12-2000

Performance Comparison of a Roundabout Versus Two-Way Stop Controlled (TWSC) Intersections

Deogratias Eustace
University of Dayton, deustace1@udayton.edu

Performance Comparison of a Roundabout Vs. Two-Way Stop Controlled (TWSC) Intersections

By Deogratias Eustace

Introduction

The superior safety record of modern roundabouts is well known in Western Europe, Australia and in most British-influenced countries around the world (1). The experience from a single modern roundabout installed in the City of Manhattan, Kansas some three years ago, also shares the same experience (2).

A major study of the performance of Manhattan, Kansas modern roundabout was conducted at Kansas State University (KSU) and was co-sponsored by Mac-Blackwell National Rural Transportation Study Center, Kansas State University, and the City of Manhattan. The study examined three intersections, one modern roundabout and two Two-Way Stop Controlled (TWSC) intersections with similar traffic conditions (2). The aim of this paper is to compare how a roundabout functions with regard with one type of the traditional intersection traffic controls, i.e., the TWSC.

Selection of Comparable Intersection

Since a roundabout was the main intersection to be studied, then a comparable intersection was determined to be one that had the same general physical layout, and operated under similar traffic loading as that of existing roundabout.

The general physical and operational features of comparable TWSC intersections where limited by the features of the existing roundabout, and were determined as shown in Table 1(2).

The selected physical and operational features given in Table 1 led to the creation of a set of possible comparable TWSC intersections within the city limits of Manhattan, KS. The two TWSC selected intersections and the roundabout are briefly explained below.

Table 1. Comparable Intersection Selection Criteria

Physical trait	General range required
Approach legs	Four
Number of approach lane	One
Type of approach lane	Collector/arterial/local
Total intersection traffic volume	5,000-10,000 vpd
Approach speed	25-35 mph

Dickens Avenue-Wreath Avenue (D-W) TWSC intersection

This is a four-leg intersection located on western side of the city. Both roads are 2-lane collectors satisfying the required criteria for this study. Wreath Avenue is a North-South road and is the major street at this intersection. Dickens, which spans East-West direction, is a minor road whose approaches are STOP controlled.

Juliette Avenue-Pierre Street (J-P) TWSC intersection

The Juliette Avenue-Pierre Avenue intersection is located south of downtown area of Manhattan City. This is the intersection of a 2-lane collector road and a 2-lane local road. Juliette Avenue is a North-South collector, prioritized as a major street. Pierre Street is a East-West local road prioritized as a minor street and hence both of its approaches are STOP controlled. Sometimes during PM peak hours, the minor street, Pierre Street carries more traffic than the major street, Juliette Avenue.

Candlewood Drive-Gary Avenue Roundabout Intersection

This is the first modern roundabout to be built in the State of Kansas (2). It is located at the intersection of two collector roads in western side of the city. The roundabout was opened in the fall of 1997. Candlewood Drive is a North-South collector while Gary Avenue is a East-West collector. All four approaches are yield-controlled. Originally it was a two-way stop controlled intersection. Due to delays and bad safety history this intersection had, the public complaints tempted the city authorities to improve the intersection traffic control system. Now it is almost three years since it was opened to traffic and no traffic crash that has been reported at this roundabout (2).

Literature Review

Flannery et al. (3) say that despite the fact that many roundabouts have replaced stop-control and signalized intersections around the world, few reports have been published regarding the reduction or increase in delay as result of their installation.

The time a driver has to wait before he can cross or merge with other streams is an important performance indicator for unsignalized intersections. This delay is used to evaluate the performance of signalized intersections, the performance of roundabouts, and traffic interaction at unsignalized intersections (4).

