APPRAISAL OF AIRPORT ROUNDABOUT ON THE ANTOA ROAD, KUMASI-GHANA USING MICRO SIMULATION MODEL

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Abstract

Roundabouts have become increasingly popular in recent years as an innovative operational and safety solution at both low volume and high volume intersections. Roundabouts have a number of advantages over traffic signals depending on the conditions. They reduce the severity of crashes since head-on and right-angle conflicts are nearly eliminated. They reduce through traffic speeds to provide a "calmer" roadway environment. This study appraised Airport roundabout on the Antoa Road in Kumasi, Ghana using micro simulation model. Traffic and geometric data were collected on the field. The analysis revealed that Airport roundabout was operating at a level of service F, which represented worst conditions. Signalized intersection with 4 approach lanes on the two principal arterials was proposed to control all the movements. Exclusive pedestrian phases were proposed to protect pedestrians.

***Keywords**: Appraisal, Airport roundabout, Capacity analysis, Antoa Road.*

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1. INTRODUCTION

As defined by the Federal Highway Administration [1], modern roundabouts are circular intersections with specific traffic control and design features. These features include yield control at entry, channelized approaches, and geometric approach curvature (deflection) to induce entering traffic to slow down to the design speed of the circulatory roadway. The crosswalks are set back from the intersection to minimize conflicts with turning vehicles. Roundabouts have characteristics that differentiate them from traffic circles, rotaries and traffic calming circles. Roundabouts have a proven safety record that is superior to other forms of traffic control [2 - 4]. The stretch of the Antoa road between the Airport roundabout and Buokrom area gets very congested especially during the morning and evening peak periods. Airport roundabout, which is on the Antoa road is a very busy roundabout and congested during the morning and evening peaks [5]. The activities of the washing bay around the airport roundabout also affect the smooth flow of traffic on the Airport-Buokrom section. There are virtually no sidewalks, resulting in pedestrians walking on the road, thereby exposing them to danger [5].

Previous studies on the performance of the roundabout attributed the congestion critical capacity and abuse to motorists and/or pedestrians. As part of the recommendations, the report proposed to improve upon the signalization and capacity at Airport roundabout. They recommended that if at-grade capacity cannot be obtained for the minimum requirements, then a grade separation scheme should be constructed at the roundabout. This could either be a flyover or an interchange [5].

These recommendations have not been implemented due to lack of funds and therefore long queues and frequent delays still persist during the morning and evening peaks of the day at the roundabout. It is in this light that this study was undertaken to appraise the capacity and performance of Airport roundabout in Kumasi to find out an effective way of resolving the traffic congestion problem.

2. METHODOLOGY

2.1 Site Selection and Description

Airport roundabout was selected based on its accident and safety records in the past and also the levels of congestion associated with the roundabout. Airport Roundabout Airport roundabout has five (5) legs with two (2) approach/entry and exit lanes on all legs, except the Manhyia/Kejetia and the Buokrom legs, which have one (1) approach/entry and exit lanes as shown in Fig 1. Airport roundabout is the intersection of two (2) Principal arterials and a local road, namely: Okomfo Anokye road - Principal Arterial, Antoa road - Principal Arterial, and Airport road – Local road as shown in Fig. 1.

