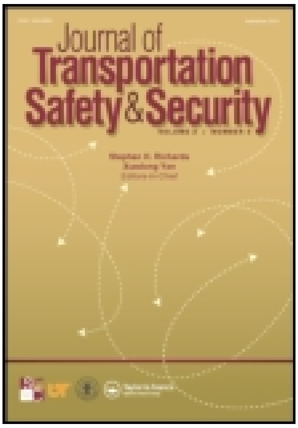

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Comprehensive Safety Evaluation of Roundabouts in Wisconsin

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The modern roundabouts are proliferating rapidly in the United States and Wisconsin is no exception to this trend. The growing number of U.S.-specific research has played an important role in their acceptance in the United States. However, as new data become available, there is a need to continue the research to better understand roundabout safety in the United States. Moreover, the growing data sets also warrant the creation of localized models to better reflect ground conditions. The objectives of this research were to continue and enhance research efforts on the roundabout safety using current data sets. The aim was to analyze roundabout crash trend and patterns to further evaluate their performance under varying situations and develop crash prediction models. The results showed interesting observations as far as crash patterns at roundabouts were concerned. Even though crash severity was reduced, it is not the same situation for crash frequencies. Further research is required to assess the safety effectiveness of roundabouts in Wisconsin. The crash prediction models from this research would help in quantifying roundabout safety, especially when selecting which locations to be converted to roundabouts.

Keywords roundabout safety, crash prediction model, crash pattern, novelty effect, negative binomial models

1. Background and Problem Statement

1.1. Background

Although modern roundabouts were first designed in the United Kingdom in the 1960s, their prevalence in the United States did not begin until the 1990s (Rodegerdts, Blogg, Wemple, Myers, Kyte, Dixon et al., 2007). Since then the construction of modern roundabouts is proliferating rapidly. There were approximately 2,500 roundabouts operating

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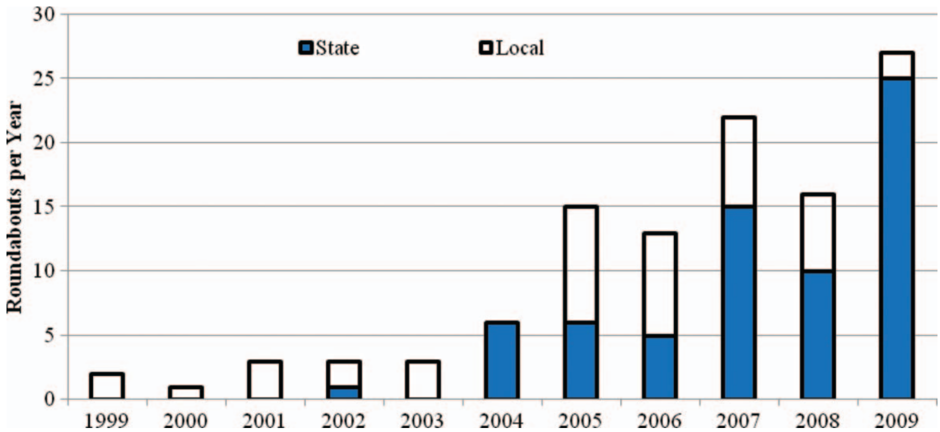

Figure 1. Number of roundabouts constructed in Wisconsin. (Color figure available online).

in the United States according to (Baranowski) whereas by the end of 2010, there will be approximately 150 roundabouts in Wisconsin alone with another 210 planned, which indicates how fast the numbers are increasing. The first roundabout in Wisconsin was built and opened to traffic in 1999. Currently, there are more than 100 roundabouts on the state trunk and local roads network. Figure 1 provides a breakdown of roundabout numbers in Wisconsin and shows how the numbers have increased in the recent years.

The initial reluctance to use roundabouts in the United States due to perceived differences in driver behavior and potential benefits has given way to a flurry of roundabouts in the past few years. The rapid growth in the number of roundabouts in Wisconsin and the United States raises a number of important research challenges, especially in the area of safety performance and evaluation for U.S.-specific data under varying conditions. A surging number of research projects on the potential safety and operational benefits of roundabouts has played a crucial role in the promotion of roundabouts being built throughout the United States. Figure 2 shows the steadily growing number of research papers published in the recent past regarding all aspects of roundabouts. The research has also