TWSC intersections are one of the most prevalent types of intersection in the United States and abroad (5). Stop signs are used to assign the right of way at such intersections. At TWSC intersections, the stop-controlled approaches are referred to as "minor street approaches". The intersection approaches that are not controlled by the stop signs are referred to as "major street approaches". The Highway Capacity Manual (HCM 94) defines the TWSC intersections as the type of intersections that assign the right of way among conflicting traffic streams according to the following hierarchy (5):

- *All conflicting movements yield the right of way to any through or right-turning vehicle on the major street approaches. These major street through and right-turning movements are hereafter referred to as the "highest priority" movements at a TWSC intersection.*
- *Vehicles turning left from the major street onto the minor street yield only to conflicting major street through and right turning vehicles. All other conflicting movements at a TWSC intersection yield to these major street left-turn movements.*
- *Vehicles turning right from the minor street onto the major street yield only to conflicting major street through movement.*
- *Minor street through vehicles yield to all conflicting major street through, right-, and left-turning movements.*
- *Minor street left-turning vehicles yield to all conflicting major street through, right-, left-turning vehicles and also to all conflicting minor street through and right-turning vehicles.*

At TWSC intersections, drivers on the controlled approaches are required to select gaps in the major street flow through which to execute crossing or turning maneuvers. In the presence of a queue, each driver on the controlled approach must also use some measurable amount of time moving into the front-of-queue position and getting ready to evaluate gaps in the major street flow (5).

At roundabout there is no sequential assignment of the right-of-way and therefore no wasted time. Left turns are not subordinated to through traffic. Vehicles enter under yield control instead of stop control and therefore have lower headways and higher capacities. There are no electrical components to malfunction. However, the Florida Roundabout Guide (FRG) (7) mentions the following as the roundabout limitations:

- Steady-state entry headways are shorter at traffic signals because of positive assignment of right-of-way.
- For very low-volume applications, TWSC and AWSC (All Way Stop-Control) are easier and less expensive to implement.
- Since roundabout operation is not periodic, it is not possible to coordinate the operation of roundabouts on arterial route to provide smooth progression for arterial flows.

Roundabouts are forms of at-grade intersection control that is becoming increasingly popular in the United States. Roundabouts are similar to traffic circles, popular in the early 1900s; however, they include design and operational improvements that enhance their performance as compared with traffic circles (3).

Roundabouts differ from traffic circles by the inclusion in their design of the following features (3): (i) Yield on entry, (ii) Deflection on approaches, and (iii) Flared entries.
Yield on entry, or "priority rule", requires entering vehicles to yield to drivers in the circulating roadway. Priority rule was adopted in Britain in the 1960s, and since that time many countries have adopted this practice (8). This change in law prevented vehicles from "locking-up" within the roundabout, and in time, resulted in a fundamental change from traffic circles to modern roundabout design. Since merging and weaving lanes (as in traffic circles) were no longer required, these modern roundabouts could be constructed in much smaller areas at a relatively modest cost (8). A more detailed comparison between modern roundabouts and old traffic circles can be found elsewhere (9). Roundabouts eliminate the need for left turn prohibitions, and they require no median to accommodate left turn lanes (10).

California Department of Transportation (11) defines the modern roundabout by two basic principles that distinguish it from a nonconforming traffic circle as:

- Roundabouts follow the "yield-at-entry" rule, in which approaching vehicles must wait for a gap in the circulating flow before entering the circle, whereas traffic circles require circulating vehicles to grant the right of way to entering vehicles.
- Roundabouts involve low speeds for entering and circulating traffic, as governed by small diameters and deflected entrances. In contrast, traffic circles emphasize high-speed merging and weaving, made possible by larger diameters and tangential entrances.

Savage and Al-Sahili (6) studied the performance of three roundabouts and three TWSC intersections that were part of one network and carried similar traffic volumes. Their study found out that as a group, TWSC had average crash rate almost twice that of roundabouts. Also, the severities of crashes at the roundabout intersections were considerably less than at the TWSC intersections. By examining the measures of effectiveness as produced by NETSIM software, they claim that although they suspected that TWSC was not operating well, the results were much worse than expected. Their conclusion was that the three roundabouts studied are operating better than the nearby TWSC intersections.

Data Analysis

The Signalized and unsignalized Intersection Design and Research Aid (SIDRA) package was used in the analysis and evaluation of the performance of the three intersections. SIDRA is computer software developed in Australia, capable of analyzing different types of intersections and widely accepted and used in the United States (12). Although other computer analysis packages are in use in the U.S., SIDRA was used instead of other software due to reasons described below. SIDRA can analyze both the roundabout and TWSC intersections while other popular software can analyze either one type of intersection only. The Australian methods are most comparable with HCM methods, and particularly SIDRA offers an option to implement the HCM procedures for many computations (7). In addition, the Australian method is based on analytical models that are easily transportable internationally. Florida DOT (7) summarizes by saying, "the roundabout analysis model should produce results that are comparable with the results of the HCM models for alternative control modes". Since HCM procedure for TWSC intersections is based on gap acceptance theories and is implemented in SDRA, it was found to be reasonable too, to use SIDRA roundabout procedure that again is based on the same theories of gap acceptance.

