ISSN No:-2456-2165

# Models for Predicting Speed at Bottleneck Locations where the Flow Rate is Greater than the Bottleneck in Port Harcourt City

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**Abstract:- Numerous measures are being implemented to address transportation challenges in Port Harcourt, a rapidly growing city with a high population in Nigeria. The city experiences heavy traffic congestion, especially on major link roads, leading to significant delays due to the bottlenecks caused by reckless parking, construction work, and other factors. To analyse speed at bottlenecks, experts apply the Lighthill Theory, a rigorous process determining speed. Bottlenecks refer to areas in the road network where traffic flow is hindered, resulting in congestion and decreased speeds. Accurately modelling speed in the presence of bottlenecks is critical to understanding traffic dynamics and developing effective strategies to manage congestion. A study was conducted at 34 locations with bottlenecks caused by various factors, including road construction, merging lanes, road capacity limitations, accidents, and vehicle breakdowns. Using Eureqa software, the project developed models that can easily calculate the speed at bottlenecks. The maximum error in predicting speeds before, at, and after the bottleneck is 0.288, 0.241, and 4.235, respectively. The mean squared error of speeds before, at, and after the bottleneck is 0.01048, 0.00908, and 0.858, respectively. These results demonstrate that the models are relatively accurate in predicting speeds at different stages of bottlenecks. The speed models gave $R^2$ values of 0.99125, 0.9977, and 0.97524 for speed before, at, and after the bottleneck, respectively, with a correlation coefficient value (r) of 0.99563, 0.99887, and 0.9883.**

***Keywords:-*** *Model, Congestion, Traffic Flow, Bottleneck, Intersection.*

## I. INTRODUCTION

The concept of speed is an integral part of our daily lives, affecting how people travel, communicate, and interact with the world. In simple terms, speed refers to the rate of change in an object's position over time, making it a scalar quantity (Wilson & Gibbs, 1901). It is calculated by dividing the distance travelled by the time taken and is typically measured in meters per second or kilometres per hour (Adoga, 2020). The credit for measuring speed for the first time goes to Italian physicist Galileo Galilei, who defined it as the distance covered per unit of time.

In traffic engineering, speed plays a crucial role in determining the safety and efficiency of roads. Traffic engineers use speed data to design roads that can handle the expected traffic volume while ensuring the safety of drivers. Several factors can affect the speed of vehicles, including speed limits, road design, traffic volume, weather conditions, vehicle characteristics, and driver behaviour (Leong *et al.,* 2020; Silvano *et al.,* 2020). Engineers use speed data to identify areas where speed limits may need adjusting or additional safety measures, such as speed cameras or traffic calming measures, may be necessary.

Bottlenecks are points or sections within a transportation network that impede or restrict traffic flow. This results in reduced speeds, potential delays, congestion, and reduced efficiency in the overall traffic flow. A bottleneck is a localized disruption of vehicular traffic on a street, road, or highway. It is caused by specific physical conditions such as the design of the road, poorly timed traffic lights, or sharp curves rather than a traffic jam. Temporary situations like vehicular accidents and construction activities can also cause bottlenecks. Driving behaviours are one of the main reasons that cause a bottleneck on the freeway or restrict the capacity of signalized intersections. In Port Harcourt, most bottlenecks are located at bus stop locations where road lanes are reduced to one lane by bus drivers who park wrongly to carry passengers, as shown in Plate 1. This is also alighted in Tang *et al.* (2009).

Plate 1 A Typical Example of a Bottleneck at a Bus Stop location.

Predictive modelling of speed is a traffic engineering technique that forecasts the speed of vehicles on a specific road or highway. This technique analyses several factors, such as traffic volume, weather conditions, and road geometry, to predict the speed of vehicles and optimize traffic flow. It involves analyzing traffic flow and identifying congested areas to predict and optimize travel times for drivers. Using historical data and statistical analysis, engineers can predict how traffic will behave in these areas and make adjustments to improve traffic flow (Rao & Rao., 2015). One way to improve road network efficiency and reduce transportation system congestion in traffic engineering is by implementing changes to road design, traffic signals, and other infrastructure (Rahane & Saharkar, 2013). In this process, known as predictive modelling, historical data related to traffic patterns is collected and analyzed, including vehicle speeds, volumes, and other relevant variables. Mathematical models and algorithms are then developed using this data to predict the speed of vehicles at bottleneck locations based on various contextual variables such as time of day, day of the week, and weather conditions (Rao & Rao., 2015).

Predictive modelling is a technique that uses different kinds of models, such as regression models, time series analysis, or machine learning algorithms. These models are trained using past data to learn patterns and relationships, which help them predict future traffic conditions and speeds at bottleneck locations. There are many applications of predictive modelling of speed due to bottlenecks. For instance, in recent years, neural networks (NN) have been widely used for short- and long-term traffic predictions (Vanajakshi & Rilett, 2007). Transportation agencies can use these models to identify congestion-prone areas and plan infrastructure improvements or traffic management strategies to alleviate bottlenecks. Moreover, these models can assist drivers by providing real-time information about expected speeds and potential delays, enabling them to make informed decisions regarding route selection and travel times. Transportation planners and policymakers can gain valuable insights into traffic flow behaviour at bottlenecks using predictive modelling. This allows them to optimize road networks, enhance traffic management strategies, and improve overall efficiency and safety for commuters and goods transportation.