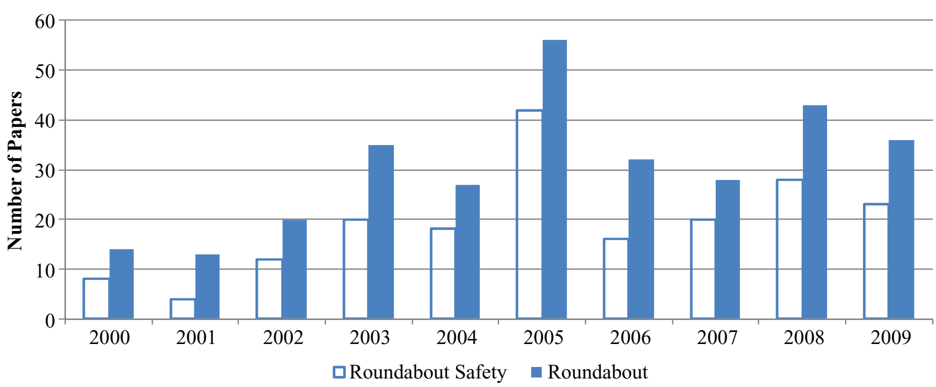

Figure 2. Number of papers on roundabout and roundabout safety (from the transportation research information service [TRIS]). (Color figure available online).

been beneficial in displacing some of the initial reluctance to roundabouts due to the lack of U.S.-specific research. However, further research efforts are essential as the increasing number of roundabouts provide a larger sample size to conduct more robust analyses.

On the other hand, more localized analyses are also important in developing region specific safety performance functions to accurately reflect local conditions and driver behavior. Such efforts will further enhance the understanding of roundabout safety and operation in the United States and promote their acceptance not only by practitioners but the general public as well.

Roundabouts are generally considered to be safer than other forms of traffic control providing the good balance between safety and mobility (Johnson & Isebrands, 2009). A number of research studies (Rodegerdts, Blogg, Wemple, Myers, Kyte, Dixon et al., 2007) have shown that roundabouts are successful in not only reducing the frequency of crashes but also the injury severity of those crashes. However, there is a continuing need to study and evaluate roundabouts as new data become available. There is also a continuing need to study the various conditions, factors, and issues associated with building new roundabouts or converting existing intersections to roundabouts.

1.2. Research Motivation

The aforementioned research challenges provided the motivation for conducting this research, especially as Wisconsin has been one of the leading states in accepting and constructing roundabouts. The idea was to further the understanding of roundabout safety through the newly available data set. There was a need to conduct formal evaluation and study the performance of roundabouts in Wisconsin given their growing numbers within the state. This would establish their true effectiveness and provide better indication of their crash reduction potential under varying conditions leading to better practices in terms of site selection and roundabout geometry.

Another important issue that served as a motivation for this research was the perception among some roundabout engineers as to the diminishing novelty effect of roundabouts in some areas. As drivers become used to roundabouts and their operations, some of the large crash reductions at roundabout locations seem to diminish over time. This phenomenon is complex and has not been established through research as of yet. This research aimed to explore this issue to gain an understanding of this novelty effect.

There was also the need for analyzing a local data set to generate specific safety models, especially as Wisconsin moves toward an implementation of Federal Highway Administration's (FHWA) SafetyAnalyst software (n.d.). SafetyAnalyst is a comprehensive suite of road safety analysis software that incorporates state-of-the-art statistical methods to analyze macroscopic and microscopic road safety on a statewide level. One of the most important challenges and operational requirement of SafetyAnalyst implementation is the need for localized safety models and safety performance functions. Although NHCRP Report 572 (Rodegerdts, Blogg, Wemple, Myers, Kyte, Dixon et al., 2007) provided safety models based on nationwide data, ideally states should have their own models to reflect the intricacies specific to different areas. This provided an additional motivation for this research to be conducted based on statewide data.

1.3. Objectives

In view of the aforementioned research challenges and requirements, the objectives of this research were to

1. Design and create a roundabout inventory database to monitor roundabout safety performance
2. Analyze patterns of crashes at roundabouts to better understand their performance under varying conditions
3. Develop localized safety prediction models for use with SafetyAnalyst and other local level analyses
4. Identify key factors affecting roundabout safety to support the decision of roundabout conversion.

2. Literature Review

A literature review of the safety models for roundabouts was conducted as part of this research to gain an understanding of the state of research in this area. Some of the main contributions towards roundabout safety have come from countries like the United Kingdom and Australia who have had roundabouts as part of their highway systems for many decades now. In the 1980s the Transportation Research group at the University of Southampton, UK, conducted a study on more than 80 four-arm roundabouts to establish safety models considering traffic volume and roundabout geometry (Maycock & Hall, 1984). The study used generalized linear models to calculate crash frequency and severity models. Relationships were also established between the various geometric features of roundabouts and their effects on crash occurrences.

Similar studies were conducted in Australia by Arndt for single-vehicles crashes at roundabouts. The first research developed linear regression models for single-vehicle crashes at roundabouts using traffic volume, speed, and geometric data as dependent variables (Arndt, 1994). A follow-up study used more sophisticated nonlinear Poisson-based regression models that were found to be more accurate in establishing crash frequency models for roundabouts (Arndt, 1994). However, as mentioned before, these studies using data from outside of the United States make their applicability to U.S. conditions questionable.

