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Analysis of Traffic Flow Obstruction Due to Volume of Private Vehicles at Major Intersections in Port Harcourt

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ABSTRACT

Traffic issues including delays and congestion, particularly at intersections, are because of the massive rise in private vehicles along Port Harcourt roadways. Any highway traffic crossroad presents a complex negotiation. This occurs when vehicles traveling in several directions try to use the same space simultaneously. The surge in the use of private cars has made traffic congestion one of the most unbearable issues in cities, affecting both the economy and city life. Thus, this study aimed to investigate the impact of private cars on traffic flow at critical intersections in Port Harcourt. In addition to conducting a thorough traffic survey at the junctions to identify the number of private vehicles, a well-designed questionnaire with a sample size of roughly 100 people was used to determine the significance of the effect through statistical analysis. Direct field surveys were used to gather information about the volume of traffic. Results showed that the percentage of private cars at the selected intersections was around 43%. With an average Z-statistical value of 2.66 at a 95% confidence level, the current growth in private cars significantly contributes to traffic congestion. Thus, encouraging a functional public transportation system might be a possible mitigation approach to reducing the burden of traffic congestion at road intersections within Port Harcourt city.

1. Introduction

An intersection is the point where two or more roadways come together. There are lots of different directions that cars could drive at intersections to accomplish their objectives. The primary duty of an intersection is to steer incoming cars in the right direction, and any adjoining route will have difficult traffic crossings to navigate. This is due to cars competing for space while travelling in different directions and pedestrians simultaneously looking in the same direction to cross the road. At crossroads, drivers must make a snap decision based on several factors, including their route, the shape of the crossing, the direction and speed of other vehicles, etc. Even a slight mistake in judgment can have serious consequences and lead to an accident. In addition, depending on the kind, geometry, and control type, it results in latency. Their effectiveness influences the amount of traffic that passes through the crossings and impacts the road's capacity.

Therefore, intersection analysis is crucial for traffic engineers, especially in the case of Port Harcourt, from both an accident and capacity perspective. Since private transportation systems have increased, traffic congestion is one of the most unbearable issues facing metropolitan regions. This affects the economy and urban society (Kumar & Sing, 2017). Port Harcourt is rapidly becoming a cosmopolitan city, causing several issues such as Housing a gentrification, Infrastructure strain, social inequality, Environmental concerns, public health concerns Economic disparities, Urban planning and managements and so on. Thus, a possible mitigation approach to reduce the burden of congestion at intersections within Port Harcourt city is to encourage a functional public transportation system. In Port Harcourt City, traffic congestion is a common occurrence. In big, expanding cities, there are significant problems with road traffic congestion (Rahane & Saharkar, 2013). Kumar and Sing (2017) claim that traffic congestion causes a severe increase in travel time by halting traffic flow. In the transportation industry, traffic congestion is defined by slower-moving traffic, more waiting cars, and longer travel durations. Traffic congestion causes delays, aggravation or tension for drivers and difficulty predicting travel times precisely. The sustainability of transportation development has often been hampered by traffic congestion in Port Harcourt.

Traffic congestion has long been a source of anxiety for Port Harcourt drivers. Although the state government recently built flyovers at several junctions to lessen traffic, these flyovers include Garrison Flyover, Rumuokoro Flyover, Eliozu Flyover and Nkpogu Flyover, the congestion remains. Building additional roads has been perceived as a Band-Aid solution because it is not always successful due to political, environmental, or economic issues, and it may occasionally increase traffic on the road (Kumar & Sing, 2017; Rahane & Saharkar, 2013). Otto and Awarri (2022) reported that, on average, private cars account for 42% of all vehicles at the intersections studied along Ikwerre Road in Port Harcourt city. This has given rise to the claim that traffic flow at intersections is impacted by the volume of private vehicles on the road. Thus, this study aims to present alternatives while revealing the true impact of private vehicles. This study also intends to create a tool for policymakers based on examining the obstruction of traffic flow caused by the number of private cars at Port Harcourt's key intersections. Rumuokoro, Rivers State University, Eliozu, Slaughter at Trans-Amadi, Amadi-Ama, and Lagos Bus Stop were the intersections considered in this study. Since these crossroads frequently experience heavy traffic during peak hours, selecting them to represent the various parts of Port Harcourt City and its surroundings was important.

