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JOURNAL OF CONTEMPORARY RESEARCH (JOCRES)

RESEARCH ARTICLE VOL. 2 (1) ISSN:2814-2241

Date Accepted: 30th June, 2023

Pages 301 - 308

THE EVALUATION OF ROUNDABOUT PERFORMANCE USING GAP ACCEPTANCE THEORY : A CASE STUDY OF EFFIO- ETTE ROUNDABOUT.

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Abstract

Roundabouts are used to control traffic at intersections of roads, but their operation is impacted by the volumes of entry and conflicting flows that, in situations of congestion, can result in long queues and delays upstream. This paper analyses vehicle gap acceptance behaviour at a selected Roundabout in the City of Calabar, Nigeria. Using video data gathered at Effio-Ette roundabout during morning peak hours of 7-8am over a period of seven days, an evaluation was conducted for accepted gaps, rejected gaps, critical gaps, follow-up time, degree of saturation and capacity estimation using the Highway Capacity Manual (HCM) Gap Acceptance approach. The study findings show that the parliamentary arm is currently the least saturated with a v/c of -0.0429, while the MCC and Akai-Effa arms are the most saturated (v/c of 0.191 and 0.120 respectively). The results of this study offer some practical suggestions for increasing the efficiency of the studied roundabout by recommending the construction of an interchange or increasing the geometry of the roundabout.

Keywords: Roundabout, Critical gap, Gap Acceptance, Lag acceptance, Queues.

1. Introduction

With rapid urbanisation and rapid motorisation in most developing nations like Nigeria, there is now a lot of pressure on existing transportation infrastructures such as intersections. Intersections are necessary for any efficient road network and must be properly designed to handle congestion effectively during peak hours.

The Roundabout over the years have been widely used to control traffic movements at intersections of roads. Roundabouts are at-grade circular intersections that allow the rotational movement of traffic in one direction (i.e., clockwise in left-hand drive traffic or anticlockwise in right-hand drive traffic) around the central island with the priority for circulating traffic over the entering traffic (Almukdad et al., 2021). Compared to other types of road intersections, roundabout minimise conflicts, reduce delays, reduce vehicle speed, provide pedestrian safety, and considered very effective in ensuring smooth traffic movement (HCM, 2010; Muley, and Almandhari, 2014). With the wide use of roundabouts for traffic control, it is important to assess its operational performance (Arroju et al., 2015). The capacity of a Roundabout is one such parameter used in evaluating its performance and safety. Roundabout capacity evaluation is critical since it is linked to delays, levels of service, crashes, operating costs, and environmental concerns (Almukdad et al., 2021). The entry capacity of a roundabout is the maximum number of vehicles that can enter a roundabout for a given approach given a certain specific geometric and traffic conditions. Several models have been established to estimate the entry capacity of roundabouts, e.g., regression model, interweave theory model and Gap Acceptance Theory (Wang and Yang 2012). According to Macioszek (2020), these methods vary depending on the modelling tool used, the geometric and traffic characteristics of the roundabout analysed, and the computational complexity. The Gap acceptance theory, however, continues to gather traction among traffic engineers and researchers and this is because the theory is most reliable since it physically reflects given traffic phenomena (Macioszek, 2020). Also, according to Suh (2108), roundabouts operates only under yield conditions, thus, capacity is heavily dependent on gap seeking logic (Suh, 2018).

1.1 The Gap acceptance theory

The gap acceptance theory uses gap parameters to estimate the entry capacity such as critical gap (t_c), and follow-up time (t_f) and degree of saturation (Guo, Liu, and Wang, 2019). Critical gap is defined as the minimum time interval between two consecutive vehicles in the circulating stream that allows a safe merging of an entry vehicle from a respective approach in the roundabout. Meanwhile, the follow-up time is calculated as the time interval between the departure of two consecutive queued vehicles from one approach in the roundabout to the circulatory stream. The degree of saturation is the ratio of the demand at the roundabout entry to the capacity of the entry (HCM, 2010).

Several studies have in the past used the gap acceptance to assess the capacity and performance of roundabout across the world (Almallah et al., 2020; Almukdad et al., 2021; Macioszek, 2020). However, the Highway Capacity manual (HCM), (2010), sets out the most popular procedure of investigating roundabout capacity based on gap acceptance.

According to HCM (2010), the roundabout capacity equation is given as follows:

$$Q = A.e^{(-B.qc)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where Q is lane capacity (pcu/h), and q_c is conflicting or circulating flow rate (pcu/h).

