

Driver Gap Acceptance Behaviour at Roundabouts in Trinidad and Tobago

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(Received 19 January 2019; Revised 01 December 2019; Accepted 14 January 2020)

Abstract: One important node used to manage conflicting traffic at intersections is the roundabout. Roundabouts operate based on the gap acceptance behavior of drivers, with a major flow in the circulatory lane of the roundabout and minor flows on the approaches which enter the roundabout when there is a gap the driver decides to accept. This study investigates the gap acceptance behaviour of motorists to determine the critical gap in Trinidad and Tobago (T&T). The research found that, for the roundabouts selected, critical gap estimates do not differ significantly based on either time of day or location. The estimated critical gaps were compared with values commonly used in the Highway Capacity Manual (HCM), so as to determine the effect on estimated intersection capacity. The results indicate that the critical gap values differ significantly from the United States (US) default values (which is one of the standards adopted by T&T), which therefore affects the estimated capacity of the roundabouts. The published values from the HCM are significantly higher than the values obtained, which means that the estimated capacities using the default US values underestimate the existing capacities in T&T.

Keywords: Roundabout, driver behaviour, critical gap, gap acceptance, capacity

1. Introduction

Roundabout capacity is dependent on various factors, which include the traffic flow rate from the numerous legs, geometry, vehicle mix and driver behaviour (Kusama and Koutsopoulos, 2011, p.710). Capacities, delays and queue lengths are interdependent and are all used in determining the Level of Service (LOS) of the roundabout intersection. Since the LOS is used during the feasibility stage in determining whether a traffic mitigation proposal is a viable option, it is important to refine the analysis by using site specific data to yield results which would bring about the most feasible solution for implementation. This highlights the importance of determining accurate gap acceptance behaviour of drivers who attempt to merge from an approach road into the traffic stream already in the roundabout.

In Trinidad and Tobago (T&T), the Ministry of Works and Transport usually mandates that international codes, mainly the American Association of State Highway Transportation Officials (AASHTO), are to be used as the basis for design of highways and main roads. The AASHTO geometric design policy was developed from extensive research conducted in the United States of America. The use of these international standards in T&T may result in geometric designs that are inappropriate since they do not take into account local data.

There are two theories of incorporating driver behavioural characteristics in traffic analysis, namely 1) the gap acceptance method (exponential model) as described in the Highway Capacity Manual (HCM) 2010 (TRB, 2010), and 2) the linear regression method of the Transport Research Laboratory (TRL). Both are endorsed by the major transportation research bodies.

In the design of roundabouts using the Highway Capacity Manual 2010 (TRB, 2010), default values in programs and average values from tables are assumed and used to determine the Level of Service and safety. There is a need for a design parameter to incorporate gap acceptance behavioural characteristics in modelling the flow of traffic and designing roadways for safety in T&T. The paper reports a study to determine the critical gaps of drivers at selected roundabouts in T&T. It seeks to determine if there are significant differences between the critical gaps for roundabouts in T&T and that of international references, and to compare the estimated capacities of the roundabouts based on the HCM 2010 model using the local critical gap versus the default values.

2. Literature Review

2.1 Factors Affecting the Critical Gap

The critical gap is the minimum time gap in the priority stream that a minor street driver is ready to accept for

crossing or entering the major stream conflict zone (Brilon et al., 1999, p.71). Figure 1 illustrates the critical gap spatially.

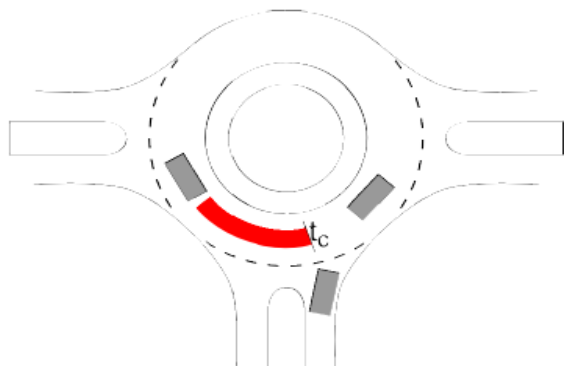


Figure 1. Spatial critical gap
Source: Abstracted from Barry (2012, p.21)

There have been various studies which indicate that the critical gap varies by region and is also heavily influenced by the behavioural characteristics of drivers (Gazzarri, et al., 2012). Gap acceptance models are strongly affected by driver behaviour and local habits. Therefore, the HCM 2010 capacity model should be calibrated to local conditions.” Based on these studies, the average critical headway is significantly lower than the values recommended by international references. Some factors that affect the critical gap are differing driver behaviours, the type of intersection and movement. Additionally, according to Shiftan et al. (2005), waiting time and queuing may also have an effect on the critical gap.

Mensah et al. (2009) hypothesised that the critical gap could be affected by local conditions such as the waiting time for drivers, queue lengths, aggression of local drivers and lastly, seasonal variation. They postulated that critical gaps would decrease as drivers became more familiar with local conditions and that could result in a decrease of the 95th percentile queue length by almost 50%. Moreover, from research conducted by Tupper (2011, 12-13, 60-75), Xu and Tian (2008, 122) and Shiftan et al. (2005, p.1), the other factors that affect the critical gap include weaving, vehicle performance characteristics, geometry of the intersection, number of lanes on minor street, design speed, traffic volumes on the minor and major streets and time of day.

There is some conflicting research about the effect of geometric design on the critical gap. Xu and Tian (2008, p.117) contended that geometric design was insignificant. This is not surprising since within a country, the design standard is assumed to be uniform and should cause minimal changes to the critical gap. This assumption was supported by research conducted by Gazzarri et al. (2012, p.318), which showed that

standard deviations in critical gap measurements of the various multi-lane roundabout sites measured were less than one tenth of a second. In such context, the current study was designed to mitigate the effects of some of these confounding variables by examining roundabouts with typical geometric and traffic flow characteristics for T&T. The HCM 2010 roundabout capacity model will be used.

