

Maximization of Traffic Flow in a Tunnel

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Abstract

A good understanding of vehicular traffic flow is an important challenge for modern societies. It has direct impact on the quality of lives of citizens. Since, most people experience the daily inconvenience of traffic congestion and pollution. In this research in particular, the ultimate aim is to understand the traffic phenomena at Ebeano-Tunnel in order to actually make decisions which will go a long way to alleviate congestions, maximize flow of traffic, eliminate accidents and minimize exhaust pollutions and other desirable ends. The research methodology was based on the collection of primary data by observers from 7:30am to 12:00 noon from Sunday to Saturday and analyzed which can serve as a tropical average for the year. In the analysis the behavior of cars entering or leaving the Ebeano-Tunnel were evaluated on the basis of their performances (that is the average speed of vehicle entering into the Tunnel and leaving the Tunnel, expected number of vehicles at a given time interval and waiting time when there is congestion). The result obtained showed that the Ebeano-Tunnel is highly congested during the day. The largest flow occurred between 10:30am to 11:00am in the morning. It is advised that an alternative route should be used during this period to avoid congestion. Moreover, with the help of the given data we were able to examine whether the traffic flow (flux) is equal to density ρ multiplied by velocity u and we found out that it is true as it is the well established traffic model.

Keywords: Traffic Flow, Traffic Density, Velocity, Conservation Law, Time Formulation

1.0 Introduction

Traffic congestion is a condition of networks that occur as use increases and is characterized by slower speeds, longer trip times and increase in queuing. The problems of traffic congestion are enormous and have posed major challenges to many cities all over the world as a complete satisfactory scientific understanding is still lacking [1].

Hemant et al [2] opined to present speed-flow analysis for urban roads with interrupted flow comprising of heterogeneous traffic. Model has been developed for heterogeneous traffic under constraints of roadway geometry, vehicle characteristics, driving behavior and traffic controls for which the developed model shall predict speed delay, average queue and maximum queue estimates for urban roads and quantity congestion for oversaturated condition. The investigation details oversaturated portion of flow in particular.

Necoara et al [3] analyzes the structural properties of the shock and rarefaction wave solutions of a macroscopic, second-order nonlocal continuum traffic flow model, namely Helbing's model. They showed that this model has two families of characteristics for the shock wave solutions: one characteristic is slower, and the other one is faster than the average vehicle speed. Corresponding to the slower characteristic they obtained 1-shocks and 1-rarefaction waves, the behavior of which is similar to that of shocks and rarefaction waves in the first-order model of Lighthill-Whitham-Richard. Finally, they succeeded in deriving the formulas for the solution of the Riemann problem associated with this model in the equilibrium case.

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Endar et al[4] discussed the behavior of traffic system controlled by traffic lights on a single lane are presented using the optimal velocity model. The effect of different traffic light control strategies on the traffic flow is discussed using three different strategies, i.e. the synchronized, green wave, and random offset strategies. It is found that the saturation of the flow occurs at the critical density, which depends on the cycle time of the traffic light and the strategy being used. On the other hand, the value of saturated flow does not depend on the cycle time or on the strategies. Moreover, the numerical investigation was carried out using the cellular automata model to get a better understanding of the microscopic behavior of the three different traffic light strategies.

Mahir and Kenan [5] pronounced a new method for obtaining an exact and numerical solution of initial value problem for a first order nonlinear partial differential equation which describes the traffic flow on highway in a class of discontinuous functions is developed. For this goal, at first, the special auxiliary problem having some advantages over the main problem has been suggested and using the solution of the auxiliary problem an original method for finding the weak solution of the main problem has been suggested. Using the advantages of the auxiliary problem the new numerical method for obtaining a solution which expresses the physical properties accurately is proposed, too.

Billy et al [6] opined on the theoretical basis for modeling univariate traffic condition data streams as seasonal autoregressive integrated moving average processes. This foundation rests on the World decomposition theorem and on the assertion that a one-week lagged first seasonal difference applied to discrete interval traffic condition data will yield a weakly stationary transformation. Moreover, empirical results using actual intelligent transportation system data are presented and found to be consistent with the theoretical hypothesis.

