Analysis of Rear-End Collisions at Roundabout Approaches

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Roundabouts are common alternatives to stop- and signal-controlled intersections and have grown in popularity in response to the promise to reduce traffic crash severity at intersections. In Wisconsin, more than 300 roundabouts have been installed. Studies of these intersections have found a 38% reduction in fatal and injury crashes. However, a 12% overall increase also was found, and this finding is not unique to Wisconsin. An increase in less-serious crashes can lead to a negative public perception about roundabout benefits. The causes of rear-end collisions (a common type of low-severity crash) were examined. Four years of crash reports from 55 roundabouts were analyzed along with the geometric conditions of the roundabouts. The 16- to 24-year-old driver age group represented a significantly higher proportion of involvement in rear-end collisions than in total crashes across the state. Negative binomial models were created for roundabout approaches. For combined one-lane and multilane roundabout approaches, annual average daily traffic, sawtooth pavement markings, and high deflection angles were significantly correlated with an increase in the expected number of rear-end collisions, and wider entry was significantly correlated with a decrease in the expected number of rear-end collisions. For one-lane approaches, "Yield" pavement markings led to an expected reduction in crashes, as did the presence of horizontal curves within 250 feet of a roundabout. These findings reflect the complexity of driving at roundabout approaches, especially for younger drivers. Results also indicate the importance of proper pavement markings at approaches.

Roundabouts are a common alternative to stop- and signal-controlled intersections around the world, and their popularity has been growing in the United States. The conversion of an intersection to a roundabout has been shown to significantly decrease delays, queue lengths, congestion, and degree of saturation (*1, 2*). Compared with intersections, roundabouts can offer lower maintenance costs, less surface area, and better traffic flow. However, one main benefit of roundabouts over intersections is increased safety. Roundabouts converted from other types of intersection control have been associated with large decreases (up to 87%) in fatal and injury crashes (*3*). The design of a roundabout is safer than that of a traditional intersection because its geometry requires drivers to slow before entering and reduces the number of conflict points from 32 to 8 (*4–6*) (Figure 1). This design also eliminates certain maneuvers (e.g., left turns through opposing traffic). Even though roundabouts reportedly reduce the severity of crashes at intersections, some studies have noted an increase in the number of property damage crashes (*7*).

In Wisconsin, roundabouts are a common alternative to traditional intersections; approximately 300 roundabouts are installed on the state network. Injury crashes decreased 38% at 30 intersections converted to roundabouts (*7, 8*). However, total crashes also increased 12% overall. The increase in total crashes was attributed to some roundabouts not being converted from stop or signal control due to safety concerns. At many intersections that were converted solely for safety concerns, total crashes did in fact decrease.

The overall increase in the number of crashes noted in Wisconsin and around the United States can lead to a negative public perception of roundabouts even though injury and fatal crashes are greatly reduced. Rear-end collisions at approaches, which typically are of low severity, were analyzed in an attempt to understand and mitigate one type of low-severity crash and improve the perception of roundabouts. The primary purpose of this research was to determine the factors that lead to many rear-end collisions at roundabout approaches by analyzing the crash causes and geometric characteristics of the roundabouts.

LITERATURE REVIEW

Rear-End Collisions

Rear-end collisions are among the most common crash types and typically are of low severity. Past research on rear-end collisions has indicated that drivers under 18 years old are much more likely than other drivers to strike a vehicle in a rear-end collision and that the probability of a driver striking another vehicle in a rear-end collision decreases with age (*9*). Another study found many rear-end collisions to be due to driver misjudgment of the time required to brake before collision (*10*). Local drivers have been found to be responsible for more rear-end collisions, suggesting that they may feel more comfortable, navigate the roundabout faster, and take more risks than nonlocal drivers, resulting in a high speed differential that can increase the likelihood and severity of rear-end collisions (*11*). Although the studies mentioned here are not specific to roundabouts, the findings may be applicable because of the unique geometry of roundabouts.

Roundabout Safety Benefits

In a nationwide survey of 35 roundabouts, the total number of crashes was reduced at 28, the number of injury accidents decreased at 29, and

