Safety Effectiveness Analysis of Roundabouts in Louisiana

A Thesis

Presented to the

Graduate Faculty of the

University of Louisiana at Lafayette

In Partial Fulfillment of the

Requirements for the Degree

Master of Science

Yi He

Fall 2017

Safety Effectiveness Analysis of Roundabouts in Louisiana

Yi He

APPROVED:

Xiaoduan Sun, Chair
Professor of Civil Engineering

Kenneth McManis
Professor & Head of Civil Engineering

Daniel Gang
Professor of Civil Engineering

Mohammad Jamal Khattak
Professor of Civil Engineering

Mary Farmer-Kaiser
Dean of the Graduate School

Acknowledgments

I would like to thank my thesis advisor, Dr. Sun, a respected professor of the Civil Engineering Department at the University of Louisiana at Lafayette. She guided me through academia with insightful comments and encouragement. She taught me to be an independent and professional researcher. Her office was always open whenever I ran into trouble or had a question about my research. During the two years of study and work with her, I have acquired experience in research and in writing papers for conferences and publications. Most importantly, I learned to see myself in the big picture, which will help to guide my future academic career.

My sincere thanks also go to the committee members of my thesis defense: Dr. Gang, Dr. McManis, and Dr. Khattak. They are the professors with whom I either took classes or engaged in research. Learning with them broadened my vision and understanding of civil engineering from various perspectives.

I thank my fellow lab mates and honest partners, Ashifur Rahman, Sabina Paudel, Ming Sun, and Ege Beyazit for the stimulating discussions, for the sleepless nights we were working together before deadlines, and for all the fun we have had in the last two years. In particular, I am grateful to Dr. Wu for enlightening me with techniques of data mining. Last but by no means least, I would like to thank my wife, my parents, and my late grandfather: I owe it all to them. Many thanks!

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AADT	Average Annual Daily Traffic
LADOTD	Louisiana Department of Transportation and Development
SPF	Safety Performance Function
CMF	Crash Modification Factor
HSM	Highway Safety Manual
FHWA	Federal Highway Administration
AASTHO	American Association of State Highway and Transportation Officials
LTRC	Louisiana Transportation Research Center
PDO	Property Damage Only
EB	Empirical Bayes

Chapter 1: Introduction

1.1 Background

The traffic circle, once regarded as a novel traffic control method, was first introduced in the United States in 1905 by William Phelps Eno with the "Columbus Circle" in New York City (*1*). By giving priority to entering vehicles, the design of the traffic circle naturally allows the traffic flow to merge at higher speeds, which was thought to be a solution to traffic congestion in metropolitan areas. However, the subsequently constructed traffic circles resulted in a large increase in traffic crashes, and the high crash frequency led to more congestion. Therefore, traffic circles fell out of favor in America after the middle of the 1950s (*2*). Meanwhile, the feedback on traffic circles from other countries was equally negative, with an increased number of crashes and more congested locations (*3*). It was thought that the traffic circle was not an effective and safe solution to meet the requirements of growing traffic volume.

Having learned from these bad experiences, in 1966 the United Kingdom proposed the "give-way" principle at all traffic circles (*4*). The main idea of the "give-way" rule is forcing the entering vehicles to give way, or yield, to circulating vehicles. The traffic circle "lock-up" problem was prevented by banning vehicles from entering the intersections until there were sufficient gaps in the circulations. Additionally, designing an appropriate radius of curvature was required in small traffic circles in order to slow the approaching vehicles' speed and mitigate the negative impacts often associated with the high speed of traffic volume in the intersections. These two changes did improve safety effectiveness by reducing both the total number and, particularly, the severity of crashes related to the traffic circles.

The successfully improved traffic circles were the prototype of modern roundabouts. Over time, more circular-sharped intersections appeared, such as rotaries or neighborhood traffic circles. The key features that distinguish roundabouts from the wide range of circular-shaped intersections are: 1) the yield control of entering traffic; 2) the channelized approaches; 3) the appropriate geometric curvature to slow speeds (*5*). Figure 1 shows a typical roundabout, with annotations of these key features.

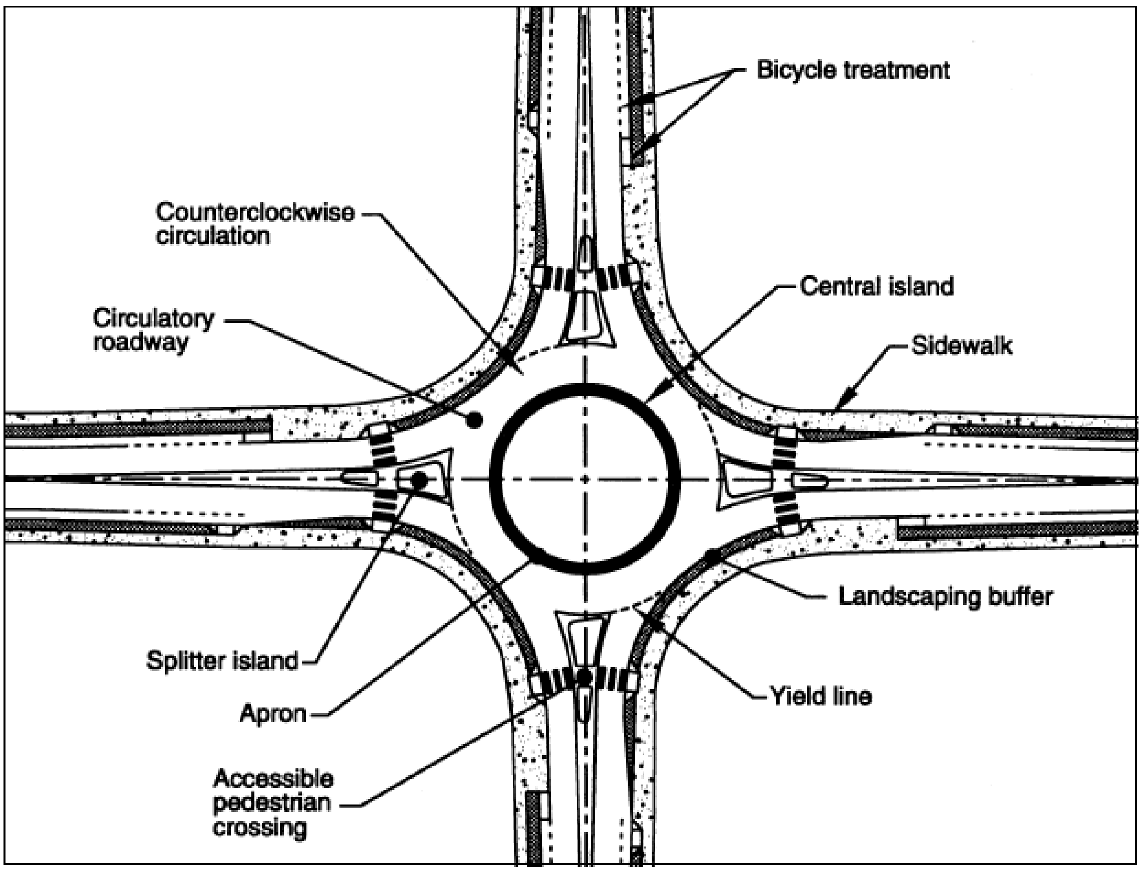

FIGURE 1 Description of key roundabout features.

Roundabout performance in the U.S. and elsewhere in the world has been well-documented (*6*). The benefits of a roundabout are twofold: improving traffic flow efficiency and reducing the number and severity of crashes, particularly injury and fatal crashes. Properly designed, a roundabout can guide all vehicles operating at a lower speed while they negotiate the circle for the intended exit approach. Also, as more maneuvering freedom is given to drivers, i.e., drivers decide when to enter an intersection, the human factor plays a bigger role in roundabout operation than in other types of intersection traffic control (*7*).

Since the first roundabout was introduced to Lafayette, Louisiana 18 years ago, the traveling public has gradually fallen in love with this type of intersection. There are currently more than 30 roundabouts in operation statewide, and hundreds of roundabouts are in the planning and designing stage. As proposed by the Lafayette Metropolitan Planning Organization, 176 roundabouts will be constructed in the city of Lafayette alone. Considering the state's goals for a "Zero Death Zone (*8*)," and with more roundabouts proposed for state and local roadways in the future, it is important for the state to evaluate the roundabout operation experience and its impact on roadway safety.

1.2 Scope of the Study

The locations of the 30 roundabouts in Louisiana which have been constructed or proposed are shown in Figure 2. To minimize the effect of regression-to-the-mean, the safety performance of 19 roundabouts that have been in operation for at least three years is comprehensively analyzed, among the 30 roundabouts in this study. The roundabouts on the new highways are excluded from this analysis due to the lack of previous years' crash data for comparison with post-construction data.

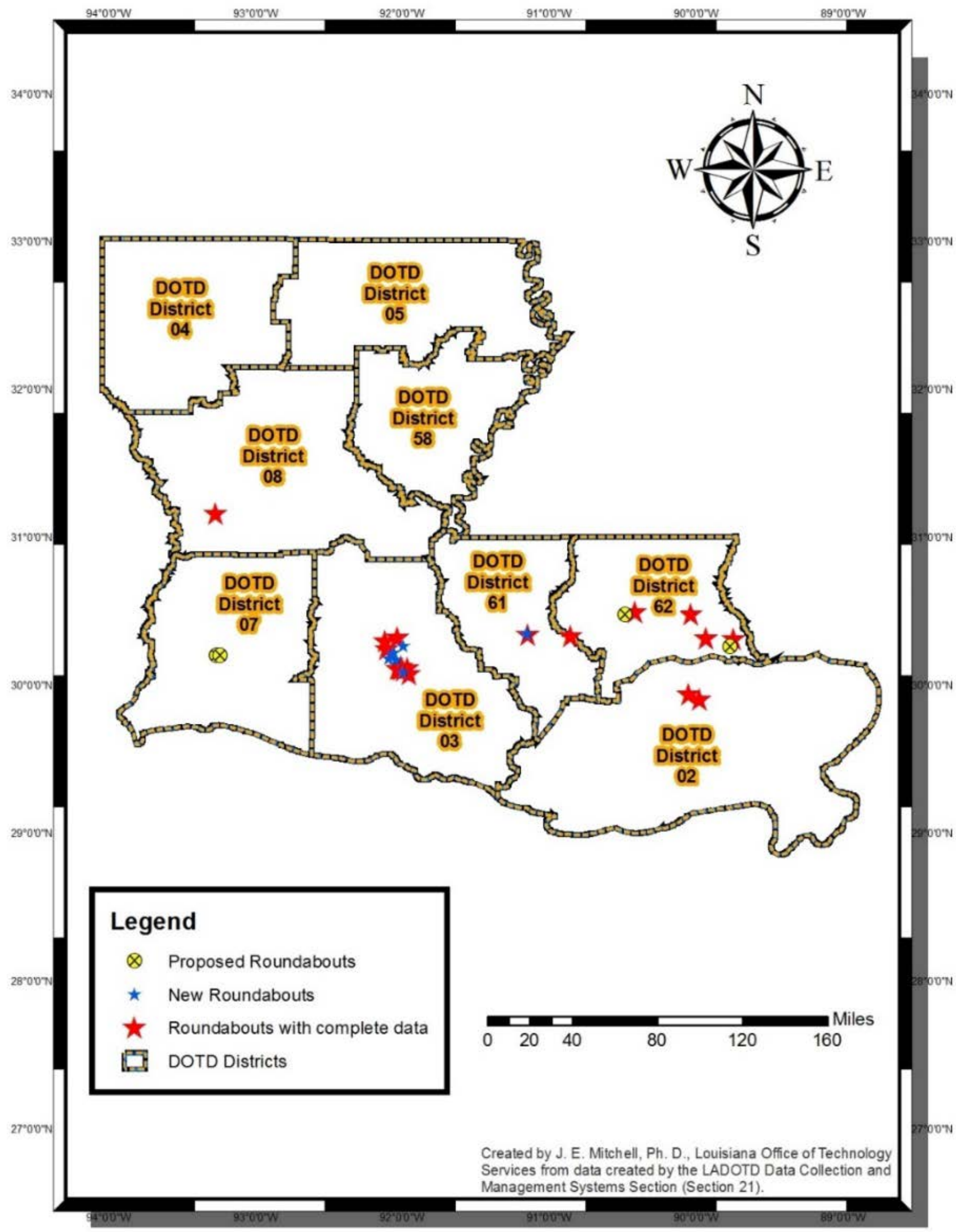

FIGURE 2 Roundabout locations in Louisiana.

