Model for Estimating Travel Time on Dynamic Highway Networks in Akure, Ondo State Nigeria

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Abstract—Travel time variability or distribution is very important to travel time reliability studies in transportation systems. This study aimed at developing a multivariate regression model for estimating travel time for dynamic highway networks in Akure Metropolis. The independent variables for the model are Traffic volume, density, speed of vehicles, and traffic flow while the dependent response variable is the Travel time. The estimated travel time was compared with the observed travel time from the real field data and the estimation using the regression model shows a significant level of accuracy. The Pearson correlation analysis revealed that traffic volume, speed, density, and flow correlated with travel time. The result analyzed using descriptive statistics in the SPSS software environment reveals an $R^2$ value of 0.998, thereby indicating that the independent variables accounted for 99% of travel time in the study area. The Hypothesis tested at 95% confidence level using ANOVA unveils that there was no significant difference between the observed and estimated travel time. The Mean Absolute Percentage Error (MAPE) of 0.049 shows that the model performed very well and is very efficient for analyzing the probabilistic relation between travel time and the independent variables. The study recommends periodic observation of travel time within the study area to update the developed model.

Index Terms—Estimation, Highway, Multiple Linear Regression, Travel Time.

I. INTRODUCTION

Highway Highways are functionally classified as serving traffic mobility and accessibility which are intended for high levels of safety and efficiency in the movement of large volumes of traffic at high speeds [6]. Traffic congestion is a major and regular occurrence on road networks in most cities of the world. Several factors attributed to be responsible for traffic congestions on road networks includes indiscriminate parking of vehicles on the road, potholes, absence of traffic light and traffic wardens, narrow road network, the attitude of road users, bad access roads [9], [13]. These factors have caused traffic congestions resulting to physical, emotional and economic problems such as fatigue and stress, increase in cost of travel, environmental pollution, delay in travel time leading to loss of man-hours and missed appointments, highway robbery, street trading and street begging (especially in developing countries), slow response time to emergencies, and deterioration of vehicles. Travel time is an important quantitative indicator representing traffic conditions. Accurate estimation of travel times is important for improving traffic operations and identifying key bottlenecks in the traffic network [14].

Akure is a developing city in Nigeria that has been experiencing high traffic volume with attendant traffic congestion and delayed travel time on its major road network due to high socioeconomic activities occasioned by increased population and also being the State capital and Local Government headquarter. It is therefore necessary to identify the key factors affecting travel time and develop an appropriate model for estimating travel time on road networks within the Metropolis to enable road users to organize their travel schedules and generally improve the reliability of the transportation system.

The problem of estimating travel time on urban roads has been a topic of research for a long time in many of the developed countries [11]. Reference [7] modeled travelled time using the Multi-Linear Regression (MLR) approach under heterogeneous traffic conditions in India. GPS laden Probe vehicle technique and video-graphy were used to develop an appropriate multivariate Corridor Travel Time Estimation Model. In the same vein, [5] developed a set of regression models that estimate arrival times for buses traveling between two points along a route in which Ridership and other independent factors were used to define travel time. The data used for the model development were obtained from Automatic Passenger Counters (APC) installed on buses within the northeast region of the United States. In the Nigerian context, a few studies have been attempted in this area of travel time estimation. Reference [2] developed a predictive model for travel time on major roads in Akure, Ondo State. Data on travel time were collected for vehicles during the morning and evening peak periods only using a floating car technique.

This current study aimed at developing an appropriate model for estimating travel time for dynamic and easy transportation along the highway networks in Akure Metropolis with specific objectives to identify key factors having significant influence on travel time; determine the extent of influence of these factors on travel time, and develop a model for estimating travel times using regression analysis. Since various independent variables such as time of the day, speed, traffic volume, road geometry, etc. bare varying effects on travel time, there is the justification in this present work to evaluate the extent of
their effects on travel time. Hence the relevance and importance of this study.