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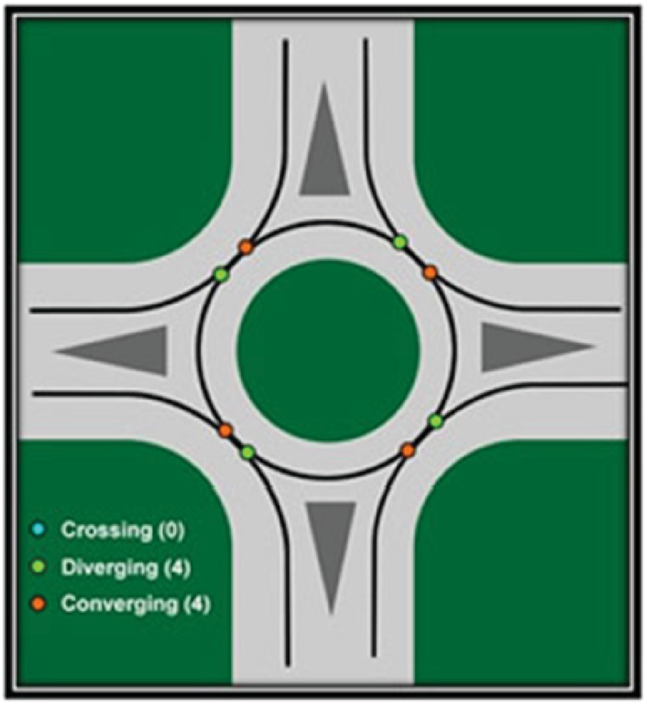
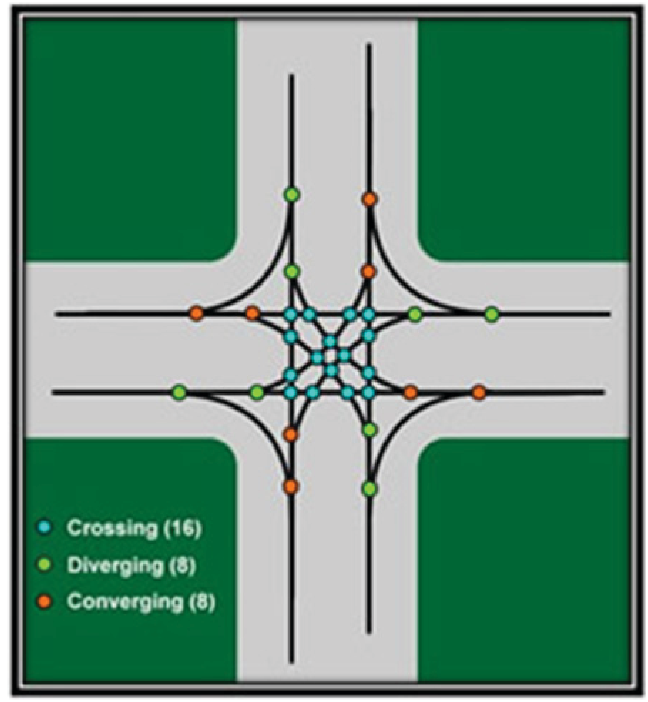


(a)



(b)

FIGURE 1 Comparison of conflict points between (*a*) roundabout and (*b*) signalized or stop-controlled intersection (*4*).

zero injury crashes were recorded after roundabout construction at 15 roundabouts (*12*). Persaud et al. also reported that converting traditional intersections from stop or signal control decreased all crashes from 72% to 35% and decreased injury crashes from 88% to 74% (*4*).

Eisenman et al. revealed that the number of injury crashes reduced from 87% to 45% in Australia, 78% to 57% in France, and 39% to 25% in the United Kingdom after converting conventional intersections to roundabouts (*12*). Hydén and Várhelyi found that Swedish roundabouts improve safety by making crashes less severe and reducing the number of expected injury crashes by 44% (*13*). They also found that roundabout implementation helps to reduce crashes that involve pedestrians and bicyclists by 80% and 60%, respectively. De Brabander et al. observed that after Belgian intersections were converted to roundabouts, injury crashes were reduced by an average of 34% (*14*). Roundabouts were more effective in reducing crashes when the speed limits of the former intersections were higher.

Crash Types

Crashes that occur at roundabouts tend to be less severe than those at signalized intersections because vehicle speeds are slower. Because of the geometric design of roundabouts, vehicles can travel through only in one direction and at a lower speed (*7*). This geometry can prevent the occurrence of head-on, right-angle, and left-turn collisions, which have high fatality and injury rates. A safety analysis of 17 roundabouts in five states (Kansas, Maryland, Minnesota, Oregon, and Washington) determined that roundabout construction changed the types of crashes that occurred at intersections (*15*). Angle, head-on, and rear-end collisions significantly decreased after intersections were converted to roundabouts. Meanwhile, the number of fixed-object and sideswipe crashes increased and were the most frequent crash types at roundabouts.

In a research study of 39 U.S. roundabouts, rear-end, exiting–circulating, and entering–circulating crashes occurred most frequently (*16*). One-lane roundabouts had a higher rate of entering–circulating crashes than exiting–circulating crashes. At multilane roundabouts, mostly exiting–circulating crashes occurred. A study of Wisconsin roundabouts evaluated the different types of crashes of roundabouts (*8*). No head-on crashes were reported at any site. Sideswipe crashes occurred most often and accounted for 42% of crashes at these roundabouts. Most crashes caused property damage only, and no fatal crashes were recorded over the study period.

Roundabout Crash Models

Many factors must be considered in evaluating the safety performance of a roundabout. In general, most research uses traffic volume and geometric characteristics to model roundabouts (*16*). The relationship between these factors and crash frequency can be evaluated with a model built on geometric factors and traffic volume. Knowing the variables that increase crash frequency, engineers can design intersections that minimize factors correlated with accidents.

A common way to measure the safety of an intersection or a roadway segment is to develop an equation that includes the factors that potentially influence crashes. Several studies have proven that roundabout crash frequency is related to not only annual average daily traffic (AADT) but also, at least in part, geometric features (*16–19*). The relationship between crash frequency and site characteristics has been addressed as nonlinear (*20*); Poisson and negative binomial regression are the most popular models to describe it (*21*). Negative binomial distribution is preferred because it appropriately accounts for the effect of overdispersion.