1.3 Objectives

By conducting a comprehensive safety performance analysis on the roundabouts, the specific objectives are to:

(1) Investigate the safety impact of each roundabout with before-and-after crash characteristics analysis;

(2) Develop a crash modification factor (CMF) that matches the Louisiana experience;

(3) Estimate the safety benefit-cost performance of the roundabouts.

1.4 Thesis Outline

Chapter 1 is primarily an introduction about the roundabout. In chapter 2, the safety performance of the roundabout in other research studies is presented in detail. Chapter 3 presents the data collection method, the data interpretation, and the information gained from the data. In chapter 4, four intersections are selected as examples for presenting the pros and cons of converting the intersections, previously controlled by different traffic facilities, into the existing roundabouts. The before-and-after study using the empirical Bayes (EB) method is discussed in detail in chapter 5. The research results and discussions can be found in chapters 6 and 7.

Chapter 2: Literature Review

2.1 Safety Performance of Roundabout

Roundabout safety performance has been well-documented. Many studies in the U.S., Europe, and Australia have found that the safety performance of roundabouts is better than that of any other types of intersections (*9*-*12*). The reasons why roundabouts might improve intersection safety may be summarized in the following three points:

(1) Roundabouts have fewer conflicting points than other traditional intersections, particularly the single-lane roundabouts. The reduced number of conflicting points means a smaller probability of crashes for road users. Figure 3 shows the different pattern of the conflicting points between the traditional "T" intersections (with three approaches) and roundabouts. Figure 4 reveals the difference of the conflicting points between traditional cross intersections (with four approaches) and roundabouts.

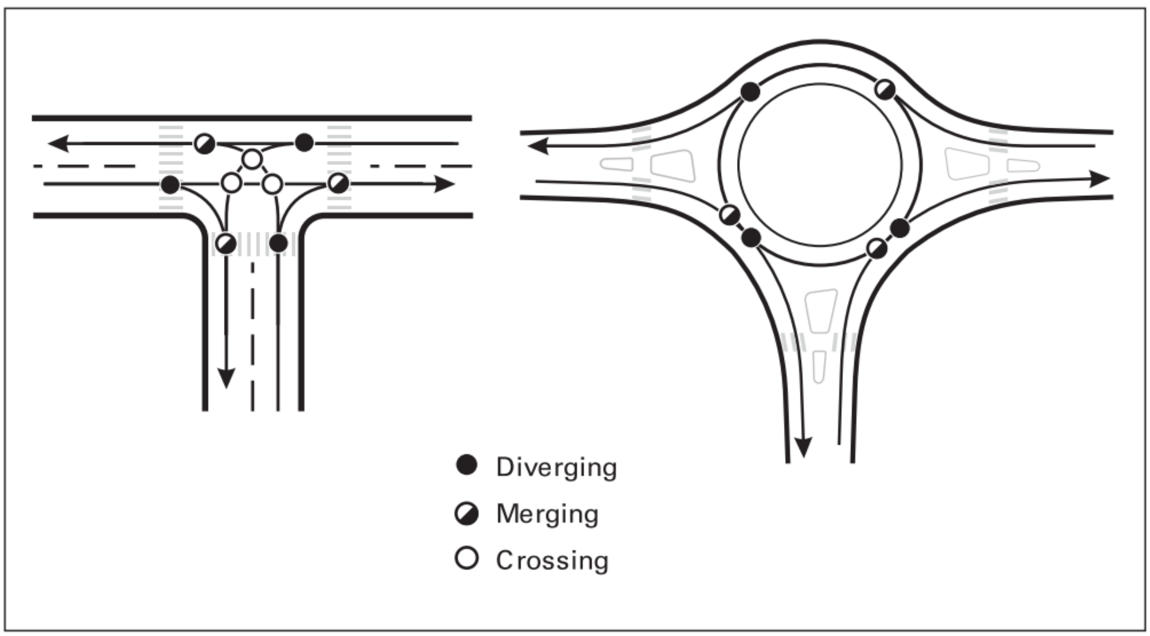

FIGURE 3 Conflicting points comparison for the "T" intersections (single-lane).

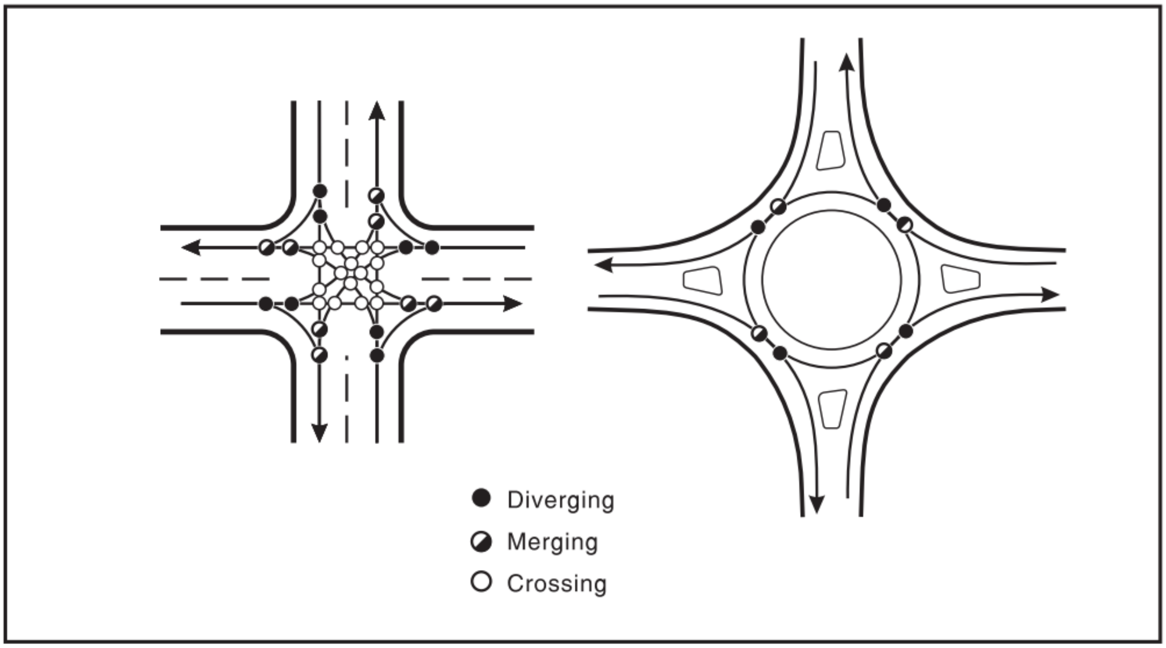

FIGURE 4 Conflicting points comparison for the cross intersections (single-lane).

(2) The physically geometric design of roundabouts helps in reducing both the absolute speed and the relative speed of vehicles entering or circulating in the intersection. A lower absolute speed allows for a longer reaction time in order to avoid potential crashes. The lower relative speed mitigates traffic flow, which sharply reduces crash severity, compared with other traditionally controlled intersections.

(3) Roundabouts are easier to navigate for pedestrians and bicycle riders, since they need only cross one direction of traffic at a time at each approach, when they travel across the intersections. In addition, the distances they need to cross are shortened by good design. Figure 5 illustrates the comparison of the cross distances and conflicting points for pedestrians and bicycle riders in the same intersection but with different designs.

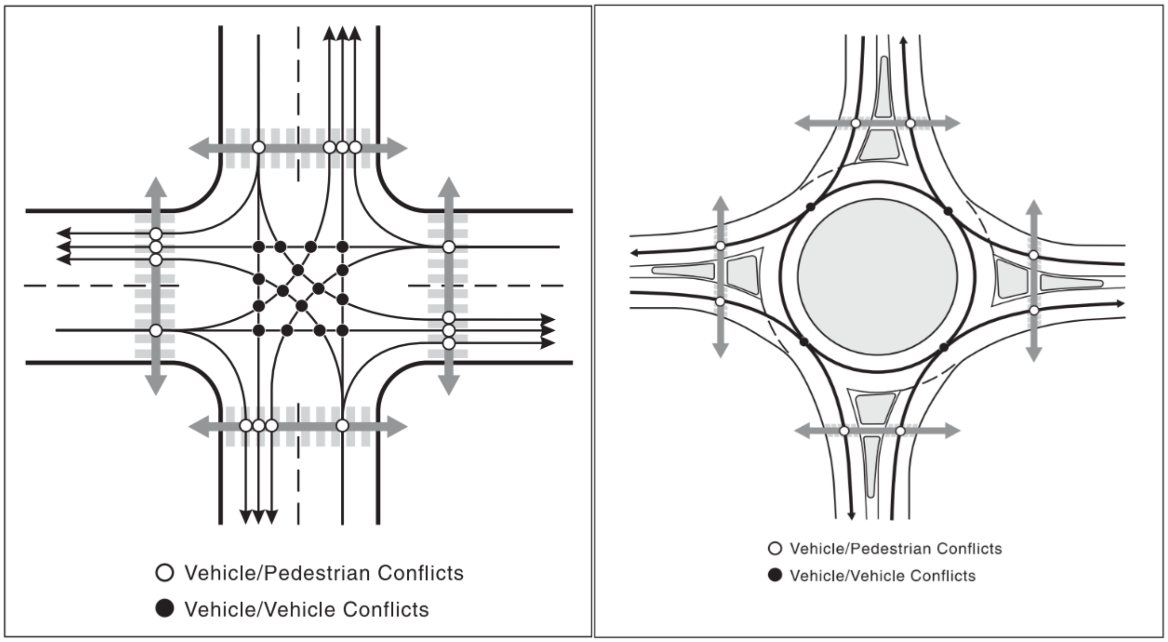

FIGURE 5 Vehicle-Pedestrian conflicting points at the traditional intersections and roundabouts.

2.2 Characteristics of Roundabout-Related Crashes

The frequency of reported crashes occurring at roundabouts is not always lower than those that take place at other types of intersections. However, by good design, the roundabout has been proven to be an efficient traffic control method that significantly helps reduce the severity of crashes (*13*). Particularly at small and medium capacity roundabouts, safety performance is better than at large or multi-lane roundabouts (*14*). Diminishing the left turn and head-on collisions, roundabouts also reduced the occurrences of right angle, right turn, and sideswipe collisions. In general, crashes occurring at roundabouts tend to be less severe than those at conventional intersections.

However, as more maneuvering freedom is given to drivers at roundabouts, i.e., drivers decide when to enter an intersection, the human factor plays a bigger role in roundabout operation than in other types of intersection traffic control. As a result, most crashes reported at roundabouts are cited as having been caused by drivers who “failed to yield” to the circulating traffic on entry (*15*). It has also been reported that roundabouts produced 20% more rear-end collisions and 27% more single vehicle collisions, which normally were considered as less-severe minor injury crashes, compared to other types of collisions (*16; 17*). The same study indicates that younger drivers, between 16 to 24 years old, have a 50% higher probability of being involved in rear-end and single vehicle crashes in roundabouts than middle-aged and older drivers. Additionally, the research concluded that the proper pavement marking at the approaching lane might significantly reduce the number of rear-end collisions, and that the landscaped central island has a positive impact on reducing single vehicle crashes and severity.

Considering that not all the roundabouts that were selected in the studies conform to the geometric design and configuration standards, previous research does not yield similar results. The Wisconsin roundabout studies published in 2011 (*18*) and 2013 (*19*) indicated that even though roundabouts significantly reduced the severity of crashes from more than 50 roundabouts selected, a 38% reduction in injury and fatal crashes was found. The changes in Property Damage Only (PDO) crashes varied by location and resulted in a 12% increase in total crashes. The intersections with stop signs on minor roads had the largest reductions in total and injury crashes after converting to roundabout. At the signalized and all way stop intersection, the injury crashes dropped 59% and 51%, and the total crashes rose 5.5% and 23.5%, respectively.

