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Capacity Assessment of Slaughter Rotary Intersection

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ABSTRACT

This paper ex-rays the capacity of slaughter roundabout in order to address the traffic challenges by studying the traffic at the intersection. Slaughter intersection is one of the busiest intersections in Port Harcourt. Traffic volume count and analysis was carried out at the intersection and converted to equivalent Passenger Car Unit per hour (PCU/hr). The study revealed that, the intersection attracts a traffic volume of 3411 PCU/hr with a practical rotary capacity of 3209 PCU/hr. These capacities are about 13.7% and 7% higher than the recommended rotary capacity of 3000 PCU/hr given by the Indian Road Congress (IRC) making the present intersection inadequate and incapable of handling the present traffic set-up at Slaughter intersection leading to traffic problems. Further analysis on the four approaches revealed that they are undersaturated with degree of saturation of 0.31 (31%), 0.29 (29%), 0.45 (45%), and 0.23 (23%) for the North, East, South and West approaches, this is an average of about 0.53 (53%) below 0.85 (85%) of recommended traffic demand. Hence, the traffic situation experienced at Slaughter roundabout from field observation, were as result of illegal trading around the intersection, road user behavior, lack of pedestrian crossing facility, absence of pavement markings, lack of packing facility and not the flow from the approaches. The study therefore recommends an improved design of the intersection, parking facilities, pedestrian crossing facilities, a stop to illegal trading and markets around the intersection, provision of a flyover in the Trans-Woji section of the intersection.

KEYWORDS: Traffic, Intersection, Congestion, Capacity, Saturation

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1. INTRODUCTION

Transportation is an important factor in the development of any society. Despite the importance of transportation to a society's economic development, it has challenges such as traffic congestion, accidents, and so on. Increase in level of urbanization and economic growth as noticed in all urban cities in the developing world has brought about the upsurge in the various traffic situations during peak hours particularly at intersections due to mix complex flow pattern. The increasing rate of human population and vehicular traffic has been one of the various problems of African cities (Mohan *et al.*, 2020).

Intersections are key features in highway geometric design and construction owing to their role in the safety of traffic flow. An intersection is a convergent area where you have two or more roads meeting with a provision for changing route or directions. Basically, intersections can be classified into three categories: At grade, Grade – separated without ramps and Grade – separated with ramps intersections (Surender & Ahuja, 2016). AASHTO (2011) recommends not more than four legs at an intersection. This is due to the fact that the number of potential conflict points at any intersection is determined by the number of approaches, turning movements, and the type of traffic control present. Roadway intersections are of great concern to traffic engineers due to conflicting traffic movements. According to Mannering *et al.* (2004), major accidents and delays occur at intersections.

Slaughter roundabout is a four-leg at-grade intersection serves as entry and exit point to the city of Port Harcourt and leads to the industrial hub of Rivers State (Trans-Amadi Industrial layout). This roundabout like every other rotary intersection was designed to reduce conflict in traffic, provide ease for vehicular maneuverings, reduce operation cost, reduce trip delays and minimize accidents. Notwithstanding, this rotary

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intersection has been notorious for traffic congestion, loss of man-hour, trip delays especially during peak hours. The question of performance of the intersection has now become a vital issue that needs to be addressed. Therefore, it has become imperative to carry out an assessment study in a bid to determining the causes of these challenges and provide dependable solution to remedy the situation for present and future.

This study aims at proffering a workable mechanism to improving the flow of traffic at Slaughter rotary intersection in Port Harcourt City.

The Objectives of this research were to:

i. Study the present traffic condition to determine the volume of traffic at the intersection.
ii. Determine the capacity of the rotary.
iii. Evaluate the demand to traffic volume (degree of saturation) of the legs constituting the intersection.