I. STUDY AREA

This study was conducted in Akure, the administrative capital of Ondo State, Nigeria. Akure is a city located in the South-Western part of the country and lies about 7°25’ North of the Equator and 5°19’ East of the Greenwich Meridian. It covers a total area of approximately 991 km². The city has a population of 484,798 with an annual growth rate of about 3.5% per annum [8] and is composed of mainly civil servants, private businessmen and women, traders and peasant farmers. The current land use is dominated by a medium density of structure within the inner core areas. Over the years, the number of vehicles on its roads had increased greatly due to increasing socioeconomic activities [1]. The traffic composition in the city is mixed comprising of motorcycles, taxis, minibuses, Lorries, and trucks (trailers) [10]. Other essential transportation facilities include pedestrian walkways, bus stops, parking lots, traffic signals, and street lights.

The study site is along the Olusegun Obasanjo/Oyemekun/Oba Adesida road which stretches from Oloko junction to Oba Osupa junction with a distance of about 7.14km as shown in Fig. 1. This route is very essential to both public and private transport modes entering and leaving the city as it serves as a major linkage to the Central Business District (CBD) of Akure Metropolis. It also connects neighboring towns and contains all types of land uses. This road has been identified to be one of the busiest in the city and has been experiencing varying degrees of traffic congestion as a result of increased economic activities within the State Capital. This justifies the rationale for selecting it for the study.

II. MATERIALS AND METHODS

The study approach consists of four germane stages commencing with the selection of an appropriate study route within the Metropolis. The second stage encompasses the collection of primary data on geometric characteristics of the road, traffic volume employing video-graphic survey technique then followed by travel time data collection using probe vehicle approach. The third stage involves data analysis in terms of traffic volume and composition from video playback using tally sheets. Travel Time Estimation model using a multiple linear regression approach and validation constituted the fourth stage in this study. The framework of the methodology adopted in this research is as presented in Fig. 2.

The study route was segmented as shown in Table I and data were collected on both directions of the road as designated in Table II.

| Routes                         | No  | From          | To            |
|--------------------------------|-----|---------------|---------------|
| Olusegun Obasanjo/Oyemekun/Oba Adesida Road | 1   | Oloko Junction | Ilesha Garage |
|                                | 2   | Ilesha Garage | Cathedral Bus Stop |
|                                | 3   | Cathedral Bus Stop | Oba Osupa Junction |

| Routes                         | Direction I | Direction II |
|--------------------------------|-------------|--------------|
| Olusegun                       | Oloko Junction to Oba Osupa |
| Obasanjo/Oyemekun/Oba Adesida Road | Oba Osupa Junction to Oloko Junction |

A. Data Acquisition

Geometric details collected in this study at different road sections are the length of the segment and width of the road which was measured with an odometer. Traffic data collection forms an integral part of this research as it serves as the source of primary data. Video-graphic survey points were established midway in each road segment to capture traffic volume, speed, and composition. Traffic Volumes on both directions of the road segment was collected using a video camera placed at vantage positions for the three different periods of the day and days of the week. A Garmin 76csx GPS Receiver onboard a vehicle was used for the acquisition of travel time information on the road segments.

B. Data Analysis

Field data collected in this study at the different periods...
of the day and days of the week were firstly analyzed before being used for the model development. The traffic volume collected from the road segments were downloaded from the video camera for onward processing. A tally sheet containing the type of vehicles i.e. motorcycle, car, bus, van, and truck was designed for classified counting of the vehicles. From the video playback, as each vehicle crosses the predefined mark, the tally sheet was carefully marked as appropriate. The traffic data was then converted to pcu/hr by multiplying each vehicle with their passenger car unit equivalent. The speed data were also extracted from the video cameras placed at opposite sides of the road to capture vehicular movement. The videos were replayed indoor and the time it took for the vehicles to cross the predefined 100m mark was noted with a stop watch.

