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Effect of Trotros on Saturation Flow at Selected Signalized Intersections on the 24th February Road, Kumasi, Ghana

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Abstract:- Trotros constitute a good proportion of urban traffic on the 24th February Road. The effect of the Trotros on saturation flow at signalized intersections could therefore be substantial. This research studies and analyses the effect of Trotros on the saturation flow at selected signalised intersections by collecting data along the route. A strong correlation was observed between the measured saturation flow using the headway method and the proportion of Trotros stopping per hour suggesting that their presence indeed impact on the capacity significantly and should therefore be considered in the capacity analysis of signalized intersections. The effect of Trotros on saturation flow rate was incorporated in the Highway Capacity Manual (HCM) model by comparing the field saturation flow to the adjusted saturation flow using the HCM model. Results show that saturation flow measured using the modified HCM equation is generally closer to observed saturation flow values.

Keywords: Capacity, Kumasi, Ghana, Saturation Flow, Traffic signals, Trotro

I. INTRODUCTION

The first traffic signal was installed in 1868 and it exploded. In 1918 the first three coloured light signals were again installed almost 50 years later and since then traffic signals are now used throughout the world, using the three colour signals of green, red and amber [1]. Traffic signals have since become the most common form of traffic control measure used in urban areas of most countries. It is a known fact that most developed countries have developed models based on their conditions, to analyse the capacity of signalised intersections. These models are best suited for their developed conditions where flow is homogeneous and lane discipline can be adhered to. In most developing countries like Ghana, Trotros are a major mode of transportation. The Trotro is a mini-van used as the main form of public transportation see Fig 1. In the city of Kumasi, Ghana, Trotros constitute about 40% of the total volume, 58% cars and the remaining 2% being trucks and others [2].

Because of this high proportion of Trotros, urban traffic characteristics in developing countries are significantly different from those of developed countries where the mini-vans do not operate as commercial vehicles. These Trotros create a nuisance in the traffic stream by dropping off and picking up passengers at unapproved locations, sometimes within the trafficked lanes thereby impeding the flow of other traffic upstream and creating a bottleneck within the system as is shown in Fig 2 below. Lane changing and overtaking manoeuvres by these Trotros are also not same as is in-built in the HCM capacity analysis model. It is therefore not possible to use their model directly since it has been developed under different driver and driving behaviours within similar traffic streams. Hence the need to modify these models to suit prevailing local conditions [3].

Figure 1: Trotro loading at a Trotro station

Figure 2: Trotro loading within the traffic stream during green indication

Saturation flow rate is the basic parameter used to derive capacity of signalized intersections. It is calculated based on the minimum headway that the lane group can sustain across the stop line. Several attempts have been made previously to model saturation flow.

Also, effect of approach volume and increasing percentage of bicycles on the saturation flow was studied. The study has shown that the saturation flow increases with the increase in approach volume. A field survey was conducted by [4] to find saturation flow and verify saturation flow and traffic volume adjustment factors used in various capacity manuals throughout the United States at Signalised intersections. Saturation flow headways for more than 20,000 observations were collected. Various factors like road geometry, traffic characteristics, and environmental and signal cycle lengths were considered to develop series of modified adjustment factors to determine modified saturation flow rates while calculating signalised intersection capacity [4].

The HCM (2000) [5] developed by Transportation Research Board (TRB), USA, includes a model (1) to calculate saturation flow rate considering the effect of various factors. It assigns an adjustment factor to each parameter, which can be calculated using empirical formulas proposed in the manual. These adjustment factors are multiplied to the base saturation flow So,which is considered to be 1900 passenger cars (pc) per hour of green time per lane (pcphgpl) for signalised intersections, to obtain the saturation flow rate S of the intersection approach.

$$S = S_o n f_w \, f_{HV} \, f_g \, f_p \, f_{bb} \, f_a \, f_{LU} \, f_{RT} \, f_{LT} \, f_{Lpb} \, f_{Rpb} \qquad (1)$$

Where,

S = saturation flow rate for the lane group in vehicles per hour of green.
S_o = ideal saturation flow rate in pcphgpl
n = number of lanes in the lane group
f_w = adjustment factor for lane width
f_{HV} = adjustment factor for heavy vehicles
f_g = adjustment factor for approach grade
f_p = adjustment factor for parking characteristics
f_{bb} = adjustment factor for blocking effect of local buses that halt within the intersection area
f_a = adjustment factor for area type (Central Business District or other areas)
f_{LU} = adjustment factor for lane utilization
f_{RT} = adjustment factors for right-turns in the lane group
f_{LT} = adjustment factors for left-turns in the lane group.
f_{Lpb} = pedestrian-bicycle adjustment factor for left-turn movements; and
f_{Rpb} = pedestrian-bicycle adjustment factor for right-turn movements.