A review of before-and-after studies was also conducted as part of the literature review to gain knowledge of the state-of-practice in this area. Although there were several examples of non-U.S. research in this area, the emphasis was on U.S.-based studies for aforementioned reasons. A study conducted in seven U.S. states—Colorado, Florida, Kansas, Maine, Maryland, South Carolina, and Vermont—where a total of 23 intersections were converted to roundabouts, used state-of-the-art empirical Bayes analysis to conduct before-and-after studies (Persaud, Retting, Garder, & Lord, 2001). The results revealed a 40% reduction in all crash severities and an overall reduction of 90% in injury crashes.

The most definitive guide on roundabout safety in the US has been the National Cooperative Highway Research Program (NCHRP) Report 572: *Roundabouts in the United States* (NCHRP 572). This research conducted an extensive review of the safety and operational aspects of roundabouts in the United States based on available nationwide data. The results recommended crash prediction models and other relationships between roundabout characteristics and their crash potential. Even though the results of this research provide the most comprehensive review of roundabouts in the United States, the use of models based on nationwide data are not the optimum solution for individual states and local areas. Hence there is a need for more localized models based on newly available data, which was the fundamental basis for this research.

3. Data Collection and Processing

In light of the need for continuing research and understanding of roundabouts and the need for local-level analysis, an extensive data collection effort was conducted in Wisconsin. Roundabout construction in Wisconsin has experienced significant growth especially in the last 3 to 5 years. As of October 2009, 68 roundabouts had been constructed on state highways and 43 on local roads. Additionally, 165 roundabouts are planned for construction on state highways and many more on local roads, distributed all over the state. The design and operations of roundabouts in Wisconsin differ from each other to accommodate varying traffic demand, resulting in distinct safety performances. Hence, there was a need to select a sample of representative roundabouts with a statistically valid crash history. Under the guidance of the Wisconsin Department of Transportation (WisDOT), the research team selected a total of 41 roundabouts representing various configurations, layouts, design features, previous traffic control, and traffic volumes. During the site selection process, attention was paid to maintain a good balance between single- and multilane roundabouts; with regards to geographic distribution in the state and previous traffic control of the intersections before conversion to a roundabout. The characteristics of the 41 roundabouts are listed in Table 1.

3.1. Geometric Data

A significant amount of effort went into the data collection process that not only provided safety and operational information, but also helped establish a comprehensive Wisconsin roundabout site inventory that would facilitate long-term performance monitoring.

Table 1
Characteristics of modern roundabouts in the scope of the study

Characteristics	Number	Percentage
Number of legs		
3	7	17.07
4	33	80.49
5	1	2.44
Number of circulating lanes		
1	18	43.90
2	23	56.10
Previous intersection traffic control		
No control	5	12.19
Two-way stop	23	56.1
All-way stop	5	12.20
Signal	8	19.51
Geographic location		
NC	2	4.88
NE	18	43.90
NW	6	14.63
SE	9	21.95
SW	6	14.63

NC = North Central; NE = Northeast; NW = Northwest; SE = Southeast; SW = Southwest.

Important data elements were identified for creating the site inventory, including geometric parameters, traffic volume, and crash data. The data collection was particularly challenging because roundabout data were stored at different places and maintained by different agencies based on jurisdiction. WisDOT maintained some (design) documents for the selected roundabouts that were used to extract detailed geometric data from the construction plans. For other locations, construction plans were requested from either the consulting firms that had designed the roundabouts or the municipal engineers overseeing the projects. Some design variables were the same for all the roundabouts such as the inscribed circle diameter (ICD) and the center island diameter (CID). Others parameters varied by approach.

Realizing that the design of each approach may be different, roundabouts were divided into three, four, or five quadrants, depending upon the number of approaches. Quadrants were numbered in accordance with the cardinal directions. For each quadrant, the entry angle, entry width, flare length, turning radius, ICD, CID, number of circulatory lanes, number of entering lanes, and the number of exiting lanes were measured. Moreover, the traffic control type before the roundabout conversion was also collected by contacting regional or city traffic engineers who had knowledge of the intersection traffic controls.

3.2. Traffic Volume Data

The total average annual daily traffic (AADT) at a roundabout was defined as the sum of AADT on each approach entering the roundabout. Traffic volume information was mainly collected from the Wisconsin Highway Traffic Volume Data published by WisDOT every year. For the roundabouts with missing AADT, individual traffic counts were conducted to fill the gaps.

In general, it was observed that in the data set, the three-legged roundabouts carried less traffic than the four-legged ones, but not for all. The three-legged roundabouts had an AADT range of 5,850 to 23,300 vehicles per day (vpd) with an average of 14,200 vpd whereas the four-legged ones had a range of 4,100 to 48,100 vpd with an average of 17,565 vpd.

