Journal of Current Research and Studies

Volume 03 Issue 06 Nov-Dec 2026
https://journalcurrentresearch.com/
ISSN:3048-9911

OPEN ACCESS

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Article Received
25/10/2026
Accepted
30/10/2026
Published
17/11/2026

Works Cited

Amadi P. N. & Oba A. L., (2026). Weekly Variation of Traffic Stream Characteristics of Abali Park to Eleme Junction Section of Aba Road, Port Harcourt: A Moving Observer Study. *Journal of Current Research and Studies*, 3(6), 27-35.

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Weekly Variation of Traffic Stream Characteristics of Abali Park to Eleme Junction Section of Aba Road, Port Harcourt: A Moving Observer Study

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ABSTRACT

Reliable information on traffic stream characteristics is the starting point for corridor management, yet such data remain scarce for many urban arterials in Nigeria. This study applied the moving observer method to quantify the weekly variation of traffic stream speed, flow and density along the 12.60 km Abali Motor Park (AMP) to Eleme Junction (ELJ) section of Aba Road, Port Harcourt. A commercial bus served as the test vehicle, and a four-person team recorded travel time and vehicle counts using stopwatches, data sheets and a GPS unit. One round trip was completed on each day of the week, giving fourteen directional observations. Flow, space mean speed and density were computed from the standard moving observer relations and examined with bar charts, a speed-density regression and a two-way analysis of variance (ANOVA) with day and direction of travel as factors. Mean flow was 203 veh/h, mean space mean speed was 27.0 km/h and mean density was 8.1 veh/km. Travel in the ELJ-AMP direction was slower (23.2 km/h) and denser (9.9 veh/km) than in the AMP-ELJ direction (30.8 km/h and 6.4 veh/km), and the five slowest streams were all in the ELJ-AMP direction. The lowest speed, 16.9 km/h, and the highest density, 14.3 veh/km, occurred on Wednesday in the ELJ-AMP direction, where the trip took 63.51 minutes. The two-way ANOVA showed that day of the week had no statistically significant effect on flow, speed or density at the 5% level, whereas direction of travel significantly affected density ($p = 0.046$); its effect on speed was not significant ($p = 0.150$). A linear speed-density model explained 62% of the variation in speed ($R2 = 0.62$). The results indicate directional congestion on the corridor and support targeted traffic management on the ELJ-AMP approach.

Keywords: moving observer method; traffic flow; space mean speed; traffic density; two-way ANOVA; Aba Road; Port Harcourt

1.0 INTRODUCTION

Road transport carries almost all passenger and freight movement in Nigerian cities, so the performance of arterial roads strongly shapes economic activity, travel cost and road safety. Port Harcourt, the capital of Rivers State and the hub of the Niger Delta oil and gas economy, is served by a small number of radial corridors that concentrate commercial, industrial and residential traffic.

Aba Road is one of the most important of these corridors. It links the city centre with the Eleme axis, where major industrial and port-related facilities are located, and it continues towards the eastern gateway of the state. Because the corridor also hosts a large motor park, roadside markets and many access points, it is exposed to frequent stops, mixed traffic and recurrent delay.

Traffic engineers describe the quality of service of a road through three macroscopic variables: flow, speed and density [1], [2]. Flow is the number of vehicles passing a point per unit time, space mean speed is the average speed of vehicles over a length of road, and density is the number of vehicles occupying a unit length of road at an instant. The three are linked by the fundamental relation that flow equals the product of speed and density, and this relation underpins capacity analysis, level-of-service assessment and signal and geometric design [3], [4]. Without measured values of these variables, decisions on lane provision, junction treatment, enforcement or public transport priority are made on judgement rather than evidence.

Several techniques exist for measuring them. Stationary methods such as manual counts, pneumatic tubes and loop detectors give flow at a point but provide limited information on the journey experienced along a whole corridor. Aerial photography and probe vehicle methods can describe a section, but they need equipment and funding that are often unavailable to researchers and local agencies. The moving observer method, first proposed by Wardrop and Charlesworth [5], is a practical alternative because a single test vehicle running in both directions of a road yields flow, mean speed and travel time at the same time, with only simple field equipment and a small crew [6], [7]. The method is still taught as a standard field technique for traffic studies and remains useful where detector infrastructure is absent [2], [4].