2.3 Empirical Bayes Method on Roundabout Safety Analysis

A notable before-and-after study with the Empirical Bayes (EB) method comes from the National Cooperative Highway Research Program (NCHRP) in 2007 (*6*). The NCHRP study collected data on 310 roundabouts from previous research conducted between 1997 and 2007 in the U.S. It included 6% roundabouts in rural areas and 94% in urban and suburban areas, which previously were comprised of 9% signalized intersections, 51% one-way or two-way stop intersections, and 10% all way stop intersections, with the remaining 30% being newly constructed roundabout intersections. The study selected 55 roundabout locations that had complete design and traffic volume information, as well as sufficient pre- and post-construction crash data (before 3 to 7 and after 3 to 4 years). The total number of crashes from all 55 roundabouts decreased 37% (from 1,159 to 726), which included a reduction of 59% in fatal crashes and a 76% reduction in injury. As the study revealed, the crash reductions differed between the previous traffic control types. By utilizing the before-after analysis method, the study showed the expected reductions in total crash and injury crash to be 45% and 76%, respectively, for signalized intersections and 44.2% and 81.8%, respectively, for stop sign on minor road intersections. For the all way stop sign intersections, the total and injury crashes increased 3.3% and 28%, respectively. The first edition of Highway Safety Manual (HSM) uses the results of this NCHRP study in computing the roundabout CMF as 0.56 for total crashes and 0.18 for injury and fatal crashes for roundabouts with a previous minor road stop control. For signalized intersections, the CMF from the HSM is 0.52 for total crashes and 0.22 for injury and fatal crashes. For all way stop intersections, the CMF from the HSM is 1.03 for total crashes.

From the above review, it is clear that the safety benefits of a roundabout can vary significantly depending upon the previous type of traffic control and the study location. There are inconsistent results between the different intersection traffic control types and land use conditions. Roundabouts have been recognized as the most complex intersection design, requiring special design expertise and operation experiences. Very few of the previous studies mentioned design factors in the performance evaluation. Considering Louisiana's unique roadway safety characteristics and needs, the evaluation of roundabout safety in the installation of future roadway facilities is needed.

Chapter 3: Data Analysis

3.1 Data Collection and Verification

The roundabout locations in Louisiana were obtained from the Louisiana Department of Transportation and Development (LaDOTD). The LaDOTD currently lists 30 roundabouts in operation in Louisiana. A review shows there are 24 roundabouts that are in place, and six roundabouts are proposed but not constructed. In order to apply the before-and-after study, 19 of the 24 roundabouts, which have been in operation for at least three years, were selected as the crash data source for this investigation. The basic information on these 19 locations is listed in Table 1.

TABLE 1 Summary Information of Nineteen Roundabouts

No.	**Intersection**	**Prior Traffic Control Type**	**AADT**	
			Before	**After**
1	LA 8 LA28 @ US 171	Signalized (T to 4-way mixed lane)	14,800	21,300
2	LA 59 @ LA 36	Signalized (4-way)	23,400	25,267
3	LA 1091 @ Brownswitch Rd	Signalized (4-way)	29,800	29,700
4	LA 431 @ LA 42	Stop on minor road (T)	18,367	17,733
5	US 190 @ LA 434	Stop on minor road (T)	24,833	18,300
6	LA 93 @ St Mary/LA 3168	Stop on minor road (4-way)	11,617	12,100
7	LA 428 at Mardi Gras	Stop on minor road (4-way)	6,133	6,000
8	E Milton/LA 92 @ Bonin	Stop on minor road (4-way)	9,433	9,500
9	Lafayette/LA 89 @ Iberia/LA 92	Stop on minor road (T to 4-way)	18,300	22,833
10	Hector Connoly @ E Angelle	Stop on minor road (T to 4-way)	13,000	13,500
11	E Fairfield @ S Morgan	Stop on minor road (T to 4-way)	6,555	6,997
12	A 327 River Rd. @ LA 327 Gardere	Stop on minor road (T to 4-way)	6,897	7,900
13	E Milton/LA 92 @ Chemin Metairie	Stop on minor road (T to 4-way)	10,702	11,469
14	Chemin Metairie @ Viaulet	Stop on minor road (T to 4-way)	800	800
15	E Milton/LA 92 @ Verot School/LA 339	All way stop (4-way)	40,533	35,033
16	Gloria Switch/LA 98 @ LA 93	All way stop (4-way)	22,400	23,767
17	Bonin @ Fortune	All way stop (4-way)	7,277	7,277
18	LA 3158 @ Old Covington Rd	All way stop(4-way)	8,333	9,300
19	LA 406 @ LA 407	All way stop(T)	20,833	22,500

One roundabout has a mixed lane configuration (50% single-lane and 50% multi-lane) and the remaining 18 roundabouts are single-lane roundabouts. All of the 19 roundabouts are currently located in urban areas, based on the roadway information. Using Google Maps, it can be ascertained that only a few roundabouts are located in suburban areas. However, the LaDOTD database does not separate the suburban from the urban, probably because of the dynamic change and expansion of suburban areas.

The previous intersections' traffic control methods varied before they were converted to roundabouts. The majority of these intersections (16 out of 19) had Annual Average Daily Traffic (AADT) less than 25,000 and three of them had an AADT greater than 25,000. Based on the FHWA design guideline (*7*), a one-lane roundabout is suitable for an AADT with less than 25,000, and two lanes are acceptable for an AADT value between 25,000 and 45,000.

To accurately identify intersection crashes, the team did not just rely on the indicator of the crash database (1 for an intersection-related crash and 0 for a non-intersection-related crash). For each intersection, all crashes within a 500-feet radius were examined by reviewing the crash narratives from the original crash reports to see if they were intersection-related or not. The radius from the center of the intersection even went to 3,000 feet for one location that experiences severe peak-hour traffic congestion. In a detailed review of more than 1,000 individual crash reports, it was possible to identify more intersection-related crashes and to correct several crash coding errors. The original crash reports were a great source of information which provided additional information concerning the what and the how of the crash, as well as the driver (or road user) and environmental conditions occurring before, during, and after a crash.

3.2 Louisiana Crash Characteristics Analysis

The observed crash severities for each location before and after a roundabout project are listed in Table 2.

TABLE 2 Observed Crashes by Severity Before and After Roundabout

Intersection	Year*	Fatal Crashes		Injury Crashes		PDO**	
		Before	After	Before	After	Before	After
LA 8 LA28 @ US 171	2011	1	0	18	12	13	55
LA 59 @ LA 36	2007	0	0	3	3	11	6
LA 1091 @ Brownswitch Rd	2012	0	0	8	2	12	25
LA 431 @ LA 42	2012	0	0	8	1	18	8
US 190 @ LA 434	2013	0	0	2	0	8	6
LA 93 @ St Mary/LA 3168	2013	0	0	9	3	26	7
LA 428 at Mardi Gras	2013	0	0	24	4	19	0
E Milton/LA 92 @ Bonin	2011	0	0	3	2	7	6
Lafayette/LA 89 @ Iberia/LA 92	2012	0	0	1	0	5	8
Hector Connoly @ E Angelle	2012	0	1	0	1	0	3
E Fairfield @ S Morgan	2007	0	0	0	0	0	3
LA 327 River Rd. @ LA 327 Gardere	2011	0	0	1	0	2	0
E Milton/LA 92 @ Chemin Metairie	2008	0	0	0	3	1	16
Chemin Metairie @ Viaulet	2013	0	0	2	1	0	1
E Milton/LA 92 @ Verot School/LA 339	2011	0	0	8	8	26	29
Gloria Switch/LA 98 @ LA 93	2011	0	1	5	3	13	10
Bonin @ Fortune	2011	0	0	3	0	3	8
LA 3158 @ Old Covington Rd	2010	1	0	3	2	4	21
LA 406 @ LA 407	2010	0	0	1	2	1	0
Total		**2**	**2**	**99**	**47**	**169**	**212**

** Year = the year that roundabout construction projects started.*
*** PDO = property damage only crashes*

As shown in Table 2, the number of fatal crashes remains the same. The two fatal crashes occurring at two different roundabouts involved a single motorcycle running-off-roadway (ROR); while the two fatal crashes occurring before the roundabout installations were right angle collisions. There is a 52% reduction in injury crashes and a 25% increase in the PDO crashes at the aggregated level. However, there are significant variations among individual intersections, particularly among the intersections with different previous traffic control types.

By dividing the 19 intersections into three categories based on their previous traffic control type, Table 3 shows some patterns in the changes of the crashes.

TABLE 3 Changes of Crashes by Prior Traffic Control Type

Categories	**Type of Prior Traffic Control**	**Year of Construction**	**Changes in Total Crashes**	**Changes in Number and Percentage by Group**
1	Signalized (T to 4-way mixed lane)*	2011	+35	+37 (+56%)
	Signalized (4-way)	2007	-5	
	Signalized (4-way)	2012	+7	
2	Stop on minor road (T)	2012	-17	-62 (-46%)
	Stop on minor road (T)	2013	-4	
	Stop on minor road (4-way)	2013	-25	
	Stop on minor road (4-way)	2013	-39	
	Stop on minor road (4-way)	2011	-2	
	Stop on minor road (T to 4-way)	2012	+2	
	Stop on minor road (T to 4-way)	2012	+5	
	Stop on minor road (T to 4-way)	2007	+3	
	Stop on minor road (T to 4-way)	2011	-3	
	Stop on minor road (T to 4-way)	2008	+18	
	Stop on minor road (T to 4-way)	2013	0	
3	All way stop (4-way)	2011	+3	+16 (+24%)
	All way stop (4-way)	2011	-4	
	All way stop (4-way)	2011	+2	
	All way stop (4-way)	2010	+15	
	All way stop (T)	2010	0	
Total Change			**-9 (-3%)**	

* *"T" is the three approaches intersection, "4-way" is the four approaches cross intersection.*

It is clear that the 11 roundabouts previously controlled by stop signs on minor roads experienced the best safety benefits, particularly for the five roundabouts with no layout changes (the same number of approaches before and after). The results of the other two groups are not consistent. In this case, the roundabouts previously controlled by stop signs on minor roads are classified in two groups by their alignment design, with or without the layout change.

Table 4 lists the changes in crash severity by four groups categorized by the previous type of traffic control and alignment design. The fatal crashes are not listed because the sample size is too small to be analyzed (2 before, 2 after). Three groups had an injury crash reduction. The best safety performance for the group was found in the intersections with stop sign on the minor road without layout change. Table 5 shows the changes by the type of crash and group. The angle crash in Table 5 includes: right-angle crash, right turn crash, and sideswipe crash.

TABLE 4 Changes in Severity of Crashes by Group

Number of Intersections in Each Group	Previous Traffic Control	Injury Crashes			PDO			Overall
		Before	After	Change	Before	After	Change	Change
3	Signalized (Group 1)	29	17	-41%	36	86	+139%	+56%
5	Stop Sign on Minor Road without Layout Change (Group 2)	46	10	-78%	78	27	-65%	-70%
6	Stop Sign on Minor Road with Layout Change (Group 3)	4	5	+25%	8	31	+287%	+208%
5	All Way Stop (Group 4)	20	15	-25%	47	68	+45%	+24%

TABLE 5 Changes in Type of Crashes by Group

Previous Traffic Control	**Angle-Crash**			**Rear-End**			**Single-Vehicle**		
	Before	**After**	**Change**	**Before**	**After**	**Change**	**Before**	**After**	**Change**
Signalized (Group 1)	35	72	+106%	24	16	-33%	7	15	+114%
Stop Sign on Minor Road without Layout Change (Group 2)	83	11	-87%	29	16	-45%	12	10	-17%
Stop Sign on Minor Road with Layout Change (Group 3)	6	11	83%	2	12	+500%	4	12	+200%
All Way Stop (Group 4)	25	18	-28%	31	39	+26%	10	27	+170%
Overall	**149**	**112**	**-25%**	**86**	**83**	**-3%**	**33**	**64**	**+94%**

In general, the safety benefit of a roundabout comes from the reduced operating speed of vehicles, the changed traffic control method for the conflicting flow, and the reduced number of conflicting points compared to the prior type of traffic control methods. Intersections with stop sign on the minor street experienced the biggest reduction in number of conflicting points. Signalized and all way stop intersections handle the conflicting points by signals and right-of-way rules. After an intersection is converted to a roundabout, drivers have the freedom to decide when to enter an intersection. More freedom comes with more responsibility.