C. Data Quality

The quality data largely depends on, among others, the method adopted in the experiment. To ensure the quality of data in this research, the road section was uniformly segmented for easy data collection. Video graphic survey stations were selected far away from junctions and midway of each segment to effectively capture traffic details. The classified counting method based on vehicle composition (motorcycle, car, bus, van, and truck) was also adopted to record traffic flow by vehicular type. Conspicuous reference marks were also placed at the beginning and end of each road segment and proper care was taken to record the actual time as vehicles cross the marks.

III. TRAVEL TIME MODELING

Reference [12] and [4] assert that the Multi-Linear Regression modeling approach bears enormous importance in dealing with travel time estimation modeling for its simplicity and the technique has been adopted for travel time prediction by many research institutes. Upholding this assertion, [3] suggested that regression-based models are fast to compute and favorable for transport planning and policy applications.

Multiple regression was adopted for this study because it relates the relationship between the independent variables and the validity of the model can be explained with its statistical significance. Particularly in this study, the regression analysis helps to realize how the dependent variable (travel time) changes with the variation of any of the independent variables (Traffic volume, average speed of vehicles, density, and flow).

The general linear equation that relates the data values of the dependent variable, (Y) to the independent observed variables (X1, X2, X3, ..., Xn) is shown in equation 1

\[ Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + \ldots + b_nX_n \]  

(1)

Where:
Y is the dependent variable (estimated travel time)
b0 is the intercept or regression constant from the regression analysis
X1, X2, X3, ..., Xn are the observed independent variables
b1, b2, ..., bn are the coefficients of the independent variables.
n is the number of observed variables

A. Validation of Travel Time Estimation Model

To validate the model estimate of travel time, total travel time for the route was computed. To assess the accuracy and validity of the model developed in this study, the following were adopted:

1) Coefficient of Determination (R²): This is a measure of how well a model predicts its outcome as it expresses the strength of the relationship between variables. R² ranges between 0 and 1. R²=1 indicates that the model accounts for all the variables, while R² =0 shows no relationship between the estimated travel time and the independent variables. It is expressed functionally in (2).

\[ R^2 = \frac{n(\sum xy) - (\sum x)(\sum y)}{\left[ n\sum x^2 - (\sum x)^2 \right] \left[ n\sum y^2 - (\sum y)^2 \right]} \]  

(2)

Where:
y is the dependent variable
x is the independent variable
n is the number of observed variables.

2) Mean Absolute Percentage Error (MAPE). This measures the accuracy of a model in predicting outcomes. The MAPE is as expressed in (3) and was used to assess the predictive performance of the developed travel time model for the study area by comparing the estimated travel time with the observed travel time. MAPE value of 0-10% = Very Good. 10-20% = Good, 20-30% = Satisfactory [11].

\[ MAPE = \frac{1}{n} \sum_{i=1}^{n} \left( \frac{T_e - T_o}{T_o} \right) * 100\% \]  

Where:
T_e is the estimated travel time
T_o is the observed travel time
n is the number of observed variables.

IV. RESULTS

A. Traffic Volume

The Passenger Car Unit (PCU) equivalent of traffic volume for days of the week at the different periods of observation are tabulated in Table III and graphically presented in Figs. 3 and 4 for both directions respectively.
### Table III: Traffic Volume on Direction I and II