1.1. Theory on Rotary Intersection (Roundabout) and Design

A rotary intersection is a type of at-grade intersection that is designed to allow traffic to flow in only one direction around a central island. Vehicles from converging areas are forced to move in an orderly fashion around the central island in a clockwise or anti-clockwise direction, weaving out of the intersection into their desired movements. This creates a conflict free system. Nevertheless, conflicts can be observed at a rotary intersection as a result of the merging and diverging traffic (Tom & Krishna, 2007). It is important to note that, a rotary intersection provides improved safety when compared to other traffic control arrangements (Sargeant & Christie, 2002). They reduce crash severity because head-on and right-angle conflicts are almost eliminated, and they can handle a higher volume of traffic with less delay than signalized control intersections. Because turn pocket lanes are not required, they probably take up less space. Furthermore, they provide superior energy and lower maintenance costs when compared to conventional systems. to other intersection treatments (De-Amico, 2012).

In the design of a rotary intersection according to Ishanya *et al.* (2017) the elements listed below must be considered to have a functional system.

i. **Design Speed**: At a rotary, all vehicles are required to slow down. As a result, the design speed of a rotary will be significantly lower. The standard practice is to keep the design speed at 30 and 40 kilometers per hour for urban and rural areas, respectively. All other geometric features are shown in Plate 1 below.

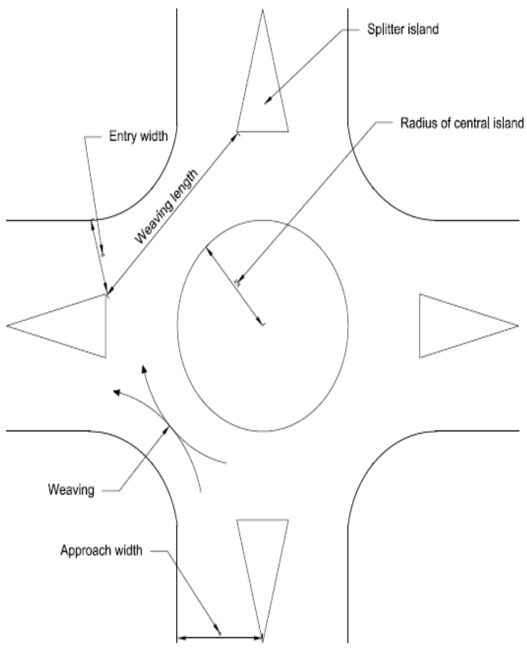

Plate 1: Geometric features in a rotary intersection

ii. **Entry, Exit and Island Radius**: The radius at the entry is determined by several factors, including design speed, super-elevation, and coefficient of friction. The entrance to the rotary is not straight, but there is a slight curvature. The exit radius should be greater than the entry radius and the radius of the rotary island, allowing vehicles to exit the rotary at a faster rate. In general, the exit

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radius should be 1.5 to 2 times the entry radius. The radius of the central island is determined by the design speed and the radius of the entry curve, so it is approximately 1.33 times the radius of the entry curve in practice.

iii. **Rotary Width**: The rotary's entry and exit widths are determined by the traffic entering and leaving the intersection, as well as the width of the approaching road. The width of the carriageway at entry and exit will be less than the width of the carriageway at the approaches to allow for faster speeds. According to the Indian Road Congress (IRC) 65 (1976), a two-lane road with a width of 7m should be kept at 7m for urban roads and 6.5m for rural roads. Also, a three-lane road of 10.5m will be reduced to 7m and 7.5m for urban and rural roads, respectively. The weaving section's width should be greater than the width at entry and exit. This is usually one lane wider than the average entry and exit width.

iv. **Weaving length/Width:** It governs how easily traffic can merge and diverge. It is determined by a variety of factors, including weaving width, weaving traffic proportion to non-weaving traffic, and so on. This is best accomplished by increasing the weaving length to weaving width ratio. The minimum value suggested by IRC 65 (1976) is a ratio of four. A very long weaving length is also risky because it may encourage over-speeding (Ishanya *et al.*, 2017).

