

# Adjusting for the Effect of Bus Blockage on Saturation Flows

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**Abstract:** *Roadside friction created by the activities of public transport vehicles at bus bays, taxi ranks, and terminals which have been located in the vicinity of most signalised intersections in Ghanaian cities tends to interfere with vehicular discharge at the intersections. Some vehicles exiting the intersection diverge from the existing traffic stream to the bus bays and taxi ranks while others from these facilities attempt to merge with the stream. In this paper, modifications based on passenger car equivalents and bus blockage time appropriate to the local public transport vehicles have been introduced into the empirical expression for adjusting for bus blockage in the HCM 2010 saturation flow model. Traffic flow data was collected at selected signalised intersections with and without roadside friction within the Kumasi Metropolis and the headway method used to estimate the field saturation flow rates. The HCM ideal flow adjustment model, which incorporated the modifications to the bus blockage factor, was then used to estimate saturation flows at the intersections. The results indicated very good agreement between the observed and model-estimated flows although for most of the intersections (73%), the model values were marginally higher than the observed flows. On average, the overestimates/underestimates were of the order of 1% for none/low, 2% for medium, and 7% for high roadside friction areas.*

**Keywords:** Bus Blockage, Saturation Flow, Signalised Intersection, Roadside Friction, Public Transport Vehicle

## 1. Introduction

Analysis of the capacity of signalised intersections makes it possible to assess the operational performance of the intersections in terms of level of service and, if necessary, vary signalisation details and sometimes geometric conditions at the intersection so that optimal performance would prevail under the existing traffic conditions. An important parameter that features in such analysis is the saturation flow rate which for a lane group represents the maximum discharge rate during the green time. Saturation flow rates are also required in the planning and design of new signal systems to control traffic movements at at-grade intersections [1].

The Highway Capacity Manual (HCM) [2] provides the procedure for estimating saturation flow based on field data or alternatively allows the ideal flow of 1900vphgpl to be adjusted to reflect all the factors that cause the flow to deviate from ideal. Empirical expressions for adjusting the ideal flow are provided in the HCM [2]. The procedure outlined in the manual is, however, continually being challenged on the basis of field observations. For example, to remove the effect of start-up delay, the exclusion of the first few vehicles is recommended in order to arrive at a stable headway for analysis. However, studies by Lin and Thomas [3] on queue discharge rate led them to establish that the stable headway assumed after the first few vehicles have passed the intersection may not manifest even after several vehicles have passed. Using field data and a new procedure for estimating saturation flow rates, Rahman et al [4] noted that the procedure in the HCM [2] could lead to underestimates of the parameter for some approaches and overestimates for the others. Shao and Liu [5] examined the distribution characteristics of headways at a number of signalised intersections and concluded that normal distribution may prevail at some intersections and lognormal

distribution at others. It was noted that the traditional method may underestimate saturation flows when the headway distribution is asymmetric. The accuracy of saturation flow rates has become important because errors in the estimated value carry over onto delay and level of service predictions [5].

The magnitude of the saturation flow rate is affected by a number of factors including approach grade, vehicular mix and characteristics, driver behaviour, roadway geometry and activities in the environment of the intersection. According to Stokes [6], the physical and operational features at or in the vicinity of intersections affect capacity at the intersection. In many developing countries including Ghana, the roadside environment is often characterised by a flurry of activity on and alongside the roads which tends to interfere with traffic flow. Side friction, which is a composite term for the degree of interaction between roadside activities and traffic flow, may result particularly from blockage of the travelled way by public transport vehicles, pedestrians, and street-side hawking among others [7]. In a study of the impact of the location of fuel service stations on signalised intersections within the Kumasi Metropolis in Ghana, Debrah [8] noted that fuel stations which are located close to signalized intersections cause the intersections to operate at sub-optimal level. In addition, other ancillary services such as vulcanisation, lubrication and grocery shops present at the stations induce traffic activities and roadside friction which ultimately impact on the overall traffic operations at the intersections [8].

Within the Kumasi Metropolis, intersections, including most signalised ones, are major points of route interchange for commuters and travellers from outlying districts. As such, most have bus stops and taxi ranks located in close proximity to serve the different travel routes. Vehicular activities at such facilities impose side friction on flow at the intersections which manifests in the slowdown of

discharging vehicles as some vehicles exiting the intersections diverge to the facilities while others from the facilities attempt to merge with through traffic. In a recent study on passenger car equivalents (PCEs) for vehicles which use the signalized intersections within the metropolis, discharge headways were established to be larger at intersections with such roadside friction than at those without [9]. In addition, higher PCEs were established for vehicles discharging through signalised intersections affected by roadside activities than those devoid of such activities. The major thrust of this study was to adjust the ideal saturation flow rate at such intersections within the Kumasi Metropolis in Ghana to reflect the impact of vehicles which operate at public transport facilities located close to the signalised intersections and which act as side friction elements.

