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An Evaluation of the Spatiotemporal Variation in the Degree of Saturation of Traffic at Signalised Roundabouts in a Typical Nigerian City

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Abstract
The degrees of saturation of traffic at the approaches to the two major signalised junctions, Fajuyi Roundabout, and Matthew Roundabout at Ado Ekiti, Nigeria, which are spaced at approximately 500m, were determined for the weekdays and weekend. In general, the results showed morning peaks at 7am-9am, evening peaks at 3pm-6pm and inter-peaks between these periods, especially around noon during weekdays at the roundabouts. There were mainly low-value peaks at 7am-9am and 3pm-5pm respectively on Saturday while the values on Sunday were mainly uniform; and the lowest. The most significant differences in the traffic flow at the two junctions were the congestion being experienced at Irona Street approach of Matthew Roundabout during weekdays, and the high degree of saturation of traffic between 12noon-5pm at the Ijigbo Street approach of the roundabout on Sunday. Even with this, there was relative similarity in the temporal variation of the degree of saturation of traffic at the two roundabouts, which was attributed to the similarity in their location, and thus traffic flow, as both are sited at the city centre. Other contributory factors include the short spacing and comparable land-use.
Keywords: degree of saturation, signalised roundabout, traffic control lights, congestion, traffic stream

1. Introduction

The increase in the economic wealth of the majority of countries in the world has led to increase in car ownership. The rural-urban migration in the developing countries in the world has made vehicles to be concentrated in the urban areas. This has resulted in increased traffic, leading to travel delays and accidents, mainly at junctions. The conflicts resulting from the cross movement of vehicles at junctions make the majority of accidents with injury to occur at these spots while accidents with most fatalities occur on highways, owing mainly to higher speed (Archer and Vogel, 2000). In Nigeria, roundabouts are the most common type of junctions built on highly trafficked roads and streets. They are commonly used to replace existing priority junctions that appear not to cope with increased traffic. Similarly, traffic control lights (signals) are installed at the roundabouts that appear not to cope with additional traffic over time. Often, this is done following persistence of traffic congestion at the junction after the introduction of traffic wardens. Optimisation of traffic signal timings through computer programming enables various timing options of complex traffic situations to be obtained in a flash. The advantages of using traffic control lights at roundabouts are numerous. These include: (i) increasing the traffic handling capacity; (ii) providing human safety by interrupting traffic to enable pedestrians to cross; (iii) reduce delays and maximise the capacity of several isolated roundabouts (junctions) over large areas through the linking of their signals; and (iv) reduce operating cost by effectively controlling traffic at a lower cost compared to manual control (Wright and Ashford, 1989; Slinn et al., 1998, Oni, 2008).

There has not been any major traffic signal software developed and commercially available in Nigeria, however, some authors have reported investigations undertaken to enhance traffic at junctions with control signals lights. Ganiyu et al. (2011) reported the use of a Timed Coloured Petri Net (TCPN) formalism to model and simulate a multiphase traffic light controlled junction with an associated fixed timing plan, however, the introduction of modelling features such as presence of pedestrians and motorcycles at the aforementioned junction were not considered. Similarly, Osigwe et al. (2011) used a fuzzy logic control to design and simulate intelligent traffic control system and reported the method enhanced traffic control in terms of total waiting time. OSCADY PRO (Optimised Signal Capacity and Delay: Phased-based Rapid Optimisation) software (Burtenshaw and Xiaoyan, 2003) developed by Transport and Road Research Laboratory (TRL), Wokingham, UK is commonly used as signal timing program for isolated junctions. In recent times, TRANSYT (TRAffic Network StudY Tool), which is globally acclaimed and used especially for large and complex systems, but also for isolated junctions, has developed an improved version, TRANSYT 15, which generate stages, phase delays and stage sequences automatically as in OSCADY PRO (TRL, 2013).