The initial results show a large crash increase in Groups 1, 3, and 4, which somewhat indicates that not all drivers handle the added freedom of the roundabout properly in intersections that were previously controlled by signals and stop signs. The poor performance of group 3 may also be explained by an increased number of conflicting points, which will be discussed more later. In summary, the above Louisiana crash characteristics analysis reveals the following:

(1) Roundabouts reduced the injury crashes significantly because of the elimination of left turn and head-on collisions and reduced right-angle, right turn, and sideswipe collisions (Table 2 and 4);

(2) Single vehicle running off roadway crashes increased significantly in the three underperforming groups (Table 5);

(3) The prior type of traffic control used makes a big difference in crash change by severity and type (Table 4);

(4) Roundabouts produced the biggest safety benefit in every aspect for intersections with stop sign on minor roadways without layout change (Table 4 and 5).

Two questions arose from the initial findings. 1) Is the prior type of traffic control solely responsible for roundabout safety performance? 2) Should the state DOTD (the Department of Transportation and Development) reconsider converting a signalized or an all way stop sign-controlled intersection to a roundabout only for safety improvement? Considering the inconsistent results within the same traffic control group, an in-depth investigation on each intersection was conducted to explore other potential compounding factors, producing more interesting and even intriguing site-specific observations.

Chapter 4: In-Depth Research

One intersection from each of the four groups that had the largest crash increase, in both the absolute numbers and percentage of crashes, is selected for discussion in this paper. One roundabout from Group 4 (which was all way stop sign controlled previously) is selected to investigate the reason for an increased number of single-vehicle crashes. One roundabout from Group 1 (traffic signal controlled previously) is selected to analyze how the additional approaching lane impedes the safety performance of roundabouts. One roundabout from Group 3 illustrates how the land use change can increase the traffic volume and further affect safety performance at the intersection. Finally, one roundabout from Group 2 with the greatest reduction in the number and severity of crashes is selected for a detailed investigation to determine the reasons for its good safety performance.

4.1 Effect of Lighting Condition

As shown in Table 6, clearly there is a problem at night for the vehicles negotiating the roundabouts in Group 3 and Group 4. The number of crashes occurring at night increased 600% and 100% for intersections in Groups 3 and 4, respectively. When only considering the single vehicle running out of the roadway (ROR) crashes, the number increased 400% for Group 1 and 3, and 450% for Group 4. The total crashes occurring for all groups of intersections increased 13.2% during the daytime and 19.8% at night. However, the pattern is different when looking into the total ROR crashes. The ROR crashes increased 46.2% in daylight conditions, and sharply rose by as much as 207% for nighttime conditions. Additionally, in Group 4, the roundabouts converted from all way stop sign controlled intersections, all five roundabouts have no streetlight.

TABLE 6 Changes in Total Crashes and ROR Crashes by Lighting Condition

Roundabout Group	Daylight		Dark		Single vehicle ROR				Street Light Installed (Yes / No)
					Daylight		Dark		
	Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	
Group 1	42	81	24	22	3	9	1	5	All Yes
Group 2	90	23	34	14	5	4	7	6	3 Yes; 2 No
Group 3	9	16	3	21	0	1	2	10	3 Yes; 3 No
Group 4	48	44	20	40	5	5	4	22	All No
Overall	**189**	**164**	**81**	**97**	**13**	**19**	**14**	**43**	**9 Yes; 10 No**

In this case, in order to investigate why the number of single vehicle crashes increased, the crashes were reviewed with lighting condition. By further reviewing crash narratives and diagrams, it was determined that these single vehicle crashes were caused by drivers not recognizing the existence of the roundabout at night. One typical example is shown in Figure 6, where LA 3158 intersects with Old Covington Road.

FIGURE 6 Before-and-after images of LA 3158 at Old Covington Hwy. roundabout.

This is a roundabout converted from an all way stop sign controlled intersection with the AADT less than 10,000. The basic crash information is listed in Table 7.

TABLE 7 Before-and-After Crash Information of LA 3158 at Old Covington Hwy. Intersection

Crash Type		Intersection Crashes		
		Before	**After**	**After-after**
Total Crash		8	23	15
Severity	Fatal	1	0	1
	Injury	3	2	1
	PDO	4	21	13
Manner of collision	Single Vehicle	0	9	8
	Rear-end	5	9	5
	Head-on	1	0	0
	Angle Crash	2	5	2
Lighting condition	Daytime	5	14	6
	Dark	3	9	9
Heavy Truck		0	2	0
Motorcycle		1	1	1
Alcohol/Drug		1	2	5
Distracted Driver		0	1	1

The traffic volume increased from 8,333 vehicles per day to 9,300 vehicles per day. From Table 7, total crashes increased from 8 to 23 after the conversion to roundabout. Fatal crashes were eliminated in the first three years (2011-2013) with the roundabout, but were observed again during the period from the 4th year to the 6th year (from 2014 to 2016). The injury crashes show a constant decreasing trend (from 3 to 2 to 1). The crash rate increased from 0.88 (in 2007-2009) to 2.26 (in 2011-2013) and reduced to 1.44 (in 2014-2016).

The number of crashes at this roundabout increased 188% while the traffic volume only increased by 12%, and ROR crashes increased from zero to nine in the first three years (shown in Figure 7), and to eight, including one fatal motorcycle crash (shown in Figure 8), between the 4th and the 6th year in operation. It was found that all 17 (nine plus eight in the six roundabout operation years) ROR crashes occurred at night. Without traffic light installment, the proportion of crashes occurring in the dark increased from 38% to 39% to

60%, which is indicative of a poor visibility problem. It is possible that, before the roundabout, a few careless or aggressive drivers did not stop at night when passing through the intersection, with crashes due to the low traffic volume. The roundabout has not been compatible with bad driving behavior at this intersection.

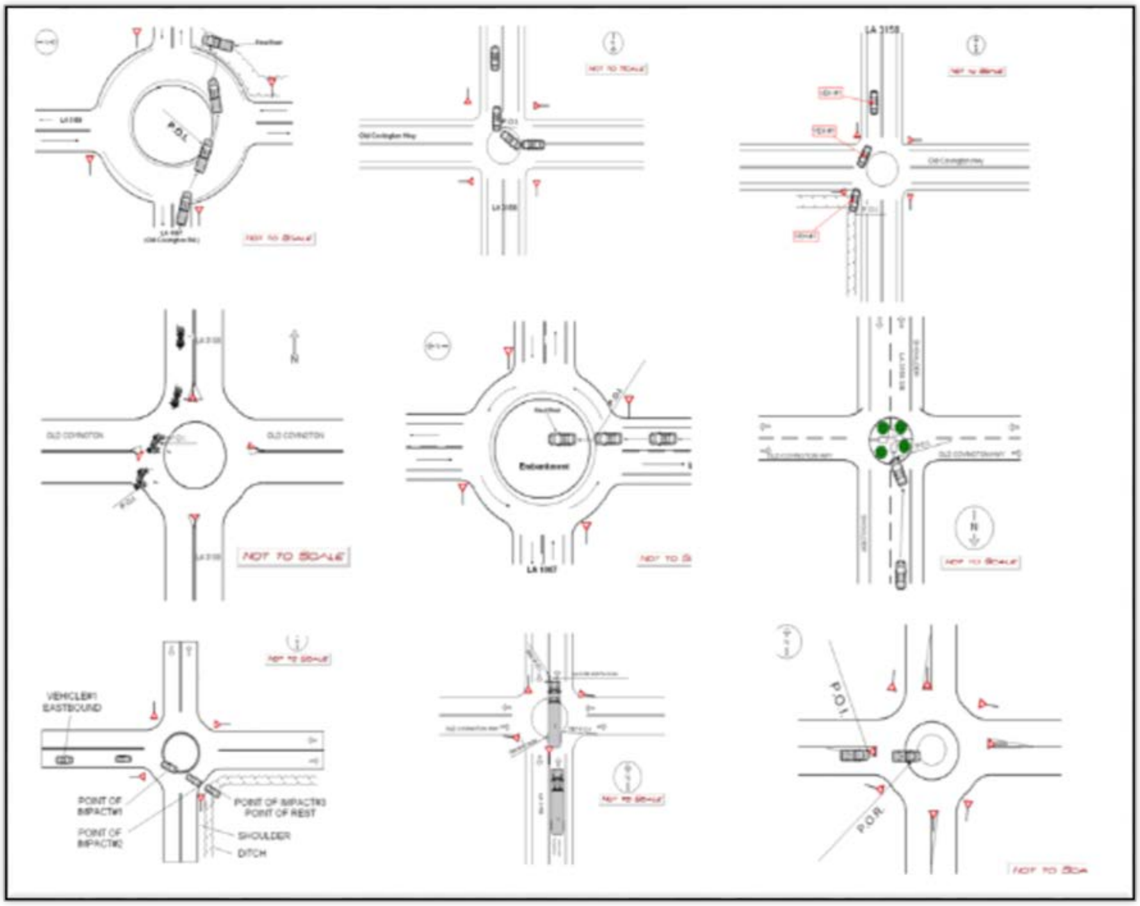

FIGURE 7 Nine ROR crashes at LA 3158 at Old Covington Hwy. roundabout during 2011 to 2013.

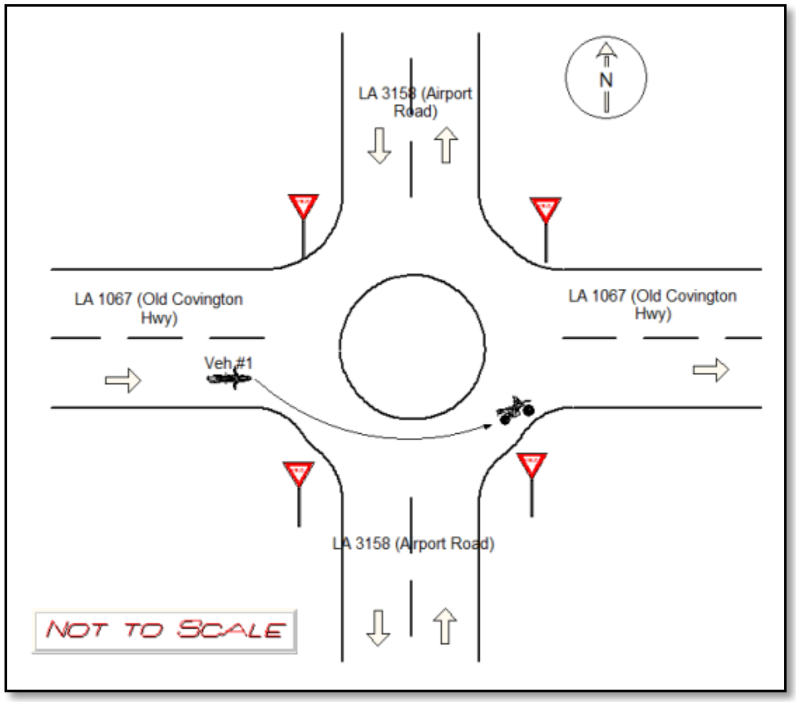

FIGURE 8 Fatal ROR crashes at LA 3158 at Old Covington Hwy. roundabout in 2015.

As indicated by the CMF published in the first edition of HSM, intersection lighting provides visibility for motorists, thus reducing, if not eliminating, the number of ROR crashes at night. Based on the FHWA roundabout design guild book (*7*), intersection lighting is not mandatory outside city limits due to its significant installation cost. However, in this case, the roundabout should be well-signed to provide precise information at night. The FHWA roundabout design guild book states, in Section 7.3.1.3, “The use of reflective pavement markers and retroreflective signs (including chevrons and the ONE-WAY signs) should be used when lighting cannot be installed in a cost-effective manner.” A flashing warning light was installed at this site, but it is the only intersection that installed a flashing warning light at the approach to the roundabout. However, the warning light is still inadequate for reducing bad lighting conditions related to crashes, as seen in the crash data from before and after the roundabout construction. Sufficient lighting could most likely help drivers to avoid ROR crashes.