## 2. Modification to Bus Blockage Factor

The HCM adjusted ideal flow used in the estimation of saturation flow rates at signalised intersections is given by the expression;

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

Where,

S = saturation flow rate for the lane group in vehicles per hour of green.

S<sub>o</sub> = ideal saturation flow rate in pcphgpl

n = number of lanes in the lane group

f<sub>w</sub> = adjustment factor for lane width

f<sub>HV</sub> = adjustment factor for heavy vehicles

f<sub>g</sub> = adjustment factor for approach grade

f<sub>p</sub> = adjustment factor for parking characteristics

f<sub>bb</sub> = adjustment factor for blocking effect of local buses that halt within the intersection area

f<sub>a</sub> = adjustment factor for area type (Central Business District or other areas)

f<sub>LU</sub> = adjustment factor for lane utilization

f<sub>RT</sub> = adjustment factors for right-turns in the lane group

f<sub>LT</sub> = adjustment factors for left-turns in the lane group.

f<sub>Lpb</sub> = pedestrian-bicycle adjustment factor for left-turn movements; and

f<sub>Rpb</sub> = pedestrian-bicycle adjustment factor for right-turn movements.

The empirical expression for the bus blockage factor is dependent, among other things, on the number of buses that halt within the intersection area and the blocking time. The expression is given as;

$$f_{bb} = \left( \frac{N - \frac{14.4N_b}{3600}}{N} \right) \quad (2)$$

Where,

N<sub>b</sub> = number of buses halting in the intersection area

N = number of lanes

In the Ghanaian context, urban public transport vehicles consist predominantly of mini and medium buses locally called *trotro*, and taxis which operate mainly in share mode. Their operational characteristics are different from those of conventional large capacity buses and their impact on saturation flow cannot, therefore, be accounted for directly

as provided for in the case of the conventional buses. It is suggested in this study that the impact of such kinds of public transport vehicles (taxis, *trotros*) on saturation flows would be better addressed if the vehicles are replaced by a corresponding number of conventional buses that would produce equivalent effect. This may be done by expressing the number of the local vehicles that halt in the intersection area and block flow using the PCE values of the vehicles expressed in relative terms to that of a bus. In addition, it is suggested that the bus blockage time in the empirical expression must be selected to reflect the appropriate behaviour of the public transport drivers in each of the intersection environment types. The modifications suggested above when incorporated in the bus blockage factor transform Eq. (2) to the following;

$$f_{bb} = 1 - \frac{t_b \left( N_{buses} + \frac{PCE_{taxi}}{PCE_{bus}} N_{taxi} + \frac{PCE_{trotro}}{PCE_{bus}} N_{trotro} \right)}{3600N} \quad (3)$$

Where,

t<sub>b</sub> = bus blockage time

N<sub>buses</sub> = number of buses

N<sub>taxi</sub> = number of taxis

N<sub>trotro</sub> = number of *trotros*

PCE<sub>bus</sub> = passenger car equivalent of bus

PCE<sub>taxi</sub> = passenger car equivalent of taxi

PCE<sub>trotro</sub> = passenger car equivalent of *trotro*

At a given intersection, the PCE and t<sub>b</sub> values to be used in Eq. (3) must be appropriate to the intersection road environment type or side friction. For the Kumasi Metropolis, three roadside friction types have been defined; none/low, medium, and high, based on vehicular and other activities in the vicinity of the intersections. Table 1 provides the criteria used in describing the nature of the roadside friction associated with signalised intersections within the metropolis.

