Safety Evaluation of Wisconsin Roundabouts: Phase 2

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By

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16. Abstract

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Using a simple before-and-after crash analysis, researchers found that two sites in which fatal crashes were found in the before condition observed no fatal crashes after the installation of a roundabout. No sites experienced a fatal crash after a roundabout was installed. For all injury (A, B, and C) crashes, the number of locations with a reduction in these crash types was greater than the number of locations with increases in these crash types. Similarly, the magnitude of decrease in injury crashes is higher than the magnitude of increase.

A second analysis method was also used to evaluate the crash data. The EB analysis was performed using Safety Performance Functions (SPFs) from the Highway Safety Manual (HSM). Researchers found that the implementation of roundabouts led to mixed results for total intersection crash frequency but a substantial decrease in crash severity. Wisconsin roundabouts had an estimated 12 percent increase in total crashes and a 38 percent decrease in injury crashes. Roundabouts nationwide are also experiencing a significant decrease in severe crashes. Increases in total crashes were primarily due to increases in PDO crashes, which could be attributed to initial driver confusion with roundabout operations.

A synthesis of the results revealed single lane roundabouts perform better than multi-lane roundabouts when considering fatal and injury crashes. TWSC intersection conversion to a roundabout had the highest safety benefit as compared to yield control, AWSC, and signalized intersections. The severity of crashes in all regions was reduced substantially for all roundabouts. Roundabouts in rural locations performed better than roundabouts in urban locations when considering total crashes.

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Abstract

For this study, researchers analyzed 30 Wisconsin roundabouts that were built in 2008 or before. Three years of before crash data and a mix of three to four years of after crash data (depending upon the built year of roundabouts) were collected, as well as geometric and volume data. An Empirical Bayes (EB) analysis was used to examine the safety benefits for total crashes and injury (K, A, B, C) crashes. A simple before-and-after crash analysis was also completed to analyze specific types of injury crashes for each roundabout.

Using a simple before-and-after crash analysis, researchers found that two sites in which fatal crashes were found in the before condition experienced no fatal crashes after the installation of a roundabout. No sites experienced a fatal crash after a roundabout was installed. For all injury (A, B, and C) crashes, the number of locations with a reduction in these crash types was greater than the number of locations with increases in these crash types. Similarly, the magnitude of decrease in injury crashes is higher than the magnitude of increase.

A second analysis method was also used to evaluate the crash data. EB analysis was performed using Safety Performance Functions from the Highway Safety Manual. Mixed results were observed for the 30 roundabouts when considering the total number of crashes, with some locations showing an increase and others showing a decrease in crashes. The results of fatal/injury crash analysis using EB methodology showed a substantial decrease in crashes for most of the locations. Overall, the results of EB analysis showed a 12 percent increase in the total number of crashes and a 38 percent decrease in fatal/injury crashes for Wisconsin roundabouts built in 2008 or before. Increases in total crashes were primarily due to increases in PDO crashes, which could be attributed to initial driver confusion with roundabout operations.

A synthesis of the results revealed that single lane roundabouts perform better than multi-lane roundabouts in terms of reduction in total number of crashes. Two-way stop controlled intersection conversion to a roundabout had the highest safety benefit as compared to yield control, all-way stop controlled, and signalized intersections. The severity of intersection crashes in all regions was reduced substantially by installing roundabouts. Roundabouts in rural locations performed better than roundabouts in urban locations when considering total crashes.

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CHAPTER 1 INTRODUCTION

As stated in a recently published Federal Highway Administration (FHWA) memorandum, modern roundabouts are considered to be a promising safety improvement (1). The memorandum is based on extensive safety research studies conducted overseas and at various locations in the United States (U.S.). Though the history of roundabout implementation in the U.S. is relatively short compared with Great Britain and other European counties, roundabouts have demonstrated a consistent record in reducing crashes, especially in reducing severe injury crashes. A study of roundabouts in the U.S. identified crash reductions of approximately 35 percent for all crash types and 76 percent for fatal and injury crashes when an intersection was converted from a signal or stop control to a roundabout (2). The reason behind the large improvement in safety records at these locations lies in the design features of roundabouts that reduce conflict points, as well as vehicular speeds. Roundabouts prohibit vehicles from making a traditional left-turning movement and all vehicles circulate counter-clockwise around a raised central island at a relatively low speed. The entering vehicles yield to vehicles in the roundabout, thus reducing all left-turn related crashes, such as head-on or angle crashes, which can result in serious injury outcomes. Lowered travel speeds also reduce the collision impact, thus reducing the crash consequence. Other design features that help to improve safety or facilitate safe movements are detailed in the FHWA Roundabout Information Guide (3).

Since the first modern roundabout was constructed, many safety evaluation studies have been conducted to quantify the safety benefits of this new intersection control strategy. The studies range from observational before-and-after to meta-analysis. However, these studies frequently show considerable differences in roundabout safety performance (2, 4, 5). Many factors can contribute to this disparity, and can be generally grouped into three categories: 1) driving population, 2) site choice, and 3) evaluation methodologies.

Though roundabouts are, by design, safer than other intersection control strategies, the safety benefits may be compromised by driver comprehension and behavior. A substandard design, as well as inappropriate signage and pavement markings, can also compromise the safety benefits. Roundabouts demand a high level of driver compliance with traffic signs and judgment towards traffic conditions, such as reducing speed when approaching the roundabouts, judging a safe gap correctly, and yielding to the vehicles in the roundabouts. Roundabouts also require drivers to process more information than traditional intersections, especially in lane choice, because the lanes are not traditionally straight or perpendicular to other approaches, but curved. The additional work load while driving may lead to a wrong lane choice, which contributes to same direction sideswipe crashes in the circulatory lanes. Site choice may also be critical because some roundabouts are constructed due to the operational benefits of increasing capacity, reducing delay, improving flow continuity, environmental considerations, and others. For these roundabouts, safety benefits may not be apparent. Safety may also be jeopardized if the design of a roundabout fails to consider particular user groups (pedestrians, bicyclists, visually impaired users, etc.) and special vehicle types (large trucks) that might be prevalent (6, 7). Daniels, et al. found that the variation in crash rates is mainly driven by traffic exposure, as well as vulnerable road users, who are more frequently involved in crashes at roundabouts than expected based on a sample of 90 roundabouts in Flanders, Belgium (5). Consistent data collection and evaluation methodologies provide a comparable basis for the studies conducted at different times and from different areas. When performing a safety evaluation, the keys to success are data collection and selection of appropriate evaluation methodologies. Data collection needs to be designed for the purpose of the evaluation and more importantly, the roundabout related crashes, not just the crashes occurring at or near the roundabout. The evaluation methodologies should overcome data issues such as regression-to-the-mean, novelty effects, and others resulting from short-term observations (4). Therefore, the Empirical Bayes (EB) analysis methodology is best suited for this purpose.

While roundabouts have significant safety benefits, they also can provide significant operational benefits in terms of continuous flow of traffic when used under the right conditions (1). Although in general, roundabouts have been shown to reduce both frequency and severity of crashes, in some cases roundabouts may offer safety tradeoffs similar to other traffic control strategies, i.e., reduce severity of crashes while PDO crashes increase (2, 3). Such cases are not dissimilar to increases in rear-end crashes after installation of a traffic signal or increase in PDO crashes after installation of a cable median barrier. Therefore, it is important to view safety evaluation of roundabouts in this respect as well.

The present study is motivated by the need for a thorough before-and-after safety evaluation of Wisconsin roundabouts. The first roundabout in Wisconsin was built and opened to traffic in 1999. Currently, there are approximately 200 roundabouts on the state trunk and local roads network with another 100 being planned by the end of the 2015 construction season. Figure 1 shows the locations of roundabouts in Wisconsin that were built in 2008 or before. Therefore, the objectives of this study are to develop unbiased evaluation methodologies, quantify the safety of roundabouts of various conditions, and support informed decision-making.

The report is organized into five chapters. This first chapter presents the research problem and needs, along with the study objectives. The second chapter describes the methodology for both the simple before-and-after analysis, as well as the Empirical Bayes analysis. The third chapter explains the data collection and processing in detail. The fourth chapter presents the results and analyses. The fifth chapter presents the research conclusions and future recommendations.

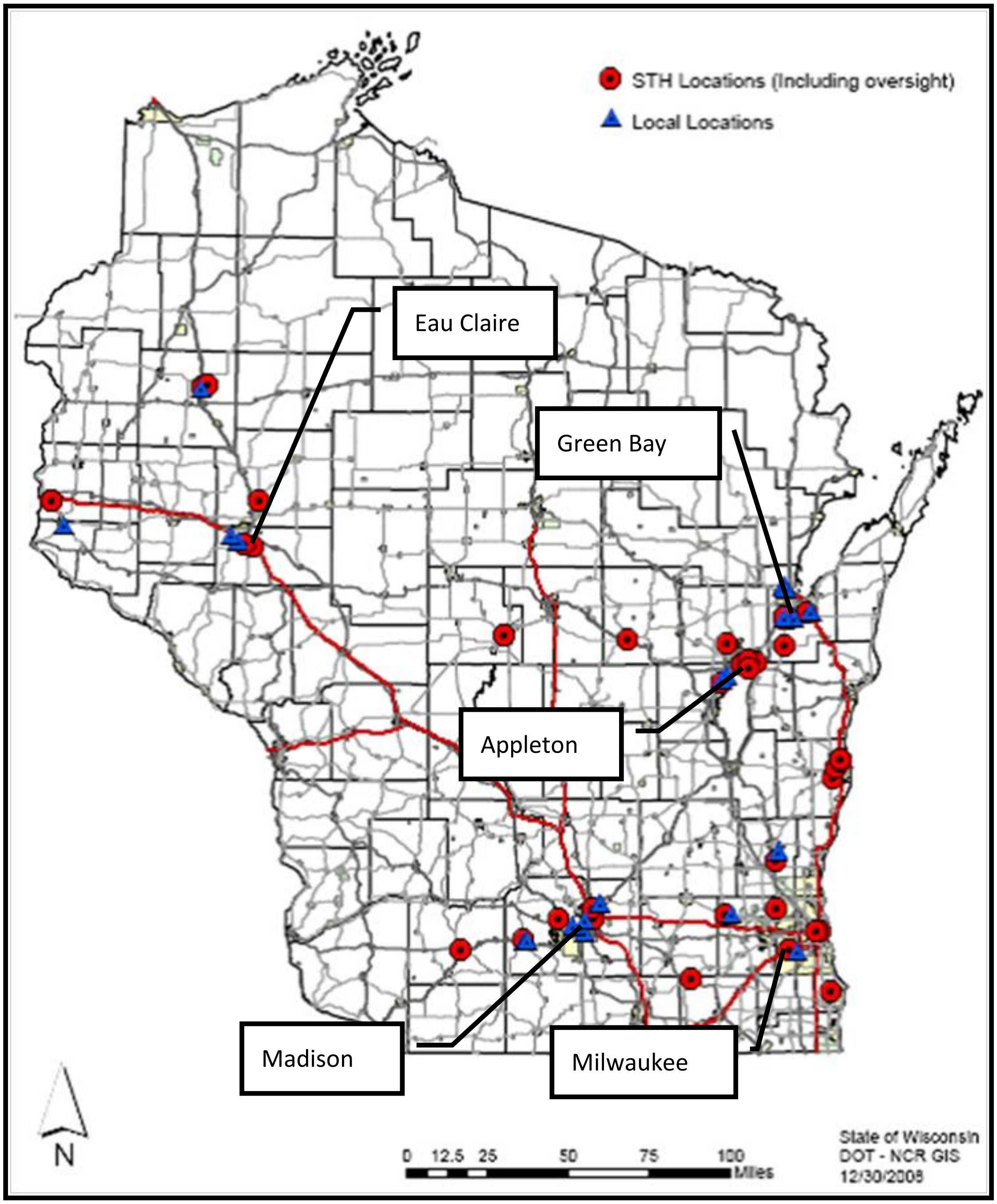

Figure 1 Statewide Distribution of Wisconsin Roundabouts that were built in 2008.

CHAPTER 2 METHODOLOGY

Simple Before-and-After Study

The safety benefit of a treatment can be measured by a before-and-after study that calculates the difference between the ratio of crash frequency before and after the implementation of the remedial measures, over a designated time frame, which is given by:

Change in safety: $\Delta = B - A$ or

Ratio (also called the index of effectiveness): $\varepsilon = B/A$

Where:

B = the number of crashes occurring in the before period without the conversion, and
A = the number of crashes in the after period.

If only the number of crashes observed during the before and after analysis time period is used, the method is an observational before-and-after analysis, or a "simple" before-and-after analysis. In general, a positive value for the change in safety, or a ratio greater than one indicates a desirable safety outcome.

Empirical Bayes (EB) Before-and-After Study

The simple before-and-after comparison assumes that conditions remain unchanged before and after the improvement, which is often not true. Therefore, a traffic volume adjustment is frequently deployed to normalize for differences in traffic volume between before and after periods. Moreover, the difference or ratio computed directly from the observed crash counts or rates between before and after periods may be biased as a result of regression-to-the-mean (RTM). RTM effect, or bias-by-selection, is a phenomenon that repeated measures of the data drifts towards the mean value in the long run. Due to this natural fluctuation, an extreme observation will usually be followed by a less extreme observation without any intervention. Locations slated for safety treatments usually have high crash counts, rates, or severities. A simple before-and-after analysis may inflate the countermeasure effectiveness by including the difference caused by RTM. Hauer suggested using the expected number of crashes that would have occurred in the after period had the countermeasure not been implemented as "B", which is the expected mean of a conditional (gamma) distribution of the long-term crash average of a location, given the observed short-term crash history. The expected mean can be formulated as the weighted average of a predicted number of crashes and site-specific crash history as follows (8):

$$E = W \times \mu + (1 - W)N \tag{1}$$

Where:
$W = \frac{1}{1+\mu Yk}$ =Weight of Prediction
E = Expected Crash Count (Estimate of Long Term Mean over Y years)
N = Observed Crashes (over Y years)
μ = Predicted Number of Crashes (SPF Calculated Value for Y years)
Y = Number of Years in Study
k = Overdispersion Parameter

The methodology of estimating the expected number of crashes is called EB analysis. When the expected number of crashes that would have occurred in the after period without safety improvements, denoted as B, is compared with the actual number of crashes after safety improvements are implemented, the procedure is called EB before-and-after analysis. Note that in the actual calculation, B is the expected average number of crashes in the after period. Any change in the traffic volume (AADT) or analysis time period needs to be factored into the comparison. An adjustment factor as shown in Equation 2 can account for these changes.

$$r_i = \left(\frac{SPF_{After}}{SPF_{Before}}\right)\left(\frac{Years_{After}}{Years_{Before}}\right) \tag{2}$$

Multiplying the 'r' factor by the EB expected number of crashes offers a correct estimate of the number of crashes that would have happened during the after time period had the treatment not been implemented.

The procedure is listed as follows:

1) Estimate EB expected average crashes in the before period for the intersection;
2) Estimate EB expected average crashes in the after period for the intersection through a traffic exposure adjustment factor r_i (B);
3) Observe average crashes in the after period for the roundabout (A);
4) Calculate the change in safety by (B-A) or the safety effectiveness index (B/A); and
5) Estimate the confidence interval of the change in safety or the safety effectiveness based on all the sites evaluated.

The safety performance can be computed for individual roundabouts. When each roundabout shows varying performance, the difference in or the ratio of the total number of crashes before and after the roundabout construction can provide a quantifiable mean (average) safety performance measure, as well as the variance of the measurement from an overall perspective.

Safety Performance Function

A safety performance function (SPF) describes the relationship between the predicted number of crashes (dependent variable) and a set of crash contributing factors (independent variables). The state-of-the-practice distribution considered for modeling crashes is Poisson-gamma (or negative binomial (NB)) (13, 14, 15, 16, 17, 18, 19). Poisson-gamma models can account for over dispersion of the crash data, which, if not properly considered, may lead to estimation inefficiency and inference errors. In safety applications, the number of crashes (N_i) at a site 'i' is assumed to follow a Poisson distribution.

$$N_i | \mu_i \sim \text{Poisson}(\mu_i) \qquad i=1,2,\ldots,n \tag{7}$$

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

$$\mu_i = (traffic\ exposure)^{\alpha} \exp(X_i\beta) \exp(e_i) \quad i = 1,2, \ldots n \tag{8}$$

SPFs are generally developed for specific transportation entities, e.g., intersections and road segments. Furthermore, SPFs are subdivided into different types of intersections and road segments. SPFs are used to estimate the predicted number of crashes, which can then be used in the EB analysis methodology by combining it with observed crashes to calculate the expected average crash number. The SPFs used in this report were selected primarily from the Highway Safety Manual (HSM) (20). Separate SPFs are provided for total and fatal/injury crashes. In some cases, separate SPFs are provided for single and multi-vehicle crashes, which were used accordingly in the safety evaluation of roundabouts. For intersections without HSM specified SPFs, SPFs from the Federal Highway Administration (FHWA) SafetyAnalyst software version 1.2 were used (21). Furthermore, the HSM also provides a fixed value for fatal/injury crashes as a proportion of the total number of crashes in cases where specific fatal/injury crash SPFs are missing. Detailed lists of SPFs used in this study are presented in Appendix B.

CHAPTER 3 DATA COLLECTION AND PROCESSING

In order to perform a robust before-and-after comparison, a minimum of three years of data are required. Hence, 40 roundabouts under Wisconsin Department of Transportation (WisDOT) oversight built in 2008 or before were included in the study. Thirty of the 40 roundabouts that were built in 2007 or before were part of a previous evaluation study (22). This research expanded the total number of roundabouts to 40 and added an additional year of crash data for the roundabouts evaluated in the previous report (22). Figure 2 shows the locations of the 40 roundabouts included in the study.