Similarly, single-lane roundabouts had lower traffic volume than multilane ones. In the sample, the AADT for the single-lane roundabouts ranged from 6,000 to 21,900 vpd with an average of 12,595 vpd. For the multilane roundabouts, AADT ranged from 4,100 to 48,100 vpd with an average of 20,170 vpd.

Although the traffic demand seems to be a critical factor in deciding the number of legs and lanes, it is not the only one. The roundabout layout is also affected by the lane use, available right of way, and so on. The area setting is determined following the description in the WisDOT *Facilities Development Manual* (*FDM*; 2010) such as the curb and gutter presence for urban areas, etc.

3.3. Crash Data

Crash data for the sample of roundabouts studied in this research were collected from the Wisconsin Crash Database. A substantial effort was required to ascertain that crashes occurring at roundabouts were related to the roundabouts, not some other unrelated factors such as deer-related, driveway crashes in the proximity, and so on. Crash data were initially retrieved based on their location description and then followed by a detailed review of the narratives and diagrams in the police report forms, the Wisconsin crash report forms (MV4000). One of the most challenging tasks was to distinguish crashes occurring between two interchange ramp roundabouts.

Table 2
Summary of detailed data used for safety analysis

Variables	Minimum	Maximum	*M*	*SD*
Central island diameter (ft)	29	90	49.62	11.06
Inscribed circle diameter (ft)	90	280	146.32	31.99
All roundabouts AADT	4,103	39,000	15,416	7,867
Three-legged roundabout AADT	5,850	23,300	14,200	6,831
Four-legged roundabout AADT	4,100	48,100	17,565	8,311
Before period total crashes/year (5-year period)	0	21	4.25	4.09
After period total crashes/year (varying periods)	0.5	27.5	4.73	5.82

AADT = Average Annual Daily Traffic.

Crash data were collected for before-and-after periods of a roundabout construction. In the sample data set, the before period started from 1994 to the year of construction, and the after period was between the construction year and December 31, 2009. Crashes occurring during the construction year were excluded from the study to minimize the effects of construction activities, driver unfamiliarity with the conditions, and other complications such as the partially open to traffic during the construction. All 41 roundabouts had a sufficient before period with at least 5 years of crash history; however, the duration of the after period varied for each one which is described below:

- 11 roundabouts with 1-year after period crash data
- 13 roundabouts with 2-year after period crash data
- 5 roundabouts with 3-year after period crash data
- 5 roundabouts with 4-year after period crash data
- 6 roundabouts with 5-year after period crash data
- 1 roundabout with 7-year after period crash data.

Crash location is defined not only by the address but also by the police definition as “intersection related,” that is, a crash is caused by the activity related to the operations of the intersection. Not limited to the intersection junction or circulatory area, the data collection allows crash occurring on roundabout approaches due to speeding or sudden stop or slowing down to be collected. A detailed manual review of the Wisconsin crash report forms (MV4000) was also conducted for all queried crash data using the narratives and diagrams sections to decide whether or not crashes were truly roundabout crashes or related to roundabout operations. An overall summary of detailed roundabout data in the sample is provided in Table 2.

4. Roundabout Crash Trend and Patterns

The first step in roundabout safety analysis was to study the temporal patterns of crashes in the before-and-after periods of a roundabout. The idea was to gain an understanding of the number and nature of crashes occurring before and after the roundabouts had been constructed. Crash data for each roundabout location were reviewed for the before-and-after periods excluding the construction year. A close examination of the data showed that crash trends varied among the studied roundabout locations. Some roundabout locations showed an increase in crashes in the after period (after conversion of the intersection to a roundabout); some roundabout locations showed a decrease in the number of crashes in the after period; and at some roundabout locations, the number of crashes remained the same with no increase or decrease. This was quite surprising given that previous studies have shown that almost all roundabout locations display at least some kind of crash reduction.

To effectively validate the inconsistent temporal crash patterns, eight of the roundabouts were removed from the pattern analysis due to no prior crash history (new constructions or roadway realignment) or extremely low number of crashes before the roundabout construction. The remaining 33 roundabout locations were then grouped by crash temporal trends into three distinct categories:

- Increase (showing increase in crashes after roundabout construction), 13 roundabouts
- Decrease (showing decrease in crashes after roundabout construction), 12 roundabouts
- Oscillation (showing neither clear increasing or decreasing trends), 8 roundabouts.

The crashes per year at each of the roundabout locations in the resulting three categories were then plotted to show the trends as illustrated in Figure 3. A simple linear regression model was fitted to each data set to quantify the trend and variation. High R^2 values for "increase" and "decrease" groups indicated a very strong temporal effect of increase or decrease in the number of crashes per year. For the oscillation group, very low R^2 suggested that the crash count fluctuates around the average, irrespective to the change over time.

