A Review of Roundabout Safety Performance in the United States

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1.0 Introduction

Roundabouts are a new form of at-grade intersection design that have been popular in Europe and Australia for many years as an alternative to two-way stop control and signalized intersections. While roundabout use is limited in the United States as of 1998, many local and state officials are planning or implementing roundabouts as a part of their roadway system. The benefits of roundabouts, in comparison to traditional forms of intersection design, include improved safety performance, reduced delay and community enhancement. This study addresses the safety performance of single lane roundabouts in the United States.

The geometric configuration of roundabouts, as compared to two-way stop control and signalized intersections, promote the reduction of severe accidents such as right angle, head-on and left turn head on. In addition, the number of decision points for drivers are reduced at roundabouts, helping to improve driver performance. Where a decision point is defined as a point or place in the intersection in which a driver is required to make a decision about their travel path. The reduction in decision points is illustrated in Figure 1 (Wallwork, 1991). Finally, the reduced speeds associated with the design of roundabouts increases driver reaction time and reduces the severity of accidents that do occur, usually reflected in the reduction of injury accidents. These characteristics of roundabouts help to support the findings found in many international safety studies conducted on the performance of roundabouts, as described in the following section.

2.0 International Safety Performance

International experience with roundabout use is generally more extensive than the United States therefore, every effort should be made to review international findings regarding the safety of roundabouts and to apply relevant findings to the design and operational control of American roundabouts. Several studies have been published on the topic of roundabout safety by researchers located in Europe and Australia. Their findings follow.

The use of roundabouts in Australia is extensive in both rural and urban areas. A large study was conducted in Victoria, Australia on 73 roundabouts before and after their installation (Austroads, 1993). Control in the before period included “Give Way to the Right”, “Stop” or “Give Way” and in one case police control. The findings of the study included a 74 percent reduction in the casualty accident rate after roundabouts were installed. Also, there was a 32 percent reduction in property damage accidents, although the authors point out that not all property damage accidents are reported so it is difficult to quantify the effects of the roundabouts on these types of accidents. Of particular interest, is a 68 percent reduction in pedestrian casualty accidents per

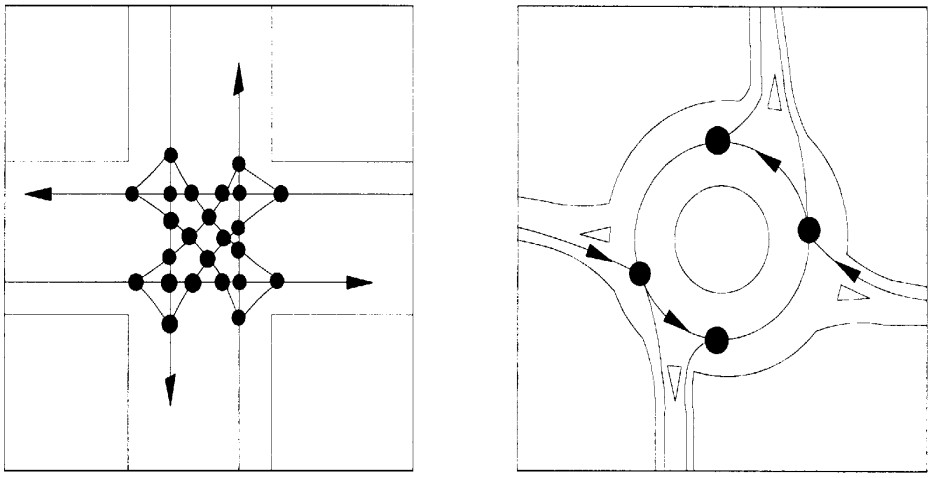

Figure 1 Decision Points at Traditional
At-Grade Intersections versus Roundabouts

year after installation of the roundabouts. Due to the low frequency of pedestrian accidents, however, this reduction was not found to be statistically significant at the 10 percent level.

The installation of roundabouts has also been extensive, recently, in Norway. Giaever reported that the use of roundabouts in Norway increased from only 15 in 1980 to more than 500 in 1992 (Giaever, 1992). This study also compared 59 roundabouts to 124 signalized intersections and found that the accident rate per million vehicles entering for roundabouts was lower as compared to signalized intersections. The study found that for 3 legged intersections, roundabouts had an accident rate of 0.03 while signalized intersections were found to have an accident rate of 0.05. Similar findings were also made for 4 legged intersections, in which the roundabout accident rate was 0.05 and the accident rate for signalized intersections was 0.10. Of the injury accidents for these same sights, only 1 pedestrian and 6 bicyclist accidents were reported for roundabouts. Comparing this to 20 percent of the injury accidents at signalized intersections involving pedestrians, the positive effects of roundabouts on pedestrian safety can be seen. The findings were not as favorable for cyclists though. Of the injury accidents reported for roundabouts, 36 percent involved two-wheeled vehicles, as compared to only 23 percent at signalized intersections.