4.2 Effect of Layout Design

For intersections with a number of approaches increasing from three to four, and with a stop-sign controlled system (on minor road) before, the observed crash reduction is not as great as that in the group without the change in number of approaches. It is worthwhile to note that enhancing connectivity and intersection capacity was the main motivation for roundabout conversion. In other words, these roundabouts were not built for safety improvements. It may not be fair to compare the safety of a three-leg intersection with a four-leg intersection because of the increased number of conflict points. As a matter of fact, changes in the number of conflicting points could, to a certain degree, explain the difference in crash reduction or increase among the four groups. Table 8 lists the changes in the number of conflicting points and their control mechanism at each intersection before and after the roundabout conversion.

TABLE 8 Number of Conflicting Points and Control Mechanism Before-and-After

Roundabout No. *	Before		After	
	Number of conflicting points	**Controlled by**	**Number of conflicting points**	**Controlled by**
1	Diverging: 3 Merging: 3 Crossing: 3 Total: 9	Traffic signal with LT phase	Diverging: 7 Merging: 10 Crossing: 4 Total: 21	
2	Diverging: 8 Merging: 8 Crossing: 16 Total: 32	Traffic signal with LT phase	Diverging: 4 Merging: 4 Crossing: 0 Total: 8	
3	Diverging: 8 Merging: 8 Crossing: 16 Total: 32	Traffic signal with LT phase	Diverging: 7 Merging: 8 Crossing: 0 Total: 15	
4, 5, 6 (T)	Diverging: 3 Merging: 3 Crossing: 3 Total: 9	Stop sign on minor road	Diverging: 3 Merging: 3 Crossing: 0 Total: 6	Yield sign control at entrance
7, 8 (4-way)	Diverging: 8 Merging: 8 Crossing: 16 Total: 32	Stop sign on minor road	Diverging: 4 Merging: 4 Crossing: 0 Total: 8	
9, 10, 11, 12, 13, 14 (T to 4-way)	Diverging: 3 Merging: 3 Crossing: 3 Total: 9	Stop sign on minor road	Diverging: 4 Merging: 4 Crossing: 0 Total: 8	
15, 16, 17, 18 (4-way)	Diverging: 8 Merging: 8 Crossing: 16 Total: 32	All way stop	Diverging: 4 Merging: 4 Crossing: 0 Total: 8	
19 (T)	Diverging: 3 Merging: 3 Crossing: 3 Total: 9	All way stop	Diverging: 3 Merging: 3 Crossing: 0 Total: 6	

* *The No. code for each roundabout is consistent with Table 1.*

Installation of a roundabout generally reduces the number of conflicting points. However, the intersections with the same initial traffic control (stop sign on minor road) but with a changed layout (three approaches before and four after roundabout conversions) did not gain the same safety benefit because of the smaller reduction in conflicting points (only a reduction of nine to eight), as shown in Figure 9. All intersections had a reduction in the number of conflicting points except intersection 1. The results in Table 8 explain why intersection 1, which previously used a traffic signal to separate all conflicting flows, experienced more than a 50% crash increase. This increase is attributed to the greater number of conflicting points currently controlled by yield signs. Roundabouts should eliminate all crossing conflicting points, but the design of intersection 1 did not. The intersections with the same initial traffic control (stop sign on a minor road) but with a changed layout (three approaches before and four after roundabout conversions) did not gain the same safety benefit because of the smaller reduction in conflicting points.

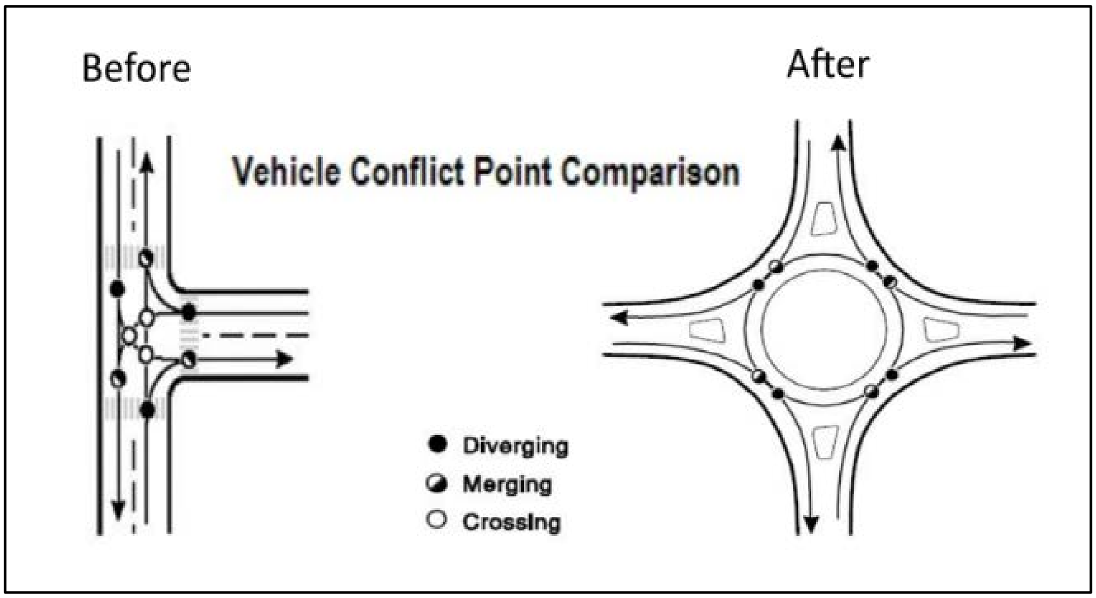

FIGURE 9 Change of conflicting points at intersection with layout change.

Following the same argument, the increased crashes at the signalized intersection could be explained by changes in the number of the conflicting points. The intersection from Group 1 that experienced the highest crash increase —from 32 to 67 — is shown in Figure 10. This intersection was changed from a three-approach to a four-approach intersection because of a new supermarket at the west-north corner.

FIGURE 10 Before-and-after images of LA 8/28 at US 171 intersection.

Several elements in this roundabout violate the common roundabout design guidelines. First, it has a mixed number of lanes (50% single-lane and 50% multi-lane), which causes confusion even with the pavement marking showing that the inner lane is for through and left-turn vehicles. When entering the roundabout from the left, highlighted in red, left-turn vehicles must make a quick and correct decision to swiftly move to the inner lane in a very short distance, if drivers can recognize the lane assignment – which is very difficult since there is no sign or pavement markings. The outer lane is designated (and marked) for through traffic. The geometric design significantly increases, rather than reducing, the conflicting points in this location, as shown in Figure 11.

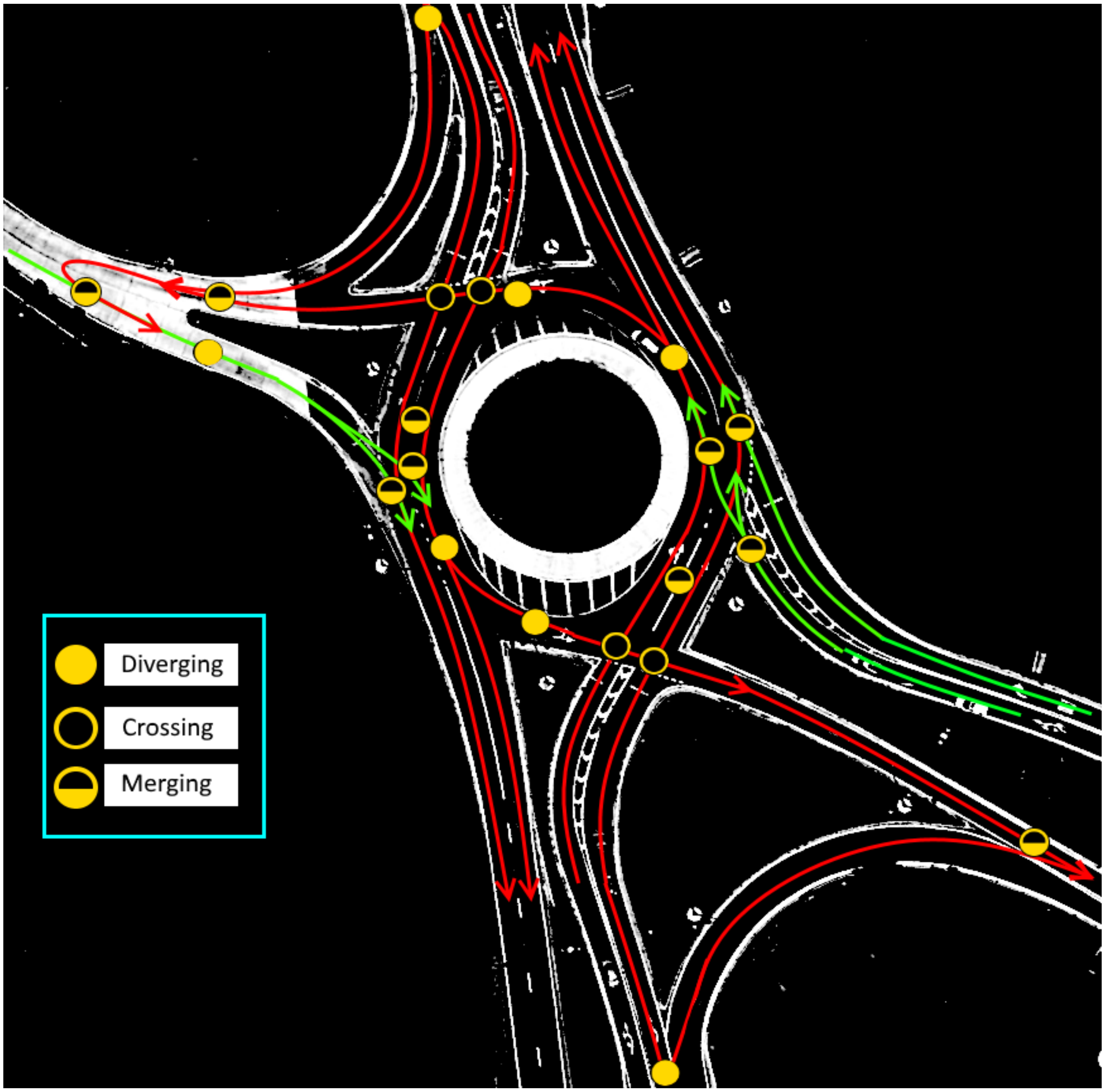

FIGURE 11 Illustration of conflicting points at intersection of LA 8/28 and US 171.

According to the basic crash information in Table 9, the confusing geometric design is not helpful for large vehicles; crashes in which drivers were at fault increased by 200%. Through reading the crash report narratives, it can be deduced that these crashes all occurred at the curve when shifting from the single lane to the outer lane (north-/southbound) to exit the roundabout. However, the "shifting lane" behaviors are unnecessary: the large-vehicle drivers were confused by the mixed-lane design in this roundabout and failed to negotiate with the curvature radius.

TABLE 9 Before-and-After Crash Information at Intersection of LA 8/28 and US 171

Crash Type		**Intersection Crashes**		
		Before	**After**	**After-after**
Total Crash		32	67	40
Severity	Fatal	1	0	0
	Injury	18	12	8
	PDO	13	55	32
Manner of collision	Single Vehicle	4	13	1
	Rear-end	12	9	3
	Head-on	0	0	0
	Angle Crash	16	45	36
Lighting condition	Daytime	22	59	31
	Dark	10	8	9
Heavy Vehicle		3	9	9
Motorcycle		0	1	1
Alcohol/Drug		4	1	0
Distracted Driver		1	1	1

Figure 12 also shows that there are severe sight distance problems for entering vehicles from the north and south approaches. The angle between the exiting and entering vehicles makes the maneuver extremely challenging, particularly for the entering vehicles on the right lane. This explains why there were so many "Failed to Yield" citations (increased from 16 to 45 after roundabout installation) issued at these entrances. The FHWA roundabout design guidelines specifically state that "*Yield lines should be located along the inscribed circle at all roundabouts except mini-roundabouts*" (*7*).

Since the AADT in this intersection is still below the FHWA recommended AADT, 25,000 for a multi-lane roundabout, this intersection could be designed as a single-lane roundabout by merging a two-lane roadway to a one-lane roadway before approaching. This design has been approved for its best safety performance. The detailed information is presented in Section 4.3.