The relationship between speed and density has been studied since the 1930s. Greenshields proposed a linear speed-density model from photographic observations on a rural highway [8], and later work introduced logarithmic and other nonlinear forms [9]. The continuum description of traffic by Lighthill and Whitham [10] explained how disturbances propagate as waves along a stream, and subsequent work on traffic flow fundamentals and dynamic network models has built on these foundations [11], [12]. Although these studies were carried out mainly in developed countries, the basic variables and the relations between them are general, and field measurements in Nigerian conditions are needed to see how well they describe mixed traffic dominated by commercial buses, tricycles, motorcycles and trucks.

Traffic on a corridor is not constant from one day to the next or from one direction to the other. Commuting, market days, religious activities, the movement of goods and incidents all create variation that can be larger than the difference between an ordinary day and a peak day on a better-managed road. Understanding whether the variation is systematic, for instance whether certain days or one direction are consistently worse, is valuable because it indicates whether control measures should be applied uniformly or targeted at specific times and locations.

The aim of this study was therefore to determine the weekly variation of traffic stream speed, flow and density on the Abali Motor Park to Eleme Junction section of Aba Road using the moving observer method. The specific objectives were to (i) compute flow, space mean speed and density for each direction on each day of the week; (ii) test, by two-way analysis of variance, whether day of the week and direction of travel significantly affect these parameters; and (iii) examine the speed-density relationship of the corridor and discuss its implications for traffic management. The study contributes locally measured data for a heavily used Port Harcourt arterial and demonstrates a low-cost procedure that can be repeated by other researchers and agencies.

2.0 MATERIALS AND METHOD

2.1 Study area

The study was carried out on Aba Road, Port Harcourt, between Abali Motor Park (AMP) and Eleme Junction (ELJ). The section is 12.60 km long and carries two-way traffic composed of private cars, commercial buses, taxis, tricycles, motorcycles and heavy goods vehicles. The section passes through built-up areas with commercial frontage, bus stops and several intersections, which makes it representative of the congested urban arterials of the city. The two ends of

the section were fixed as the start and end points of every run so that the length used in the computations was identical for all observations.

2.2 Materials

The materials used for the field study were stopwatches for recording travel and stopped times, a report or data sheet for recording the counts, writing materials, a test vehicle and a Global Positioning System (GPS) unit for confirming positions along the route and the start and end of each run. A commercial bus was used as the test vehicle because it reflects the driving behaviour and the speed of a large share of the traffic stream on the corridor. A team of four personnel participated in each run: one driver, one person operating the stopwatch and recording travel time, and two observers who counted vehicles in the opposing and the same direction of travel.

2.3 Field procedure

The moving observer method was applied as described in standard traffic engineering texts [1], [2], [7]. The test vehicle was driven along the section in one direction while the crew recorded the total travel time and three counts: the number of vehicles met travelling in the opposite direction, the number of vehicles that overtook the test vehicle, and the number of vehicles that the test vehicle overtook. The vehicle was then driven back along the same section and the same quantities were recorded for the reverse direction. The driver was instructed to travel at a speed judged to be representative of the stream, passing and being passed in approximately equal numbers where conditions allowed, and no deliberate attempt was made to either lead or follow the traffic. One round trip was completed on each day of the week from Sunday to Saturday, so that fourteen directional runs were obtained in total. The recorded observations are presented in Table 1.

