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Investigating Safety Impact of Center Line Rumble Strips, Lane Conversion, Roundabout, and J-Turn Features on Louisiana Highways

by

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16. Abstract

Over the past several years, Louisiana has installed quite a few relatively new crash countermeasures, such as center line rumble strips (CLRS) on rural two-lane highways, restriping four-lane undivided roadways to three-lane or five-lane roadways with center lane for left turns, restricting median openings on high speed corridors (RCUT), and roundabouts. Evaluating the effectiveness of these crash countermeasures is crucial for the state highway safety improvement programs. According to the results of this study, these four countermeasures are generally cost-effective and successful in reducing crashes, particularly severe crashes. Estimated crash modification factors (CMFs) for total crashes are 0.83 for CLRS by the Empirical Bayes (EB) method. The CMF for the lane conversion to three and five-lane highways are 0.61 and 0.70 by EB method for segment, and 0.69 and 0.76 by Improved Prediction Method for segment plus intersection. The CMF for RCUT is 0.86 and 0.69 by Improved Prediction Method for RCUT section and intersection only. The CMF for RCUT intersection only is 0.80 by EB method. The CMF for roundabout with stop-sign on minor street (without layout change) is 0.32 and 0.28 by Improved Prediction and EB method. Except roundabout, the ratio of benefit to cost (B/C) is bigger or much bigger than one. Being the most expensive countermeasure, the B/C ratio of roundabout is less than one, but that estimation did not count the benefit from the improved traffic flow performance (reduced delay or saving in travel time) and long-time safety benefits (only three after years).

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ABSTRACT

Over the past several years, Louisiana has installed quite a few relatively new crash countermeasures, such as center line rumble strips (CLRS) on rural two-lane highways, restriping four-lane undivided roadways to three-lane or five-lane roadways with center lane for left turns, restricting median openings on high speed corridors (RCUT), and roundabouts. Evaluating the effectiveness of these crash countermeasures is crucial for the state highway safety improvement programs. According to the results of this study, these four countermeasures are generally cost-effective and successful in reducing crashes, particularly severe crashes. Estimated crash modification factors (CMFs) for total crashes are 0.83 for CLRS by the Empirical Bayes (EB) method. The CMF for the lane conversion to three and five-lane highways are 0.61 and 0.70 by EB method for segment, and 0.69 and 0.76 by Improved Prediction Method for segment plus intersection. The CMF for RCUT is 0.86 and 0.69 by Improved Prediction Method for RCUT section and intersection only. The CMF for RCUT intersection only is 0.80 by EB method. The CMF for roundabout with stop-sign on minor street (without layout change) is 0.32 and 0.28 by Improved Prediction and EB method. Except roundabout, the ratio of benefit to cost (B/C) is bigger or much bigger than one. Being the most expensive countermeasure, the B/C ratio of roundabout is less than one, but that estimation did not count the benefit from the improved traffic flow performance (reduced delay or saving in travel time) and long-time safety benefits (only three after years).

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IMPLEMENTATION STATEMENT

The project findings suggest the state may consider implementing the four countermeasures evaluated by this research at the locations that will have potential for total or targeted crash reduction, particularly the fatal and injury crash reductions. Implementing these crash countermeasures at suitable locations will help the state to reach the “Destination Zero Deaths” goal as identified in the Louisiana Strategic Highway Safety Plan.

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PART I: CENTERLINE RUMBLE STRIPS (CLRS)

INTRODUCTION

The rural two-lane highways constitute more than 70% of the state-controlled roadway network and more than 50% of the local roads. The rural two-lane highways possess a low geometric standard (e.g., narrow lanes, inadequate shoulders, large edge drop-offs, etc.) with low AADT. Approximately 38% fatal crashes (2,200) and 40% of fatalities occurred on the rural two-lane highways during 2006-2015. Additionally, about 48,000 injury crashes and over 67,000 property damage only (PDO) crashes occurred on rural two-lane highways in these years. Over 20% of the fatal crashes were cross-centerline crashes, mainly head-on and opposite direction sideswipe crashes *[1]*.

The risk of a cross-centerline crash (also known as opposite direction crash or cross-over crash) can be reduced by implementing expensive countermeasures like median barriers or roadway widening *[2]*. Rumble strips along the centerline is an inexpensive countermeasure designed to prevent head-on and opposite direction sideswipe crashes by creating a tactile vibration and audible rumbling. The noise and vibration generated by the rumble strip grooves is intended to alert distracted or inattentive drivers to take corrective action before further leaving their lane. Studies have shown alertness enhancing effect of rumble strips on drowsy and fatigued drivers resulting in reduced variability in lateral position of the vehicles *[3]*. Thus, CLRS can prevent drivers from potentially colliding with oncoming vehicles, and consequently serve as an effective navigational aid in maintaining the intended travel lane even during poor visibility at nighttime or in inclement weather *[4]*.

Reducing the high proportion of crashes occurring on rural two-lane highways through implementation of effective crash countermeasures is crucial to achieve Louisiana's goal of halving the traffic fatalities and serious injuries by 2030. The Louisiana Department of Transportation and Development (DOTD) recommended a systemic deployment of low-cost countermeasures *[5]*. Since these rural two-lanes are of low hierarchical road classes that serve very low AADT and VMT (vehicle miles traveled), investment on low-cost countermeasures are reasonable, economically feasible, and likely to have higher impact.

