International Journal of Structural and Civil Engineering Research

ISSN 2319 – 6009 www.ijscer.com
Vol. 2, No. 3, August 2013

Research Paper

APPRAISAL OF STADIUM JUNCTION SIGNALIZED INTERSECTION ON THE 24TH FEBRUARY ROAD, KUMASI-GHANA USING MICRO SIMULATION MODEL

J K Borkloe[1]*, E K Nyantakyi[1] and P A Owusu[1]

*Corresponding author: **Julius Kwame Borkloe,** ✉ juliusborkloe1@yahoo.com

The importance of signalized intersections cannot be over emphasized in the smooth operation of traffic on both very heavy and busy arterial roads and urban street facilities. To design an efficient and effective traffic management operation system at intersections, traffic simulation models have mostly and widely been used in both transportation and traffic analyses because it is safer, faster, and cheaper than field implementation and testing. In view of the heavy traffic which still persist at the approach of the stadium junction on the Accra-Kumasi section of the road corridor during peak hours, this study appraised the performance of the signalized intersection using micro simulation models in Synchro/SimTraffic. This involve collecting traffic, geometric and signal control data including key parameters with the greatest impact on the calibration process on the field and using the Chi-square test and t-test analyses at 5% significant level to conclude that, headway was a better predictor with saturation flow compared to speed for both field and simulated conditions. This gave an indication that changes in phasing plan with an accompanying geometric improvement would improve upon the intersection's level of service.

Keywords: Appraisal, Signalized intersections, Synchro/SimTraffic, Traffic geometry, Signal control

INTRODUCTION

"Simulation is defined as dynamic representation of some part of the real world which is achieved by constructing a computer model and moving it through time" (Drew, 1968). It involves the wide use of computer models to design and analyze traffic and transportation systems. Indeed, computer simulation started when D L Gerlough published his dissertation: "Simulation of freeway traffic on a general-purpose discrete variable computer" at the University of California, Los Angeles, in 1955 (Kallberg, 1971). Since then, computer simulation has become a widely used tool in transportation engineering with a variety of applications from

1 Department of Civil Engineering, Kumasi Polytechnic, P.O. Box 854, Kumasi, Ghana.

scientific research to planning, training and demonstration.

The Stadium Junction is a minor signalized intersection and its approach is traversed by the same main arterial road entering Kumasi from Accra. The road corridor is relatively heavily trafficked (BCEOM and ACON Report, 2004) and observation of the intersection is characterized by long vehicular queues at the approaches of the intersection, especially during morning and evening peak periods of the day. (BCEOM and ACON Report, 2004)

Previous studies by (BCEOM and ACON Report, 2004) on the performance of the intersection attributed the congestion to critical capacity, intersection controls and abuse to motorists and/or pedestrians. It was concluded that most of the sections on the 24th February road have their capacities approaching critical (v/c ratio>0.6) and that this contributes in part to the congestion which results in delay and subsequent poor performance of the road. The report indicated that, this section of the 24th February road will be highly critical in the next 3 to 5 years (period from 2004 – 2009) and therefore as part of its recommendations, made proposals to improve upon the signalization and capacity at the intersection by revision of the signal timing, phasing plan and also inclusion of concurrent Non Motorized Traffic (NMT) phase at the Stadium Junction intersection. In the study by (BCEOM and ACON, 2004) although the micro simulation Synchro/SimTraffic was reportedly used for the analysis, the models were however not calibrated. And even though some of the recommendations have been implemented at the intersection, long queues and frequent delays still persist during peak hour conditions. Since in the application of micro simulation tools, one major step is calibrating the model before the prediction can be said to mimic site conditions, there is therefore the need to calibrate of the model. Also micro simulation tools application is relatively new in Ghana and the procedures for calibration, and application in modeling is not very well understood by practicing engineers. This study therefore seeks to contribute to the knowledge base in the area by calibrating the Synchro/ SimTraffic models and using the concept to predict the performance of the Stadium Junction intersection and to appraise performance measures using micro simulation models in Synchro/SimTraffic.

METHODOLOGY

Calibration of Synchro for Site Conditions

The Carole Turley (2007) method of calibration was adopted by collecting required input data for the Synchro model and also for the calibration. These were then followed by comparing calibration data with the simulated results from the field and finally calibrating the model.

Site Description

The Stadium Junction intersection is on the 24th February Road, which is an East-West principal arterial of about 5.4 km length from KNUST junction to the UTC traffic light. The intersection with Hudson road is signalized and about 3.6 km west of the KNUST junction. It is 950 m away from Anloga junction and 350 m away from the Amakom traffic light. The intersection has three legs with one approach/

entry and exit lanes on the minor road (Hudson road), and two approach/entry and exit lanes on the 24th February road. The two approach/ entry and exit lanes road is a 2-lane dual carriageway, which is paved over its entire length. It is the intersection of a Principal arterial and a Minor arterial. Figure 1 is sectional map of Kumasi showing the intersection under study.