As can be seen from (1), the effect of type of vehicles is considered only in terms of heavy vehicle adjustment factor which is obtained using the following equation:

$$f_{HV} = \frac{100}{100 + \%HV(E_T - 1)} \qquad (2)$$

Where %HV is the heavy vehicle percentage and ET is the passenger car equivalent of the corresponding heavy vehicle.

The effect of the Trotros (loading and offloading within and around the trafficked lanes in the local setting) in mixed traffic conditions is not reflected. Attempts have been made to model the effects ofmixed traffic flow on saturation flow. A proposed probabilistic approach based on first-order second-moment method to estimate saturation flow at signalized intersections, under heterogeneous traffic conditions was investigated [6]. They make a comparison between the conventional method of estimating saturation flow i.e. headway method and their newly proposed probabilistic approach. The authors found probabilistic approach to be more appropriate for Indian condition. An analysis of the traffic characteristics and operations at signalised intersections of Dhaka, Bangladesh concluded that there is a need for different modelling approaches to analyse the saturation flow rates at the intersections of developing nations and the concept of passenger car unit (PCU), which is widely used as a signal design parameter, is not applicable in case of mixed traffic comprising of both motorised and non-motorised vehicles [7]. A trial new microscopic simulation technique, where a co-ordinate approach to modelling vehicle location is adopted has also been developed [8]. Based on these simulation results an equation was developed to estimate the saturation flow from the influencing variables like road width, turning proportion, percentage of heavy and non-motorised vehicles. A Simulation model HETEROSIM was proposed by [9] to estimate the saturation flow rate of heterogeneous traffic. Simulation results were used to study the effect of road width on saturation flow measured in passenger car units (PCU) per unit width of road.

An analysis of the impacts of different light-duty trucks (LDTs) [10] and [11] on the capacity of signalized intersections. Simple regression models have also been developed to estimate saturation flow at signalized intersections having heterogeneous traffic [12]. Summarizing the review of past literature, it is clear that the model proposed by [5] can be adapted to developing countries after necessary calibration. Considering this, the objective of the current research is to study the impact of the Trotro category of vehicles on saturation flow rate and to modify the HCM 2000 model to suit Ghanaian conditions incorporating the contribution of Trotros.

II. METHODOLOGY

2.1 Site Selection and Description

The signalized intersections were selected based on their accident and safety records in the past, the reducing impacts of other factors and levels of congestion associated with the selected intersections. Fig. 3 shows the map of Kumasi. Selected intersections are shown with a yellow circle and labelled accordingly. All selected intersections are located on the 24th February Road. Detailed descriptions are given in subsequent sub headings.