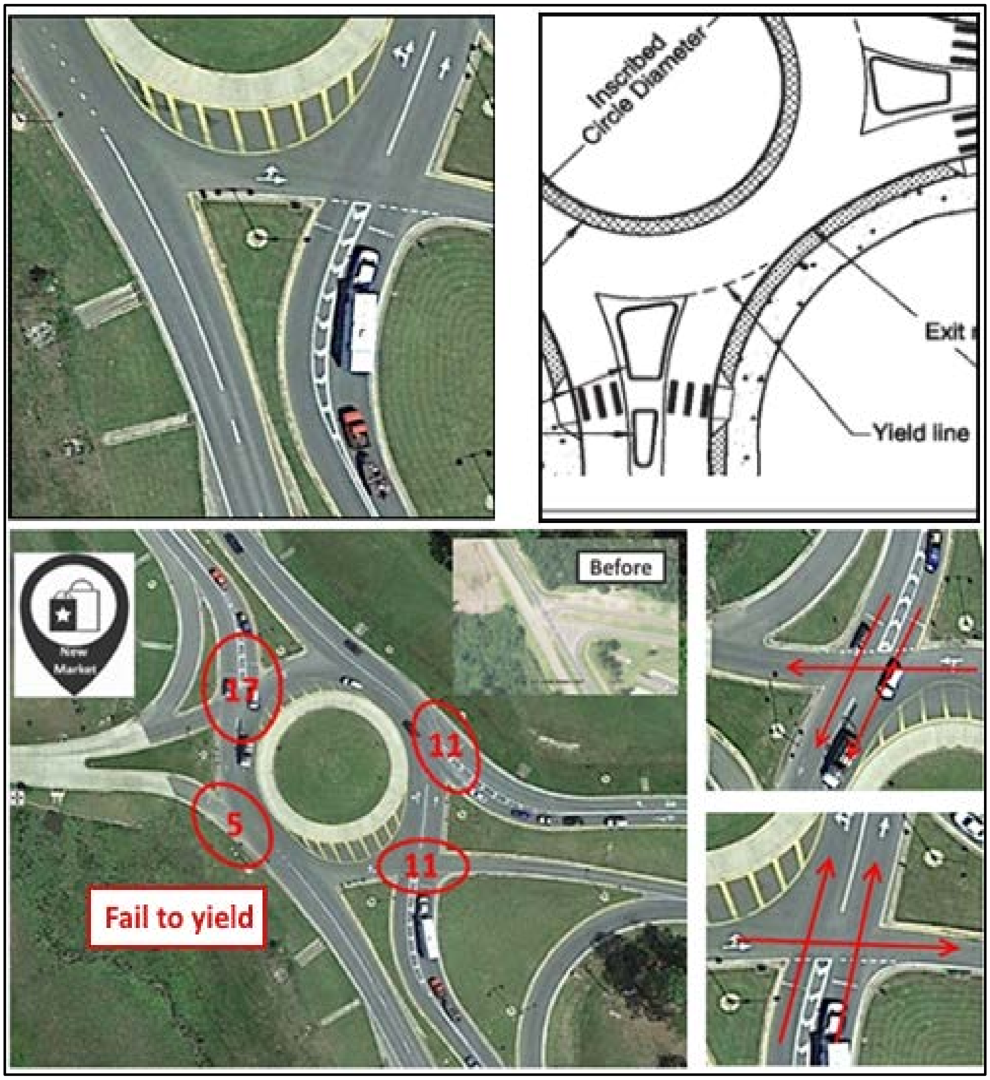

FIGURE 12 The substandard entrance layout design and number of “fail-to-yield” citations issued at entrances.

4.3 The Best Safety Performed Roundabout by Merging Lane

The roundabout located at the intersection of LA 428 and Mardi Gras Blvd. (shown in Figure 13) was previously controlled by a stop sign on the minor road. The before-and-after crash information is listed in Table 10. The traffic volume (AADT) slightly decreased from 6,133 to 6,000 vehicles day. Shown in the table, the total crashes rapidly decreased from 43 to 4, with a huge reduction of injury crashes, also, from 24 to 4. All other types of crashes were reduced.

FIGURE 13 Before-and-after images of LA 428 at Mardi Gras Blvd. roundabout.

TABLE 10 Before-and-After Crash Information at Intersection of LA 428 at Mardi Gras Blvd

Crash Type		**Intersection Crashes**	
		Before	**After**
Total Crash		43	4
Severity	Fatal	0	0
	Injury	24	4
	PDO	19	0
Manner of collision	Single Vehicle	0	1
	Rear-end	1	1
	Head-on	0	0
	Angle Crash	42	2
Lighting condition	Daytime	28	2
	Dark	15	2
Heavy Vehicle		1	0
Motorcycle		0	0
Alcohol/Drug		1	0
Distracted Driver		1	0

It can be deduced that the angle crash decreased from 42 to 2 due to the successful design. This intersection was formerly a wide intersection with a boulevard, having increased risks of producing more angle crashes. However, after it was converted to a roundabout intersection, at about 300 feet before entering the roundabout from northbound and southbound directions on LA 428, the number of lanes merged from two to one (in Figure 14). This merge lane located before the approaching lane prevents construction of a multi-lane roundabout and sequentially narrows the wide space in this intersection location, resulting in a significant reduction in the number of conflicting points in this intersection.

FIGURE 14 Merging lane before the entrance of roundabout.

4.4 Effect of Land Use Development

The intersection of LA 92 and Chemin Metairie Road experienced the largest crash increase in Group 3. The land use surrounding all six intersections in this group has changed, particularly at this location, which was the justification for increasing the number of approaches from three to four with the roundabout. The southbound extension of the minor roadway made the intersection an important gateway to a rapidly growing community at the time of the roundabout construction. After the roundabout construction, this minor road also became a major connector linking the newly developed township (beyond the scope of the picture, Figure 15) to a major metropolitan arterial highway (Ambassador Parkway). The crashes increased from 1 to 19 in the first three years of roundabout operation while the official AADT only increased 15%. The total number of crashes increased from 19 to 21 between the first and second three years of roundabout operation, but injury crashes were reduced from 3 to 1 during the same time periods. The most alarming fact is that the crashes occurring at nighttime kept increasing between the first and second three years' period of roundabout operation. This roundabout has no streetlight. It is possible that the actual AADT on Chemin Metairie Road is much higher than the official AADT obtained from the local road. It is reasonable to assume the changes in land use and road functionality are mainly responsible for the crash increase. However, without an accurate traffic count, it is hard to quantify the impact of increased traffic volume.

FIGURE 15 Land use development around intersection of E. Milton Ave./LA 92 at Chemin Metairie Rd. before-and-after years.

Chapter 5: Methodology

5.1 Crash Modification Factor (CMF) Development

The well-accepted Empirical Bayes (EB) method was used to develop the CMF. The CMF is used to precisely describe the safety change between the before and after periods by considering the regression-to-the-mean effect while normalizing changes in AADT, type of traffic control, number of approach lanes, and different area setting (*20*-*23*). In this study, the CMF was determined for 11 of the 19 roundabouts. The 11 roundabouts were converted from the stop sign on minor road controlled intersections, and all 11 roundabouts are single lane roundabouts. The remaining eight roundabouts from the other two groups (signal controlled or all way stop controlled) was not considered to develop the CMF since they do not show a crash reduction at the aggregate level, and had variations within the group due to the differences in design and operating conditions among the roundabouts in the same group. Thus, it is important, or maybe even critical, to conduct an in-depth analysis at the disaggregate level when developing the CMF for a complex crash countermeasure, such as a roundabout, to avoid the potential risk of deriving a CMF that does not reflect the situation accurately.

The safety improvement of an intersection after its conversion to roundabout can be calculated with the following equation:

$$Safety\ Improvement = \frac{N_{observed,\ after}}{N_{expected,\ after}} \tag{1}$$

where,
$N_{observed,\ after}$ = the observed number of crashes that have occurred at the converted roundabout in the after years.

$N_{expected,\ after}$ = the expected number of crashes would have occurred at an intersection without the roundabout conversion in the after years.

The only varied characteristic between expected number of crashes before and after years without roundabout conversion is the traffic volume, so $N_{expected,\ after}$ can be derived from $N_{expected,\ before}$ with the factors indicating the traffic volume difference.

In accounting for regression-to-the-mean effect, $N_{expected,\ before}$ is the weighted average from two crash numbers:

$$N_{expected,\ before} = w_i \times N_{predicted,\ before} + (1 - w_i) \times N_{observed,\ before} \quad (2)$$

where,
$N_{expected,\ before}$ = the number of crashes expected at an intersection before conversion to roundabout;
$N_{predicted,\ before}$ = the prediction number of crashes calculated from the intersection with similar traffic and alignment characteristics;
$N_{observed,\ before}$ = the number of crashes observed at an intersection before conversion to roundabout;
w_i= weighted adjustment to be placed on the predictive model estimate for each intersection.

The safety performance function (SPF) of the previously controlled by stop on minor road intersections was applied to estimate the weights (w) and the number of crashes expected at an intersection ($N_{expected,\ before}$). The SPF is a statistical model that predicts the mean crash frequency for similar locations with the same characteristics, which include traffic volume, traffic control type, geometric design, etc.

5.2 Evaluate the Predictive Value

The 11 roundabouts analyzed in this study were all installed at urban areas. The predictive models for these locations can be presented in the following equations:

$$N_{spf} = N_{int} + N_{ped} + N_{bike} \quad (3)$$

$$N_{int} = N_{single} + N_{multi} \quad (4)$$

where,
N_{spf} = predicted number at an intersection crash in a specific year;
N_{int}= predicted number of intersection crashes in a specific year (excluding vehicle-pedestrian and vehicle-bicycle collisions);
N_{ped} = predicted number of vehicle-pedestrian collisions at an intersection in a specific year;
N_{bike} = predicted number of vehicle-bicycle collisions at an intersection in a specific year;
N_{single} = predicted number of single-vehicle crashes at an intersection in a specific year;
N_{multi} = predicted number of multiple-vehicle collisions at an intersection in a specific year.

The SPF for single vehicle crashes and multiple-vehicle collisions uses the following

equations:

$$N_{single} = exp^{a_s + b_s \times \ln(AADT_{Major}) + c_s \times \ln(AADT_{Minor})} \quad (5)$$

$$N_{multi} = exp^{a_m + b_m \times \ln(AADT_{Major}) + c_m \times \ln(AADT_{Minor})} \quad (6)$$

where,
$AADT_{major}$ = average annual daily traffic volume (vehicles/day) of the major approach road at an intersection in a specific year;
$AADT_{minor}$ = average annual daily traffic volume (vehicles/day) of the minor approach road at an intersection in a specific year;
a_s, b_s, c_s = regression coefficients for a single vehicle (from the HSM *table 12-10*);
a_m, b_m, c_m = regression coefficients for multiple vehicles (from the HSM *table 12-12*).

The SPF for vehicle-pedestrian collisions and vehicle-bicycle collisions use the following

equations:

$$N_{ped} = f_{ped} \times N_{int} \quad (7)$$

$$N_{bike} = f_{bike} \times N_{bike} \quad (8)$$

where,
f_{ped} = pedestrian crash adjustment factor (from the *HSM table 12-16*);
f_{bike} = bicycle crash adjustment factor (from the *HSM table 12-17*).