Port Harcourt is a rapidly growing city, but its traffic congestion is also increasing due to bottlenecks that significantly affect travel times (Otto & Awarri, 2022; Otto & Ogboda, 2022). However, there is a lack of comprehensive understanding and predictive models that can accurately estimate the effects of these bottlenecks on traffic speed in Port Harcourt. This knowledge gap hampers effective traffic management, infrastructure planning, and decision-making processes. Therefore, it is necessary to develop predictive models to determine traffic speed and forecast future congestion patterns in Port Harcourt. By addressing this problem, stakeholders can make informed decisions, optimize traffic operations, and implement effective strategies to alleviate congestion, improve traffic flow, and enhance overall mobility within the city.

This study aims to create a predictive model for determining the speed at bottleneck locations. To achieve this goal, the following steps will be taken:

- Measuring the traffic volume at the bottleneck location.
- Measuring the density at the bottleneck location.
- Measuring the speed before, at, and after the bottleneck.
- Creating predictive models to determine the speed at bottleneck locations.

This study was conducted at 34 locations namely, Rumuokoro, Eliozu, Rumuola, Agip, Slaughter (Trans-Amadi), Amadi-Ama, Lagos Bus Stop, RSU, Ikoku, Mile 1 Emenike, Rumueme, St. Johns, GRA, Waterlines, Artillery, Rumuigbo, Education, Okilton, UTC, Open Door, Wimpey, Rumuokuta, Market Junction, Mile 1 Park, Amadi Roundabout, Ordinance, Amadi – Ama, NLNG Roundabout, Woji, Eastern Bye-Pass, Obiri-Ikwerre, Eleme Junction, Location intersections. These intersections were selected because of the volume of vehicular movements and bus stop locations that cause bottlenecks during the peak periods (7 am to 9 am and 5 pm to 8 pm).

## II. MATERIALS AND METHODS

### A. *Materials*

The study utilized the following materials:

- Stopwatch or timer: Used to measure the time vehicles take to traverse a certain distance.
- Measuring tape: Employed to measure the length of the road segment.
- Cameras: Video or surveillance cameras were utilized for visual observations and review activities for further analysis.
- Software tools: Data management and analysis were performed using Eureqa, Microsoft Excel, Spreadsheets, or Statistical software.

### B. *Methods*

➢ *Data Collection*

Traffic counts were conducted for buses, trucks, and private cars during peak weekday traffic periods at each location. The road's geometric features were manually measured and recorded using a standard measuring tape. Additionally, information about the roadway geometry at identified bottleneck locations helped to determine their cause and suggest corrective action. The activation times and delay impact of bottlenecks were estimated. Speed data was gathered using a stopwatch. This study considered an average of 50 vehicles at each intersection, amounting to 1700 vehicles.

➢ *Determination of Vehicle-Free Speeds ($V_{sf}$)*

Speed is the ratio of the distance travelled with time. A metric system often measures it in meters/second (m/s) or kilometres/hour (km/h). To calculate vehicle speed, the predetermined study length of 100m and the time it took the vehicles to move through the road segment as recorded on the stopwatch data; speed is also volume per density. This was done in a location with no speed-calming devices or bumps to determine the free speed. The speed gotten represents the free flow speed ($V_{sf}$).

$$V_{sf} = \frac{D}{T} \tag{1}$$

Where $V_{sf}$ = Free Flow Speed (m/s), D = Distance (meter), and T = Elapsed Time (seconds).

➢ *Determination of Vehicle Spacing (s):*

Spacing refers to the distance between the leading vehicle's front bumper and the following vehicle's front bumper, usually measured in meters. This was physically measured where the bottlenecks were observed.

➢ *Determination of Traffic Density (Concentration):*

Traffic density is the number of vehicles occupying a unit length of roadway lane at a given instant. It is expressed in vehicles per metre.

$$K = \frac{N}{L} \tag{2}$$

Where K = Density (Veh/m), N = Number of vehicle (Veh), L = Length (meter)

$$K_j = \frac{1000}{s} \tag{3}$$

Where:

$K_j$ = Jam Density (concentration).
S = Average spacing.

➢ *Determination of Maximum Traffic Volume ($Q_{max}$):*

Traffic volume refers to the number of vehicles passing through a specific point within a given time. It is typically measured in vehicles per hour.

$$V = \frac{N}{T} \tag{4}$$

Where **V** = Volume (Veh/hr), **N** = Number of vehicle (Veh) and **T** = Time (hour)

After determining the free speed and jam density, Equation 5 was used to determine the maximum flow.

$$Q_{max} = \frac{V_{sf} \times K_j}{4} \tag{5}$$

Where:

$K_j$ = Jamming Density (concentration).
S = Average spacing.
Q = Traffic volume/ flow.
Vsf = Average mean speed.