To accomplish the goal of the study, the following objectives were addressed.

i. Determine the volume of private cars at the intersections.
ii. Determine the average travel speed at the intersections due to the presence of private cars.
iii. Determine the average travel speed at the intersections due to reduced volume of private cars, and
iv. Determine the significance of the effect of private vehicles on traffic flow using statistical methods.

2. Materials and Methods

2.1 Materials

Video cameras, measuring tapes, pens, stopwatches, and tally sheet papers were used by field observers to perform the investigations.

2.2 Methods

Two steps were taken to accomplish the study's aim: a field survey and an office desk study. Traffic volumes and the actual geometric features of the nearby road alignments at the crossroads were measured during the survey. A camera positioned at a location for proper visibility was employed in conjunction with the manual counting method to collect data. Using a regular measuring tape, the geometric characteristics of the junctions were measured by hand and documented in September 2023. Additionally, a manual traffic count was carried out at the intersection. The intersections include, Rumuokoro, Rivers State University, Eliozu, Slaughter in Trans-Amadi, Amadi-Ama, and Lagos Bus Stop.

The two peak traffic periods for each approach leg, from 06:30 am to 10:30 am and 04:30 pm to 7:30 pm, were the times the data was gathered over three months (weekdays) at Rumuokoro, Rivers State University, Eliozu, Slaughter at Trans-Amadi, Amadi-Ama, and Lagos Bus Stop. At each site/location, a traffic count of various vehicle types, including trucks, buses, taxis, and private cars, was carried out. As per the Transport and Road Research Laboratory (1980), it is necessary to convert the reported traffic volumes of every vehicle to its corresponding Passage Car Units (PCU). This was done to make the analysis more accessible. Comparably, measurements and records were made of the geometric properties of adjoining roads.

2.2.1 *Determination of Traffic Volume and Flow at Intersections*

Traffic surveys and observations were conducted at the intersections during peak hours (6.30 am to 10.30 am and 4 pm to 8.30 pm) to estimate the traffic volume and correctly classify the cars. The Lighthill and Whitham theory was also applied to understand the traffic flow. Understanding fluid flow based on kinematic waves is essential for understanding traffic flow, claim Lighthill and Whitham (1955). This theory addresses traffic problems using the "continuous flow" method from fluid dynamics and seeing that at each stage of the journey, the concentration (K) determines the flow (Q). Figure 1 illustrates how applying the previously discussed theory is limited to handling bottlenecks for flows more significant than the bottleneck's capacity to address the study's problem.

The flow QA of the traffic situation shown by point A is greater than the bottleneck capacity Qmax. The car speed drops from $\frac{Q_A}{K_A}$ to $\frac{Q^l_{max}}{K_j}$, through the bottleneck. The flow condition on the second half of the Q–K is shown at point B, where the road turns away from the bottleneck and the concentration is equal to the bottleneck capacity (Q1max.). As indicated by the $\frac{Q^l_{max}}{K_B}$, traffic travels slowly after the shock wave. Compared to the speed at which cars pass through the bottleneck, it is far slower. This indicates that cars are passing through the bottleneck more quickly than the traffic in rear of them.

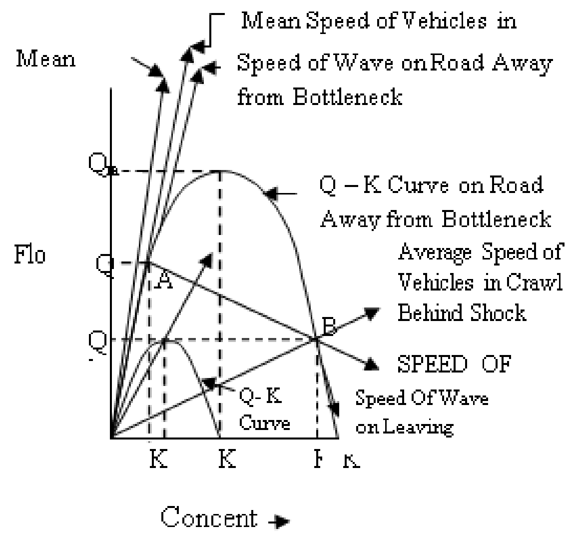

Figure 1: Q – K Curves of Bottleneck with Flow Greater than Bottleneck. (Source: Highway Capacity Manual (HCM) By Transportation Research Board Part B).

The velocity of the shock wave is given by equation 1.