2.4 Computation of flow, speed and density

For a given direction of traffic, the stream flow is estimated by combining a run made against the stream with a run made with the stream. If x is the number of vehicles met while travelling against the stream, y is the number of vehicles that overtook the test vehicle minus the number it overtook while travelling with the stream, and ta and tw are the travel times against and with the stream, then the flow q of the stream is given by:

$$q = \frac{(x+y)}{(t_a+t_w)} \qquad (1)$$

The mean journey time of the stream over the section is then obtained by correcting the travel time of the test vehicle with the stream for the net overtaking, as:

$$\bar{t} = t_w - \frac{y}{q} \qquad (2)$$

The space mean speed of the stream is computed from the length L of the section as:

$$v = \frac{L}{\bar{t}} \qquad (3)$$

and the density follows from the fundamental relation of traffic flow:

$$k = \frac{q}{v} \qquad (4)$$

In these equations q is expressed in vehicles per minute during the calculation and converted to vehicles per hour for reporting, t is in minutes, L is in kilometres, v is in km/h and k is in vehicles per km. As an illustration, for the stream travelling from ELJ to AMP on Wednesday, x = 322 vehicles met during the AMP-ELJ run, y = 169 − 93 = 76, tw = 63.51 min and ta = 35.39 min. Equation (1) gives q = 398 / 98.90 = 4.02 veh/min, or 241 veh/h; Equation (2) gives $\bar{t}$ = 63.51 − 76 / 4.02 = 44.62 min; Equation (3) gives v = 12.60 / (44.62 / 60) = 16.9 km/h; and Equation (4) gives k = 241 / 16.9 = 14.3 veh/km. The same procedure was applied to the other thirteen streams.

2.5 Data analysis

The computed parameters were first summarised in tables and presented as bar charts by day and direction. The speed-density relationship was examined by least squares linear regression in the form of the Greenshields model [8]:

$$v = v_f\left(1 - \frac{k}{k_j}\right) \qquad (5)$$

where vf is the free-flow speed and kj is the jam density. The effect of the day of the week and the direction of travel on flow, speed and density was tested with a two-way analysis of variance without replication, using the additive model [13]:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij} \qquad (6)$$

where Yij is the observed value for day i and direction j, μ is the overall mean, αi is the effect of day i (seven levels), βj is the effect of direction j (two levels) and εij is the random error. Because only one run was made per day and direction, the test of each factor uses the residual mean square as the error term. The significance level was set at 5%.

Table 1: Travel from Eleme Junction (ELJ) to Abali Motor Park (AMP)

Days of the Week	Direction of Travel	Duration of Travel (mins.)	Vehs. met in opposite direction	Vehs. overtaking test veh.	Vehs. overtaken by test veh.	Length of road section (Km)
Sunday	ELJ - AMP	28.35	145	93	76	12.60
	AMP - ELJ	26.11	116	72	78	
Monday	ELJ - AMP	26.57	183	77	107	12.60
	AMP - ELJ	32.03	268	132	119	
Tuesday	ELJ - AMP	51.04	218	151	127	12.60
	AMP - ELJ	35.01	289	106	98	
Wednesday	ELJ - AMP	63.51	228	169	93	12.60
	AMP - ELJ	35.39	322	122	84	
Thursday	ELJ - AMP	31.46	242	106	124	12.60
	AMP - ELJ	29.15	202	152	114	
Friday	ELJ - AMP	32.03	188	136	99	12.60
	AMP - ELJ	34.16	256	103	89	
Saturday	ELJ - AMP	32.46	187	85	108	12.60
	AMP - ELJ	42.40	256	157	69	

3.0 RESULTS AND DISCUSSION

3.1 Travel time and computed stream parameters

The travel times in Table 1 show that most runs took between 26 and 36 minutes, which corresponds to an average journey speed of roughly 21 to 29 km/h over the 12.60 km section. Two runs ELJ-AMP runs on Tuesday and Wednesday took 51.04 and 63.51 minutes respectively, about twice as long as the typical run. Both coincided with high counts of opposing vehicles (218 and 228) and of vehicles overtaking the test vehicle (151 and 169), which indicates that the test vehicle moved more slowly than most of the stream during congested conditions. Table 2 gives the flow, mean journey time, space mean speed and density obtained from Equations (1) to (4).