Traffic congestion continues to hinder economic and social development and also has a negative impact on the environment. A simple mathematical model is used to analyze the different types of road intersections in terms of their performance in relation to managing traffic congestion and to establish the condition for stability of the road intersections after sufficiently longer periods of time (steady-state). In the analysis, single and double lane un-signalized, signalized and roundabout intersections are evaluated on the basis of their performance (expected number of vehicles and waiting time). Experimental scenarios are carefully designed to analyze the performance of the different types of intersections. It is noted that under light traffic, roundabout intersections perform better than un-signalized and signalized in terms of easing congestion. Thus, under heavy traffic, signalized intersections perform better in terms of easing traffic congestion compared to un-signalized and roundabout intersection. It is further noted that for stability of a road intersection the proportion of the time a road link stopping at an intersection is delayed should not exceed the utilization factor[1]

Daganzo [7] converse that few drivers would dispute the fact that congestion is caused by bottleneck, both recurrent and non-recurrent, and that the resulting queues can cause further problems if they become too long. Long queues can entrap cars that do not wish to pass through the bottleneck that generated them hence, compounding the problem and causing spillovers. These can have widespread effects such as “gridlock”.

The earliest arrival flow problem, also called universal maximum flow problem [8] is an extension of the maximum dynamic s-t flow problem with an additional property: The cumulative amount of flow having reached the sink in every considered time period and all preceding time periods of the considered one have to be maximal. The earliest arrival flow translated in the evacuation content means that until every considered time period the maximal amount of evacuees enter the area. Considering, for example, an impending dam failure, this is useful and a reasonable property.

Wah and Cho [9] converse on the mathematical model for fluid dynamic flows on road networks which is based on conservation laws. This nonlinear frame is based on the conservation of cars. They focus on traffic circle, which is a finite number of roads that meet at some junctions. The traffic circle with junctions having either one incoming and two outgoing or two incoming and one outgoing roads. They also describe the numerical schemes with the particular boundary conditions used to produce approximated solutions of the problem.

Amar et al [10] examines the value of real-time traffic information gathered through Geographic Information Systems for achieving an optimal vehicle routing within a dynamically stochastic transportation network. They presented a systematic approach in determining the dynamically varying parameters and implementation attributes that were used for the development of a web-based transportation routing application integrated with real-time GIS services. They proposed and implemented an optimal routing algorithm by modifying Dijkstra’s algorithm in order to incorporate stochastically changing traffic flows. Also, describing the significant features of Web application in making use of the real-time dynamic traffic flow information from GIS services towards achieving total costs savings and vehicle usage reduction. Thus, these features help users and vehicle drivers in improving their service levels and productivity as the Web application enables them to interactively find the optimal path and in identifying destinations effectively.

James and Eze [11] discussed the solution to traffic flow problem by method of characteristics with the help of an initial condition to obtain unique solution. They also, discusses the traffic lights and the relationship between the traffic streams – flow rate q , density ρ , and velocity u .

Nigeria is not an exception as it is popularly termed “go slow” or “hold up”. Perhaps, Nigeria has one of the greatest challenges of traffic congestion in most of her cities like Abuja, Lagos, Kano, Enugu, Kogi, Porthacourt etc. The study however considers a macroscopic deterministic traffic flow model to analyze the situation in one of the above named cities

tunnel. The case of Ebeano tunnel in Enugu state Nigeria, primary data were collected and analyzed to suit the well-known traffic flow model as to aid efficient and effective decisions on ways and methods of minimizing traffic congestions, accidents, exhaust pollution, costs incurred due to traffic congestions, health hazards as a result of traffic emissions of CO, NO₂ and HN gases and reduction of economic activities leading to the depletion of Gross Domestic Product/ Gross National Product (GDP/GNP) [12]

The Ebeano tunnel which happens to be the only tunnel in Nigeria and the shortest in the whole world as it measures only 75.5 meters in length and has a width of 17.6 meters compared to a tunnel like laerdal located in Norway opened in the year 2000 measuring 24.5km which is 15.2 miles.