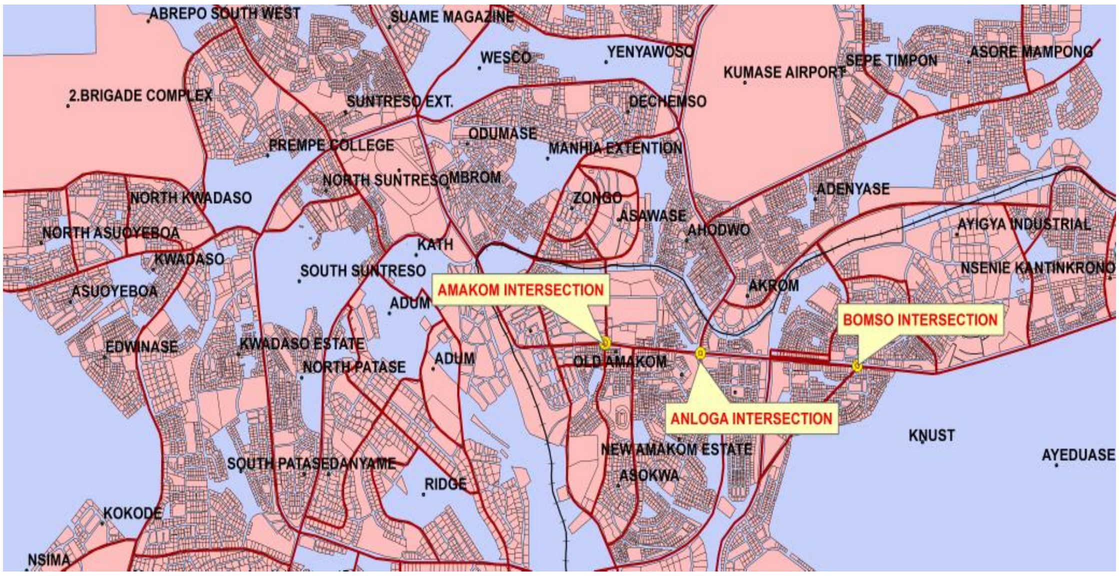

Figure 3: Map Showing Location of Study Sites

2.1.1 24th February/Bomso Road Intersection (Bomso Intersection)

The intersection with Bomso and 24th February roads is signalised and it is about 550 meters west of the KNUST junction. The intersection has four (4) legs with one (1) approach/entry and exit lanes on each leg of the minor roads, (Bomso/Ayigya roads), and two (2) approach/entry and exit lanes on the 24th February road. It is the intersection of a Principal arterial and Collector roads, namely:

- 24th February Road – Principal Arterial
- Bomso Road – Collector Road
- Ayigya Road – Collector Road

On the approach from Adum there is a lay-bye where Trotros and taxis stop for passengers. The average lane width is 3.62m, median of 2.0m and the terrain is relatively flat. Roadside friction is mainly attributable to street hawking and transit activity on the two lay-byes on the approach from and exit to Adum. Traffic composition consists of 58% cars, 37% medium buses (Trotros) and 5% trucks. The layout is shown in Fig 4.

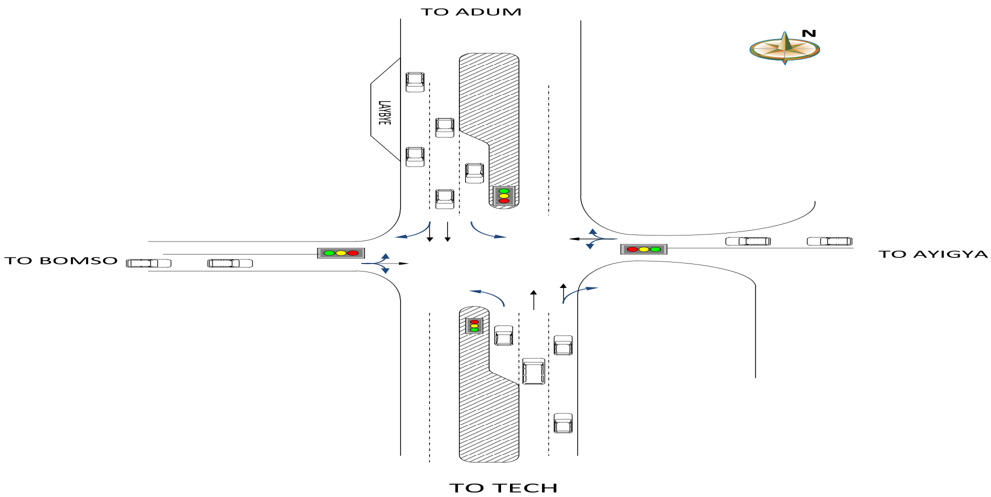

Figure 4: General Layout of Bomso Signalized Intersection

2.1.2 24th February/Eastern Bypass Intersection (Anloga Intersection)

The Anloga intersection is a signalised intersection comprising three (3) principal arterials. It is about 2.6 km west of the KNUST junction. The intersection has four (4) legs with the following configuration:

- East/West approaches - 24th February road, having two (2) approach through and exit lanes
- North-East approach - Okomfo Anokye road, having one (1) approach through lane and two (2) exit lanes

- South-East approach –Eastern By-Pass, having one (1) approach through lane and two (2) exit lanes

The intersection operates on a four phased plan. It is characterized by a lot of roadside friction in the form of hawkers, pedestrians, lay-byes and the wood factory. The traffic composition consists of 58% cars, 39% medium buses (Trotros) and 3% trucks. Fig 5 shows the general layout of the Anloga intersection.