2.2 Importance of Critical Gap to Capacity

Fundamentally, three methodologies can be used to assess the capacity of roundabouts. These methodologies are: 1) interweave theory model, 2) gap acceptance theory, and 3) regression analysis theory (Wanga and Yang, 2012, p.3)

Miller (1972, p.216) conducted thorough methods for the estimation of critical gaps and their impact on the capacities of roundabouts using the gap acceptance theory, whereas others (Tian et al., 2000, p.407) did research using the regression analysis theory. Research conducted into the capacities of roundabouts in Beijing has shown that roundabout capacities should be measured in terms of the entry capacity, rather than weaving section capacity (Wanga and Yang, 2012, p.159). This notion was further supported by analysis of the HCM gap acceptance theory which calculates the capacity by using information about entry vehicles. The Tanner (1997) formula is considered to be typically representative of this model. It should also be noted that the capacity formula is suggested for a single lane, and completely symmetrical roundabout.

In support of the importance of the critical gap effect on capacities, Gazzarri et al. (2012, p.310) stated that two parameters that may be changed to reflect local driving behaviour are the critical headway and follow-up headway (referred to as critical gap and follow-up time in earlier studies). These factors affect the critical gap which in turn affects the operational factors of the highway system (Mensah et al., 2009, p.8). Additionally the critical gap is used to incorporate the behavioural aspect of the analysis of capacity for intersections in models for determining the expected capacity and delays.

According to Akçelik (2011) and Akçelik and Associates Pty Ltd (2012), SIDRA is a modelling software used by traffic engineers that incorporates the critical gap into the design and analysis of the performance of roundabouts. Moreover, the critical gap is used, along with the follow up headway, in sensitivity analyses of the effects of (a) the driver behaviour and traffic characteristics, and (b) the intersection geometry. The critical gap together with the follow up headway is usually 60% of the critical gap (Akcelike and Associates Pty Ltd, 2012, p.116). It is used to determine the capacities of roundabouts. Therefore, based on the critical gap information used in the analysis, the capacity of roundabouts can be under- or over-estimated (Barry, 2012, pp.31-33).

2.3 Critical Gap Estimation Methods

One of the fundamental methods of estimating the critical gap was developed by Raff in the 1950s (Raff and Hart, 1983, p. 255-258). The method states that the critical gap can be obtained from the intersection between the graphical plot of the cumulative functions of accepted gaps and rejected gaps (see Figure 2). The equation can be represented as:

$$1 - F_r(t) = F_a(t) \tag{1}$$

where,

- t = headway of major stream;
- $F_a(t)$ = cumulative probability of accepted gap; and
- $F_r(t)$ = cumulative probability of rejected gap.

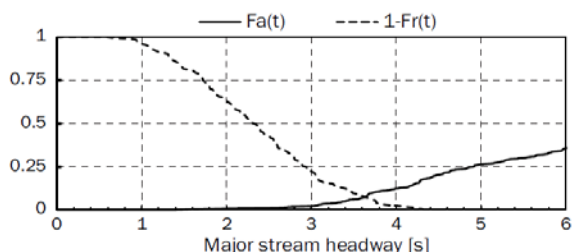


Figure 2. Graphical representation of the intersection
Source: Adopted from Vasconcelos (2012)

Table 1 shows a summary of various methods for the determination of the critical gap and their suitability. Raff’s method has been deemed to be a very good estimator of the critical gap once all the gaps are used. It was decided to use the simple approach that gives similar quality results as the more complex methods.

Table 1. Benefits of the different method of analysis for critical gaps

Methods	Variation	Estimates Critical Gap	Ease of Use	Use of Data
Average Accepted Gap	All accepted gaps	No	Very Good	Poor
	Accepted gaps < 12 seconds			Very Poor
Raff Method	All gaps	Yes	Very Good	Very Good
	All accepted gaps and maximum rejected gaps			Good
Cumulative Acceptance	All accepted gaps	Yes	Very Good	Poor
	Accepted gaps < 12 seconds			Very Poor
Equilibrium of Probabilities	All accepted gaps and rejected gaps	Yes	Poor	Very Good
	All accepted gaps and maximum rejected gaps			Good
Fit Maximization	All accepted gaps and rejected gaps	Yes	Good	Very Good
	All accepted gaps and maximum rejected gaps			Good

Source: Abstracted from Tupper (2011, p. 45)

3. Data Collection and Processing

The research monitored the real world gap acceptance behaviour, and was carried out without the drivers being aware. The studied roundabouts were selected, taking into consideration the different conditions that would affect the measured critical gap, such as different geometries, flows, approach conditions and times of day.

Only one lane of each multi-lane roundabout was measured and the longitudinal gap was not considered. The first step was to identify the suitable sites for data retrieval. This was done by listing the possible sites at which data could be collected and then eliminating unsuitable sites. Factors that affected the suitability are:

1. Establishing an effective camera position;
2. Located in Trinidad;
3. Two-lane geometry;
4. Standard circular geometry;
5. Limited to no interruptions by pedestrians, traffic lights, vending or bicycles.
6. Defect free pavement surface.

Nine (9) major roundabouts throughout Trinidad were considered, as follows:

- Roxy Roundabout (Irregular oval shape),
- Arthur Lok Jack Roundabout at Mt. Hope,
- Trincity Mall Roundabout,
- Couva Interchange Roundabouts (West and East),
- Tarouba Link Road and South Trunk Road Roundabout (always saturated and has a deficient pavement surface),
- Maritime Roundabout,
- Grand Bazaar Roundabout (Single lane),
- Price Plaza Roundabout (Vending activity affects the usage), and
- Aranguez Overpass Roundabouts (North and South).

These roundabouts were evaluated to determine their suitability for the study. Those roundabouts were eliminated from consideration if there were extraneous elements which would tend to affect the driver’s gap acceptance behaviour such as high levels of saturation, vending occurring near the circular roadway, and pavements with undulating surfaces of the roundabout lanes. As a result, three roundabouts namely, the Arthur Lok Jack roundabout in Mt. Hope, the Maritime roundabout in Barataria and the Aranguez Overpass South roundabout, were selected. These roundabouts had differing geometric layouts but shared a similar standard design with respect to their layouts.