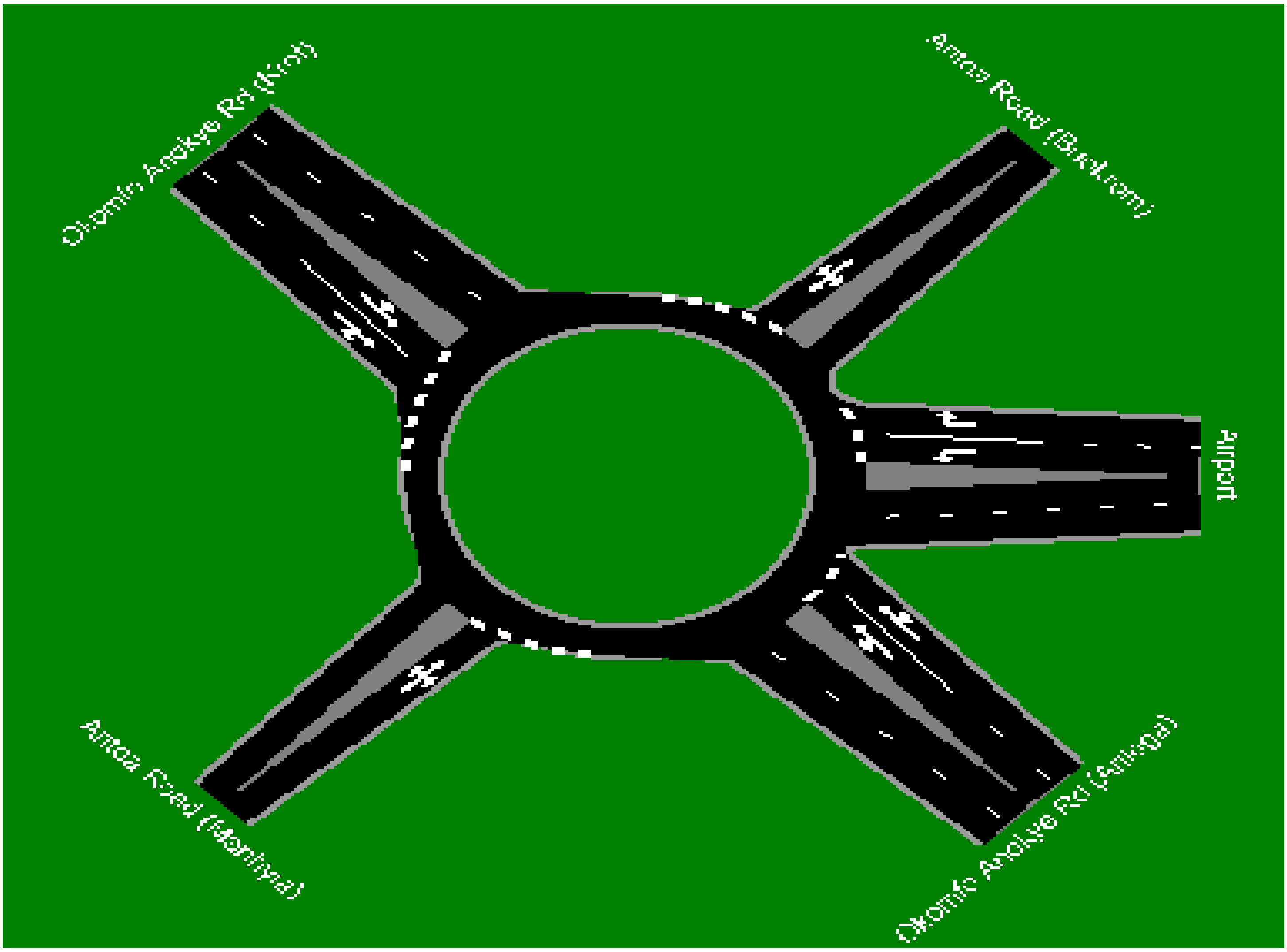

Fig-1: Geometry of Airport Roundabout; Source: BCEOM and ACON Report (2004)

2.2 Study Area

2.2.1 Okomfo Anokye Road

The Okomfo Anokye Road is a principal arterial running mostly in a North/South direction (Anloga Junction to Airport Roundabout) and mostly in an East/West direction (Airport roundabout to Suame Roundabout). It covers a distance of about 6.4 km, (from Anloga Junction to Suame Roundabout). The road is a paved 2-lane dual carriageway (4-lane 2-way), over its entire stretch. The road forms part of the ring road and it provides a major vital link between the Western By-Pass, Mampong Road and Offinso Road and the 24th February Road. This vital link serves as a bypass route, especially for the North/South travellers of the country.