SITES AND DATA

Approximately 300 roundabouts are installed in Wisconsin. Roundabouts on the state trunk network and installed in or before 2008 were considered for this analysis to ensure that adequate data (4 years) were available. Of all Wisconsin roundabouts, 66 were on the State Trunk Network and had enough crash data available for study. However, 11 of these roundabouts were omitted from the study because of new construction after 2008 or spacing too close to another intersection. In total, 55 roundabouts representing all regions of Wisconsin were included in the final analysis. The locations of all the roundabouts studied are mapped in Figure 2.

Data for a total of 1,140 crashes at the 55 study roundabouts were examined for the years 2009 through 2012. The rear-end collisions were of particular interest. For this study, rear-end collisions that occurred while navigating the circulating lanes or upstream of the roundabout were omitted to focus on rear-end collisions that occurred at approaches. At the 55 roundabouts, 202 roundabout approaches were examined. In total, 176 rear-end collisions occurred at approaches in the roundabouts studied. These crashes occurred at 80 of the 202 approaches, and 122 approaches did not have any rear-end collisions during the analysis period.

For this study, specific crash data and geometric data were analyzed to conduct a comprehensive examination of rear-end collisions at roundabout approaches.

CRASH-SPECIFIC ATTRIBUTES

The reports from the 176 crashes were examined for crash-specific attributes, especially crash cause, age of driver at fault, and weather conditions at the time of the crash. The at-fault driver was determined from the crash report narrative and typically was the driver of the following vehicle. The proportions of rear-end collisions caused by drivers of each age group are illustrated in Figure 3. The observed proportion of rear-end collisions for each age group was compared with the proportion of licensed drivers involved in any crash in Wisconsin (*22*).

Drivers 25 to 44 years old were involved in the highest proportion of rear-end collisions. The youngest (16 to 17 years old) and oldest

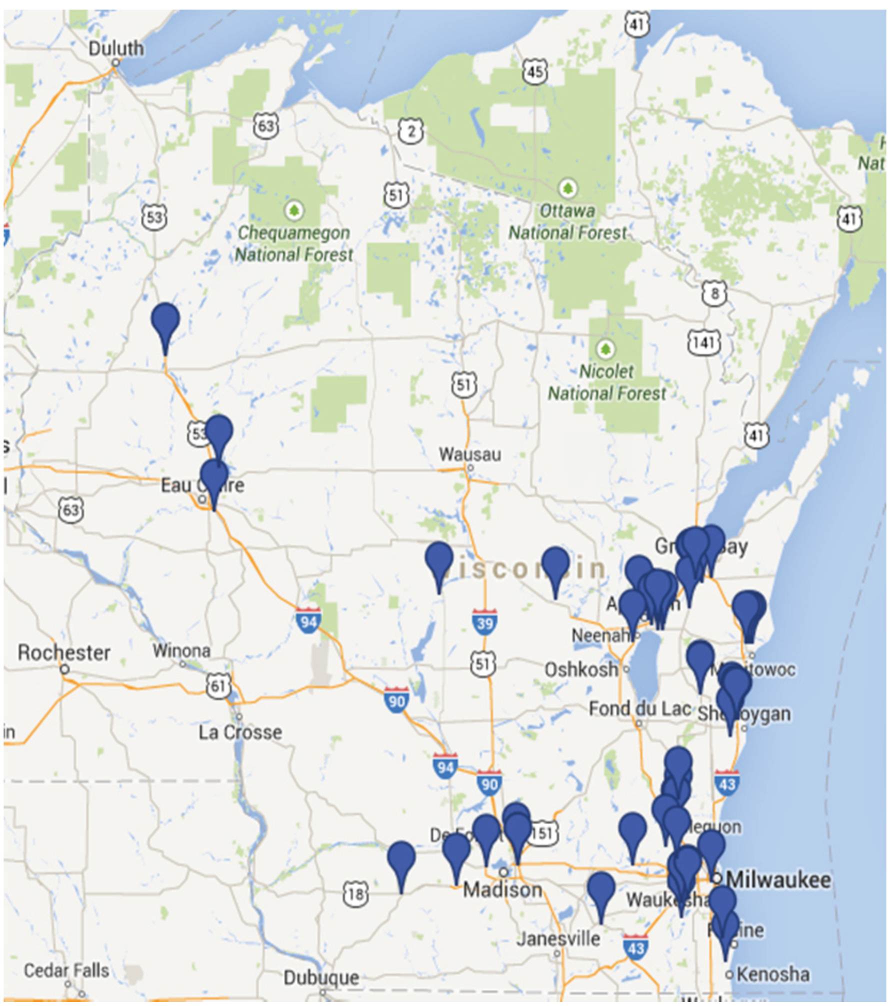


FIGURE 2 Study locations of roundabouts.