Slope of the line AB = $\frac{Q_A - Q^l_{max}}{K_B - K_A}$ (1)

The two main equations employed in resolving the mathematical traffic issues associated with this research are equations 2 and 3.

Jamming concentration, Kj = $\frac{1000}{S}$ (2)

Traffic volume/ flow, Q = $\frac{V_{sf} \times K_j}{4}$ (3)

Where, Kj = Jamming concentration, S = Average spacing, Q = Traffic volume/ flow, and Vsf = Average mean speed.

2.2.2 Determination of the Effect of Private Vehicles

For the data analysis, primary and secondary data collection was required. Furthermore, questionnaires were used to collect primary data from road users. One hundred and twenty (120) questionnaires that were given to different respondents served as the initial source of data that was used to evaluate and test the hypothetical questions formulated for the study. One hundred (100), or 83.3% of the total, gave back the answers. The selection of these people was based on the belief that they possessed a solid understanding of the challenges surrounding our intersections and roads. Additionally, secondary data from previously published studies connected to the current topic was acquired. As a reference point, it was only used to help arrange the study's aim. It was also used to compare the research conclusions based on its findings and the various interpretations of its findings. A challenge encountered during the data collection procedure involved formulating a questionnaire that would efficiently elicit the necessary responses from the participants. Getting the questionnaires from the respondents within the time limit required to ensure the timely completion of the research study was another major challenge encountered during the data collection phase. Additionally, time was lost when some of the responses had to be returned to the respondents since they were not provided correctly.

2.2.3 Procedure of Analysis

The analysis for the research was done using functions in Excel. Additionally, it required five essential stages to finish the subsequent process.

i. Sorting questionnaire responses.
ii. Determining each independent variable's sample mean, including "critical" and "not critical" means, and standard deviations, including "critical" and "not critical," for each independent variable.
iii. Determining the critical and non-critical sample distributions (often referred to as sample characteristics) for every independent variable.
iv. Applying distinct T-tests to every independent variable

2.2.4 Sorting of Responses

The initial stage of the analysis involved extracting responses from the different respondents and converting them into numerical data. A spreadsheet displays the weightings of associated responses for each independent variable based on whether the variable is critical, not critical, or irrelevant (i.e., not necessary). It is crucial to remember that the research project used the following codes: 0 = not applicable; 1-5 = not critical; and 1-5 = critical.

2.3 Determination of Sample Means

Sample means were computed for each independent variable using Equation 4, the arithmetic mean equation (Wadsworth, Jr. 1990:2.8). The calculation involves dividing the total number of samples of the independent variables by their total number of weights. This was categorized by computing sample averages for the number of critical and non-critical responses. To calculate the sample and mean for each independent variable for both critical and non-critical responses, the following equation was created using Excel functions:

$$\boldsymbol{\mu = \frac{1}{N}\sum_{i=1}^{k} Xi} \tag{4}$$

Where, μ = sample mean of each independent variable for each response; Xi = weightings of each independent variable for each response; N = sample size of each independent variable for each response.

2.4 Determination of Sample Standard Deviations

Additionally, the standard deviation of each independent variable was computed (Wadsworth Jr., 1990). However, sample means and standard deviations for critical and non-critical responses were used to categorize these. Using Excel Software (Microsoft Inc., USA), the standard deviation of each independent variable was calculated with equation 5.

$$\sigma = \sqrt{\frac{1}{N-1}\sum (Xi-\mu)^2} \tag{5}$$

Where, σ = standard deviation of each independent variable for each response; μ = sample mean of each independent variable for each response; Xi = weightings of each independent variable for each response; N = sample size of each independent variable for each response; and $N-1$ = unbiased estimator.

2.4.1 Sample Distribution

The sample characteristics for each independent variable were ascertained by utilizing Excel Software (Microsoft Inc., USA) to analyze the distributions of the samples for both critical and non-critical replies. Put differently, sample characteristics were established using the sample coefficient of kurtosis and standard error of kurtosis (Tabachnic & Fidell, 1966; Abramowitz & Stegun, 1972; Moors, 1986; Dodge & Rousson, 1999; Kenney & Keeping, 1962; Darlington, 1970). Kurtosis is defined as the degree of peakedness of a distribution and can be considered a normalized version of the fourth central moment. However, the coefficient of kurtosis of each independent variable for every response was found using equation 6.

$$\beta = \frac{\sum (X-\mu)^4}{N\sigma^4} - 3 \tag{6}$$

Where, β = Coefficient of kurtosis of each independent variable for each response.