The parameters A and B in equation 1 are calculated with the help of critical headway and follow-up headway as follows:

$$A = \frac{3600}{tf} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

$$B = \frac{tc-\left(\frac{tf}{2}\right)}{3600} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

Where t_c denotes critical headway (seconds), and t_f is follow-up headway (seconds)

According to HCM (2010), the default parameters for A and B are as follows: A = 1,130, B = 0.0010 for single lane entry and single-lane circulating stream (corresponding to t_f = 3.19 s and t_c = 5.19 s) and for a two-lane entry and multilane circulating stream A = 1,130, B = 0.0007 for right lane (corresponding to tf = 3.19 s and tc = 4.11 s) or A = 1,130, B = 0.00075 for left lane (corresponding to tf = 3.19 s and tc = 4.29 s).

However, capacity of roundabouts varies from location to location depending on driving behaviours. Therefore, it is critical to objectively estimate the capacity of roundabouts for better infrastructure design selection.

Effio-Ette roundabout in Calabar, Southern Nigeria currently experiences high levels of queues and delays particularly during the morning and evening peak periods. The current study seeks to test the applicability of the gap acceptance theory on the performance under the prevailing conditions at Effio-Ette roundabout in Nigeria.

2. Methodology

2.1 Site characteristics

A 2-lane roundabout in the City of Calabar in Cross River state, Nigeria was selected for this study. The Roundabout is a four-leg intersection connecting MCC road (Single-lane), Marian Road (Dual-Carriage), Akai-Effa (Single-Lane), and Parliamentary roads (Dual-Carriage). The inscribed circle diameter (ICD) of the Roundabout is 18m. The characteristics including entry width, approach half width, ICD, entry radius, effective flare length, entry angle and merging angle are reported in Table1.

Figure 1: Area view of Effio-Ette Roundabout (ICD=18m)

Table 1: Characteristics of the Roundabout

Approach	**Geometric Elements**			
	Entry Width (m)	**Exit Width (m)**	**Approach half width (m)**	**Lane Type**
Marian	10.4	7.97	7.96	Dual
Akai-Efa	16.3	5.9	5.9	Single
MCC	19.3	4.3	4.33	Single
Parliamentary	11.35	7.37	7.37	Dual

2.2 Data collection

Data was collected using a high-quality camera positioned at an acceptable height to record the vehicles entering the roundabout site during morning and evening peak hours, for a period of seven days. Also, a traffic count of vehicle types, vehicle entering, circulating, and exiting the roundabout from all 4-arms was collected.

For analyses, the data was extracted from the videos through a manual process of watching/observing and noting when a vehicle approaches the roundabout, which will estimate the accepted and rejected gaps and follow-up time of circulating vehicles. For each approach, all the accepted and rejected gaps were extracted for the estimation of the critical gap. Accepted gap was considered when a vehicle came to a complete stop and then approached the roundabout between two consecutive circulatory vehicles. A rejected gap, on the other hand, was defined as a driver coming to a complete stop and then failing to enter the roundabout in a specific space between two consecutive circulation vehicles. Follow-up time was recorded as the time interval between the entry of two consecutive queued vehicles to the circulatory roadway under the condition of having no circulating vehicles within one quarter upstream of the roundabout (Kang, Nakamura, and Asano, 2012).

2.3 Data analysis

For critical gap, and follow-up time were estimated for each approach. Also, the capacity of the Roundabout was determined using entering and circulating flows from each approach, with degree of saturation calculated thereafter. The Raff Method (Raff and Hart, 1950) was used to estimate the critical gap, while the HCM (2010) was used to estimate the capacity of the roundabout.

3.0 Results

3.1 Analysis of critical gap

By following Raff's method, the intersection points between the cumulative distributions of the accepted and rejected gaps at the roundabout was 3.0 seconds, as shown in figure 2. Also, the results showed that Sunday had the lowest critical gap of 1.5 seconds, while Tuesday and Friday had the highest critical gap of 5.3 seconds.

Table 2: Gap Parameters Summary

Gap length (t sec)	**Cumulative number of accepted gaps less than t sec**	**Cumulative number of rejected gap greater than t sec**
0	0	1080
1	11	1052
2	198	967
3	648	703
4	995	494
5	1197	347
6	1322	261
7	1378	196
8	1413	153
9	1455	125
10	1478	104
11	1501	90
12	1521	76
13	1534	60
14	1544	55
15	1549	45
16	1557	36
17	1565	24
18	1568	21
19	1574	20
20	1579	17