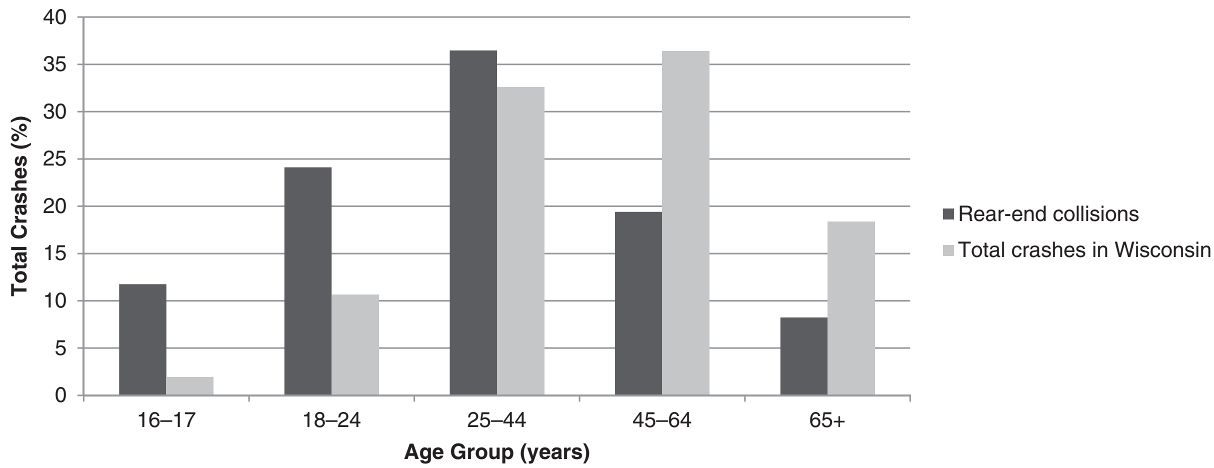


FIGURE 3 Percentage of rear-end collisions at approaches to roundabouts compared with percentage of total crashes by age group of at-fault driver.

(65 years old and older) age groups each accounted for about 10% of the rear-end collisions. However, when the rear-end collision data were compared with the proportion of drivers in a given age group involved in any crash in Wisconsin (light gray), the observed number of younger drivers involved in rear-end collisions at roundabout approaches (dark gray) is more pronounced. Even though 16- and 17-year-old drivers were involved in only 2% of crashes in Wisconsin, the same age group accounted for 12% of all crashes at the roundabouts studied. Similarly, drivers aged 18 to 24 accounted for approximately 11% of crashes in Wisconsin; however, they were involved in 24% of crashes at roundabouts.

A z-test (Equation 1) was conducted to determine whether different proportions of rear-end collisions at roundabout approaches were significantly different from proportions of all crashes in Wisconsin by age group. The proportion of rear-end collisions (P) at roundabout approaches was compared with the total proportion of rear-end collisions in each age group n:

$$z = \frac{P_2 - P_1}{\sqrt{p * (1 - p) * \left(\frac{1}{n_1} + \frac{1}{n_2} \right)}} \tag{1}$$

where the pooled proportion (p) is calculated as

$$p = \frac{n_1 p_1 + n_2 p_2}{n_1 + n_2} \tag{2}$$

The results of the statistical tests are listed in Table 1.

TABLE 1 Total Wisconsin Crashes Versus Roundabout Crashes

Age Group (years)	z-Score	p-Value	Age Group (years)	z-Score	p-Value
16–17	3.17	.001[a]	45–64	2.03	.042[a]
18–24	2.80	.005[a]	65+	0.98	.327
25–44	0.65	.516			

[a]Significance at 95%.

Younger drivers (16 to 24 years old) were involved in a significantly higher proportion of rear-end collisions at roundabout approaches than younger drivers involved in all crashes in Wisconsin. This difference may be due to a lack of familiarity and experience at roundabouts or a younger driver's propensity to drive faster and more recklessly than older counterparts. Drivers aged 45 to 64 had a significantly lower proportion of rear-end collisions at roundabout approaches compared with total crashes for the same age group. This finding may be due to more experience and understanding how to navigate roundabouts and therefore be able to take full advantage of their safety benefits.

Crash causes were determined from diagrams and narratives in the crash reports or from the primary cause indicated by the law enforcement officer. The cause categories were associated with distracted driving, following too closely, impaired driving or reduced alertness, improper maneuver, mechanical or vehicle, speed, or weather; Figure 4 shows the proportion of rear-end collisions caused by each crash type. Crashes that did not fit these seven categories were generalized as "following too closely." Even though the cause of the crash may have been the close proximity of the following car, this category fails to recognize any other factors that may have influenced the rear-end collision (e.g., distraction or vehicle speed).

The distracted driving category included adjusting the radio, talking to a passenger, watching circulating traffic instead of the leading vehicle, and looking away from the leading vehicle. Driver's use of a cell phone would have been included in this category; however, no cell phone use was indicated in the crash report narrative, and Wisconsin crash reports from 1997 to the present do not include an indicator for cell phone use. The impaired driving category included alcohol and drug impairment, medical conditions, falling asleep, and road rage (in one case, a driver intentionally hit another vehicle). Mechanical or vehicle issues included crashes in which the vehicle could not stop in time (e.g., the driver said the brakes failed or that the tires were bald). Even though crashes caused by mechanical or vehicle issues really may be related to speed or following too closely, the officer's narrative regarding what the driver said occurred was considered the main cause of the crash.