Measures of Effectiveness

SIDRA describes the performance of an intersection in terms of measures of effectiveness (MOE's). The MOE's are given by SIDRA software as the output and these provide a comprehensive look at how a particular intersection operates. It gives the average values for the whole intersection. However, it includes the same values for each approach too. This can be very useful if one needs to compare the individual approach against the intersection average performance. The MOE's outputs from SIDRA that were used are summarized in Table 2.

The hourly traffic volumes were obtained from the videotapes and recorded manually on specially prepared sheets for every 15-minute intervals. Only those hourly volumes, which were tested and showed to be comparable statistically, were used (2). SIDRA uses the peak hour volumes for calculations. Thus PHF's (Peak Hour Factors) were determined and the hourly volumes were converted into peak hourly volumes. Again these peak hourly volumes were tested statistically to make sure that they are still consistent and comparable among the three intersections under study (2).

Table 2. Measures of Effectiveness (MOE's) Criteria from SIDRA Output

Measure of Effectiveness	S hort Description
95% Queue	Length of the queue for all approaches at the
Average Delay	Average vehicle delay for all entering vehicles
Proportion Stopped	Proportion of entering vehicles that are required to stop

Results and Discussion

The results from SIDRA output were analyzed and are here presented in the form of graphs, which can easily help to make the comparison of three different intersections. Of the many MOE's, only three of them have been used to analyze the performance of the intersections.

Figure 1 shows the relationship between the average intersection delays (all approaches) versus intersection entering volumes. It is clearly observed that the roundabout has the highest average delay with a mean of around 8 seconds/vehicle. The Dickens-Wreath TWSC intersection has the lowest average delay but not much different from that observed at the Juliette-Pierre TWSC intersection. However, both TWSC have shown very high variability in terms of average delay as compared with the roundabout.

The means and standard deviations of the average delays of the three intersections are summarized in Table 3. The Juliette-Pierre TWSC intersection has the highest delay variability for different total entering volumes. In terms of the average delay for all approaching movements, the roundabout performs the worse. The low average delay at TWSC intersections may be partly due to freedom given to main street traffic which experiences very little or no delay and that is reflected in the very high standard deviation values scored by these types of intersection (see Table 3).