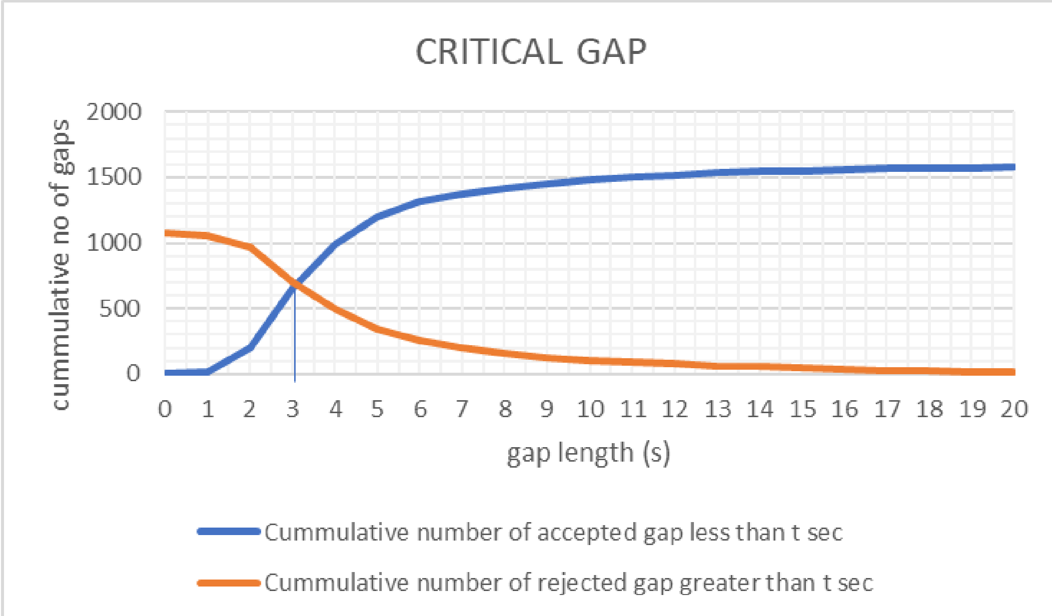

Figure 2: Average critical Gap

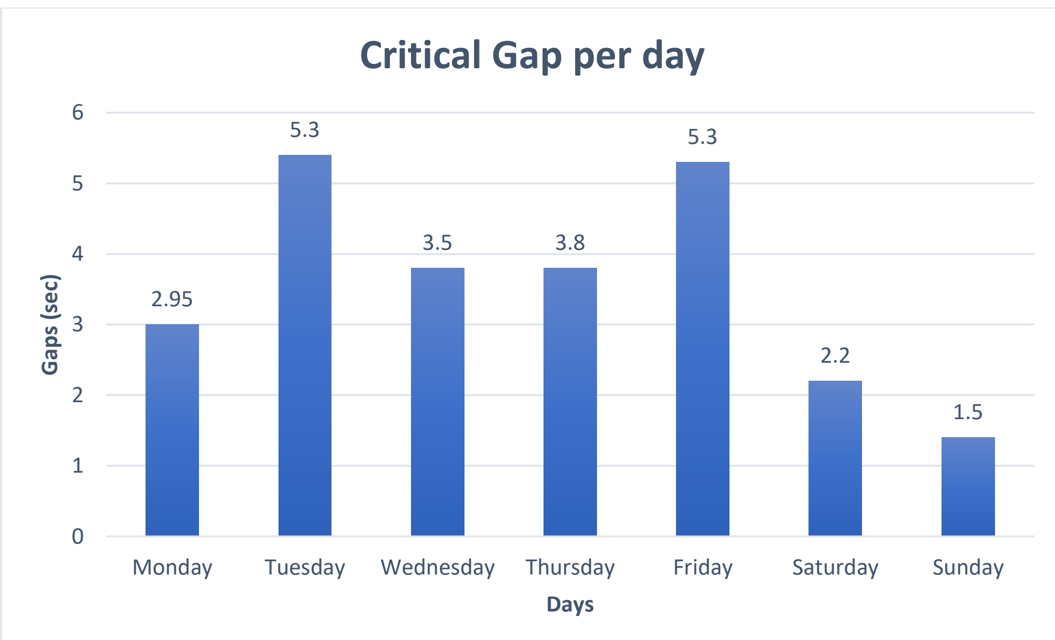

Figure 3: Critical gap per day

3.2. Analysis of follow-up time

The average follow-up-time for the roundabout was found to be 3.06s. As seen in Figure 4, Sunday had the highest follow-up time of 4.27s with Tuesday having the lowest follow-up time of 2.13s.