This procedure aligns with the Lighhill and Whitham theory (Herman, 1960).

➢ *Determination of Speeds Before, At and After the Bottleneck*

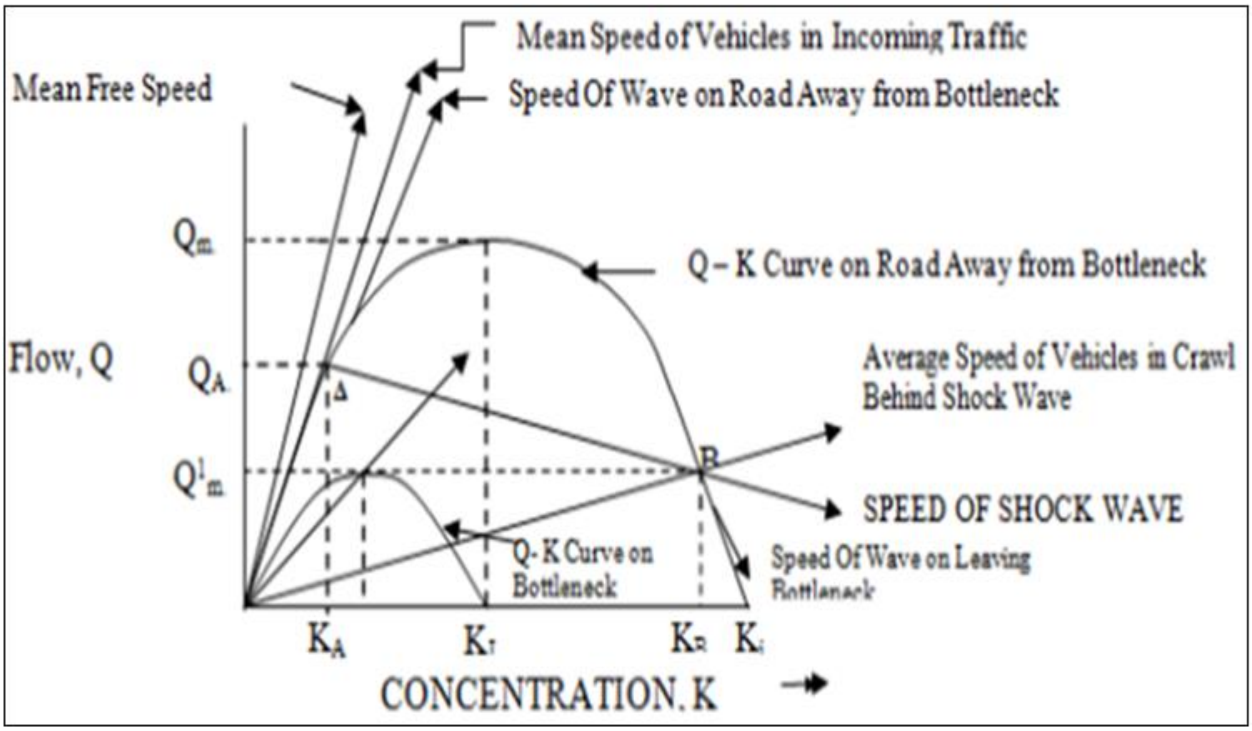


Fig 1 Q - K Curves of Bottleneck, with Flow Greater than Bottleneck

Point A represents a traffic situation with flow, ($Q_A$) greater than the bottleneck capacity $Q_{max}$. The speed of the vehicles through the bottleneck drops from $\frac{Q_A}{K_A}$ to $\frac{Q^l max}{K_j}$. Point B represents the flow condition on the second half of the Q – K curve of the road away from the bottleneck, with a concentration equal to the bottleneck capacity $Q^l_{max}$. The crawl speed of traffic behind the shock wave is represented by $\frac{Q^l max}{K_B}$ which is very much lower than the speed of vehicles through the bottleneck itself. This shows that the speed of vehicles through the bottleneck itself is higher than the speed of crawl behind. The speed of the shock wave is represented by the slope of the line $AB = \frac{Q_A - Q^l max}{K_B - K_A}$

Using the slopes of lines OC, OB, and OA, speed before, at, and after the bottleneck, can be determined as shown in Figure 1.

➢ *Development of Nonlinear Regression Models for Prediction of Speed*

The research utilized Eureqa software to identify equations and hidden mathematical relationships within data. Eureqa is an Artificial Intelligence software that employs a machine learning technique known as Symbolic Regression to unveil intrinsic relationships in data and present them in a simple mathematical form. To develop the nonlinear regression using Eureqa, the variables (both dependent and independent) were first placed in the cells, and settings were adjusted to ensure that the model developed satisfies the expected conditions. The software provides different equations to fit in with $R^2$ values, and the best fit is chosen from all the equations provided. Dr. Hod Lipson developed this software (Praksova 2011).