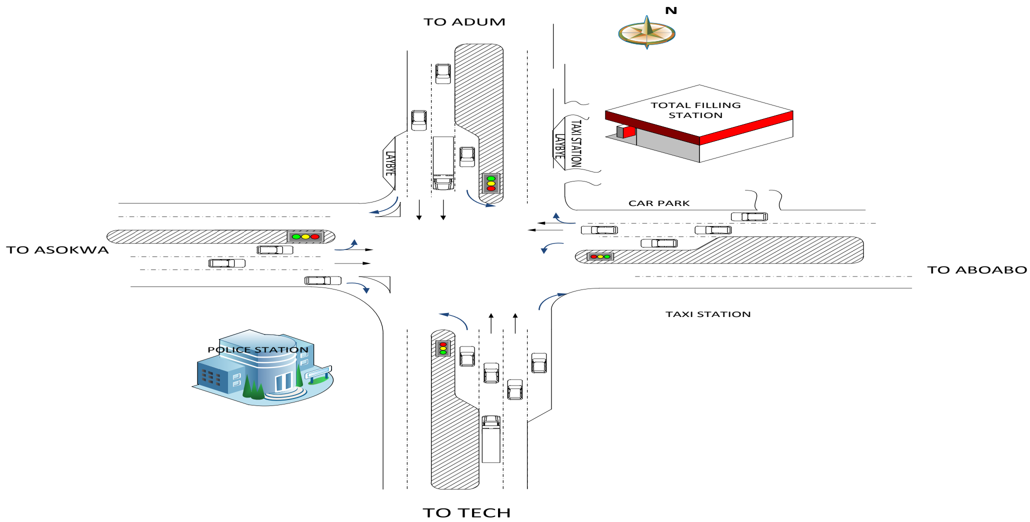

Figure 5: General Layout of Anloga Signalized Intersection

2.1.3 24th February/Yaa Asantewaa Road Intersection (Amakom Intersection)

The Amakom traffic light, formerly called the Amakom roundabout (it used to be a roundabout before being changed to a signalized intersection), and is a four legged signalised intersection. It is about 4 km west of the KNUST junction. The intersection has four (4) legs with one (1) approach/entry and exit through lanes on each leg of the minor road, (Yaa Asantewaa road), and two (2) approach/entry and exit through lanes on the 24th February road. It is the intersection of a Principal arterial and a Collector road:

- 24th February Road – Principal Arterial, and
- Yaa Asantewaa road – Collector Road

The intersection operates on a four phased plan. Traffic composition consists of 62% cars, 35% medium buses (Trotros) and 2% trucks. The layout is as shown in Fig 6.