The intersections along this road are the main cause of bottlenecks on the road. The intersection controls are not good enough and driver indiscipline also compounds it. The Adukrom intersection experiences illegal U-turns within the intersection, which creates hazardous conditions for on-coming traffic. There are lots of delay and conflicting movements at the Asokore Mampong Road/Aboabo Road intersection. This is due to the existing phasing plan/signal timings. There is a lot of diverted traffic joining the Asokore Mampong leg from Buokrom to avoid the congestion at the Airport Roundabout. This makes the approach volume heavy as against a small green time allotted to it.

2.2.2 Antoa Road

The Antoa road is a principal arterial, which runs mostly in a North-South direction. The road covers an urban, (study) length of about 6 km, (from Kejetia/Dr. Mensah to Buokrom area). The road is a single carriageway and it is paved throughout its entire length. The Antoa Road has a short one-way section, about 150 meters between "Dr. Mensah" and Odumase road intersection.

The Kejetia, (Dr Mensah) area is very congested as it is in the central business district. The road in this area is narrow with residences closely abutting it. The stretch of the Antoa road between the Airport roundabout and Buokrom area gets very congested especially during the morning and evening peak periods. A lot of diverted traffic from the Mampong road joins the Antoa road at the Buokrom Estate road intersection. The activities of the washing bay around the airport roundabout also affect the smooth flow of traffic on the Airport-Buokrom section. There are virtually no sidewalks, resulting in pedestrians walking on the road, thereby exposing them to danger.

2.2.3 Airport Road

The airport road leads to the Kumasi Airport.

2.3 Basic Theoretical Background

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 [6]. 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 [7].The car-following theory is of significance in microscopic traffic flow theory and has been widely applied in traffic safety analysis and traffic simulation [8, 9]. 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 [10], car-following models can be classified as stimulus-response models [11,12], safety distance models [13], psycho-physical models [14], and artificial intelligence models [15, 16].

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 [17]. 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 [18]. 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. [17] first developed a car-following model with lateral discomfort. He improved a stopping distance based approach that was proposed by [13], and presented a new car-following model, taking into account lateral friction between vehicles.[19] 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.

2.3.1 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.

2.3.1.1 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 equation 1.

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

Where,

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

- χ_F = speed of the following vehicle,
- χ_L = speed of the leading vehicle,

αF = sensitivity of the following vehicle, and
t = time.

2.3.1.2 PITT Car-following Model

FRESIM uses the PITT car-following model, which is expressed in terms of desired space headway, shown in the equation 2.

$$h_s(t) = L + m + kV_2 + bk[V_1(t) - V_2(T)]^2 \qquad \text{Eq. (2)}$$

Where,
hs(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,
v1(t) = speed of leading vehicle at time t, and
v2(t) = speed of following vehicle at time t.

Equation above can be solved for the following vehicle's acceleration, given by the equation 3.

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

Eq. (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.

2.4 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:

2.4.1 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.

2.4.2 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.

2.4.3 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.

2.4.4 Turning Movement Counts

Data was collected manually at Airport roundabout because it was difficult getting good elevation observer positions. Turning movement counts were collected between 0600hours and 1800 hours during the morning and evening peak periods of the day at the roundabout. Two enumerators each were positioned on each leg of the approach to the roundabout. The number of vehicles entering and leaving the two principal arterials such as Antoa road and Okomfo Anokye road and the local road such as the Airport road were counted using the vehicle number plate method. All the Turning movement counts were conducted at 15min intervals.

2.4.5 Intersection Capacity Analysis for Suame Roundabout

The Department of Transport of the UK recommends a research carried out by the Transport and Road Research Laboratory (TRRL) that predicts an equation for the determination of the capacities of roundabouts. The predictive equation for entry capacity into the circulatory area was used for entry capacity determination and is given by equation 4.