Many studies have identified CLRS (Centerline Rumble Strips) as a key low-cost countermeasure to prevent head-on and sideswipe crashes, and potentially run-off-road to the left crashes *[2, 6, 7, 8, 9, 10, 11]*. Inspired by the success of other states and based on the positive reports on the performance of CLRS installed on LA 1019 Highway in 2006, the DOTD decided to install CLRS statewide several years ago. The potential routes were selected for implementation based on the pavement maintenance records (less than 10 years from last overlay treatment), lane width (minimum 11 ft. wide), speed limits higher than 55 mph, and federal aid eligibility. Due to the absence of any design guidelines the *Manual on Uniform Traffic Control Devices* (MUTCD), the Federal Highway Administration (FHWA) developed some design guideline for the centerline rumble strips. In Louisiana, the width of the rumble strips design was limited to 6 in. considering the possibility of run-off roadway crashes. The space between rumbles and resulting length from center to center were 5 in. and 12 in., respectively (See Appendix A for the details). Between 2010 and 2012, many projects with such design were initiated by DOTD to install CLRS on more than 2,100 miles of rural two-lane highways *[12]*.

Many studies have been conducted to evaluate the safety effectiveness of CLRS. The Empirical Bayes (EB) method has been the popular analysis tool because the method overcomes the regression-to-the-mean bias, and incorporates other crash contributing factors that may change over time and thus, affect crash pattern *[13]*. The Insurance Institute for Highway Safety (IIHS) sponsored a study on CLRS in seven states *[14]*. This was the first widespread study that evaluated safety effectiveness of CLRS using the EB method. A total of 98 treatment sites along approximately 210 miles of two-lane rural roads were evaluated. The analysis showed a 14% reduction in all crashes and a 15% reduction in injury crashes. The targeted crashes (head-on and opposite direction sideswipe crashes) were reduced by 21%, and targeted injury crashes were reduced by 25%.

The EB method was also used in Torbic et al. study, in which effectiveness of CLRS was assessed on rural and urban highways, using data from Minnesota, Pennsylvania, and Washington *[15]*. A 4.1% reduction was revealed on the total number of crashes, which was not significant at 90% confidence level. There was a 9.4% reduction in total fatal and injury crashes, a 37% reduction in cross-over crashes, and a 44.5% reduction in fatal and injury cross-over crashes; all above estimated reductions were significant at 90% confidence level.

Several studies show that the CLRS is effective in reducing cross centerline crashes. A few studies included the potential safety benefits of installing CLRS along with shoulder rumble strips *[16] [17]*. Studies that utilized the EB method in estimating safety effectiveness of CLRS on rural two-lane highways have been summarized in Table 1.

Table 1

Summary of the studies used EB method for CLRS on rural two-lane highways

Study	Year	No. of sites	Length (miles)	Crash type(s)	Percentage Reduction
Torbic et al. *[15]*	2009	962	462.06	All	4.1
				Fatal and injury	9.4
				Target*	37.0
				Target fatal and injury	44.5
Persaud et al. *[14]*	2003	98	210.8	All	14
				Injury	15
				Target*	21
				Target injury	25
				Day	8
				Night	15
Rhys et al. *[17]*	2012			All	29.21
				Fatal and injury	32.05
				Target*	67.19
Kay et al. *[18]*	2015		4,200	All	15.8
				Target*	27.3
				Target PDO	16.2
Olson et al. *[19]*	2011	69	493.03	All	12.68
				Injury	4.58
				PDO	22.4

*Target crashes are head-on and opposite direction sideswipe crashes

The Highway Safety Manual (HSM) of 2010 adopted the IIHS study results as a record of crash modification factor (CMF) of CLRS on rural two-lane highways *[20]*. Although the IIHS study involved analysis of CLRS in seven states, it is only applicable to AADT higher than 5,000 and less than 22,000. In Louisiana, 90% of state-maintained rural two-lane highways have an AADT of less than 5,000 as shown in Figure 1, which was plotted based on the state 2014 highway section database *[21]*.

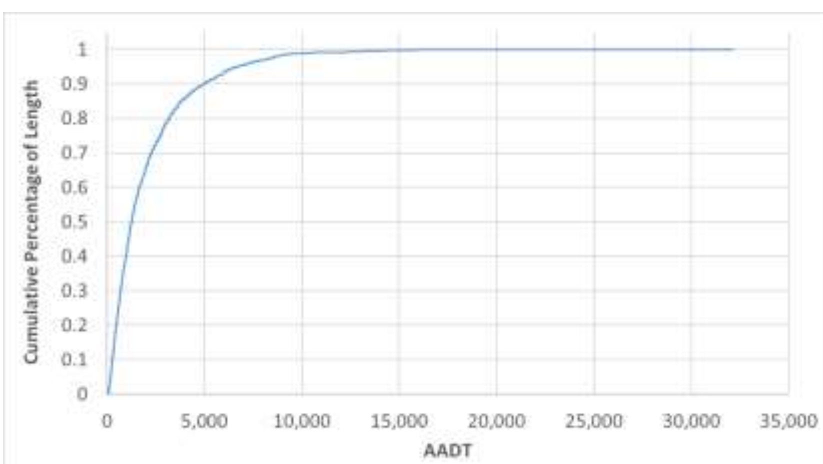


Figure 1
Cumulative distribution of AADT on rural two-lane highways in Louisiana

Considering the relatively low AADT (comparing to the states under previous CLRS studies) and Louisiana's unique roadway safety culture, the CMF developed with the data from other states may not be compatible. For example, Louisiana has a much higher percentage of adults (2.5%) who reported driving after drinking too much compared with the national average (1.9%) *[22]*. The death rate in crashes involving a drunk driver in Louisiana (5.2 per 100,000 population) is also much higher than that of the national average (3.3 per 100,000 population). The need to evaluate the safety effectiveness of CLRS on rural two-lane highways in Louisiana is self-evident.