Figure1. Intersection Average Delay for All Approaches

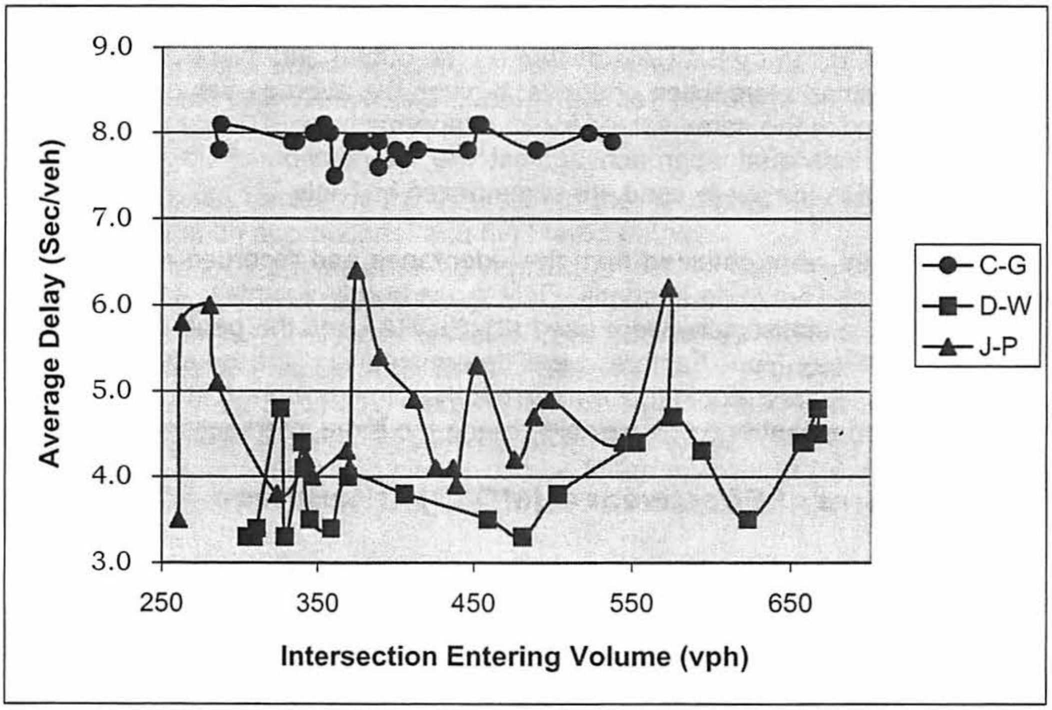


Table 3. Mean and Standard Deviation of Average Delays

Intersection	Mean Value (sec)	Standard Deviation (sec)
D-W TWSC	4.0	0.54
J-P TWSC	4.7	0.84
C-G Roundabout	7.9	0.16

The average 95 % queue values for the three intersections are shown in Figure 2. All three curves show similar trend, that the queue increases with increasing amount of traffic entering the intersection. Although the roundabout has shown to have highest average intersection delay (Figure 1), however, it does not create very long average queue. In this case, the Juliette-Pierre TWSC intersection has the longest queue, followed by the Candlewood-Gary roundabout. The Dickens-Wreath TWSC intersection has the lowest queue and its rate of increase of queue with respect to entering traffic volume is relatively moderate.

In terms of 95% queue length, the roundabout has performed in-between the two TWSC intersections, thus, it is inconclusive, which has performed better between the two types of intersection control according to this measure of effectiveness (MOE).