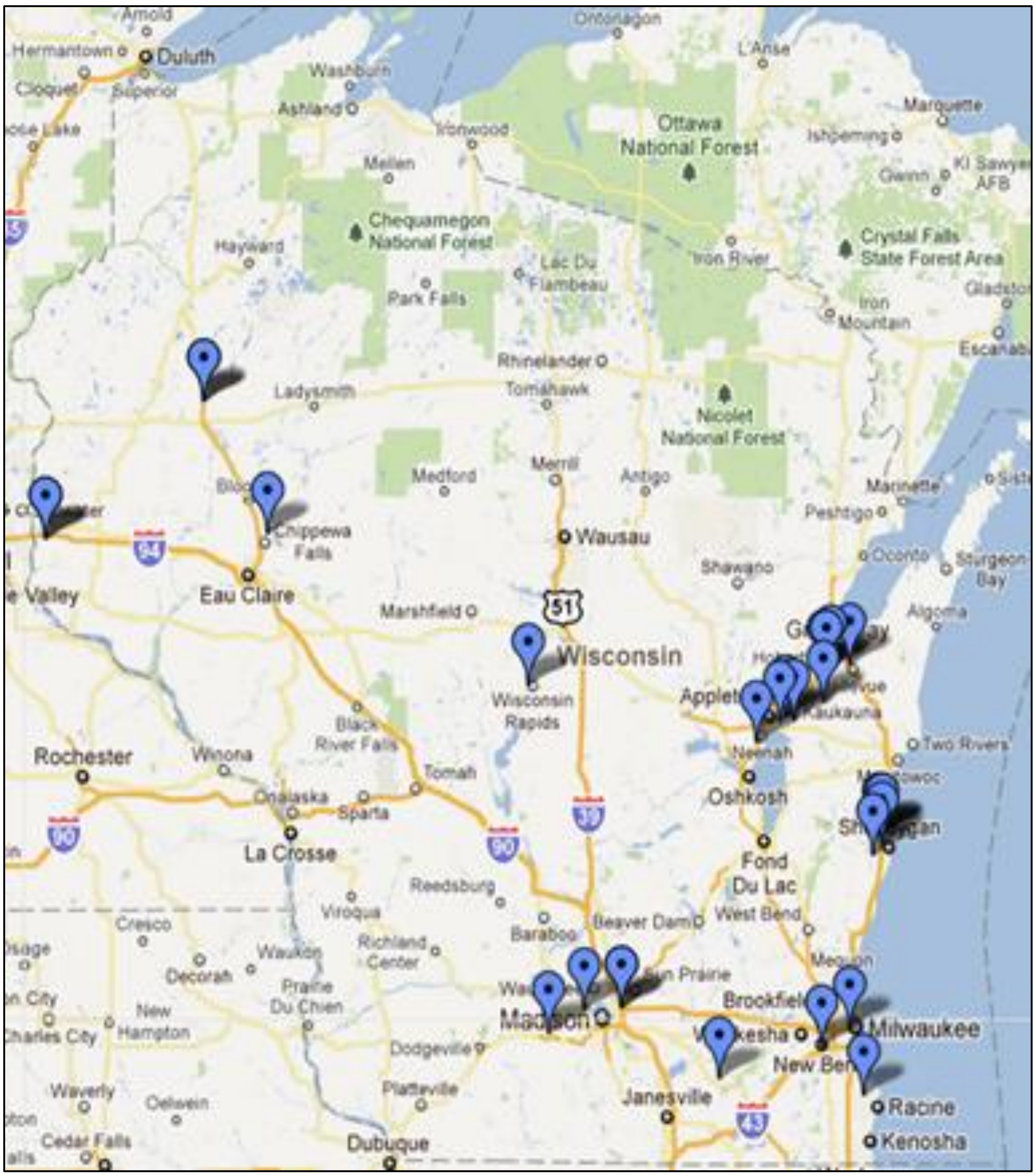

Figure 2 Locations of Roundabouts used for this study.

Crash Data

Crash data were retrieved from the WisTransPortal for each roundabout location for both the before and after periods (11). Relevant crash information was gathered based on the date when a crash occurred and the study area defined for a particular roundabout. Crashes during a three year before period and a four year after period were collected for 30 roundabouts built in 2007 or before, while crashes during three year before and after periods were collected for roundabouts built in 2008. Crashes that occurred during the construction year were excluded. Crash location is defined not only by the address, but also by the police definition as "intersection related", i.e., 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 for crashes occurring on roundabout approaches due to speeding, sudden stop, or slowing down to also be included. A detailed manual review of each Wisconsin crash report form (MV4000) was also conducted for all queried crash data using police narratives and diagrams to determine whether or not crashes were truly roundabout crashes or related to roundabout operations.

The importance of manually reviewing each MV4000 police report cannot be underestimated. This helps to distinguish crashes occurring at nearby intersections from those occurring at the roundabout. One example is the roundabout at CTH A and CTH JJ in Outagamie County. As displayed in Figure 3, there is another intersection also named CTH A and CTH JJ northwest of the roundabout. Both intersections are three-legged and yield-sign controlled on CTH JJ. Without referring to the actual diagram in the police report, it would be impossible to tell one from the other. More common situations are crashes occurring within the proximity of a roundabout that are driveway-related. Crash diagrams and narratives can help in identifying such crashes; however, the quality of diagrams varies from report to report. In general, an electronically filed crash report with a roundabout template will remind or help the officer in choosing the proper intersection configurations. Another example of using a police report diagram is to distinguish crashes occurring on one of two interchange ramp roundabouts, as exhibited in Figure 4. In this study, when there are no effective ways to separate crashes occurring at one interchange ramp roundabout from the other, the crashes were split between the two ramp terminals.

Based on discussion with Wisconsin Department of Transportation engineers, crashes occurring during the construction year of the roundabout were excluded from the study to minimize the effects of construction activities and other complications such as being partially open to traffic during the construction. Six of the roundabouts built in 2007 or before, and four of the roundabouts built in 2008, were omitted due to either a lack of pre-construction data or unique geometry. Specifically:

- Six roundabouts were newly constructed intersections and had no historic crashes;
- One roundabout combined several closely spaced intersections; and

- Three roundabouts had significant changes from before period, e.g. changes in the number of approaches to the intersection in the after period.

Detailed information about the roundabouts is shown in Appendix A.

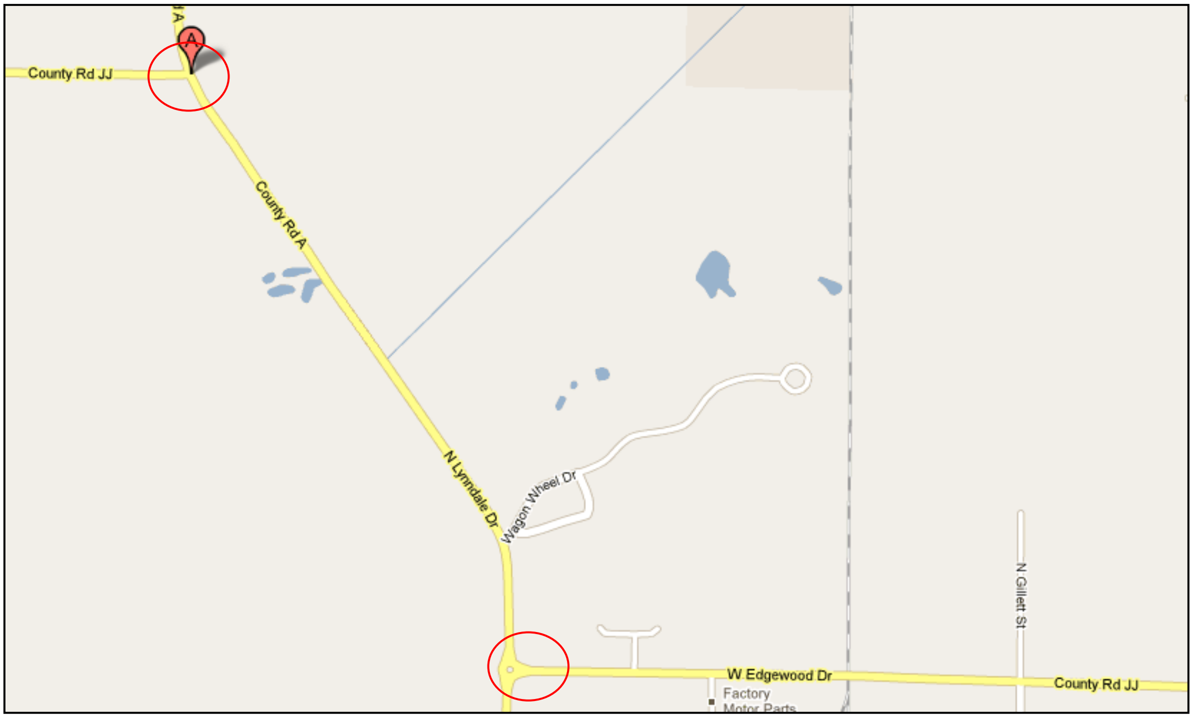

Figure 3 Example of Roundabout Location

Figure 4 Example of Roundabouts at Ramp Terminals

Geometric and Traffic Data

Important roundabout design features include the number of approaches, speed limit, number of circulating lanes, lane width, inscribed circle diameter (ICD), center island diameter (CID), and the total AADT. The AADT at a roundabout was defined as the sum of AADT on each approach entering the roundabout. Traffic volume information was primarily collected from the Wisconsin Highway Traffic Volume Data, which is published annually by WisDOT (23). For the roundabouts with missing AADT, individual traffic counts were conducted.

In general, researchers observed in the dataset that three-legged roundabouts carried less traffic than four-legged roundabouts. The three-legged roundabouts had an AADT range of 11,700 to 23,300 vehicles per day (vpd), with an average of 16,250 vpd, while the four-legged roundabouts had a range of 8,250 to 74,900 vpd, with an average of 18,150 vpd. Similarly, single-lane roundabouts had lower traffic volumes than multi-lane roundabouts. In the roundabouts observed for this research study, the AADT for the single-lane roundabouts ranged from 8,250 to 17,000 vpd with an average of 12,030 vpd. For the multi-lane roundabouts, AADT ranged from 9,200 to 74,900 vpd, with an average of 24,510 vpd.

In addition to current AADT levels, the intersection configuration and traffic data before roundabout conversion were collected, including AADT, number of intersection approach legs, number of major roadway lanes, existence of major roadway median, speed limit, and more importantly, the traffic control type before the roundabout conversion.

WisDOT Region and area type were collected. The area type was categorized as urban if the municipality where the roundabout was located had a population greater than 5000. The characteristics of the 30 roundabouts are listed in Table 1. Detailed characteristics about each roundabout are listed in Appendix A.

Table 1 Characteristics of Modern Roundabouts in the Scope of the Study

Characteristics	Number	Percentage
Area Type*		
Urban	18	60.0%
Rural	12	40.0%
Previous intersection traffic control		
No control/Yield (NC)	2	6.7%
Two-way Stop Controlled (TWSC)	15	50.0%
All-way Stop Controlled (AWSC)	6	20.0%
Signalized	7	23.3%
WisDOT Region		
NC	1	3.3%
NE	16	53.3%
NW	3	10.0%
SE	5	16.7%
SW	5	16.7%
Roundabouts Type		
Single Lane	15	50.0%
Multi-Lane	15	50.0%

CHAPTER 4 RESULTS

Simple Before-and-After Analysis

A simple before-after analysis was completed for 30 roundabout locations in Wisconsin. As stated in Chapter 3, a total of 40 roundabouts built in Wisconsin in 2008 or before were considered in this research. However, 10 roundabouts were omitted from the before-and-after and EB analysis because the conditions in the before period varied significantly from the after period, hence a direct comparison was not considered reasonable.

Table 2 shows the observed crash statistics for 30 study roundabouts in the before and after period. The frequency is classified by crash outcome (K, A, B, C, and PDO). For the roundabouts at interchange ramp terminals, crash reports were verified manually to assign the crash to one of the roundabouts. It should be noted that the simple before-and-after analysis does not take into consideration the RTM effects. Table 2 shows three-year before and four-year after crash data for the 24 roundabouts built in 2007 or before and three-year before and three-year after crash data for the 6 roundabouts built in 2008.

Table 2 Before and After Crash Data for Wisconsin Roundabouts Built in 2008 or Before

Roundabout	WisDOT Region	Before (three years)						After (four years)					
		K	A	B	C	PDO	Total	K	A	B	C	PDO	Total
STH 54/Gaynor St/17th St	NC			2	6	8	16			2	1	24	27
CTH F/S. Ninth St.	NE			1			1			1	2	4	7
CTH F/Suburban Dr.	NE					2	2				2	1	3
STH 32/57 and STH 96	NE			1		4	5			1	2	9	12
STH 141 / Allouez Ave	NE			1	2	6	9			2	2	17	21
STH 32/STH 57 Broadway	NE		1	2	10	38	51		2	7	19	127	155
STH 55/CTH KK	NE		1	4	4	9	18			1		4	5
Lake Park/Plank Rd (CTH LP/CTH P)	NE					1	1			1		5	6
CTH N / Emons Road	NE			1	3	1	5			5	3	21	29
STH 28/32 (high speed)	NE				1	4	5				1	14	15
STH 42/ I-43, Interchange Ramps (West)*	NE			1	2	7	10			1	4	11	16
STH 42/ I-43, Interchange Ramps (East)*	NE				2	7	9		1	1	1	10	13
STH 42/Vanguard, Wal-Mart entrance	NE				1	1	2			1	1	9	11
Breezewood ln/Tullar Rd	NE				1	2	3			1		10	11
US 53 ramps and CTH O (West)*	NW				1	7	8			1	1	5	7
US 53 ramps and CTH O (East)*	NW					4	4			1	3	5	9
STH 124/CTH S	NW		1	3	7	5	16				1	7	8
Canal St/25th Ave	SE					1	1				2	13	15
STH 38/CTH K	SE			4	5	21	30		2	1	2	23	28
Elkhorn Rd (Bus 12)/Bluff Rd/Clay St	SE		1			1	2					5	5
STH 78/STH 92, 8th St, Springdale, CTH ID	SW			2		15	17				3	28	31
Thompson and Commercial (North)	SW	1	1	3	7	6	18		1		10	45	56
Thompson and STH 30 (South)	SW			1	4	8	13				1	11	12
Old STH 12/Parmenter	SW			1		3	4			1	1	13	15
Roundabout	WisDOT Region	Before (three years)						After (three years)					
		K	A	B	C	PDO	Total	K	A	B	C	PDO	Total
STH EE (Grant St.) & Lawrence Dr.	NE			1	1	5	7			2	1	5	8
USH 10 & CTH N	NE	2	2	8	3	8	23			1		10	11
CTH A (N. Lynndale Dr.) & CTH JJ	NE				1	2	3		1		1	7	9
STH 16 (Wisconsin Ave.) & Walnut. St	SE				4	16	20				2	14	16
STH 74(Main St.)/McLaughlin Rd. & CTH V	SE						0				1	1	2
USH 18 & Bennett Rd.	SW			3	3	2	8			1	2	6	9
Grand Total		3	7	39	68	194	311	0	7	32	69	464	572

Table 3 shows the number of locations with increase, no change, or decrease in crashes between before and after periods. There were no fatal (K) crashes in the after period. The two sites with fatal (K) crashes in the before period did not experience fatal crashes after the roundabout was installed. For all injury (A, B, and C) crashes, the magnitude of decrease in injury crashes was higher than the magnitude of increase. For PDO and total crashes, the number of locations with increases in crashes was 25, as opposed to 4 locations with decreases in crashes, with 1 location having the same number of PDO crashes as before. Overall, roundabouts in Wisconsin had a decrease in fatal and injury crashes, but an increase in PDO crashes.

Table 3 Summary of Roundabout Locations Crash Trends using Simple Before-and-After Analysis

Change in Crashes	Number of locations					
	K	A	B	C	PDO	Total Crashes
Increase	0	4	10	11	25	23
No change	28	22	12	9	1	0
Decrease	2	4	8	10	4	7

The following summarizes the trends for fatal and injury crashes as observed in Table 3.

- Fatal (K) crashes: Two of 30 locations had two fatal crashes in the before period. No fatal crashes occurred in the after period. No location had an increase in fatal crashes.

- Incapacitating (A) crashes: Six of 30 locations had crashes in the before period. Four locations had none in the after period, one location increased and one location remained unchanged. The other three locations with increases in the after period did not have crashes in the before period. They increased from zero to one, one and two crashes, respectively.

- Non-Incapacitating (B) crashes: Seventeen of 30 locations had crashes in the before period. Of the 17, four locations had no crashes in after period, one location reduced from eight to one, two locations reduced from four to one, five locations did not change, and one location observed crashes increasing from two to seven. Five locations found crashes increasing from zero to one.

- Possible Injury (C) crashes: 20 of 30 locations had crashes in the before period. Of the 20, three locations had no crashes in the after period, seven locations did not change, 10 locations found crashes reduced collectively from 39 to 10, but one of those locations alone increased from 10 to 19. Eight locations that had zero crashes in the before period experienced crashes in after period.

