices, strategies and spatial changes. This thesis explores the relationship between macroscopic traffic quantities, such as average network density, average flow and average speed and safety. This has been achieved through the assessment of traffic studies, the result obtained from the analysis will be used to validate a mathematical model, which will improve safety. Such relationship will also help policy makers to conduct cost benefit analysis as well as evaluate different policies.

2.0 MATERIALS AND METHODS

This chapter describes the procedures adopted in carrying out the mathematical model to evaluate flow data gotten.

2.1 Area of Study

The study was carried out on G.U. Ake Road Eliozu, Port Harcourt.

2.2 Equipment Used

Some of the equipment used include; test car, stop watch, pencils, erasers, sharpeners and field data sheet.

2.3 Methods

The following methods were used in carrying out this research work.

1) Manual traffic count

2) Moving car observer method

For a complete description of traffic stream modelling, one would require flow, speed, and density, obtaining these parameters simultaneously is a difficult task if we use separate techniques. Since we have a fundamental equation of traffic flow, which gives the flow as the product of density and space mean speed, if we know any two parameters, the third can be computed. Moving car or moving observer method of traffic stream measurement has been developed to provide simultaneous measurement of traffic stream variables. In this method, the speed and flow can be obtained by travelling in a car against and with the flow and noting down the journey time, the number of vehicles overtaking the test car, thus:

$$q_n = \frac{x_2+y_n}{t_s+t_n} \qquad (2.1)$$

where;

x_s = opposing traffic count of vehicles met when the test car was travelling south.

y_n = number of vehicles overtaking the test car minus the number overtaken by the test car, when the test car is travelling North.

Also;

$$\bar{t_n} = t_n \frac{y_n}{q_n} \qquad (2.2)$$

Where;

$\bar{t_n}$ = mean journey time in the north bound direction

t_n = Journey time when the test car travelled in the north bound direction.

3.0 Results and Discussion

The main objective of this section is to analyze the field data collected from the traffic counts.

Speed-Density Relationship

4.1 RESULTS AND DISCUSSION

TABLE 4.1: Typical analyzed (moving car observer data) count

No.	No. Of vehicles overtaking the test car M_o	No. Of vehicles overtaken by the test car M_p	Relative flow against test car M_a	Relative flow with test car $M_w = M_o - M_p$	Travelling time against the flow t_a	Travelling time with the flow t_w	Flow rate (veh/hr.)	Average time (min.)	Speed (km/hr.)	Density (veh/km.)
1.	43 40	35 38	380 340	8 2	14	11	931.2	10.48	30.34	30.69
2.	45 32	36 49	410 375	9 -17	20	13	761.8	12.29	25.87	29.45
3.	60 52	70 48	536 460	-10 4	15	12	1173.3	12.51	25.41	46.17
4.	80 53	56 45	480 385	24 8	14	12	1163.1	10.76	29.55	39.36
5.	75 65	30 48	610 550	45 12	12	13	1572.0	11.28	28.19	55.76

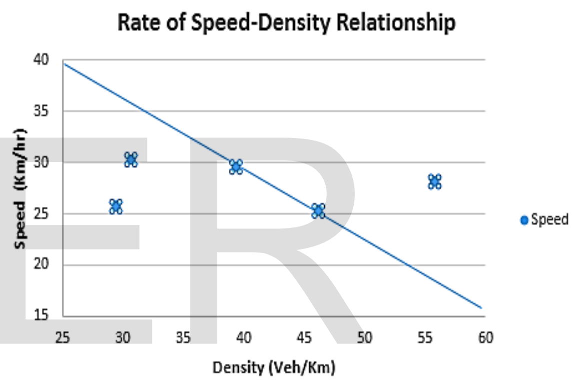

Fig 3.1: Rate Speed-Density Relationship

Figure 3.1 presents the relationship between the average speed and average density over the observed period. This is significantly for most speed-density models in which the average speed generally decreases linearly with the increase of density. Here the speed approaches free flow speed as the density approaches zero.

As the density increases, the speed of the vehicles on the roadway decreases. The speed reaches approximately zero when the density equals the Jam density.