Figure 1: Map of Kumasi showing Stadium Junction Intersection on the 24th February Road

Source: from Department of Urban Roads, Ghana

Basic Theoretical Background

The concept of "Car-following" describes the detailed movement of vehicles proceeding close together in a single lane. This theory is based on the assumption that each driver reacts in some specific fashion to a stimulus from the vehicle ahead of him.

One of the oldest and most well known cases of the use of simulation in theoretical research is the "car-following" analysis based on the Generalized General Motors (GM) models. In these models a differential equation governs the movement of each vehicle in the platoon under analysis (Gerlough and Huber, 1975). Car-following, like the intersection analysis, is one of the basic equations of traffic flow theory and simulation, and the analysis has been active after almost 40 years from the first trials (McDonald *et al.*, 1998). The car-following theory is of significance in microscopic traffic flow theory and has been widely applied in traffic safety analysis and traffic simulation (Luo *et al.*, 2010; Tordeux *et al.*, 2010). There have been many car-following models in the past 60 years, and the models can be divided into two categories. One is developed from the viewpoint of traffic engineering and the other is based on statistical physics. From the perspective of traffic engineers (Brackstone and McDonald, 1999), car-following models can be classified as stimulus-response models (Gazis *et al.*, 1961; Newell, 1961), safety distance models (Gipps, 1981), psycho-physical models (Wiedemann, 1974), and artificial intelligence models (Kikuchi and Chakroborty, 1992; Wu *et al.*, 2000).

The car-following theory is based on a key assumption that vehicles will travel in the center line of a lane, which is unrealistic, especially in developing countries. In these countries, poor road conditions, irregular driving discipline, unclear road markings, and different lane widths typically lead to non-lane-based car-following driving (Gunay, 2007). Heterogeneous traffic, characterized by diverse vehicles, changing composition, lack of lane discipline, etc., results in a very complex behavior and a non-lane-based driving in most Asian countries (Mathew and Radhakrishnan, 2010). Therefore, it is difficult for every vehicle to be moving in the middle of the lane. Vehicles are positioned laterally within their lanes, and the off central-line effect results in lateral separations. However, to the limit of our knowledge, the effect of lateral separation in the car-following process has been ignored by the vast majority of models. A few researchers have contributed efforts on this matter. Gunay (2007) first developed a car-following model with lateral discomfort. He improved a stopping distance based approach that was proposed by (Gipps, 1981), and presented a new car-following model, taking into account lateral friction between vehicles.

Jin *et al.* (2010) proposed a non-lane-based car following model using a modified full-velocity difference model. All the above models have assumed that drivers are able to perceive distances, speeds, and accelerations. However, car-following behavior is a human process. It is difficult for a driver of the following vehicle to perceive minor lateral separation distances, and drivers may not have precise perception of speeds and distances, not to mention accelerations.

Car-Following Models

The logic used to determine when and how much a car accelerates or decelerates is crucial to the accuracy of a microscopic simulation model. Most simulation models use variations on the GM model. Although it was developed in the 1950s and 1960s, it has remained the industry standard for describing car-following behavior and continues to be verified by empirical data. A variation on the GM model is the PITT car-following model, which is utilized in FRESIM. The GM family of models is perceived to be the most commonly used in microscopic traffic simulation models and are, therefore, the focus of this article.

Generalized General Motors Models

The first GM model modeled car-following is a stimulus-response process in which the following vehicle attempts to maintain space headway. When the speed of a leading vehicle decreases relative to the following vehicle, the following vehicle reacts by decelerating. Conversely, the following vehicle accelerates when the relative speed of the leading vehicle increases. This process can be represented by the first GM model, given below:

$$\ddot{\chi}_F = \alpha_F \times \left(\dot{\chi}_L(t) - \dot{\chi}_F(t) \right) \quad ...(1)$$

where

$\ddot{\chi}_F$ = acceleration of the following vehicle,

$\dot{\chi}_F$ = speed of the following vehicle,

$\dot{\chi}_L$ = speed of the leading vehicle,

α_F = sensitivity of the following vehicle, and

t = time.

PITT Car-following Model

FRESIM uses the PITT car-following model, which is expressed in terms of desired space headway, shown in the equation below.

$$h_s(t) = L + m + kV_2 + bk\left[V_1(t) - V_2(T)\right]^2 \quad ...(2)$$

where

$h_s(t)$ = Desired space headway at time *t*,

L = Length of leading vehicle,

m = Minimum car-following distance (PITT constant),

k = Car-following sensitivity factor for following vehicle,

b = Relative sensitivity constant,

$V_1(t)$ = Speed of leading vehicle at time t, and

$V_2(t)$ = Speed of following vehicle at time t.

Equation above can be solved for the following vehicle's acceleration, given by the equation below.

$$a = \frac{2 \times \left[x - y - L - m - V_2 \left(K + T \right) - bk \left(V_1 \left(t \right) - V_2 \left(t \right) \right)^2 \right]}{T^2 + 2KT} \quad ...(3)$$

where

a = The acceleration of the following vehicle,

T = The duration of the scanning interval,

x = Position of the leading vehicle, and

y = Position of the following vehicle.

Algorithm on Synchro/SimTraffic software

Simulation is basically a dynamic representation of some part of the real world achieved by building a computer model and moving it through time. The results obtained from any simulation model will be as good as the model replicates the specific real world characteristics of interest to the analyst.