The degree of saturation of traffic is very important in traffic engineering as it used to know the ability of the carriageway to cope with the traffic demand it is subjected to. It relates the actual traffic flow to the maximum capacity of traffic sustainable by the carriageway. At signalised junctions (roundabouts), it is used to know the capability of both the signal control lights and the geometric design of the junction, including its approaches to cope with traffic flow with time. Traffic congestion is generally accepted to occur when the degree

of saturation is greater than 0.85 (85%). Investigations on the temporal degree of saturation at signalised junctions in Nigeria are not common despite the fact that such information will enhance the assessment of poorly performing junctions, in an attempt to change existing geometric designs or signal timings. In most cases, the degree of saturation is averaged for a day. Jimoh et al (2014) reported that the average degree of saturation of the traffic at non-signalised Tanke-Tipper Garage Roundabout in Ilorin, Nigeria was greater or equal to 1. Likewise, Asenime and Mobereola (2015) reported that the average service utilisation at the Maryland Interchange, Lagos was between 0.6 and 1.0. In many cases, the need to improve the junction facilities and characteristics are reported. While some authors, using questionnaires as instrument of research have reported the inability of the existing junctions to cope with traffic volume owing to bad geometric design, poor land-use and manual traffic control (Awosusi and Akindutire, 2010; Ukpata and Etika, 2012; Fadairo, 2013), others have used GIS to illustrate the same problem (Olusina and Samson, 2014; Ojiako et al., 2015). Direct field observations were used by Aderamo and Atomode (2012) to identify the need for signalising of the major junctions in Ilorin, Nigeria. Using an indirect approach, Utang and Peterside (2011) studied the spatio-temporal variations in urban vehicular emission in Port Harcourt city, Nigeria and suggested that the construction of roundabouts with appropriate geometric design at main junctions in the city would minimise traffic congestion.

2. Study Area

Ado Ekiti, a city in the southwest part of Nigeria is the study area. It is the capital of Ekiti State, which is one of the 36 states in Nigeria. The Federal Republic of Nigeria (Figure 1) is situated on the west coast of Africa. The latitudinal and longitudinal extent of the country is 4° to 14°N and 2° to 15°E respectively. It covers an area of 923,768 sq. km and has a coastline of 853km, which is bounded by Gulf of Guinea in the south. The total land boundary, which is 4047km, is bounded by Benin in the west, Niger in the north and Cameroon and Chad in the east. As at 2015, it has a population of 182.2 million, a GDP of $481.1billion and a GDP growth of 2.7% (World Bank, 2015). The data published by the Federal Road Safety Corps of Nigeria showed that the total cases of road traffic accidents reported in 2012 and 2013 were 14783 and 13583 respectively. Out of these, 40683 and 40057 persons were injured; 6573 and 6544 were fatalities respectively. The likely causative factors of the road traffic accidents in 2013 were mostly speed violation, loss of control and dangerous driving (FRSC, 2013).

Ado Ekiti is located between latitude 7º25’ and 7º47’north of the equator, and between longitude 5º5’ and 5º30’ east of the Greenwich Meridian (Figure 1). The population of Ado Ekiti from the last census in 2006 was 308,621 (NPC, 2006). The projected population of Ado Ekiti, in 2013, when the study was undertaken is 479,593, using a growth rate of 6.5%. The total cases of road traffic crashes in Ekiti State in 2012 and 2013 were 154 and 157 respectively. Out of these, 69 and 42 persons were killed; and 322 and 350 persons were injured respectively. Out of those killed in 2013, 39 were adults and 3 were children. Out of those injured in 2013, 319 were adults and 31 were children (FRSC, 2013). The majority of accidents occur in Ado Ekiti, which have more than 50% of the registered vehicles in Ekiti. From observations, the majority of accidents in Ado Ekiti involving injury appear to occur at or near a junction. It is therefore imperative to assess the traffic flow at junctions in the city. The road network of Ado Ekiti is shown in Figure 2. The signalised junctions used in this study are Fajuyi Roundabout and Ijigbo Roundabout. There are the major signalised roundabouts in Ado Ekiti, and are spaced approximately 500m apart (Figure 2). Fajuyi Roundabout comprises four approaches - Okesa Street, Adebayo Street, Iyin Road and Secretariat Street. There is a carriageway, adjacent to Secretariat Street, leading to some government quarters at the roundabout. Its traffic flow, although insignificant is counted with that of Secretariat Street, as they receive the same control light. Matthew Roundabout comprises four approaches namely, Irona Street, Ajilosun Street Matthew Street and Ijigbo Street.