OBJECTIVE

The purpose of this part of the project was to investigate the safety effectiveness of CLRS on Louisiana rural two-lane highways. Specifically, the objectives were to:

- Conduct a before/after crash characteristics analysis.
- Develop the state specific CMF of CLRS.
- Estimate the safety benefit-cost ratio of CLRS installation.

SCOPE

This study on the CLRS effectiveness was limited to the prior selected rural two-lane highway segments in Louisiana. With the temporal features of the Google Street View, the research team was able to identify and exclude the roadway segments that experienced other changes beside the CLRS installation over the study time period of six years (three years before and after).

METHODOLOGY

Data Collection and Verification

The statewide CLRS project data was obtained from DOTD which has the rumble strip project locations and pertinent project dates. Project locations are presented by the control section, logmile, and length of the section. To verify each control section, a couple of tools were used. The DOTD converter, shown in Figure 2, is a free online tool which converts control section to geographic coordinates (latitude and longitude) *[23]*. This converter was used to identify locations where CLRS were installed as shown in Figure 3. The second verification tool is "Google Street View," which was used to visually inspect the highway sections using the coordinates identified by DOTD converter.

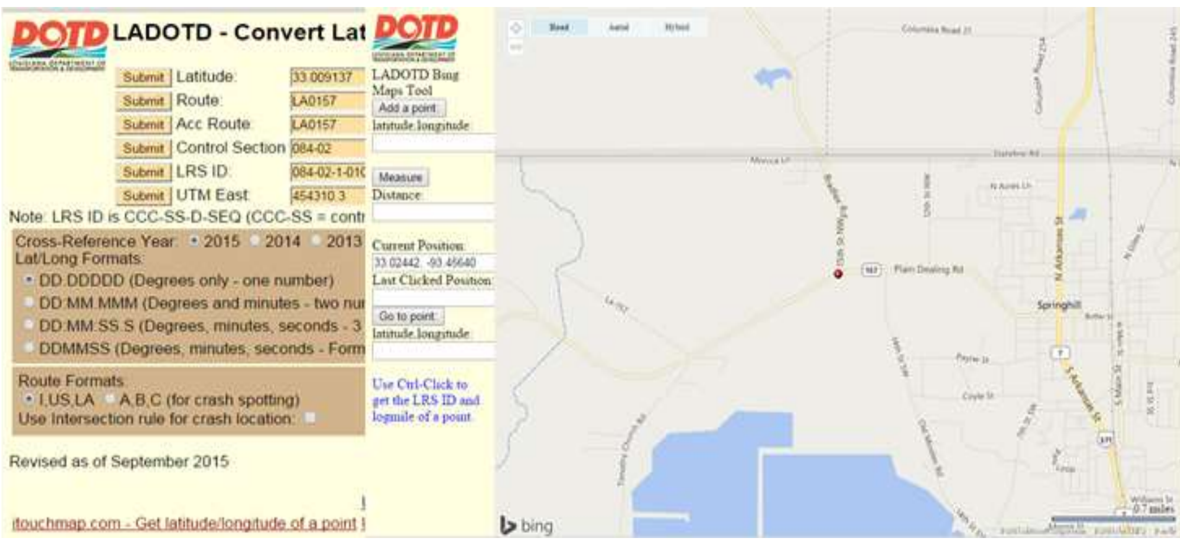


Figure 2
Identification of sections using DOTD Converter

(a)
(b)

Figure 3
Verification of sections with (a) absence of CLRS, and (b) presence of CLRS using *Google Street View*

The crash data were collected from the DOTD "Crash 1 Database", which contain the attributes of each crash such as the highway section information, crash information, and associated vehicle information *[1]*. All variables necessary for analysis are extracted and were then queried for control sections and logmiles where rumble strips were installed.

The intersection crashes were eliminated from the analysis. The physical area of an intersection does not contain CLRS, and CLRS are not intended to prevent intersection crashes. According to the DOTD *crash data analysis guidelines*, intersection crashes are crashes either labeled as intersection crashes in the police report or occurred within 150 ft. of the intersection (not identified as intersection crashes by the police at the scene) *[24]*. Table 2 shows the final site selection by district, which is also displayed in Figure 4.