Additionally, the standard error of kurtosis of each independent variable was calculated and categorized for critical and non-critical replies. To determine whether there is a significant kurtosis issue, the standard error of kurtosis (Equation 7) was used to compare with absolute kurtosis based on the degree of peakedness. The standard error of kurtosis was implemented with Excel Software (Microsoft Inc., USA) for each variable (critical and non-critical) as recommended in the literature (Tabachnic and Fidell, 1966).

$$SEK = \sqrt{\frac{24}{N}} \tag{7}$$

Where SEK = Standard error of kurtosis.

2.4.2 Independent t-Test

An independent *t*-test was performed to modify the hypothetical questions and fulfill the study's aim. On the other hand, using the underlying *t*-test, Excel Software (Microsoft Inc., USA) was used to conduct the independent *t*-test. There were five basic steps involved in doing the *t*-test. Before applying the *t*-test theory, obtaining the mean and standard deviation of every independent variable for every response is necessary. The procedures for running the *t*-test are as follows:

i. Dividing the standard deviation of critical response (σ_c) by the number of critical response (N_c) (equation 8).

$$\frac{\sigma_c}{N_c} \tag{8}$$

ii. Dividing the standard deviation of non-critical response (σ_n) by the number of non-critical responses (N_n) (equation 9).

$$\frac{\sigma_n}{N_n} \tag{9}$$

iii. Adding equations 8 and 9 to get equation 10.

iv. $$\frac{\sigma_c}{N_c} + \frac{\sigma_n}{N_n} \tag{10}$$

v. Subtracting the mean of the non-critical response (μ_n) from the mean of the critical response (μ_c), we have equation 11.

$$\mu_c - \mu_n \tag{11}$$

vi. Dividing equation 11 by equation 10 to obtain the Z statistic as shown in equation 12.

$$Z = \frac{\mu_c - \mu_n}{\frac{\sigma_c}{N_c} + \frac{\sigma_n}{N_n}} \tag{12}$$

Equation 12 states that for every independent variable, if *Z* is 1.96 or above with a less than 5% chance of error for a two-tailed *t*-test — the null hypothesis can be rejected in favour of the alternative hypothesis. If Z is smaller than 1.96, it suggests that the null hypothesis cannot be rejected because there is a more than 5% chance that it will be. This makes the Z statistic significant because it calculates the error associated with rejecting the null hypothesis in favour of the alternative hypothesis.

3. Results and Discussion

3.1 Traffic Count at Selected Intersections

The traffic volume at six road intersections at Rumuokoro, Eliozu, Slaughter, Amadi-Ama, Lagos Bus Stop, and Rivers State University during peak period is shown in Figure 1. Across the six intersections, it is evident that private vehicles make up most of the traffic.

Private vehicles were followed by 14-seater buses in traffic volume except at Eliozu and Amadi-Ama intersections where Taxis outnumbered 14-seater buses in traffic volume. Overall, the number of private vehicles at the studied road intersections fall within 42–45%, which is corroborated by recent studies suggesting that in Port Harcourt, the average number of private automobiles at junctions is estimated to be 42–45% (Otto & Awarri, 2022; Otto & Ogboda, 2022). Additionally, Figure 1 shows that there are a smaller number of trucks across the six road intersections studied. This situation may be attributed to the fact that trucks are mainly employed for transporting goods rather than humans, or due to compliance by truck drivers to extant planning restrictions on the movement of trucks at certain periods of the day designed to ease traffic during peak periods.

3.2 Traffic Flow Rate at Intersections

Table 1 displays the traffic flow rates for the six intersections that were the subject of this investigation. As can be observed in Table 1, an average free speed of 65km/h was recorded. However, the speed was only 9.21km/h on average before the bottleneck and increased to 32.50km/h and 51.53km/h as the vehicles gradually passed through the bottleneck areas due to indiscriminate on-street parking, pedestrian crossings, and passenger boarding/deboarding at bus stops close to the intersections. This traffic pattern is an all-too-common experience as has been reported in prior research (Otto and Awarri, 2022).

3.3 Traffic Flow Rate at Intersections with Anticipated Reduction in Private Vehicles

An extensive inspection of the intersections was done to find out the actual condition of the road during traffic. While private automobile use has increased people's comfort and mobility on the road, it has been shown that unregulated use of these cars affects intersection speed. This is because of the strong demand for available space.