3. Materials and Methods

The traffic data used in the study were obtained from field data - manual traffic counts and the geometric characteristics of the carriage way, including the roundabouts, which were obtained from the Ministry of Works. The relevant maps were obtained from desk studies. Prior to the field data acquisition, a preliminary survey of the study area was undertaken to study the land-use, human activities, vehicular flow pattern, control light timings, junction characteristics and unforeseen circumstances. This was done to ensure that the data obtained from the desk study was accurate and also to plan for the best way to obtain the field data. The traffic counts were collected on Monday, Wednesday and Saturday at Fajuyi Roundabout. Traffic flows on Monday and Wednesday respectively were taken to represent typical weekday traffic flows while the traffic on Saturday was taken to represent the peak traffic flow scenario at the weekend. The traffic counts were collected throughout the weekdays and weekend at Ijigbo Roundabout. Owing to the volume of the traffic data collected at the two roundabouts, there were taken to be representative of the traffic flow during weekdays and weekends.

Figure 1: Map of Nigeria showing States, Cities, Main Road and other Physical features (UN, 2014)

The traffic flow characteristics of the acquired data were calculated using standard equations. The saturation flow is obtained using the equation reported by Burtenshaw and Xiaoyan (2003) in OSCADYPRO user guide.

Thus:

The saturation flow (Kimber et al, 1986) is calculated as:

$$S_a = 2080 - 140\delta n - 428\delta G + 100(w - 3.25) \quad (1)$$

$$S_t = \frac{S_a}{\left(1+\left(\frac{1.5}{r}\right)\right)} \quad [2]$$

where:

Sa and St = are the saturation flows (pcu/hr) for straight-ahead and turning traffic respectively.'

δn = takes the value 1 for nearside lane (including single lane); 0 otherwise.

δG = take the value 1 for an uphill entry; 0 otherwise.

G = is the gradient (percent)

w = is the lane width (metres)

r = is the radius of turn (metres)