Across the fourteen streams, flow ranged from 147 to 277 veh/h with a mean of 203 veh/h, space mean speed ranged from 16.9 to 41.0 km/h with a mean of 27.0 km/h, and density ranged from 4.1 to 14.3 veh/km with a mean of 8.1 veh/km. The flow values are consistent with a single carriageway on which a large share of the vehicles are buses, tricycles and goods vehicles that stop frequently, and they are well below the flow normally associated with the capacity of an uninterrupted multilane facility [3], [4]. The wide range of speed and density, on the other hand, shows that traffic conditions on the corridor can change quickly from free-moving to congested

Table 2: Computed traffic stream parameters by day and direction of the stream

Day	Stream direction	t_w (min)	x (veh)	y (veh)	Flow q (veh/h)	Mean journey time (min)	Speed v (km/h)	Density k (veh/km)
Sunday	ELJ-AMP	28.35	116	17	147	21.39	35.3	4.1
Sunday	AMP-ELJ	26.11	145	-6	153	28.46	26.6	5.8
Monday	ELJ-AMP	26.57	268	-30	244	33.96	22.3	10.9
Monday	AMP-ELJ	32.03	183	13	201	28.14	26.9	7.5
Tuesday	ELJ-AMP	51.04	289	24	218	44.44	17.0	12.8
Tuesday	AMP-ELJ	35.01	218	8	158	31.96	23.7	6.7
Wednesday	ELJ-AMP	63.51	322	76	241	44.62	16.9	14.3
Wednesday	AMP-ELJ	35.39	228	38	161	21.26	35.6	4.5
Thursday	ELJ-AMP	31.46	202	-18	182	37.39	20.2	9.0
Thursday	AMP-ELJ	29.15	242	38	277	20.92	36.1	7.7
Friday	ELJ-AMP	32.03	256	37	266	23.67	31.9	8.3
Friday	AMP-ELJ	34.16	188	14	183	29.57	25.6	7.2
Saturday	ELJ-AMP	32.46	256	-23	187	39.85	19.0	9.8
Saturday	AMP-ELJ	42.40	187	88	220	18.44	41.0	5.4

3.2 Variation of speed

Figure 1 shows the mean speed by day and direction. The mean speed of the AMP-ELJ stream, 30.8 km/h, was about 7.5 km/h higher than that of the ELJ-AMP stream, 23.2 km/h. The five slowest streams, with speeds between 16.9 and 22.3 km/h, were all in the ELJ-AMP direction (Wednesday, Tuesday, Saturday, Thursday and Monday), whereas the highest speeds, 41.0 and 36.1 km/h, were recorded in the AMP-ELJ direction on Saturday and Thursday. Only on Sunday and Friday did the ELJ-AMP stream travel faster than 30 km/h. At speeds below about 20 km/h the stream is operating in congested conditions, in which small disturbances propagate backwards as shock waves and recovery to free-flow conditions is slow [10], [11].