EB Analysis with Safety Performance Function (SPF)

SPFs can be found for a variety of highway facilities and intersection types in HSM. Appropriate SPFs were identified using the pre-roundabout intersection geometric characteristics (number of legs, number of lanes) and area setting (urban, rural), as well as traffic control types (Yield, TWSC, AWSC, Signalized). In some cases, separate SPFs were used for single and multi-vehicle crashes, when available. If SPFs were not available in the HSM, the FHWA SafetyAnalyst software version 1.2 was used to obtain SPFs. A detailed list of SPFs used in this research is provided in Appendix B.

Tables 4 and 5 show the EB analysis results for total number of crashes and injury (K, A, B, and C) crashes, respectively, for 30 roundabout locations in Wisconsin. The first two columns are intersection IDs and descriptions; followed by observed crashes during the three-year before period, the expected number of crashes during the three or four-year after period without roundabout installation, and the observed number of crashes during the three or four-year after period with roundabout installation. The last two columns are before-and-after comparison results showing an increase or decrease in crashes based on the difference between the crashes with or without a roundabout installation. Shaded cells with negative values show an increase, whereas positive values show a decrease in the percentage of crashes after roundabout construction. Detailed results and calculations of the EB methodology are provided in Appendix C. Based on the results presented in Table 4 and 5, a few findings for the 30 roundabouts locations are highlighted below:

1. Mixed results for total crash frequency
   - 13 locations (43 percent) observed a decrease or no change in total crashes.
   - 17 locations (57 percent) showed an increase in total crashes.
     - 5 of the 17 RABs observed increases of 1 to 3 total crashes, or less than 1 per year
     - 3 of 17 RABs contributed to approx. 50% of the total increase in crashes
   - Among the 17 locations with increased crash records, Canal St./25th Ave., Old STH 12/Parmenter, and CTH A/CTHJJ experienced an increase of more than 100 percent in total crashes, which was much higher than the values observed at other locations.
   - Overall, Wisconsin experienced a 12% increase in crashes across the 30 roundabouts evaluated in this report.

2. Significant decrease in crash severity
   - 21 locations (70 percent) had a decrease in fatal (K) and injury (A, B, and C) crashes whereas 9 locations (30 percent) had an increase in injury crashes.
   - Overall, Wisconsin experienced a decrease of 38% for injury crashes across the 30 roundabouts.

3. A review of the locations that experienced an increase in total or injury crashes shows that for the majority of the sites, the actual number of crashes was very small, resulting in exaggerated percentage increase (i.e., one crash in the before condition to three crashes in the after period). Three roundabouts experienced significant increases in crash frequency and severity and contribute substantially to the summary statistics.

Table 4 EB Analysis Results for Total Crashes

Location	Intersection Type	SPF/Crash Type	Observed Total Crashes - Before	EB Expected Crashes - Adjusted by AADT and Years in After Period (B)	Observed Total Crashes - After (A)	B-A	Percent Increase or Decrease = 100(B-A)/B]
STH 54/Gaynor St/17th St	4Urb4ST	Multi-Veh	15.00	15.235	15.00	0.23	-63.97
		Single-Veh	1.00	1.232	12.00	-10.77	
CTH F/S. Ninth St.	2Urb4ST	Multi-Veh	1.00	3.074	6.00	-2.93	-87.13
		Single-Veh	0.00	0.666	1.00	-0.33	
CTH F/Suburban Dr.	2Urb4ST	Multi-Veh	2.00	2.996	3.00	0.00	16.23
		Single-Veh	0.00	0.585	0.00	0.59	
STH 32/57 and STH 96	2Urb4STALL	Combined	5.00	6.756	12.00	-5.24	-77.63
STH 141 / Allouez Ave	2Rur4ST	Combined	9.00	24.581	21.00	3.58	14.57
STH 32/STH 57 Broadway	4Urb4SG	Multi-Veh	48.00	110.037	149.00	-38.96	-35.29
		Single-Veh	3.00	4.529	6.00	-1.47	
STH 55/CTH KK	2Rur4ST	Combined	18.00	20.479	5.00	15.48	75.58
Lake Park/Plank Rd (CTH LP/CTH P)	2Urb4ST	Multi-Veh	1.00	2.964	2.00	0.96	-65.23
		Single-Veh	0.00	0.667	4.00	-3.33	
CTH N / Emons Road	2Rur4ST	Combined	5.00	18.371	29.00	-10.63	-57.86
STH 28/32	2Rur4ST	Combined	5.00	8.646	15.00	-6.35	-73.49
STH 42/ I-43, Interchange Ramps (West)	4Rur4SG	Combined	10.00	34.290	16.00	18.29	53.34
STH 42/ I-43, Interchange Ramps (East)	4Rur4SG	Combined	9.00	22.717	13.00	9.72	42.77
STH 42/Vanguard, Wal-Mart entrance	4Rur4SG	Combined	2.00	16.107	11.00	5.11	31.71
Breezewood ln/Tullar Rd	2Urb4YD	Multi-Veh	3.00	5.006	11.00	-5.99	-91.72
		Single-Veh	0.00	0.732	0.00	0.73	
US 53 ramps and CTH O (West)	2Urb4ST	Multi-Veh	7.00	8.701	5.00	3.70	28.63
		Single-Veh	1.00	1.108	2.00	-0.89	
US 53 ramps and CTH O (East)	2Urb4ST	Multi-Veh	4.00	7.139	7.00	0.14	-13.85
		Single-Veh	0.00	0.766	2.00	-1.23	
STH 124/CTH S	2Rur4ST	Combined	16.00	19.443	8.00	11.44	58.85
Canal St/25th Ave	4Urb3STALL	Combined	1.00	2.245	15.00	-12.76	-568.26
STH 38/CTH K	4Urb3ST	Multi-Veh	26.00	21.845	7.00	14.84	-8.86
		Single-Veh	4.00	3.876	21.00	-17.12	
Elkhorn Rd (Bus 12)/Bluff Rd/Clay St	4Urb4YD	Multi-Veh	1.00	2.385	2.00	0.38	-47.76
		Single-Veh	1.00	0.999	3.00	-2.00	

Location	Intersection Type	SPF/Crash Type	Observed Total Crashes - Before	EB Expected Crashes - Adjusted by AADT and Years in After Period (B)	Observed Total Crashes - After (A)	B-A	Percent Increase or Decrease = 100(B-A)/B]
STH 78/STH 92, 8th St, Springdale	4Urb4SG	Multi-Veh	12.00	13.819	31.00	-17.18	-90.39
		Single-Veh	5.00	2.463	0.00	2.46	
Thompson and Commercial (North)	4Urb4STALL	Combined	18.00	33.907	56.00	-22.09	-65.16
Thompson and STH 30 (South)	4Urb3STALL	Combined	13.00	23.972	12.00	11.97	49.94
Old STH 12/Parmenter	4Urb4STALL	Combined	4.00	5.259	15.00	-9.74	-185.25
STH EE (Grant St.) & Lawrence Dr.	2Urb4STALL	Combined	7.00	10.610	8.00	2.61	24.60
USH 10 & CTH N	2Rur4ST	Combined	23.00	22.124	11.00	11.12	50.28
CTH A (N. Lynndale Dr.) & CTH JJ	2Rur3SG	Combined	3.00	2.740	9.00	-6.26	-228.44
STH 16 (Wisconsin Ave.) & Walnut. St	4Urb4SG	Multi-Veh	19.00	17.192	14.00	3.19	11.70
		Single-Veh	1.00	0.928	2.00	-1.07	
STH 74/McLaughlin Rd. & CTH V	4Rur4ST	Combined	0.00	1.791	2.00	-0.21	-11.66
USH 18 & Bennett Rd.	4Rur4ST	Combined	8.00	9.611	9.00	0.61	6.36

Table 5 EB Analysis Results for Fatal and Injury Crashes

Location	Intersection Type	SPF/Crash Type	Observed Total Crashes - Before	EB Expected Crashes - Adjusted by AADT and Years in After Period (B)	Observed Total Crashes - After (A)	B-A	Percent Increase or Decrease = 100(B-A)/B]
STH 54/Gaynor St/17th St	4Urb4ST	Multi-Veh	8.00	7.031	1.00	6.031	59.33
		Single-Veh	*	0.345	2.00	-1.655	
CTH F/S. Ninth St.	2Urb4ST	Multi-Veh	1.00	1.932	3.00	-1.068	-41.58
		Single-Veh	*	0.187	0.00	0.187	
CTH F/Suburban Dr.	2Urb4ST	Multi-Veh	0.00	0.925	2.00	-1.075	-83.73
		Single-Veh	*	0.164	0.00	0.164	
STH 32/57 and STH 96	2Urb4STALL	Combined	1.00	1.678	3.00	-1.322	-78.77
STH 141 / Allouez Ave	2Rur4ST	Combined	3.00	5.284	4.00	1.284	24.29
STH 32/STH 57 Broadway	4Urb4SG	Multi-Veh	12.00	28.595	26.00	2.595	4.74
		Single-Veh	1.00	0.798	2.00	-1.202	
STH 55/CTH KK	2Rur4ST	Combined	9.00	7.677	1.00	6.677	86.97
Lake Park/Plank Rd (CTH LP/CTH P)	2Urb4ST	Multi-Veh	0.00	1.248	0.00	1.248	30.28
		Single-Veh	*	0.187	1.00	-0.813	
CTH N / Emons Road	2Rur4ST	Combined	4.00	6.475	8.00	-1.525	-23.55
STH 28/32	2Rur4ST	Combined	1.00	1.794	1.00	0.794	44.27
STH 42/ I-43, Interchange Ramps (West)	4Rur4SG	Combined	3.00	13.658	5.00	8.658	63.39
STH 42/ I-43, Interchange Ramps (East)	4Rur4SG	Combined	2.00	9.328	3.00	6.328	67.84
STH 42/Vanguard, Wal-Mart entrance	4Rur4SG	Combined	1.00	10.561	2.00	8.561	81.06
Breezewood ln/Tullar Rd	2Urb4YD	Multi-Veh	1.00	2.185	1.00	1.185	58.15
		Single-Veh	*	0.205	0.00	0.205	
US 53 ramps and CTH O (West)	2Urb4ST	Multi-Veh	1.00	1.950	1.00	0.950	11.52
		Single-Veh	*	0.310	1.00	-0.690	
US 53 ramps and CTH O (East)	2Urb4ST	Multi-Veh	0.00	1.772	3.00	-1.228	-101.35
		Single-Veh	*	0.214	1.00	-0.786	
STH 124/CTH S	2Rur4ST	Combined	11.00	7.971	1.00	6.971	87.45
Canal St/25th Ave	4Urb3STALL	Combined	0.00	1.599	2.00	-0.401	-25.05
STH 38/CTH K	4Urb3ST	Multi-Veh	9.00	5.196	2.00	3.196	21.84
		Single-Veh	*	1.202	3.00	-1.798	
Elkhorn Rd (Bus 12)/Bluff Rd/Clay St	4Urb4YD	Multi-Veh	1.00	1.448	0.00	1.448	100.00
		Single-Veh	*	0.280	0.00	0.280	

Location	Intersection Type	SPF/Crash Type	Observed Total Crashes - Before	EB Expected Crashes - Adjusted by AADT and Years in After Period (B)	Observed Total Crashes - After (A)	B-A	Percent Increase or Decrease = 100(B-A)/B]
STH 78/STH 92, 8th St, Springdale	4Urb4SG	Multi-Veh	2.00	3.418	3.00	0.418	19.76
		Single-Veh	0.00	0.321	0.00	0.321	
Thompson and Commercial (North)	4Urb4STALL	Combined	12.00	13.235	11.00	2.235	16.89
Thompson and STH 30 (South)	4Urb3STALL	Combined	5.00	9.357	1.00	8.357	89.31
Old STH 12/Parmenter	4Urb4STALL	Combined	1.00	1.505	2.00	-0.495	-32.89
STH EE (Grant St.) & Lawrence Dr.	2Urb4STALL	Combined	2.00	2.362	3.00	-0.638	-27.01
USH 10 & CTH N	2Rur4ST	Combined	15.00	9.329	1.00	8.329	89.28
CTH A (N. Lynndale Dr.) & CTH JJ	2Rur3SG	Combined	1.00	1.105	2.00	-0.895	-81.08
STH 16 (Wisconsin Ave.) & Walnut. St	4Urb4SG	Multi-Veh	4.00	3.793	1.00	2.793	50.48
		Single-Veh	0.00	0.245	1.00	-0.755	
STH 74/McLaughlin Rd. & CTH V	4Rur4ST	Combined	0.00	1.185	1.00	0.185	15.64
USH 18 & Bennett Rd.	4Rur4ST	Combined	6.00	6.898	3.00	3.898	56.51

*No SPF Available - proportion of total single-vehicle crashes was used

In summary, most of the 30 roundabouts show promising safety improvements in terms of reduction in crash severity levels. Though mixed results were observed in total crash frequency after the roundabout conversion, a significant decrease (38 percent) was observed for injury crashes. In order to understand the varying safety performance across individual roundabouts being evaluated, the safety evaluation results were further analyzed with respect to the geometric characteristics and traffic conditions prior to roundabout construction for further insight. The following analysis was focused on four aspects: number of lanes, traffic control, regions, and urban or rural locations.

Single-lane versus Multi-lane

As shown in Table 6, the number of single lane and multi-lane roundabouts were 15 each. Seven of the single-lane roundabout locations and six of the multi-lane roundabout locations experienced a decrease in total crashes. Multi-lane roundabouts had a 19 percent increase in total crashes; conversely, single-lane roundabouts had a 4 percent decrease in all crashes. The opposite was observed when examining fatal and injury crashes. Only three out of 12 multi-lane roundabouts experienced an increase in injury crashes compared with seven out of 12 of the single-lane roundabouts. Considering injury crashes, multi-lane roundabouts had an overall decrease of 41 percent, while single-lane roundabouts showed a 33 percent decrease. Table 7 compares the differences between single-lane, multi-lane, and spiral lane roundabouts.

Table 6 Roundabout Safety Performance by Number of Lanes

		Single-lane	**Multi-lane**
	Number of RABs	15	15
Total Crashes	**RABs with Increased Crashes**	8	9
	RABs with Decreased Crashes	7	6
	Total Expected Crashes	168	344
	Total Observed Crashes	161	411
	% of Changes	4%	-19%
KABC Crashes	**RABs with Increased Crashes**	7	3
	RABs with Decreased Crashes	8	12
	Total Expected Crashes	55	120
	Total Observed Crashes	37	71
	% of Changes	33%	41%

Table 7 Roundabout Safety Performance by Roundabout Types

		Single-lane	Dual-lane	Spiral
	Number of RABs	15	11	4
Total Crashes	**RABs with Increased Crashes**	8	7	2
	RABs with Decreased Crashes	7	4	2
	Total Expected Crashes	168	262	82
	Total Observed Crashes	161	333	78
	% of Changes	4%	-27%	5%
KABC Crashes	**RABs with Increased Crashes**	7	3	0
	RABs with Decreased Crashes	8	9	4
	Total Expected Crashes	55	87	33
	Total Observed Crashes	37	60	11
	% of Changes	33%	31%	67%

Traffic Control Strategies

The NCHRP Report 572 study reported reductions of approximately 35 percent for all crashes and 76 percent for injury crashes when an intersection was converted to a roundabout from a signal or stop control (2). However, the safety benefits vary considerably among traffic control alternatives, including yield, two-way stop controlled (TWSC), all-way stop controlled (AWSC), and signal control. Table 8 shows that the total number of crashes increased after the conversion of yield, AWSC, and signalized intersections to a roundabout by 75 percent, 43 percent, and 12 percent, respectively. Total number of crashes decreased by 5 percent after the conversion of TWSC intersections to a roundabout. The conversion from a signalized intersection to a roundabout requires more considerations such as left-turning volume, left-turn storage space, and the space between intersections because the safety benefits are conditional to these unique situations.

A reduction in the severity of crashes was observed in the conversion of all types of intersections to roundabouts with the highest decrease observed in the conversion of yield control intersections, followed by TWSC, signal control, and AWSC intersection conversions.

Table 8 Roundabout Safety Performance by Traffic Control Type

		No Control/Yield	TWSC	AWSC	Signalized
	Number of RABs	2	15	6	7
Total Crashes	**RABs with Increased Crashes**	2	8	4	3
	RABs with Decreased Crashes	0	7	2	4
	Total Expected Crashes	9	196	83	225
	Total Observed Crashes	16	187	118	251
	% of Changes	-75%	5%	-43%	-12%
KABC Crashes	**RABs with Increased Crashes**	0	4	4	2
	RABs with Decreased Crashes	2	11	2	6
	Total Expected Crashes	4	69	30	72
	Total Observed Crashes	1	40	22	45
	% of Changes	76%	42%	26%	37%

Regions

The evaluation of safety performance of roundabouts for the five regions in Wisconsin, namely Southwest (SW), Southeast (SE), Northeast (NE), North Central (NC), and Northwest (NW) was also conducted. NE region has the most roundabouts (16) while NC region has only 1 roundabout. Table 9 shows a general increase in the number of total crashes for all regions except NW. However, NW has only 3 roundabouts and NC only has 1 roundabout; therefore, caution should be used when interpreting the results. Nevertheless, results show that the severity of crashes was reduced for all roundabouts in all regions.