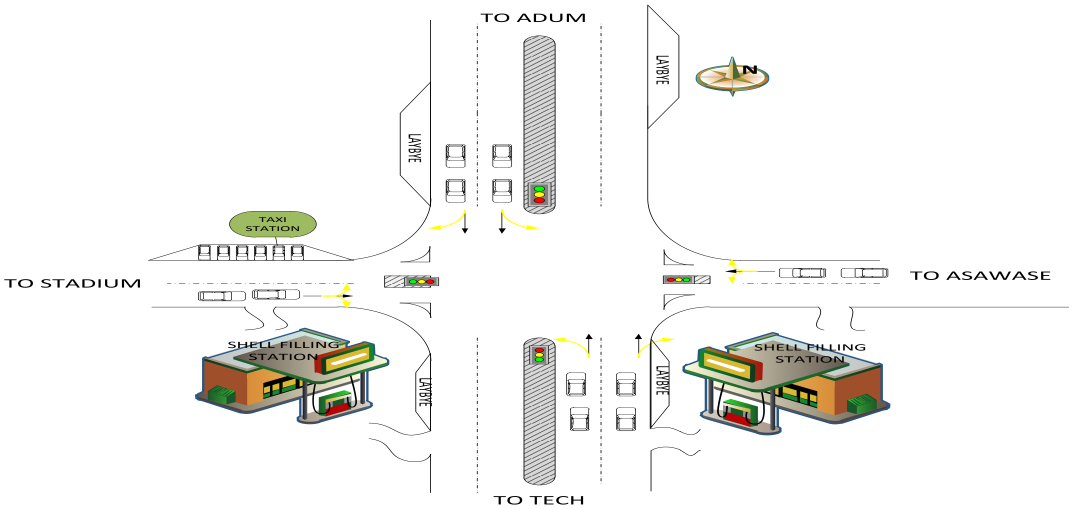

Figure 6: General Layout of Amakom Signalized Intersection

2.2 Saturation Flow Rate Measurement

Saturation flow rate is defined as the maximum discharge rate during green time. It is expressed either in passenger car unit (pcu)/hour or vehicles/hour. Saturation period and direction wise classified traffic volume is necessary to calculate saturation flow for a particular lane group.

Headway method was used to measure field saturation flow rates. Theoretical saturation flow rate was also calculated using the HCM 2000 model. A correlation between measured saturation flow, number of Trotros stopping per hour Trotros and approach volume was calculated. Theoretical and measured saturation flow rates are compared and if found to be comparable within acceptable error limits then it can be concluded that the HCM 2000 model is good enough for local conditions, and the process ends. If not then factors to be considered for calibrating of HCM 2000 model will be identified. New adjustment factors are then derived and the modified HCM 2000 model validated for local Ghanaian conditions by comparing the modified theoretical saturation flow with measured saturation flow. The results of turning movement counts done at the selected signalized intersections are given in Table I. Saturation flow measurements were done only for through movement.

2.3 Videotaping traffic at the Selected Signalized Intersections

Video camcorder was used to record traffic flow data at the selected signalized intersections. Required data for saturation flow analysis were collected from the video recordings. These were then followed by comparing calibration data with simulated results from the field and finally calibrating the model by introducing a new adjustment factor f_T.

All signals identified are operating as pre-timed signals.

III. RESULTS AND DISCUSSIONS

Table I shows a summary of turning movement data at the selected study sites and the results of the saturation flow rate measured using the headway method and that of the HCM 2000.

Table I: Summary of Traffic Data and Saturation Flow rates

Intersection	Direction from	Movement	Volume	Volume of Trotros	Field Saturation Flow	Adjusted Saturation Flow
Bomso	KNUST	T	1412	523	**1324**	**1650**
		L	107	40		
		R	40	15		
	Adum	T	1262	467	**1353**	**1713**
		L	139	52		
		R	202	75		
Anloga	KNUST	T	1718	671	**1417**	**1725**
		L	156	61		
		R	563	220		
	Adum	T	1447	565	**942**	**1710**
		L	440	172		
		R	86	34		
Amakom	KNUST	T	1151	415	**1895**	**1792**
		L	73	27		
		R	381	138		
	Adum	T	1095	395	**1525**	**1793**
		L	175	63		
		R	287	104		

Source: From Study

A correlation between measured saturation flow and the volume of Trotros yields a strong negative correlation (-0.52) indicating that the saturation flow decreases with an increase in the percentages of the mini buses. Further a correlation was also performed on the number of stops by these Trotros (Table II) interfering with the flow of traffic per hour and the measured saturation flow. This also yields a very strong negative correlation of (-0.74) implying that it is rather the stopping effect of the buses that cause a reduction in the saturation flow rate and not their mere presence. Negative correlations also mean that there is an inverse relationship.

This confirms the relationship in the HCM 2000 quoted already in (2) above. The heavy vehicle factor is therefore modified as in (3) below to give the Trotro adjustment factor.

$$f_T = \frac{N_T}{N_T + \%S_T(2E_T - 1)} \qquad (3)$$

Where N_T is the number of Trotros in the traffic stream per hour, S_T is the number of Trotros stopping per hour, E_T is the passenger car equivalent for Trotros and f_T is the Trotro adjustment factor.

Table II: Saturation Flow and Number of Trotros stopping per hour

Intersection	Direction from	Movement	Field Saturation Flow	Adjusted Saturation Flow	No of Trotros stopping per hour
Bomso	KNUST	T	1324	1650	146
	Adum	T	1353	1713	165
Anloga	KNUST	T	1417	1725	283
	Adum	T	942	1710	312
Amakom	KNUST	T	1895	1792	98
	Adum	T	1525	1793	97

Source: From Study

Substituting the values from Tables I and II into equation 3 results in Table IV. The last column is the new adjusted saturation flow rate incorporating the new Trotro adjustment factor.