| Days   | Periods       | “Total Volume (pcu/hr)” Direction I | “Total Volume (pcu/hr)” Direction II |
|--------|---------------|-------------------------------------|---------------------------------------|
| Monday | 7:30am-8:30am | 3829                                | 3533                                  |
|        | 12pm-2pm      | 3159                                | 3411                                  |
|        | 4pm-6pm       | 3990                                | 3642                                  |
| Tuesday| 7:30am-8:30am | 3878                                | 3739                                  |
|        | 12pm-2pm      | 3117                                | 3480                                  |
|        | 4pm-6pm       | 3848                                | 3751                                  |
| Wednesday| 7:30am-8:30am | 3047                                | 2884                                  |
|         | 12pm-2pm      | 3227                                | 3653                                  |
|         | 4pm-6pm       | 3376                                | 3446                                  |
| Thursday| 7:30am-8:30am | 3687                                | 3369                                  |
|         | 12pm-2pm      | 2428                                | 2708                                  |
|         | 4pm-6pm       | 3865                                | 3802                                  |
| Friday  | 7:30am-8:30am | 4435                                | 4859                                  |
|         | 12pm-2pm      | 3801                                | 3679                                  |
|         | 4pm-6pm       | 3640                                | 4011                                  |
| Saturday| 7:30am-8:30am | 3502                                | 3496                                  |
|         | 12pm-2pm      | 3936                                | 3928                                  |
|         | 4pm-6pm       | 4213                                | 4099                                  |
| Sunday  | 7:30am-8:30am | 2966                                | 2807                                  |
|         | 12pm-2pm      | 2762                                | 2983                                  |
|         | 4pm-6pm       | 3293                                | 3112                                  |

#### B. Traffic Composition

Fig. 5 and Fig. 6 shows the percentage of vehicular composition and their respective percentage in the study area.

#### C. Spot Speed

The Speed of vehicles as deduced from videographic survey is presented in Table IV and Fig. 7.

### Table IV: Speed Profile for the Study Area

| Time       | “Speed (km/hr)” Direction I | “Speed (km/hr)” Direction II |
|------------|-----------------------------|------------------------------|
| 7:30AM-8:30AM | 32.37, 38.26               | 32.37, 38.26                |
| 12:00PM-2:00PM | 40.67, 45.30             | 40.67, 45.30                |
| 4:00PM-6:00PM | 32.15, 36.32              | 32.15, 36.32                |

#### D. Travel Time Model Development

The Statistical Package for Social Sciences version 16 (SPSS 16) software was used to analyze the field data obtained from the study area. The software was deployed in developing the multiple linear regression model.
E. Correlation and Multi-Collinearity Analysis

To identify key factors affecting travel time and determining the extent of their influence as intended in this study, the variables were firstly analyzed to understand the effect of each on travel time and the relationship between them. To check for linearity in the dependent and independent variables, the data were subjected to correlation and multi-collinearity analysis. From the result of the correlation analysis, it was inferred that traffic volume, speed, density, and flow highly correlated with travel time. The independent variables showed a maximum correlation coefficient of about 0.984 and a minimum correlation coefficient of about 0.452 with the dependent variable.

The bell-shaped histogram plot in Fig. 8 indicates that the data followed a normal distribution. It also implies linearity in the relationship between the variables, and hence validating the appropriateness of linear regression analysis for the data.

![Histogram of travel time variables](image)

F. Travel Time Model for Akure Highway

A summary of the statistical description of data obtained at the various periods from Monday to Sunday is presented in Table V.

| Variable | Mean | Std. Deviation | N  |
|----------|------|----------------|----|
| Time     | 13.68| 1.87228        | 21 |
| Volume   | 3523.80 | 501.57142   | 21 |
| Speed    | 31.56 | 4.50072        | 21 |
| Density  | 493.52| 70.24840       | 21 |
| Flow     | 259.86| 38.15619       | 21 |

G. Development of Multiple Linear Regression Model

The Variables contained in Table V were utilized to develop a Multiple Linear Regression travel time model for this road section. In this study, the observed travel time was considered as the dependent variable while traffic volume, speed, density, and traffic flow were the independent variables. The coefficients of the independent variables obtained from the regression analysis are presented in Table VI.

| Model | Unstandardized Coefficient B | Std. Error | Standardized Coefficients Beta | t     | Sig.   |
|-------|------------------------------|------------|--------------------------------|-------|--------|
| (Constant) | 9.666 | 3.258 | - | 2.966 | 0.009 |
| Volume  | 0.005 | 0.001 | 1.349 | 5.323 | 0.000 |
| Speed   | 0.116 | 0.098 | 0.279 | 1.183 | 0.253 |
| Flow    | -0.067 | 0.012 | -1.363 | -5.448 | 0.000 |

The resultant model equation to estimate travel time is given in (4)

_{Travel Time} = 9.666 + 0.005 * Volume + 0.116 * speed − 0.067 * flow

(4)

H. Validation of the Regression Model

The R^2 value of 0.998 as presented in Table VIII was obtained from the regression analysis, while MAPE of 0.049 as seen in Table VIII was deduced between the observed and estimated travel time for the study area.