Flow-Density Relationship

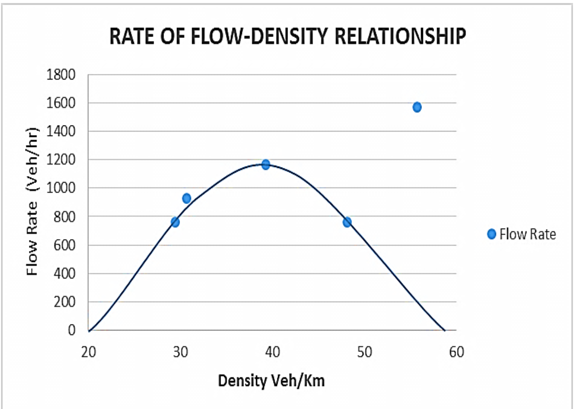

Fig 3.2: Rate of Flow-density Relationship

Figure 3.2 presents the relationship between density and rate of flow which examined. Densities were obtained from flow rate and the velocities. The flow and density varies with time and location. The relation between the density and the corresponding flow on a given stretch of road is referred to as one of the fundamental diagram of traffic flow. Increase in density gives a corresponding increase in flow of vehicles.

Flow-Speed Relationship

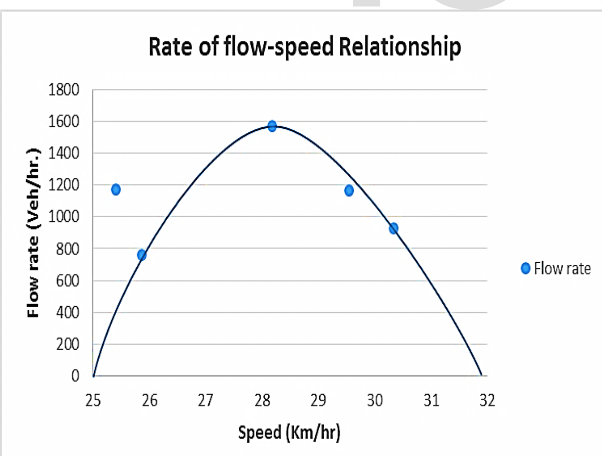

Fig. 3.3: Rate of flow-speed relationship

Figure 3.3 presents the relationship between flow and speed which was observed over a period of time. Flow is zero because there is no vehicles on the road and there are too many vehicles so that vehicles cannot move. At maximum flow, the speed is between zero and free flow speed.

Volume Analysis

TABLE 4.2: Manual Traffic Count data from G.U. Ake Road to Rukpoku

Volume		Time (4pm-5pm)				Total
		4pm-4:15pm	4:15pm-4:30pm	4:30pm-4:45pm	4:45pm-5:00pm	
Cars	Veh/hr	307	375	365	398	1445
	Pcu/hr	307	375	365	398	1445
Motorcycles	Veh/hr	8	7	4	12	31
	Pcu/hr	6	5.25	3	9	23.25
Trucks	Veh/hr	10	10	16	16	52
	Pcu/hr	20	20	32	32	104
3-wheelers	Veh/hr	5	1	0	0	6
	Pcu/hr	4	0.8	0	0	4.8
Buses	Veh/hr	13	9	8	15	45
	Pcu/hr	39	27	24	45	135
Bicycle	Veh/hr	0	1	0	1	2
	Pcu/hr	0	0.5	0	0.5	1
Minibuses	Veh/hr	5	7	6	5	23
	Pcu/hr	7.5	10.5	9	7.5	34.5
Total	Veh/hr	348	410	399	477	1747.55
	Pcu/hr	383.5	439.05	433	492	