Table 2
Site information of nine highway districts

District	Length (mile)	Number of Control Sections	Before Years	After Years
2	68.15	10	2008-10	2012-14
3	171.75	31	2008-10	2012-14
4	367.13	43	2007-09	2013-15
5	240.87	36	2008-10	2012-14
7	215.81	27	2008-10	2013-15
8	277.54	40	2008-10	2013-15
58	185.56	29	2008-10	2012-14
61	142.58	26	2008-10	2013-15
62	195.94	39	2008-10	2012-14
Total	**1,865.33**	**281**		

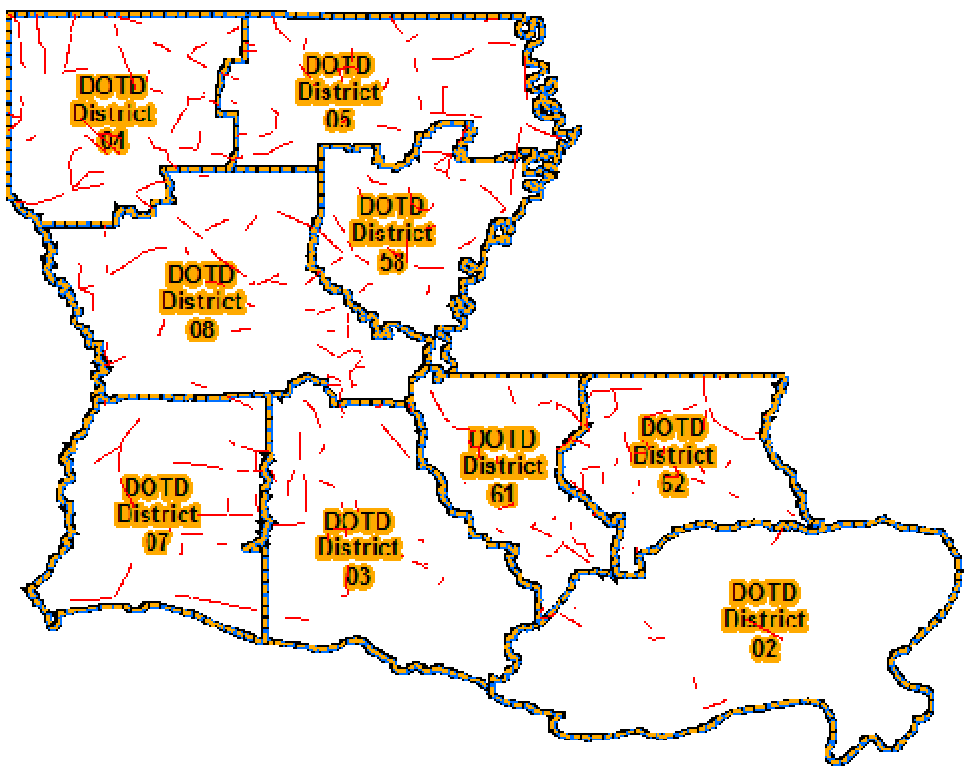


Figure 4
Final selected sections for analysis

Before and After Crash Analysis

Traffic Flow Characteristics

Table 3 lists the changes in AADT at the aggregate level, which shows an increase of 1.5% during the after period. The AADT density plot in Figure 5 reveals the crash increase in low AADT during the after years. Y-axis in the diagram shows the density of a range of AADT.

Table 3
Change of AADT in before/after period

AADT	Before	After
Minimum	240	188
Maximum	18,633	22,367
Mean	3,337	3,389

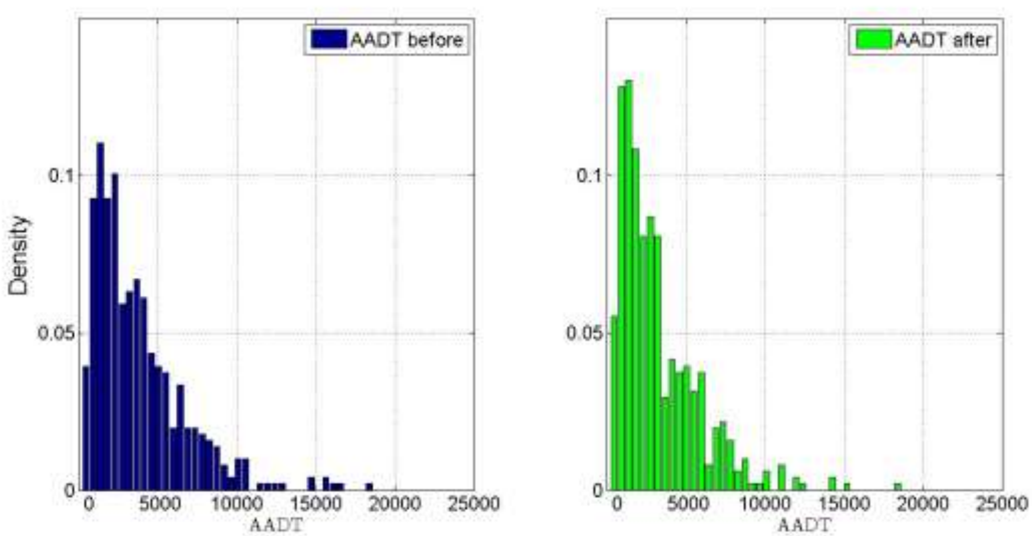


Figure 5
Density of AADT in before/after periods

Figure 6 is a scatter plot between crash rate and AADT for the before and after time periods. Under same or similar AADT, crash rates were generally lower in the after periods than the before periods.