v. **Saturation flow** – It is an important road traffic performance measure of rate of traffic flow. This is the number of vehicles that will pass the stop line when there is a continuous movement. According to Chang-qiao and Xiao-ming (2012), saturation flow is used as a fundamental parameter to measure an intersection's capacity and timing of signals. The saturation flow values may be assumed as 1850, 1875, 1975, 2075, 2550, and 2900 PCU per hour for the approach roadway widths of 3.0, 3.5, 4.0, 4.5, 5.0 and 5.5m respectively. While for width above 5.5m, the saturation flow is calculated using Equation 2.1 below

$$S = 525w \qquad (2.1)$$

Where, w is the road width.

vi. **Capacity** – The practical capacity of a rotary intersection is directly determined by the capacity of each weaving section, and by the geometrical layout. The Transport and Road Research Laboratory which has pioneered research on this aspect, recommends the formula and that is a modification of the well-known Wardrop's formula (1957) given by,

$$Q_w = \frac{280w\left[1+\frac{e}{w}\right]\left[1-\frac{P}{3}\right]}{1+\frac{w}{L}} \qquad (2.2)$$

Where:

e is the average entry and exit width of weaving,

w is the weaving width,

L is the weaving length

$$P = \frac{b + c}{a + b + c + d} \qquad (2.3)$$

p is the proportion of weaving traffic to the non-weaving traffic; a and d, are the non-weaving traffic, while b and c, are the weaving traffic. The figure below shows four types of movements at a weaving section, a and d are the non-weaving traffic and b and c are the weaving traffic.

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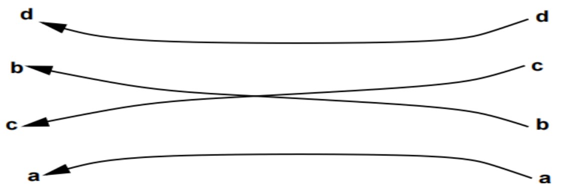

Plate 2: Flow pattern for weaving and non-weaving traffic.

Therefore, in the design of a rotary intersection, the traffic volume of such intersection must be evaluated. Traffic volume is a fundamental measure of traffic on a road in a given interval of time. It is expressed as vehicles per hour. But in a situation where traffic is mixed, having various kinds of vehicles, it is a common practise to convert such flow into equivalent passenger car unit (PCU), by using certain equivalency factors stated in the Highway Capacity Manual (2010)

2. MATERIALS AND METHODS

2.1 Materials

In carrying out this research work, the following equipment were used - a data entry sheet, a pen, stop-watch, and measuring tape.

2.2 Methods

This research was conducted using manual method of counting to determine the traffic volume. To achieve this, field observation of the traffic flow was carried out in order to ascertain the vehicular volume at the intersection. The observed traffic volume which comprised of vehicle types grouped generally as cars, goods, and buses was taken. This was recorded and converted to equivalent Passenger Car Units per hour (PCU/hr) based on recommended conversion factors. This data was collected for a period of one (1) month at the Slaughter roundabout and its approach legs, twice daily in the morning between 6:30am and 10:30am and at evening between 4:00pm and 08:00pm. The choice of timing and days are ideal as they are the peak periods of this intersection. Similarly, the geometric features of the roundabout which included weaving length, weaving width, approach width, exit width, and radius of the central island were measured using tapes and values were recorded.

The practical capacity of the intersection was obtained using the Wardrop's formula given by Equations 2.2 and 2.3. The degree of saturation for each leg which is a measure of the ratio demand to traffic volume was determined using Equation 3.1 as expressed in Govind *et al*, (2020).

$$\text{Degree of Saturation} = \frac{\text{Actual Flow}}{\text{Saturation Flow}} \quad (3.1)$$

3. RESULTS AND DISCUSSION

The results of the traffic survey carried out are presented below. The data presented in Table 1 is the exiting geometric features of the intersection. This shows that the approach legs are symmetrical.