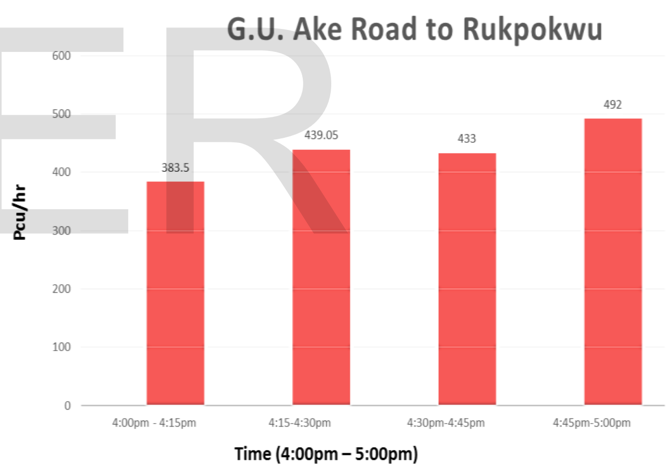

Fig. 3.4 Volume of Traffic Flow G.U. Ake Road to Rukpokwu

From the volume count, it is observed that between 4:45pm and 5pm the total of 477 vehicles passes the roadway in 15 minutes which is the highest volume count coming from G.U Ake road to Rukpokwu. In P_{cu} the value is 492 per/15 minutes.

TABLE 4.3: Manual Traffic Count data from Rukpoku to G.U. Ake road

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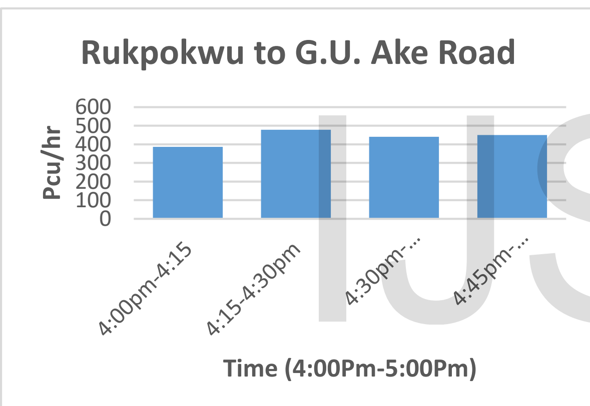

Fig. 3.5 Volume of Traffic Flow Rukpokwu to G.U. Ake

From the volume count, it is observe that between 4:15pm to 4:30pm the total of 434 vehicles passes the road way in 15 minutes which is the highest volume count going from Rukpokwu to G.U. Ake road.

In Pcu the value is 478.55 Pcu/15 minutes. Which means that the road way is congested within that period. The traffic volume using moving observer method is higher than the manual method.

Model Development

Best fit curve technique was used to develop the relationship between the traffic stream variables; flow, speed and density based on the collected data by neglecting the fundamental relationship between the three variables. The developed relationships are presented in equation.

$$q(\rho) = 30.34\rho - 0.5441\rho^2 \quad (2.3)$$

$$q(\rho) = \rho(30.34\rho - 0.5441\rho^2) \quad (2.4)$$

Comparing equation (5) with the LWR flow – density relation, we have

U_{max} = 30.34km/hr

ρ_{max} = 55.76 Veh/hr

Q_{max} = 1572.0Veh/hr

The results of the study agrees with those of LWR model, which gives a quadratic relationships between flow and density. The flow density curve was found to be quadratic of the form

$$q(\rho) = 30.34\rho - 0.544/\rho^2 \quad (2.5)$$

4.0 Conclusion

The conclusion of this research work is based on the objectives and findings of the research:

(i) That using macroscopic model of kinematic wave theory to develop a mathematical model on G.U Ake Road yielded a maximum flow, average density and average speed which will help prevent congestion and improve efficiency.

(ii) That the horizontal alignment on G.U Ake Road which was poorly designed can be modified to improve safety by increasing the bend radius on the roadway (using a new design)

4.1 Recommendations

From the analysis and observations, we were able to establish the following recommendations based on the study carried out.

i) A signal which literally stops traffic and then permits it to go (in intervals yielding the density corresponding maximum flow) would result in an increased flow of cars on the road.
ii) Realignment of horizontal curves on the roadway by increasing the bend radius using a new design.

iii) To obtain accurate information on the road segment, loop detectors should be installed on the various road in the cities of Nigeria.

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6.0 References

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