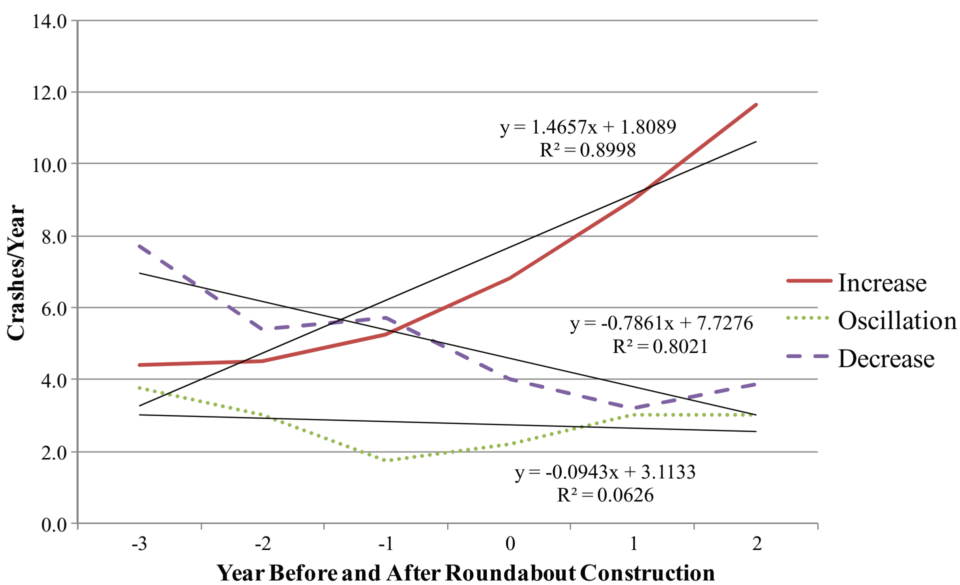

Figure 3. Three temporal trends of roundabout crashes. (Color figure available online).

In addition to the temporal effects, roundabout daily traffic volume was of particular interest because it is the primary contributing factor for the number of crashes. The relationship between AADT and crashes was studied, in the before-and-after periods, to establish a relationship between the two. The total AADT and the sum of AADT on each approach entering the roundabout were used to portray the traffic demand at the roundabouts. Due to the missing AADT values either before or after the roundabout construction, a relative short analysis time period (3 years before the roundabout and any number of years after the roundabout up to 5 years) was used with the assumption that traffic remains at the same level during the time period. Although it is not ideal to assume that traffic volume remains the same before and after the roundabout construction, several roundabout traffic impact analysis (TIA) studies actually reported a slight decrease in traffic volume after the roundabout opening. The data collected in this research did not show any significant increase in traffic volume after opening the roundabout to the public.

The selected 33 roundabouts had a relatively wide range of total AADT, from 4,100 to 48,100 vpd. Figure 4 shows the comparison between 3-year average number of crashes before the roundabout construction (dashed line) and average number of crashes after construction (solid line), plotted against AADT. There are visible differences in the intersection safety performance between low, median, and high AADT regimes. For AADT lower than 11,550 vpd and higher than 21,750 vpd, there are clearly more crashes occurring after the construction of roundabouts except for two locations. In between, the roundabouts generally outperform other intersection forms. Even though, the results are far from conclusive given the disparity and lack of statistical tests, the observations in this analysis reveal additional information regarding the varying performance of roundabouts.