The $N_{predicted}$ is the summary of N_{spf} for the n[th] year during the before and after conversion period. In this study, three years were used for each period:

$$\mathrm{N}_{\text{predicted, before}} = \sum\nolimits_{before\ years} \mathrm{N}_{\text{spf}} \tag{9}$$

$$\mathrm{N}_{\text{predicted, after}} = \sum\nolimits_{after\ years} \mathrm{N}_{\text{spf}} \tag{10}$$

5.3 Evaluate the Expected Value

As discussed in equation (2), the expected number of crashes without roundabout installation (in the before period) can be derived from the weighted average of the predicted and observed number of crashes. The weighted adjustment parameter can be derived from the following equation:

$$w = \frac{1}{1 + N_{predicted} \times k} \tag{11}$$

where,
w = weighted adjustment to be placed on the predictive model estimate;
k = over dispersion parameter of the associated SPF used to estimate $N_{predicted}$ (from *HSM table 12-10* and *table 12-12*)

It is noted that with the increment of the over dispersion parameter, the weighted adjustment factor decreases; thus, more emphasis is placed on the observed crashes rather than the SPF predicted crash frequency. The adjusted value of the EB $N_{expected,\ \ after}$, and its variance $N_{expected,\ \ after}$is calculated by the following equations:

$$N_{expected,\ \ after} = N_{expected,\ \ before} \times \frac{N_{predicted,\ \ after}}{N_{predicted,\ \ before}} \tag{12}$$

$$Var(N_{expected,\ \ after}) = N_{expected,\ \ after} \times \frac{N_{predicted,\ \ after}}{N_{predicted,\ \ before}} \times (1 - w) \tag{13}$$

5.4 Evaluate the CMF and Variance of CMF

The CMF and its variance can be calculated from the following equations (14) and (15), combined with equation (1):

$$CMF = \frac{Safety\ Improvement}{1 + \frac{Var(N_{expected,\ \ after})}{(N_{expected,\ \ after})^2}} \tag{14}$$

$$Var(CMF) = (CMF)^2 \frac{\frac{1}{N_{observed,\ \ after}} + \frac{Var(N_{expected,\ \ after})}{(N_{expected,\ \ after})^2}}{\left[1 + \frac{Var(N_{expected,\ \ after})}{(N_{expected\ ,after})^2}\right]^2} \tag{15}$$

5.5 CMF by EB Method Calculation

Table 11 enlists the value of CMF, standard deviations, and 95% confidence interval (CI) of the CMF for 11 roundabouts using this EB method. A more detailed calculation table can be found in the Appendix. The highest value of CMF is 7.41 and the lowest is 0. The wide range of CMF indicates that the result is not accurate enough to evaluate the safety performance. In order to investigate the effect of alignment design on the safety performance, the CMF were derived specifically from 5 of the 11 roundabouts, which were converted from the intersections controlled by stop sign on minor road without the layout change, and have much smaller variances. The results are listed in Table 12. For five roundabouts, the CMF values range from 0.21 to 0.83. The 95% values are lower than 1 in most cases except in one location.

The estimated CMF of these five roundabouts is 0.28, which is recommended to be used for the engineers when analyzing the roundabouts converted from the stop on minor road controlled intersections (without layout change) in the future. The CMF derived from 11 roundabouts is also reliable, but not as accurate as the CMF derived from the specific 5 roundabouts (without layout change). EB methods offer a certainty in crash reduction based on our analysis. As shown in Table 11, CMFs are impressive, which are derived from the 11 roundabouts converted from the stop sign on minor road controlled intersections, where the expected crash reduction in this group can be 46% (CMF is 0.54). When specifically considering the five roundabouts without the layout change in this group, as can be found from Table 12, the expected crash reduction is 72% (CMF is 0.28), which is much higher than that found in the NCHRP study. The higher CMF value indicates that the roundabouts in Louisiana that were converted from the intersections with stop sign on minor road perform better than the statewide roundabouts in terms of improving intersection safety effectiveness.

TABLE 11 CMF for All 11 Roundabouts Converted from Stop Sign on Minor Road Controlled Intersections

Roundabout	**CMF**	**Var(CMF)**	**S.D.(CMF)**	**95% of CMF**
LA 431 @ LA 42	0.39	0.021	0.144	(0.10, 0.68)
Chemin Metairie Rd.@ Viaulet Rd.	2.57	3.091	1.758	(0, 6.08)
US 190 @ LA 434	0.83	0.147	0.384	(0.06, 1.59)
LA 93 @ St Mary/LA 3168	0.20	0.005	0.069	(0.06, 0.34)
LA 428 @ Mardi Gras Blvd.	0.21	0.011	0.105	(0, 0.41)
E. Milton Rd. /LA 92 @ Bonin Rd.	0.23	0.009	0.096	(0, 0.52)
Lafayette Rd./LA 89 @ Iberia Rd./LA 92	0.84	0.143	0.378	(0, 1.97)
Hector Connoly Rd.@ E. Angelle Rd.	2.44	1.863	1.365	(0, 6.54)
E. Fairfield Rd.@ S. Morgan Rd.	1.86	1.288	1.135	(0, 5.26)
E. Milton Rd./LA 92 @ Chemin Metairie Rd.	7.41	12.6	3.550	(0, 18.06)
LA 327/ River Rd. @ LA 327/ Gardere Rd.	0	0	0.002	(0, 0.01)
Overall	0.51	0.006	0.075	(0.28, 0.73)

TABLE 12 CMF for 5 Roundabouts Converted from Stop Sign on Minor Road Controlled Intersections without Layout Change

Roundabout	**CMF**	**Var(CMF)**	**S.D.(CMF)**	**95% of CMF**
LA 431 @ LA 42	0.39	0.021	0.144	(0.10, 0.68)
US 190 @ LA 434	0.83	0.147	0.384	(0.06, 1.59)
LA 93 @ St Mary/LA 3168	0.20	0.005	0.069	(0.06, 0.34)
LA 428 @ Mardi Gras Blvd.	0.21	0.011	0.105	(0, 0.41)
E. Milton Rd. /LA 92 @ Bonin Rd.	0.23	0.009	0.096	(0, 0.52)
Overall	0.28	0.0029	0.054	(0.12, 0.45)

Chapter 6: Benefit / Cost Performance Analysis

Based on the LaDOTD information, the cost of crashes according to the crash severity is listed in Table 13. This information is provided by the Highway Safety Research Group in 2016.

TABLE 13 Louisiana-Specific Cost of Crashes by Severity

Crash Severity	Crash Cost
Fatal	$1,710,561
Severe Injury	$489,446
Moderate Injury	$173,578
Complaint Injury	$58,636
PDO	$24,982

Table 14 lists the injury crashes by injury level used in the Louisiana crash report. The benefit calculation is the same as with other countermeasures studied in this project.

TABLE 14 Changes in Number of Crashes by Injury Types

Previous Traffic Control	**Severe injuries**		**Moderate injuries**		**Complaint injuries**		**Total**	
	Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Signalized	0	0	7	4	22	13	29	17
Stop on Minor road (No layout change)	0	0	4	1	42	9	46	10
Stop on Minor road (Layout change)	0	0	1	3	3	2	4	5
All way Stop	1	0	1	1	18	14	20	15
Overall	1	0	13	9	85	38	99	47

The design-construction cost of a roundabout varies between $555,000 and $1.2 million dollars, based on the data from LaDOTD and other local government agencies. The Benefit / Cost (B/C) ratio is listed in Table 15 by group, and in Table 16 by intersection. Due to the crash increase, there is no benefit in the signalized group, and B/C is less than one for other groups (0.26 and 0.91 for all way stop and stop on minor road, respectively). However, the long-term B/C ratio will be greater than 1 because of sustainable crash reduction in injury crashes. It is also worthwhile to note that traffic benefit and savings from traffic signal maintenance are not included in the calculation.

TABLE 15 Benefit / Cost Ratio Estimation by Previous Control Type

Previous Traffic Control	**Benefit from crash reduction**	**Cost of Project**	**Benefit/Cost**
Signalized	-$200,642	$3,882,000	0
Stop on Minor road (No layout change)	$3,729,804	$4,103,127	0.91
Stop on Minor road (Layout change)	-$863,106	$3,900,000	0
All Way Stop	$199,368	$3,524,000	0.06

TABLE 16 Benefit / Cost Ratio Estimation by Each Roundabout Project

Intersection	Benefit from injury crash reduction	Benefit from reduction in PDO crashes	Cost of Project	B/C Ratio
LA 8/ LA 28 @ US 171	$696,642	-$1,049,244	$2,070,000	0
LA 59 @ LA 36	-$114,942	$124,910	$842,000	0.01
LA 1091 @ Brownswitch Rd.	$466,758	-$324,766	$970,000	0.14
LA 431 @ LA 42	$410,452	$249,820	$1,200,000	0.55
US 190 @ LA 434	$117,272	$49,964	$1,000,000	0.17
LA 93 @ St Mary/LA 3168	$466,758	$474,658	$550,000	1.71
LA 428 @ Mardi Gras Blvd.	$1,402,604	$474,658	$793,127	2.37
E. Milton Rd. /LA 92 @ Bonin Rd.	$58,636	$24,982	$560,000	0.15
Lafayette Rd./LA 89 @ Iberia Rd./LA 92	$58,636	-$74,946	$800,000	0
Hector Connoly Rd.@ E. Angelle Rd.	-$58,636	-$74,946	$850,000	0
E. Fairfield Rd.@ S. Morgan Rd.	$0	-$74,946	$550,000	0
LA 327/ River Rd. @ LA 327/ Gardere Rd.	$58,636	$49,964	$700,000	0.16
E. Milton Rd./LA 92 @ Chemin Metairie Rd.	-$405,792	-$374,730	$450,000	0
Chemin Metairie Rd.@ Viaulet Rd.	$58,636	-$24,982	$550,000	0.06
E. Milton/LA 92 @ Verot School Rd.	$0	-$74,946	$1,100,000	0
Gloria Switch Rd. /LA 98 @ LA 93	$117,272	$74,946	$579,000	0.33
Bonin Rd. @ Fortune Rd.	$290,850	-$124,910	$539,000	0.31
LA 3158 @ Old Covington Rd.	-$56,306	-$424,694	$556,000	0
LA 406 @ LA 407	$372,174	$24,982	$750,000	0.53

Chapter 7: Discussion and Conclusion

This study confirms that the roundabout is a proven intersection type that can reduce injury and fatal crashes. This capability is due to the reduced angle-collisions and eliminations of head-on and left-turn crashes. As revealed in the investigation, the roundabout is a complex intersection type. The roundabout analysis is more intriguing than other traffic control facilities because of the observed inconsistency in crash changes even within the same category. The improvement in safety for a roundabout depends on the previous traffic control type as well as other design specifics. The further analysis has shown that the design, lighting, and changes in the number of conflicting points are also responsible for safety improvement. The biggest safety benefit for a roundabout occurs at intersections with two-way stop sign control (without the layout change) due to the reduced number of conflicting points and the similar degree of freedom for maneuvering. For the all way stop sign controlled intersection, the freedom to maneuver seems to challenge a very small percentage of drivers.

Although the results showed no reductions in the total number of crashes at the aggregate level for the roundabouts converted from the traffic signal controlled intersections and all way stop sign controlled intersections, the in-depth analysis at the individual roundabout shows promise for a better performance with these roundabouts. The features specific to each individual roundabout determines its safety performance. Other contributing factors that potentially explain the increased number of crashes when converting an intersection to a roundabout are listed in Table 17. The detailed geometric design is more critical to the roundabout than to the non-roundabout intersections. It is possible for a roundabout to reduce not only injury crashes but also total crashes at intersections originally controlled by traffic signals or by all way stop-signs if the roundabout is properly designed with adequate lighting. It is important to recognize that the key difference between a roundabout and the other two control methods (signalized or all way stop sign) is the drivers' freedom in deciding when to enter the intersection. More consideration for human factors is required in the design of the roundabout.

TABLE 17 Summary of Potential Compounding Factors

Roundabout No. *	Change in Total Crashes	Potential Compounding Factors for Changes
Group 1: Converted from Signalized Intersection		
1	+35	Design elements (as discussed in this paper)
3	+7	It should be a two-lane roundabout with higher than 25,000 AADT. Design alignment (intersecting angle) is not desirable
Group 2: Converted from Stop Sign on Minor Road without Layout Change Intersection		
7	-39	Merging two-lanes in each direction into one-lane road before the roundabout serves very well for this roundabout
Group 3: Converted from Stop Sign on Minor Road with Layout Change Intersection		
9	+2	One street connection within 150 feet
10	+5	The problem was corrected by adding an exclusive right-turn lane to a new shopping center with the proper signage and pavement markings in May 2017 (after more than 3 years of roundabout operation)
11	+3	Inside a new subdivision with substandard sign and pavement marking
12	-3	With excellent lighting (inside a Casino area)
13	+18	Huge land use change (as discussed in the paper)
Group 4: Converted from All Way Stop Controlled Intersection		
15	+3	Due to the ROW limit, this roundabout is limited to a one-lane with AADT higher than 35,000, three driveways within 150 feet including a car dealer right by the circle.
18	+15	Lack of lighting (as discussed in the paper)

* *The No. for each roundabout refers to the same No. code as listed in Table 1.*

To investigate if the roundabout operation time has any impact on the intersection safety performance, this study also analyzed the crashes for roundabouts in operation for six years. Table 18 shows the changes in the AADT and crashes at 11 intersections that had crash increases in the first three years of the roundabout operation. The results indicate that while the fatal and injury crashes were continuously decreasing, the total crashes still show an increasing trend. For the three intersections with six years of roundabout operation in Group 2, there is either no change or a crash reduction.