Table 9 Roundabout Safety Performance by Region

		NC	NE	NW	SE	SW
	Number of RABs	1	16	3	5	5
Total Crashes	**RABs with Increased Crashes**	1	8	1	4	3
	RABs with Decreased Crashes	0	8	2	1	2
	Total Expected Crashes	16	319	37	51	89
	Total Observed Crashes	27	332	24	66	123
	% of Changes	-64%	-4%	35%	-29%	-38%
KABC Crashes	**RABs with Increased Crashes**	0	6	1	2	1
	RABs with Decreased Crashes	1	10	2	4	4
	Total Expected Crashes	7	106	12	15	34
	Total Observed Crashes	3	68	7	10	20
	% of Changes	59%	36%	43%	34%	42%

Urban or Rural Location

Table 10 shows the breakdown of roundabout safety evaluation by location in urban or rural areas. Thirteen of the 18 urban roundabouts experienced an increase in total number of crashes while four of the 12 rural roundabouts showed an increase in total number of crashes. Rural roundabouts display a better performance in the reduction of total number of crashes by 26 percent. Conversely urban roundabouts display an increase in total number of crashes by 36 percent. In examining fatal and injury crashes, both rural and urban location experienced a decrease in crashes. Urban roundabouts have a higher fatal and injury crash reduction percentage of 41 percent than rural roundabouts with 33 percent reduction. The number of roundabouts with decreased crashes is more than the number of roundabouts with increased crashes in both rural and urban location.

Table 10 Roundabout Safety Performance by Urban/Rural Location

		Rural	Urban
	Number of RABs	12	18
Total Crashes	**RABs with Increased Crashes**	4	13
	RABs with Decreased Crashes	8	5
	Total Expected Crashes	201	312
	Total Observed Crashes	149	423
	% of Changes	26%	-36%
KABC Crashes	**RABs with Increased Crashes**	2	8
	RABs with Decreased Crashes	10	11
	Total Expected Crashes	55	120
	Total Observed Crashes	37	71
	% of Changes	33%	41%

Exploratory Analysis of Roundabouts Excluded from EB Analysis

As previously mentioned in Chapter 3, 10 roundabouts out of a total of 40 that were built in 2008 or before were excluded from the analysis (6 were built in 2007 or before, 4 were built in 2008) due to either a lack of pre-construction data or unique geometry. In the absence of specific before conditions at those locations, it was difficult to select an SPF that would enable the use of EB methodology for safety evaluations because SPFs are developed for specific intersection configurations, e.g. four-legged signalized intersection etc. Table 11 shows a list of the 10 roundabouts.

Table 11 Roundabout Locations not included in the EB Safety Study

	Roundabout Location	City	WisDOT Region	Reason Not Included in Study
1	Lake Park & Kensington	Appleton	NE	Intersection did not exist previously, no before data
2	CTH O (Superior) & Wilgus/STH 40	Sheboygan	NE	Intersection did not exist previously, no before data
3	STH 35 & Hanley (west ramp terminal)	Hudson	NW	Original intersection was at-grade, while new configuration is grade-separated making comparison not possible
4	STH 35 & Hanley (east ramp terminal)	Hudson	NW	Original intersection was at-grade, while new configuration is grade-separated making comparison not possible
5	5th/6th Street & Florida	Milwaukee	SE	Original intersection was several closely spaced intersections and new configuration is a roundabout, making comparison difficult
6	STH 22 & Royalton	Waupaca	NC	Intersection did not exist previously, no before data
7	STH 53 & Old Town	Eau Claire	NW	Original intersection was one highway which intersects with one roadway and new configuration is a four-leg roundabout, making comparison difficult
8	I-43 SB Off Ramp/Moorland Road	New Berlin	SE	Location had modifications made through 2009
9	I-43 NB Off Ramp/Moorland Road	New Berlin	SE	Location had modifications made through 2009
10	Hanson Rd & Portage	Madison	SW	Intersection did not exist previously, no before data

In order to analyze the safety performance of the 10 roundabouts locations, a different procedure was employed to get a sense of the safety performance of these locations. Instead of identifying a single SPF to represent the conditions before the construction of the roundabouts, all possible options were considered; namely TWSC, AWSC, and signal control. The SPFs were used for these three conditions to calculate the predicted number of crashes that would have occurred based on the geometric and traffic conditions after the roundabout had been installed. The idea was to get an estimate of what the safety conditions would have been had any one of the three alternatives been constructed instead of the roundabout. The predicted number of crashes were compared with the observed crashes after the roundabout was constructed to get the percentage increase or decrease in crashes. The analysis was completed for both total and fatal/injury crashes. Note that the SPFs used for TWSC, AWSC, and signal control conditions only provide the predicted number of crashes as a national average because the SPFs were not calibrated to Wisconsin data. Therefore, the numbers should be used in terms of increase or decrease in the safety performance rather than the actual magnitude of specific numbers.

Table 12 shows the results of the comparisons between observed number of total crashes at roundabouts and the predicted number of crashes at same locations with other intersection control options. In Table 12, the red arrow pointing downwards means that the other type of intersection control shows more predicted number of crashes than observed number of crashes for the roundabout, i.e., the roundabout performed better based on only the predicted number of crash results for the other types of intersection control. The green arrow pointing upwards means that the other types of intersection control predicted number of crashes is less than the observed crashes at the roundabout. Table 13 shows similar types of results as shown in Table 12 for fatal/injury crashes. Detailed results of the analysis are presented in Appendix D.

Table 12 Safety Performance Comparisons between Roundabouts and Other Intersection Control Options Using Crash Prediction of Total Crashes

		Observed Number of Total Crashes	Predicted Number of Total Crashes		
S. No.	Intersection	RAB	Two-way Stop Control	All-way Stop Control	Signalized
1	Lake Park/Kensington	5	↑	↑	↑
2	CTH O (Superior) & Wilgus/40	3	↓	↓	↓
3	STH 35 and Hanley (east)*	3	↓	↓	↓
4	STH 35 and Hanley (west)*	2	↓	↓	↓
5	5/6 Street and Florida	16	↑	↑	↑
6	STH 22 and Royalton	4	↑	↓	↓
7	STH 53 and Old Town	17	↑	↑	↑
8	I 43 and CTH O (SB)	52	↑	↑	↑
9	I 43 and CTH O (NB)	36	↑	↓	↑
10	Hanson Road and Portage	0	↓	↓	↓

Table 13 Safety Performance Comparisons between Roundabouts and Other Intersection Control Options Using Crash Prediction of Fatal/Injury Crashes

		Observed Number of Fatal/Injury Crashes	Predicted Number of Fatal/Injurt Crashes		
S. No.	Intersection	RAB	Two-way Stop Control	All-way Stop Control	Signalized
1	Lake Park/Kensington	2	↑	↑	↑
2	CTH O (Superior) & Wilgus/40	0	↓	↓	↓
3	STH 35 and Hanley (east)*	0	↓	↓	↓
4	STH 35 and Hanley (west)*	0	↓	↓	↓
5	5/6 Street and Florida	0	↓	↓	↓
6	STH 22 and Royalton	0	↓	↓	↓
7	STH 53 and Old Town	4	↑	↑	↑
8	I 43 and CTH O (SB)	8	↑	↑	↑
9	I 43 and CTH O (NB)	8	↑	↑	↑
10	Hanson Road and Portage	0	↓	↓	↓

CHAPTER 5 CONCLUSIONS

For this study, a total of 40 roundabouts built in Wisconsin in 2008 or before were considered. Thirty roundabout locations were analyzed using simple before-and-after and EB analysis, while the 10 other roundabouts were analyzed separately using a different procedure. Three years of before crash data and four (in the case of roundabouts built in 2007 or before) or three (in the case of roundabouts build in 2008) years of after crash data were gathered, as well as geometric and volume data. A simple before and after crash analysis was completed to analyze specific types of injury crashes for each roundabout. An EB analysis was used to examine the safety benefits for total crashes and injury (K, A, B, C) crashes.

Simple Before-and-After Analysis

Two locations that had fatal crashes in the before period did not show any fatal crashes in the after period. No fatal crashes were observed for any of the roundabout locations in the after period. For all injury (A, B, and C) crashes, the number of locations with reduced crashes is greater than the number of locations with increased crashes. The magnitude of decrease in injury crashes is higher than the magnitude of increase. For PDO and total crashes, 23 locations observed increases in the number of crashes as opposed to 7 locations experiencing decreases. Overall, roundabouts in Wisconsin had a marked decrease in fatal and injury crashes, but an increase in PDO crashes. The increase in PDO crashes, which weighted the overall increase in crashes at several locations, can be less attributed to a safety issue and more attributed to drivers understanding the navigational requirements of roundabouts.

Empirical Bayes Crash Analysis

The EB analysis was performed using SPFs primarily from the HSM and, in some cases, from FHWA SafetyAnalyst software version 1.2. The different conclusions that can be drawn from the results are summarized below:

- Mixed results for total crash frequency
  - 13 locations (43 percent) had a decrease in total number of crashes; 17 locations (57 percent) showed an increase.
  - Nationally, a 35 percent reduction was observed for all crashes, while Wisconsin experienced a 12 percent increase in total number of crashes (2).

- Substantial decrease in crash severity
  - 21 locations (70 percent) had a decrease in fatal (K) and injury (A, B, and C) crashes whereas 9 locations (30 percent) had an increase.
  - No location observed fatal crashes in the after period.

- Wisconsin experienced a decrease of 38 percent for injury crashes. Roundabouts nationwide are also experiencing a significant decrease in severe crashes.

A breakdown of the EB results for roundabouts by various types shows that single lane roundabouts performed better than multi-lane roundabouts in terms of total crash results. TWSC intersection conversion to a roundabout had the highest safety benefit as compared to yield, AWSC, and signalized intersections. The severity of crashes in all regions was reduced substantially for all the roundabouts. Roundabouts in rural location are safer then roundabouts in urban location when considering total crashes.

Crash reductions observed at Wisconsin roundabouts were not as high as reported in other studies (10). However, it is premature to conclude that the safety benefits of Wisconsin roundabouts are not equally or more effective than those in other states without first understanding the differences in the data and study methodologies. Several locations had a relatively low number of crashes and injury severity crashes before conversion to a roundabout. Operational and non-engineering reasons, rather than safety, were the motivation for constructing roundabouts at these locations.

Future Research

This research study has shown that the majority of roundabout installations have led to improvements in traffic safety, especially in terms of crash severity. Although the results show an overall increase in the total number of crashes based on the 30 roundabouts studied in this research, additional research is required to ascertain the exact cause behind this increase. Detailed review of the crashes at some of the locations that show a substantial increase in the total number of crashes could reveal further insight into the crash trends and safety issues at such locations, an example of which is presented in Appendix E of the full report. The two trends that were shown in this analysis were: failure to yield to both circulating lanes and wrong lane choice.

Another recommendation is the ability to conduct a study of driver behavior at roundabout locations using incident and near-miss data using video data collection. This method can be used to understand potential safety issues, especially in the immediate period after construction; identify safety concerns; and/or evaluate countermeasures. An example of such a study can be seen in research conducted by Schroeder (24). It is also recommended that this research be continued in the future, with the addition of more locations, to increase the sample size of roundabouts studied in Wisconsin.

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Appendix A- Wisconsin Roundabout Data

Characteristics of Each Roundabout in the Study

STD #	Roundabout Name (Streets)	Region	County	Years of Before Crash Data	Year of After Crash Data	REQUIRED (*for Intersection Safety Performance Function Base Conditions*) Roundabout Open to the Traffic	AADT-Before AADT-Major	AADT-Before AADT-Minor	AADT-Before AADT-Total	AADT-After AADT-Major	AADT-After AADT-Minor	AADT-After AADT-Total	Number of Lanes	Area type	Number of Legs	Intersection Traffic Control-Before
2	17/2ND AND GAYNOR	NC	Wood	2001-2003	2005-2008	9/15/2004	17,875	3,875	21,750	12,500	5,600	18,100	2	3	4	2
4	MATTHEW AND NINTH AND CTH F (SCHEURING)	NE	Brown	2001-2003	2005-2008	11/1/2004	8,700	3,300	12,000	10,100	1,800	11,900	1	3	4	2
5	SUBURBAN AND CTH F (SCHUERING)	NE	Brown	2001-2003	2005-2008	11/1/2004	7,400	3,250	10,650	6,450	1,800	8,250	1	3	4	2
6	STH 32/57 (GREENLEAF) & STH 96 (DAY)	NE	Brown	2004-2006	2008-2011	8/31/2007	7,250	3,500	10,750	7,250	3,500	10,750	1	3	4	3
7	USH 141 & ALLOUEZ AVE	NE	Brown	2004-2006	2008-2011	10/1/2007	7,000	1,700	8,700	10,100	3,500	13,600	1	1	4	2
8	STH 32/57 (CLAUDE ALLOUEZ) & BROADWAY	NE	Brown	2004-2006	2008-2011	7/12/2007	32,500	15,600	48,100	50,000	24,900	74,900	2	3	4	4
9	STH 55 & CTH KK	NE	Calumet	2003-2005	2007-2010	8/3/2006	10,300	4,500	14,800	8,950	3,650	12,600	1	1	4	2
10	CTH LP/LAKE PARK & CTH P/PLANK	NE	Calumet	2004-2006	2008-2011	11/1/2007	8,250	3,850	12,100	7,300	4,450	11,750	1	2	4	2
12	CTH N / Emons Road	NE	Outagamie	2004-2006	2008-2011	8/31/2007	7,800	800	8,600	12,200	2,100	14,300	1	1	4	2
15	STH 28 & STH 32	NE	Sheboygan	2003-2005	2007-2010	9/1/2006	8,350	2,950	11,300	5,300	3,750	9,050	1	1	4	2
17	STH 42 & I 43 RAMPS (West)*	NE	Sheboygan	2004-2006	2008-2011	11/2/2007	10,700	1,300	12,000	23,000	3,000	26,000	2	1	4	4
41	STH 42 & I 43 RAMPS (East)*	NE	Sheboygan	2004-2006	2008-2011	11/2/2007	15,100	4,700	19,800	20,000	8,076	28,076	2	1	4	4
18	STH 42 & VANGUARD Wal-Mart Entrance	NE	Sheboygan	2004-2006	2008-2011	11/3/2007	11,600	1,500	13,100	20,000	7,000	27,000	2	1	4	4
19	BREEZEWOOD & TULLAR	NE	Winnebago	2002-2004	2006-2009	9/15/2005	13,000	4,800	17,800	11,350	4,800	16,150	1	3	4	1
20	USH 53 & CTH O RAMPS (west)*	NW	Baron	2003-2005	2007-2010	6/1/2006	7,300	3,100	10,400	7,770	3,299	11,069	1	3	4	2
21	USH 53 & CTH O RAMPS (east)*	NW	Baron	2003-2005	2007-2010	6/1/2006	12,850	2,600	15,450	14,200	3,000	17,200	1	3	4	2
22	STH 124 & CTH S	NW	Chippewa	2003-2005	2006-2009	10/15/2005	8,250	3,600	11,850	5,100	4,700	9,800	1	1	4	2
27	CANAL AND 25TH ST.	SE	Milwaukee	2003-2005	2006-2009	9/15/2005	13,600	10,500	24,100	18,400	4,900	23,300	2	3	3	3
28	STH 38 & CTH K(NORTHWESTERN)	SE	Racine	2004-2006	2008-2011	11/15/2007	14,200	2,300	16,500	8,960	4,160	13,120	2	3	3	2
29	Elkhorn Rd (Bus 12)/Bluff Rd/Clay St	SE	Walworth	2004-2006	2008-2011	10/15/2007	10,050	2,100	12,150	7,100	2,100	9,200	2	2	4	1
35	STH 92/8TH AND STH 92/SPRINGDALE	SW	Dane	2001-2003	2005-2008	4/27/2004	20,000	8,000	28,000	17,400	6,650	24,050	2	3	4	4
36	THOMPSON AND COMMERICAL	SW	Dane	2001-2003	2005-2008	10/18/2004	14,000	4,108	18,108	15,500	9,600	25,100	2	3	4	3
37	THOMPSON AND STH 30	SW	Dane	2001-2003	2005-2008	10/18/2004	9,695	4,284	13,979	13,575	3,300	16,875	2	3	3	3
38	USH 12 RAMP & PARMENTER	SW	Dane	2003-2005	2007-2010	10/15/2006	10,200	4,500	14,700	9,000	5,950	14,950	2	3	4	3
101	STH EE (Grant St.) & Lawrence Dr.	NE	Brown	2005-2007	2009-2011	2008	5,000	4,700	9,700	7,100	5,300	12,400	1	3	4	3
102	USH 10 & CTH N	NE	Calumet	2005-2007	2009-2011	2008	6,800	5,600	12,400	6,000	6,000	12,000	1	1	4	2
103	CTH A (N. Lynndale Dr.) & CTH JJ	NE	Outagamie	2005-2007	2009-2011	2008	9,000	4,800	13,800	7,200	4,500	11,700	1	1	3	4
104	STH 16 (Wisconsin Ave.) & Walnut. St	SE	Waukesha	2005-2007	2009-2011	2008	9,000	4,800	13,800	15,900	8,000	23,900	2	3	4	4
105	STH 74(Main St.)/McLaughlin Rd. & CTH V	SE	Waukesha	2005-2007	2009-2011	2008	13,400	5,000	18,400	12,400	5,500	17,900	2	1	4	2
106	USH 18 & Bennett Rd.	SW	Iowa	2005-2007	2009-2011	2008	9,700	1,600	11,300	10,460	2,000	12,460	2	1	4	2

Area Type: 1. Rural, 2. Suburban, 3. Urban

Intersection Traffic Control Before: 1. No Control or yield, 2. Minor Road Stop Control, 3. All-Way Stop Control, 4. Signalized Intersection