Table 1: Criteria Used for Classification of Roadside Friction

Roadside Friction Agents		
None/ Low	Medium	High
At most one of these must prevail:	A combination of two of the following must prevail:	A combination of at least three of the following must prevail:
<ul style="list-style-type: none"> <li>•Taxi Rank</li> <li>•Lay-by/Bus Bay</li> <li>•Fuel Station</li> <li>•Trotro Station</li> </ul>	<ul style="list-style-type: none"> <li>•Taxi Rank</li> <li>•Lay-by/Bus Bay</li> <li>•Fuel Station</li> <li>•Trotro Station</li> </ul>	<ul style="list-style-type: none"> <li>•Taxi Rank</li> <li>•Lay-by/Bus Bay</li> <li>•Fuel Station</li> <li>•Trotro Station</li> </ul>

## 3. Field Assessment

### 3.1 Site Selection and Description

Eleven signalized intersections were selected to reflect the three different road environment characteristics in non-CBD areas within the Kumasi Metropolis. In all, five of the intersections were associated with high roadside friction, three with medium roadside friction and the remaining with none/low side friction. Fig. 1 is a map of the Kumasi Metropolis showing the locations of the selected intersections. Figures 2, 3 and 4 typify intersections with none/low, medium, and high roadside friction, respectively.



Figure 1: Map of the Kumasi Metropolis showing study sites



Figure 4: The Anloga Signalized Intersection (high roadside friction)



Figure 2: The Pine Avenue Signalized Intersection (none/low roadside friction)



Figure 3: The Asokwa Signalized Intersection (medium roadside friction)

### 3.2 Data collection and analysis

A video camcorder was used to record traffic flow at all the signalized intersections selected for the study. Data on approach grade, lane geometry, presence or otherwise of taxi ranks, bus stops, fuel stations, etc., was also collected. Headway data for through traffic movements was extracted from the video recordings. Flow data for a total of 1,316 cycles were analysed and the headway method used to estimate field saturation flow rates as follows;

$$S = 3600/h \quad (4)$$

Where,  $S$  = the field or observed saturation flow rate and  $h$  is the average saturation headway in seconds.

For the prediction of the saturation flow rates using the HCM model, PCE values in Table 2 developed for vehicles at the intersections by Obiri-Yeboah et al [9] appropriate to the roadside friction types were used in the modified bus blockage factor in Eq. (3).

Table 2: PCE Values for Vehicles at Signalized Intersections with/without Side Friction [9]

Public Transport Vehicle Type	PCE	
	None/Low friction	Medium/High Friction
Taxi (Small vehicle)	1.00	1.00
Trotro (Medium vehicle)	1.35	1.65
Bus (Large vehicle)	2.25	3.05

In areas where the side friction is described as none/low, the default value of the bus blockage time ( $t_b$ ) in the HCM model was maintained. However, for the medium and high friction areas, the values adopted were 20s and 18s, respectively. The lower  $t_b$  value associated with the high friction areas is explained by the fact that because most of the time there is a high supply of passengers at the bus stops and taxi ranks at such locations, the public transport vehicles tend to load quickly and, hence, spend less time blocking through traffic compared to medium friction areas. In the case of none/low areas, observations have established that most of the public transport vehicles are taxis which take

very short time to serve passengers and move straight on without any lingering.

#### 4. Results and Discussions

Table 3 contains a summary of the adjustment factors based on site characteristics pertaining to each of the intersections using the appropriate empirical expressions provided in the HCM, except for the  $f_{bb}$  factor which was derived using the modified expressions proposed in this paper. Table 4 contains the results of the observed saturation flow rates and the adjusted ideal rates using the factors in Table 3. For ease of discussion, the intersections have been grouped according to the intensity of side friction per the criteria used in this study.

**Table 3:** Summary of Adjustment Factors

Name of Intersection	Approach	$f_w$	$f_{hv}$	$f_g$	$f_{LT}$	$f_{RT}$	$f_p$	$f_{bb}$
Briginia	Stadium	1.00	0.98	1.03	1.00	1.00	1.00	0.92
	Asafo	1.00	0.94	0.97	1.00	1.00	1.00	0.94
Pine Avenue	Adum	0.97	0.98	0.98	1.00	1.00	1.00	0.98
	Officers Mess	0.96	0.96	1.00	1.00	1.00	1.00	0.99
Stadium	Childrens' Park	1.00	0.96	0.98	1.00	0.99	1.00	0.97
	Asokwa	1.00	0.92	1.02	0.95	0.99	1.00	0.97
Bomso	University	0.99	0.85	0.99	0.95	0.99	1.00	0.89
	Top High	1.01	0.89	0.99	0.95	0.99	1.00	0.90
Amakom	Afful Nkwanta	1.01	0.95	0.99	0.99	0.98	1.00	0.88
	Labour	1.02	0.95	1.01	0.99	0.98	1.00	0.86
Asokwa	Asafo	0.96	0.91	0.99	0.95	1.00	1.00	0.80
	Atonsu	0.99	0.91	0.99	0.95	1.00	1.00	0.90
Krofrom	Dichemso	0.99	0.95	0.99	0.99	0.99	1.00	0.83
	Suame	1.02	0.95	0.99	1.00	0.99	1.00	0.80
Aboabo	Anloga	0.99	0.85	1.00	0.95	0.98	1.00	0.86
	Dichemso	0.99	0.87	0.98	0.95	0.98	1.00	0.85
Abrepo	Suame	1.01	0.85	0.99	1.00	0.98	0.95	0.83
	Neoplan	1.01	0.93	0.99	1.00	0.98	1.00	0.77
Anloga	Oforikrom	1.01	0.93	1.03	0.95	0.98	0.95	0.83
	Afful Nkwanta	1.01	0.91	1.02	0.95	0.98	1.00	0.79
KNUST	Top High	0.99	0.91	0.99	1.00	1.00	1.00	0.80
	Kentinkrono	1.01	0.82	1.00	1.00	1.00	1.00	0.83

