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Modeling Trailer-Traffic Flow on a Kenyan Highway

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Abstract

Traffic flow modelling is studied in order to ease congestion on roads. However, congestion is also caused by irregular occurrences, such as traffic accidents, poor roads, vehicle disablement, spilled loads and hazardous materials. This study explored the area of poor roads which was considered to be as a result poor planning for road network repairs. Traffic flow was categorized to be either in low, intermediate, or high volume. Modelling for every flow required a different distribution namely the Exponential, Pearson type III and Normal distributions for low, intermediate and high traffic flow volume respectively. However, we modelled the trailers traffic flow using a model that covered all the 3 states, in this case,the Pearson type III distribution. Further,we investigated the shape of the probability distribution function assumed by the trailers. After data collection,extraction and analysis, Pearson type III distribution model was calibrated to fit. Lastly, Kolmogorov-Smirnov and Chi- square tests of goodness of fit was run on the observed data. Although, the data was also fitted into Normal, Erlang, Exponential, Beta and Gamma Distributions, Pearson type III distribution provided the best fit.

Mathematics Subject Classification: 49K05

Keywords: Traffic flow, Modelling, Congestion, Road network, Trailers, Probability distribution

1 Introduction

Traveling by road is the main mode of transport and communication since it is cheap, reliable and accessible to every Kenyan. This makes it an important part of our lives as day- to- day productive activities have a pivot on it. It is estimated that nearly 16 million tonnes of cargo is handled at Kenya's Mombasa port every year, with the majority of incoming and outgoing goods being transported via road to various destination. A proportion of this cargo is transported to Uganda via road since it's a land - locked Country. Majority of this load was ferried via Rail transport, which has for years been characterized by poor infrastructure, inefficiencies and has come to a near halt.

Traffic is regarded as the key parameter in road deterioration. According to Helman[8], approximately 40% road traffic congestion occurs due to traffic incidents, poor road networks, work zones and poor signal timings. Therefore, improving road networks not only improves traffic safety, but also alleviates road congestion issues thereby contributing to economic growth. It is safe to assume that there is a relationship between traffic flow and weight exerted on the road. Hence it is essential to know the traffic flow composition in terms of traffic flow volume and the magnitude of the loads (axle load). Modeling traffic flow parameters could in turn help us quantify the expected (or probabilistic) quantity of load exerted on the road surface.

Traffic flow modeling is one of the main societal and economical problems related to transportation in major countries. The aim of traffic modeling is to find stochastic processes to represent the behavior of traffic. In this respect, managing traffic in various networks requires a clear understanding of traffic flow operations.

The International Labor Office Report (ILO) [13], observed that road transport was the major economic-social effect in Sub-Saharan Africa. In the year 1990, the ILO estimated that 3,000 people were killed through road crashes in Kenya. This was blamed on poor road network state since only 19% of the road network in Kenya was well maintained compared to the rest which was neglected. Poor road networks have serious impact on the economy as a whole, therefore, roads must be managed in a prudent and effective manner to realize the dream of Kenya as enshrined in the Vision 2030[11].

Knowledge of the traffic flow operation can help in determining the causes of traffic congestion, what determines the time and location of traffic breakdown, how the congestion propagates through the network and proper planning for maintenance.

Light vehicles such as cars and delivery vans make a very small contribution to the structural damage of the roads in comparison to the trailers[7].Therefore vehicles of less than 1.5 tonnes empty weight for example: motorcycles, cars, small (mini and midi) buses or small trucks with single rear tyres for structural damage assessment purposes were ignored in this study. In this study,trailers wheel load, tyre pressure, frequency and duration together with environmental factors are all important to performance of the roads. However, the most significant parameter is contributed by traffic loading, especially that contributed by heavy goods vehicles like trailers[3]. It is in this regard that this study evaluated the trailers traffic flow model on the Kenyan road. The evaluation was done on Kisumu-Maseno Highway along Kisumu-Busia Highway since it connects Kenya to Uganda and majority of the cargo to Uganda passes through the highway.

Instead of providing preventative maintenance at an early stage, roads network in Kenya are left until much more expensive reconstruction is needed. Unfortunately, the short span of extra service years, during the delay of maintenance, is purchased at a very high price in terms of increased upgrade costs and increased accidents. It is for that reason that approximated loads exerted on the road surface is needed to orderly prioritize roads for maintenance at the earlier, cost-effective time. This study took a statistical approach towards traffic flow modeling.

2 Related Literature

Research on the subject of traffic flow modeling started more than fifty years ago, when Lighthill and Whitham [9] presented a model based on the analogy of vehicles in traffic flow and particles in a fluid. This model applied for very high and low density thereby ignoring the moderate density. This led to development of a finer model by Sopasakis and Katsoulakis [14]. This model incorporated the interaction between vehicles using the rule of "look ahead". The authors argued that a vehicle decelerates when there is another vehicle in front.Wong and Wong [15] improved the study of Sopasakis and Katsoulakis by coming up with a model arguing that faster vehicles could overtake slower vehicles under uncongested condition as well as congested condition (though less easily), and slower vehicles would slow down the faster ones.