Table III: Table showing the Trotro adjustment factor

Intersection	Direction from	Movement	%St	f_T	new adjusted saturation flow rate
Bomso	KNUST	T	28	0.89	1463
	Adum	T	35	0.85	1450
Anloga	KNUST	T	42	0.87	1499
	Adum	T	55	0.81	1385
Amakom	KNUST	T	24	0.88	1577
	Adum	T	25	0.87	1560

Source: From Study

The field saturation flow was then compared to the new adjusted saturation flow rate.

Table IV: Comparison of Field Saturation Flow rates and New Adjusted Saturation Flow Rates

Intersection	Direction from	Movement	Field Saturation Flow	new adjusted saturation flow	Error (%)
Bomso	**KNUST**	**T**	**1324**	**1463**	**9**
	Adum	**T**	**1353**	**1450**	**7**
Anloga	**KNUST**	**T**	**1417**	**1499**	**5**
	Adum	**T**	**942**	**1385**	**32**
Amakom	**KNUST**	**T**	**1895**	**1577**	**-20**
	Adum	**T**	**1525**	**1560**	**2**

Source: From Study

Table IV is translated into Figure 7 to show the error bars. The bars represent the statndard deviation and the error margins associated with this distribution. New adjusted saturation flow rates fall within acceptable error limits.

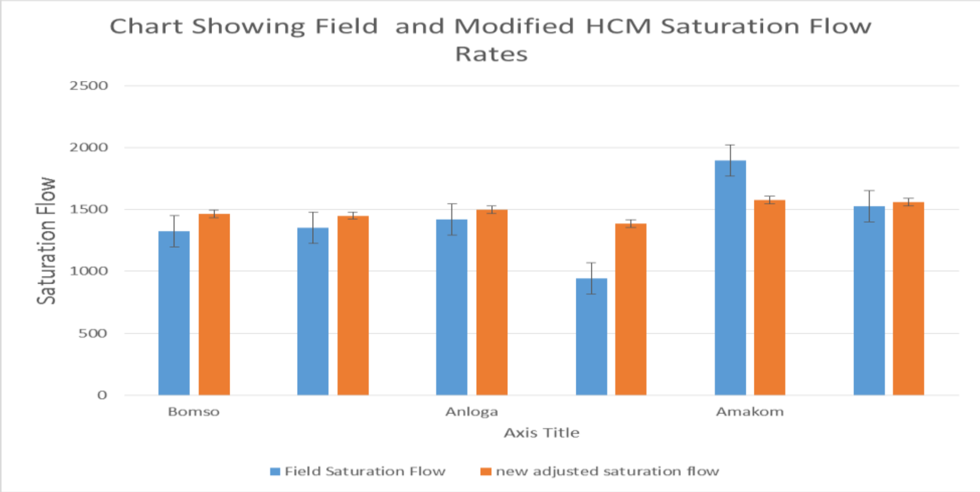

Figure 7: A Plot of Field and Modified Saturation Flow Showing Error Bars

[13] in predicting saturation flow estimations attributed errors to three primary sources namely the temporal variance in saturation flow predictions related to saturation flow models, omission of certain capacity factors in predictive models and lastly, an inadequate functional relationship between model variables and saturation flow rates. He further admits that there is a considerable standard error of prediction reaching between 8-10%.

From Table 4 above it can be seen that, all intersections except the Anloga from Adum approach that does not fall within the acceptable error margin. This could be due to the fact that the presence of the fuel stations and the Trotro station as well as the lay-bye located just ahead of the intersection could be considerably interfering with the flow of traffic and thereby must be looked at in future work.

IV. CONCLUSIONS

It can be concluded from the study that there is a relationship between the percentage of Trotros in the travel stream and the number that stop to pick up and drop passengers around the intersection approaches. Saturation flows is inversely proportional to the percentage of Trotros within the traffic stream and the number of stops made by Trotros around the intersection approaches and the new Trotro adjustment factor can be incorporated into the HCM 2000 model to better predict saturation flows.

From the study it was observed at one intersection that there is a significant reduction in the saturation flow rate even after adjusting for the effect of Trotros and it was attributed to the presence of roadside friction from the presence of a fuel station, lay-bye and a Trotro station just ahead of the intersection approach. Further research is therefore recommended in this area.

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