Schoon and Van Minnen also conducted a study on roundabout safety in the Netherlands (Schoon and Van Minnen, 1994) . Schoon and Van Minnen found that of 46 retro-fitted roundabouts, the casualty rate per year for the roundabouts reduced by 1.47 casualties/intersection/year. The casualty rate of cyclists and moped riders also reduced by 0.52 casualties/intersection/year or 74 percent. It should be noted that the before period of this study was longer than the after period. While the study's findings were encouraging and there were no reported fatalities on the roundabouts, in 1990 this all changed. In 1990, four fatalities

involving cyclists riding along a marked bike lane within the circulating roadway, were reported. All of the accidents occurred when the cyclists drove into exiting trucks. Since the occurrence of these accidents, considerations are being made to eliminate the bike lanes within the circulating roadways.

An accident study was conducted in France in 1994 on 12,000 roundabouts located throughout France. Of the 12,000 roundabouts studied, only 1,339 accidents occurred during the study period of one year. That equates to a frequency of only 11 accidents per year per 100 roundabouts. Of the accidents reported, less than 25% of the accidents involved serious injury or fatalities. Comparisons were also made between the safety performance of rural intersections "traditionally controlled" and roundabouts. The authors reported that roundabouts averaged fatal or serious type injuries 38 times for every 100 accidents, while "traditionally controlled" intersections in rural areas reported 55 injury or fatal accidents for every 100 accidents. Similarly, roundabouts were found to perform better in terms of safety as compared to signalized intersections in urban areas. The authors reported that signalized intersections as compared to roundabouts with similar traffic flows, had accident frequencies four times higher than roundabouts (Guichet, 1997).

An earlier study conducted in France reviewed the safety performance of 522 roundabouts in 1988. During 1988, 78 injury accidents occurred at the 522 roundabouts located throughout France. Of the 78 injury accidents reported, the authors showed how the number of accidents per 100 roundabouts increased as the number of entries increased. For example, the number of accidents per 100 roundabouts increased from 12.9 to 25.9 as the number of entries increased from 3 to 6+. Another 202 injury accidents that were reported over a period of 4 years at 175 roundabouts located in the West of France were studied. Of the 202 injury accidents reported, 37% of the accidents occurred as a result of failing to yield on entry. Also, of the 202 injury accidents reported, 85 accidents involved cyclists or moped drivers. The accidents involving cyclists or moped drivers most often occurred due to a refusal to yield priority to the bicycle or moped, 50.6% (Alphand, et al., 1991).

A study was conducted in London, England on the safety performance of 38 roundabouts. A before and after study was conducted at the sites, in which the average study period was 19 months and with all study sites operating for more than 5 months. The authors reported a decrease in total accidents of 31% that was statistically significant at the 95% confidence level. Pedestrian accidents were also reported to have reduced by 46%. Fatal and serious injury accidents were also found to be reduce by 69% from 17% of all accidents in the before period to only 10% in the after period. While most types of accidents decreased, rear-end accidents were reported to increase by 60% (Lalani, 1975).

The international safety performance of roundabouts has been positive, in that, roundabouts have been found to reduce accident severity and frequency as compared to traditional forms of intersection design. While international safety performance can be applied to some extent in the United States, domestic safety performance is most useful to designers, planners and traffic engineers designing roundabouts in this country. To assist practioners in this country, a safety performance study of eight single lane roundabouts was performed through a comparison of

accident and injury rates and frequencies before and after the installation of roundabouts. Finally, an in-depth review of the accident reports for these study sites was performed for the after period data to determine if any geometric or site location characteristics could be adjusted to further improve the safety performance of the single lane roundabouts. The characteristics of the study sites and the data obtained for the study are presented in the following sections.

3.0 Study Site Characteristics

The safety performance of a sample of single lane roundabouts located in the States of Florida and Maryland has been evaluated through an accident analysis study. The site selection process and the data collection procedure are discussed in the following two sections.

3.1 Site Selection

The use of roundabouts in the United States is limited as of 1998. A recent National Cooperative Highway Research Program Study (NCHRP, Project 20-5) conducted an exhaustive survey of the United States to determine the number and location of roundabouts in this country (NCHRP Project 20-5, 1998). The survey revealed there were approximately 15 single lane roundabouts operating in this country in 1997. Of these 15 sites, six are operating in residential areas or in commercial areas that carry very little traffic. From the remaining nine single lane sites, eight sites were chosen as part of the study group to determine the safety performance of single lane roundabouts in the United States.