Appendix B- List of Safety Performance Functions

Safety Performance Functions Used in EB Analysis

SPF Type	Intersection Type	Total Crashes					Fatal and Injury Crashes				
		a	**b**	**c**	**k**	**Source**	**a**	**b**	**c**	**k**	**Source**
	2Rur3ST	-9.86	0.79	0.49	0.54	HSM 10-18	-9.35	0.71	0.21	0.81	SA 1.2
	2Rur4ST	-8.56	0.6	0.61	0.24	HSM 10-19	-9.36	0.66	0.4	0.5	SA 1.2
multi	2Urb4ST	-8.9	0.82	0.25	0.4	HSM 12-30	-11.13	0.93	0.28	0.48	HSM 12-30
single	2Urb4ST	-5.33	0.33	0.12	0.65	HSM 12-33	see note below	0.28			
	2Urb4STALL	-12.37	1.22	0.27	2.13	SA 1.2	-10.02	1.27	-0.22	1.12	SA 1.2
multi	2Urb4YD	-8.9	0.82	0.25	0.4	HSM 12-30 (URB4ST)	-11.13	0.93	0.28	0.48	HSM 12-30 (URB4ST)
single	2Urb4YD	-5.33	0.33	0.12	0.65	HSM 12-33	see note below	0.28			
	4Rur4SG	-7.182	0.722	0.337	0.277	HSM 11-22	-6.393	0.638	0.232	0.218	HSM 11-22
	4Rur4ST	-10.008	0.848	0.448	0.494	HSM 11-22	-11.554	0.888	0.525	0.742	HSM 11-22
multi	4Urb3ST	-13.36	1.11	0.41	0.8	HSM 12-30	-14.01	1.16	0.3	0.69	HSM 12-30
single	4Urb3ST	-6.81	0.16	0.51	1.14	HSM 12-33	see note below	0.31			
	4Urb3STALL	-12.37	1.22	0.27	2.13	SA 1.2	-10.02	1.27	-0.22	1.124	SA 1.2
multi	4Urb4SG	-10.99	1.07	0.23	0.39	HSM 12-30	-13.14	1.18	0.22	0.33	HSM 12-30
single	4Urb4SG	-10.21	0.68	0.27	0.36	HSM 12-33	-9.25	0.43	0.29	0.09	HSM 12-33
multi	4Urb4ST	-8.9	0.82	0.25	0.4	HSM 12-30	-11.13	0.93	0.28	0.48	HSM 12-30
single	4Urb4ST	-5.33	0.33	0.12	0.65	HSM 12-33	see note below	0.28			
	4Urb4STALL	-12.37	1.22	0.27	2.13	SA 1.2	-10.02	1.27	-0.22	1.12	SA 1.2
multi	4Urb4YD	-8.9	0.82	0.25	0.4	HSM 12-30 (URB4ST)	-11.13	0.93	0.28	0.48	HSM 12-30 (URB4ST)
single	4Urb4YD	-5.33	0.33	0.12	0.65	HSM 12-33	see note below	0.28			
	2Rur3SG	-6.57	0.66	0.2	3.03	SA 1.2	-7.83	0.75	0.14	2	SA 1.2

Note: Since there are no models for fatal-and-injury crashes at three- and four-leg stop-controlled intersections in HSM Table 12-12, Equation 12-25 is replaced with the following equation in these cases:

Nbisv(FI) = Nbisv(total) × fbisv (12-27)

Where:
fbisv = proportion of fatal-and-injury crashes for combined sites.

The default value of fbisv in Equation 12-27 is 0.31 crashes per year for 3ST and 0.28 crashes per year for 4ST intersections. It is recommended that these default values be updated based on locally available data.

Appendix C- Detailed Results and Analysis of EB Methodology

EB Analysis of Total Crashes

Site #	Location	Intersection Type	SPF/Crash Type	AADT Major-Before	AADT Minor-Before	SPF Predicted Annual Crashes	Overdispersion Factor k	Years in the Before Period	Observed Total Crashes-Before	Expected Crashes – EB	AADT Major-After	AADT Minor-After	SPF Predicted Annual Crashes After	Adjustment Factor Due to SPF Before and After	Years in the After Period	Expected Crashes -EB Adjusted by AADT and Years in After Period (B)	Observed Total Crashes-After (A)	B-A	B-A [% Reduction=100(B-A)/B]	B-A [% Reduction=100(B-A)/B]
2	STH 54/Gaynor St/17th St	4Urb4ST	Multi-Veh	17,875	3,875	3.301	0.400	3	15.00	4.658	12,500	5,600	2.700	0.818	4	15.235	15.00	0.23	1.54	-63.97
			Single-Veh	17,875	3,875	0.330	0.650	3	1.00	0.332	12,500	5,600	0.307	1.000	4	1.232	12.00	-10.77	-874.19	
4	CTH F/S. Ninth St.	2Urb4ST	Multi-Veh	8,700	3,300	1.757	0.400	3	1.00	0.791	10,100	1,800	1.707	0.971	4	3.074	6.00	-2.93	-95.16	-87.13
			Single-Veh	8,700	3,300	0.256	0.650	3	0.00	0.171	10,100	1,800	0.250	0.977	4	0.666	1.00	-0.33	-50.06	
5	CTH F/Suburban Dr.	2Urb4ST	Multi-Veh	7,400	3,250	1.533	0.400	3	2.00	0.972	6,450	1,800	1.182	0.771	4	2.996	3.00	0.00	-0.14	16.23
			Single-Veh	7,400	3,250	0.242	0.650	3	0.00	0.164	6,450	1,800	0.215	0.890	4	0.585	0.00	0.59	100.00	
6	STH 32/57 and STH 96	2Urb4STALL	Combined	7,250	3,500	1.969	2.130	3	5.00	1.689	7,250	3,500	1.969	1.000	4	6.756	12.00	-5.24	-77.63	-77.63
7	STH 141 / Allouez Ave	2Rur4ST	Combined	7,000	1,700	3.631	0.240	3	9.00	3.175	10,100	3,500	7.029	1.936	4	24.581	21.00	3.58	14.57	14.57
8	STH 32/STH 57 Broadway	4Urb4SG	Multi-Veh	32,500	15,600	10.453	0.390	3	48.00	15.581	50,000	24,900	18.456	1.766	4	110.037	149.00	-38.96	-35.41	-35.29
			Single-Veh	32,500	15,600	0.584	0.360	3	3.00	0.745	50,000	24,900	0.887	1.521	4	4.529	6.00	-1.47	-32.48	
9	STH 55/CTH KK	2Rur4ST	Combined	10,300	4,500	8.291	0.240	3	18.00	6.329	8,950	3,650	6.707	0.809	4	20.479	5.00	15.48	75.58	75.58
10	Lake Park/Plank Rd (CTH LP/CTH P)	2Urb4ST	Multi-Veh	8,250	3,850	1.748	0.400	3	1.00	0.790	7,300	4,450	1.640	0.938	4	2.964	2.00	0.96	32.53	-65.23
			Single-Veh	8,250	3,850	0.256	0.650	3	0.00	0.171	7,300	4,450	0.250	0.977	4	0.667	4.00	-3.33	-499.56	
12	CTH N / Emons Road	2Rur4ST	Combined	7,800	800	2.447	0.240	3	5.00	1.949	12,200	2,100	5.765	2.356	4	18.371	29.00	-10.63	-57.86	-57.86
15	STH 28/32	2Rur4ST	Combined	8,350	2,950	5.650	0.240	3	5.00	2.453	5,300	3,750	4.979	0.881	4	8.646	15.00	-6.35	-73.49	-73.49
17	STH 42/ I-43, Interchange Ramps (West)	4Rur4SG	Combined	10,700	1,300	6.911	0.277	3	10.00	3.722	23,000	3,000	15.917	2.303	4	34.290	16.00	18.29	53.34	53.34
41	STH 42/ I-43, Interchange Ramps (East)	4Rur4SG	Combined	15,100	4,700	13.665	0.277	3	9.00	3.863	20,000	8,076	20.089	1.470	4	22.717	13.00	9.72	42.77	42.77
18	STH 42/Vanguard, Wal-Mart entrance	4Rur4SG	Combined	11,600	1,500	7.687	0.277	3	2.00	1.617	20,000	7,000	19.144	2.490	4	16.107	11.00	5.11	31.71	31.71
19	Breezewood ln/Tullar Rd	2Urb4YD	Multi-Veh	13,000	4,800	2.682	0.400	3	3.00	1.399	11,350	4,800	2.400	0.895	4	5.006	11.00	-5.99	-119.75	-91.72
			Single-Veh	13,000	4,800	0.305	0.650	3	0.00	0.191	11,350	4,800	0.292	0.956	4	0.732	0.00	0.73	100.00	
20	US 53 ramps and CTH O (West)	2Urb4ST	Multi-Veh	7,300	3,100	1.498	0.400	3	7.00	2.035	7,770	3,299	1.601	1.069	4	8.701	5.00	3.70	42.53	28.63
			Single-Veh	7,300	3,100	0.239	0.650	3	1.00	0.269	7,770	3,299	0.246	1.028	4	1.108	2.00	-0.89	-80.55	

21	US 53 ramps and CTH O (East)	2Urb4ST	Multi-Veh	12,850	2,600	2.279	0.400	3	4.00	1.587	14,200	3,000	2.564	1.125	4	7.139	7.00	0.14	1.95	-13.85
			Single-Veh	12,850	2,600	0.282	0.650	3	0.00	0.182	14,200	3,000	0.297	1.051	4	0.766	2.00	-1.23	-161.10	
22	STH 124/CTH S	2Rur4ST	Combined	8,250	3,600	6.334	0.240	3	16.00	5.513	5,100	4,700	5.584	0.882	4	19.443	8.00	11.44	58.85	58.85
27	Canal St/25th Ave	4Urb3STALL	Combined	13,600	10,500	5.707	2.130	3	1.00	0.477	18,400	4,900	6.718	1.177	4	2.245	15.00	-12.76	-568.26	-568.26
28	STH 38/CTH K	4Urb3ST	Multi-Veh	14,200	2,300	1.532	0.800	3	26.00	7.141	8,960	4,160	1.171	0.765	4	21.845	7.00	14.84	67.96	-8.86
			Single-Veh	14,200	2,300	0.264	1.140	3	4.00	0.771	8,960	4,160	0.332	1.257	4	3.876	21.00	-17.12	-441.74	
29	Elkhorn Rd (Bus 12)/Bluff Rd/Clay St	4Urb4YD	Multi-Veh	10,050	2,100	1.766	0.400	3	1.00	0.793	7,100	2,100	1.329	0.752	4	2.385	2.00	0.38	16.13	-47.76
			Single-Veh	10,050	2,100	0.254	0.650	3	1.00	0.280	7,100	2,100	0.226	0.892	4	0.999	3.00	-2.00	-200.22	
35	STH 78/STH 92, 8th St, Springdale	4Urb4SG	Multi-Veh	20,000	8,000	5.332	0.390	3	12.00	4.184	17,400	6,650	4.403	0.826	4	13.819	31.00	-17.18	-124.33	-90.39
			Single-Veh	20,000	8,000	0.350	0.360	3	5.00	0.712	17,400	6,650	0.303	0.865	4	2.463	0.00	2.46	100.00	
36	Thompson and Commercial (North)	4Urb4STALL	Combined	14,000	4,108	4.589	2.130	3	18.00	5.953	15,500	9,600	6.534	1.424	4	33.907	56.00	-22.09	-65.16	-65.16
37	Thompson and STH 30 (South)	4Urb3STALL	Combined	9,695	4,284	2.965	2.130	3	13.00	4.265	13,575	3,300	4.166	1.405	4	23.972	12.00	11.97	49.94	49.94
38	Old STH 12/Parmenter	4Urb4STALL	Combined	10,200	4,500	3.196	2.130	3	4.00	1.420	9,000	5,950	2.959	0.926	4	5.259	15.00	-9.74	-185.25	-185.25
101	STH EE (Grant St.) & Lawrence Dr.	2Urb4STALL	Combined	5,000	4,700	1.355	2.130	3	7.00	2.232	7,100	5,300	2.147	1.584	3	10.610	8.00	2.61	24.60	24.60
102	USH 10 & CTH N	2Rur4ST	Combined	6,800	5,600	7.385	0.240	3	23.00	7.622	6,000	6,000	7.145	0.968	3	22.124	11.00	11.12	50.28	50.28
103	CTH A (N. Lynndale Dr.) & CTH JJ	2Rur3SG	Combined	9,000	4,800	3.110	3.030	3	3.00	1.072	7,200	4,500	2.650	0.852	3	2.740	9.00	-6.26	-228.44	-228.44
104	STH 16 (Wisconsin Ave.) & Walnut. St	4Urb4SG	Multi-Veh	18,100	5,400	4.378	0.390	3	19.00	6.014	15,900	8,000	4.172	0.953	3	17.192	14.00	3.19	18.57	11.70
			Single-Veh	18,100	5,400	0.294	0.360	3	1.00	0.304	15,900	8,000	0.300	1.018	3	0.928	2.00	-1.07	-115.58	
105	STH 74/McLaughlin Rd. & CTH V	4Rur4ST	Combined	13,400	5,000	6.464	0.494	3	0.00	0.611	12,400	5,500	6.317	0.977	3	1.791	2.00	-0.21	-11.66	-11.66
106	USH 18 & Bennett Rd.	4Rur4ST	Combined	9,700	1,600	2.950	0.494	3	8.00	2.719	10,460	2,000	3.475	1.178	3	9.611	9.00	0.61	6.36	6.36

EB Analysis of Fatal and Injury Crashes

Site #	Location	Intersection Type	SPF/Crash Type	AADT Major-Before	AADT Minor-Before	SPF Predicted Annual Crashes	Overdispersion Factor k	Years in the Before Period	Observed Total Crashes-Before	Expected Crashes-EB	AADT Major-After	AADT Minor-After	SPF Predicted Annual Crashes After	Adjustment Factor Due to SPF Before and After	Years in the After Period	Expected Crashes -EB Adjusted by AADT and Years in After Period (B)	Observed Total Crashes-After (A)	B-A	B-A [% Reduction=100(B-A)/B]	B-A [% Reduction=100(B-A)/B]
2	STH 54/Gaynor St/17th St	4Urb4ST	Multi-Veh	17,875	3,875	1.335	0.480	3	8.00	2.21	12,500	5,600	1.062	0.79	4	7.031	1.00	6.031	85.78	59.33
			Single-Veh	No SPF Available - Use proportion of Total Single-Veh crashes												0.345	2.00	-1.655	-479.87	
4	CTH F/S. Ninth St.	2Urb4ST	Multi-Veh	8,700	3,300	0.653	0.480	3	1.00	0.50	10,100	1,800	0.634	0.97	4	1.932	3.00	-1.068	-55.25	-41.58
			Single-Veh	No SPF Available - Use proportion of Total Single-Veh crashes												0.187	0.00	0.187	100.00	
5	CTH F/Suburban Dr.	2Urb4ST	Multi-Veh	7,400	3,250	0.560	0.480	3	0.00	0.31	6,450	1,800	0.418	0.75	4	0.925	2.00	-1.075	-116.29	-83.73
			Single-Veh	No SPF Available - Use proportion of Total Single-Veh crashes												0.164	0.00	0.164	100.00	
6	STH 32/57 and STH 96	2Urb4STALL	Combined	7,250	3,500	0.591	1.120	3	1.00	0.42	7,250	3,500	0.591	1.00	4	1.678	3.00	-1.322	-78.77	-78.77
7	STH 141 / Allouez Ave	2Rur4ST	Combined	7,000	1,700	0.582	0.500	3	3.00	0.78	10,100	3,500	0.990	1.70	4	5.284	4.00	1.284	24.29	24.29
8	STH 32/STH 57 Broadway	4Urb4SG	Multi-Veh	32,500	15,600	3.466	0.330	3	12.00	3.88	50,000	24,900	6.387	1.84	4	28.595	26.00	2.595	9.07	4.74
			Single-Veh	32,500	15,600	0.138	0.090	3	1.00	0.14	50,000	24,900	0.190	1.38	4	0.798	2.00	-1.202	-150.71	
9	STH 55/CTH KK	2Rur4ST	Combined	10,300	4,500	1.109	0.500	3	9.00	2.29	8,950	3,650	0.929	0.84	4	7.677	1.00	6.677	86.97	86.97
10	Lake Park/Plank Rd (CTH LP/CTH P)	2Urb4ST	Multi-Veh	8,250	3,850	0.649	0.480	3	0.00	0.34	7,300	4,450	0.604	0.93	4	1.248	0.00	1.248	100.00	30.28
			Single-Veh	No SPF Available - Use proportion of Total Single-Veh crashes												0.187	1.00	-0.813	-435.32	
12	CTH N / Emons Road	2Rur4ST	Combined	7,800	800	0.462	0.500	3	4.00	0.82	12,200	2,100	0.914	1.98	4	6.475	8.00	-1.525	-23.55	-23.55
15	STH 28/32	2Rur4ST	Combined	8,350	2,950	0.815	0.500	3	1.00	0.55	5,300	3,750	0.665	0.82	4	1.794	1.00	0.794	44.27	44.27
17	STH 42/ I-43, Interchange Ramps (West)	4Rur4SG	Combined	10,700	1,300	3.287	0.218	3	3.00	1.73	23,000	3,000	6.502	1.98	4	13.658	5.00	8.658	63.39	63.39
41	STH 42/ I-43, Interchange Ramps (East)	4Rur4SG	Combined	15,100	4,700	5.517	0.218	3	2.00	1.72	20,000	8,076	7.483	1.36	4	9.328	3.00	6.328	67.84	67.84
18	STH 42/Vanguard, Wal-Mart entrance	4Rur4SG	Combined	11,600	1,500	3.577	0.218	3	1.00	1.30	20,000	7,000	7.239	2.02	4	10.561	2.00	8.561	81.06	81.06
19	Breezewood ln/Tullar Rd	2Urb4YD	Multi-Veh	13,000	4,800	1.054	0.480	3	1.00	0.62	11,350	4,800	0.929	0.88	4	2.185	1.00	1.185	54.23	58.15
			Single-Veh	No SPF Available - Use proportion of Total Single-Veh crashes												0.205	0.00	0.205	100.00	
20	US 53 ramps and CTH O (West)	2Urb4ST	Multi-Veh	7,300	3,100	0.545	0.480	3	1.00	0.45	7,770	3,299	0.588	1.08	4	1.950	1.00	0.950	48.73	11.52
			Single-Veh	No SPF Available - Use proportion of Total Single-Veh crashes												0.310	1.00	-0.690	-222.41	
21	US 53 ramps and CTH O (East)	2Urb4ST	Multi-Veh	12,850	2,600	0.879	0.480	3	0.00	0.39	14,200	3,000	1.004	1.14	4	1.772	3.00	-1.228	-69.29	-101.35
			Single-Veh	No SPF Available - Use proportion of Total Single-Veh crashes												0.214	1.00	-0.786	-366.24	