Once a vehicle is assigned performance and driver characteristics, its movement through the network is determined by three primary algorithms:

Car Following

This algorithm determines behavior and distribution of vehicles in traffic stream. Synchro varies headway with driver type, speed and link geometry whereas SimTraffic generates lower saturation flow rates.

Lane Changing

This is always one of the most temperamental features of simulation models. There are three types of lane-changing which includes

- Mandatory lane changes (e.g., a lane is obstructed or ends)
- Discretionary lane changes (e.g., passing)
- Positioning lane changes (e.g., putting themselves in the correct lane in order to make a turn): There is heavy queuing and this is a common problem for modeling positioning lane changes. Vehicles often passed back of queue before attempting lane change and their accuracy relates to degree of saturation and number of access points such as congested conditions which requires farther look ahead and densely-spaced access (i.e., short segments) which presents a problem.

Gap Acceptance

Gap acceptance affects driver behavior at unsignalized intersections, driveways (e.g., right-in-right-out) and right-turn-on-red (RTOR) movements. If default parameters are too aggressive, vehicle delay will be underestimated and there is serious implication for frontage roads. Conversely, parameters which are too conservative may indicate need for a signal when one isn't necessary. Gap acceptance parameters are network-wide in SimTraffic.

Data Collection for Synchro

Microscopic simulation model Synchro has many model parameters and in order to build a Synchro simulation model for the intersection and calibrate it for the local traffic conditions, two types of data were required. The first type was the basic input data which include data on network geometry, traffic volume, turning movements and traffic control systems. The second type was the observation data employed for the calibration of simulation model parameters such as average link speeds, headways and saturation flows using standard procedures.

Manual Collection of Data at Stadium Intersection

Manual collection of data was done at Stadium Junction intersection because it was difficult getting good elevation observer positions. Traffic volume data and geometric data as indicated in Table 1 for turning movements were collected manually at the intersection on Wednesday, the 13^{th} of May 2012 between 0700 h and 1000 h during the morning peak period of the day. Traffic signal timings were also determined manually using stop watches at the intersection. Two enumerators each were positioned on each approach. The number of vehicles turning left, right and through traffic were counted and the number of times an approach signal indicated green and red were also recorded. Two other enumerators each also recorded headways and speeds of vehicles as they traverse the intersection.

From Table 1, it can be observed that, the intersection registered a peak hour volume of 2,434 vehicles. This value represented the worst traffic situation for an average day.

SIGNAL CONTROL DATA FOR STADIUM INTERSECTION

Cycle length is the time required for one complete sequence of signal indications (phases). Usually it is measured in seconds. Cycle lengths and signal phases for the intersection were recorded using

Table 1: Summary Peak Hour Traffic Volume and Geometric Data at Stadium Junction Intersection

From	To	Movement Code	Veh/hr	% Heavy Veh	No of Lanes	Lane Width	Storage Lengths	% of App Vol	App Vol (veh/hr)	% of total Int volume	Total Int Vol (veh/hr)
	Stadium Jn	WBL	432	8	1	2.9	73	30.9			
Anloga Jn	Amakom	WBT	967	1	2	3.5		69.1	1399	57.5	
	N/A	WBR									
	N/A	EBL									
Amakom	Anloga Jn	EBT	805	5	2	3.7		95.2	846	34.8	2434
	Stadium Jn	EBR	41	13			shared	4.8			
	Amakom	NBL	106	4	1	3.6		56.1			
Stadium	N/A	NBT							189	7.7	
	Anloga Jn	NBR	83	20	1	2.7	34	43.9			

Source: from study

stopwatches. Cycle length for the intersection was obtained as 68 s. Table 2 shows the signal timing data.

The resulting effective green time (g) was calculated using the equation below

$$g = G + Y + R - (l_1 + l_2) \quad ...(4)$$

where l_1 = start up lost time

l_2 = clearance lost time

CALIBRATION DATA FOR STADIUM JUNCTION INTERSECTION

Speeds and headways data were collected in order to calibrate the model for local conditions to realistically model traffic at the intersection.

Spot Speed Data

Despite the fact that speed, is the most important parameter which describes the state of a given traffic stream, it is also very important to note that in a moving traffic stream, each vehicle travels at a different speed. Thus, the traffic stream does not have a single characteristic speed but rather a distribution of individual vehicle speeds. The spot speed data to and from KNUST approaches at intersection were collected using the Doppler principle (radar). The speed data were collected as the tail of the vehicles cross the stop bar. The first four vehicles in queue were not counted because they were accelerating from rest. A radar gun was

Table 2: Summary of Signal Timing Data for Stadium Junction Intersection

Direction	Cycle Length (C)	Actual Green Time (G)	Actual Yellow Time (Y)	Actual Red Time (R)	Total Lost Time(l_1+l_2)	Effective Green Time (g)
From KNUST	68	35	4	2	4	37
To KNUST	68	30	4	2	4	32