## III. RESULTS AND DISCUSSION

➢ *Traffic Flow at the Study Locations*

The data, and analysis of the results obtained from the traffic study/count conducted in Port Harcourt at Rumuokoro, Eliozu, Rumuola, Agip Slaughter (Trans-Amadi), Amadi-Ama, Lagos Bus Stop, Rsu, Ikoku, Mile 1, Emenike, Rumueme, St. Johns, GRA, Waterlines, Artillery, Rumuigbo, Education, Okilton, UTC, Open Door, Wimpey, Rumuokuta, Market Junction, Mile 1 Park, Amadi Roundabout, Ordinance, Amadi – Ama, NLNG Roundabout, Woji, Eastern Bye-Pass, Obiri-Ikwerre, Eleme Junction, Location segments are presented in below in Table 1.

Table 1 Traffic Flow Rate at Road Segments in Port Harcourt as a Result of Bottlenecks

| Location | Spacing (m) | Density (k) Veh/km | Jam Density (k) Veh/km | Speed (Km/hr) | Observed Flow Q (Veh/hr) | Max Flow Q (Veh/hr) | Min Flow Q (Veh/hr) | Speed at Bottleneck (km/hr) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | **Before** | **At** | **After** |
| Rumuokoro | 12.50 | 80 | 160 | 65 | 2024 | 2600 | 1300 | 8.63 | 32.50 | 47.80 |
| Eliozu | 5.25 | 190 | 381 | 68 | 1982 | 6476 | 3238 | 10.95 | 34.00 | 62.32 |
| Slaughter (Trans-Amadi) | 12.50 | 80 | 160 | 66 | 2456 | 2640 | 1320 | 8.40 | 33.00 | 41.71 |
| Amadi-Ama | 5.25 | 190 | 381 | 63 | 2127 | 6000 | 3000 | 9.87 | 31.50 | 56.81 |
| Lagos Bus Stop | 5.80 | 172 | 345 | 65 | 2402 | 5603 | 2802 | 9.82 | 32.50 | 57.07 |
| Rsu | 8.50 | 118 | 235 | 65 | 1472 | 3824 | 1912 | 10.03 | 32.50 | 57.99 |
| Rumuola | 7.17 | 139 | 279 | 66 | 1771 | 4604 | 2302 | 10.19 | 33.01 | 58.90 |
| Ikoku | 6.68 | 150 | 299 | 66 | 2041 | 4968 | 2484 | 10.11 | 33.19 | 58.66 |
| Mile One | 6.80 | 147 | 294 | 68 | 1997 | 5023 | 2511 | 10.47 | 34.15 | 60.66 |
| Emenike | 7.30 | 137 | 274 | 67 | 1235 | 4582 | 2291 | 11.01 | 33.45 | 62.04 |
| Rumueme | 6.50 | 154 | 308 | 58 | 2046 | 4474 | 2237 | 8.67 | 29.08 | 50.50 |
| St. Johns | 8.40 | 119 | 238 | 65 | 1942 | 3853 | 1927 | 9.46 | 32.37 | 55.16 |
| Gra | 7.50 | 133 | 267 | 60 | 1552 | 3970 | 1985 | 9.16 | 29.78 | 53.02 |
| Waterline | 7.80 | 128 | 256 | 61 | 1046 | 3898 | 1949 | 10.02 | 30.41 | 56.42 |
| Artillery | 7.00 | 143 | 286 | 57 | 2150 | 4071 | 2036 | 8.25 | 28.50 | 48.08 |
| Rumuigbo | 6.90 | 145 | 290 | 66 | 1046 | 4783 | 2391 | 11.24 | 33.00 | 62.17 |
| Education | 6.50 | 154 | 308 | 69 | 2010 | 5285 | 2643 | 10.63 | 34.36 | 61.40 |
| Okilton | 5.90 | 169 | 339 | 70 | 1108 | 5932 | 2966 | 12.22 | 35.00 | 66.56 |
| Utc | 6.20 | 161 | 323 | 68 | 1599 | 5468 | 2734 | 11.00 | 33.90 | 62.42 |
| Open Door | 8.00 | 125 | 250 | 59 | 1704 | 3688 | 1844 | 8.78 | 29.50 | 51.14 |
| Agip | 7.50 | 133 | 267 | 70 | 1069 | 4666 | 2333 | 11.83 | 34.99 | 65.72 |
| Wimpey | 7.00 | 143 | 286 | 71 | 1124 | 5062 | 2531 | 12.04 | 35.43 | 66.69 |
| Rumuokuta | 7.30 | 137 | 274 | 60 | 2240 | 4093 | 2047 | 8.59 | 29.88 | 49.99 |
| Market Junction | 8.50 | 118 | 235 | 67 | 2100 | 3917 | 1958 | 9.61 | 33.29 | 55.97 |
| Mile 1 Park | 7.80 | 128 | 256 | 58 | 1950 | 3722 | 1861 | 8.42 | 29.03 | 49.06 |
| Amadi Roundabout | 9.00 | 111 | 222 | 61 | 1850 | 3415 | 1707 | 8.85 | 30.73 | 51.54 |
| Ordinance | 6.42 | 156 | 312 | 57 | 1218 | 4406 | 2203 | 9.27 | 28.27 | 52.33 |
| Amadi – Ama | 7.17 | 139 | 279 | 63 | 1119 | 4384 | 2192 | 10.44 | 31.44 | 58.57 |
| Nlng Roundabout | 6.10 | 164 | 328 | 61 | 1153 | 5008 | 2504 | 10.31 | 30.53 | 57.31 |
| Woji | 6.56 | 152 | 305 | 60 | 2350 | 4584 | 2292 | 8.76 | 30.08 | 51.08 |
| Eastern Bye-Pass | 6.56 | 152 | 305 | 66 | 1750 | 5029 | 2515 | 10.38 | 33.00 | 59.65 |
| Obiri-Ikwerre | 6.77 | 148 | 295 | 59 | 2550 | 4355 | 2178 | 8.36 | 29.50 | 48.49 |
| Eleme Junction | 8.13 | 123 | 246 | 62 | 2000 | 3814 | 1907 | 8.99 | 31.00 | 52.38 |
| Location | 6.42 | 156 | 312 | 64 | 2150 | 4987 | 2493 | 9.66 | 32.00 | 56.14 |
| Average | 7.34 | 141.08 | 282.17 | 63.83 | 1774 | 4505 | 2253 | 9.84 | 31.91 | 56.05 |