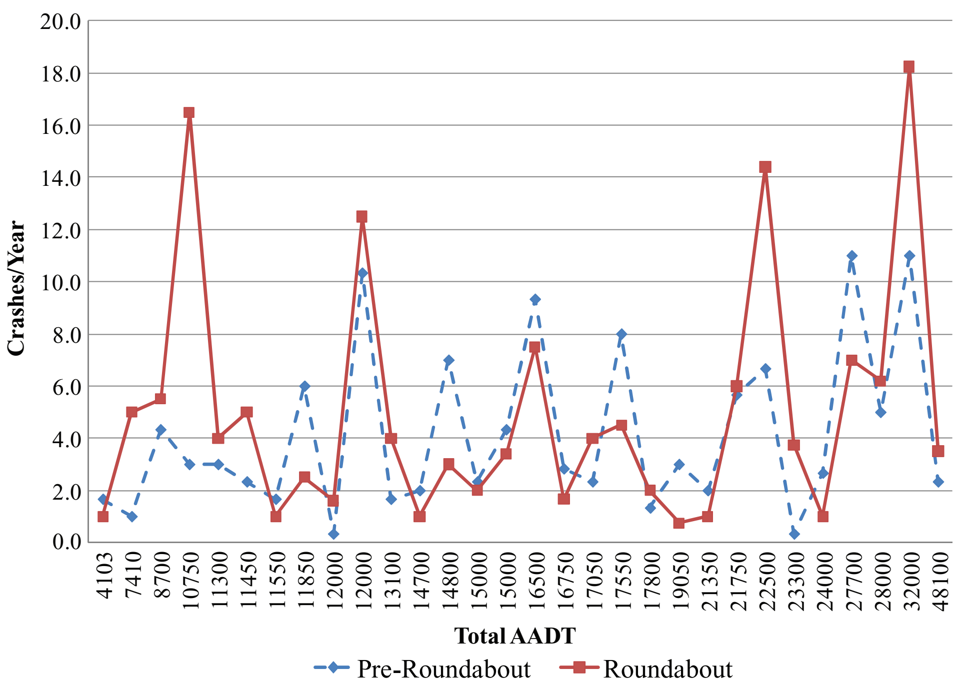

Figure 4. Crashes per year before and after construction of roundabouts. AADT = Average Annual Daily Traffic. (Color figure available online).

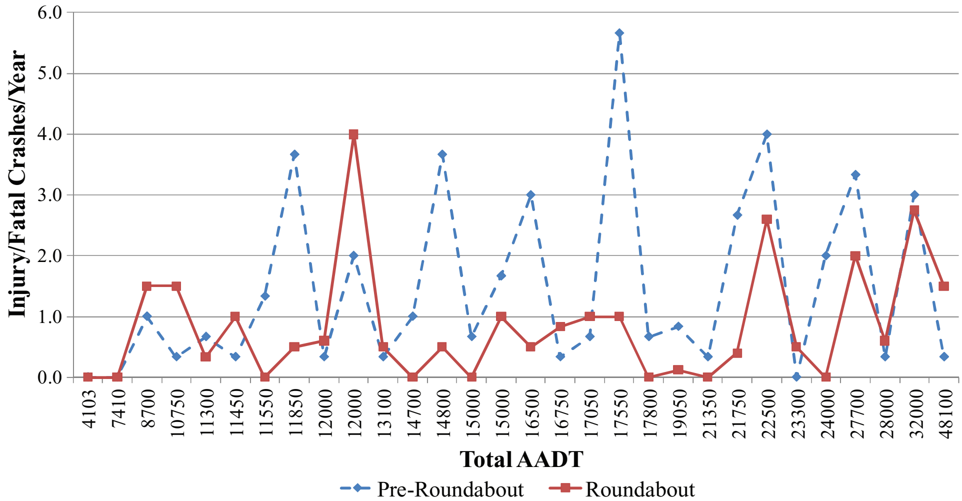

Figure 5. Injury crashes per year before and after construction of roundabouts. AADT = Average Annual Daily Traffic. (Color figure available online).

The differences in crash severity before and after the installation of a roundabout were also studied and are illustrated in Figure 5. The result is more consistent and overwhelmingly positive. All roundabouts except for one exhibit better safety performance.

For all roundabout locations in this study, the average annual number of crashes after the construction of roundabouts was studied at different time intervals. The time intervals were defined as first 6-month period after roundabout construction, the first one year, and 2 years or more after roundabout construction. Figure 6 displays the overall trend that does not show a clear increasing or decreasing pattern; instead, crashes are rather stable after the construction of the roundabout with minor fluctuations.

In summary, without studying the roundabouts individually, the novelty effect of roundabout crashes was not apparent by tracking all the roundabouts on a 6-month interval basis after the construction year of the roundabout. Before and after the roundabout construction, all three crash trends, that is, increase, decrease, and oscillation in crashes were observed. The total number of crashes increased in both high (larger than 21,750 vpd) and low (less

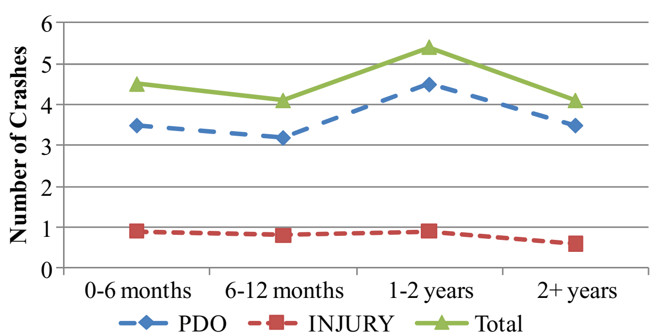

Figure 6. Roundabout crashes postconstruction. PDO = property damage only. (Color figure available online).

than 11,550 vpd) AADT regimes, but crash severities were drastically reduced in almost all AADT regimes.

5. Intersection-Level Crash Prediction Models

To further enhance the research on roundabout safety, the objective of this research was to calculate an intersection-level crash prediction model for roundabouts. The aim was to create a model based on the latest available data that is more localized to better reflect the conditions in Wisconsin. The model development will be leveraged with other modeling effort made at the national level. The comparison is expected to shed light on appropriate model functional from and transferability.