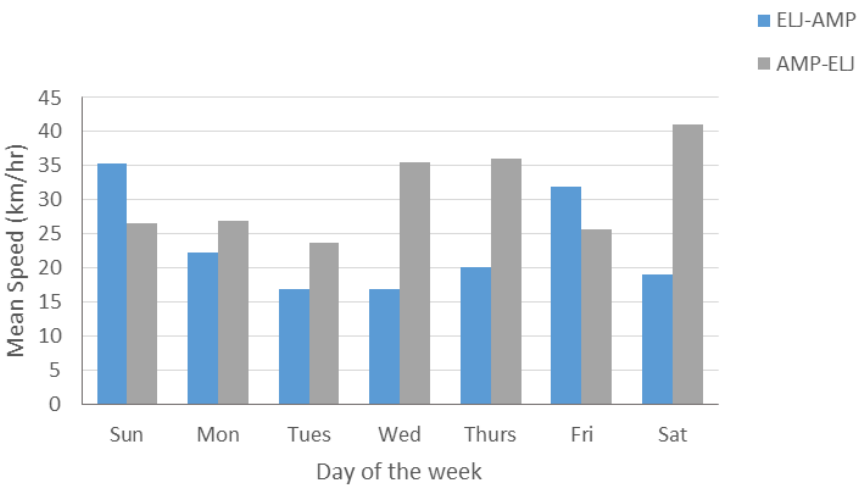


Figure 1: Mean speed by day of the week and direction of travel

When days are compared, Tuesday had the lowest mean speed (20.3 km/h) and Sunday the highest (31.0 km/h), followed closely by Saturday (30.0 km/h). Mean speed on the five weekdays was 25.6 km/h compared with 30.5 km/h across Saturday and Sunday, a modest difference that agrees with the expectation that commuting and commercial activity reduce speeds during the working week. The pattern across the weekdays is not monotonic, which suggests that incidents, stopping behaviour at the motor park and weather on the day of survey can matter as much as the day itself.

3.3 Variation of flow

The flow results are shown in Figure 2. Daily mean flow was lowest on Sunday (150 veh/h) and highest on Thursday (230 veh/h) and Friday (224 veh/h). The mean for the five weekdays was 213 veh/h, compared with 177 veh/h for Saturday and Sunday, a reduction of about 17% at weekends. The reduced Sunday flow reflects the lower level of commuting, trading and freight movement on the rest day, and the higher weekday flows reflect the opposite. The flow in the two directions was similar (212 veh/h for ELJ-AMP and 193 veh/h for AMP-ELJ), which is expected because most trips on a corridor are two-way.

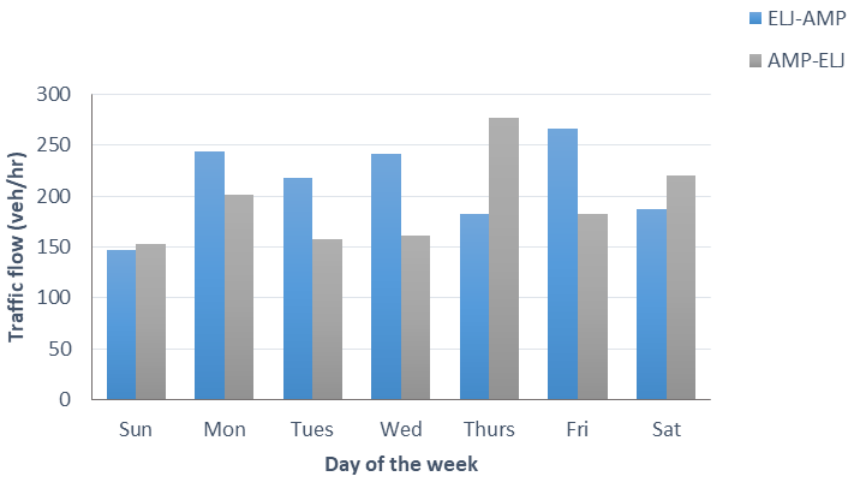


Figure 2: Traffic flow by day of the week and direction of travel

3.4 Variation of density

Figure 3 presents the density results. The ELJ-AMP stream had a mean density of 9.9 veh/km against 6.4 veh/km for the AMP-ELJ stream. The highest density of 14.3 veh/km occurred in the ELJ-AMP stream on Wednesday, followed by 12.8 veh/km on Tuesday and 10.9 veh/km on Monday. Because flow in the two directions was similar while speed was much lower in the ELJ-AMP direction, the higher density follows directly from the relation k = q/v: similar numbers of vehicles per hour remained in the section for a longer time. This is the typical signature of a stream that is delayed at a bottleneck. Daily mean density was lowest on Sunday (5.0 veh/km) and highest on Tuesday (9.8 veh/km).

The direction effect has a plausible physical explanation. The ELJ-AMP stream approaches the motor park and the associated roadside commercial activity, where buses and tricycles stop to load and unload and vehicles join and leave the stream, while the AMP-ELJ stream leaves this area with less interference. Local bottlenecks at intersections or on the approach to the motor park would produce the same pattern. A conclusion on the exact location of the delay would require speed and delay data measured along the section.

