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# Capacity Evaluation Along Benin-Lagos Expressway by Traffic Flow and Time Headway Approach

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**Abstract**

Highway capacity is defined as the maximum number of vehicles which can be accommodated in a given roadway under prevailing conditions. It is affected by desired speed, number of lanes, vertical grade, composition of traffic etc. In this paper, the traffic flow and time headway approach were employed to determine the capacity of a section of the Benin - Lagos Expressway in Edo State, Nigeria. The moving observer method was used to acquire the necessary data in the mornings (i.e. between 7:00-9:00am) and at evenings (i.e. between 4:00-6:00pm). The Greenshield model was also employed to show the relationship between the space mean speed and the density. From the analysis carried out, it was observed that the average space headway and average time headway were respectively 0.025km (25m) and 2.26sec, indicating a moderate traffic flow as it relates to the time headway and space headway. This indicates a relatively low probability of accident occurrence based on the mean free speed. The model developed gave a mean free speed of 66.161km/hr, which is the allowable maximum driving speed when flow and density are zero. The jam density obtained was 102 veh/km. Capacities obtained due to flow and time headway are 1687veh/hr and 1593veh/hr respectively.

## 1. Introduction

Determination of the capacities of transportation systems and facilities is a major issue in the analysis of transportation flow in urban areas and towns. The capacity of a highway may be described as its ability to accommodate traffic. However, the term has been interpreted in many ways by different authorities. Fundamentally, capacity can be been defined as the flow which produces a minimum acceptable journey speed and also as the maximum traffic volume for comfortable free-flow conditions in highways [1]. Capacity can be expressed as basic, possible and practical capacity depending on the assumptions made during estimation [2]. Highway capacity is affected by factors, such as desired speed, number of lanes, separation of directions, vertical grade, composition of traffic, peak traffic factor and capacity of intersections. In other to ensure adequate accommodation of traffic, other highway factors such as time gap should be within acceptable limit. The time gap is defined as the time difference between the rear of a vehicle and the front of its follower, which affects both safety and the saturation flow rate of a roadway segment [3]. Also, capacity can be expressed in terms of vehicles per hour, particularly for quick estimation of volume-to-capacity ratio on a highway[4]. This representation is the common form capacity is presented.
Capacity analysis requires quantitative evaluation of the capability of a road section to carry traffic, and it uses a set of procedures to determine the maximum flow of traffic that a given section of

highway will carry under prevailing roadway traffic and control conditions [5]. There are various models to study the mechanism of traffic breakdown and to establish a traffic flow models which precisely simulates the stochastic and dynamic processes of traffic flow at a bottleneck in order to effectively capture a highways capacity [6]. These models attempt to develop the relationship between speed and flow, speed and density, and flow and density [7]. Off these models, the Greenshield model presents a simple and easy to use model. Other modifications of the Greenshield model by Greenberg, Pipes-Munjal, Krystek, Newell and Underwood tend to use exponential and logarithmic functions for developing traffic flow models consistent with different specific traffic conditions. A review of current literature show vehicle headway distribution models is widely used in traffic engineering fields, since they reflect the fundamental uncertainty in drivers' car-following maneuvers and meanwhile provide a concise way to describe the stochastic feature of traffic flows [8]. The single regime and multi-regime traffic flow models are generally applied in traffic modelling. In the former, the entire range of operation is represented by a single model, whereas in the latter, two multiple models are used to represent traffic flow (this was proposed mainly for empirical accuracy) [7]. However, the single regime model was considered for traffic flow and time headway analysis were considered in this research. The time headway of vehicles is of fundamental importance in traffic engineering applications like capacity, level-of-service and safety studies [9]. The concept of level of service in highway traffic flow illustrates the differences in the characteristics of the flow which may be examined by a study of the headways between vehicles. Time headways are the time intervals between the passage of successive vehicles past a point on the highway. Since the inverse of the mean time headway is the rate of flow, headways have been described as the fundamental building blocks of traffic flow. When the traffic flow reaches its maximum value then the time headway reaches its minimum value [10]. Although a large number of studies exist in the field of time headway modelling, there is still a paucity of research related to time headway distribution study in two-lane bidirectional roads and four-lane divided roads with respect to varying flow rate levels [11]. It is important to note that there exists a correlation between the driving efficiency of drivers and traffic congestions on a highway [12].
In this research, capacities and densities are represented in veh/km and veh/h, respectively. The functional relationships between flow (veh/km), density (veh/h) and speed (km/h) in traffic congestion have a long history of research [13]. Road capacity can be determined using standard time headway between vehicles. More specifically, road capacity can be analyzed using average time headway per unit of traffic flow. Time headway is made up of occupancy time and time gap. Study of vehicle time headways has been a subject to many aspects of traffic flow studies because time headway between any two successive vehicles is considered as an important parameter affecting capacity, safety, delay, driver behavior and level of service of a transportation system [11].