According to Darroch[6] and Tanner[2], most researchers modeled traffic flow as singly arriving Poisson process. For instance, Vandaele et al.[10] uses $M/M/1$(1 server queue model where arrivals are determined by a Poisson process and job service times have an exponential distribution)and $M/G/1$(1 server queue model where arrivals are modulated by a Poisson process, service times have a General distribution) queues to model the traffic flow while Daganzo[5] used a cell transmission model, whereby the road sections are divided into shorter road segments (cells). Mathematical equations are introduced to describe the interactions between these cells, and thus was used to predict the evolution of traffic over time and space. Cell transmission is a mathematical model that is used for the development of traffic simulations.

Cheah and Smith [4] uses the queue model $M/G/C/C$ for modeling pedestrian traffic flows by assuming that any arrival that finds all C servers busy does not enter but is lost to the system. They further argue that service times of the customers are distributed according to a general distribution G, and the service rate of the servers, say μ, is a function of the number of the customers in the system, say n, namely, $\mu = f(n)$. Jain and Smith [12] modified Cheah and Smith[4] queuing model by using $M/G/C/C$ state-dependent queuing models for modeling and analyzing vehicular traffic flows, where the service rate (the vehicular traveling speed) is assumed to be a decreasing function of the number of vehicles on the link to represent the congestion caused by the traffic volume. Vandaele et al. utilize queuing theory to describe uninterrupted traffic flows. Buckley[1] on the other hand developed a semi Poisson model for traffic flow in his study. The model was based on the assumption that the reason for the traffic process to deviate from the Poisson process is the existence of a zone of emptiness in front of each vehicle. The author concluded that the model gave a good fit for the data with high traffic volumes and chi-square method was hard to use to get statistically good fits for the data.

From these models, it's clear that most traffic flow distribution models are probability distribution models. One basic model is negative exponential distribution model. This model or its variations as well as Erlang distribution, Normal distribution and Pearson Type III can be used in traffic flow distribution modeling. On the other hand, models associated with the properties of driver and vehicle is developed for special purpose and the data collection procedure, parameter estimation and general modeling is complex. Although some of these models consider congestion, they ignore the impact of traffic flow on the road surface. Congestion is also caused by irregular occurrences, such as traffic accidents, poor road network, vehicle disablement, and spilled loads and hazardous materials.

The main motivation of this study was to determine the continuous impact of load on the road surface, with an aim of approximating the total weight exerted at particular time period.

3 Results and Discussion

These are the main results of the paper:

(i) The trailers traffic flow model on Kenyan Highway is:

$$f(t) = 0.00275(0.003t - 0.0117)^{1.2}e^{-0.003t} \qquad 3.9 \leq t \leq \infty$$

(ii) The trailers traffic flow model follows a Pearson type III distribution. To support this conclusion, we ran a KS goodness of fit test and a Chi-square goodness of fit test where we found that the computed value was less than the critical value for several level of significance. For example at $\alpha = 0.05, KS_{2501} computed = 0.00798 < KS_{Critical} = 0.02715$ and similarly, at $\alpha = 0.05, \chi^2_{computed} = 2.3082 < \chi^2_{Critical} = 19.675$.

(iii) There is 99% chance that the observed number of trailers (1832 trailers) passed on the Kisumu- Maseno- Busia Highway during a period of exactly 28 days. Therefore, for exactly 28 days, 1828 trailers (0.998238 x 1832 =1,828) passed on the highway. For a period of 1 year, 21,936 trailers will have passed on the highway (1828 x 12= 21,936). This implies that for a period of 1 year, the approximated load in Kilograms (Kg) that will have been exerted to the road surface is 21,936 trailers x 2800 Kg (being the permissible weight to be ferried by a 3 axle trailers) = 61,420,800 Kg = 61,420.8 tonnes

(iv) The advisable day for road repairs is on Tuesday from 6.00 am to 11.00 am when the trailer's traffic flow volume is minimal. Consequently, road users should be cautious when using the highway between 3.00 pm and 6.00 pm since in all the days that is when there is high traffic volume of trailers.

(v) Trailer's traffic flow model assumes a Pearson type III distribution. This distribution depicts a a generalized model since it in-corporate a family of skewed models alongside their shifted counterparts.

4 Conclusion

From the analysis, we can conclude that traffic flow distribution model follows a Pearson type III (Generalized Gamma) distribution. The parameters of the model may vary depending on the usage of the road. However, since this study was carried out on a Highway connecting Kenya to Uganda, a similar replication of the model with same parameters could be expected to be deduced on other Highways connecting Kenya to neighboring Countries like Tanzania. Hence, the model can be used in major Kenyan Highways. Also, applying the model, estimates of the load exerted on the road surface for a certain period of time can be deduced. This in turn can help the Kenya Highway Authority plan in time for road maintenance.

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