Table 1 presents data on traffic counts and flows at the main intersections of Port Harcourt. The findings show that the average free speed on the roads during off-peak hours was 63.83 km/h. However, the speed significantly decreased to 9.84 km/h before the bottleneck due to various factors such as roadside markets, on-street parking, pedestrian crossings, and passenger boarding/alighting at bus stops near the intersections. The speed increased to 31.91 km/h at the bottleneck and 56.05 km/h when the vehicles passed through the bottleneck location. This led to speed reductions of 15.42%, 49.99%, and 87.81%, respectively. Similar results were also observed by Otto and Awarri (2022).

The study found that the average traffic jam density in Port Harcourt intersections is 282 vehicles per kilometre, with a maximum flow of 4505 vehicles per hour. As the

ISSN No:-2456-2165

density increases, the flow also increases, but at jam density, there is congestion and a decrease in flow, leading to an inverse linear relationship between density and flow. Similarly, density and speed have an inverse linear relationship, with higher densities causing longer delays and slower speeds. This study supports the findings of Otto and Awarri (2022).

- *Models for Predicting Speed Before, At and After the Bottleneck*

The model developed for speed prediction before, at and after a bottleneck is a function of free speed (S), observed flow (Q), and density (K). This relationship is well known in traffic engineering as the fundamental relation of traffic flow. Equations 6,7 and 8 were the equations developed.

$$V = 0.176S + 0.016K - 1.48 - 0.00122Q \qquad (6)$$

$$V = 0.521S + 0.000887Q - 1.61 - 1.02e^{-5SQ} - 5.54e^{-8Q^2} \qquad (7)$$

$$V = 0.992S + 0.439K - 38.71 - 1.29e^{-6Q^2} - 0.00127K^2 \qquad (8)$$

Where:

V = Speed
S = Free Flow speed
K = Density
Q = Observed Flow.

Table 2 displays the predicted speeds using Equations 6, 7, and 8. Additionally, Figures 2, 3, and 4 demonstrate the model's accuracy with $R^2$ values.