Source: from study

Table 3: Computed Saturation Flow, Headway and Speed Data

Performance Measures	Direction	No. of vehicles	Mean	Maximum	Minimum	Standard Deviation
Saturation Flow (pcu/hr/lane)	From KNUST	30	1226	2707	360	570.71
	To KNUST	30	1643	2727	678	511.65
Headway(secs)	From KNUST	30	3.7	10.0	1.33	1.99
	To KNUST	30	2.44	5.31	1.32	0.89
Speed(km/hr)	From KNUST	30	26.9	33	22	3.02
	To KNUST	30	24.8	28	22	1.67

Source: from study

Table 4: Comparison of Computed and Simulated Performance Indicators

Performance Measures	Direction	Computed Values, Sc	Simulated Values, Sa	Ratio (Sc/Sa)	Chi square Test (P-value)
Saturated Flow (pcu/hr/lane)	From KNUST	1226	1267	0.968	0.2494
	To KNUST	1643	1643	1.000	
Headway (secs)	From KNUST	3.7	3.06	1.209	0.58011
	To KNUST	2.44	3.18	0.767	
Speed (km/hr)	From KNUST	26.9	25	1.076	0.4792
	To KNUST	24.8	22	1.127	

Source: from study

operated by a single person. Operators randomly targeted the vehicles and recorded the digital speed readings displayed on the unit. Through traffic speeds to-and-from KNUST approaches at the intersection were recorded for a maximum of 30 vehicles inclusive of private cars, commercial vehicles and heavy goods vehicles.

Headway and Saturation Flow Data

The headway is the time starting from when the tail of the lead vehicle crosses the stop bar until the front of the following car crosses the stop bar. Headway data for three cycles each were collected at the intersection with a stop watch. Table 3 shows the summary of computed saturation flow, headway and speed for the intersection.

Calibration of the Synchro Models

Chi Square Test Analysis (P-values)

This analysis was used to determine the level of significance between the computed and simulated saturation flows, speeds and headways for the intersection. $P < 0.05$ was considered significant and $P > 0.05$ was considered insignificant.

Paired Sample T-Test Analysis

This analysis was carried out to either confirm or reject the chi squared test analysis. It was also used to evaluate the variation in the computed and simulated saturation flows, speeds and headways for the intersection.

Regression Analysis

Calibration of the model was based on regression analysis using traffic volume data to-and-from KNUST approaches of the stadium junction intersection. It was carried to establish whether speed or headway had a strong correlation with saturation flow. The predictors were speed and headway whiles the dependent variable was saturation flow.

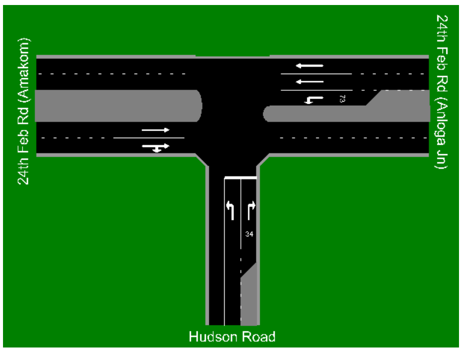
Performance Assessment at Stadium Junction Intersection

Levels of service and delay were used to assess the performance at the intersection. A Level of service is a letter designation that describes a range of operating conditions on a particular type of facility. The 1994 Highway Capacity defines levels of service as "qualitative measures that characterize operational conditions within a traffic stream and their perception by motorists and passengers." Six levels of service are defined for capacity analysis. They are given letter designations A through F, with LOS A representing the best range of operating conditions and LOS F the worst. Delay is defined in terms of the average stopped time per vehicle traversing the intersection.

Change of Phase Without Geometric Improvement

For effective investigation of the optimized cycle lengths and offsets for the intersection, three different alternatives with three-phase operational plan in Figure 2 were considered at the intersection.

Figure 2: Geometry of 24th February/ Hudson Road Intersection



Source: BCEOM and ACON Report, 2004

Change of Phase with Geometric Improvement

The best alternative chosen was further investigated upon by the addition of lane(s) to the through put traffic at the intersection. This was done to determine improvements in the level of service at the intersection. This is because improvement in the Level of Service (LOS) would result in overall and enhanced performance at the intersection.

Sensitivity Analysis

This was carried out to verify in detail the sensitivity of the obtained results to the variation of the input parameters.

RESULTS AND DISCUSSION

Saturation flow rates, Headway and Spot Speed Data

Table 3 show the summary of computed saturation flow, headway and spot speed data Stadium intersection.

Explanation of Saturation Flow Values

Saturation flow, which is the maximum rate of flow of traffic across the stop line at an intersection, is a very important measure in Junction design and signal control applications. Low values of Saturation flow means less vehicles can cross the stop line when the signal turns green. Data collection techniques for the determination of saturation flow are well elaborated by the Transport Research Laboratory United Kingdom (TRL, 1993).

The saturation flow from KNUST junction approach was 1226 pcu per hour per lane and that to KNUST junction approach was 1643 pcu per hour per lane for the Stadium intersection. This was attributed to vehicle mix, geometry of intersection, driver behavior, public transport proportion in traffic stream, stops near intersection along routes (within 20 m) and pedestrian indiscriminate crossing due to location of attractions and roadside activity. These were identified as principal factors affecting flow, which collaborates Turner and Harahap (1993); Lu and Pernia, (1999) and Minh and Sano (2003), who have severally reported similar results.