Field data was collected using video recordings of traffic at the roundabouts for a typical weekday. No notices or announcements were made public to indicate that the recordings would be taking place, so as to avoid any alteration in the behavioural characteristics of the drivers. The cameras were discretely placed on signage of the roundabouts and were not easily seen by the drivers. Video playback software - LUT version 3 player - was used to decode the information required.

The critical and follow-up gaps were estimated for each roundabout (see Table 2). In total, 1,206 gaps in traffic were observed at these three roundabouts. The video observations took into consideration varied site and traffic conditions. The recordings started at 6 AM and were stopped at 6 PM. Temporary markers were painted onto the roadway to help measure the duration of the accepted and rejected gaps.

Table 2. Summary of Roundabout Data Collection

Town/Location	Roundabout	Inscribed Circle Diameter (m)	Entry Lanes	Leg	Lane Analysed	Date and Time
Mt Hope	Arthur Lok Jack	60	2	South	Inner	Wednesday 29/04/2015 06:00 - 8:00 AM and 2:00 - 4:00PM
Barataria	Maritime	45	2	East	Outer	Tuesday 28/04/2015 06:00 - 8:00 AM and 2:00 - 4:00PM
Aranguez	Aranguez Overpass South	52	2	South	Outer	Thursday 28/05/2015 6:00 - 7:00 AM and 2:00 - 4:00PM

4. Results

4.1 The Maritime (Barataria) Roundabout

The Maritime (Barataria) roundabout is located at the intersection of 10th Avenue and Lady Young south roadway (see Figure 3). Data was analysed during the peak flow periods in both the AM and PM. Figures 4 and 5 show the cumulative accepted versus rejected gaps for the Maritime Roundabout in AM and PM, respectively.

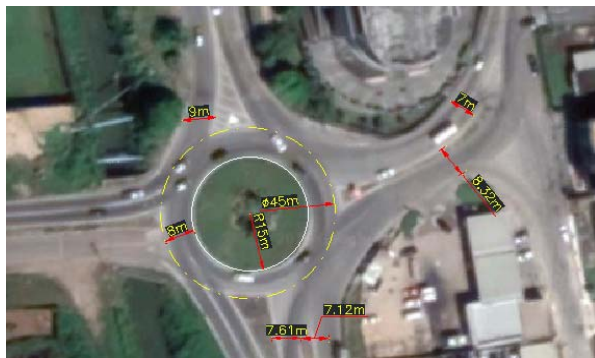


Figure 3. An aerial photograph of the Maritime roundabout
Source: Google Earth, accessed 25/09/2019)

maximum rejected gap was near to 9 seconds which came from a large truck manoeuvring around the roundabout. The capacities were calculated and compared using the HCM 2010 model with the default gap parameters and the measured critical gaps (see Figures 6 and 7).

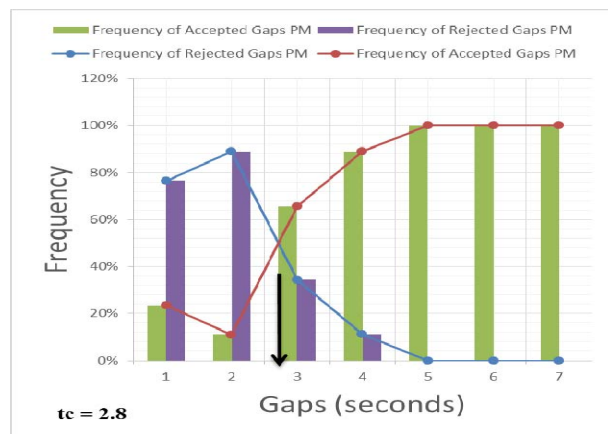


Figure 5. Plot of the Cumulative Accepted vs Rejected Gaps for the Maritime Roundabout PM

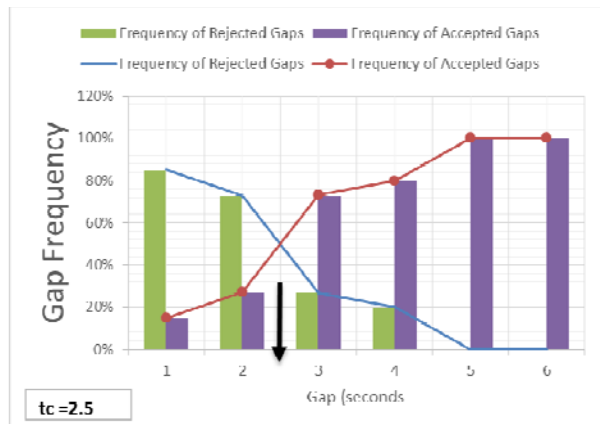


Figure 4. Plot of the Cumulative Accepted vs Rejected Gaps for the Maritime Roundabout AM

As shown in Table 3, the critical gap variation between the morning and afternoon estimations yielded a difference of 19.14%. It should be noted that the minimum accepted gap measured for the AM and PM time periods were 0.56 and 0.6 seconds respectively. The

Table 3. Summary of Gaps at the Maritime Roundabout

Gaps	Mean (sec)	Standard Deviation (sec)	Minimum (sec)	Maximum (Lag) (sec)
Accepted AM	2.9	2.5	0.6	17.4
Rejected AM	1.5	0.7	0.7	9.0
Accepted PM	2.2	1.3	0.6	6.7
Rejected PM	1.7	0.6	0.8	10.1

Gaps	Seconds
t_c AM	2.35
t_c PM	2.8
Δ AM vs PM	0.45
Δ %	19.14%
Maritime t_c	2.6
Δ Lane Capacity of Approach	170
Δ Capacity %	19%
Δ Degree of Sat	0.076
Δ Degree of Sat%	20%

The critical gap value used in the SIDRA model to determine the capacity corresponds to the maximum volumes observed. The maximum volumes were measured in the morning periods, therefore the AM critical gaps were used in the calculations of the capacities. A change in the critical gap value from the

default HCM 2010 to the value measured in this study results in an increased estimated capacity of 170 vehicles per hour.

the cumulative accepted versus rejected gaps for the Arthur Lok Jack Roundabout in AM and PM, respectively.