22	STH 124/CTH S	2Rur4ST	Combined	8,250	3,600	0.876	0.500	3	11.00	2.46	5,100	4,700	0.709	0.81	4	7.971	1.00	6.971	87.45	87.45
27	Canal St/25th Ave	4Urb3STALL	Combined	13,600	10,500	1.031	1.124	3	0.00	0.23	18,400	4,900	1.790	1.74	4	1.599	2.00	-0.401	-25.05	-25.05
28	STH 38/CTH K	4Urb3ST	Multi-Veh	14,200	2,300	0.550	0.690	3	9.00	1.86	8,960	4,160	0.385	0.70	4	5.196	2.00	3.196	61.51	21.84
			Single-Veh	**No SPF Available - Use proportion of Total Single-Veh crashes**												1.202	3.00	-1.798	-149.65	
29	Elkhorn Rd (Bus 12)/Bluff Rd/Clay St	4Urb4YD	Multi-Veh	10,050	2,100	0.658	0.480	3	1.00	0.50	7,100	2,100	0.477	0.72	4	1.448	0.00	1.448	100.00	100.00
			Single-Veh	**No SPF Available - Use proportion of Total Single-Veh crashes**												0.280	0.00	0.280	100.00	
35	STH 78/STH 92, 8th St, Springdale	4Urb4SG	Multi-Veh	20,000	8,000	1.688	0.330	3	2.00	1.05	17,400	6,650	1.375	0.81	4	3.418	3.00	0.418	12.23	19.76
			Single-Veh	20,000	8,000	0.092	0.090	3	0.00	0.09	17,400	6,650	0.082	0.89	4	0.321	0.00	0.321	100.00	
36	Thompson and Commercial (North)	4Urb4STALL	Combined	14,000	4,108	1.315	1.120	3	12.00	3.50	15,500	9,600	1.242	0.94	4	13.235	11.00	2.235	16.89	16.89
37	Thompson and STH 30 (South)	4Urb3STALL	Combined	9,695	4,284	0.817	1.124	3	5.00	1.44	13,575	3,300	1.327	1.62	4	9.357	1.00	8.357	89.31	89.31
38	Old STH 12/Parmenter	4Urb4STALL	Combined	10,200	4,500	0.862	1.120	3	1.00	0.47	9,000	5,950	0.692	0.80	4	1.505	2.00	-0.495	-32.89	-32.89
101	STH EE (Grant St.) & Lawrence Dr.	2Urb4STALL	Combined	5,000	4,700	0.345	1.120	3	2.00	0.52	7,100	5,300	0.525	1.52	3	2.362	3.00	-0.638	-27.01	-27.01
102	USH 10 & CTH N	2Rur4ST	Combined	6,800	5,600	0.920	0.500	3	15.00	3.29	6,000	6,000	0.871	0.95	3	9.329	1.00	8.329	89.28	89.28
103	CTH A (N. Lynndale Dr.) & CTH JJ	2Rur3SG	Combined	9,000	4,800	1.204	2.000	3	1.00	0.44	7,200	4,500	1.009	0.84	3	1.105	2.00	-0.895	-81.08	-81.08
104	STH 16 (Wisconsin Ave.) & Walnut. St	4Urb4SG	Multi-Veh	18,100	5,400	1.376	0.330	3	4.00	1.35	15,900	8,000	1.287	0.94	3	3.793	1.00	2.793	73.64	50.48
			Single-Veh	18,100	5,400	0.079	0.090	3	0.00	0.08	15,900	8,000	0.083	1.06	3	0.245	1.00	-0.755	-308.07	
105	STH 74/McLaughlin Rd. & CTH V	4Rur4ST	Combined	13,400	5,000	3.881	0.742	3	0.00	0.40	12,400	5,500	3.809	0.98	3	1.185	1.00	0.185	15.64	15.64
106	USH 18 & Bennett Rd.	4Rur4ST	Combined	9,700	1,600	1.602	0.742	3	6.00	1.91	10,460	2,000	1.926	1.20	3	6.898	3.00	3.898	56.51	56.51

Appendix D – Detailed Results of Exploratory Analysis for Roundabouts Excluded from EB Analysis

Safety Performance Comparisons between Roundabouts and Other Intersection Control Options Using Crash Prediction of Total Crashes

	Observed Number of Total Crashes	Predicted Number of Total Crashes		
Intersection	**RAB**	**Two-way Stop Control**	**All-way Stop Control**	**Signalized**
Lake Park/Kensington	5	2.72	2.57	2.10
CTH O (Superior) & Wilgus/40	3	7.77	9.24	17.11
STH 35 and Hanley (east)*	3	23.03	18.36	47.33
STH 35 and Hanley (west)*	2	25.77	21.59	52.09
5/6 Street and Florida	16	9.88	12.98	9.98
STH 22 and Royalton	4	1.64	4.96	6.96
STH 53 and Old Town	17	1.66	1.23	5.42
I 43 and CTH O (SB)	52	11.67	20.74	14.28
I 43 and CTH O (NB)	36	18.83	38.41	24.26
Hanson Road and Portage	0	0.70	1.31	3.22

Safety Performance Comparisons between Roundabouts and Other Intersection Control Options Using Crash Prediction of Fatal/Injury Crashes

	Observed Number of Fatal/Injury Crashes	Predicted Number of Fatal/Injurt Crashes		
Intersection	**RAB**	**Two-way Stop Control**	**All-way Stop Control**	**Signalized**
Lake Park/Kensington	2	0.98	0.80	1.14
CTH O (Superior) & Wilgus/40	0	2.79	3.01	7.34
STH 35 and Hanley (east)*	0	13.42	5.96	19.93
STH 35 and Hanley (west)*	0	15.09	7.06	21.69
5/6 Street and Florida	0	3.67	3.45	2.96
STH 22 and Royalton	0	0.73	1.38	2.63
STH 53 and Old Town	4	0.75	1.30	3.36
I 43 and CTH O (SB)	8	4.64	6.85	4.52
I 43 and CTH O (NB)	8	8.00	6.95	7.77
Hanson Road and Portage	0	0.32	0.57	1.19

Prediction Analysis of Total Crashes for Roundabouts Excluded from EB Analysis

Site #	Location	Intersection Type	SPF/Crash Type	AADT Major-Before	AADT Minor-Before	SPF Predicted Annual Crashes After	Years in the After Period	Predicted Crashes - Adjusted by AADT and Years in After Period (B)	Observed Total Crashes-After (A)	B-A	B-A [% Reduction=100(B-A)/B]	B-A [% Reduction=100(B-A)/B]
	Lake Park/Kensington	Int/Urb; 3-leg minor-rd STOP	Combined	3,000	3,000	0.680	4	2.719	5.00	-2.28	-83.90	-83.90
		4Urb3STALL	Combined	3,000	3,000	0.644	4	2.575	5.00	-2.43	-94.19	-94.19
		Int/Urb; 3-leg signalized	Combined	3,000	3,000	0.526	4	2.104	5.00	-2.90	-137.70	-137.70
	CTH O (SUPERIOR) & WILGUS/40	2Urb4ST	Multi-Veh	8,550	3,000	1.691	4	6.766	2.00	4.77	70.44	61.39
			Single-Veh	8,550	3,000	0.251	4	1.005	1.00	0.00	0.48	
		2Urb4STALL	Combined	8,550	3,000	2.310	4	9.240	3.00	6.24	67.53	67.53
		Int/Urb; 4-leg signalized	Combined	8,550	3,000	4.278	4	17.111	3.00	14.11	82.47	82.47
	STH 35 AND HANLEY (east)*	4Rur4ST	Combined	14,800	3,200	5.758	4	23.032	3.00	20.03	86.97	86.97
		Int/Rur; 4-leg all-way STOP	Combined	14,800	3,200	4.591	4	18.363	3.00	15.36	83.66	83.66
		4Rur4SG	Combined	14,800	3,200	11.832	4	47.328	3.00	44.33	93.66	93.66
	STH 35 AND HANLEY (west)*	4Rur4ST	Combined	16,900	3,200	6.444	4	25.775	2.00	23.77	92.24	92.24
		Int/Rur; 4-leg all-way STOP	Combined	16,900	3,200	5.397	4	21.590	2.00	19.59	90.74	90.74
		4Rur4SG	Combined	16,900	3,200	13.022	4	52.087	2.00	50.09	96.16	96.16
	5/6 STREET AND FLORIDA	4Urb4ST	Multi-Veh	10,250	4,650	2.190	4	8.760	12.00	-3.24	-36.99	-61.87
			Single-Veh	10,250	4,650	0.281	4	1.124	4.00	-2.88	-255.76	
		4Urb4STALL	Combined	10,250	4,650	3.244	4	12.976	16.00	-3.02	-23.31	-23.31
		4Urb4SG	Multi-Veh	10,250	4,650	2.302	4	9.208	12.00	-2.79	-30.33	-60.39
			Single-Veh	10,250	4,650	0.192	4	0.768	4.00	-3.23	-420.77	
	STH 22 and Royalton	Int/Rur; 3-leg minor-rd STOP	Combined	6,100	4,000	0.548	3	1.645	4.00	-2.36	-143.20	-143.20
		Int/Rur; 3-leg all-way STOP	Combined	6,100	4,000	1.654	3	4.961	4.00	0.96	19.37	19.37
		Int/Rur; 3-leg signalized	Combined	6,100	4,000	2.320	3	6.959	4.00	2.96	42.52	42.52
	STH 53 and Old Town	4Rur4ST	Combined	3,600	250	0.554	3	1.662	17.00	-15.34	-922.65	-922.65
		Int/Rur; 4-leg all-way STOP	Combined	3,600	250	0.411	3	1.233	17.00	-15.77	-1278.53	-1278.53
		4Rur4SG	Combined	3,600	250	1.806	3	5.417	17.00	-11.58	-213.82	-213.82
	I 43 and CTH O (SB)	4Urb4ST	Multi-Veh	20,700	3,200	3.549	3	10.648	43.00	-32.35	-303.82	-345.77
			Single-Veh	20,700	3,200	0.339	3	1.017	9.00	-7.98	-785.16	
		4Urb4STALL	Combined	20,700	3,200	6.913	3	20.738	52.00	-31.26	-150.74	-150.74

		4Urb4SG	Multi-Veh	20,700	3,200	4.481	3	13.443	43.00	-29.56	-219.87	-264.07
			Single-Veh	20,700	3,200	0.280	3	0.840	9.00	-8.16	-971.56	
	I 43 and CTH O (NB)	4Urb4ST	Multi-Veh	26,000	11,200	5.853	3	17.558	27.00	-9.44	-53.77	-91.16
			Single-Veh	26,000	11,200	0.425	3	1.274	9.00	-7.73	-606.42	
		4Urb4STALL	Combined	26,000	11,200	12.804	3	38.411	36.00	2.41	6.28	6.28
		4Urb4SG	Multi-Veh	26,000	11,200	7.629	3	22.886	27.00	-4.11	-17.98	-48.38
			Single-Veh	26,000	11,200	0.458	3	1.375	9.00	-7.62	-554.33	
	Hanson Road and Portage	Int/Rur; 3-leg minor-rd STOP	Combined	2,550	1,500	0.233	3	0.700	0.00	0.70	100.00	100.00
		Int/Rur; 3-leg all-way STOP	Combined	2,550	1,500	0.438	3	1.313	0.00	1.31	100.00	100.00
		Int/Rur; 3-leg signalized	Combined	2,550	1,500	1.072	3	3.216	0.00	3.22	100.00	100.00

Prediction Analysis of Fatal/Injury Crashes for Roundabouts Excluded from EB Analysis

Site #	Location	Intersection Type	SPF/Crash Type	AADT Major-Before	AADT Minor-Before	SPF Predicted Annual Crashes After	Years in the After Period	Predicted Crashes - Adjusted by AADT and Years in After Period (B)	Observed Total Crashes-After (A)	B-A	B-A [% Reduction=100(B-A)/B]	B-A [% Reduction=100(B-A)/B]
	Lake Park/Kensington	Int/Urb; 3-leg minor-rd STOP	Combined	3,000	3,000	0.246	4	0.982	2.00	-1.02	-103.65	-103.65
		4Urb3STALL	Combined	3,000	3,000	0.199	4	0.797	2.00	-1.20	-150.97	-150.97
		Int/Urb; 3-leg signalized	Combined	3,000	3,000	0.286	4	1.143	2.00	-0.86	-75.02	-75.02
	CTH O (SUPERIOR) & WILGUS/40	2Urb4ST	Multi-Veh	8,550	3,000	0.626	4	2.504	0.00	2.50	100.00	100.00
			Single-Veh	8,550	3,000	NO SPF		0.281	0.00	0.00	100.00	
		2Urb4STALL	Combined	8,550	3,000	0.753	4	3.013	0.00	3.01	100.00	100.00
		Int/Urb; 4-leg signalized	Combined	8,550	3,000	1.836	4	7.342	0.00	7.34	100.00	100.00
	STH 35 AND HANLEY (east)*	4Rur4ST	Combined	14,800	3,200	3.354	4	13.416	0.00	13.42	100.00	100.00
		Int/Rur; 4-leg all-way STOP	Combined	14,800	3,200	1.491	4	5.964	0.00	5.96	100.00	100.00
		4Rur4SG	Combined	14,800	3,200	4.982	4	19.927	0.00	19.93	100.00	100.00
	STH 35 AND HANLEY (west)*	4Rur4ST	Combined	16,900	3,200	3.773	4	15.093	0.00	15.09	100.00	100.00
		Int/Rur; 4-leg all-way STOP	Combined	16,900	3,200	1.765	4	7.058	0.00	7.06	100.00	100.00
		4Rur4SG	Combined	16,900	3,200	5.422	4	21.687	0.00	21.69	100.00	100.00
	5/6 STREET AND FLORIDA	4Urb4ST	Multi-Veh	10,250	4,650	0.838	4	3.351	0.00	3.35	100.00	100.00
			Single-Veh	10,250	4,650	NO SPF		0.315	0.00	0.00	100.00	
		4Urb4STALL	Combined	10,250	4,650	0.861	4	3.445	0.00	3.45	100.00	100.00
		4Urb4SG	Multi-Veh	10,250	4,650	0.681	4	2.722	0.00	2.72	100.00	100.00
			Single-Veh	10,250	4,650	0.059	4	0.236	0.00	0.24	100.00	
	STH 22 and Royalton	Int/Rur; 3-leg minor-rd STOP	Combined	6,100	4,000	0.242	3	0.725	0.00	0.73	100.00	100.00
		Int/Rur; 3-leg all-way STOP	Combined	6,100	4,000	0.461	3	1.382	0.00	1.38	100.00	100.00
		Int/Rur; 3-leg signalized	Combined	6,100	4,000	0.877	3	2.630	0.00	2.63	100.00	100.00
	STH 53 and Old Town	4Rur4ST	Combined	3,600	250	0.251	3	0.752	4.00	-3.25	-431.94	-431.94
		Int/Rur; 4-leg all-way STOP	Combined	3,600	250	0.434	3	1.302	4.00	-2.70	-207.34	-207.34
		4Rur4SG	Combined	3,600	250	1.119	3	3.357	4.00	-0.64	-19.16	-19.16
	I 43 and CTH O (SB)	4Urb4ST	Multi-Veh	20,700	3,200	1.451	3	4.352	7.00	-2.65	-60.83	-72.53
			Single-Veh	20,700	3,200	No SPF		0.285	1.00	-0.72	-251.25	
		4Urb4STALL	Combined	20,700	3,200	2.283	3	6.849	8.00	-1.15	-16.80	-16.80

		4Urb4SG	Multi-Veh	20,700	3,200	1.437	3	4.310	7.00	-2.69	-62.42	-76.80
			Single-Veh	20,700	3,200	0.072	3	0.215	1.00	-0.79	-365.31	
	I 43 and CTH O (NB)	4Urb4ST	Multi-Veh	26,000	11,200	2.547	3	7.641	7.00	0.64	8.38	-0.03
			Single-Veh	26,000	11,200	**No SPF**		0.357	1.00	-0.64	-180.33	
		4Urb4STALL	Combined	26,000	11,200	2.315	3	6.945	8.00	-1.05	-15.19	-15.19
		4Urb4SG	Multi-Veh	26,000	11,200	2.477	3	7.430	7.00	0.43	5.79	-2.95
			Single-Veh	26,000	11,200	0.114	3	0.341	1.00	-0.66	-193.35	
	Hanson Road and Portage	Int/Rur; 3-leg minor-rd STOP	Combined	2,550	1,500	0.106	3	0.318	0.00	0.32	100.00	100.00
		Int/Rur; 3-leg all-way STOP	Combined	2,550	1,500	0.189	3	0.566	0.00	0.57	100.00	100.00
		Int/Rur; 3-leg signalized	Combined	2,550	1,500	0.397	3	1.192	0.00	1.19	100.00	100.00

Appendix E – Roundabout Detailed Crash Diagrams Memo

Objective

According to previous research (1, 2, 3), the implementation of roundabouts shows a consistent trend in reducing crashes, especially severe injury collisions. Therefore, roundabouts have been considered one of the safer intersection improvement designs. Numerous roundabouts have been implemented and opened to traffic throughout the state of Wisconsin for several years. However, after reviewing some of the crash data, some roundabouts had higher crash rates than expected. A comprehensive safety evaluation will help to better understand the causes of crashes in roundabouts and determine whether roundabouts improve safety.