Table 1: Existing Geometric Features of Slaughter Intersection

Parameter	Approach			
	South	North	West	East
Entry width, e_1 (m)	8.50	8.50	8.50	8.50
Exit width, e_2 (m)	9.00	9.00	9.00	9.00
Weaving length, l (m)	34.40	34.40	34.40	34.40
Approach width (m)	10.10	10.10	10.10	10.10
Weaving radius (m)	26.10	26.10	26.10	26.10
Central island radius (m)	14.70	14.70	14.70	14.70

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Table 2 gives the converted traffic volume count in Passenger Car per hour (PC/hr) at the intersection. This data shows that the total traffic flow entering the intersection is 3411PCU/hr with the South bound leg having the highest traffic flow of 1326PCU/hr and the least traffic flow volume of 582PCU/hr observed at the East bound leg. The above data has been programmed into a bar chart to give a pictorial view of traffic flow as shown in Figure 1.

Table 2: Traffic Flow at Slaughter Intersection

Approach	Flows (PCU/hr)			Total Flow
	Left Turning	Straight Ahead	Right Turning	
North (from Garrison Road)	213	562	94	**869**
East (from Industrial Layout Road)	269	174	139	**582**
South (from Trans-Woji Road)	330	548	448	**1326**
West (from Peter-Odili Road)	125	299	210	**634**
Total	**937**	**1583**	**891**	**3411**