Figure 2. Average 95% Queue Length for All Approaches

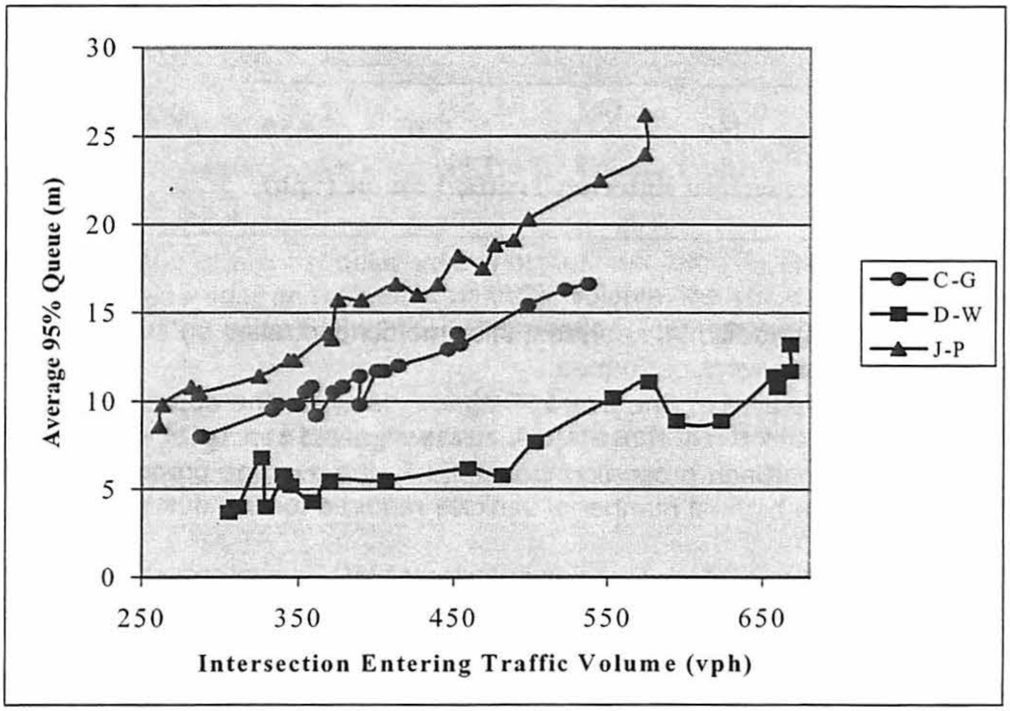
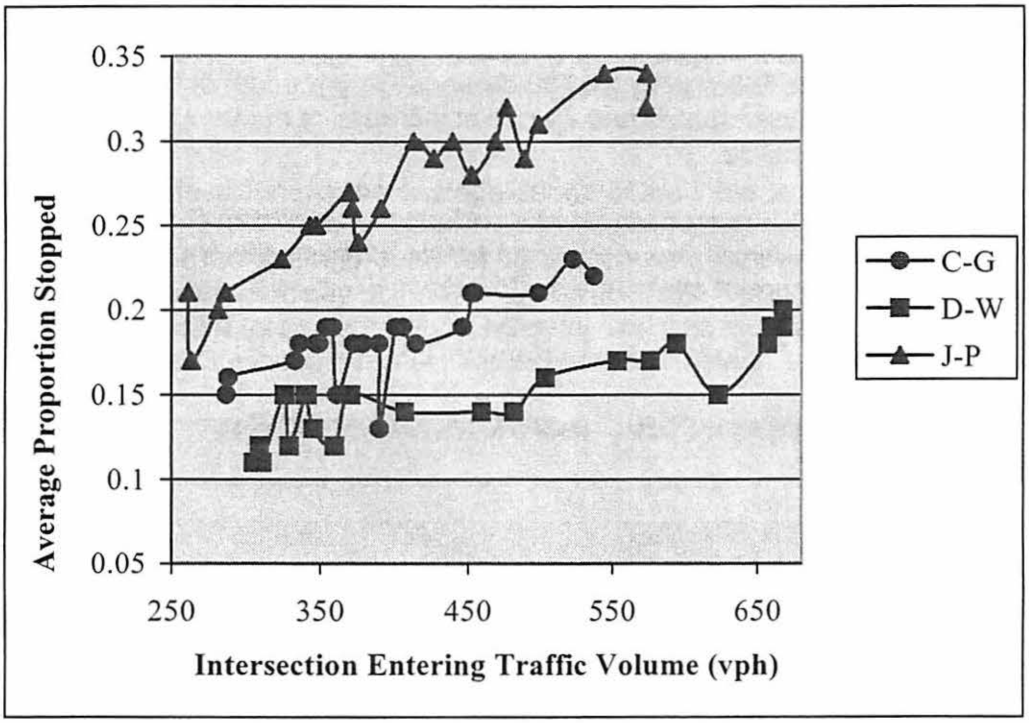


Figure 3 summarizes the results of the average proportion stopped. These are the proportion of vehicles which have to stop due to others being already in the intersection. It is not surprising that the average proportion stopped curves show similar trend as that depicted by the average 95% queue length curves. There is an inherent relationship between the two MOE's because the queue length is measured from the number of stopped vehicles at the intersection.

Due to high variability of average delays as tendered by the TWSC intersections (refer to Table 3), it was found worthwhile to analyze further as this may be deceiving in terms of intersections' performance. The high standard deviations suggest that there are some approaches which are experiencing higher delays which are concealed and not explicitly revealed in the low average values.

Figure 3. Average Proportion Stopped for All Approaches



Then it was decided to perform additional analyses, this time concentrating on individual approaches. The following additional analyses were performed:

- The maximum approach delay, i.e., the average vehicle delay for the approach with the highest average delay;
- The maximum (highest) approach proportion stopped, i.e., the average proportion of entering vehicles for approach with the highest number of vehicles required to stop due to vehicles already in the intersection;
- Since two TWSC intersections seem to differ in terms of MOE's performance indicators, it was thought that the number of left turns (%LT) and proportion of minor road entering traffic volume to major road entering traffic volume may have effect.

Figure 4 shows the results from the analysis of the approach experiencing the highest delay for each intersection.