Following too closely was the cause of rear-end collisions most often noted at the roundabout approaches studied (approximately 43%). As explained earlier, this category was applied to most rear-end collisions when the law enforcement officer could not gain any

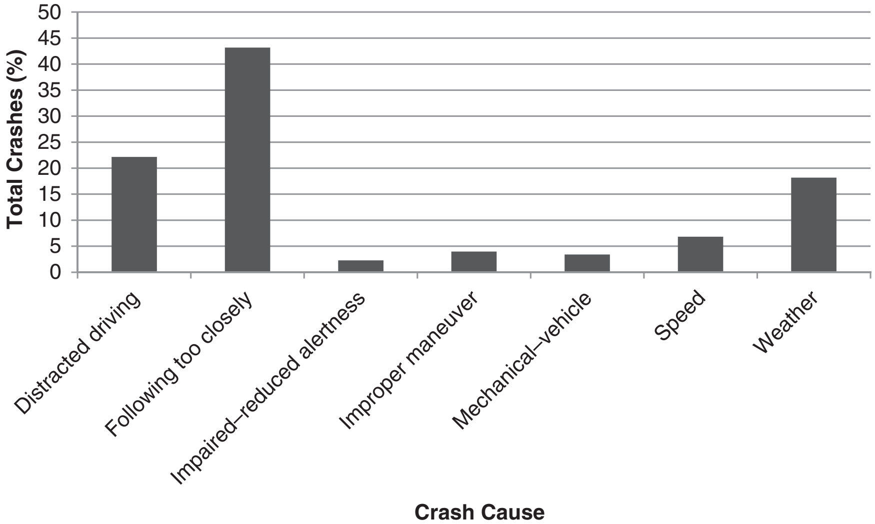


FIGURE 4 Causes of rear-end collisions at roundabout approaches.

additional information from drivers, witnesses, or the crash scene; however, all crash reports that listed following too closely as the cause were reexamined for more information and classified more specifically when possible. Distracted driving was the next most frequent crash cause at 22%. Weather was the main cause of 18% of the crashes. Each of the four remaining categories was associated with 7% or less of rear-end collisions at approaches. Because the sample sizes of most crash causes were small, statistical testing was not performed.

GEOMETRIC CHARACTERISTICS MODEL

Because most rear-end collisions happen at approaches, the geometric attributes of approaches were investigated to determine possible geometric causes of rear-end collisions. Traffic volume data were obtained from the Wisconsin Department of Transportation (DOT). Geometric data were obtained from aerial images of the roundabouts. Of the 55 roundabouts studied, 37 roundabouts had four approaches and 18 had three approaches. Several approach-specific geometric attributes were identified at each approach. In total, 13 approach-specific road attributes were gathered for each of the 202 roundabout approaches. The predictor variables added to the model for each approach attribute are listed in Table 2. Ranges are given for continuous variables, and frequencies of occurrence for each characteristic are shown for categorical variables.

In addition to the approach-specific attributes, eight general roundabout attributes were examined for the 55 roundabouts studied to determine their impact on rear-end collisions. The general roundabout attributes as well as the frequency or range of each predictor variable are listed in Table 3.

Of the 13 approach-specific predictor variables included in the models, three were continuous and 10 were categorical; the predictor variable was present or was not present. Ranges of values are given for continuous variables, from the minimum to the maximum values observed at study intersections. Most of the categorical variables modeled the presence or absence of an attribute, and the frequency is provided. Speed was modeled as a categorical variable in this model, either high speed (45 mph or greater) or low speed (less than 45 mph) according to roundabout design considerations in the Wisconsin DOT *Facilities Development Manual* (*23*). Most roundabout approaches had one or two lanes; only two approaches had three lanes. Therefore, the number of approach lanes was condensed to two options: one lane or two or more lanes. Other factors were added because of their unique effect on approach geometry. The "YIELD" marking, an option included in *The Manual on Uniform Traffic Control Devices for Streets and Highways* chapter on roundabout markings, was present at less than one-half of the studied roundabouts (*24,* Chapter 3C). Horizontal curves on an approach within 250 feet of the roundabout also were examined. The presence of a horizontal curve was a unique feature at some approaches and also was a surrogate for sight distance, which could not be measured directly. Most (179 of 202) approaches did not have horizontal curves near the roundabout.

Of the eight general roundabout attributes modeled, four were continuous and four were categorical. The continuous variables included a measure of the traffic experienced at the roundabout (as AADT) and the general roundabout geometry. The log of the AADT data was used for the model. Although the AADT of the specific approach and the circulating AADT would have produced a more accurate representation of the traffic volumes, these data were not available, so AADTs of major and minor roads were used instead. The categorical data indicate that more roundabouts were in urban areas (nearly 69%) than in rural areas and that most of the center islands were landscaped (nearly 80%). The landscaping attribute was added because of the potential impact of increased salience as a driver approaches the roundabout. More roundabouts examined had one circulating lane (57%), but almost as many had two (43%).