**Table 4:** Summary of Observed and Adjusted Saturation Flow Rates

Ser. No.	Intersection Name	Approach	Saturation Flow Rate (vphgpl)		Adj./ Obs.	Side Friction
			Adjusted	Observed		
1	Briginia	Stadium	1740	1644	1.06	None/Low
		Asafo	1620	1652	0.98	None/Low
2	Pine Avenue	Adum	1744	1731	1.01	None/Low
		Officers Mess	1712	1728	0.99	None/Low
3	Stadium	Childrens' Park	1705	1710	1.00	None/Low
		Asokwa	1637	1606	1.02	None/Low
4	Bomso	University	1330	1324	1.00	Medium
		Top High	1442	1366	1.06	Medium
5	Amakom	Afful	1568	1554	1.01	Medium

		Nkwanta				
		Labour	1558	1525	1.02	Medium
6	Asokwa	Asafo	1251	1219	1.03	Medium
		Atonsu	1447	1440	1.00	Medium
7	Krofrom	Dichemso	1447	1357	1.07	High
		Suame	1455	1329	1.09	High
8	Aboabo	Anloga	1284	1289	1.00	High
		Dichemso	1270	1244	1.02	High
9	Abrepo	Suame	1245	1160	1.07	High
		Neoplan	1319	1193	1.11	High
10	Anloga	Oforikrom	1343	1286	1.04	High
		Afful Nkwanta	1305	1170	1.12	High
11	KNUST	Top High	1360	1260	1.08	High
		Kentinkrono	1294	1209	1.07	High

The ratio of the adjusted flow rate to the observed provides an indication of the extent to which the model either matched or overestimated/underestimated the field values. It is seen that there was generally good agreement between the predicted and observed flow rates, although some marginal differences existed between the two. Based on the table data, about 73% of the approach flows were slightly overestimated by the HCM model compared to 2% which were underestimated. The level of overestimation appeared to be dependent on the intensity of roadside friction; on average, the levels were 1%, 2%, and 7%, for none/low, medium, and high roadside friction categories, respectively. The small differences between the predicted and the observed saturation flow rates probably reflect aspects of the impact of roadside friction that could not be captured by the modifications introduced into the bus blockage adjustment factor. This needs further study in order to improve the accuracy of saturation flow predictions using the HCM ideal flow adjustment model.

#### 5. Conclusions

Roadside vehicular activities at bus stops, taxi ranks, and similar such facilities located in the vicinity of non-CBD signalised intersections within the Kumasi Metropolis in Ghana create side friction which has adverse impact on saturation flows at the intersections. In this study, modifications were introduced into the bus blockage factor in the HCM saturation flow prediction model to account for the impact of roadside vehicular local minibuses/taxis interference in the form of blockage to signalised intersection flows. The modifications used passenger car equivalents to convert non-conventional local public transport vehicles into equivalent conventional buses and adjusted the bus blockage time to reflect local conditions. The saturation flow rates predicted by adjusting the ideal flow using the HCM model were in very good agreement with the measured field values, although the model values tended to be slightly higher than the field values. Where there were overestimates or underestimates, they were on average of the order of 1% for none/low, 2% for medium, and 7%, for high roadside friction areas. To improve the accuracy of saturation flow predictions, further work is recommended to address other aspects of roadside friction that probably could not be captured by the modifications

introduced into the bus blockage adjustment factor in the HCM saturation flow prediction model.

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