A comparison of the observed and estimated travel time using the model developed for this road section is presented in Table IX.

| Variable | Mean | Std. Deviation | N  |
|----------|------|----------------|----|
| Time     | 13.68| 1.87228        | 21 |
| Volume   | 3523.80 | 501.57142   | 21 |
| Speed    | 31.56 | 4.50072        | 21 |
| Density  | 493.52| 70.24840       | 21 |
| Flow     | 259.86| 38.15619       | 21 |

I. Hypothesis Testing

The variance of observed and estimated travel time for the different periods of the days of observation was tested. One-way ANOVA was used in testing the hypothesis at 95% confidence level.

- Null Hypothesis: H_0: μ1 = μ2 = μ3. There is no significant difference between the observed and estimated travel time for the study area.
- Alternative Hypothesis: H_1: μ1 ≠ μ2 ≠ μ3. There is a significant difference between the observed and estimated travel time for the study area.

From Table X, the calculated statistic, F=0.06 and the table statistic, F_{crit}=3.55; since F < F_{crit}, it suggests that the null hypothesis (H_0) is accepted. The conclusion, therefore,
is that there is no significant difference between the observed and estimated travel times for this road section.

J. Discussion

Based on the analysis performed in this study, it was found that high traffic volumes with corresponding longer travel time occurred during the morning (7:30 am–8:30 am) and evening (4:00 pm–6:00 pm) peak periods for all days of the week. These periods represent the times in which workers and travelers maximally utilize the road within the Metropolis. Furthermore, it was revealed that traffic composition on Olusegun Obasanjo/Oyemekun/Oba Adesida road is mainly of cars (80%); followed by motorcycles (13%); while buses, van, and trucks share equally about 2% of the traffic make-up on both directions. It was also deduced that it would take 13 mins 56 secs, 13 mins 22 secs, and 15 mins 8 secs during the morning peak, free flow and evening peak periods respectively to traverse through direction I; and 15 mins 24 secs, 14 mins 16 secs and 14 mins 49 secs for the same periods on direction II on this road section. The speed analysis revealed that 40.95km/hr is the average speed of vehicles on this road as the highest speed was recorded on Sunday afternoon. The Pearson correlation analysis shows that the independent variables (volume, speed, density, and flow) used in this study correlated with travel time as the observed data followed a normal distribution. An R² value of 0.998 was obtained from the regression analysis which indicates that the model was able to explain 99% of the relationship between the travel time and independent variables considered in this study. The MAPE of 0.049 also shows that the model performed very well. The Hypothesis tested at 95% confidence level using ANOVA unveils that there is no significant difference between the observed and estimated travel time model.

V. Conclusion

In this study, a multiple linear regression model was developed to estimate travel time using geometric and traffic data collected from segmented sections of the Olusegun Obasanjo/Oyemekun/Oba Adesida Road in Akure Metropolis. Data analysis and model development were performed using the Statistical Package for Social Sciences version 16 (SPSS 16) software. Based on the analysis of the results obtained, the study successfully identified travel time for various periods on different days of the week and established the corresponding peak volumes, spot speed, density, and traffic flow. It was also revealed that the independent variables: traffic volume, flow and, speed had significant impacts on travel time within the study area. The study, therefore, recommends that the developed travel time model should be used to estimate vehicular travel time within the study area in Akure Metropolis. In the same vein, for an efficient transport system and environmental sustainability, travel time should be measured periodically on various road sections within Akure Metropolis to update the developed model from time to time. Highway maintenance agencies within the state are further encouraged to adopt travel time reliability measures to better manage and operate the transportation system within the State.

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