Results of Calibration of Synchro Models

Chi-squared Analysis (p-Values)

Table 4 shows the results of the comparison between computed and simulated saturation flows, speeds and headways for the intersection using the Chi Square Test (*p*-value).

P-values > 0.05 meant that there were no significant differences between the computed and simulated values in terms of saturation flow, headway and speed data for the intersection as seen in Table 4. Indicating that the field saturated flow, headway and speed values were similar to the simulated saturated flow, headway and speed values obtained from Synchro.

T-Test Analysis

For saturation flow at each approach of the intersection, the test results showed that there was no significant difference between the computed and simulated saturation flow since *p*-value > 0.05. For headways at each approach of the intersection, the test results showed that there was no significant difference between the computed and simulated headways since *p*-value > 0.05.

For speeds however at each approach of the intersection, the test results showed that there was significant difference between the computed and simulated speeds since *p*-value < 0.05. It was found that a certain percentage of the variation in the simulated speed values was explained by the field speed values and Eta squared values explained in Table 5 below.

Detailed Results of level of significance test carried out at Stadium Junction Intersection (T-Test Analysis)

Paired t-test results in Table 5 showed there was no significant (*p*> 0.05) saturation flow variation of vehicular movements between the

Table 5: Results of paired Sample Test at Stadium Junction Intersection (Sat flow SIM)

Approaches	Paired Difference					t	Eta squared (%)	Sig. (2-tailed) p-value
	Mean	SD	Standard Error Mean	95% confidence interval of the difference				
				Lower	Upper			
Saturation from KNUST	-41.067	571.345	104.313	-254.410	172.277	-0.394	0.53	0.697
Saturation to KNUST	0.633	509.752	93.068	-189.71	190.978	0.007	0.00017	0.995
Speed from KNUST	1.900	2.280	0.416	1.049	2.751	4.565	41.8	0.000
Speed to KNUST	2.800	0.997	0.182	2.428	3.172	15.389	89.1	0.000
Headway from KNUST	0.5213	1.997	0.365	-0.225	1.267	1.430	6.59	0.164
Headway to KNUST	0.623	0.913	0.167	-0.964	-0.283	-3.741	32.23	0.001

Source: from study

field and the simulated situation for approaches from both direction. Eta squared statistic 0.0053 indicated a small size effect; meaning only 0.53% of the variation in the simulated saturation flow was explained by the field saturation flow from KNUST. Again Eta squared statistic 1.69×10^{-6} indicated a small size effect which meant that only 0.00017% of the variation in the simulated saturation flows was explained by the field saturation to KNUST.

Paired t-test results in Table 5 showed there was significant (p<0.05) speed variation of vehicular movements between the field and the simulated situation for approaches from both direction. Eta squared statistic 0.418 indicated a large size effect; meaning 41.8% of the variation in the simulated speed was explained by the field speed from KNUST. Again Eta squared statistic 0.891 indicated a large size effect which meant that 89.1% of the variation in the simulated speeds was explained by the field speeds to KNUST.

Paired t-test results in Table 5 showed there was no significant (p> 0.05) headway variation of vehicular movements between the field and the simulated situation from KNUST and significant (p<0.05) headway variation of vehicular movements between the field and the simulated situation to KNUST. Eta squared statistic 0.0659 indicated a moderate size effect; meaning 6.59% of the variation in the simulated headway was explained by the field headway from KNUST. Again Eta squared statistic 0.3223 indicated a large size effect which meant that 32.23% of the variation in the simulated headways was explained by the

Table 6: Comparison of Field and Simulated Saturation flow, Speed and Headway

From KNUST Approach	R	R Square (R^2)	Adjusted R Square (R^2)	Standard Error of the Estimate
Field Conditions	0.856	0.733	0.713	305.676
Simulated Conditions	1.000	1.000	1.000	0.000

Source: from study

Table 7: Results of Field and Simulated Conditions Co-efficients

Performance Measures	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error				Tolerance	VIF
Constant	2404.311	508.995		4.724	0.000		
Speed for KNUST Approach	-10.446	19.046	-0.055	-0.548	0.588	0.973	1.028
Headway for KNUST Approach	-242.446	28.918	-0.845	-8.384	0.000	0.973	1.028
Constant	949.000	0.000					
SpeedSIM	4.3×10^{-14}	0.000	0.000			0.756	1.323
HeadwaySIM	100.000	0.000	1.000			0.756	1.323

Source: from study

field headways to KNUST.

REGRESSION ANALYSIS

From the analysis, it was established that headway had a strong correlation with saturation flow from KNUST approach with $R^2_{field} = 0.733$ and $R^2_{simuated} = 1.000$. Similarly headway had a strong correlation with saturation flow to KNUST approach with $R^2_{field} = 0.85$ and $R^2_{simuated} = 1.000$ as shown in Table 6.