## 2.0.Model Development

The Greenshield model [14] for macroscopic traffic flow analysis was employed in this research because it gives a good fit to the experimental data obtained in this investigation. Greenshield put forward the model proposing a linear relationship between space mean speed $\bar{u}_s$ and density k**.** The model is represented mathematically as;

$$\bar{u}_s = u_f - \left[\frac{u_f}{k_j}\right] k \quad (1)$$

Where: $\bar{u}_s$ = space mean speed, $u_f$ is free flow speed, $k_j$ is the jam density, $q_{max}$ is the capacity of the roadway and $k$ is the density.
Thus, corresponding relationships for flow and density and flow and speed can be developed as shown in Equations 2 to 4.

$$q = \bar{u}_s k \tag{2}$$

Substituting Equation (2) into Equation (1), we obtain:

$$\bar{u}_s^2 = u_f \bar{u}_s - \frac{u_f}{k_j} q \tag{3}$$

Also, we can obtain,

$$q = u_f k - \frac{u_f}{k_j} k^2 \tag{4}$$

Considering Equation (3) and differentiating $q$ with respect to $\bar{u}_s$, we obtain:

$$2u_s = u_f - \frac{u_f}{k_j} \frac{dq}{d\bar{u}_s} \tag{5}$$

For maximum flow,

$$\frac{dq}{d\bar{u}_s} = 0 \qquad k = 2\bar{u}_s \frac{u_f}{k_j} \qquad u_0 = \frac{u_f}{2}$$

However, the space mean speed $u_o$ at which the flow is maximum is equal to half the free mean speed is:

$$u_0 = \frac{u_f}{2} \tag{6}$$

Considering Equation (4) and differentiating $q$ with respect to k, we obtain:

$$\frac{dq}{dk} = u_f - 2k \frac{u_f}{k_j} \tag{7}$$

For maximum flow,

$$\frac{dq}{dk} = 0$$

However, the density $k_0$ at which the flow is maximum is equal to half the jam density;

$$k_0 = \frac{k_j}{2} \quad (8)$$

Maximum flow otherwise refers to as the capacity is mathematically expressed in Equation (9):

$$q_{max} = \frac{k_j u_f}{4} \quad (9)$$

### 3.0. Results and Discussion

Table 1 shows the data collected throughout the course of the research along the Benin-Lagos expressway from university of Benin Main Gate at 6º 24’ 00”N 5º 36’ 31”E to Ekosodin junction at 6º 24’ 32”N 5º 36’ 22”E measuring 990m. From the Table 1, it was observed that the travel time along traffic is always less than travel time against traffic. This can be attributed to the presence of speed bumps; illegal bus stops as well as traffic law enforcers which tends to lengthen travel time. The table also shows the days of the week at which each data was collected.

**Table 1: Data collected during the research with moving observer method**

| DAY | SESSION | $m_a$ | $t_a$(hr) | $m_o$ | $m_p$ | $t_w$(hr) |
|---|---|---|---|---|---|---|
| FRIDAY | MORNING | 78 | 0.028 | 2 | 7 | 0.025 |
| | EVENING | 110 | 0.029 | 0 | 10 | 0.022 |
| SATURDAY | MORNING | 80 | 0.027 | 1 | 6 | 0.020 |
| | EVENING | 70 | 0.024 | 3 | 8 | 0.020 |
| MONDAY | MORNING | 70 | 0.026 | 2 | 6 | 0.021 |
| | EVENING | 80 | 0.024 | 3 | 7 | 0.022 |
| TUESDAY | MORNING | 80 | 0.025 | 1 | 6 | 0.020 |
| | EVENING | 76 | 0.028 | 3 | 7 | 0.022 |
| WEDNESDAY | MORNING | 80 | 0.029 | 2 | 10 | 0.022 |
| | EVENING | 90 | 0.028 | 1 | 6 | 0.022 |
| THURSDAY | MORNING | 70 | 0.025 | 4 | 10 | 0.021 |
| | EVENING | 100 | 0.028 | 0 | 10 | 0.021 |
| FRIDAY | MORNING | 98 | 0.026 | 3 | 11 | 0.018 |
| | EVENING | 75 | 0.028 | 2 | 7 | 0.021 |

Table 2 shows the daily averages of flow, space mean speed and density which is obtained by summing up values corresponding to morning and evening session for a particular day and dividing by two (2). These averages are needed to compute other parameters like the space headway and the time headway required for the computation of the maximum flow, i.e. capacity. It is also needed in the model development using the Greenshield model and calibration by employing the linear regression method.