A summary of the pace at which a 50-% reduction in the number of private cars is possible is presented in Table 2. During off-peak hours, the typical free speed before the intersections was 65km/h. As indicated in Table 2, the typical operating speed along the route during the peak period of the survey was found to be 50km/h shortly before the intersections. This was verified using the Lighthill and Whitham theory. After replacing 50% of the 14-seater buses, taxis, and private vehicles with 45-seater buses, the hourly traffic volume dropped to 1072 Veh/hr, causing the speed to increase to 60km/h. This suggests that the best way to increase road capacity is to reduce the number of private automobiles on the road and enhance the public transportation system since inadequate road capacity is the main cause of congestion.

3.4 Interpretation of Statistical Analysis Results from Responses

Equations 4 to 12 were used to determine the mean, standard deviation, coefficient of kurtosis, standard error of kurtosis, and Z-value for each intersection's critical and non-critical responses (Table not shown).

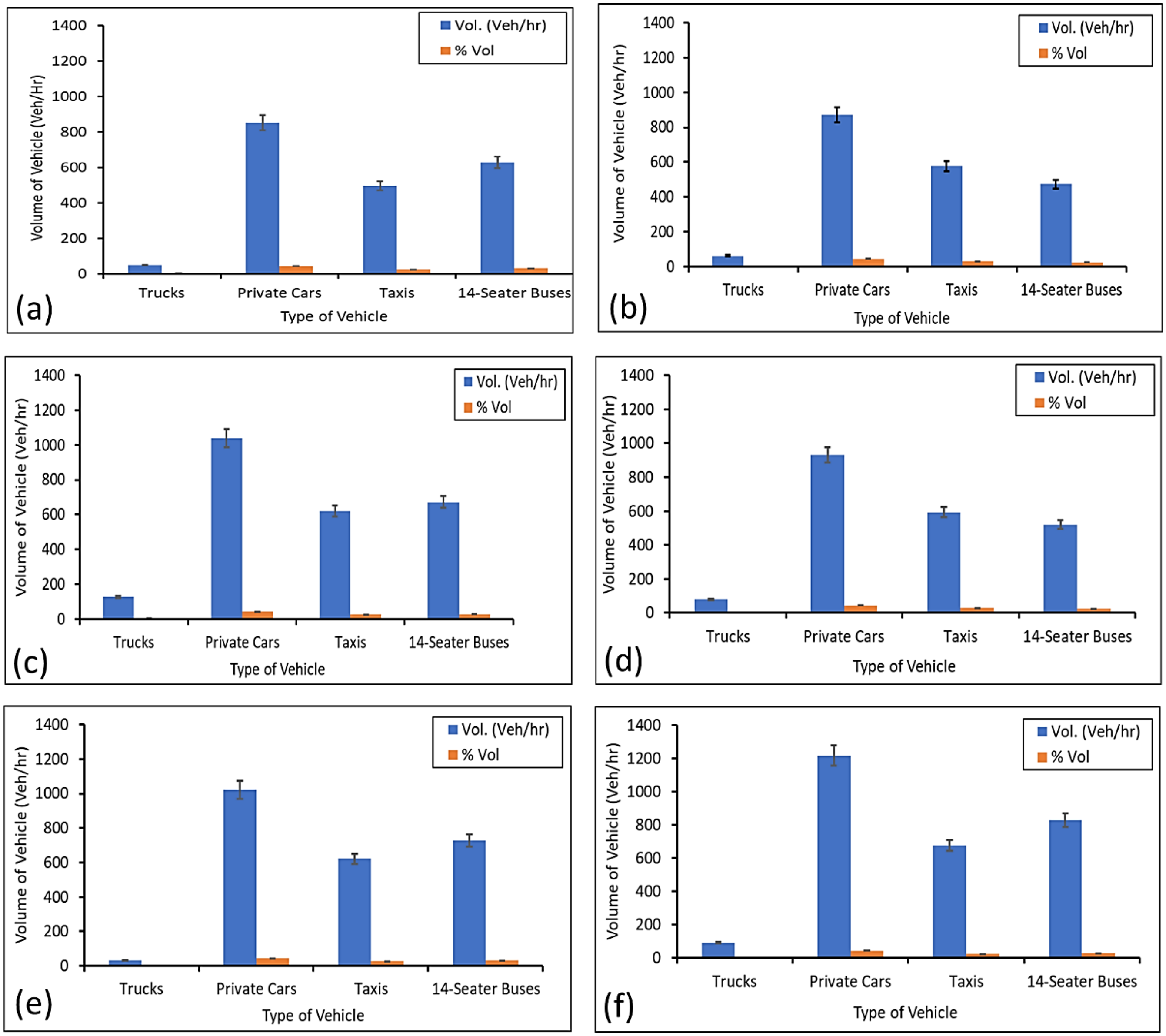

Figure 1: Average Traffic Volume Count at (a) Rumuokoro, (b) Eliozu, (c) Slaughter, (d) Amadi-Ama, (e) Lagos Bus Stop, and (f) Rivers State University Intersections During Peak Periods.

Table 1: Traffic Flow Rate at Intersections at Near Capacity

Location	Free Flow Speed	Spacing	Density (k)	Jam Density (k)	Observed Flow (Q)	Max. Flow (Q)	Min. Flow (Qm)	Speed because of Bottleneck		
								Before	At	After
Rumuokoro	65	12.5	80	160	2024	2600	1300	8.63	32.50	47.80
Eliozu	68	5.25	125	250	1982	4250	2125	10.10	34.00	58.84
Slaughter (Trans-Amadi)	66	12.5	80	160	2456	2640	1320	8.40	33.00	41.71
Amadi-Ama	63	5.25	190	381	2127	6000	3000	9.87	31.50	56.81
Lagos Bus Stop	65	5.8	172	345	2402	5603	2802	9.82	32.50	57.07
Rivers State University	63	8.5	118	235	2814	3706	1853	8.42	31.50	46.95

Table 2: Traffic Flow at Intersections (Present and Future)

Type of Veh	Volume of Vehicle	Number of Passengers	Total	Free Speed (Km/hr)	Observed Speed (Km/hr)	Calculated Speed (Km/hr)	Predicted Speed (Km/hr)
Before elimination of 14-seater buses and Taxis							
Trucks	91	2	2814	65	50	49.20	-
Private Cars	1218	3					
Taxis	677	5					
14-Seater Buses	828	14					
After elimination of 14-seater buses and Taxis; and introduction of 45-seater buses							
Trucks	91	2	1072	65	-	-	60
Private Cars	609	3					
Taxis	-	-					
45-seater Buses	372	45					