The primary aim of constructing the Ebeano tunnel is to create a short route for all Ogui residents for quick access to Enugu- Abakaliki express. Though this aim was achieved but the question still remains on how to maximize time? If the primary aim was to create a short route then the short route should be covered in lesser time. Time we know is money, any time lost has a great value on individuals which can lead to a great loss in country's GNP/GDP. The Ebeano tunnel like other Nigerian roads is not free from traffic congestion or traffic jam as the tunnel use increases and characterized by slower speed, longer time spent, increased queuing in moving from point *x* to *y*. This congestion results from the following:

Absence of Alternative Roads: An accident in the tunnel will render the road useless as there are no alternative routes for diversion which will lead to loss of human lives, man-hours, loss of businesses due to inability to meet up appointments, Increase in the cost of goods and services and general reduction in economic activities and thereby reducing the Gross National Product. In the year 2000, it was estimated that drivers in 75 of the largest metropolitan areas of the world spent more than sixty-eight billion dollars in person hours of lost time and wasted fuel an equivalent of N10676 billion naira.

Absence of Information Flow: Unlike other tunnels in the world with Police stations, hospitals etc with a good information flow, Ebeano tunnel demarcated by two junctions controlled by a road traffic wardens lack information flow in other word's any accident that occurs within that range cannot be detected by these road traffic wardens for appropriate action, this will in turn lead to continuous flow of traffic towards the accident scene leading to loss of man hours.

Poor Road Management/Construction: This social malady has caused a lot, not only to Ebeano tunnel but to the entire Nigerian roads. The main back bone to poor construction is corruption on the part of our Nigerian politicians, government officials and policy makers and implementers. Contracts are hurriedly awarded to their pseudos' that lack merit and the roads are in turn poorly and shabbily constructed with inferior materials which will periodically show signs of "pot holes". The Ebeano tunnel which was constructed barely five (5) years ago suffers from these pot holes which reduce traffic flow.

Lack of Statistical Data: Due to lack of data relating to the Ebeano Tunnel, there is no forecasting or planning on the part of the engineers as regards to the impact of traffic congestions on the GDP/GNP. In USA for instance, empirical survey has shown that about 67 billion dollars are lost annually due to traffic congestion but such statistical data don't exist in Nigeria and most of the under developing economies. Another tragedy is that most of the works done on Road traffic congestions in Nigeria depend on well-known traffic flow models which are alien to us or foreign to our situation, culture, tradition and orientation.

Absence of alternative means of transportation: Enugu like other cities in the country lack an alternative means of transportation like metro lines, trains etc. The truth is that in spite of poor road designs and infrastructure. The problem of traffic congestion is even more aggravated by the introduction of motorcycles, tri-cycles popularly called "Okada and KekeNapep". The problem is even worse by lack of adequate designs and considerations for bicycles and pedestrians in arriving at decisions

2.0 Methodology

The research methodology was based on the collection of primary data by observers [13] from 7:30am to 12:00 noon from Sunday to Saturday and analyzed using the macroscopic deterministic traffic flow model. The study involves the use of traffic phenomena at Ebeano-Tunnel in order to actually make decisions that will go a long way to alleviate congestions, maximize flow of traffic, eliminate accidents and minimize automobile exhaust pollution and other desirable ends.

3.0 Main Result

Metropolitan Enugu located in the Eastern part of Nigeria endowed with many modern and social economic activities with universities, polytechnics, airport, teaching hospitals which contributes to a high immigration from other cities resulting into heavy traffic. The data used in this study were collected during a survey mounted by the researchers where car inflow and outflow data were taken between 7:00am-12:00noon for seven days. Night flow was not taking into consideration because Enugu lacks social night activities unlike other cities where social life's activities are rampant as most of her citizens are civil servants. The following data were gathered between 7:00am-12:00 noon.