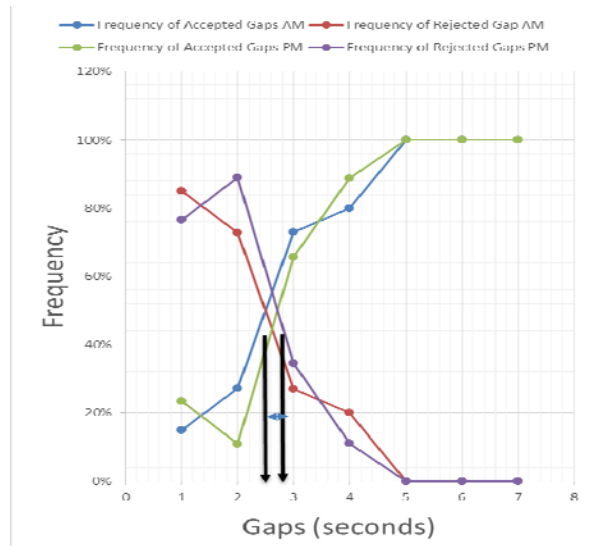


Figure 6. Plot of the Cumulative Accepted vs Rejected Gaps for Maritime Roundabout AM vs PM

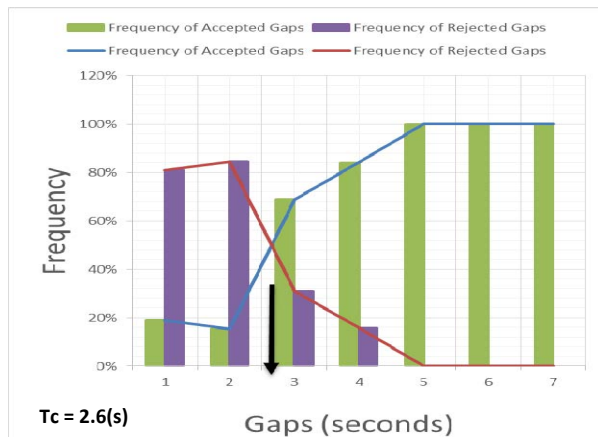


Figure 7. Plot of the Cumulative Accepted vs Rejected Gaps for Maritime Roundabout AM and PM Combined

4.2 The Arthur Lok Jack (Mt Hope) Roundabout

The Arthur Lok Jack Roundabout is located at the intersection of the Uriah Butler Highway (northern section), the entrances to Arthur Lok Jack and the southern entrance to The University of the West Indies (see Figure 8). This is a four-leg roundabout that has predominant flows in the north and south bound directions. These north and south approaches are fed with traffic from the Eastern Main Road and the Churchill Roosevelt Highway respectively Data from the southern approach was analysed during the peak flow periods in both the AM and PM. Figures 9 and 10 show

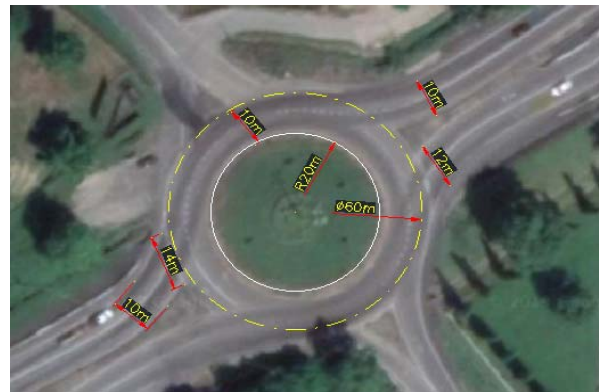


Figure 8. An aerial photograph of the Arthur Lok Jack (Mt Hope) roundabout
Source: Google Earth, accessed 25/09/2019

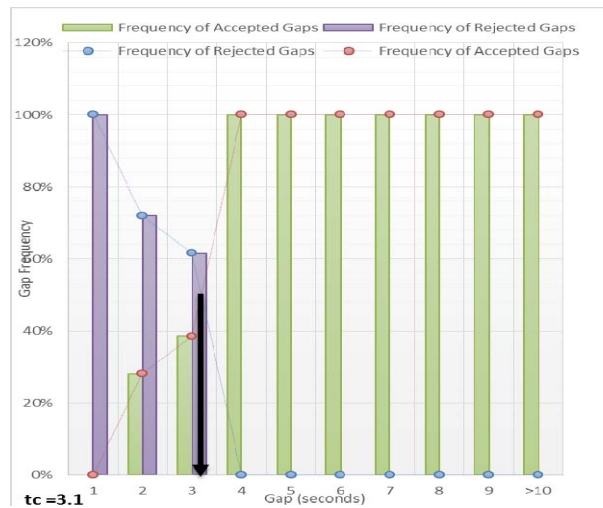


Figure 9. Plot of the Cumulative Accepted vs Rejected Gaps for the Arthur Lok Jack Roundabout AM

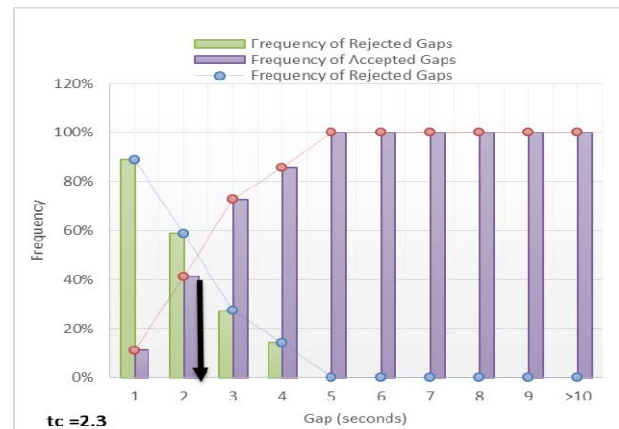


Figure 10. Plot of the Cumulative Accepted vs Rejected Gaps for the Arthur Lok Jack Roundabout PM

Table 4 shows a summary of gaps at the Arthur Lok Jack roundabout. There was a larger difference between the critical gap values for the morning and afternoon as compared to Maritime. The variation between the AM and the PM for this roundabout was comparable to the difference obtained for the Aranguez South roundabout. In addition, the lowest critical gap measured at Arthur Lok Jack roundabout was in the afternoon period. The minimum accepted and rejected gaps were around 1 second for both morning and afternoon periods. This may suggest that on the day of the observation, that similarly small gaps were both accepted and rejected at this roundabout (see Figures 11 and 12).