The summary statistics, interpretation of sample distribution, and Z-Test results of the six intersections considered in this study are displayed in Tables 3, 4, and 5, respectively.

To determine whether there was a significant kurtosis problem, standard error of kurtosis was computed for each answer for the independent variables, multiplied by two, and the absolute kurtosis value was compared. If the absolute value is more significant than twice the predicted standard error kurtosis, there can be a severe distribution or kurtosis problem (Tabachnic and Fidell, 1966). According to Redmond (1996), a negative kurtosis implies that the distribution can be platykurtic, meaning that it has a concave distribution for high values or a reasonably flat distribution for other values. The same is true for zero kurtosis, which raises the possibility of a mesocratic distribution that is a regularly distributed sample.

The distribution is anticipated to be leptokurtic, meaning it will have a relatively high peak, and its kurtosis value will be positive. The subsequent interpretations of each independent variable, as indicated in Table 4, are based on these descriptions, which indicate that if the sample size was drawn from the entire Port Harcourt population, the responses for each critical and non-critical responses had no problems with their distribution and could be utilized to accurately represent the population distribution. The results for each intersection would remain the same even if the sample size was increased from N = 100 to N = infinity.

The Z-statistic for every intersection was calculated to arrive at the research conclusions. Table 5 summarizes the Z-statistics. Table 5 demonstrates that each independent variable has a Z-statistic of more than 1.96. For each independent variable, the critical Z-value that establishes whether to accept or reject the null hypothesis in favour of the alternative hypothesis is 1.96. Stated differently, if the estimated Z-value for every independent variable is less than 1.96, the null hypothesis is supported.

However, if the estimated Z-value for any independent variable is more than 1.96, the alternative hypothesis has a less than 5% chance of being rejected instead of the null hypothesis. Upon examination of the Z-calculated results, the null hypothesis is deemed invalid. As a result, the alternate theory is acknowledged. This implies that the quantity of private vehicles impacts traffic flow.