It can be observed from Figure 4 that the Candlewood-Gary roundabout performs better with the Dickens-Wreath intersection having values very close to that of roundabout. Again, the roundabout has almost uniform maximum delays while the Dickens-Wreath TWSC intersection has almost comparable values with the exception of high variability at higher entering traffic volumes. The Juliette-Pierre TWSC intersection shows a different trend, besides having very high delays, they almost increase continuously with increasing entering traffic volume. This analysis again, reveals the superiority of a roundabout in distributing delays among all intersection approaches without penalizing motorists from certain approaches unfairly. Since the minor street at Juliette-Pierre intersection sometimes carries higher traffic volumes than the major street, Figure 4 reveals the weakness of a TWSC system in handling high traffic volumes from minor street.

Figure 4. Maximum Delay for Approach Having Highest Delay

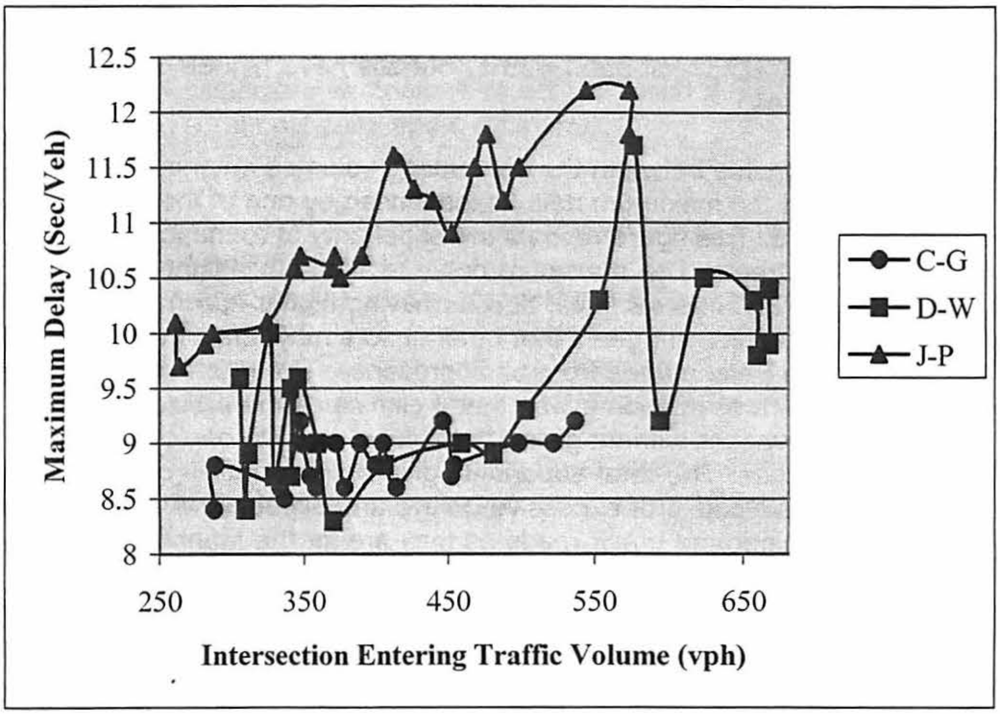
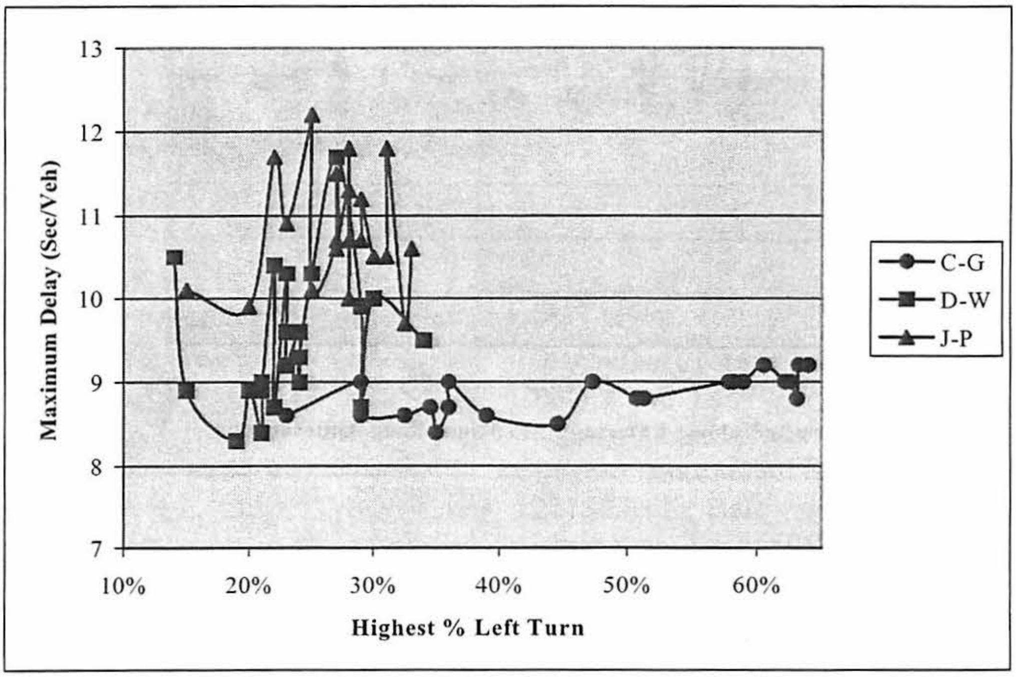