Data Collection and Methodology

Information about the roundabouts included in this study is shown in the following table:

Roundabout Locations

	WisDOT Region	County	Municipality	Intersection	Open to the traffic
A	NE	Brown	DePere	STH32/57 and S. Broadway	07/12/2007
B	SE	Milwaukee	Milwaukee	Canal St. and 25th Ave.	09/15/2005
C	SW	Dane	Madison	N. Thompson and Commercial St.	10/18/2004

Please note the locations of roundabouts A (DePere) and B (Milwaukee) are different compared to the before conditions. Crash data on roundabouts are collected from the WisTransPortal (4). In order to have reliable data to support the results, three-year periods of crash data before and after the construction of the roundabouts are required. The crashes in the construction year were excluded to minimize the effects of the construction. For instance, if a roundabout was opened to the public in 2005, data from 2002-2004 and 2006-2008 would be analyzed. For this study, a roundabout crash is defined as a crash occurring at the intersection or circulatory area, as well as any crash occurring at the roundabout legs due to following too closely or slowing down. To obtain meaningful information on crashes, each Wisconsin crash report (MV4000) has to be reviewed manually and carefully.

Generally, the safety evaluation of roundabouts is measured by the comparison of before and after data. There are several aspects to be considered in this study.

1. Before-and-after crash data: This study was conducted by calculating the differences of crash frequency occurring in the three years before and the three years after the construction of the roundabout. The frequency is classified by crash injury severity: K, A, B, C and PDO.
2. Crash types for each Quadrant: The geometry of a four-leg roundabout is divided into four quadrants: Q1, Q2, Q3, and Q4. A three-leg roundabout is divided into three quadrants: Q1, Q2, and Q3. The purpose of this study is to determine which quadrant has the highest crash rate, and which collision types occur in each quadrant. This analysis will provide a general overview of the most dangerous areas in a roundabout.

3. Main cause of crash: Tables A-4, B-4 and C-4 list the main cause of each crash and the quadrant in which it occurred. From the table, the primary causes of crashes in roundabouts can easily be determined. They are: wrong lane choice, fail to yield to both lanes, changing lane, following too closely, fail to yield right-of-way, and inattentive driving. Inattentive driving means the driver hit a pole or object, or was driving carelessly. In any case, the crash was not at all related to the roundabout geometry or other parties on the road.
4. Crash type summary year by year: Crash data sorted by collision type is collected for the period beginning three years before construction and ending three years after construction. From this data, the changing crash frequency by year can be seen.

Results

A. Roundabout A: The crash diagram can be seen in Figure A and detailed information of the crash data is shown in Table A-1.

    1. Before-and-after crash data (Table A-2): The crash frequency increased after construction of the roundabout.
    2. Crash types for each Quadrant (Table A-3): Most of the crashes occurred in Quadrant 1. Sideswipe crash types were higher than other types. Angle crashes ranked second. These two crash types occur frequently when vehicles are circulating and change lanes suddenly without following proper roundabout regulations.
    3. Main cause of crash (Table A-4): Wrong lane choice ranks first among all causes. In this case, motorists do not follow the pavement marking instructions and make right turns or left turns arbitrarily. Of all quadrants, Quadrant 1 has the most crashes due to wrong lane choice.
    4. Crash type summary year by year (Table A-5): Sideswipe and Angle crash types are the two main crash types. Total crashes remain high after construction of the roundabout, but the sideswipe and angle crashes decreased year by year.

B. Roundabout B: The crash diagram can be seen in Figure B and detailed information of the crash data is shown in Table B-1.

    1. Before-and-after crash data (Table B-2): The current roundabout is not a three leg intersection as it was before construction. Therefore, although the crash frequency increases, it is not related to the construction of the roundabout.
    2. Crash types for each Quadrant (Table B-3): The crashes in Quadrants 1 and 2 are approximately the same. Quadrant 3 does not have many conflict points, so only one crash occurred during the three year period. Sideswipe crashes were the primary crash type.
    3. Main cause of crash (Table B-4): Following too closely ranks first, but it only occurred three times in three years. In such a small geometry and low volume roundabout, the cause of the crashes is not very meaningful.

4. Crash type summary year by year (Table B-5): Five sideswipe crashes occurred in 2005, the cause is unknown. Overall, the crash data was insignificant.

C. Roundabout C: The crash diagram can be seen in Figure C and detailed information of the crash data is shown in Table C-1.

   1. Before-and-after crash data (Table C-2): According to Table C-2, the number of crashes doubled after construction of the roundabout. However, the injury severity decreased dramatically. Most of the crashes were property damage only.
   2. Crash types for each Quadrant (Table C-3): Quadrant 2 has the highest rate of crashes. Vehicles coming from the west side exiting the ramp and vehicles coming from the east side preparing to enter the ramp would pass through this quadrant. Heavy traffic volumes may cause the higher crash rate. Sideswipe crashes are still the main type of crash.
   3. Main cause of crash (Table C-4): Failure to yield to both lanes ranks first, especially in Quadrant 2. Motorists should wait for all vehicles in the roundabout to pass before entering the roundabout.
   4. Crash type summary year by year (Table C-5): Crashes remained the same in the six years after construction, except the year 2007. Although 2011 crashes decreased, 2012 crash data is still needed to confirm whether the roundabout implementation was successful.

In summary, all of the roundabouts show good safety improvement in terms of reducing the crash severity, although the total number of crashes did increase after implementation of the roundabouts. The main causes of crashes were wrong lane choice and failure to yield to both lanes. The reason for this is that many motorists are not familiar with the driving principles of roundabouts. Fortunately, the driving speed within roundabouts is relatively low, so if a crash occurs, the likelihood of a severe injury is low. Most of the crash types were sideswipe and angle. Rear-end crashes, which occurred less frequently, occurred when some drivers slowed down while approaching the roundabout, while others failed to do so. After observing all long-term crash data, there were no noticeable improvements in total crash reduction. Analysis of the data suggests that many drivers still do not understand correct roundabout driving procedures.

General Recommendation

Roundabouts demand a high level of driver compliance and require drivers to process more information than in a traditional intersection. As previously mentioned, the two major crash causes are wrong lane choice and failure to yield to both lanes. Possible explanations for this are that drivers do not understand how to navigate the roundabout and that they consider a roundabout to be a normal intersection. Educating motorists on how to drive though roundabouts is crucial. Adding a roundabout section to driver education programs and licensing requirements is suggested. Clear and conspicuous signs are needed in order to instruct motorists. Under "Yield" signs, a supplemental plaque that says "To ALL Lanes" could help improve driver understanding that vehicles should yield to vehicles in all circulating lanes.

The intersection of STH 32/ STH 57 and S. Broadway

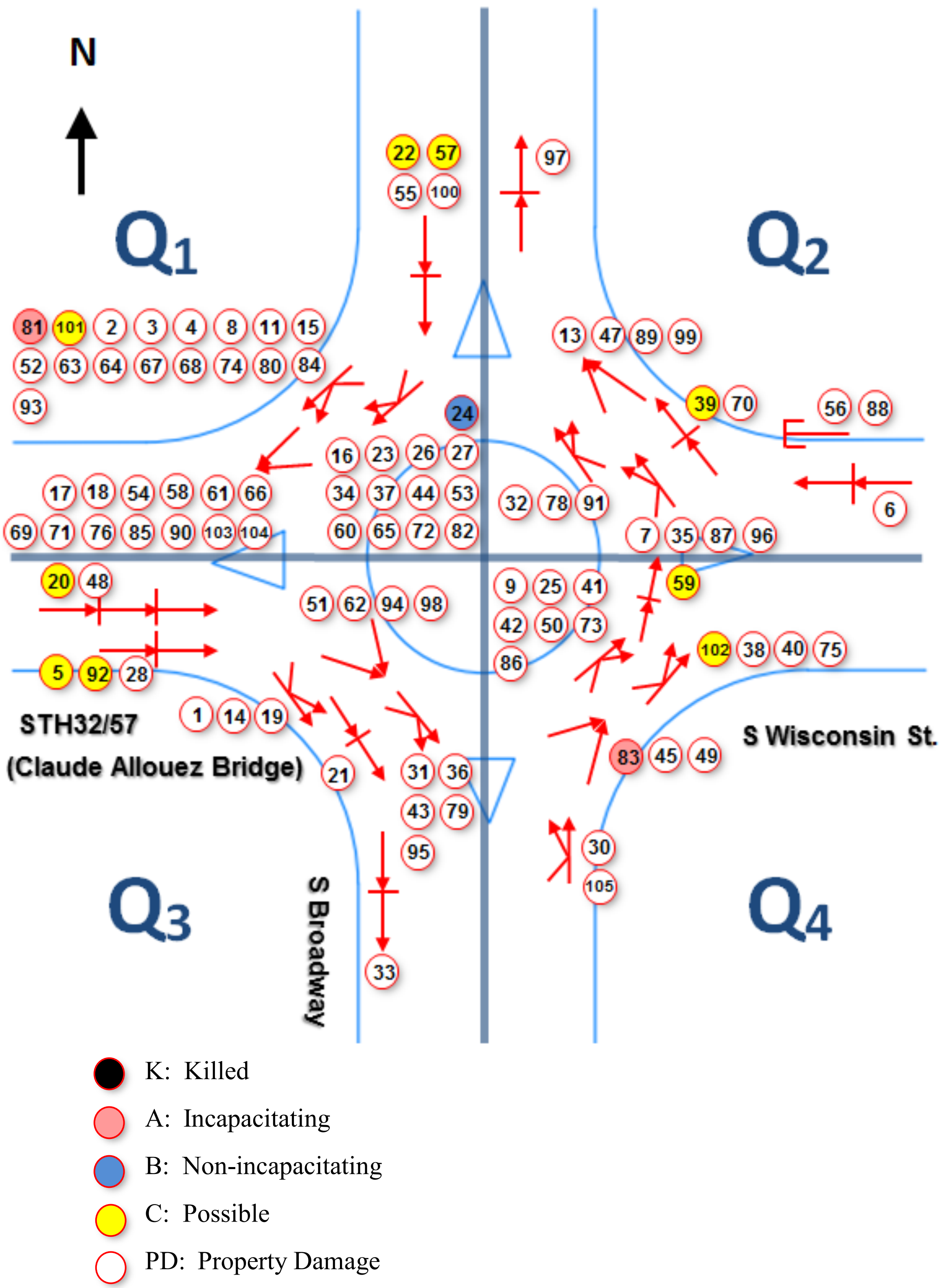

Figure E Crash Diagram of STH32/57 and S. Broadway

Table N-1 Roundabout Crash Summary (2008-2010)

No.	Date	Time	Type	Road Condition	Injure Severity	Q Number	Main Cause
1	2/7/2008	11:43	Sideswipe			3	CL
2	3/6/2008	05:32	Sideswipe			1	WLC
3	3/7/2008	17:16	Sideswipe			1	FYBL
4	3/7/2008	17:56	Sideswipe			1	CL
5	3/7/2008	18:37	Rear-end		C	3	FC
6	3/14/2008	11:39	Rear-end			2	FC
7	3/26/2008	16:18	Sideswipe			2	WLC
8	3/26/2008	17:55	Sideswipe			1	FYBL
9	4/17/2008	06:51	Sideswipe			4	WLC
10	4/17/2008	16:45	Sideswipe				x
11	4/21/2008	17:25	Sideswipe			1	WLC
12	4/28/2008	17:46	Angle				x
13	4/30/2008	07:57	Angle			2	WLC
14	6/10/2008	14:16	Sideswipe			3	WLC
15	6/17/2008	16:18	Sideswipe			1	WLC
16	6/23/2008	20:18	Sideswipe			1	WLC
17	7/2/2008	08:41	Angle			1	ID
18	7/15/2008	11:20	Angle			1	FYBL
19	7/20/2008	11:25	Sideswipe			3	WLC
20	7/21/2008	14:38	Rear-end		C	3	FC
21	8/1/2008	08:33	Rear-end			3	CL
22	8/15/2008	13:26	Rear-end		C	1	FC
23	8/21/2008	20:10	Sideswipe			1	FYBL
24	9/9/2008	05:59	Sideswipe		B	1	FYBL
25	9/16/2008	15:08	Sideswipe			4	WLC
26	11/20/2008	07:49	Sideswipe			1	FYBL
27	12/5/2008	11:09	Sideswipe			1	WLC
28	12/22/2008	15:57	Rear-end	ICE		3	ICE
29	1/21/2009	14:38	Sideswipe	SNOW	C		x
30	1/28/2009	17:58	Sideswipe			4	ID
31	2/2/2009	18:00	Sideswipe			3	WLC
32	2/3/2009	11:12	Sideswipe	WET		2	WLC
33	2/3/2009	14:52	Rear-end			3	FC
34	2/6/2009	15:30	Sideswipe			1	WLC
35	2/13/2009	12:13	Sideswipe			2	FYBL

36	2/18/2009	15:20	Angle	SNOW		3	FYROW
37	2/23/2009	07:52	Sideswipe			1	WLC
38	3/3/2009	07:58	Sideswipe			4	WLC
39	3/9/2009	16:44	Rear-end	WET	C	2	CL
40	3/12/2009	18:18	Sideswipe			4	FYBL
41	3/13/2009	12:08	Sideswipe			4	FYBL
42	3/18/2009	08:21	Sideswipe			4	FYBL
43	4/8/2009	09:30	Sideswipe			3	WLC
44	4/15/2009	15:53	Sideswipe			1	WLC
45	4/17/2009	14:15	Angle			4	FYBL
46	4/23/2009	17:30	Sideswipe				x
47	4/24/2009	15:40	Angle			2	FYBL
48	5/6/2009	16:43	Rear-end			3	FC
49	5/27/2009	17:59	Angle	WET		4	FYBL
50	5/29/2009	17:28	Sideswipe			4	FYBL
51	6/5/2009	20:14	Sideswipe			3	CL
52	6/9/2009	10:22	Sideswipe			1	WLC
53	6/17/2009	13:44	Sideswipe			1	WLC
54	6/24/2009	21:36	Angle			1	WLC
55	7/20/2009	20:04	Rear-end			1	FC
56	7/22/2009	16:50	NO			2	ID
57	8/3/2009	18:30	Rear-end		C	1	FC
58	8/12/2009	15:40	Angle			1	WLC
59	8/18/2009	14:52	Rear-end		C	2	FC
60	8/24/2009	16:09	Sideswipe			1	FYBL
61	8/24/2009	15:58	Angle			1	WLC
62	8/24/2009	16:36	Angle			3	WLC
63	8/27/2009	06:48	Sideswipe			1	WLC
64	8/30/2009	15:14	Sideswipe			1	WLC
65	9/14/2009	12:12	Sideswipe			1	WLC
66	10/26/2009	14:44	Angle	WET		1	FYBL
67	10/30/2009	18:38	Sideswipe	WET		1	WLC
68	12/10/2009	15:34	Sideswipe	SNOW		1	WLC
69	12/14/2009	04:30	Angle	ICE		1	FYBL
70	12/15/2009	15:45	Rear-end	SNOW		2	FYROW
71	1/3/2010	15:14	Angle			1	FYBL
72	1/14/2010	15:40	Sideswipe			1	WLC
73	1/30/2010	21:55	Sideswipe			4	WLC

74	2/16/2010	15:47	Sideswipe	WET		1	WLC
75	3/5/2010	12:01	Sideswipe			4	CL
76	3/5/2010	14:47	Angle			1	WLC
77	3/19/2010	15:51	Sideswipe				x
78	4/5/2010	17:13	Sideswipe			2	FYBL
79	4/10/2010	12:24	Sideswipe			3	FYBL
80	5/4/2010	18:59	Sideswipe			1	WLC
81	5/16/2010	11:21	Sideswipe		A	1	WLC
82	5/17/2010	07:18	Sideswipe			1	WLC
83	5/22/2010	11:02	Angle		A	4	FYBL
84	5/25/2010	19:20	Sideswipe			1	WLC
85	5/27/2010	16:59	Angle			1	WLC
86	6/2/2010	18:02	Sideswipe	WET		4	WLC
87	6/3/2010	07:05	Sideswipe			2	CL
88	6/3/2010	09:30	NO			2	ID
89	6/14/2010	18:35	Angle			2	FYBL
90	6/16/2010	11:38	Angle			1	WLC
91	6/18/2010	11:28	Sideswipe			2	FYBL
92	6/29/2010	16:06	Rear-end		C	3	FC
93	7/16/2010	19:34	Sideswipe			1	WLC
94	7/16/2010	21:30	Angle			3	FYBL
95	7/19/2010	15:45	Sideswipe			3	FYBL
96	8/13/2010	11:00	Sideswipe			2	WLC
97	8/13/2010	14:01	Rear-end	WET		2	FC
98	8/23/2010	12:20	Angle			3	FYBL
99	8/26/2010	14:00	Angle			2	WLC
100	8/27/2010	12:27	Rear-end			1	FC
101	9/7/2010	07:15	Sideswipe		C	1	WLC
102	9/19/2010	10:57	Sideswipe		C	4	FYBL
103	9/27/2010	19:54	Angle			1	WLC
104	11/2/2010	07:37	Angle			1	WLC
105	11/18/2010	16:25	Sideswipe			4	ID

"x" denotes that the crash report is missing. There are five crash reports missing during these three years.