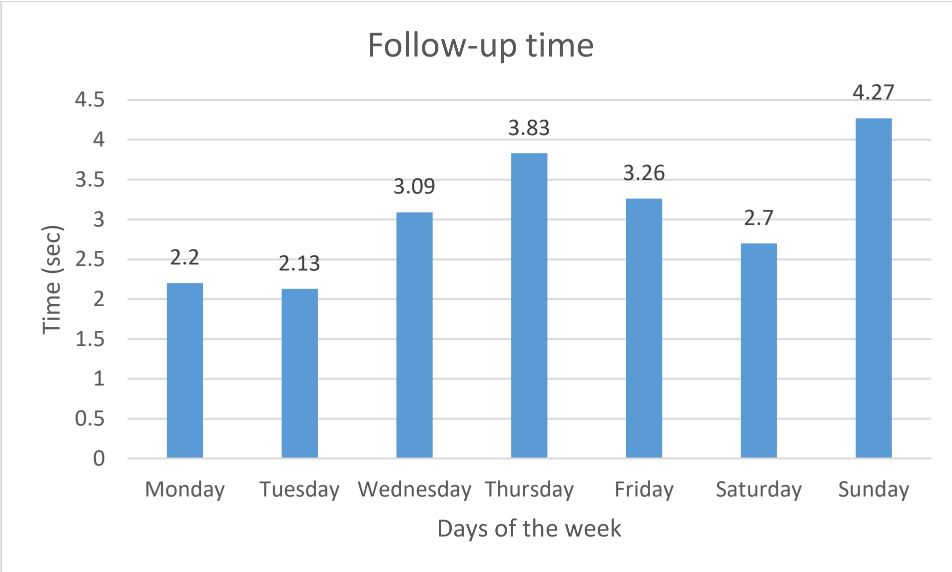

Figure 4: Follow-up time per day

3.3. Analysis of capacity and degree of saturation.

The relationship between entry flow and circulating flow determines the roundabout's capacity. In this study, Equation 1, 2 and 3 from HCM (2010) were used to estimate the roundabout entry capacity. As seen in table 3, the MCC and Akai- Effa approaches had the highest entry flows while the Parliamentary Approach had the least entry flow. Also, the results show that the Marian, Akai-Effa and MCC arms have degree of saturation above 0.85.

Table 3: Summarized capacity analysis on the Roundabout.

Approach	Entry Flow (V)	Capacity (C)	Degree of saturation V/C	V/C >0.85
Marian	712	834	0.853	**0.003**
Akai-Effa	785	809	0.970	**0.120**
Parliamentary	682	845	0.807	-0.042
MCC	829	796	1.041	**0.191**

4.0 Discussions

The current study seeks to evaluate the performance of a roundabout using the gap parameters of critical gap, follow-up time and degree of saturation.

The average critical gap of the roundabout was found to be 3.0 seconds. However, Sunday had the lowest critical gap of 1.5 seconds. Also, the average follow-up time at the study roundabout was found to be 3.06 seconds, with Sunday having the highest follow-up time of 4.27 seconds. Gap parameters are estimated differently from one region to another due to the difference in driving behaviour and varying geometric parameters of roundabouts (Mathew et al., 2017), thus it is difficult to compare gap parameters between different locations. However, aggressive driving behaviour could lead to lowering the gap parameters (i.e., lower critical gap, and shorter follow-up time) (Almallah et al., 2020), while roundabout with large, inscribed circle diameter (ICD) allow for higher driving speeds compared to those with smaller ICD (Puan, 2004). The high follow-up time on Sunday may be related to reduced traffic on that day, however, the low critical gap for Sunday a contrasting result, could have been because of aggressive driving at the time of data collection.

Results from the current study show that the Akai-Effa and MCC arms have degree of saturation above 0.85. The degree of saturation provides a direct assessment of the sufficiency of a given roundabout. While there are no absolute standards for degree of saturation, the HCM 2010 procedure suggests that the degree of saturation for an entry lane should not be more than 0.85 for satisfactory operation. When the degree of saturation exceeds this range, the operation of the roundabout will likely deteriorate rapidly, particularly over short periods of time. Queues may form and delay begins to increase exponentially. The finding might be because the MCC and Akai-Effa approaches which are the most saturated are both single-carriageway compared to other approaches that are dual-carriageways.

One of the limitations in this study is the limited observation periods. Due to the complex and time-consuming tasks of the data collection and data extraction, data was only collected during morning peak period. Future studies could focus on including different periods (evening peak and off peak), and multiple roundabouts with different geometric characteristics.

5.0 Conclusions

This study aimed to evaluate the performance of a roundabout using the gap acceptance parameters (i.e critical gap, follow-up time, capacity, and degree of saturation). The parameters were obtained using video footage that was recorded at Effio-Ette Roundabout. The average critical gaps and follow-up time were found to be 3.0 seconds and 3.06 seconds respectively. The degree of saturation of MCC and Akai-Effa approaches were found to be 1.041 and 0.970 respectively, both above 0.85. The results from the current study could serve to help policy makers and traffic engineers in the design of future roundabouts. The study recommends that to ameliorate the delays and queues currently experienced at Effio-Ette Roundabout, there is need to either remodel the roundabout by increasing the size of the geometric parameters particularly of the saturated approaches or construct a grade-separated intersection.

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