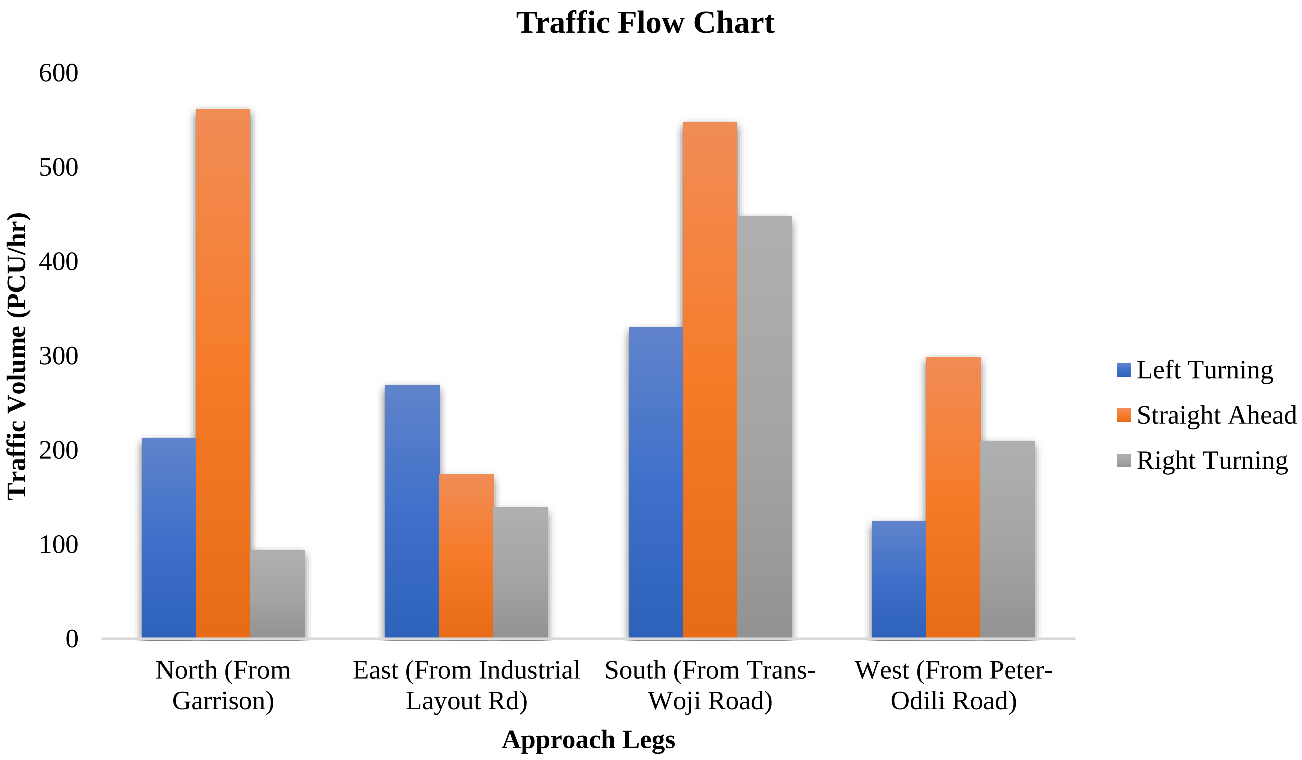

Figure 1: Traffic flow chart for the Slaughter intersection

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Table 3 gives a summary of the in- and out-flow of each intersecting approach. It is observed from the data that movements are much (leaving and entering) the South (Trans-Woji Road) approach of the intersection. This was followed by the North (Garrison axis), then the East (Industrial Layout Road) and lastly the West (Peter-Odili Road).

Table 3: Traffic Flow at various Approach of Slaughter Intersection

Approach	In-flow (PCU/hr)	Out-flow (PCU/hr)	Total (PCU/hr)
North (from Garrison Road)	812	869	**1681**
East (from Industrial Layout Road)	960	582	**1542**
South (from Trans-Woji Road)	1041	1326	**2367**
West (from Peter-Odili Road)	598	634	**1232**

The practical capacity of the intersection was calculated from the existing road features and the volume of traffic (See Plate 1) as follows using Equation 2.2 and 2.3 and summaries in Table 4.

$$P_{NE} = \frac{548+125+174+269}{548+125+174+269+330+139} = 0.70$$

$$\therefore Q_{P(NE)} = \frac{280\times 12.25\left[1+\frac{8.75}{12.25}\right]\left[1-\frac{0.70}{3}\right]}{1+\frac{12.25}{34.4}} = 3324\,PCU/hr$$

$$P_{ES} = \frac{330+548+213+299}{330+548+213+299+448+125} = 0.71$$

$$\therefore Q_{P(ES)} = \frac{280\times 12.25\left[1+\frac{8.75}{12.25}\right]\left[1-\frac{0.71}{3}\right]}{1+\frac{12.25}{34.4}} = 3310\,PCU/hr$$

$$P_{SW} = \frac{125+299+562+269}{125+299+562+269+210+213} = 0.75$$

$$\therefore Q_{P(SW)} = \frac{280\times 12.25\left[1+\frac{8.75}{12.25}\right]\left[1-\frac{0.81}{3}\right]}{1+\frac{12.25}{34.4}} = 3252\,PCU/hr$$

$$P_{WN} = \frac{174+330+562+213}{174+330+562+213+94+269} = 0.78$$

$$\therefore Q_{P(WN)} = \frac{280\times 12.25\left[1+\frac{8.75}{12.25}\right]\left[1-\frac{0.77}{3}\right]}{1+\frac{12.25}{34.4}} = 3209\,PCU/hr$$