Table 4. Summary of Gaps at the Arthur Lok Jack Roundabout

Gaps	Mean (sec)	Standard Deviation (sec)	Minimum (sec)	Maximum (Lag) (sec)
Accepted AM	5.1	3.2	1.5	14.3
Rejected AM	2.0	0.6	1.1	3.4
Accepted PM	4.4	2.9	1.2	14.3
Rejected PM	1.9	0.8	1.0	3.9

Gaps	Seconds
t_c AM	3.1
t_c PM	2.3
Δ AM vs PM	0.8
Δ %	2.8
Arthur Lok Jack t_c	34.78%
Δ Lane Capacity of Approach	13
Δ Capacity %	1%
Δ Degree of Sat	0.004
Δ Degree of Sat%	2%

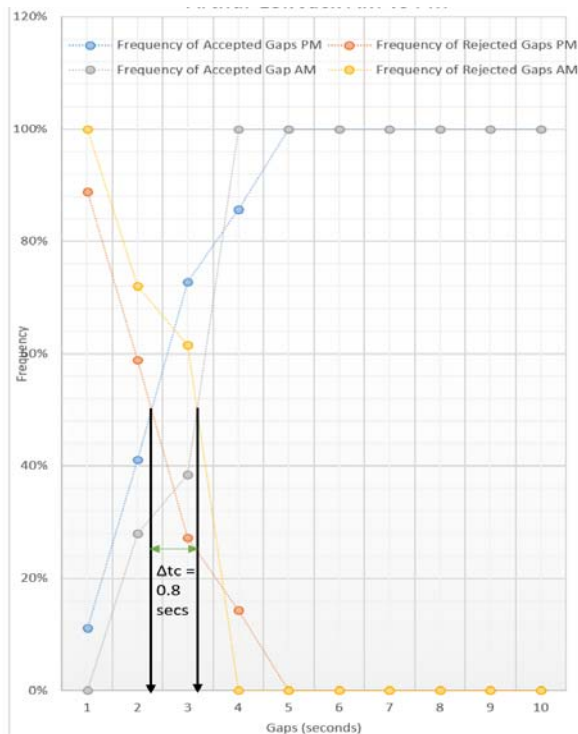


Figure 11. Plot of the Cumulative Accepted vs Rejected gaps for the Arthur Lok Jack Roundabout AM vs PM

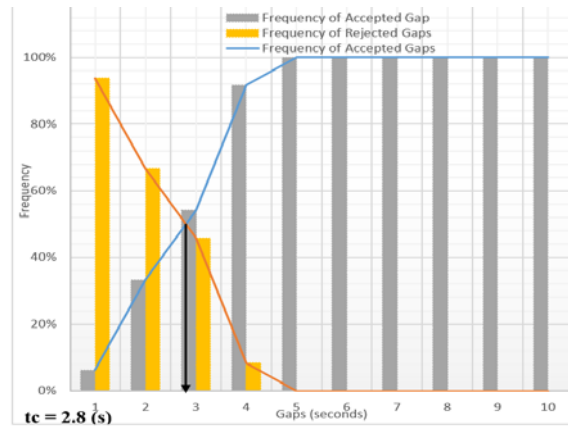


Figure 12. Plot of the Cumulative Accepted vs Rejected gaps for the Arthur Lok Jack Roundabout AM vs PM combined

The difference between the critical gaps measured in the morning and afternoon was 0.8 seconds. This difference was an increase as compared to the difference observed at the Maritime roundabout. The associated increase in capacity using the different critical gaps in the SIDRA HCM 2010 analysis was 13 vehicles per hour, a 1% percent increase, and therefore much lower than the increase in the observed inner lane capacity at Maritime.

4.3 The Aranguez South Roundabout

This roundabout is located at the intersection of Garden Road and the Aranguez South Link Road. This is a three-leg roundabout that has predominant flows in the south bound direction. The south approach receives its traffic from the westbound side of the Churchill Roosevelt Highway. Data was analysed during the peak flow periods in both the AM and PM. Figures 14 and 15 show the cumulative accepted versus rejected gaps for Aranguez South Roundabout in AM and PM, respectively.



Figure 13. Aerial photograph of the Aranguez South roundabout
Source: Google Earth, accessed 25/09/2019

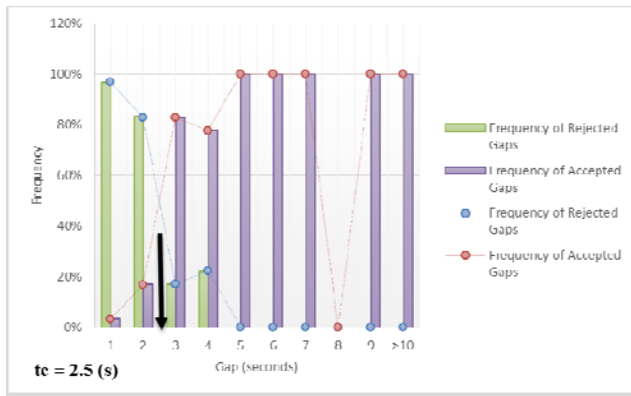


Figure 14. Plot of the Cumulative Accepted vs Rejected Gaps for the Aranguez South roundabout, AM

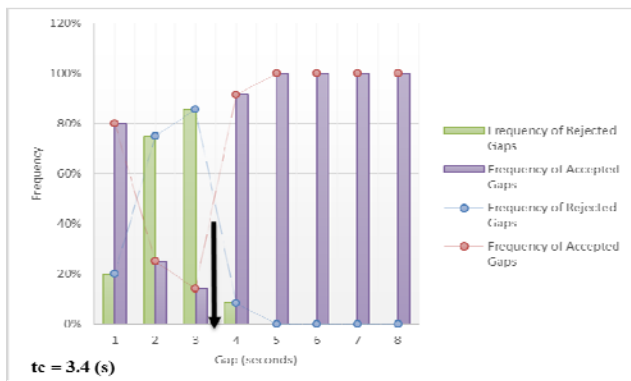


Figure 15. Plot of the Cumulative Accepted vs Rejected Gaps for the Aranguez South roundabout, PM

Table 5 shows a summary of the critical gap variation between the morning and afternoon estimations, yielding a difference of 36%. This difference was the highest variation between the morning and afternoon of all the observed roundabouts. Furthermore, the critical gap in the afternoon period was the highest critical gap measured amongst the roundabouts. It should also be noted that the minimum accepted gap measured for the AM and PM time periods was 1 second. The critical gap used to calculate the capacity was 2.5 seconds which resulted in a 62% difference in capacity as compared with those obtained with the default HCM 2010 values (see Figures 16 and 17). This was the highest increase in capacity among all of the three roundabouts under study.