Table 3: Summary Statistics of the Intersections

Location	Variable Weight	Sample Size	Mean	Standard Deviation	Coefficient of Kurtosis	Standard Error of Kurtosis
Rumuokoro	A	71	4.253521127	0.805664054	-1.280414479	0.581401900
	B	28	3.714285714	1.301200097	-1.702999038	0.925820100
Eliozu	A	49	4.102040816	0.714285714	-0.974560592	0.699854212
	B	50	3.480000000	0.677329691	0.024880146	0.692820323
Slaughter (Trans-Amadi)	A	58	4.275862069	0.720455593	-0.931844951	0.643267521
	B	30	3.700000000	0.651258728	-0.608827575	0.894427191
Lagos Bus Stop	A	51	4.588235294	0.571890570	0.1171665810	0.685994341
	B	44	4.181818182	0.691231704	-0.831656890	0.738548946
Amadi-Ama	A	31	4.612903226	0.715421524	1.0509350070	0.879882690
	B	48	4.125000000	0.890254566	-1.718653488	0.707106781
Rivers State University	A	46	4.652173913	0.736882059	1.3590339760	0.722315119
	B	45	4.244444444	1.111010096	-0.556778865	0.730296743

Table 4: Interpretation of Sample Distribution

Intersection	Type of response	Significant problem	Nature of distribution
Eliozu	A	No	Platykurtic
	B	No	Platykurtic
Rumuokoro	A	No	Platykurtic
	B	No	Leptokurtic
Rivers State University	A	No	Platykurtic
	B	No	Platykurtic
Slaughter (Trans-Amadi)	A	No	Leptokurtic
	B	No	Platykurtic
Lagos Bus Stop	A	No	Leptokurtic
	B	No	Platykurtic
Amadi-Ama	A	No	Leptokurtic
	B	No	Platykurtic

Table 5: Independent *Z*-Test

Location	Variable Weight	Step 1	Step 2	Step 3	Step 4	Step 5 = *Z* Statistics
Eliozu	A	0.01135		0.057818813		2.242558697
	B		0.046471432		0.539235412	
Rumuokoro	A	0.01458		0.028123853		3.709210436
	B		0.013546594		0.622040816	
Rivers State	A	0.01242		0.034130272		3.117084665
University	B		0.021708624		0.575862069	
Slaughter	A	0.01121		0.026923352		2.476894
(Trans-Amadi)	B		0.015709811		0.406417112	
Lagos Bus Stop	A	0.02308		0.041625084		2.391421492
	B		0.01854697		0.487903226	
Amadi Ama	A	0.01602		0.040708288		2.020834195
	B		0.024689113		0.407729469	

4.0 Conclusions

This study investigated the impact of private cars on traffic flow at critical intersections in Port Harcourt. Results obtained support the following conclusions.

1. Rumuokoro, Eliozu, Slaughter (Trans-Amadi), Amadi-Ama, Lagos Bus Stop, and RSU intersections have the highest average traffic volumes of 852, 871, 1038, 931, 1021, and 1218 cars per hour, respectively. The average value across all intersections is 43%.
2. Prior to the intersections, an average free flow speed of 65km/h was observed. Due to the bottlenecks created at the bus stations near the intersections, the free flow speed decreased to 9.21km/h before the intersection and rose to 32.0km/h and 51.53km/h as cars progressively moved through the areas with traffic congestion.
3. With a hypothetical 50% decrease in private vehicles and taxis and replacement of 14-seater buses with 45-seater buses, there was a 50-% increase in free flow speed from 51.53 to 60km/h.
4. With 95% confidence, the statistical analysis showed that a steady increase in private automobiles impacted traffic flow, with an average Z-value of 2.66, which was higher than the 1.96 threshold.
5. All the intersections studied maintained a similar feature that provided same approach of collating data, the intersections are rotary with each approach and exit of a double carriageway. The median is completely a concrete structure that allows sight distances and clearing purpose for both vehicles and pedestrians. The median size varies between 0.5 and 1.0m and indicates traffic flow direction, the shoulders are 1.5m wide, and Road Carriageway is 7.3m, depending on the elevated approach.

5.0 Recommendations

From the outcome of the current investigation, the following recommendations are made.

1. A robust public transportation system should be developed to promote the use of public transportation.
2. Increase road tax for personal vehicles to discourage the use of personal vehicle.
3. Investment opportunities for the private and public sectors should be created, and the government should be prepared to cover the operational expenses of public transportation networks.

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