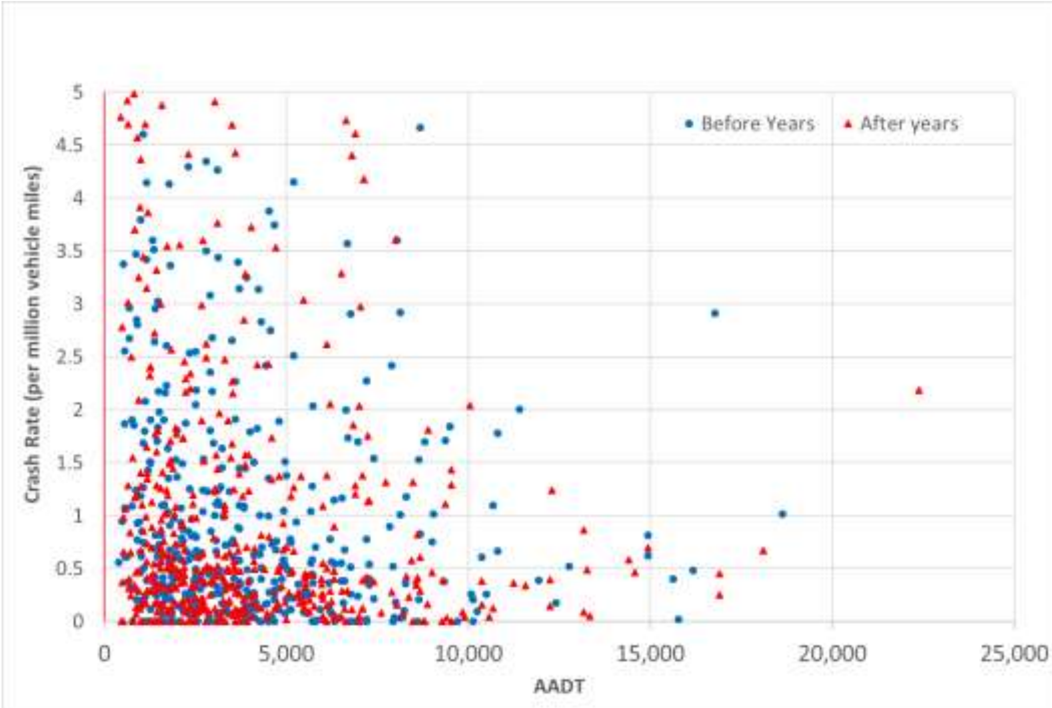


Figure 6
AADT vs crash rate in before/after periods

Crash Characteristics
As shown in Table 4, the observed total crashes decreased by 15.1%, fatal crashes by 31.2% and injury crashes by 22.1% in the after three years.

Table 4
Change in total crashes and crashes by severity in before/after period

Crashes		Before	After	Percent Reduction
Total crashes		5,829	4,950	15.1%
Crashes per mile per year		1.04	0.88	
Crashes by severity	Fatal	141	97	31.2%
	Injury	2,516	1,960	22.1%
	PDO	3,172	2,893	8.8%

The before and after crash analysis by collision type also shows the crash reductions by every type of collision manner (Table 5). It is expected that target crashes (head on and opposite direction sideswipe) will decrease as a result of CLRS installation. Head-on crashes are reduced by 41.3% and opposite direction sideswipe crashes are also reduced by 34.1%. Overall target crashes are reduced by 36.7%. Non-collision and same direction sideswipe crashes also decreases remarkably, by 16.1% and 13.4%, respectively.

Table 5
Change in crashes by manner of collision in before/after period

Manner of collision	Before	After	Percent Reduction
Non-collision	3,378	2,835	16.1%
Head-on	150	88	41.3%
Rear-end	938	929	1.0%
Right angle	236	222	5.9%
Left turn	271	252	7.0%
Right turn	23	22	4.3%
Sideswipe (same direction)	194	168	13.4%
Sideswipe (opposite direction)	270	178	34.1%
Others	369	256	30.6%
Target crashes (Head-on and Opposite direction sideswipe crashes)	420	266	36.7%

Table 6 shows the crashes by time of the day before and after the CLRS installation. Percentage wise there were minor changes in the after-period crashes compared with before-period crashes.

Table 6
Number of crashes by time period before and after

Time of the Day	Before	After
6 am - 12 pm	1,398 (24.3%)	1,217 (24.6%)
12 pm - 6 pm	1,962 (34.1%)	1,710 (34.6%)
6 pm - 12 am	1,105 (19.2%)	958 (19.4%)
12 am - 6 am	1,292 (22.4%)	1,054 (21.3%)

Table 7 presents the number of crashes in different lighting conditions before and after CLRS installation. Crash reduction was observed under all types of lighting conditions.

Table 7
Number of crashes by lighting condition in before and after years

Lighting Condition	Before	After
Daylight	3,280	2,737
Dark	2,328	2,004
Dawn and Dusk	192	178

The changes in single vehicle crashes, distracted/inattentive driver crashes, alcohol-related, and pedestrian-involved crashes can be seen in Figure 7. Those crashes decreased by 17.5%, 11.2%, 23%, and 56.8%, respectively.