Table1 Primary data gathered at Ebeano tunnel

Time (AM)	No of cars passing every 30 minutes (IN FLOW) (OUTFLOW)		No of cars per hr for inflow.	No of cars per hr for outflow	Net Flow every hr	Linear Densities
7:00-7:30	209	194	418	388	30	0.98
7:30-8:00	260	200	520	400	120	1.59
8:00-8:30	282	224	564	448	116	1.54
8:30-9:00	293	299	586	598	12	0.16
9:00-9:30	316	303	632	606	26	0.34
9:30-10:00	353	338	706	676	30	0.40
10:00-10:30	367	346	734	692	42	0.56
10:30-11:00	384	387	768	774	06	0.08
11:00-11:30	320	384	640	768	128	1.70
11:30-12:00	301	346	602	692	90	1.19

The length(x) of the tunnel is 75.5 meters and the width is 17.6 meters.

From Table 1, the largest flow of traffic occurred during 10:30-11:00 am. Thus, the flow q depends on time, q(t) as shown in Figure 1. At different positions along the Tunnel, the flow might be different. Thus the flow also depends on x and we write q(X, T)

TABLE 2 Relationship between the traffic variables velocity (u), density (ρ), and flux (q), where $q = \rho u$.

Velocity(u) (km/hr)	Density(ρ) (Cars/km)	Flux(q) (Uniform Velocity x Linear Density)
0.152	0.98	0.149
0.152	1.59	0.242
0.152	1.54	0.234
0.152	0.16	0.024
0.152	0.34	0.052
0.152	0.40	0.061
0.152	0.56	0.085
0.152	0.08	0.012
0.152	1.70	0.258
0.152	1.19	0.181

In addition, the uniform velocity was obtained as follows;

$$velocity = \frac{Displacement}{Time} = \frac{0.076Km}{0.5hr} = 0.152Km/hr$$

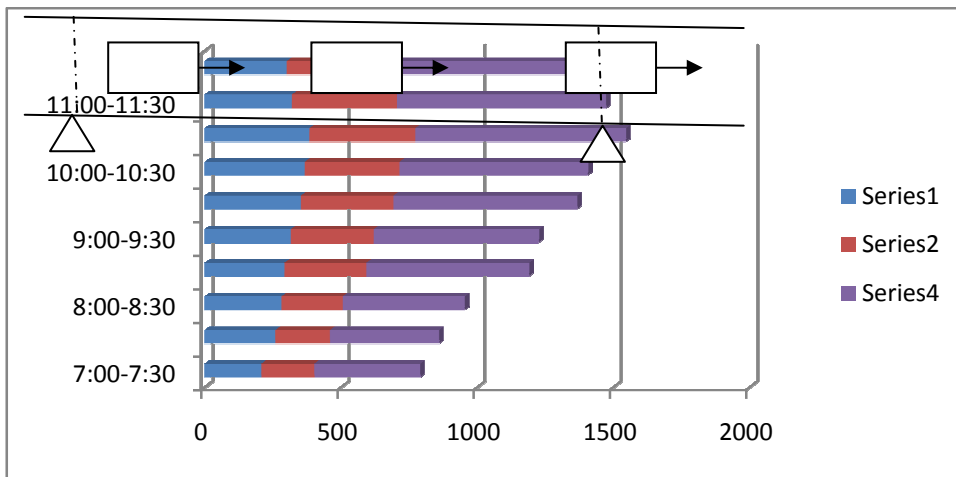


Figure 1 Configuration Meters

4.0 Discussion

The results obtained from the macroscopic deterministic analysis clearly shows that the Ebeano tunnel is highly congested especially during the day which has led to the following:

Wasting time of motorists and passengers which yields to a non-productive activity for most people as congestion tends to reduce regional economic health.

Air pollution and carbon dioxide emissions (which may contribute to global warming owing to increase idling, acceleration and braking. Increase in fuel use may also in theory cause rise in fuel costs.

Inability to forecast travel time accurately, leading to drivers allocating more time to travel “just in case”, and less time on productive activities.