The population critical gap was determined assuming driver behavioural characteristics are consistent across the selected roundabouts in Trinidad. This assumption is tested with the null hypothesis that the three roundabout samples belong to the same population (see t-test 2). Then, if the mean does not significantly differ, it can be used to represent the population as its variations would be random errors. Figure 18 shows the cumulative accepted versus rejected gaps for the population.

Table 5. Summary of Gaps at the Aranguez South Roundabout

Gaps	Mean (sec)	Standard Deviation (sec)	Minimum (sec)	Maximum (Lag) (sec)
Accepted AM	3.1	1.7	0.6	9.9
Rejected AM	1.8	0.5	0.9	4.1
Accepted PM	3.7	1.8	0.9	7.5
Rejected PM	2.3	0.6	1.4	3.6

Gaps	Seconds
t_c AM	2.5
t_c PM	3.4
Δ AM vs PM	0.9
Δ %	36.0%
Aranguez South t_c	2.6
Δ Lane Capacity of Approach	655
Δ Capacity %	62%
Δ Degree of Sat	0.068
Δ Degree of Sat%	28%

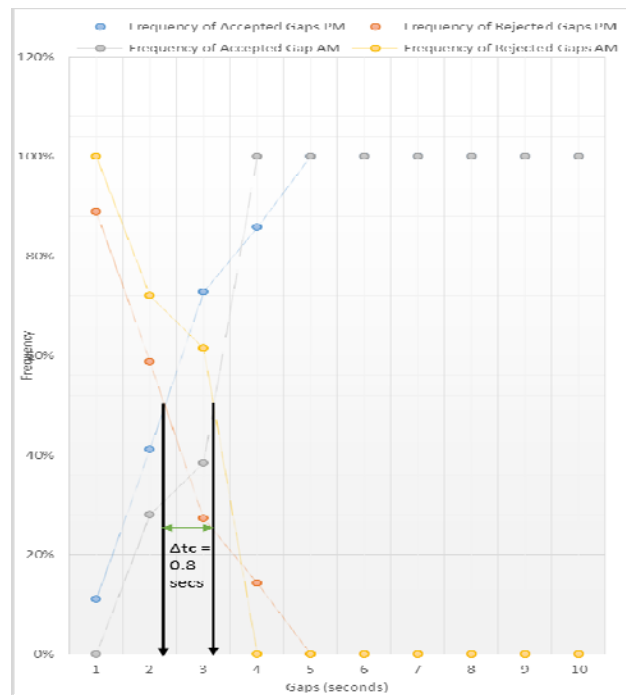


Figure 16. Plot of the Cumulative Accepted vs Rejected Gaps for the Aranguez South Roundabout AM vs PM

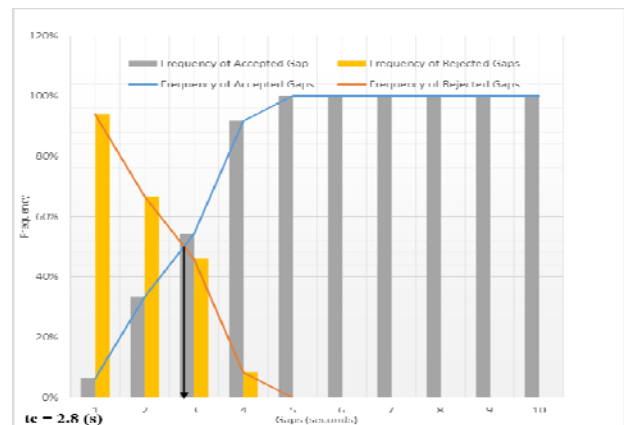


Figure 17. Plot of the Cumulative Accepted vs Rejected Gaps for the Aranguez South Roundabout AM and PM combined

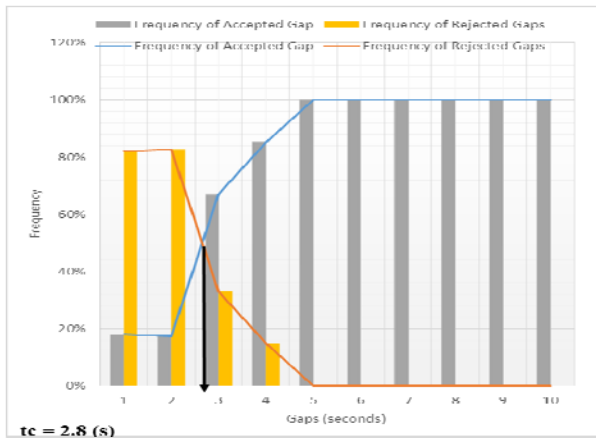


Figure 18. Plot of the Cumulative Accepted vs Rejected Gaps for the Population

5. Data Analysis

5.1 Testing Framework

A number of paired comparisons were undertaken. It is hypothesised that:

1. The critical gap would vary significantly between the morning and afternoon periods,
2. The combined sample of the critical gap for all sites will vary significantly from the population critical gap, and
3. The sample mean critical gap will significantly differ from those stated in the HCM 2010.

Figure 19 shows a flow chart of the significance testing framework. Null hypotheses 1 and 2 were tested using the students t-test. The significance level (α), i.e. the probability of the occurrence of wrongfully rejecting the null hypothesis, was set at 5%. For hypothesis 3, this was quantified by the use of differences as they were calculated values and not observed.