Table 2 Validation of Models

| **Location** | **Free Speed S (km/hr)** | **Density (k) Veh/km** | **Observed Flow Q (Veh/hr)** | **Measured Speed at Bottleneck V (km/hr)** | | | **Predicted Speed at Bottleneck V (km/hr)** | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | **Before** | **At** | **After** | **Before** | **At** | **After** |
| Rumuokoro | 65 | 80 | 2024 | 8.63 | 32.50 | 47.80 | 8.78 | 34.05 | 51.48 |
| Eliozu | 68 | 190 | 1982 | 10.95 | 34.00 | 62.32 | 11.14 | 35.58 | 65.01 |
| Slaughter (Trans-Amadi) | 66 | 80 | 2456 | 8.40 | 33.00 | 41.71 | 8.43 | 34.95 | 52.47 |
| Amadi-Ama | 63 | 190 | 2127 | 9.87 | 31.50 | 56.81 | 10.08 | 33.10 | 60.05 |
| Lagos Bus Stop | 65 | 172 | 2402 | 9.82 | 32.50 | 57.07 | 9.81 | 34.39 | 62.43 |
| Rsu | 65 | 118 | 1472 | 10.03 | 32.50 | 57.99 | 10.06 | 33.56 | 58.56 |
| Rumuola | 66 | 139 | 1771 | 10.19 | 33.01 | 58.90 | 10.22 | 34.36 | 62.02 |
| Ikoku | 66 | 150 | 2041 | 10.11 | 33.19 | 58.66 | 10.12 | 34.78 | 63.11 |
| Mile One | 68 | 147 | 1997 | 10.47 | 34.15 | 60.66 | 10.47 | 35.75 | 64.87 |
| Emenike | 67 | 137 | 1235 | 11.01 | 33.45 | 62.04 | 10.99 | 34.34 | 62.68 |
| Rumueme | 58 | 154 | 2046 | 8.67 | 29.08 | 50.50 | 8.74 | 30.50 | 55.18 |
| St. Johns | 65 | 119 | 1942 | 9.46 | 32.37 | 55.16 | 9.46 | 33.84 | 58.49 |
| Gra | 60 | 133 | 1552 | 9.16 | 29.78 | 53.02 | 9.25 | 30.79 | 55.04 |
| Waterline | 61 | 128 | 1046 | 10.02 | 30.41 | 56.42 | 10.01 | 31.00 | 55.75 |
| Artillery | 57 | 143 | 2150 | 8.25 | 28.50 | 48.08 | 8.23 | 29.99 | 53.35 |
| Rumuigbo | 66 | 145 | 1046 | 11.24 | 33.00 | 62.17 | 11.19 | 33.70 | 62.43 |
| Education | 69 | 154 | 2010 | 10.63 | 34.36 | 61.40 | 10.64 | 35.97 | 65.65 |
| Okilton | 70 | 169 | 1108 | 12.22 | 35.00 | 66.56 | 12.22 | 35.84 | 67.37 |
| Utc | 68 | 161 | 1599 | 11.00 | 33.90 | 62.42 | 11.10 | 35.13 | 65.04 |
| Open Door | 59 | 125 | 1704 | 8.78 | 29.50 | 51.14 | 8.84 | 30.64 | 53.57 |
| Agip | 70 | 133 | 1069 | 11.83 | 34.99 | 65.72 | 11.68 | 35.80 | 65.40 |
| Wimpey | 71 | 143 | 1124 | 12.04 | 35.43 | 66.69 | 11.92 | 36.31 | 67.11 |
| Rumuokuta | 60 | 137 | 2240 | 8.59 | 29.88 | 49.99 | 8.51 | 31.51 | 55.60 |
| Market Junction | 67 | 118 | 2100 | 9.61 | 33.29 | 55.97 | 9.57 | 34.94 | 60.13 |
| Mile 1 Park | 58 | 128 | 1950 | 8.42 | 29.03 | 49.06 | 8.42 | 30.37 | 53.01 |
| Amadi Roundabout | 61 | 111 | 1850 | 8.85 | 30.73 | 51.54 | 8.87 | 32.06 | 54.09 |
| Ordinance | 57 | 156 | 1218 | 9.27 | 28.27 | 52.33 | 9.50 | 28.93 | 53.68 |
| Amadi - Ama | 63 | 139 | 1119 | 10.44 | 31.44 | 58.57 | 10.47 | 32.14 | 58.91 |
| Nlng Roundabout | 61 | 164 | 1153 | 10.31 | 30.53 | 57.31 | 10.50 | 31.22 | 58.41 |
| Woji | 60 | 152 | 2350 | 8.76 | 30.08 | 51.08 | 8.69 | 31.82 | 57.10 |
| Eastern Bye-Pass | 66 | 152 | 1750 | 10.38 | 33.00 | 59.65 | 10.45 | 34.33 | 62.89 |
| Obiri-Ikwerre | 59 | 148 | 2550 | 8.36 | 29.50 | 48.49 | 8.17 | 31.39 | 55.67 |
| Eleme Junction | 62 | 123 | 2000 | 8.99 | 31.00 | 52.38 | 8.97 | 32.47 | 56.30 |
| Location | 64 | 156 | 2150 | 9.66 | 32.00 | 56.14 | 9.67 | 33.64 | 61.07 |
| Average | 63.83 | 141.08 | 1774 | 9.84 | 31.91 | 56.05 | 9.86 | 33.21 | 59.22 |