The adjusted R^2 value was expressed in percentage as 71.3%. Thus the model (headway and speed) explained 62.2% of the variance in the saturation flows for field condition as shown in Table 6. Similarly, the adjusted R^2 value was expressed in percentage as 100%. Thus the model (headway and speed) explained 100% of the variance in the saturation flows for simulated conditions.

For the field condition, the model showed that headway (–0.845) made a strong contribution in explaining the saturation flow when the variance in the model was controlled for as compared to that of speed (–0.055) which made less contribution to the model as can be seen in Table 7. Headway had a significance level of 0.000 which was less than 0.05; thus greatly contributed to the prediction of saturation flow whiles speed (0.548) made insignificant contribution.

The field equation connecting saturation flow (q), speed (u) and headway (h) is:

$$q = -10.446u - 242.446h + 2404.311 \quad ...(5)$$

For the simulated condition, the model showed that headway (1.000) made a unique contribution in explaining the saturation flow when the variance in the model was controlled for as compared to that of speed (0.000) which made no contribution to the model as can be seen in Table 7.

The simulated equation connecting saturation flow (q), speed (u) and headway (h) is:

$$q = \left(4.3 \times 10^{-14}\right)u + 100h + 949 \quad ...(6)$$

The adjusted R^2 value was expressed in percentage as 83.9%. Thus the model (headway and speed) explained 83.9% of the variance in the saturation flows for the field condition.

Similarly, the adjusted R^2 value was expressed in percentage as 100%. Thus the model (headway and speed) explained 100% of the variance in the saturation flows for the simulated condition as can be seen in Table 8.

For the field condition, the model established that headway (0.917) made a unique contribution in explaining the saturation flow when the variance in the model was controlled for as compared to that of speed (0.017) which made less contribution to the model as shown in Table 9. Headway had a significance level of 0.000 which was less than 0.05, thus greatly contributed to the prediction of saturation flow though speed (0.832) made insignificant contribution.

The field equation connecting saturation flow (q), speed (u) and headway (h) is:

$$q = -5.109u - 528.143h + 3057.240 \quad ...(7)$$

For the simulated condition, the model

Table 8: Comparison of Field and Simulated Saturation flow, Speed and Headway

From KNUST Approach	R	R Square (R^2)	Adjusted R Square (R^2)	Standard Error of the Estimate
Field Conditions	0.922	0.850	0.839	205.364
Simulated Conditions	1.000	1.000	1.000	0.000

Source: from study

Table 9: Results of Field and Simulated Conditions co-efficients

Performance Measures	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error				Tolerance	VIF
Constant	3057.240	571.109		5.353	0.000		
SpeedField	-5.109	23.856	-0.017	-0.214	0.832	0.917	1.090
Headway	-528.143	44.824	-0.917	-11.783	0.000	0.917	1.090
Constant	1337.000	0.000					
SpeedSIM	1.47x10-14	0.000	0.000			0.756	1.323
HeadwaySIM	100.000	0.000	1.000			0.756	1.323

Source: from study

established that headway (1.000) made a unique contribution in explaining the saturation flow when the variance in the model was controlled for as compared to that of speed (0.000) which made no contribution to the model as shown in Table 9.

The simulated equation connecting saturation flow (q), speed (u) and headway (h) is:

$$q = \left(1.47 \times 10^{-14}\right)u + 100h + 1337 \quad ...(8)$$

Comparison of Computed and Simulated Performance Indicators

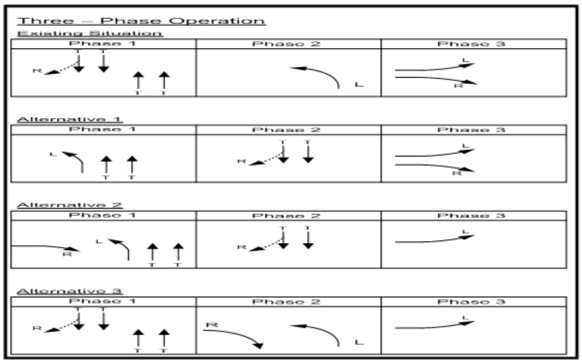
Computed manual performance indicators at the intersection were compared with the simulated performance indicators generated by the calibrated Synchro model as shown in Table 10.

Level of service D approached unstable flow, with tolerable operating speeds being maintained, though considerably affected by changes in operating conditions as shown in Table 10. Drivers had little freedom to maneuver, and comfort and convenience were low. These conditions could be tolerated, however, for short periods of time. It represented intermediate conditions.

Analysis of Alternative Phasing Plans

Change in phasing plan without Geometric Improvement

Figure 3: Existing traffic with alternative phasing plans at Stadium Junction intersection



Source: from study

Figure 3 shows the existing traffic situations together with their possible alternative phasing plans at the Stadium Junction intersection.

Out of the three possible alternative phasing plans at the Stadium Junction intersection, alternative 2 gave out the best optimized cycle length of 60 s with an offset of 41 s and an intersection delay of 45.7 s as in Table 11. These indicators compared to the existing indicators were better in terms of cycle length, v/c ratio and delay and yet the LOS was still D. Level of service D approached unstable flow, with tolerable operating speeds being maintained, though considerably affected by changes in operating conditions. Drivers had little freedom to maneuver, and comfort and convenience were low. These conditions could be tolerated, however, for short periods of time. It represented intermediate conditions. Site observations at the intersection however showed that the traffic congestion was mostly associated with the left turning traffic towards stadium. The storage length for the vehicles was exceeded and therefore the vehicles spilled back into the double lane for the through traffic. This therefore reduced the saturation flow for the through traffic at the intersection when the indication turned green.