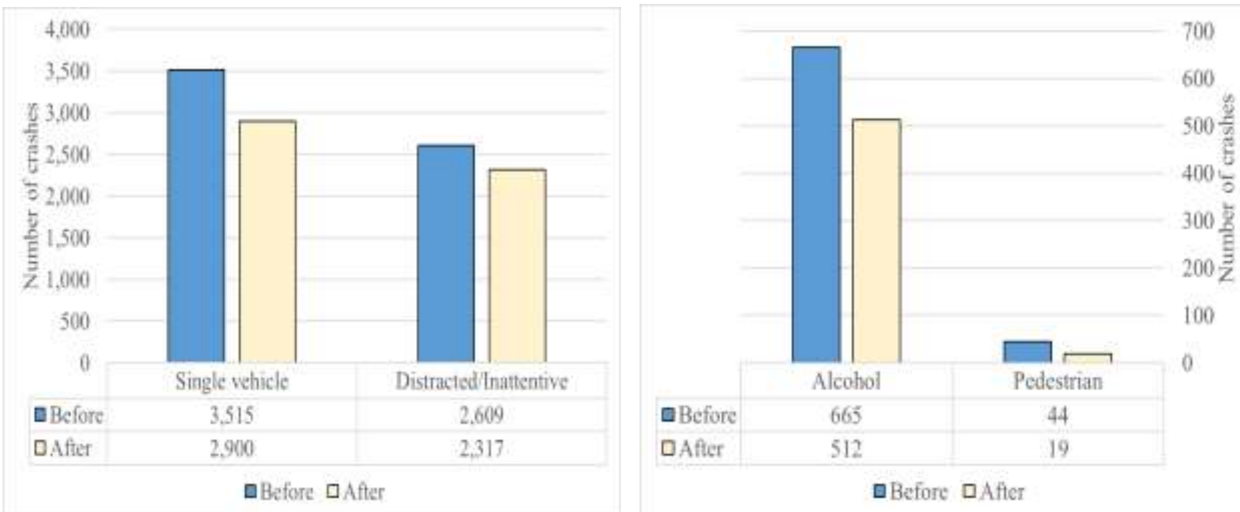


Figure 7
Changes in single-vehicle crashes, and distracted/inattentive driver crashes (left) change in alcohol-related and pedestrian crashes (right)

CMF Development

The EB method was used to develop the CMF of CLRS. The details of the EB method application can be found in many studies *[8, 13, 14, 25, 26]*. There are three steps in the analysis, which are described in the followings.

Step 1: Safety Performance Function (SPF)

The SPF estimates the predicted crashes using measurable roadway traits such as AADT, length of roadway segment, roadway width, shoulder width, number of lanes, and etc. This study used the SPF developed by DOTD for rural two-lane highways to estimate predicted annual total non-intersection crashes *[27]*.

$$P = 0.0028 * L^{0.9458} * AADT^{0.7489} \quad (1)$$

where,
P = the predicted annual crashes
AADT = Annual Average Daily Traffic
L = Length of road segment (miles).

Step 2: Estimation of Expected Crashes

The expected yearly crashes (E_b) before centerline rumble strip installation is estimated from predicted average crash frequency (P_b) and observed crash frequency (O_b) in before years.

$$E_b = w * P_b + (1 - w) * O_b \qquad (2)$$

The statistical weighting adjustment w to from the regression estimate is

$$w = \frac{P_b}{P_b + \frac{1}{k}} \qquad (3)$$

where, k is the overdispersion parameter of the negative binomial distribution that is assumed for the crash counts in estimating the SPF. The overdispersion parameter in the SPF has itself been modeled as a function of length.

$$k = \frac{1}{2.64 * L^{0.9458}} \qquad (4)$$

Variance of expected before period crashes is estimated by

$$\mathrm{var}(E_b) = (1 - w) * E_b \qquad (5)$$

Expected crashes, E_b, is then multiplied by a factor, C, to consider the extent of the after period, the change in traffic volumes, and other extraneous factors that affect crash pattern. The factor C is estimated as,

$$C = \frac{P_a}{P_b} \qquad (6)$$

where, P_a is predicted average crash frequency in after years.

The crashes that could have occurred per year in the after period had the countermeasure is not in place,

$$E_a = C * E_b \qquad (7)$$

The variance of total crashes in the after period is

$$\mathrm{var}(E_a) = C^2 * \mathrm{var}(E_b) = C^2 * (1 - w) * E_b \qquad (8)$$

Step 3: Estimation of Safety Effectiveness

To estimate the total safety effectiveness, let,

$$\pi = \sum E_a \qquad (9)$$

$$\lambda = \sum O_a \qquad (10)$$

Here, O_a is the observed crash frequency in the after period.

The after period crash count is assumed to be Poisson distributed, and therefore the variance is equal to the sum of the counts.

An unbiased estimation of safety effectiveness is

$$\theta = \frac{\frac{\lambda}{\pi}}{1 + \frac{\mathrm{var}(\pi)}{\pi^2}} \tag{11}$$

The variance of safety effectiveness (CMF) is:

$$\mathrm{var}(\theta) = \frac{\theta^2[\frac{\mathrm{var}(\lambda)}{\lambda^2} + \frac{\mathrm{var}(\pi)}{\pi^2}]}{[1 + \frac{\mathrm{var}(\pi)}{\pi^2}]^2} \tag{12}$$

There are differences in number of control sections and total length of rural two-lanes where CLRS have been installed in DOTD each district. Table 8 presents the estimated safety effectiveness (CMF, θ) in each district and associated standard deviation (or standard error, **σ**).