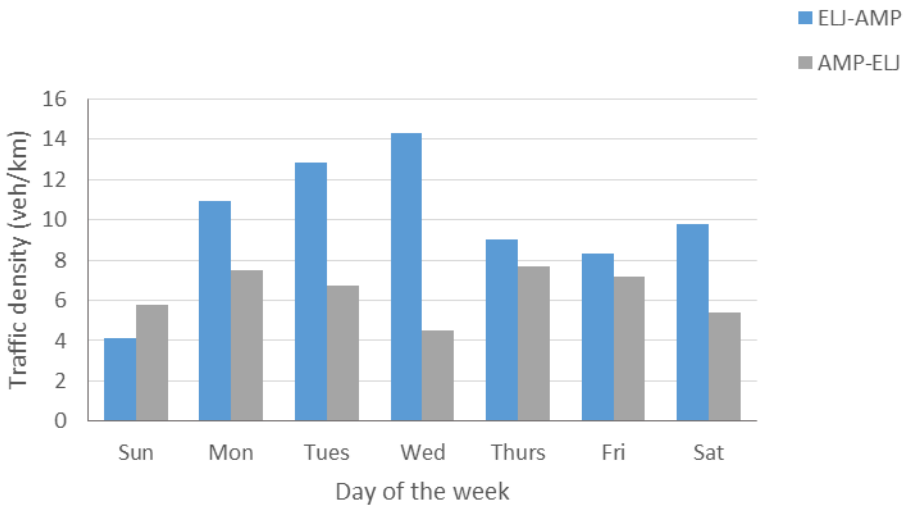


Figure 3: Traffic density by day of the week and direction of travel

3.5 Two-way ANOVA

The results of the two-way ANOVA for the three parameters are summarised in Table 3. Day of the week did not produce a statistically significant effect on flow ($F(6,6) = 0.693$, $p = 0.666$), speed ($F(6,6) = 0.367$, $p = 0.876$) or density ($F(6,6) = 0.767$, $p = 0.622$). Direction of travel did not significantly affect flow ($F(1,6) = 0.554$, $p = 0.485$) or speed ($F(1,6) = 2.723$, $p = 0.150$), but it significantly affected density ($F(1,6) = 6.293$, $p = 0.046$).

Table 3: Two-way ANOVA (without replication) for flow, speed and density

Parameter	Source	Sum of squares	df	Mean square	F	p-value
Flow	Day	9182.88	6	1530.48	0.693	0.666
	Direction	1224.47	1	1224.47	0.554	0.485
	Error	13253.06	6	2208.84		
Speed	Day	159.86	6	26.64	0.367	0.876
	Direction	197.82	1	197.82	2.723	0.150
	Error	435.87	6	72.65		
Density	Day	31.84	6	5.31	0.767	0.622
	Direction	43.55	1	43.55	6.293	0.046
	Error	41.53	6	6.92		

The absence of a significant day effect does not prove that the days are identical; it means that, with one run per day and direction, the day-to-day differences cannot be separated from random variation. The error mean square is large relative to the day effect, particularly for flow, because the counts of vehicles met and overtaking vary widely from run to run. The direction result for density is only just significant ($p = 0.046$). The 7.5 km/h difference in mean speed between the directions is not statistically significant at the 5% level because of the large error variance, but it agrees in direction with the density result and with the clear pattern in Figures 1 and 3, in which the five slowest and densest streams all travelled from ELJ to AMP. Practical rather than purely statistical significance is often the more relevant criterion in engineering applications [13], and differences of this size are important for travel time and level of service.