$$Qe = K*(F - f_c\,Qc) \qquad \text{Eq. (4)}$$

Where,
Qe is the entry flow into the circulatory area in passenger car units per hour (pcu/hr)
Qc is the flow in the circulatory area in conflict with the entry flow in passenger car units per hour (pcu/hr).
$K = 1-0.00347(\phi - 30) - 0.978(1/r - 0.05)$
$F = 303X_2$
$f_c = 0.21tD(1+0.2X_2)$
$tD = 1+0.5/(1+M)$
$M = \exp[(D - 60)/10]$
$X_2 = v + (e - v)/(1+2S)$
$S = 1.6(e - v)/l'$
e = entry width (metres) - measured from a point normal to the rear kerbside
v = approach half-width: measured along a normal from a point in the approach stream from any entry flare
l' = average effective flare length: measured along a line drawn at right angles from the widest point of the entry flare
S = sharpness of flare: indicates the rate at which extra width is developed within the entry flare
D = inscribed circle diameter: the biggest circle that can be inscribed within the junction
ϕ = entry angle: measures the conflict angle between entering and circulating traffic
r = entry radius: indicates the radius of curvature of the nearside kerb line on entry.

2.4.6 Intersection Capacity Analysis

The intersection Capacity analysis was performed using intersection capacity utilization (ICU) to determine the Level of service (LOS) at Suame roundabout. An initial analysis was performed for the existing rotary intersection to determine its performance. Once the ICU was fully calculated, the ICU LOS for the roundabout was subsequently calculated based on the criteria given by [20] Table -1.

Table -1: Intersection Capacity Utilization LOS and Grading Criteria

LOS	ICU (%)	Grading Criteria
A	≤ 55	Intersection has no congestion
B	55<ICU<64	Intersection has very little congestion
C	64<ICU<73	Intersection has no major congestion
D	73<ICU<82	Intersection normally has no congestion
E	82<ICU<91	Intersection is on the verge of congested conditions
F	91<ICU<100	Intersection is over capacity and likely experiences congestion periods of 15 to 60 consecutive minutes
G	1005<ICU<109	Intersection is 9% over capacity and experiences congestion periods of 60 to 120 consecutive minutes.
H	>109%	The intersection is 9% or greater over capacity and could experience congestion periods of over 120 minutes per day.

3. RESULTS AND DISCUSSION

3.1 Turning Movement Counts

Summary of total approach volume for each approach at Airport roundabout is shown in Table 2.

Table -2: Summary of Total Approach volume at Airport Roundabout

Approaches	Anloga Jn	Krofrom	Kejetia	Buokrom	Airport	Total
Anloga Jn	0	1452	900	860	26	3238
Krofrom	1896	0	189	563	35	2683
Kejetia	989	198	0	960	33	2180
Buokrom	542	322	1230	0	13	2107
Airport	65	36	49	23	0	173
Total	3492	2008	2368	2406	107	

Source: from study

It can be deduced from Table 2 that 31.2% of vehicles moved from Anloga Junction approach to the other approaches at Airport roundabout. This was followed by 25.8% of vehicles from Krofrom, 21.0% of vehicles from Kejetia whiles 20.3% of vehicles moved from Buokrom approach. Airport approach had 1.7% of vehicles moving to other approaches.

3.2 Capacity Analysis

Hourly flow rate for the approaches at Airport Roundabout is shown in Table 3

Table -3: Capacity calculations for Airport Roundabout

Approaches	Hourly flow rate (veh/hr)
East Bound North (EBN), V_1	1452
East Bound West (EBW), V_2	900
East Bound South (EBS), V_3	860
East Bound South East (EBSE), V_4	26
West Bound North (WBN), V_5	198
West Bound East (WBE), V_6	989
West Bound South (WBS), V_7	960
West Bound South East (WBSE), V_8	33
North Bound East (NBE), V_9	1896
North Bound West (NBW), V_{10}	189
North Bound South (NBS), V_{11}	563
North Bound South East (NBSE), V_{12}	35
South Bound North (SBN), V_{13}	322
South Bound West (SBW), V_{14}	1230
South Bound East (SBE), V_{15}	542
South Bound South East (SBSE), V_{16}	13
South East North (SEN), V_{17}	36
South East West (SEW), V_{18}	49
South East South (SES), V_{19}	23
South East East (SEE), V_{20}	65

Source: from study

From Table 3, it was realized that North Bound East (NBE), V_9 had the highest hourly flow rate of 1896veh/hr at Airport roundabout. This meant that 1896 vehicles traversed the north bound east direction in an hour. Similarly, South Bound South East (SBSE), V_{16} had the lowest hourly flow rate of 13veh/hr meaning 13 vehicles traversed the South Bound South East direction within an hour.