Change in Phasing Plan with Geometric Improvement

The best alternative from the phasing plan was further investigated upon by adding lane(s) to the through put traffic at the intersection. Table 12 shows the summary of performance indicators with geometric improvement.

There was the need to introduce geometric improvement as correctional measure. When one lane was added to the major through put traffic from each approach, the v/c ratio was 0.78 with a corresponding reduction in delay as in Table 12. When 2 lanes each were added to each major through put approach, the v/c ratio was again 0.78 with a corresponding reduction in delay. Level of service D approached unstable flow, with tolerable operating speeds being maintained, though considerably affected by changes in operating conditions. Drivers had little freedom to maneuver, and comfort and convenience were low. These conditions could be tolerated, however, for short periods of time. It represented intermediate conditions. Similarly, the existing reservation was further checked against the geometric improvement.

Sensitivity Analysis

This was carried out to verify in detail the sensitivity of the obtained results to the variation of the input parameters.

When the mean input parameters values from Table 3 such as speed and headway were substituted in the modeled equations or obtained results as shown in Table 13, the

Table 10: Comparison Of Computed And Simulated Performance Indicators

Performance Indicators	Stadium	
	Computed	Simulated
Cycle Length (sec)	68	65
Volume to capacity ratio (v/c) ratio	1.53	0.78
Intersection Delay (sec)	37	47.7
Intersection Level of Service, LOS	D	D
Intersection Capacity Utilization, ICU (%)		63.2
Offsets		41

Source: from study

Table 11: Results of performance indicators for three Different Alternatives

Performance Indicators	Existing Situation	Alternative 1	Alternative 2	Alternative 3
Cycle Length	65	65	60	60
v/c ratio	0.78	0.78	0.78	0.78
Int. Delay (s)	47.7	47.7	45.7	45.7
Int. LOS	D	D	D	D
ICU (%)	63.2	63.2	63.2	63.2
Offsets	41	41	41	41

Source: from study

Table 12: Summary of performance indicators with geometric improvement

Performance Indicators	Existing Situation	Alternative 1	Alternative 2	Alternative 3
Cycle Length	65	60	60	60
v/c ratio	0.78	0.78	0.78	0.78
Int. Delay (s)	47.7	45.7	40.7	39.0
Int. LOS	D	D	D	D
ICU (%)	63.2	63.2	56.2	52.1
Offsets	41	41	41	41

Source: from study

Table 13: Sensitivity Analysis of Saturation Flow

Conditions	Approaches	Obtained Results	Speed, u (km/h)	Headway, h (s)	Saturation Flow, q (pcu/hr/lane)
Field	From KNUST	$q = -10.446u - 242.446h + 2404.311$	26.63	2.59	1498
	To KNUST	$q = -5.109u - 528.143h + 3057.240$	28.43	2.56	1560
Simulated	From KNUST	$q = \left(-4.3 \times 10^{-14}\right)u + 100h + 949$	26.63	2.59	1208
	To KNUST	$q = \left(1.47 \times 10^{-14}\right)u + 100h + 1337$	28.43	2.56	1971

Source: from study

following saturation flow values were obtained for the field and simulated conditions from and to KNUST approaches.

From the sensitivity analysis in Table 13, it was deduced that 80.4% indicated that there was no variation between the saturation flow values of the field and simulated conditions from the KNUST approach with 19.4% indicating that there was slight variation between the saturation flow values of the field and simulated conditions from KNUST approach. Similarly, 79.1% indicated that there was no variation between the saturation flow values of the field and simulated conditions to KNUST approach with 20.9% indicating that there was slight variation between the saturation flow values of the field and simulated conditions to KNUST approach. The variations in the saturation flows for field and simulated conditions was attributed to the fact that headway made the strongest contribution in explaining the saturation flow when the variance in the model was controlled for as compared to that of speed which made a small contribution to the model. The sensitivity analysis further confirmed that the obtained results from the simulation model were good as the model replicated the specific real world characteristics of interest. Generally, the obtained results showed no variations to the input parameters from the sensitivity analysis from and to KNUST approaches and that the obtained results could be validated at intersections with similar traffic volume characteristics, roadway geometry and signal timing.

CONCLUSION

Headway had a strong correlation with saturation flow for both field and simulated conditions of the model. Changes in phasing plan without geometric improvement at the intersection did not improve upon the overall intersection's level of service and therefore with the inclusion of geometric improvement, the intersection's level of service was enhanced. The existing control system needed to be replaced with a more effective, efficient and reliable control scheme to ensure smooth and safe operations. The storage length for left-turning vehicles should be increased from 73 m to 100 m to prevent vehicles from spilling back into the double lane for the through traffic.