CL: Changing lane in roundabout
FC: Following too close
FYBL: Failed to yield to both lanes
FYROW: Failed to yield right-of-way
UR: Unknown reason
WLC: Wrong lane choice

Table O-2 Before-and-after crash data

Open in the year of 2007		K	A	B	C	PDO	TOTAL
Frequency	Before (2004 to 2006)		1		7	24	32
	After (2008 to 2011)		2	1	10	92	105
Percentage	Before (2004 to 2006)		3%		22%	75%	100%
	After (2008 to 2011)		2%	1%	10%	88%	100%

Table P-3 Crash types for each quadrant (2008-2010)

	Q1	Q2	Q3	Q4	Total	100%
Sideswipe	30	7	8	13	58	58%
Rear-end	4	4	7	1	16	16%
Angle	13	4	4	3	24	24%
No	0	2	0	0	2	2%
Total Crash	47	17	19	17	100	100%

Table Q-4 Crash main cause in order (2008-2010)

Rank	Main Cause	Q1	Q2	Q3	Q4	Crashes
1	WLC (Wrong lane choice)	31	5	5	5	46
2	FYBL (Failed to yield both lanes)	10	5	4	8	27
3	FC (Follow too close)	4	2	5	1	12
4	CL (Changing lane)	1	2	3	1	7
5	ID(Inattentive Driving)	1	2	0	2	5
6	FYROW (Failed to yield right-of-way)	0	1	1	0	2
	Ice	0	0	1	0	1

Table R-5 Crash type summary year by year

	Angle	Rear-end	Sideswipe	No	Head	
2004	5	2	3	0	0	10
2005	3	3	2	2	0	10
2006	2	6	1	2	1	12
2007	7/12/2007 Roundabout open to traffic					
2008	3	6	17	0	0	26
2009	10	7	22	1	0	40
2010	11	3	19	1	0	34
2011	4	7	19	5	0	35

The intersection of Canal St. and 25th Ave.

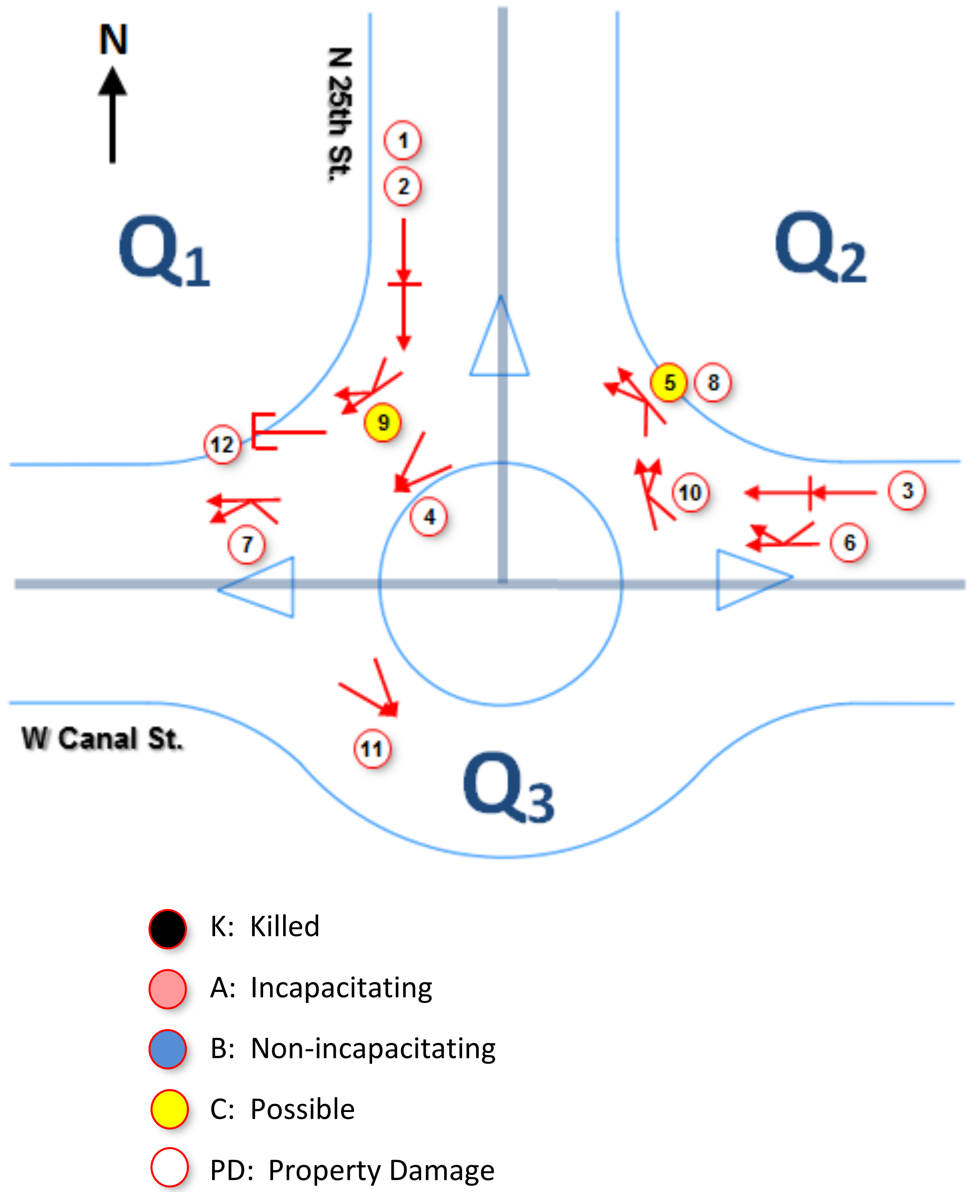

Figure B Crash Diagram of W. Canal St. and N. 25th St.

Table B-1 Roundabout Crash Summary (2006-2008)

No.	Date	Time	Type	Road Condition	Injure Severity	Q Number	Main Cause
1	2/4/2006	22:30	Rear-end			1	FC
2	12/8/2006	14:00	Rear-end			1	FC
3	2/17/2007	02:25	Rear-end			2	FC
4	3/17/2007	07:20	Angle			1	FYBL
5	6/5/2007	13:30	Sideswipe		C	2	CL
6	1/25/2008	08:00	Sideswipe	WET		2	UR
7	2/18/2008	17:00	Sideswipe	WET		1	CL
8	6/20/2008	22:45	Sideswipe			2	WLC
9	7/13/2008	08:46	Sideswipe		C	1	FYBL
10	8/21/2008	16:42	Sideswipe	WET		2	FYROW
11	11/12/2008	05:15	Angle	WET		3	FYROW
12	12/28/2008	03:23	NO	SNOW		1	UR

CL: Changing lane in roundabout
FC: Following too close
FYBL: Failed to yield to both lanes
FYROW: Failed to yield right-of-way
UR: Unknown reason
WLC: Wrong lane choice

Table B-2 Before-and-after crash data

Open in the year of 2005		K	A	B	C	PDO	TOTAL
Frequency	Before (2002 to 2004)					1	1
	After (2006 to 2008)				2	10	12
Percentage	Before (2002 to 2004)					100%	100%
	After (2006 to 2008)				17%	83%	100%

Table B-3 Crash types for each quadrant (2006-2008)

	Q1	Q2	Q3	Total	100%
Sideswipe	2	4	0	6	50%
Rear-end	2	1	0	3	25%
Angle	1	0	1	2	17%
No	1	0	0	1	8%
Total Crash	6	5	1	12	100%

Table B-4 Crash main cause in order (2006-2008)

Rank	Main Cause	Q1	Q2	Q3	Q4	Crashes
1	FC (Follow too close)	2	1	0	0	3
2	CL (Changing lane)	1	1	0	0	2
	FYBL (Failed to yield both lanes)	2	0	0	0	2
	FYROW (Failed to yield right-of-way)	0	1	1	0	2
	UR (Unknown reason)	1	1	0	0	2
6	WLC (Wrong lane choice)	0	1	0	0	1

Table B-5 Crash type summary year by year

	Angle	Rear-end	Sideswipe	No	
2002	1				1
2005	9/15/2005 Roundabout open to traffic				
2006	0	2	0	0	2
2007	1	1	1	0	3
2008	1	0	5	1	7
2009	0	0	1	0	1
2010	0	0	1	1	2
2011	0	0	2	2	4

The intersection of N. Thompson Dr. and Commercial Ave.

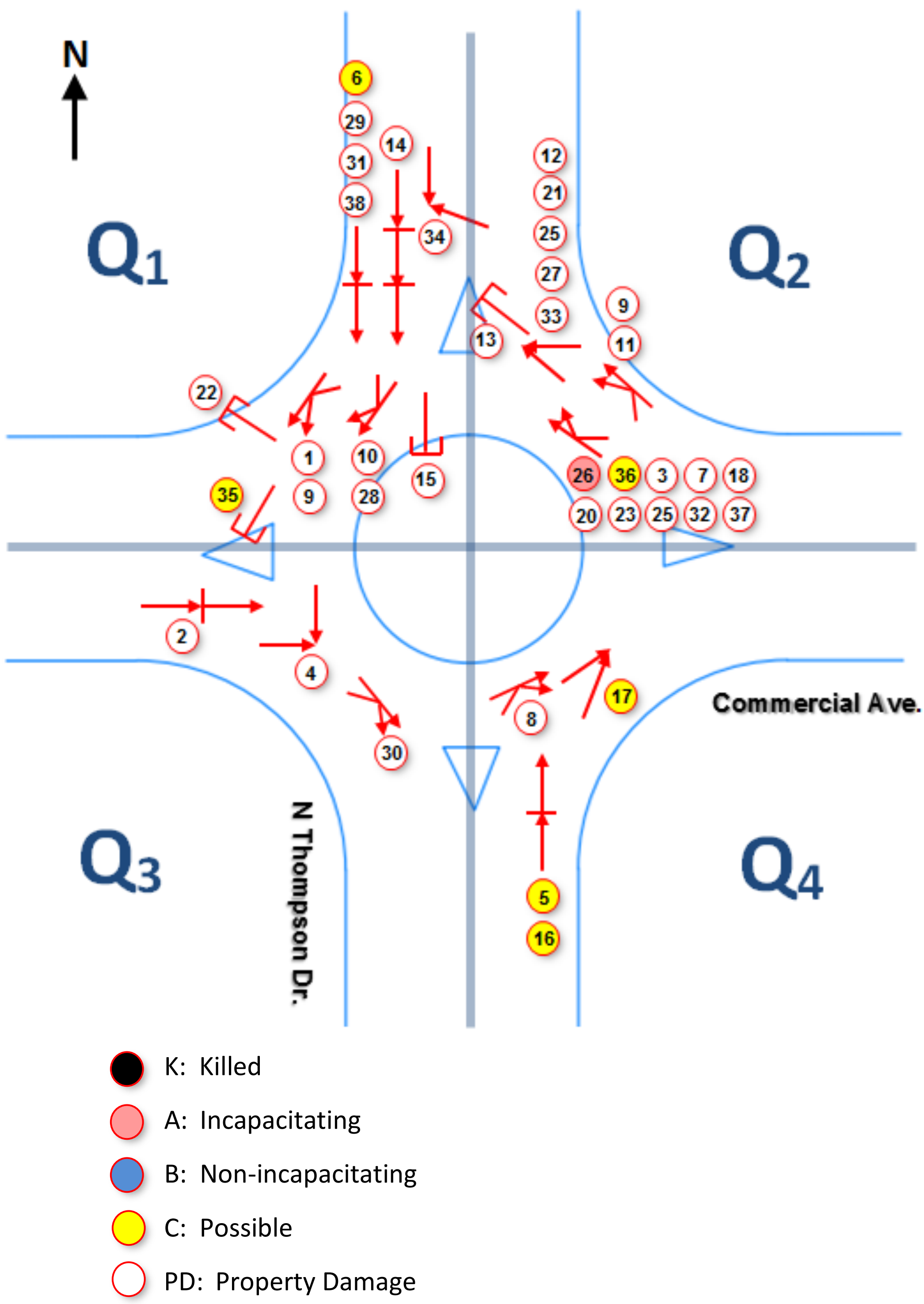

Figure C Crash Diagram of N. Thompson Dr. and Commercial Ave.

Table C-1 Roundabout Crash Summary (2005-2007)

No.	Date	Time	Type	Road Condition	Injure Severity	Q Number	Main Cause
1	2/21/2005	12:05	Sideswipe	Wet		1	FYBL
2	3/15/2005	14:14	Rear-end			3	FC
3	4/11/2005	14:42	Sideswipe			2	FYBL
4	4/20/2005	17:57	Angle			3	FYROW
5	5/10/2005	11:21	Rear-end		C	4	FC
6	5/14/2005	15:15	Rear-end	Wet	C	1	FC
7	5/20/2005	14:23	Sideswipe			2	FYBL
8	5/29/2005	12:18	Sideswipe			4	FYBL
9	6/11/2005	12:40	Sideswipe			2	WLC
10	7/28/2005	16:55	Sideswipe			1	FYBL
11	8/24/2005	18:45	Sideswipe			2	CL
12	9/24/2005	12:04	Angle			2	FYBL
13	10/8/2005	14:30	NO			2	Unknown
14	12/7/2005	08:07	Rear-end			1	FC
15	12/14/2005	13:00	NO	Snow		1	Snow
16	12/20/2005	12:09	Rear-end		C	4	FC
17	1/5/2006	17:50	Angle		C	4	FYBL
18	1/19/2006	14:57	Sideswipe			2	FYBL
19	3/6/2006	07:24	Sideswipe			1	WLC
20	4/3/2006	16:45	Sideswipe			2	FYBL
21	4/20/2006	17:14	Angle			2	FYBL
22	4/29/2006	19:10	NO	Wet		1	Unknown
23	5/27/2006	08:09	Sideswipe			2	FYBL
24	6/27/2006	16:51	Angle			2	FYBL
25	6/28/2006	08:03	Sideswipe			2	FYBL
26	7/12/2006	17:26	Sideswipe		A	2	CL
27	7/13/2006	18:05	Angle			2	FYBL
28	10/16/2006	10:47	Sideswipe			1	FYBL
29	10/25/2006	16:29	Rear-end			1	FC
30	11/7/2006	13:59	Sideswipe			3	FYBL
31	11/20/2006	21:59	Rear-end			1	FC
32	11/25/2006	09:40	Sideswipe			2	CL
33	12/21/2006	11:17	Angle	Wet		2	FYBL

34	2/11/2007	13:53	Angle			1	Inattentive
35	5/5/2007	07:00	NO		C	1	Drinking
36	7/11/2007	13:50	Sideswipe		C	2	FYBL
37	9/7/2007	07:41	Sideswipe	Wet		2	FYBL
38	12/1/2007	10:30	Rear-end	Snow		1	Snow

CL: Changing lane in roundabout
FC: Following too close
FYBL: Failed to yield to both lanes
FYROW: Failed to yield right-of-way
UR: Unknown reason
WLC: Wrong lane choice

Table C-2 Before-and-after crash data

Open in the year of 2004		K	A	B	C	PDO	TOTAL
Frequency	Before (2001 to 2003)	1	1	3	7	7	19
	After (2005 to 2007)		1		6	31	38
Percentage	Before (2001 to 2003)	5%	5%	16%	37%	37%	100%
	After (2005 to 2007)				16%	84%	100%

Table C-3 Crash types for each quadrant (2005-2007)

	Q1	Q2	Q3	Q4	Total	100%
Sideswipe	4	12	1	1	18	47.37%
Rear-end	5		1	2	8	21.05%
Angle	1	5	1	1	8	21.05%
No	3	1			4	10.53%
Total Crash	13	18	3	4	38	100%

Table C-4 Crash main cause in order (2005-2007)

Rank	Main Cause	Q1	Q2	Q3	Q4	Crashes
1	**FYBL (Failed to yield both lanes)**	3	13	1	2	19
2	**FC (Follow too close)**	4	0	1	2	7
3	**CL (Changing lane)**	0	3	0	0	3
4	**WLC (Wrong lane choice)**	1	1	0	0	2
	Snow	2	0	0	0	2
	Unknown Reason	1	1	0	0	2
7	**Drinking**	1	0	0	0	1
	FYROW (Failed to yield right-of-way)	0	0	1	0	1
	ID(Inattentive Driving)	1	0	0	0	1

Table C-5 Crash type summary year by year

	Angle	Rear-end	Sideswipe	No	
2001	6	0	0	0	6
2002	3	4	0	0	7
2003	3	2	1	0	6
2004	**10/18/2004 Roundabout open to traffic**				
2005	2	5	7	2	16
2006	5	2	9	1	17
2007	1	1	2	1	5
2008	2	2	7	5	16
2009	4	3	7	0	16
2010	4	2	5	2	14
2011	1	2	2	1	8