Rear-end collisions were modeled as the response variable, with the general and approach-specific characteristics modeled as predictor variables. Because rear-end collisions are a random, nonnegative integer event, the negative binomial model was used to estimate the number of crashes for certain roundabout characteristics. The log link was used to create the generalized linear model. The form is presented in Equation 3 and its variance in Equation 4:

$$\log(\mu) = \alpha + \sum_{i=1}^{I} \beta_i x_i \tag{3}$$

TABLE 2 Approach-Specific Geometric Attributes

Attribute	Variable Type	Frequency of Occurrence
Deflection angle[a]	Continuous	na
Flare or entry width[b]	Continuous	na
Flare length[c]	Continuous	na
Posted speed	Categorical	
<45 mph		110 (54.5%)
≥45 mph		92 (45.6%)
Number of approach lanes	Categorical	
1		113 (55.9%)
2+		89 (44.1%)
Presence of “Yield” pavement markings	Categorical	
Yes		85 (42.1%)
No		117 (57.9%)
Presence of pedestrian crossing	Categorical	
Yes		70 (34.7%)
No		132 (65.3%)
RAB in corridor	Categorical	
Yes		19 (9.4%)
No		183 (90.6%)
Yield sign on left side of approach	Categorical	
Yes		182 (90.1%)
No		20 (9.9%)
Continuous right-turn lane	Categorical	
Yes		19 (9.4%)
No		183 (90.6%)
“Sawtooth” or “shark teeth” pavement markings	Categorical	
Yes		10 (5.0%)
No		192 (95%)
Approach lane is highway ramp	Categorical	
Yes		16 (4.0%)
No		194 (96.0%)
Horizontal curve within 250 ft of roundabout	Categorical	
Yes		23 (11.4%)
No		179 (88.6%)

NOTE: na = not applicable.
[a]Ranges from 5° to 54°.
[b]Ranges from 9 to 22 ft.
[c]Ranges from 0 to 275 ft.

TABLE 3 General Roundabout Characteristics

Attribute	Type	Range	Frequency
AADT, major road (vpd)	Continuous	1,750–50,000	
AADT, minor road (vpd)	Continuous	1,000–24,900	
Center island radius (ft)	Continuous	29–66	
Inscribed circle diameter (ft)	Continuous	92–254	
Urban or rural	Categorical		
Urban			139 (68.8%)
Rural			63 (31.2%)
Number of circulating lanes	Categorical		
1			116 (57.4%)
2			86 (42.6%)
Number of approaches	Categorical		
3			54 (26.7%)
4			148 (73.3%)
Center island landscaping	Categorical		
Yes			161 (79.7%)
No			41 (20.3%)

NOTE: AADT = annual average daily traffic; vpd = vehicles per day.

$$\text{var} = \mu + D\mu^2 \tag{4}$$

where

μ = expected number of crashes at an approach,
α = intercept,
β_i = coefficient of ith variable,
x_i = ith explanatory variable, and
D = overdispersion parameter.

Three models were created with the geometric data shown in Table 2. One used all 21 predictor variables to model the frequency of rear-end collisions at approaches. The other two controlled for the number of lanes at each roundabout approach. Separate models were created for one approach lane and two or more approach lanes because the geometry and driver behavior differ between multilane and one-lane approaches.

The first model used the number of approach lanes as a predictor variable and had 21 predictor variables; the model-fitting steps are listed in Table 4. Model coefficients and p-values are included as well as goodness-of-fit metrics for each model step shown. First, correlated variables were removed from the full model. The variable representing the number of circulating lanes was removed because of

TABLE 4 Model Coefficient Estimates for Development of Rear-End Collision Prediction Model

Predictor	Model 1[a]	Model 2[b]	Model 3[b]	Model 4[c]
Approach specific				
Deflection angle	.028 (.123)	.033 (.033)	.032 (.038)	.034 (.028)
Entry width	−.148 (.028)	−.166 (.003)	−.173 (.002)	−.175 (.002)
Flare length	.003 (.334)			
Posted speed	.334 (.356)			
Number of approach lanes	−.030 (.942)			
Yield pavement markings	−.132 (.725)			
Pedestrian crossing	.649 (.047)	.461 (.084)	.414 (.116)	
Roundabout in corridor	.690 (.148)			
Yield sign left of approach	.940 (.226)			
Continuous right-turn lane	−.146 (.767)			
Sawtooth pavement markings	1.153 (.060)	1.109 (.016)	1.185 (.010)	1.071 (.019)
Ramp approach lane	.061 (.926)			
Horizontal curve within 250 ft	−.703 (.157)			
General roundabout				
AADT, major road	1.029 (.002)	.825 (<.001)	.815 (<.001)	.811 (<.001)
AADT, minor road				
Center island radius				
Inscribed circle diameter	.001 (.972)			
Urban or rural	.119 (.730)			
Number of circulating lanes				
Number of approaches	.500 (.258)			
Center island landscaped	.599 (.180)	.643 (.099)		
Model intercept	−7.391 (.031)	−5.546 (.020)	−5.402 (.022)	−5.726 (.016)
Goodness-of-fit metrics				
−2LL	−348.060	−357.026	−359.926	−362.394
AIC	386.061	371.026	371.926	372.394
Corrected AIC	390.379	371.621	372.37	372.709
BIC	448.345	393.973	391.594	388.784
χ^2 likelihood	49.595	40.630	37.730	35.262
Degrees of freedom	18	6	5	4
p	<.001	<.001	<.001	<.001

NOTE: Values in parentheses are *p*-values. LL = log likelihood; AIC = Akaike information criterion; BIC = Bayesian information criterion.
[a]Full model with correlated variables.
[b]Interim modeling steps.
[c]Final model.

correlation with the number of approach lanes. Similarly, the radius of the center island was removed because of a high correlation with the inscribed circle diameter, entry width was removed because of a high correlation with flare length, and minor-road AADT was removed because of correlation with major-road AADT.