The eight sites chosen for the safety study were all retro-fitted roundabouts, meaning that they had been converted from stop controlled intersections to roundabouts. All of the sites have single lane approaches and one lane in the circulating roadway. They all have yield signs on entry and use deflection on approaches and exits to slow drivers through the roundabouts. The sites also conform to other roundabout characteristics in that they do not have parking within the circulating roadway or on any of their approaches. The location of the eight sites chosen for this study and other pertinent information are presented in Table 1.

3.2 Data Collection Procedure

An accident analysis study was conducted using data from the sample of eight single lane roundabouts previously described. For this study, the accident analysis study included a comparison of accident frequency and accident rates before and after the installation of roundabouts. In addition, injury rates and frequencies were compared before and after the installation of roundabouts at the eight study sites. To perform the accident analysis study, accident data were compiled from local agencies for each of the sites. Hard-copy accident reports were acquired from each of the local agencies that the study roundabouts were located. The availability of accident data was dependent on the date of construction of each roundabout. For all but one of the study sites, two years before and after accident data were available through the local agency. The site located in Carroll County, Maryland, however, was open to traffic in August of 1996, therefore only 16 months of after accident data were available.

Location	Date of Construction	Control Before Roundabout	Average Daily Traffic All Approaches	Peak Hour Volume All Approaches
Palm Beach County, Florida	November 1994	2-way stop control	7,600 vpd	510 vph
Lisbon, Maryland	April 1993	2-way stop control	8,500 vpd	856 vph
Tallahassee, Florida	August 1994	1-way stop control (T-intersection)	17,825 vpd	1,085 vph
Fort Walton Beach, Florida	May 1994	1-way stop control (T-intersection)	12,000 vpd	1,245 vph
Lothian, Maryland	October 1995	2-way stop control	15,000 vpd	1,345 vph
Washington County, Maryland	January 1996	2-way stop control	7,000 vpd	800 vph
Cecil County, Maryland	August 1995	2-way stop control	6,000 vpd	800 vph
Carroll County, Maryland	August 1996	2-way stop control	12,500 vpd	1,300 vph

Table 1 Safety Performance Study Sites

To calculate accident rates, average daily traffic volumes needed to be obtained. Because roundabouts are a relatively new form of intersection control, all of the local agencies had conducted preliminary engineering studies that included volume data collection before the roundabouts were installed. Volume data after the installation of the roundabouts were collected through video taping the peak hour periods for five of the study sites. The percent change in peak hour volume was applied to the average daily volume in the before period to obtain an estimate of the average daily traffic after roundabout installation. Before and after volume data were available from the local agencies for the last three sites listed in Table 1. These data were used directly to determine the accident rates for these sites.

4.0 Comparison of Accident Frequency

As shown in Table 2, all of the sites, with the exception of Palm Beach County, Florida, had a reduction in accident frequency after the installation of single lane roundabouts. This finding is consistent with many similar studies conducted on larger data sets in other countries. Overall the study sites as a group had a reduction in accident frequency per year of 3.8 accidents per year. These preliminary findings are encouraging when considering the use of single lane roundabouts as an alternative to TWSC intersections which have a history of severe right angle or left turn head on accidents.

Study Site	Accident Frequency/Year Before Period	Accident Frequency/Year After Period
Palm Beach Co., Florida	1.5	1.5
Lisbon, Maryland	7.5	2.5
Tallahassee, Florida	4.5	1.5
Ft. Walton Beach, Florida	8.0	2.0
Lothian, Maryland	13.0	4.0
Washington County, Maryland	4.5	0.0
Cecil County, Maryland	3.0	0.0
Carroll County, Maryland	5.3	0.7

Table 2 Accident Frequency per Year for Study Sites

4.1 Comparisons of Accident Rates

The accident rates for each of the study sites were also calculated and are presented in Table 3. The accident rates for the study sites were calculated using the procedure presented in the Highway Safety Improvement Program Guide (FHWA, 1981) and shown in equation 1:

$$R_{sp} = (A)(1{,}000{,}000)/(365)(T)(V) \qquad \text{Equation 1}$$

where,

R_{sp} = Accident rate at a spot in accidents per million vehicles
A = Number of accidents for the study period
T = Period of study (years or fraction of years)
V = Average Daily Traffic (ADT) during the study period. For intersections, V equals the sum of the entering volumes on all approach legs.