Delays which may result in late arrival for employments, meetings, and education resulting in loss of businesses, disciplinary actions or other personal losses

4.1 Congestion Reduction Strategies

Based on findings of this research, there is an urgent need for the government to embark on congestion reduction strategies so as to free our roads from the evil of traffic jam. Some of these strategies are:

Enhanced transport coordination: the various modes of public transport including intermediate public transport have to work in tandem. They should complement rather than involve themselves in cutthroat competition. Therefore there is an urgent need for a transportation system that is seamlessly integrated across all modes in Enugu metropolis. Since the ultimate objective is to provide an adequate and efficient transport system, there is a need to have a coordinating authority with the assigned role of coordinating the operations of various modes [14]. This coordinating authority may be appointed by the state or federal government and may have representatives from various stakeholders such as private taxi operators, bus operators, railways and the government. The key objective should be to attain the integration of different modes of transport to improve the efficiency of service delivery and comfort for commuters, which in turn can dissuade the private car owners from using their vehicles and thereby reducing the number of cars on the roads which can eventually lead to congestion reduction.

Road Capacity Expansion: Road widening is often advocated as ways to reduce traffic congestion. However, it tends to be expensive and may provide only modest congestion reduction benefits over the long run, since a significant portion of added capacity is often filled with induced peak period vehicle traffic. A large amount of additional capacity would be needed to reduce urban traffic congestion. Some research indicates that roadway capacity expansion provides only slight reductions in urban traffic congestion (TTI, 2009).

Improved road infrastructure: These include;

- Junction improvement
- Grade separation using bridges (or, less often tunnels) freeing movements from having to stop for other crossing movement.
- Reversible lanes, where certain sections of highway operate in the opposite direction on different times of the day or days of the week, to match asymmetric demand. This may be controlled by variable message signs or by movable physical separation.
- Bus lanes e.g Bus Rapid Transit (BRT)
- Separate lanes for specific user groups (usually with the goal of higher people throughput with fewer vehicles).

Supply and demand: congestion can be reduced by either increasing road capacity (supply) or by reducing traffic (demand). Capacity can be increased in a number of ways, but needs to take account of latent demand otherwise it may be used more strongly than anticipated. Increased supply can include, adding more capacity over the whole of a route or at bottlenecks, creating new routes, and traffic management improvements. Reduction of demand can include, parking restriction, park and ride, reduction of road capacity, congestion pricing, road space rationing, and incentives to use public transport, telecommuting, and online shopping.

Intelligent transportation system: intelligent transportation systems include the application of a wide range of new technologies, including traffic reporting via radio or possibly mobile phones, parking guidance and information, automated highway systems, traffic counters, navigation systems, transit improvement and electronic charging. These can provide great reduction in congestion as well as variety of transportation improvements.

Encouraging “Green Modes”: Any traffic congestion reduction strategy in Enugu metropolis should encourage development of “green modes” such as bicycles, cycle rickshaws and pedestrians [14]. First of all, the safety concerns of cyclists and pedestrians have to be addressed adequately. For this purpose, there has to be a segregated right-of-way for

bicycles and pedestrians. Apart from reducing congestion, it will also help improve safety, increase the average speed of traffic and reduce emissions resulting from slow speeds. To enable longer trip lengths on bicycles, bicycle technology should be improved.

Drivers' Enlightenment: There should be proper and adequate enlightenment for the drivers on the dangers inherent in congestion and also dissuading those from certain congestion-causing habits such as wrong overtaking, one way driving, disobeying of traffic signals and traffic wardens.

5.0 Conclusion

Based on the findings of this research, it was concluded that poor road condition, inadequate road infrastructures, absence of integrated transport system, drivers' behavior, accident and inadequate traffic planning are the salient factors that are responsible for road traffic congestion at Ebeano tunnel in Enugu metropolis.

It is also established that traffic congestion constraints can be ameliorated by embarking on various strategies such as enhanced transport coordination, road capacity expansion, improved road infrastructures, drivers' enlightenment and application of Intelligent Transport System.

More-over, the Ebeano tunnel lacks basic facilities that can upgrade it to international standard like the ones in developed countries e.g. Germany, Austria and latest in Switzerland. These facilities include an effective and efficient, light system, police station, telecommunication posts to relay information in cases of accidents, and congestions.

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