pcu= passenger car unit

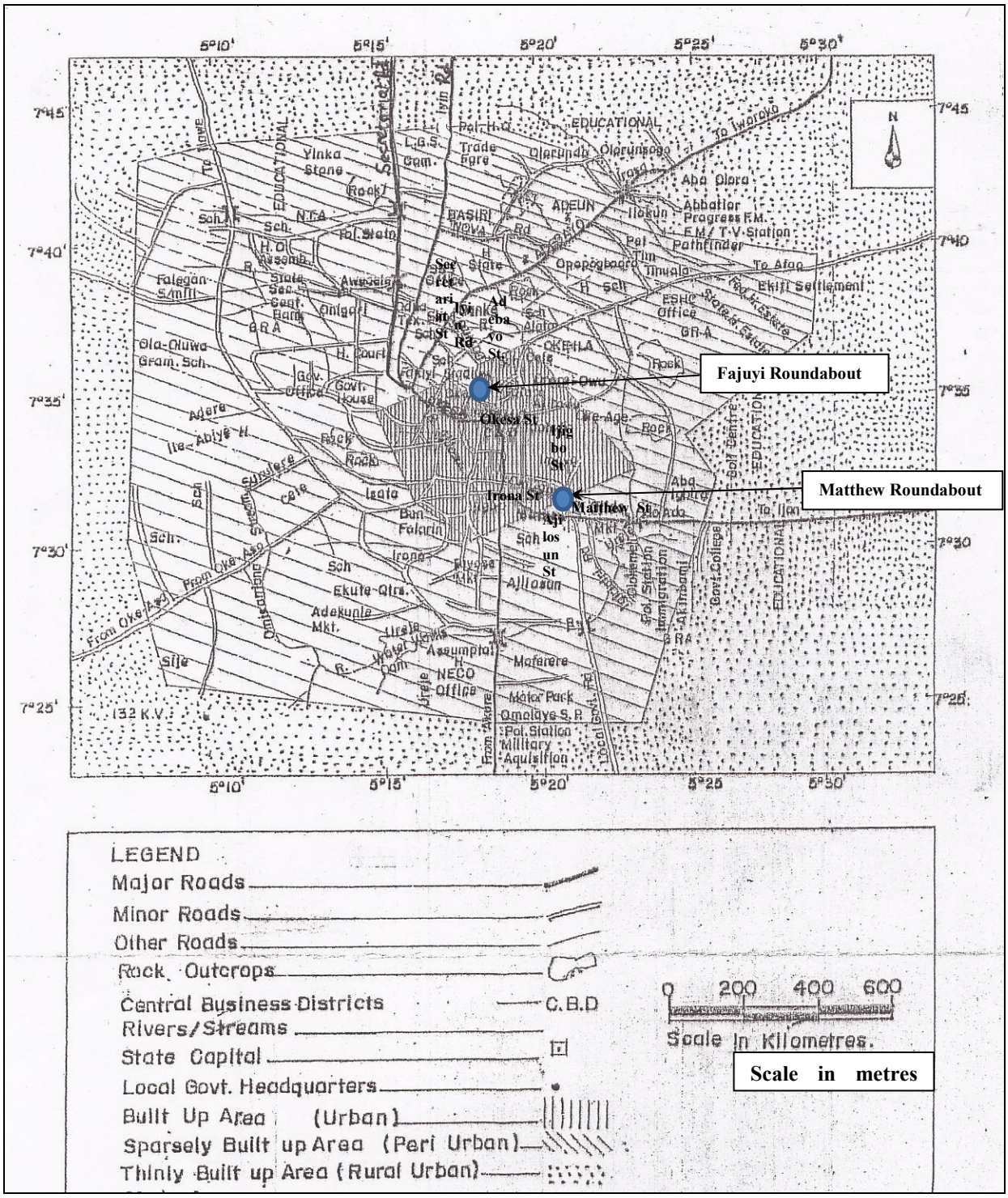

Figure 2: Figure 1: Map of the Road Network of Ado Ekiti (Ado Ekiti Local Government, nd; EKSU, 2010).

The maximum saturation flow (capacity) is calculated as:

$$Maximum\ saturation\ flow = \frac{saturation\ flow \times green\ time}{cyle\ time} \quad (3)$$

The degree of saturation is calculated as:

$$Degree\ of\ saturation = \frac{Demand}{Capacity} \quad (4)$$

4. Results and Discussion

The control light timings for the traffic at Fajuyi Roundabout and Matthew Roundabout are shown in Tables 1

and 2 respectively. The clearance time is 1s for all the approaches.

Table 1: Traffic Control Light Timings at Fajuyi Roundabout

Approach	Green Time(s)	Red Time(s)	Clearance Time(s)	Cycle Time (s)
Iyin Road	15	20	1	36
Adebayo Street	36	30	1	67
Okesa Street [First Traffic Signal]	20	45	1	66
Okesa Street [Second Traffic Signal]	36	29	1	66
Secretariat Street	15	20	1	36

Table 2: Traffic Control Light Timings at Matthew Roundabout.