3.6 Speed-density relationship

Figure 4 plots the speed against the density for the fourteen streams. The relationship is negative and fairly strong, with the fitted line $v = 43.71 - 2.052k$ ($R2 = 0.62$, $r = -0.79$, $p < 0.001$). Comparing with Equation (5), the intercept

corresponds to a free-flow speed of about 44 km/h and the slope implies a jam density of about 21 veh/km. These values describe the central part of the data and should not be extrapolated beyond the observed density range of 4 to 14 veh/km. The free-flow speed of 44 km/h is lower than what is normally assumed for an urban arterial, consistent with the effect of frequent stops, access points and mixed traffic on the corridor. Under the Greenshields model the capacity is vf kj / 4, about 233 veh/h, which is below the highest observed flow of 277 veh/h. This confirms that the fitted model is a simplification, and that the sample, with a limited number of observations, cannot define the upper part of the flow-density curve. The correlation between flow and density was positive and of borderline significance (r = 0.53, p = 0.050), consistent with most observations lying on the uncongested branch of the flow-density curve.

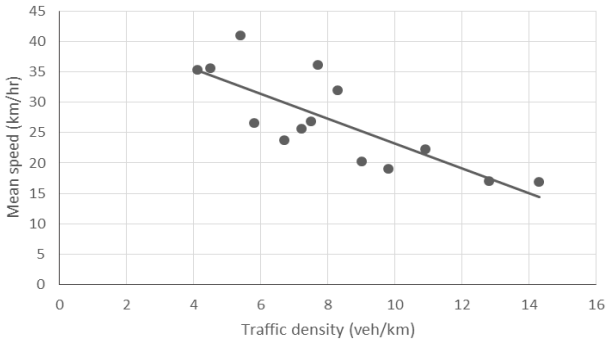


Figure 4: Speed-density relationship with fitted linear model

3.7 Implications for traffic management

Three practical points follow from the results. First, congestion on the corridor is directional rather than general: the ELJ-AMP stream was consistently slower and denser, so measures should be focused on that direction and on the section around the motor park and the approaches to the junction. Possible measures include designated bus bays and loading areas, enforcement against on-street stopping, geometric improvement or channelisation at the main junctions, and signal or marshal control during the hours in which delay is highest. Second, the very long trips on Tuesday and Wednesday, which took 51 and 64 minutes, about twice as long as the usual trip, show that reliability of travel time is a problem in addition to average speed. Travellers and freight operators must allow a large buffer for planned journeys, which raises cost, and simple travel-time monitoring with the moving observer method or probe vehicles would help the agency to detect these episodes. Third, the weekday-weekend difference in flow of about 17% indicates that demand management and the timing of freight and public transport services can be adjusted to the different levels of demand on different days.

4.0 CONCLUSIONS

The moving observer method was used to determine the speed, flow and density of traffic on the 12.60 km section of Aba Road between Abali Motor Park and Eleme Junction on each day of the week. The main conclusions are as follows.

1. The mean flow, space mean speed and density of the corridor were 203 veh/h, 27.0 km/h and 8.1 veh/km respectively, with a wide range of conditions, from free-moving traffic at 41 km/h to congested traffic at 17 km/h and 14.3 veh/km.

2. The ELJ-AMP direction was clearly worse than the AMP-ELJ direction, with a lower mean speed (23.2 against 30.8 km/h) and a higher mean density (9.9 against 6.4 veh/km), while flow was similar in both directions (212 and 193 veh/h).

3. Tuesday and Wednesday in the ELJ-AMP direction were the most congested periods observed, with travel times of 51.04 and 63.51 minutes.

4. Two-way ANOVA showed that day of the week had no statistically significant effect on flow, speed or density at the 5% level, but that direction of travel significantly affected density ($p = 0.046$), while its effects on speed ($p = 0.150$) and flow ($p = 0.485$) were not significant.

5. Speed fell linearly with density ($v = 43.71 - 2.052k$, $R2 = 0.62$), which supports the use of the Greenshields model for describing the stream over the observed density range, although the fitted capacity is lower than the highest observed flow.

It is recommended that traffic management efforts on the corridor concentrate on the ELJ-AMP direction and the area of the motor park, that travel-time reliability be monitored routinely, and that future studies include replicated runs, peak and off-peak periods and vehicle classification to strengthen the statistical analysis. The procedure used here requires only simple equipment and can be repeated by local agencies and researchers on other corridors in Port Harcourt and elsewhere.

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