The objective in the modeling process was to use the most basic variables available to engineers in the project planning stage. Safety evaluations may be based on the expected number of crashes among candidate forms of intersections and intersection traffic control strategies. Given the data requirements in the planning stage, the variables chosen for developing the model may be AADT, existing traffic control, the number of legs, the number of lanes, etc. A regional effect was also considered because in Wisconsin, Southeast (SE) and Northeast (NE) regions built roundabouts many years ago and now have more roundabouts than any other regions combined. It is anticipated that the drivers in the two regions must have more driving experience with roundabouts.

Many design features of a roundabout are affected and driven by the traffic demand, that is, AADT, resulting in correlated parameters. For example, ICD is the sum of CID and the width of all circulatory lanes (circulatory lane width times the number of lanes). Including correlated variables in the model may lead to instable and inefficient estimates for the coefficients. Also, it will be difficult to explain individual effects of variables if they are dependent. To identify correlated variables, a Pearson-correlation test was performed for all the variables considered in the models. In Table 3, Pearson-correlation coefficients clearly show the extremely high correlation (0.931) between CID and ICD and high correlation

Table 3
Pearson-correlation coefficients[a] of model variables

	AADT	Leg	Lane	CID	ICD
AADT	1.000	0.105	0.407	0.348	0.442
		(0.514)	(0.008)	(0.038)	(0.007)
Leg	0.105	1.000	–0.140	−0.053	–0.036
	(0.514)		(0.382)	(0.757)	(0.834)
Lane	0.407	–0.140	1.000	0.344	0.506
	(0.008)	(0.382)		(0.040)	(0.002)
CID	0.348	–0.053	0.344	1.000	0.931
	(0.038)	(0.757)	(0.040)		(<.0001)
ICD	0.442	–0.036	0.506	0.931	1.000
	(0.007)	(0.834)	(0.002)	(<.0001)	

AADT = Average Annual Daily Traffic; CID = central island diameter; ICD = inscribed circle diameter.

[a]The lower value in each cell is the *p* value.

between the number of lanes and ICD (0.506). As a result, only one of the variables can be included in the model functional form. Usually, it is the one that either has higher correlation with the dependent variable or helps to improve the overall model performance.

The state-of-the-practice distribution considered for modeling crashes is Poisson-gamma (or negative binomial) (Lord, Washington, & Ivan, 2005; Miaou, 1993; Miaou & Lord, 2003). Poisson-gamma models can easily handle the crash data overdispersion that, if not properly considered, may lead to estimation inefficiency or inference errors. In highway safety applications Poisson-gamma models have the following structure:

Let y_i denote the number of crashes at site i and the distribution of y_i conditional on its mean μ_i is assumed to follow a Poisson distribution independently over sites.

$$y_i|\mu_i \sim \text{Poisson}\,(\mu_i) \quad i = 1, 2, \ldots, n \tag{1}$$

The log function used to link the mean number of crash counts with all possible covariates and unstructured errors is defined as

$$\mu_i = AADT^{\alpha} \exp(\mathbf{X}_i \boldsymbol{\beta}) \exp(\varepsilon_i) \quad \mathrm{i} = 1, 2, \ldots, \mathrm{n} \tag{2}$$

where,

AADT: average daily entering traffic to the roundabout,
$\mathbf{X_i}$: the vector of variables,
α,$\boldsymbol{\beta}$: regression coefficients (bold represents vector), and
ε_{i}: an unstructured random effect independent of **X**.

The Poisson-gamma model was specified by assuming that $\exp(\varepsilon_{\mathrm{i}})$ follows a gamma distribution independently. In most crash prediction literature, it is widely accepted that its mean is one and variance $1/\phi$ for some positive quantity (or parameter) ϕ. In other words,

$$\exp(\varepsilon_i) \sim \text{gamma}\,(\phi,\phi), \tag{3}$$

and ϕ is usually called an inverse dispersion parameter. Let $\boldsymbol{\beta} = (\alpha, \boldsymbol{\beta})'$, based on this particular parameterization, y_i follows a negative binomial distribution with mean $\exp(\mathbf{x}\boldsymbol{\beta})$ and variance $\exp(\boldsymbol{x\beta})(1+ \exp(\boldsymbol{x\beta})/\phi)$. Here, $\boldsymbol{\beta}$ and ϕ can be estimated via maximum likelihood estimate (MLE) in the SAS GENMOD procedure.