Study Site	R_{sp} Before Installation of Roundabout	R_{sp} After Installation of Roundabout
Palm Beach Co., Florida	0.54	0.54
Lisbon, Maryland	2.42	0.81
Tallahassee, Florida	0.69	0.23
Ft. Walton Beach, Florida	1.83	0.45
Lothian, Maryland	2.37	0.73
Washington County, Maryland	1.76	0.0
Cecil County, Maryland	1.37	0.0
Carroll County, Maryland	1.81	0.24

Table 3 Accident Rate per Year for Study Sites

Again, as in the comparison of accident frequencies, all of the sites experienced a reduction in accident rate when controlled as single lane roundabouts as compared to their minor stop controlled design.

4.2 Comparison of Injury Accidents

Next, injury and fatality data for the study sites were collected from the accident reports. The injury rate per year is shown in Table 4. Overall the study group had a reduction in injury accidents per year of 1.25 injury accidents per year in the after period. It should be noted that the injuries in the before period included a fatality at the Palm Beach County site as a result of a right angle accident. In the after period, one of the injury accidents that occurred at Lothian, Maryland happened as a result of a driver experiencing insulin shock and losing control of his vehicle.

4.3 Comparison of Injury Accident Rates

Injury accident rates were next calculated for the eight study sites using the number of injury accidents in place of number of accidents in equation 1. Injury accident rates are useful to practioners in that they factor in the exposure rate of users of the intersection, thus making the comparison of intersection performance equal. Table 5 contains a comparison of injury accident rates in the before and after period for each of the study sites.

Study Site	Injury Accidents/Year Before Period	Injury Accident/Year After Period
Palm Beach Co., Florida	0.5	0.0
Lisbon, Maryland	1.5	0.5
Tallahassee, Florida	0.0	0.0
Ft. Walton Beach, Florida	2.0	0.0
Lothian, Maryland	4.5	1.5
Washington County, Maryland	1.0	0.0
Cecil County, Maryland	1.0	0.0
Carroll County, Maryland	2.25	0.75

Table 4 Injury Accidents per Year for Study Sites

Study Site	Injury Accident Rate/Year Before Period	Injury Accident Rate/Year After Period
Palm Beach Co., Florida	0.18	0.0
Lisbon, Maryland	0.48	0.16
Tallahassee, Florida	0.0	0.0
Ft. Walton Beach, Florida	0.46	0.0
Lothian, Maryland	0.82	0.34
Washington County, Maryland	0.39	0.0
Cecil County, Maryland	0.46	0.0
Carroll County, Maryland	0.49	0.16

Table 5 Injury Accident Rate per Year for Study Sites

4.4 The Effect of Geometric Design on Safety Performance

To identify any geometric elements that may be influencing the safety performance of the study sites in the after period, a review of hard-copy accident reports was conducted. From these hard

copy accident reports, Figure 2 was developed. Figure 2 includes a break down, by accident type, of the 33 accidents reported in the after period, when the intersections were operated as roundabouts. As shown in Figure 2, 27.3 percent of the accidents reported were side-swipe accidents that occurred when entering drivers failed to yield to circulating drivers. Of the side-swipe accidents reported, two of every three side-swipe accidents occurred because of driver traffic violation. This type of accident may reduce as driver experience with roundabout operation increases.

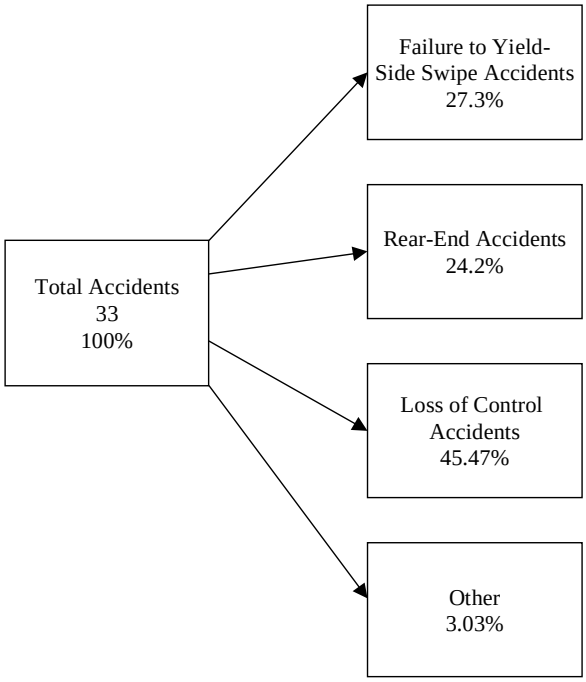

Figure 2 Accident Categories

Of greater importance, 40 percent of the total accidents reported at the study sites were classified as “loss of control” accidents. Of the loss of control accidents reported, three of every five were the result of entering drivers approaching the roundabout at excessive speeds, as stated in the accident reports. Entry design is a key element in roundabout design in that it is necessary to slow drivers as they approach roundabouts to allow them to safely reduce their speeds prior to entry. Also given that 14 of the 15 loss of control accidents occurred at high speed rural road locations, the speed reduction attributable to the approach curve does not appear to be adequate.