Table 8
Results from EB Analysis

District	Length (mile)	Number of Control Sections	θ (σ)
2	68.15	10	0.777 (0.068)
3	171.75	31	0.846 (0.051)
4	367.13	43	0.714 (0.033)
5	240.87	36	1.033 (0.071)
7	215.81	27	0.769 (0.054)
8	277.54	40	0.859 (0.042)
58	185.56	29	1.011 (0.098)
61	142.58	26	0.781 (0.05)
62	195.94	39	0.869 (0.036)
Total	**1,865.33**	**281**	**0.831 (0.016)**

DISCUSSION OF RESULTS

Summary of Analysis

The before and after crash analysis clearly indicates the very positive results on the CLRS: a 15.1% reduction in total crashes, 31.2% fatal crashes, and 22.1% injury crashes in the three years after the CLRS installation. The target crashes (head-on, opposite direction sideswipe crashes) decreased by 36.7%. The crash reductions happened in all time periods, lighting, and driver conditions.

The CMF estimated by the EB method is 0.831, which means the expected crash reduction is 16.9% for the CLRS installation. As shown in Table 9, the reduction is for certain even the percentage may vary between 12.1% and 21.7%.

Table 9
EB results

θ	σ	$\theta - 3\sigma$	$\theta + 3\sigma$
0.831	**0.016**	**0.783**	**0.879**

Safety Benefit-Cost Analysis

According to DOTD's information, the cost of centerline ground-in rumble strips is about $700 per mile. But, it does not include the cost of pavement stripping and other pavement markers installed along with rumble strips. In the total estimation, in addition to pavement stripping and markers, the costs for temporary signs and barricades, and mobilization cost during construction are also included. Table 10 lists the cost estimations.

Table 10
Cost estimation of CLRS installation

Description	Unit	Unit Cost	Quantity	Costs
Miles of Roadway			1,865	
Temporary Signs and Barricades	LS	5%		$646,992
Mobilization	LS	5%		$646,992
Reflectorized Raised Pavement Markers	Ea	$3.50	246,224	$861,784
Plastic Pvmt. Strip (Solid Line)	Mile	$1,800	5,596	$10,072,800
Plastic Pvmt. Strip (Brkn Line)	Mile	$750	933	$699,750
Rumble Strips (Centerline Ground-In)	Mile	$700	1,865	$1,305,500
Total				**$14,233,818**

The observed crash reduction in three years before and after installation of CLRS (i.e. observed before crashes – observed after crashes) by severity is considered here as the benefits. Table 11 shows the cost of crash according to injury type. The crash cost was obtained from DOTD's website *[28]*.

Table 11
Estimation of safety benefits

Injury Type	Observed Crash Reduction	Crash Cost	Safety Benefit
Fatal	44	$1,710,561	$75,264,684
Severe	11	$489,446	$5,383,906
Moderate	196	$173,578	$34,021,288
Complaint	349	$58,636	$20,463,964
None	279	$24,982	$6,969,978
Total Benefit			**$142,103,820**

Finally, the benefit-cost ratio is estimated as 9.98.

PART II: LANE CONVERSION

INTRODUCTION

Four-lane undivided highways (abbreviated as 4U in HSM) in urban and suburban areas are commonly prone to rear-end and left turn crashes due to speed differentials caused by left turning vehicles with through vehicles. The crash-susceptibility of undivided four-lane highways is particularly prevalent in areas with higher driveway density. Louisiana has about 250 miles of urban four-lane undivided state-owned highways, which is 1.6% of total state-controlled road network. Between 2011 and 2015, approximately 45,000 crashes occurred on the four-lane undivided highways, which is 9% of total crashes in the state during the same period. Among those crashes, 30% resulted in injuries, of which major crash types are rear-end (40%), right angle (24%), and left turn (15%) crashes.

Separating left turn vehicles from through traffic by reconfiguring the undivided four-lane roadway to a three-lane roadway (abbreviated as 3T in HSM) or a five-lane highway (abbreviated as 5T in HSM) with a two-way left turn lane in the middle, as shown in Figures 8 and 9, is an inexpensive countermeasure. This lane reconfiguration is sometimes called the road diet because of the reduced number of lanes or reduced lane width. The three-lane configuration can utilize additional space for non-motorized travel modes or on street parking, creating an opportunity for "complete streets" environment. Road diet is being recognized as a better and safer alternative design to undivided four-lane roadways while maintaining the highway functions. The three-lane roadways with two-way left turn lane inherently possess less mid-block conflict points, less crossing and through traffic conflict points at intersections, better sight distance for vehicles taking left turns *[29]*. In general, the 3T can handle AADT up to 20,000 *[30]*.

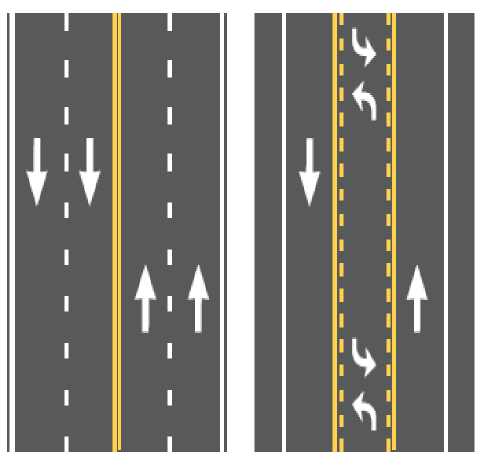


Figure 8
Before/after image of a typical road diet (four- to three-lane highway) conversion [reproduced from road diet informational guide]