TABLE 18 Summary of Changes in AADT and Crashes between Before and After the Roundabout in Two Post-Construction Periods

Element	% Changes between Before and After Three Years	% Changes between Before and the Post Three to Six Year Time Period
AADT	4.70%	+8%
Total Crashes	+71%	+88%
Fatal Crashes	-50%	-50%
Injury Crashes	-21%	-37%
PDO Crashes	+133%	+171%
Single-Vehicle	+229%	+186%
Rear-End	+28%	+21%
Angle	+71%	+138%
Day time	+58%	+75%
Night time	+103%	+157%

Despite the wide differences in crash frequency change, one thing is clear: the roundabout DOES reduce crash severity, mainly because of the lower operating speed. The biggest safety benefit comes from the roundabouts converted from the stop sign on minor road intersections, where a 46% crash reduction was observed. The CMF was developed from the roundabouts converted from the stop sign on minor road controlled intersections. To investigate the effect of alignment design, the CMF was also developed from the roundabouts converted from the stop sign on minor road controlled intersections without the layout change. Because other groups did not show any crash reduction at the aggregate level, and had variations within the group due to differences in design and operating conditions among the roundabouts in the same group, the CMF was not developed from the other two groups (the roundabouts converted from the signalized or all way stop intersections). Thus, it is important, or maybe even critical, to conduct an in-depth analysis at the disaggregate level when developing the CMF for a complex crash countermeasure like a roundabout to avoid the potential risk of deriving a CMF that does not reflect the situation accurately.

Bibliography

[1] Persaud, B., R. Retting, P. Garder, and D. Lord. Safety Effect of Roundabout Conversions in the United States: Empirical Bayes Observational Before-After Study. *Transportation Research Record: Journal of the Transportation Research Board,* Vol. 1751, 2001, pp. 1-8.

[2] Ourston, L. Nonconforming Traffic Circle Becomes Modern Roundabout. In *Compendium of Technical Papers, 64th ITE Annual Meeting*, 1994.

[3] Troutbeck, R. Capacity and design of traffic circles in Australia. *Transportation Research Record*, No. 1398, 1993.

[4] Vincent, R., A. Mitchell, and D. Robertson. User guide to TRANSYT version 8, 1980.

[5] Jacquemart, G. *Modern roundabout practice in the United States*. 1998.

[6] Rodegerdts, L. *Roundabouts in the United States*. Transportation Research Board, 2007.

[7] Rodegerdts, L. A. *Roundabouts: An informational guide*. Transportation Research Board, 2010.

[8] Neuman, T. R. *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan: A guide for addressing unsignalized intersection collisions*. Highway Research Board of the Division of Engineering and Industrial Research, National Academy of Sciences, National Research Council, 1965.

[9] Schoon, C., and J. Van Minnen. Accidents on Roundabouts: II. Second study into the road hazard presented by roundabouts, particularly with regard to cyclists and moped riders. *SWOV Institute for Road Safety Research, Leidschendam, The Netherlands. Report R-93-16*, 1993.

[10] Brilon, W., and B. Stuwe. Capacity and design of traffic circles in Germany. *Transportation Research Record*, 1993, p. 61.

[11] Gårder, P. *The Modern Roundabout: The Sensible Alternative for Maine*. Maine, Bureau of Planning, Research & Community Services, Transportation Research Division, 1997.

[12] Maycock, G., and R. Hall. *Accidents at 4-arm roundabouts*. 1984.

[13] Brown, M. *The design of roundabouts*. 1995.

[14] Alphand, F., U. Noelle, and B. Guichet. Roundabouts and Road Safety. In *Intersections without traffic signals II*, Springer, 1991, pp. 107-125.

[15] Brilon, W., and L. Bondzio. White Paper: Summary of International Statistics on Roundabout Safety. (*unpublished),* July, 1998.

[16] Burdett, B., A. R. Bill, and D. A. Noyce. Evaluation of roundabout-related single-vehicle crashes. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2637, 2017, pp. 17-26.

[17] Burdett, B., I. Alsghan, L.-H. Chiu, A. R. Bill, and D. A. Noyce. Analysis of rear-end collisions at roundabout approaches. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2585, 2016, pp. 29-38.

[18] Qin, X., G. Khan, A. Bill, and D. A. Noyce. Comprehensive safety evaluation of roundabouts in Wisconsin. *Journal of Transportation Safety & Security,* Vol. 3, No. 4, 2011, pp. 289-303.

[19] Bill, A., R. Szymkowski, G. Khan, D. Noyce, and T. Director. Safety Evaluation of Wisconsin Roundabouts: Phase 2.

[20] Retting, R. A., B. N. Persaud, P. E. Garder, and D. Lord. Crash and injury reduction following installation of roundabouts in the United States. *American journal of public health,* Vol. 91, No. 4, 2001, p. 628.

[21] Hauer, E., D. Harwood, F. Council, and M. Griffith. Estimating safety by the empirical Bayes method: a tutorial. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1784, 2002, pp. 126-131.

[22] Persaud, B., and C. Lyon. Empirical Bayes before–after safety studies: lessons learned from two decades of experience and future directions. *Accident Analysis & Prevention,* Vol. 39, No. 3, 2007, pp. 546-555.

[23] Isebrands, H., and S. Hallmark. Statistical analysis and development of crash prediction model for roundabouts on high-speed rural roadways. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2312, 2012, pp. 3-13.

Appendix

Calculation details for EB method (11 roundabouts).

Intersections	Total Crash (Before)	$N_{spf, tot, int, b}$	overdispersion parameter,k	Weighted average, w	M_i	VAR(M_i)	$N_{spf, tot, int, a}$
LA 431 @ LA 42	26	6.761	0.970	0.132	23.455	20.351	6.450
Chemin Metairie Rd.@ Viaulet Rd.	2	0.195	0.970	0.841	0.482	0.077	0.237
US 190 @ LA 434	10	11.157	0.970	0.092	10.107	9.173	7.363
LA 93 @ St Mary/LA 3168	35	47.524	0.970	0.022	35.272	34.507	65.681
LA 428 @ Mardi Gras Blvd.	43	3.219	0.525	0.592	19.461	7.945	3.158
E. Milton Rd. /LA 92 @ Bonin Rd.	10	4.278	0.525	0.445	7.452	4.134	18.491
Lafayette Rd./LA 89 @ Iberia Rd./LA 92	6	6.726	0.970	0.153	6.111	5.175	9.221
Hector Connoly Rd.@ E. Angelle Rd.	0	3.332	0.970	0.309	1.031	0.712	3.960
E. Fairfield Rd.@ S. Morgan Rd.	0	1.913	0.970	0.539	1.031	0.475	2.069
E. Milton Rd./LA 92 @ Chemin Metairie Rd.	1	3.077	0.970	0.335	1.696	1.128	3.342
LA 327/ River Rd. @ LA 327/ Gardere Rd.	3	2.034	0.970	0.507	2.510	1.238	2.424
Total	**136**	**90.216**	**0.889**	**0.012**	**108.608**	**84.915**	**122.396**
Ci	π	$VAR(\pi)$	**Total Crash (After)**	$\hat{\theta}$	$SD(\widehat{\theta})$	$\hat{\theta}$-3*sd($\widehat{\theta}$)	$\hat{\theta}$+3*sd($\widehat{\theta}$)
0.954	22.376	18.522	9	0.39	0.144	-0.04	0.82
1.215	0.586	0.113	2	2.57	1.758	-2.71	7.84
0.660	6.670	3.995	6	0.83	0.384	-0.33	1.98
1.382	48.748	65.911	10	0.20	0.069	-0.01	0.41
0.981	19.092	7.647	4	0.21	0.105	-0.11	0.52
4.322	32.211	77.238	8	0.23	0.096	-0.06	0.52
1.371	8.378	9.726	8	0.84	0.378	-0.30	1.97
1.188	1.225	1.006	5	2.44	1.365	-1.65	6.54
1.082	1.115	0.556	3	1.86	1.135	-1.55	5.26
1.086	1.842	1.330	19	7.41	3.550	-3.24	18.06
1.192	2.992	1.758	0.0001	0.00	0.002	-0.01	0.01
1.357	**145.235**	**187.802**	**74**	**0.51**	**0.075**	0.28	0.73

Calculation details for EB method (5 roundabouts).

Intersections	Total Crash (Before)	$N_{spf, tot, int, b}$	overdispersion parameter,k	Weighted average, w	M_i	VAR(M_i)	$N_{spf, tot, int, a}$
LA 431 @ LA 42	26	6.761	0.970	0.132	23.455	20.351	6.450
US 190 @ LA 434	10	11.157	0.970	0.085	10.098	9.244	7.363
LA 93 @ St Mary/LA 3168	35	47.524	0.970	0.022	35.272	34.507	65.681
LA 428 @ Mardi Gras Blvd.	43	3.219	0.525	0.592	19.461	7.945	3.158
E. Milton Rd. /LA 92 @ Bonin Rd.	10	4.278	0.525	0.445	7.452	4.134	18.491
Total	**124**	**72.939**	**0.792**	**0.017**	**95.737**	**76.181**	**101.143**
Ci	π	$VAR(\pi)$	**Total Crash (After)**	$\hat{\theta}$	$SD(\hat{\theta})$	$\hat{\theta}$-3*sd($\hat{\theta}$)	$\hat{\theta}$+3*sd($\hat{\theta}$)
0.954	22.376	18.522	9	0.39	0.144	-0.04	0.82
0.660	6.664	4.026	6	0.83	0.384	0.06	1.59
1.382	48.748	65.911	10	0.20	0.069	-0.01	0.41
0.981	19.092	7.647	4	0.21	0.105	-0.11	0.52
4.322	32.211	77.238	8	0.23	0.096	-0.06	0.52
1.387	**129.091**	**173.343**	**37**	**0.28**	**0.054**	**0.12**	**0.45**

He, Yi. Bachelor of Engineering, Harbin Institute of Technology, Fall 2013; Master of Science, University of Louisiana at Lafayette, Fall 2017.
Major: Engineering, Civil Engineering option.
Title of Thesis: Safety Effectiveness Analysis of Roundabouts in Louisiana
Thesis Director: Dr. Xiaoduan Sun
Pages in Thesis: 63; Word in Abstract: 216

Abstract

Louisiana currently has 30 roundabouts in operation and hundreds of roundabouts in the planning and design stage. The Louisiana Department of Transportation and Development (DOTD) is very interested in knowing the safety performance of existing roundabouts in the state.

As revealed in this paper, the safety effectiveness of a roundabout depends on its prior traffic control type, conformity to the geometric design guidelines, changes in layout of intersection, and nighttime lighting conditions. All 19 roundabouts investigated by this study demonstrated significant reduction in injury crashes because of lower operating speed, reduced right-angle collisions, and elimination of head-on and left turn crashes. Based on changes in the number of conflicting points and traffic control method, it is understandable why the most significant and consistent safety improvement was associated with the roundabouts previously controlled by stop signs on minor streets. The Crash Modification Factor (CMF), as estimated by the Empirical Bayes (EB) method, for this group of roundabouts is 0.28 with a standard deviation of 0.054. The roundabout is economically justified for its safety benefit alone based on the benefit-cost ratio analysis for this group of roundabouts.

The study did identify a few compounding factors at the individual intersections, such as questionable geometric design elements, increased number of conflicting points, unpredictable human behavior, and lack of lighting at night.

Biographical Sketch

Yi He received his Bachelor of Engineering in 2013 at the Harbin Institute of Technology in China. After working in industry, he pursued a graduate study opportunity at the University of Sydney, Australia. After new opportunities became available, Yi He relocated to Louisiana. After two years' study and research in the Department of Civil Engineering, Yi He completed graduate study at the University of Louisiana at Lafayette, receiving a Master of Science in Civil Engineering in Fall 2017.