The Maryland roundabout design guide suggests that rumble strips be applied to high speed approaches to roundabouts, for example rural roundabouts (Maryland SHA, 1995). Another technique suggested for approaches to high speed rural roundabouts is the use of successive reverse curves as shown in Figure 3. Successive reverse curves are intended to slow vehicle speeds further upstream of the approach curve, which is often required at high speed rural locations. This technique may help to reduce the failure to yield and loss of control accidents that are attributable to excessive speeds prior to the yield point of the study roundabouts. In the recently completed Queensland study, it was found that at a high speed rural roundabout, where

this technique was applied, the single vehicle accident rate reduced from 0.73 accidents per year, without the treatment, to 0.41 accidents per year in the after period (Queensland Main Roads, 1997). Based on the number of loss of control accidents that occurred at high speed approaches to rural roundabouts at the eight study sites, this type of treatment may prove to be useful in reducing this type of accident.

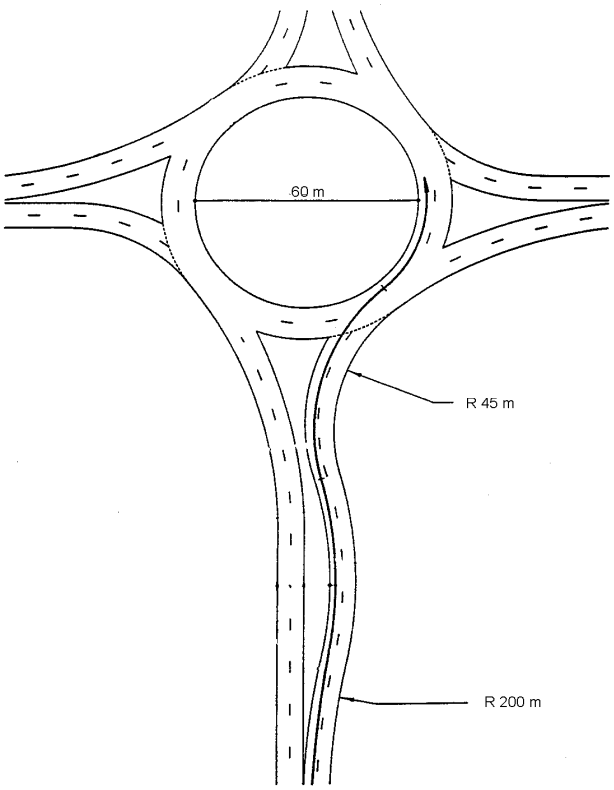

Figure 3 Reverse Curves on Approach (Queensland Department of Main Roads, 1997)

5.0 Study Findings and Recommendations

The safety performance of the eight single lane roundabout study sites has been reviewed and compared to their safety performance as minor stop controlled intersections. As of January 1998, the eight roundabouts included in the study were performing better in terms of reduced accident frequency and rate and injury frequency and rate then they did in their before periods. The findings from this safety study of eight single lane roundabouts is consistent with the majority of findings from international safety studies. As stated earlier, the reduction in accidents at roundabouts versus minor stop controlled intersections, is largely attributable to the reduction in decision points. Single lane roundabouts only require drivers to scan one stream of traffic to locate an acceptable gap, versus minor stop controlled intersections that require minor stream drivers to scan at least two streams of traffic before negotiating the intersection. This reduction in decision points often results in fewer accidents, as was found in this study. In

addition, the reduced entry speeds of roundabouts as compared to traditional at-grade intersection design, helps by allowing drivers more time to react to hazardous situations. Another advantage of roundabouts as compared to traditional at-grade intersections is the use of a center island. The center island of roundabouts greatly reduce the occurrence of severe accidents such as right angle, left-turn head-on, and head-on accidents, thereby reducing the number of injury accidents.

While the safety performance of single lane roundabouts in the United States is promising to date, care should be given to continue to conduct in-depth reviews of accident reports and statistics on a regular basis to help ensure the proper design and installation of roundabouts. Many of the design parameters and site selection criteria applied in the United States have been taken directly from international practice and have yet to be confirmed through domestic operational and safety performance studies. As a greater number and variety of designs of roundabouts are applied in the United States, a better understanding of the optimal design to be sought will be possible.

6.0 Author Information

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