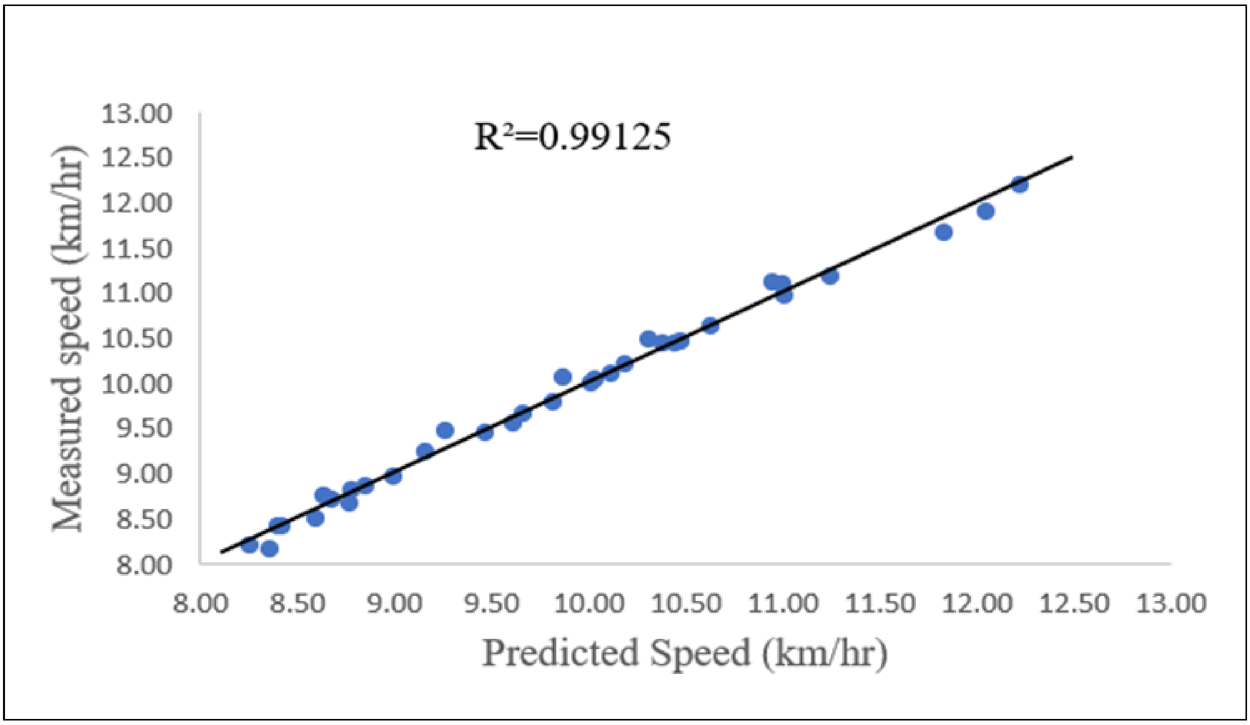


Fig 2 Variation of Measured Speed against Predicted Speed before the Bottlenecks

Equation 6 was formulated to forecast the speed leading up to a bottleneck, and it yielded an $R^2$ value of 0.99125. This suggests that the model is highly accurate in its speed predictions. Upon examination of Figure 2, it was noted that the predicted speed aligns closely with the actual measured speed. The correlation coefficient value (r) was determined to be 0.99563, signifying a positive linear connection between the predicted and measured speeds. This outcome indicates that the relationship between the predicted and measured speeds accounts for roughly 99.13% of the variance.

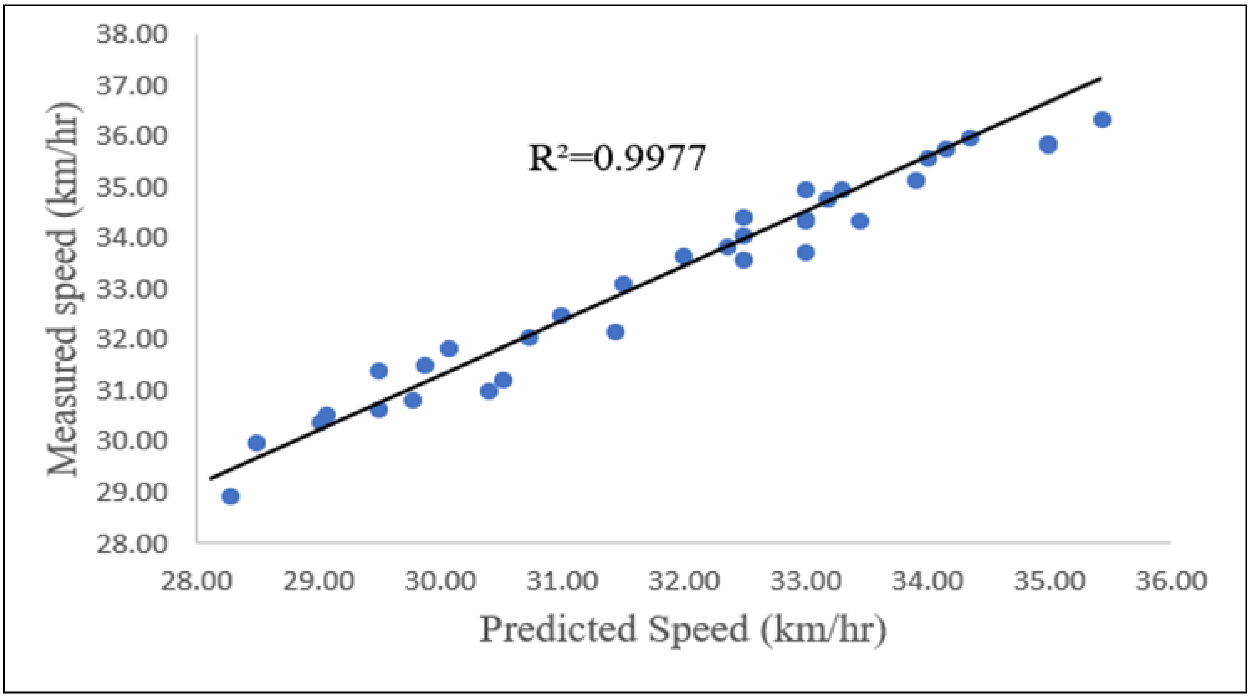


Fig 3 Variation of Measured Speed against Predicted Speed At the Bottlenecks

Equation 7 was formulated and employed to determine the speed at bottlenecks, yielding an impressive $R^2$ value of 0.9977. Upon examining Figure 3, it becomes clear that the projected speed closely aligns with the actual measured speed outcomes, as evidenced by a correlation coefficient value (r) of 0.99887. This result points to a flawless linear relationship and implies that nearly 99.77% of the variability is explained by this connection.