Figure 5 shows the trend of highest delay versus highest left turn (%LT) at each intersection for all entering volumes considered. For each entering traffic volume, the value of the approach with highest left turn volume and the value for highest left turn ratio to approach entering volume were used.

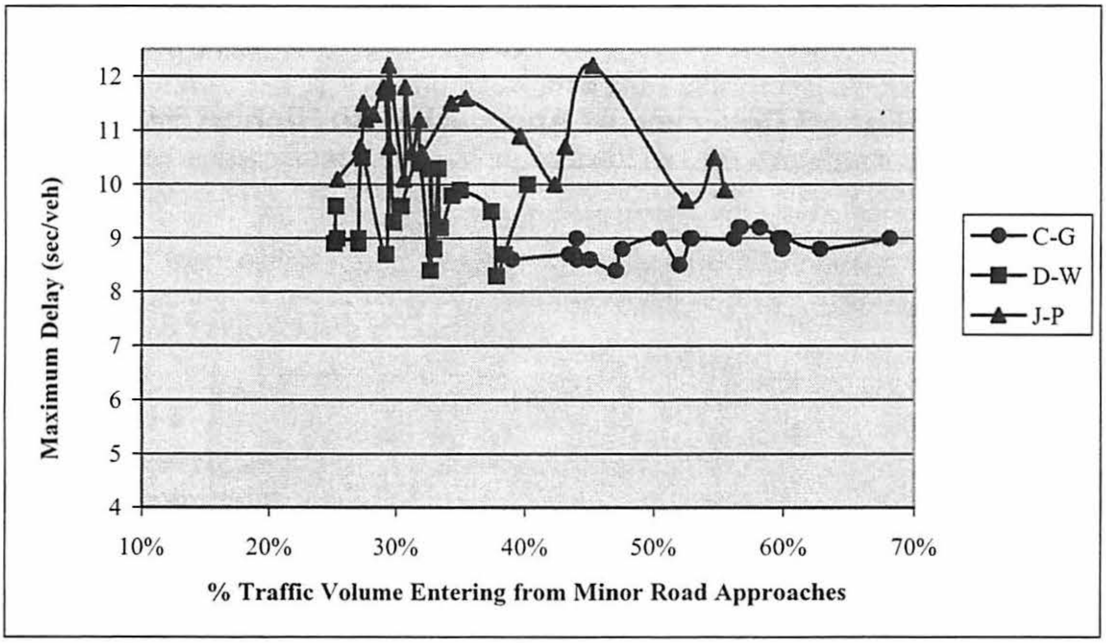
Figure 5.
Approach with Highest Delay versus Approach with Highest %LT Volume



This reveals a new picture altogether. The Candlewood-Gary roundabout performs better than both the TWSC intersections, with lowest "highest delays" which is almost uniform for all percentages of left turn volumes. The roundabout handles the traffic volumes with the highest %LT values (23-64%) and still has the lowest maximum (highest) delays. The two TWSC intersections handled lower left turn percentages (%LTs - about 14-35%) but still have higher maximum delays compared to the roundabout values.