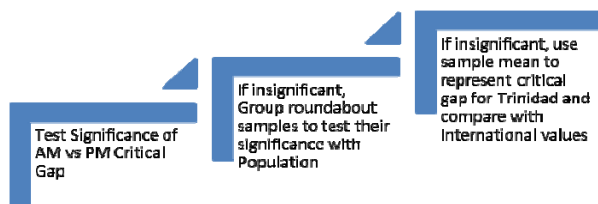


Figure 19. A Flow Chart of the Significance Testing Framework

Using the t-test in this study, it was assumed that:

- The data is distributed along a nominal distribution (it can be verified by the checking for skew),
- A two-sided test is to be more suitable,
- Each observation in the study had an equal chance of participating in the study,
- Drivers were not aware of their driving patterns being recorded, and
- The critical gap holds for both inner and outer lanes and tested separately.

5.2 Testing of Hypotheses

Three hypotheses were tested. These are listed below and records of respective the computations are summarised in Tables 6, 7, and 8, respectively.

- t-test 1: Measured Gap AM versus PM,
- t-test 2: Samples represents the Population, and
- t-test 3: Combined Measured Gap vs HCM gap.

Table 6. Test for Significance of Hypothesis 1

Variables	Overall observed Outer Lane	Overall Observed Inner Lane
Expected Value	2.83	2.65
Mean AM	2.65	2.65
Mean PM	2.83	2.83
Standard Deviation AM	0.40	0.40
Standard Deviation PM	0.55	0.55
Level of Probability	0.05	0.05
Number of data points	3.00	3.00
Standard Error AM	0.23	0.23
Standard Error PM	0.32	0.32
Actual t value AM	0.80	-
Actual t value PM	-	0.58
Critical t value	4.30	4.30
Significance t-Test 1	Accept Null Hypothesis	Accept Null Hypothesis
	With accepting the Null Hypothesis, there is an insignificant difference of measured critical gap in the AM	With accepting the Null Hypothesis, there is an insignificant difference of measured critical gap in the PM

Table 7. Test for Significance of Hypothesis 2

Variables	Overall observed
Expected Value	2.80
Mean Critical Gap	2.67
Standard Deviation of samples	0.12
Level of Probability	0.05
Number of data points	3.00
Standard Error	0.07
Actual t value	2.00
Critical t value	4.30
Significance t-Test 2	Accept Null Hypothesis
	With accepting the Null Hypothesis, there is no significant difference between the sample mean and population

Table 8. Test for Skew and Significance Testing of Hypothesis 3

Variables	Overall observed Outer Lane	Overall Observed Inner Lane
Expected Value	4.30	4.11
Population Mean	2.67	2.67
Standard Deviation	0.12	0.12
Level of Probability	0.05	0.05
Number of data points	3.00	3.00
Standard Error	0.07	0.07
Actual t value	24.50	21.65
Critical t value	4.30	4.30
Significance t-Test 3	Reject Null Hypothesis	Reject Null Hypothesis
	With rejecting the Null Hypothesis, there is a 95% chance that the measured critical gap differs from the HCM 2010 critical gap	With rejecting the Null Hypothesis, there is a 95% chance that the measured critical gap differs from the HCM 2010 critical gap

Several limitations of the *t*-test are identified. Firstly, the *t*-test gives correlation and does not imply causation. Secondly, the expected values published in the HCM 2010 are a range, and the mean values were used. Also, these mean values were consistent with the value used in the SIDRA analysis.

6. Discussions and Interpretation of the Results

The results of the hypothesis testing showed 1) that there was no significant difference between the measured critical gaps in the morning and afternoon, 2) that there was no significant difference between the population mean and the grouped sample mean, and 3) that there was a significant difference of the group sample mean and the critical gap values referenced in the HCM 2010.

The summary of findings is given in Table 9. The associated increases in the capacities were minimal except in the case of Aranguez South where there was a 62% difference. The majority of the gaps were estimated between 2 to 3 seconds. Only two estimations were over 3 seconds but all were under the stated values of the HCM 2000, HCM 2010 and NCHRP 572.

Table 9. Summary of the Critical Gaps and Capacities of Three Roundabouts in Trinidad

Gaps	Arthur Lok Jack	Maritime	Aranguez South
tc AM (s)	3.1	2.35	2.5
tc PM (s)	2.3	2.8	3.4
Δ AM vs PM %	34.78%	19.07%	36.00%
tc Combined AM and PM	2.8	2.6	2.6
Δ Capacity %	1%	19%	62%
Δ Degree of Sat%	2%	20%	28%

The comparisons of the critical gaps determined at selected roundabouts Trinidad are in Table 10 which shows that the gaps determined were lower than most of the international values. Critical gap values were determined for each roundabout for both the morning and afternoon periods and overall, so the variability of time and its effect on the gap values could be investigated. The overall results showed a variation of the critical gaps observed at all three roundabouts under study. This variation was due to the flow conditions, as well as the varying geometries at different roundabouts. There were also insignificant differences observed between the critical gaps for each of the roundabouts according to the time of day.

The population critical gap was determined assuming driver behavioural characteristics are consistent across Trinidad. The three different roundabout samples were determined to belong to the same population. The mean does not significantly differ, and it was used to represent the population as its variations would be random errors. Moreover, lack of traffic law enforcement in Trinidad may result in road users not following the operational rules of a roundabout.

Table 10. International Critical Gap References

Country	Mean Critical Gap (sec)	Observation
Australia		
2 lane	2.9	Model based on conflicting flow and number of lanes, diameter and entry width
Denmark		
2 lane, rural	4	Parameters by Regression
Poland		
Medium 2 lane (L)	4.3	Parameters by Regression
Medium 2 lane (R)	4.6	
Portugal		
2 lane	3.7	Maximum Likelihood method and Raff
Sweden		
2 lane roundabouts (L)	4.5	Maximum Likelihood method
2 lane roundabouts (R)	4.15	
United States (HCM 2010)		
2 lane roundabouts (L)	4.3	Maximum Likelihood method
2 lane roundabouts (R)	4.11	Maximum Likelihood method
United States (NCHRP 572)		
2 lane roundabouts (L)	4.85	Maximum Likelihood method
2 lane roundabouts (R)	4.15	
Trinidad		
2 lane roundabout (L)	3.1	Raff at Arthur Lok Jack
2 lane roundabout (R)	2.35	Raff at Maritime
2 lane roundabout (L)	2.5	Raff at Aranguez South

For example, road users drive on the shoulder lane of the roundabout which introduces an additional parameter to the capacity which theoretically comprises of the circulatory lanes, entry lanes and the exit lanes. Also noteworthy is the fact that, due to the improper use and incorrect education on the use of a roundabout, many users do not enter into the correct lanes and weave dangerously within the circulatory lanes of the roundabout. Alternatively, some road users merge into the circulatory stream dangerously, therefore accepting very small gaps.