**Table 2: Daily Average of Flow, Space Mean Speed and Density**

| DAY | FLOW $q(veh/hr)$ | SPEED $u_s(km/hr)$ | DENSITY $k(veh/km)$ |
|---|---|---|---|
| FRIDAY | 1669 | 35.6 | 47 |
| SATURDAY | 1537 | 42.6 | 36 |
| MONDAY | 1528 | 41.0 | 38 |
| TUESDAY | 1554 | 41.5 | 38 |
| WEDNESDAY | 1556 | 37.8 | 41 |
| THURSDAY | 1630 | 39.2 | 42 |
| FRIDAY | 1737 | 42.8 | 40 |

Table 3 showing average space headway and average time headway corresponding to data of flow, space mean speed and density data recorded for each day along the Benin-Lagos expressway. It is observed that the average time headway is 2.26sec and the average space headway is 0.025km indicating a high traffic flow on the highway. Based on the space headway computed, it indicates that the probability of accident occurrence might be low, though depending on the average operating speed of the vehicles in the traffic stream.

Table 3: Average-space headway and Average-time headway

| Flow (veh/hr) | Space-Mean Speed (km/hr) | Density (veh/km) | Space Headway (km) | Time Headway (sec) |
|---|---|---|---|---|
| 1669 | 35.6 | 47 | 0.021 | 2.12 |
| 1537 | 42.6 | 36 | 0.028 | 2.37 |
| 1528 | 41.0 | 38 | 0.027 | 2.37 |
| 1554 | 41.5 | 38 | 0.027 | 2.34 |
| 1556 | 37.8 | 41 | 0.024 | 2.29 |
| 1630 | 39.2 | 42 | 0.024 | 2.20 |
| 1737 | 42.8 | 40 | 0.025 | 2.10 |

From the linear regression, an equation can be developed between density and mean speed as shown in equation (10):

$$\bar{u}_s = 66.161 - 0.648k \qquad (10)$$

Comparing Equation (10) to Equations (1), we can obtain the mean free speed $u_f = 66.161km/hr$, i.e. the maximum speed obtainable on Benin-Lagos expressway. Equation 10 can be estimated as:

$$0.648 = \left(\frac{66.161}{k_j}\right) \quad (11)$$

From Equations 9 and 11, we can estimate $K_j$ = 102veh/km, $q_{max}$ = 1687 veh/hr and from Table 3, the average time headway is estimated as 2.26 sec.

Therefore,

$$Capacity, c = \frac{3600}{\bar{h}} = \frac{3600}{2.26} = 1593veh/hr$$

From the computation carried out, the maximum flow obtained from the research using the moving observer method and Greenshield was $1687veh/hr$ while the capacity of the highway using the average time headway calculated from the observed data was $1593veh/hr$. The slight difference between these values could be attributed to the size of data acquired. Table 4 gives an indication of traffic volumes and headway times used to access how busy a roadway is. Comparing the value obtained in this research to this table show that the road section studied experiences a moderately high traffic volume.

Table 4: Comparison of traffic volume, vehicle number and average time headway [15].

| **TRAFFIC VOLUME** | **VEHICLE NUMBER (Veh/hr)** | **AVERAGE TIME-HEADWAY (sec)** |
|---|---|---|
| LOW | <400 | >9 |
| MEDIUM | 400-1200 | 2.5-9 |
| HIGH | >1200 | <2.5 |

## 4.0.Conclusion

It was observed that the average space headway and average time headway were respectively 0.025km (25m) and 2.26sec in the studied roadway. This indicates a relatively moderate traffic flow in regards to time headway and space headway. These values can used to predict the possibility of accidents and congestions. Based on the mean speed observed from data, this research predicts a low probability of accident. Also, the model employed for the traffic flow analysis of the roadway estimated a mean free speed of 66.161km/hr, which is the allowable maximum driving speed when flow and density are zero. This value gives an indication of the desired speed at which drivers can travel under favorable environmental conditions in the roadway investigated.

A jam density of 102 veh/km was estimated by the employed model in this study. This estimated value gives an indication of the number of vehicles required in a kilometer for a traffic congestion to occur. However, the corresponding capacities obtained due to flow and time headway analysis are 1687veh/hr and 1593veh/hr respectively. At the capacity of the road obtained, the estimated space mean speed and the density are 33.081Km/hr and 54veh/km, respectively.

The values obtained from flow and time capacity computation for the studied highway are necessary for the traffic management and monitoring of the studied highway. Capacity data obtained could be used as tool for maintenance planning and evaluation of average travel times within the roadway studied by road management authorities. It is obvious that environmental and physical factors inherent in the studied highway had significant impact on the data obtained. This research would be relevant in the design and development of speed control device which could help regulate speed of motorist in order not to exceed the design speed of specific highways. Data collected for free mean speed, jam density and time headway serve as important information for the design of speed control device in the studied roadway.

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