The following variables were included in the candidate models: traffic data (total entering AADT), geometric parameters (number of legs with 3-legged as the baseline, number of lanes with single lane as the baseline, ISD, CID, and the ratio of CID to ISD), and regions (NC, NE, NW, SE, with SW as the baseline), and traffic controls (no control, two-way stop, all-way stop, with signal as the baseline). Nine models were tested and the best model was selected based on a combination of the following criteria:

1. smaller Akaike information criterion (AIC) values
2. smaller dispersion factor k
3. meaningful coefficients for the parameters.

The results of several models were compared and are listed in Table 4. The first five models were designed following the ones suggested in NCHRP Report 572: *Roundabouts in the United States*, referred as the national study or the NCHRP study (Rodegerdts, Blogg, Wemple, Myers, Kyte, Dixon et al., 2007). Models 6 to 8 are the variations from the national study. Model 9 introduced new variables as regions and traffic control type before the roundabout. AADT is the only statistically significant variable for all the tested models.

Table 4
Model selection: AIC, dispersion, and number of significant variables

Model	AIC	Dispersion	Intercept [a]	Entering AADT [a]	Leg (3-legged)	Lane (single)	NC	NE	NW	SE	Two-way Stop	All-way Stop	Ratio = CID/ICD	ICD	CID
1	266.68	0.589	–10.414	1.234											
2	270.21	0.578	–9.019	1.1	–0.181	–0.203									
3	239.24	0.629	–7.701	1.055	–0.108	–0.194							–2.599		
4	236.82	0.575	–8.627	0.914	–0.076	–0.09								0.009	
5	238.07	0.601	–8.546	0.966	–0.122	–0.239									0.017
6	268.43	0.581	–9.410	1.136	–0.17										
7	237.30	0.629	–7.942	1.083		–0.163							–2.795		
8	236.15	0.603	–8.906	0.999		–0.209									0.017
9[b]	232.82	0.330	–4.456	0.636			0.939	0.227	–0.429	0.934[a]	–0.797[a]	–0.211			

AIC = Akaike information criterion; NC = North Central; NE = Northeast; NW = Northwest; SE = Southeast; ICD = inscribed circle diameter; CID = central island diameter.
[a]Cells are statistically significant at 10% level of significance.
[b]Recommended model.

The coefficient for AADT is close to one in all models except for Model 9, indicating a near linear relationship between the crash count and AADT. On the other hand, the coefficient estimates for AADT in the national study range from 0.5 to 0.7. The value dispersion parameter k is smaller as compared to the NCHRP study, suggesting a more homogeneous dataset because the NCHRP study used roundabouts from different states.

Although most signs for the estimated coefficients of the variables are consistent with the national study, they are not statistically significant in this study at 10% level of significance. Interestingly, both newly introduced variables (region and previous traffic control) in Model 9 were statistically significant. NW region seemed to have the lowest number of roundabout crashes, followed by SW, NE, SE, and NC. Compared with signalized intersections, converting from two-way stop or all-way stop seemed to reduce more crashes with two-way stop showing larger safety benefits. No control was eventually excluded from both models to avoid the bias because these roundabout locations are either new intersections or realignment projects. Model 9 outperformed others with the smallest AIC value, smallest dispersion parameter k while having more meaningful and statistically significant variables at a level of at least 10%.

6. Conclusions and Recommendation

As Wisconsin and the United States move ahead with building greater numbers of roundabouts, there is a need to continually study their safety impacts as newer data are available. With these goals in mind, this research found some interesting results based on Wisconsin's data. Crash pattern analysis at 41 different roundabout locations provided inconclusive results as far as reducing crash frequency was concerned. However, there was no doubt about the reduction in crash severity at roundabout locations. Crash severity was reduced in all crashes for all crash types. Further research and more data are required to better understand the safety effectiveness of roundabouts in Wisconsin. Furthermore, there is also the need to study the individual roundabout locations to thoroughly evaluate the safety performance at those locations.

One of the interesting findings of this research was the study of the novelty effect of roundabouts as perceived by some safety engineers. This research shows that without studying the roundabouts individually, the novelty effect of roundabout crashes was not apparent by tracking all the roundabouts on a 6-month interval basis after the construction year of the roundabout.

The crash prediction models from this research may play an important role in the successful implementation and expansion of SafetyAnalyst. SafetyAnalyst software is ideal when used with state-specific safety performance functions. As the number of roundabouts grows, the need for more localized and roundabout specific crash prediction models will become more critical. However, due to the limited number of sites, the crash prediction models developed in this study should be used with caution. Moreover, the models were strictly developed with the crash data and roundabouts in Wisconsin. A calibration with local crash data is recommended before being implemented anywhere else. Nevertheless the results of this research will provide the first steps in better safety evaluations in Wisconsin. Again, future research in this area is also essential as new data are available to create more accurate models. The issues studied in this research are crucial to better understanding roundabout safety, especially when selecting which locations to convert to roundabouts. The results of this research may provide additional information for other states in evaluating roundabout safety.

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