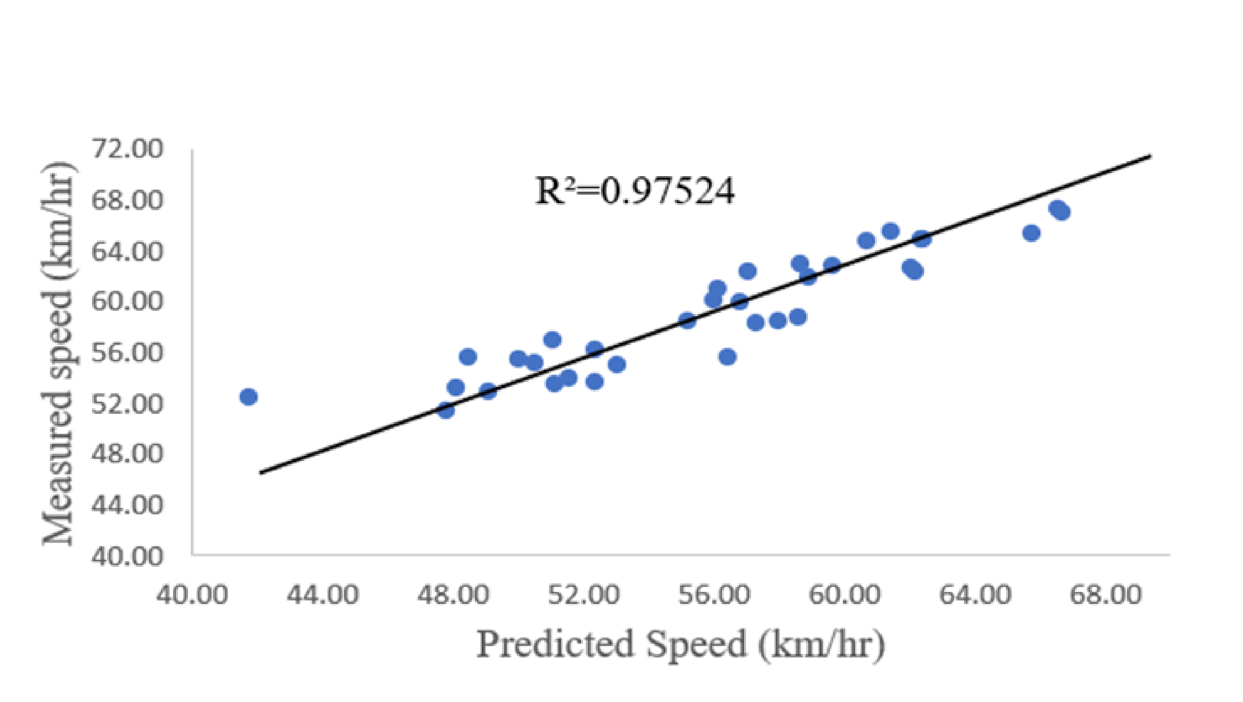


Fig 4 Variation of Measured Speed against Predicted Speed After the Bottlenecks

Based on the analysis of Equation 8, It is possible to accurately forecast the speed that follows a bottleneck with an impressive $R^2$ value of 0.97524. The data presented in Figure 4 confirms the reliability of these predictions, as the correlation coefficient (r) between the predicted and measured speeds is an impressive 0.9883. This analysis demonstrates a strong positive linear correlation between forecasted and actual speeds. Approximately 97.52% of the variability in velocity can be explained by this correlation.

## IV. CONCLUSION

➢ *Based on the Research Aim and Objectives, the Following Conclusions have been made:*

- The traffic jam density in Port Harcourt intersections has an average of 282 vehicles per kilometre, with a maximum flow of 4505 vehicles per hour. As the density increases, flow also increases, but at jam density, there is congestion, which decreases the flow. This results in an inverse linear relationship between density and flow and density and speed. A higher density leads to increased time delay and reduced speed.
- Before the bottlenecks, the average free-flow speed was recorded to be 63.83 km/hr. However, this speed decreased to 9.84 km/hr due to the bottleneck. It gradually increased to 31.91 km/hr and 56.04 km/hr as the vehicles passed through the bottlenecks. The speed decrease was 15.45%, while the speed increase was 49.99% and 87.81%.
- The models developed based on this data can be used to predict the speed before, at, and after bottlenecks in Port Harcourt and similar areas. The predicted speed models are a function of free speed (S), observed flow (Q), and density (K). These models can provide insight for traffic planners and help predict speed due to bottlenecks in areas where construction activities take place.

## RECOMMENDATIONS

➢ *The Following Recommendations are based on the above Findings and Conclusions:*

- Using the developed predicted model to estimate the speed before, at and after bottleneck at intersections is recommended.
- Before construction work on the roadway, these models can be used to predict speed before, at and after bottleneck to determine travel time in planning.
- This predicted model can be used easily by classroom students to predict speed at bottlenecks instead of going through a rigorous process.

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