Table - 4: Approach Flow at Airport Roundabout

Approach Flow (veh/hr)	Approach Volume, Va
$Va,E = V_1+V_2+V_3+V_4$	3238
$Va,W = V_5+V_6+V_7+V_8$	2683
$Va,N = V_9+V_{10}+V_{11}+V_{12}$	2180
$Va,S = V_{13}+V_{14}+V_{15}+V_{16}$	2107
$Va,SE = V_{17}+V_{18}+V_{19}+V_{20}$	173

Source: from study

Va,E approach had the highest approach flow of 3238veh/hr as shown in Table 4 at Airport roundabout. This meant that 3238vehicles came from Va,E approach in an hour. 2683veh/hr came from Va,W approach, followed by Va,N approach which had 2180veh/hr. Va,S approach gave 2107veh/hr and Va,SE approach gave a lowest approach volume of 173 veh/hr.

Table -5: Circulating flows at Airport Roundabout

Circulating Flow	Flow, Qc (veh/hr)	Flow in pcu/hr (x1.1)	Factored Flow (x1.125)
Vc,E = $V_1+V_2+V_3+V_4$	1858	2044	2299
Vc,W = $V_5+V_6+V_7+V_8$	3088	3397	3821
Vc,N = $V_9+V_{10}+V_{11}+V_{12}$	3403	3743	4211
Vc,S = $V_{13}+V_{14}+V_{15}+V_{16}$	3177	3495	3932
Vc,SE = $V_{17}+V_{18}+V_{19}+V_{20}$	5177	5695	6407

Vc,SE approach had the highest circulating flow of 5177veh/hr at Airport roundabout, Vc,N approach which gave a circulating flow of 3403veh/hr as shown in Table 5. Vc,S approach had a circulating flow of 3177veh/hr with Vc,W approach having the lowest circulation flow of 18585veh/hr. Similarly, in terms of flow in pcu, Vc,SE approach gave the highest flow of 5695pcu/hr and the Vc,E approach gave the least flow of 2044pcu/hr.

Entry capacity, circulating flow and reserve capacities for each approach at Airport roundabout is shown in Table 6.

Table -6: Entry capacity, circulating flow and reserve capacity for the approaches at Airport Roundabout

Parameters	Airport	Krofrom	Anloga Jn	Buokrom	Kejetia
Entry width, e	7.7	7.7	7.7	7.7	7.7
Approach Half width, v	7	7	7	7	7
Average Effective Flare Length, l’	15	15	15	15	15
Sharpness of Flare, S	0.07467	0.07467	0.07467	0.07467	0.07467
Inscribed Circle Diameter, D	78	78	78	78	78
Entry Angle, Φ	60	60	60	60	60
Entry Radius, r	60	60	60	60	60
M	6.04965	6.04965	6.04965	6.04965	6.04965
X_2	7.60905	7.60905	7.60905	7.60905	7.60905
tD	1.07093	1.07093	1.07093	1.07093	1.07093
fc	0.56714	0.56714	0.56714	0.56714	0.56714
F	2305.5418	2305.5418	2305.5418	2305.5418	2305.5418
K	0.9285	0.9285	0.9285	0.9285	0.9285
Qc	1752	3821	4211	3932	6407
Qe	1218	128	-77	70	-1233

Source: from study

From Table 6, it was realized that the Kejetia approach had the highest circulatory flow of 6407pcu/hr at Airport roundabout. This meant that 6407 of the flow in the circulatory area was in conflict with the entry flow of -1233. Airport approach had the lowest circulatory flow of 1752pcu/hr. This again meant that 1752 of the flow in the circulatory area was in conflict with the entry flow of 1218.

The flow to capacity ratios of each approach at Airport Roundabout is shown in Table 7.