A comparison and a capacity analysis were performed using the standard values of the Highway Capacity Manual 2010. The analysis used the maximum volumes as the best model of the expected capacities at the roundabout sites. The calculated values were compared to the HCM values and it was determined that the estimations for Aranguez South in the afternoon (3.4 seconds) and Arthur Lok Jack in the morning period (3.1 seconds) were those closest to the guided values of the HCM 2010 values of 4.3 and 4.11 seconds. The Arthur Lok Jack roundabout gap estimate for the afternoon was the furthest from the HCM 2010 value (80 percent lower). Hence, the Aranguez South roundabout had the lowest critical gap for all the morning periods and therefore was used for the capacity analysis at this site. This resulted in a value 72 percent higher than the expected HCM 2010.

There was a statistically significant difference between the critical gaps measured in the morning and those published in the HCM 2010 for the sub dominant (outer) lane. This was not the case for the mean of the afternoon gaps when compared to the dominant (inner) lane HCM 2010 standard.

7. Conclusion

The objectives of this study were 1) to determine the critical gaps for drivers at selected roundabouts in Trinidad, 2) to determine if they differed significantly from international values, and 3) to use the measured values to determine the differences in capacities from that of the HCM default values. With the use of video technology the critical gaps as defined by Raff and Hart (1983) were determined at the three roundabouts under study. Comparisons were made between different times of day and their effects on the predicted and actual capacities of the roundabouts. It was discovered from the samples taken in this study that the time of day did not result in a significant variation of the critical gap. Furthermore, it was shown that the estimated critical gaps at the three roundabouts were not statistically significantly different.

The results of the research showed significant differences between the critical gaps in T&T and those from international sources included the default gaps used in the Highway Capacity Manual 2010. The differences determined resulted in increases of the calculated capacities at the three roundabouts by as much as 72% when the locally derived critical gaps were used. The results showed the importance of using locally derived measures, as far as possible in designing and determining the performance of roundabouts.

References:

- AASHTO (2004), *Geometric Design of Highways and Streets*, American Associated of State Highway Transportation Officials, Washington, DC.
- Barry, C. (2012), *Calibration of the HCM 2010 Roundabout Capacity Equations for Georgia Conditions*, Master's Thesis. Georgia Institute of Technology, USA.
- Brilon, W., Koenig, R., and Troutbeck, R. (1997), "Useful estimation procedures for critical gaps", *Proceedings of the Third International Symposium on Intersections without Traffic Signals*, Washington, July, pp.71-87 (Transportation Research Board)
- FHA (2000), *Roundabouts: An Informational Guide*, Federal Highway Administration, Portland
- Gazzarri, A., Martello, M.T., Pratelli, A., and Souleyrette, R.R. (2012), "Estimation of gap acceptance parameters for HCM 2010 roundabout capacity model applications", *Proceedings of the Eighteenth International Conference on Urban Transport and the Environment*, Southampton (WIT Press)
- Kusuma, A., and Koutsopoulos, H.N. (2011), "Critical gap analysis of dual lane roundabouts", *Procedia - Social and Behavioural Sciences*, Vol.16, pp.709-717.
- Mensah, S., Eshragh, S., and Faghri, A. (2009), *A Critical Gap Analyses of Modern Roundabouts*, University of Delaware, Delaware
- Miller, J.A. (1972), "Nine estimators of gap acceptance parameters", In: Newell, G.G.F. (ed.), *Traffic Flow and Transportation: Proceedings*, Elsevier, New York, pp.215-235
- Raff, M.S. and Hart, J.W.A. (1983), "A volume warrant for urban stop sign", *Traffic Engineering and Control*, Vol.24, No.5, May, pp.255-258.
- Shifftan, Y., Shmueli-Lazar, S., and Polus, A. (2005), "Evaluation of the waiting-time effect on critical gaps at roundabouts by a logit model", *European Journal of Transport and Infrastructure Research*, Vol. 5, No.1, pp.1-12.
- Tian, Z., Troutbeck, R., Kyte, M., Brilon, W., Vandehey, M., Kittelson, W., and Robinson, B. (2000), "A further investigation on critical gap and follow-up time", *Proceedings of the 4th International Symposium on Highway Capacity*, Maui/Hawaii, pp.409-421 (Transportation Research Circular E-C018)
- Tian, Z., Vandehey, M., Robinson, B.W., Kittelson, W., Kyte, M., Troutbeck, R., Brilon, W., and Wu, N. (1999), "Implementing the maximum likelihood methodology to measure a driver's critical gap", *Transportation Research Part-A: Policy and Practice*, Vol.33, No.3, pp.187-197.
- TRB (2010), *Highway Capacity Manual 2010*, Transportation Research Board, 5th Edition, Washington, DC
- Tupper, S.M. (2011), *Safety and Operational Assessment of Gap Acceptance through Large-Scale Field Evaluation*, Master's Thesis, University of Massachusetts, Amherst, USA
- Vasconcelos, A.L.P. (2012), "Comparison of procedures to estimate critical headways at roundabouts", *PROMET – Traffic and Transportation*, Vol. 25, pp.43-53.
- Wanga, W., and Yang, X. (2012), "Research on capacity of roundabouts in Beijing", *Procedia - Social and Behavioural Sciences*, Vol.43, pp.157-168.
- Xu, F., and Tian, Z.T. (2008), "Driver behaviour and gap-acceptance characteristics at roundabouts in California", *Journal of the Transportation Research Board*, Vol.2071, pp.117-124

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