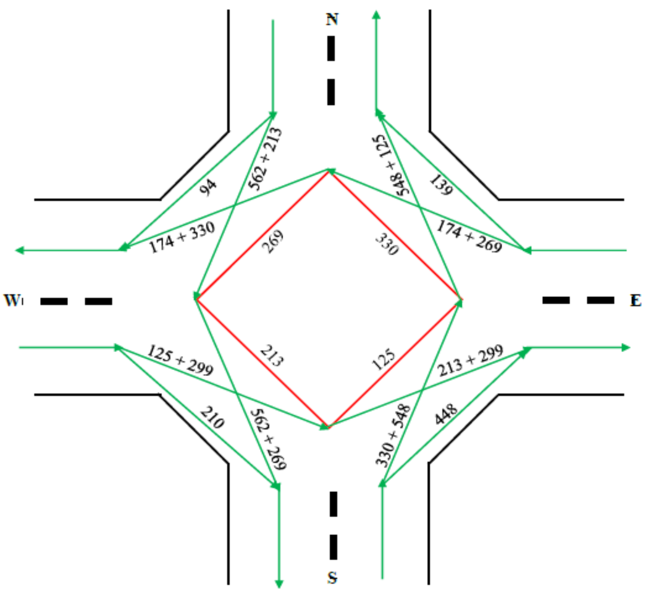

Plate 3: Traffic Negotiation at Slaughter Rotary Intersection

The practical capacity of the intersection was evaluated using Equation 2.2 and presented in Table 4. From the computed capacity of sections, West-North section which has the highest proportion of weaving to non-weaving traffic gave a capacity of 3209 PCU/hr, this was taken as the practical capacity of the intersection. This is because the practical capacity is the lowest of

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all the sections. Comparing this with the observed capacity, of 3411PCU/hr, the intersection can no longer withstand the present-day traffic. The observed capacity is 6.3% higher than the practical capacity of the intersection. The maximum allowable capacity of a rotary intersection is 3000PCU/hr. The results obtained from the existing road features, the practical capacity and observed capacity are 7% and 13.7% higher than the allowable respectively.

Looking at the practical capacity and the allowable under normal traffic conditions, the intersection should not experience congestion.

Table 4: Practical Capacity of the Weaving Sections

Section	Weaving Ratio (P)	Capacity, Q (PCU/hr)
North-East	0.70	3324
East-South	0.71	3310
South-West	0.75	3252
West-North	0.78	3209

Table 5 shows the efficiency of the capacity of the legs. The result indicates that the degree of saturation using Equation 3.1 for the North, East, South, and West approaches are 0.32, 0.29, 0.45, and 0.23 respectively, with the South (Trans-Woji Road) having the highest degree of 0.45 (45%). These values are within the acceptable limits which means that the approach legs have the required capacity.

Table 5: Degree of Saturation of the Approach Legs

Approach	Actual Flow (PCU/hr)	Saturation Flow (PCU/hr)	Degree of Saturation	Result
North (from Garrison Road)	1681	5303	0.32	< 0.85 OK
East (from Industrial Layout Road)	1542	5303	0.29	< 0.85 OK
South (from Trans-Woji Road)	2367	5303	0.45	< 0.85 OK
West (from Peter-Odili Road)	1232	5303	0.23	< 0.85 OK

5. CONCLUSION

The following conclusions were drawn to this research based on findings in line with the research aim and objectives:

i. The observed traffic volume entering and leaving the intersection is 3411 PCU/hr. This value is 6.3% higher than the capacity of the rotary intersection.

ii. The capacity of the rotary is 3209PCU/hr being the minimum of all the weaving sections of the intersection.

iii. The demand to traffic volume at the intersecting legs were 0.32, 0.29, 0.45, and 0.23 respectively from the saturation. Hence, it is within the acceptable range of 0.85 (85%) as recommended (Govind *et al*, 2020).

iv. The delay experienced at the intersection is as a result of inadequate rotary capacity to meet up the present-day traffic volume couple with poor packing facility, road side market, absence of pedestrian crossing facility, road user behavior and poor traffic control

Based on the findings and conclusions drawn, it is important to make the following recommendations:

i. There is need for an improved capacity of the intersection in other to handle the present-day traffic volume.
ii. The provision of a parking facility to curb incessant parking around the intersection.
iii. Introduction of a flyover along the Trans-Woji alignment of the intersection to reduce the conflict points and increase the capacity of the intersection.
iv. Provision of pedestrian crossing facilities, road signs, and markings.
v. The implementation of the rule of law.

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