Approach	Green Time (s)	Red Time (s)	Clearance Time (s)	Cycle Time (s)
Ajilosun Street	75	42	1	118
Irona Street	16	93	1	110
Matthew Street	19	34	1	54
Ijigbo Street	45	72	1	118

The temporal degree of saturation for the approaches at Fajuyi Roundabout is shown in Figures 3 to 6. The degree of saturation has been calculated from the formulae stated in equations 1-4. Owing to non-marking of the lanes at the approaches, the degree of saturation for the approaches at both roundabouts has been calculated from the aggregation of the degree of saturation of the traffic streams. Generally, there appeared to be morning and evening peaks and inter-peak periods of degree of saturation of traffic during the weekdays. However, there appeared to be only morning and evening peaks during the weekends, which have relatively low degree of saturation of traffic. At Okesa Street approach, there appeared to be inter-peaks of 10am-11am and 1pm-2pm between morning and evening peak periods of 7am-8am and of 4pm-5pm respectively during weekdays. At the weekend, there appeared to be morning and evening peak periods of 7am-8am and 4pm-5pm respectively. The approach appeared to be only congested on Wednesday morning. At Adebayo Street approach, there appeared to be peak period at various times – 7am-10am, 11am-12noon, 2pm-6pm during weekdays. At the weekend, there appeared to be peak periods during 8am-9am, 11am-12noon and 4pm-5pm. At Secretariat Street approach, there was low traffic between 7am-8am. This is not surprising as traffic was towards the Secretariat Street owing to resumption of work mainly by the civil servants and bankers that have offices along this street. Activities that require vehicular movement after resumption by these workers made the degree of saturation of traffic to peak nearly every hour till 4pm when these workers close during the weekdays. Conversely, there was a peak flow of 7am-9am and 3pm-5pm during Saturday. This was a period when people buy things at the shops located along the street, as people prefer to do their shopping in the mornings or late afternoons owing to the scorching sun. At Iyin Road, There were peak morning and evening periods of 7am-10am and 3pm-5pm respectively during the weekdays and weekend. However, there were also hourly inter-peaks between these periods during the weekdays.

Fajuyi Roundabout:

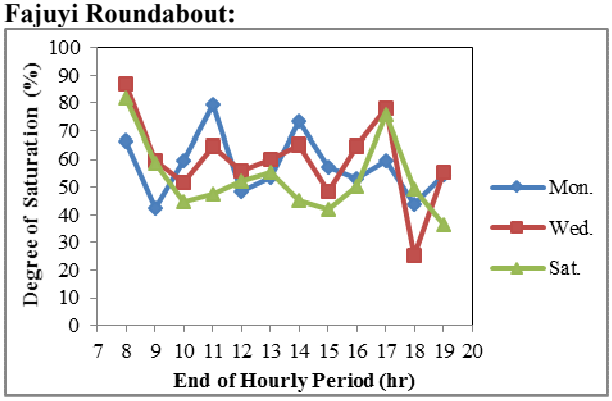

Figure 3: Okesa Street Approach

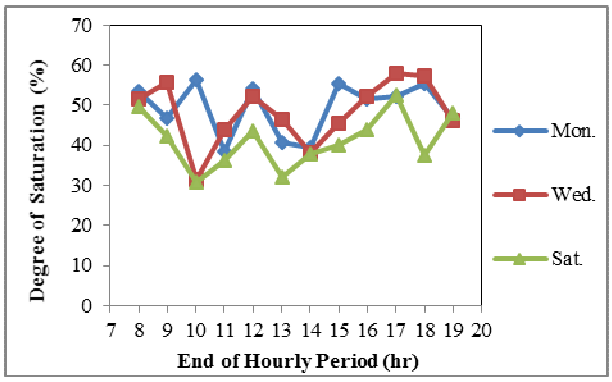

Figure 4: Adebayo Street Approach

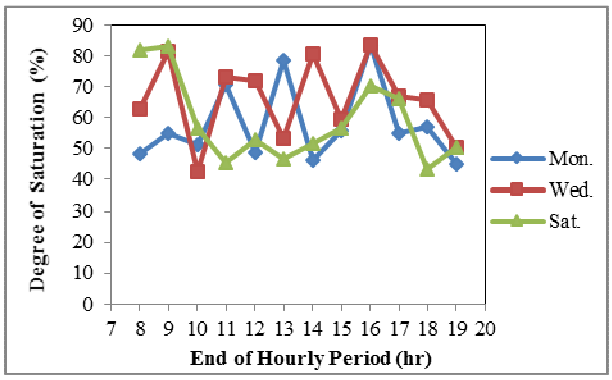

Figure 5: Secretariat Street Approach

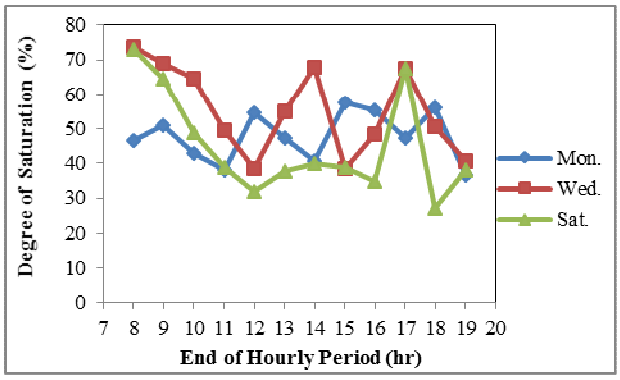

Figure 6: Iyin Road Approach

The temporal degree of saturation for the approaches at Matthew Roundabout is shown in Figures 7 to 10. In general, the degree of saturation of traffic appeared to be higher during the weekdays. At Ijigbo Street approach, there appears to be peak morning, midday and evening traffic flows at 7am-9am, 11am-1am and 3pm-5pm during weekdays. However, there appeared to be a peak flow during 12noon-5pm on Sunday. This was likely to be caused mainly by the movement of various church goers back home as there are many churches in the vicinity of the roundabout. The extended peak period was likely caused by the volume of church goers, variance in the closing periods of the churches and visits made by people to relatives after the church service. The traffic flow during Saturday was caused mainly by regular shoppers, and thus appeared uniform. At Matthew Street approach, there were generally peak periods at 7am-9am and 4pm-6pm respectively during weekdays except for Tuesday that had an evening peak at 3pm -6pm. The inter-peak periods appeared to have a constant volume of traffic and there was no significant difference between peak and non-peak periods of traffic during the day. This was owing to the land-use, as the street and the adjoining areas are mostly residential; occupied by the working class- artisans, and therefore there is no traffic rush to the office in the mornings. The workers of Federal Polytechnic and Afe Babalola University, which are located far away from this approach, have better alternate carriageways to get to the city centre and thus have not influenced the traffic along the approach significantly. As expected, the degree of saturation of traffic during weekends appeared uniform and relatively low. At Ajilosun Street approach, the degree of saturation appeared to be relatively low. There appeared to be peak periods at 8am-10am and 3pm-5pm respectively during the weekdays. There were no

significant inter-peaks except for Tuesday. There was a peak at 7am-9am and 4pm to 5pm on Saturday. However, the degree of saturation on Sunday appeared relatively uniform. At Irona Street approach, there were peak periods at 7am-9am and 4pm-6pm during weekdays, although there appeared to be an inter-peak at 10am-11am on Tuesday. The approach appeared to be congested during the weekdays as the degrees of saturation at these periods are greater than 85%. This is owing to the excess traffic volume from the adjacent Irona market and the narrowness of the carriageway by pedestrians shopping at the market, thereby slowing the traffic flow. There was relatively uniform low flow during the weekend.

Matthew Roundabout:

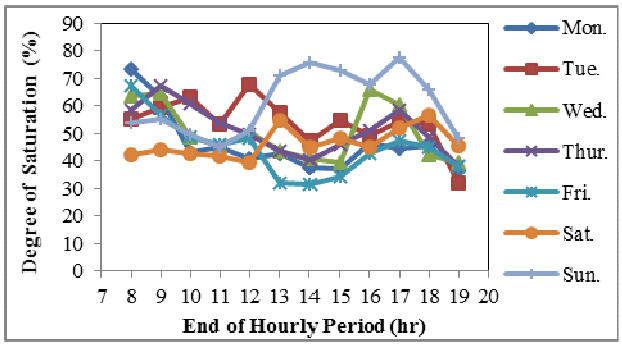

Figure 7: Ijigbo Street Approach

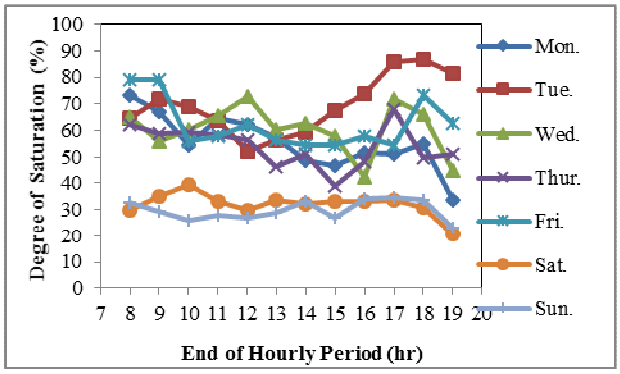

Figure 8: Matthew Street Approach

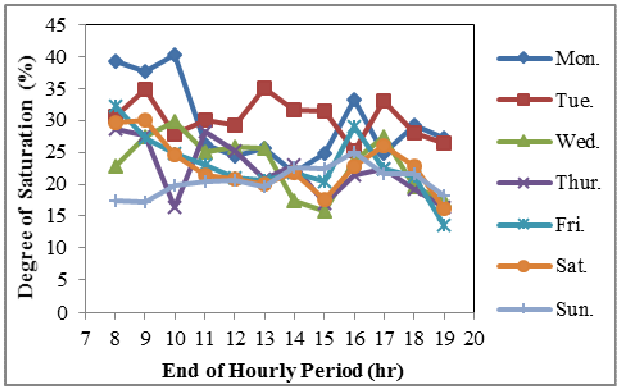

Figure 9: Ajilosun Street Approach

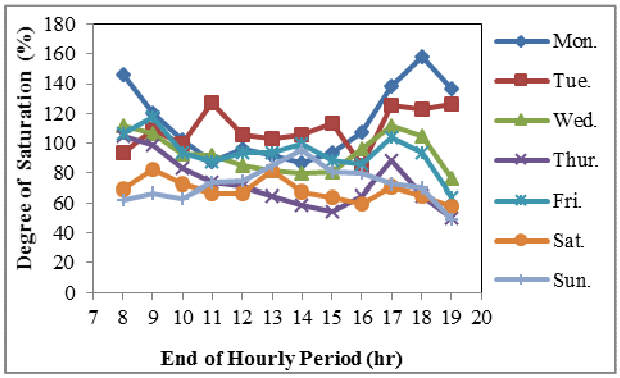

Figure 10: Irona Street Approach

In general, the degree of saturation of traffic at the two roundabouts, which are spaced at approximately 500m apart, appeared similar. This is likely due to the location of the roundabouts, which are located at the core of the city, as similar traffic passes through them owing to similar land-use. In addition, the relatively short spacing is likely to make some traffic to pass through both roundabouts consecutively.

5. Conclusion

The degree of saturation of traffic has been calculated from the traffic demand and capacity at two major signalised roundabouts in Ado Ekiti, which is a typical Nigerian city, from 7am to 7pm. The degree of saturation of traffic at the roundabouts appeared similar owing to the similar location (both being at city centre), short spacing and similar land-use. The degree of saturation of traffic at both roundabouts appeared to be high during weekdays, compared to the weekend. There were generally peak morning and evening periods at 7am-9am and 3pm-6pm respectively. There were also inter-peaks, especially at noon, but also at various hours between 10am and 3pm for both roundabouts. The most significant difference in traffic flow at both roundabouts was the relatively high degree of saturation of traffic at Irona Street approach of Matthew Roundabout. It is the only approach that is mainly congested at both roundabouts during the weekdays. Similarly, there appeared to be high volume of traffic flow during Sunday at the Ijigbo Street approach of this roundabout on Sunday.

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