The obtained results showed no variations to the input parameters from the sensitivity analysis from and to KNUST approaches and that, the obtained results could be validated at intersections with similar Traffic volume characteristics, roadway geometry and signal timing. Obtained results from micro simulation models can help the traffic engineer to comprehend the problems existing and design improvement plans at the intersection to reduce frequent delays and queue spillbacks which will consequently improve upon the levels of service at the intersection. Obtained results could be used in forecasting the future traffic conditions based on the present.

ACKNOWLEDGMENT

The authors would like to acknowledge the management of Kumasi Polytechnic, Kumasi headed by the Rector Prof. N N N Nsowah-Nuamah, for providing financial assistance and also Department of Urban Roads (DUR), Kumasi for giving information on signalized intersections in the Kumasi Metropolis. Several supports from staff of the Civil Engineering Department, Kumasi Polytechnic, Kumasi are well appreciated.

REFERENCES

1. BCEOM and ACON Report (2004), "Consultancy Services for Urban Transport Planning and Traffic Management Studies for Kumasi and Tamale for DUR (Ministry of Transportation, Ghana)", Chapter 5, pp. 4-6, 8, 67, 86-87,117.
2. Brackstone M and McDonald M (1999), "Car-following: a historical review", *Transportation Research Part F*, Vol. 2(4), pp. 181-196.
3. Carole Turley (2007), "Calibration Procedure for a Microscopic Traffic Simulation Model", A Thesis submitted to the faculty of Brigham Young University, pp 2-19.
4. Drew D R (1968), *Traffic flow theory and control,* New York: McGraw-Hill
5. Gazis D C, Herman R and Rothery R W (1961), "Follow-the leader models of traffic flow", *Operations Research*, Vol. 9, No. 4, pp. 545-567. [doi:10.1287/opre.9.4.545]
6. Gerlough D and Huber M (1975), *Traffic flow theory. A monograph.* TRB Special Report 165. Washington, DC.
7. Gipps P G (1981), "A behavioral car-following model for computer-simulation", *Transportation Research Part B: Methodological*, Vol. 15(2), pp. 105-111. [doi:10.1016/0191-2615 (81)90037-0]
8. Gunay B (2007), "Car following theory with lateral discomfort", *Transportation Research Part B: Methodological*, Vol. 41(7), pp. 722-735. [doi:10.1016/j.trb.2007.02.002]
9. Jin S, Wang D H, Tao P F and Li P F (2010), "Non-lane-based full velocity difference car following model. *Physica A: Statistical Mechanics and Its Applications*, Vol. 389(21), pp. 4654-4662. [doi:10.1016/j.physa.2010.06.014]

10. Kallberg H (1971)., "Traffic simulation (in Finnish)", Licentiate thesis, Helsinki University of Technology, Transportation Engineering, Espoo.

11. Kikuchi C and Chakroborty P (1992), "Car following model based on a fuzzy inference system", *Transportation Research Record*, Vol. 1365, pp. 82-91.

12. Liu P, Lu J, Fan J, Pernia J and Sakolow G (1999), "Effect of U-Turns on Capacity of Signalized Intersections, in Transportation Research Record 1920", *Journal of the Transportation Research Board*, 2005, pp. 74-80.

13. Luo L H, Liu H, Li P and Wang H (2010), "Model predictive control for adaptive cruise control with multi-objectives: comfort, fuel-economy, safety and car-following", *Journal of Zhejiang University-SCIENCE A (Applied Physics and Engineering)*, Vol. 11(3), pp. 191-201. [doi:10.1631/jzus.A0900 374]

14. Mathew T V and Radhakrishnan P (2010), "Calibration of micro simulation models for nonlane-based heterogeneous traffic at signalized intersections", *Journal of Urban Planning and Development*, Vol. 136(1), pp. 59-66. [doi:10.1061/ (ASCE)0733-9488(2010)136:1(59)]

15. McDonald M, Brackstone M and Sultan B (1998), "Instrumented vehicle studies of traffic flow models", Proceedings of the Third International Symposium on Highway Capacity, Vol. 2, Ryysgaard R (Ed.), pp. 755-774, Copenhagen: Transportation Research Board and Danish Road Directorate.

16. Minh and Sano (2003), "Traffic Policy Evaluations Using Micro Traffic Simulation: A Case Study of Thailand", Paper for Presentation at the 2003 Meeting of the Transportation Research Board, Washington, D.C., USA.

17. Newell G F (1961), "Nonlinear effects in the dynamics of car following", *Operations Research*, Vol. 9(2), pp. 209-229.

18. Turner and Harahap (1993), "Simplified Saturation Flow Data Collection Method: Overseas Centre", Transport Research Laboratory, Crowthorne Berkshire RG456AU, United Kingdom PA1292/93

19. Wiedemann R (1974), *Simulation des Straß Enverkehrsflusses Schriftenreihe des Instituts für Verkehrswesen der Universität Karlsruhe* (in German).

20. Wu J P, Brackstone M and McDonald M (2000), "Fuzzy sets and systems for a motorway microscopic simulation model", *Fuzzy Sets and Systems*, Vol. 116(1), pp. 65-76. [doi:10.1016/ S0165-0114(99)00038-X]