The full version containing only noncorrelated variables is presented as Model 1 in Table 4. Next, insignificant (high *p*-value) terms were removed from the model, and several variables were removed in intermediate steps. Model 2 reflects several steps of removing insignificant variables to improve the fit; six variables remained at this step, and model fit metrics were improving. The final Model 4 has four significant variables: major-road AADT, "sawtooth" pavement markings, deflection angle, and entry width. The goodness-of-fit metrics improved from the baseline full model. For example, AIC was reduced from 386.1 in Model 1 to 372.4 in Model 4. The dispersion parameter (*D*) was 1.087.

Three of four significant variables in the final Model 4 had a positive coefficient, meaning the presence will have an e^{β} multiplicative effect on the expected number of rear-end collisions at an approach (Table 4). The model suggests that the number of rear-end collisions will increase when the major road has a large AADT. In general, the greater the traffic volume at the roundabout, the higher the number of rear-end collisions at an approach. Deflection angle and sawtooth pavement markings at the approach also were significant variables with positive coefficients in the regression model. Higher deflection angles, or the roundabout approach being brought more closely to perpendicular to the circulating lanes, led to an increase in rear-end collisions. The sawtooth markings at the yield approach may be significant due to the presence of two yield markings: one at the edge of the inscribed circular diameter and the sawtooth marking perpendicular to the approach lane. These markings may cause drivers to yield at different locations in the approach and lead to rear-end collisions. The only negative coefficient was entry width. The result can be interpreted as wider entry lanes to the circulating lanes lead to a reduction in rear-end collisions.

Next, rear-end collisions in roundabouts were modeled controlling for approach lane. Continuous right-turn lanes, which did not occur at one-lane roundabouts, were excluded. The model results for rear-end collisions at one-lane roundabout approaches are listed in Table 5. As in Table 4, the full Model 1 in Table 5 excludes correlated variables. For one-lane approaches, the center island radius was excluded because of correlations with speed and inscribed circle diameter.

Model 1 in Table 6 is the full model for multilane roundabout approaches without correlated variables. For roundabout approaches with two or more lanes, minor-road AADT was excluded because of correlation with major-road AADT. Whether the roundabout was urban or rural was removed because of correlation with speed, and center island diameter was removed because of correlation with

TABLE 5 Model Coefficient Estimates for Development of Rear-End Collision Prediction Model: One Approach Lane

Predictor	Model 1[a]	Model 2[b]	Model 3[b]	Model 4[c]
Approach specific				
Deflection angle	.042 (.123)			
Entry width	−.111 (.425)	−.190 (.017)	−.216 (.005)	−.240 (.002)
Flare length	.004 (.234)			
Posted speed	.682 (.360)			
Yield pavement markings	−.840 (.189)	−.932 (.092)	−.954 (.083)	−1.088 (.044)
Pedestrian crossing	.676 (.244)			
Roundabout in corridor	−.666 (.521)			
Yield sign left of approach	.582 (.546)			
Continuous right-turn lane				
Sawtooth pavement markings	1.640 (.259)			
Approach is highway ramp	−.032 (.984)			
Horizontal curve within 250 ft	−2.225 (.049)	−2.085 (.049)	−2.124 (.045)	−2.273 (.032)
General roundabout				
AADT, major road	1.033 (.255)	.0681 (.198)		
AADT, minor road	.383 (.468)			
Center island radius				
Inscribed circle diameter	−.045 (.236)	−.033 (.171)	−.037 (.124)	
Urban or rural	−.348 (.545)			
Number of circulating lanes	−.542 (.680)			
Number of approaches	.859 (.417)			
Center island landscaped	.590 (.534)			
Model intercept	−11.808 (.183)	−4.874 (.388)	1.849 (.400)	−.588 (.697)
Goodness-of-fit metrics				
−2LL	−165.188	−178.132	−179.806	−182.296
AIC	203.188	190.132	189.806	190.296
Corrected AIC	211.360	190.924	190.367	190.667
BIC	255.008	206.496	203.443	201.206
χ^2 likelihood	40.455	27.511	25.837	23.347
Degrees of freedom	15	5	4	3
p	<.001	<.001	<.001	<.001

NOTE: Values in parentheses are p-values.
[a]Full model with correlated variables.
[b]Interim modeling steps.
[c]Final model.

inscribed circle diameter. Presence of a yield sign on the left side of the approach could not be tested because of the homogeneity of the sign's presence on the left side of the approach.

Significant predictors for one-lane roundabouts (Model 4 in Table 5) were all found to be negative. Entry width, presence of a horizontal curve within 250 feet of the roundabout, and the presence of the YIELD pavement marking lead to an expected decrease in rear-end collisions at roundabout approaches. Fewer rear-end collisions may be expected as the entry widens because vehicles have more room to maneuver in times of conflict. The presence of a horizontal curve may encourage drivers to reduce speed, leading to lower speeds as vehicles approach the roundabout. The utility of YIELD pavement markings suggests that their salience may help drivers prepare and react appropriately at the entrance to the roundabout circulating lanes. The only significant predictor for roundabout approaches with two or more lanes was AADT (Model 4 in Table 6). Again, higher traffic leads to an expected increase in rear-end collisions.