An effort to model the relationship between the percentage volumes entering the intersection from minor street approaches and the maximum delay experienced by one of the approaches at the intersection is given in Figure 6. This figure reveals the superiority of roundabout of handling higher traffic volumes from minor streets. The maximum delay is almost constant with increasing minor street traffic volume. The TWSC intersections, despite having higher maximum delay values, also their performance fluctuates, which suggests that other factors may affect their performance at the same time, such as, left turn percentages from all approaches. The roundabout may perform better due to the fact that it operates in such a way that it eliminates the problem of left turns. It provides right of way to all approaches without giving "total superiority" to one or two approaches only as does the TWSC intersection. The total superiority given to the major road approaches at the TWSC intersection is the main cause of excessive delays and especially if the traffic volumes are almost equal between the minor and major roads as they are for the Manhattan roundabout intersection. With the ratio of minor road traffic volumes (39-68%) at the roundabout, if it were a TWSC, the delay situation would have been worse as Figure 6 reveals. That can be one of the reasons that prompted the City of Manhattan to change the intersection control type at the Candlewood Avenue-Gary Avenue intersection from a TWSC to a modern roundabout in 1997.

Figure 6. Relationship between Minor Street Traffic vs. Maximum Delay



Conclusion

The average delay is a good measure of the performance of intersections. However, this average value may conceal some facts and hence lead into wrong conclusions. It may not be the best way if the standard deviations of the delay values of the individuals approaches is large and traffic volume of the minor street approaches is comparable with that of the major street approaches.

The roundabout has revealed that it is superior if traffic volumes approaching it have a higher percentage of left turns and if the minor street carries relatively high volumes too. The delay at roundabout is more predictable and can be easily modeled. However, for low traffic volumes, the benefit of a roundabout over TWSC intersection diminishes. At low traffic volumes, a roundabout can be a better option over TWSC if there is a considerable percentage of left turns and if the minor street and major street volumes are comparable (i.e., almost carry equal volumes).

References

1. *Public Roads (Autumn 1995) – Roundabouts.* Extracted from the following Web Site: http://www.tfhrc.gov/pubrds/fall95/p95a41.htm
2. Russell, E. R., M. J. Rys, and G. Luttrell. *Modeling Traffic Flows and Conflicts at Roundabout.* Draft Final Report, Project No. 1088. Kansas State University, December 1999.
3. Flannery, A., L. Elefteriadou, P. Koza, and J. McFadden. Safety, Delay, and Capacity of Single-Lane Roundabouts in the United States. *In Transportation Research Record 1646*, 1999, pp. 63-70.
4. Troutbeck, R. J. Average Delay at an Unsignalized Intersection with Two Major Strean Each Having a Dichotomized Headway Distribution. In *Transportation Science*, Vol. 20. No. 4, Nov. 1986, pp. 272-286.
5. TRB. *Highway Capacity Manual.* Special Report 209, Third Edition. Transportation Research Board, Washington, D.C. 1994.
6. Savage, W. F. and K. Al-Sahili. Traffic Circles-A Viable Form of Intersection Control? In *ITE Journal.* September 1994, pp. 40-44.
7. *The Florida Roundabout Guide* (FRG). Florida Department of Transportation, Tallahassee, FL, 1998.
8. O'brien, A. and E. Richardson. Use of Roundabouts in Australia. In *Institute of Traffic Engineers.* Compendium of Technical Papers for the 55th Annual Meeting, 1985, pp. 180-187.
9. Taekratok, T. *Modern Roundabouts for Oregon.* Oregon Department of Transportation, Research Unit. Salem, OR., June 1998.
10. Todd, K. Modern Rotaries: A Transportation Systems Management Alternative. In *Transportation Research Record 737.* TRB, Washington, D.C., 1979, pp. 61-72.
11. CALTRANS. *Roundabouts.* Extracted from California Department of Transportation Web site: http://www.ca.gov/hq/oppd/dib/db80.htm. Design and Local Programs, CALTRANS, September 8, 1998.
12. Jacquemart, G. *Roundabout Practice in the United States.* NCHRP Synthesis 264. TRB, National Research Council, Washington, DC, 1998, pp. 30.

Deogratias Eustace
PhD. Candidate
Kansas State University
Department of Civil Engineering
2118 Fiedler Hall
Manhattan, KS 66506
Email: deu4455@ksu.edu