Table -7: Flow to Capacity ratios at Airport Roundabout

Approaches	Circulating flow, Qc	Entry capacity (pcu/hr)	Entry flow (pcu/hr)	Reserve capacity (%)	Flow to capacity ratio
Anloga Jn	4211	-77	3238	-166	2.66
Krofrom	3821	128	2683	3589	-34.89
Kejetia	6407	-1233	2180	-1598	16.98
Buokrom	3932	70	2107	-2893	29.93
Airport	1752	1218	173	114	-0.14

Source: from study

It was realized again from the capacity analysis that Airport roundabout was at full capacity based on the overall volume to capacity ratio as shown in Table 7. The above flow to capacity ratios revealed that Airport roundabout was operating at a level of service F. Level of service F described a forced-flow operation at low speeds, where volumes were below capacity. These conditions usually resulted from queues of vehicles backing up a restriction downstream at the roundabout. Speeds were reduced substantially and stoppages occurred for short or long periods of time because of the downstream congestion. It represented worst conditions.

3.3 Intersection Capacity Analysis

Performance of Airport roundabout after capacity analysis is shown in Table 8

Table 8: Performance of Airport roundabout

Intersection	Control Type	v/c ratio	ICU %	ICU LOS
Airport Roundabout	Roundabout	4.48	187.9	H

Source: from study

The result from Table 8 showed that Airport roundabout was performing beyond capacity in that, the roundabout was 9% or greater over capacity and was experiencing congestion over 2 hours per day.

3.4 Signalization and Improvement of Airport Roundabout

The proposed Geometry for Airport Roundabout is shown in Fig.2.