CONCLUSIONS

The roundabout intersection design has been shown to reduce the severity of traffic crashes. Although less-severe crashes make roundabouts safer than alternative intersection designs, the crash frequency at intersections has increased. This increase in low-severity crashes leads to a negative perception of roundabouts that may be unwarranted. The rear-end collision is one type of low-severity crash that can occur at roundabouts. This research studied the causes of rear-end collisions at roundabout approaches.

Crash report data indicated that 16- to 24-year-old drivers represented a significantly higher proportion of involvement in rear-end collisions than in total crashes involving their age group. Given the propensity for younger drivers to be involved in rear-end collisions at roundabouts, additional training and education may be needed for younger drivers to better understand roundabout operation and learn how to navigate them safely. Distracted driving was one of the most common crash causes (22%). Weather and following too closely each accounted for more than 18% of crashes, which suggests drivers may be too comfortable at roundabouts, particularly in inclement weather. The crash reports reveal instances in which drivers did not behave properly or behaved differently than they would have at an intersection with more traditional control. Training, awareness, and education focused on getting drivers to slow down and drive cautiously at roundabouts can help mitigate these types of rear-end collisions.

Twenty-one geometric attributes of roundabouts and their approaches were examined. Three models were created: one with all 21 predictors and two that controlled for the number of approach

TABLE 6 Model Coefficient Estimates for Development of Rear-End Collision Prediction Model: Two or More Approach Lanes

Predictor	Model 1[a]	Model 2[b]	Model 3[b]	Model 4[c]
Approach specific				
Deflection angle	.030 (.308)			
Entry width	–.169 (.107)			
Flare length	.001 (.844)			
Posted speed	.216 (.692)			
Yield pavement markings	.479 (.458)			
Pedestrian crossing	.688 (.186)			
Roundabout in corridor	1.035 (.084)	.866 (.079)		
Yield sign left of approach				
Continuous right-turn lane	–.134 (.806)			
Sawtooth pavement markings	2.250 (.034)	1.392 (.038)	1.234 (.063)	
Approach is highway ramp	–.154 (.844)			
Horizontal curve within 250 ft	.219 (.755)			
General roundabout				
AADT, major road	.775 (.086)	.812 (.010)	.807 (.009)	.720 (.016)
AADT, minor road				
Center island radius				
Inscribed circle diameter	.012 (.590)			
Urban or rural				
Number of circulating lanes	.010 (.990)			
Number of approaches	.408 (.481)			
Center island landscaped	.408 (.478)			
Model intercept	–3.564 (.432)	–6.097 (.042)	–6.921 (.019)	–7.217 (.012)
Goodness-of-fit metrics				
–2LL	–165.628	–174.034	–177.172	–180.798
AIC	201.629	184.035	185.173	186.799
Corrected AIC	212.316	184.814	185.686	187.102
BIC	245.168	196.129	194.848	194.055
χ^2 likelihood	23.596	15.190	12.052	8.426
Degrees of freedom	17	4	3	2
p	<.131	<.004	<.007	<.015

NOTE: Values in parentheses are *p*-values.
[a]Full model without correlated variables.
[b]Interim modeling steps.
[c]Final model.

lanes. For the full model, results of backward stepwise negative binomial regression indicated that four variables were significant. The regression model found that the significant factors that could be used to predict rear-end collisions were AADT of the major road, deflection angle, entry width, and presence of sawtooth pavement markings at the roundabout approach. The one-lane approach model found entry width, the presence of YIELD pavement markings, and the presence of horizontal curves within 250 feet of the roundabout to be significant factors. Only AADT was significant for the multilane approach model.

Overall, these findings suggest that higher traffic volume at a roundabout will lead to more rear-end collisions. Wider entry lanes lead to fewer crashes overall, and the number of rear-end collisions decreases as the deflection angle is brought closer to 90°. Sawtooth pavement markings also lead to increased crashes, possibly because they may cause drivers to yield at different locations in the roundabout approach and cause the following vehicles to rear-end the leading vehicle if their yielding location differs. In contrast, the YIELD pavement marking leads to decreased crashes at one-lane approaches. The salience of the pavement marking, when properly applied, may give drivers a clear indication of what is required at roundabout approaches. These findings suggest the importance of markings at roundabout approaches.

As more crash data become available, future studies specifically will examine the causes of crashes with sample sizes too small to test for significance. The scope of crash types analyzed at roundabout approaches will be expanded to examine how geometry affects them to develop a more comprehensive understanding of crashes at roundabout approaches. A driving simulator will be used to determine where vehicles yield to pavement markings at roundabout approaches—both the edge of the inscribed circular diameter and the sawtooth marking perpendicular to the approach lane—potentially clarifying the findings of the present research. Finally, expanding the data set by examining and comparing with other states' roundabout approach crash data would confirm and increase the understanding of the geometric causes of crashes at roundabout approaches. This study and future studies will shed light on crash causes at roundabout approaches and improve the safety and perception of roundabouts.

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