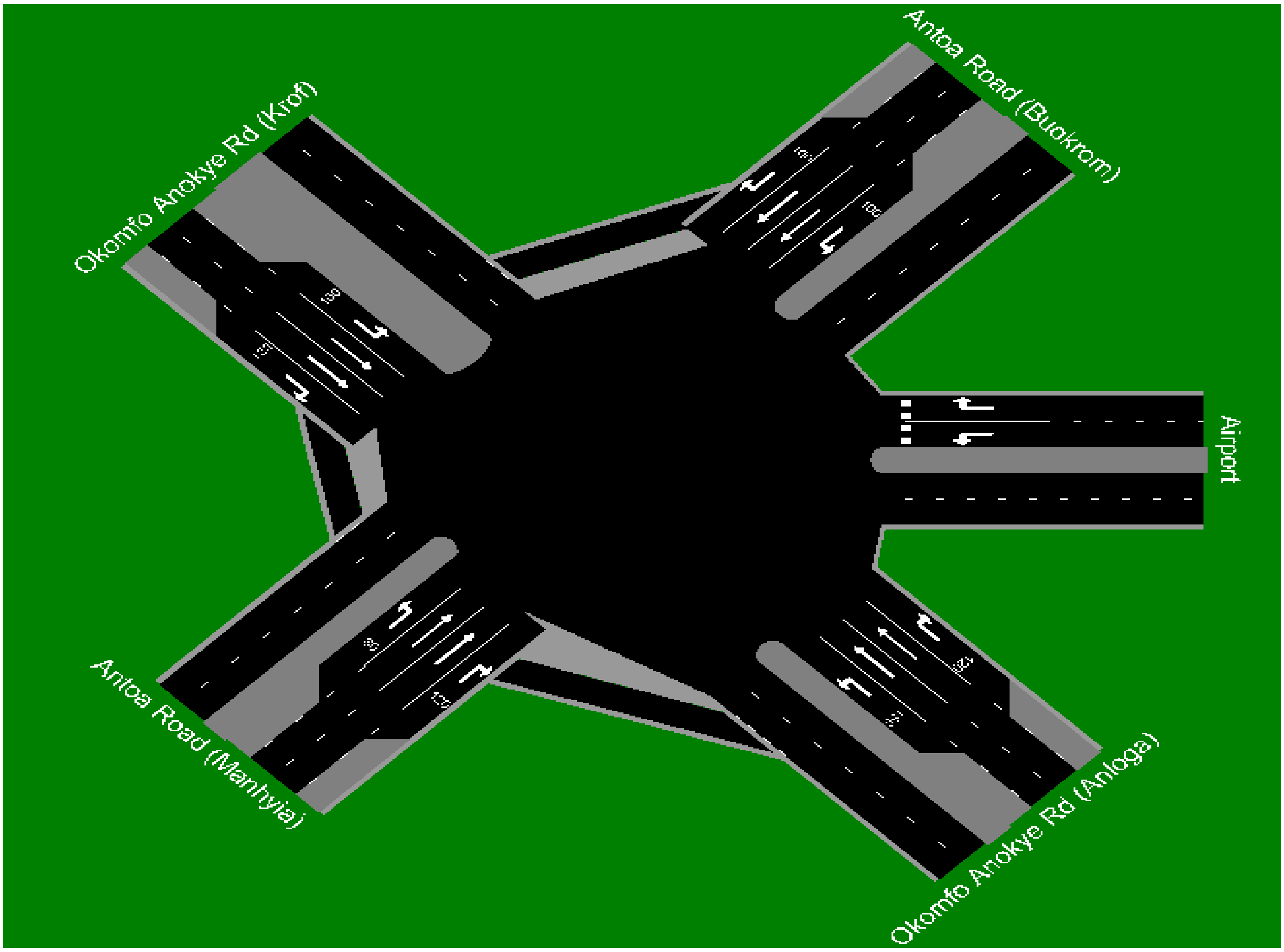

Fig 2: Proposed Geometry for Airport Roundabout; Source: from study

Signalized intersection with 4 approach lanes for the principal arterials was proposed as shown in Fig. 2. The Airport roundabout signalization was basically to improve on vehicular movement. However, signalization was proposed considering the non-availability of funds. By critical and careful examination of the conditions, signalization of the Airport roundabout was proposed to control all the movements. The proposed geometric data in Table 9 when implemented will improve upon the performance of the intersection. The central island would be channelized to aid motorists to move from one approach to the other in order to prevent conflicts and enhance safety. Pedestrian movements would be separated in order not to interrupt the flow by considering the number of lanes at each approach to the roundabout. A pedestrian footbridge was thus proposed on all legs to the roundabout.

Table -9: Proposed Geometric Data for Airport Roundabout

Intersection: Airport Roundabout							
Movement	From (Area)	To (Area)	Veh/hr	% of Heavy vehicles	No. of Lanes	Lane width (m)	Storage Length (m)
NWBL		Kejetia	900	8	1	3.3	150.0
NWBT	Anloga Jn	Krofrom	1452	11	2	3.3	
NWBR		Buokrom	860	7	1	4.8	120.0
NWBR2		Airport	26	0			shared
SEBL		Airport	35	0	1	4.0	150.0
SEBL2	Krofrom	Buokrom	563	7			shared
SEBT		Anloga Jn	1896	18	2	3.3	
SEBR		Kejetia	189	12	1	4.8	120.0
NEBL		Krofrom	198	9	1	4.0	80.0
NEBT	Kejetia	Buokrom	960	17	2	3.3	
NEBR		Airport	33	0	1	4.8	120.0
NEBR2		Anloga Jn	989	16			shared
SWBL2		Airport	13	0			shared
SWBL	Buokrom	Anloga Jn	542	10	1	4.0	100.0
SWBT		Kejetia	1230	17	2	3.3	
SWBR		Krofrom	322	13	1	4.8	100.0
WBL		Kejetia	49	0	1	3.4	
WBL2	Airport	Anloga Jn	65	0			shared
WBR		Krofrom	36	0	1	3.4	
WBR2		Buokrom	23	0			shared

Source: from study

CONCLUSIONS

Airport roundabout was performing at full capacity based on the overall volume to capacity ratio. Suame Roundabout should be signalized to control all the movements.

It is cheaper to implement the signalised intersection to control and alleviate vehicular movement than implementing the interchange. The central island should be channelized to enable motorists move from one approach to the other in order to prevent conflicts and enhance safety. A pedestrian footbridge should be constructed on all legs to the roundabout.

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