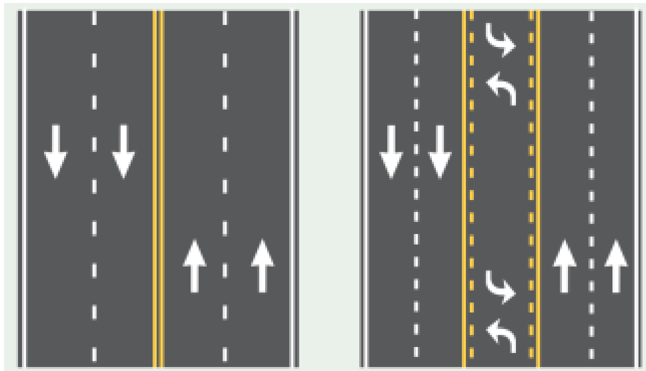


Figure 9
Before/after image of a typical four to five-lane highway section [reproduced from road diet informational guide]

The current design policies for urban roadways discourage the five-lane highway (5T). The DOTD allows reconfiguration of 4U to 5T highway currently, however, it is not recommended in the Louisiana minimum design guidelines for the newly constructed or reconstructed urban arterial highways. The design of 5T requires additional approval from the department chief engineer if it is to be constructed *[31]*. Based on the current HSM, under the same AADT (within the application range), the 5T would have the higher expected annual crashes than the undivided four-lane roadways do *[20]*.

Numerous case studies are available showing the reduction in total crashes and target crashes due to the 3T road diet implementation, but only few studies utilized EB approach *[32]*. Table 12 lists the studies which used EB to assess safety of converting 4U to 3T conversion. Few of the studies used the same data.

Table 12
Previous studies on road diet

Study	**Year**	**Method**	**No. of sites**	**Length (miles)**	**Crash variable/ location**	**CMF**
Pawlovich et al. *[33]*	2006	Full Bayes Full Bayes	15 (treatment), 15 (control)	15	Crash/mile	0.748
					Crash rate	0.872
Harkey et al. *[34]*	2008	EB	45 (treatment), 346 (control)	40.5	Iowa	0.536
					California & Washington	0.811
					Total	0.707
Persaud et al. *[35]*	2010	Full Bayes	15 (treatment), 296 (control)	15	All	0.53

In Harkey et al. study, results for Iowa treatment sections and HSIS (California and Washington) sections were significantly different in terms of safety effectiveness, although EB was used in both cases. The study concluded that the difference may be a function of traffic volumes and characteristics of the urban environments where the road diets were implemented *[34]*. Crash reduction is not necessarily the main objective of all lane conversion projects. Many projects have other major implement consideration of delay minimization, and others *[36]*. Since road diet has not been implemented in a large scale, applicability of CMF is not expected to be the same in different context.

There are very few studies on the safety benefits of this 4U to 5T conversion, which have been reported in the previous literature review by this author *[37]*. That previous study on this topic was the first comprehensive research on the 4U to 5T conversions for safety, in which four sites were thoroughly investigated. The project technical report published in 2013 lists the CMF from the four sites are 0.45, 0.43, 0.47, and 0.65, respectively *[38]*.

In 2007, a comparison between 4U and 5T was made to see the design alternatives in Oklahoma, which found 5T as a better option in reducing rear-end and head-on crashes compared to 4U roadways. This comparison was used to evaluate US 81 for improvement along an approximate 30-mile segment *[39]*.

Road diet informational guide documents 5T as an additional roadway configuration and suggests it especially for higher capacity purposes *[36]*. Although the road diet is critically acclaimed as an inexpensive countermeasure, some studies reported an increase in rear-end crashes because of the speed differential between through traffic and right turn traffic, increased delay, and increased travel time. In Grand Rapids, Michigan, it has been reported that, after three-lane conversion, rear-end crashes nearly tripled with longer travel times and additional delay at intersections *[32]*. Five-lane conversion might overcome all these limitations, since it utilizes the road width to accommodate left turn lane, one through lane and another through lane shared with right turn.

Due to the budgetary constraints and the urgent needs to reduce crashes on 4U roadways, more roadway segment in urban and suburban areas were converted to 5T after the first study conducted in Louisiana. For the 4U roadways with the AADT less than 20,000, 3T configuration has been utilized in the state as well in the past several years.

OBJECTIVE

The goal of this part of the research is to evaluate safety performance of both five-lane and three-lane conversions. Specifically, the objectives are to:

- Conduct before and after crash analysis for the two types of lane conversions.
- Develop the corresponding CMFs.
- Estimate safety benefit and cost ratio to justify the project.

SCOPE

This study is limited to urban four-lane roadway conversions only by restriping to either five-lane roadway (six sites) or three-lane roadway (four sites), with a two-way left turn lane in the middle. These conversions also impact intersection crashes, but the study did not investigate intersection crashes exclusively. Non-intersection crashes were addressed with the EB method due to the availability of required safety performance functions. A combined analysis of segment crashes and intersection crashes were performed using Improved Prediction method.

METHODOLOGY

Data Collection and Verification

The location data of lane conversions was collected from meetings with DOTD representatives. From informal descriptions received from DOTD, exact locations and conversion years were verified using "Google Street View" and "DOTD Lat/Long conversion tool." From visual inspection of the sites through street view, access data (driveway information) was collected. Only recent conversion projects were selected with at least three after years available for analysis. Table 13 contains the list of projects for both types of conversions; whereas, Figure 10 presents the locations on a map.

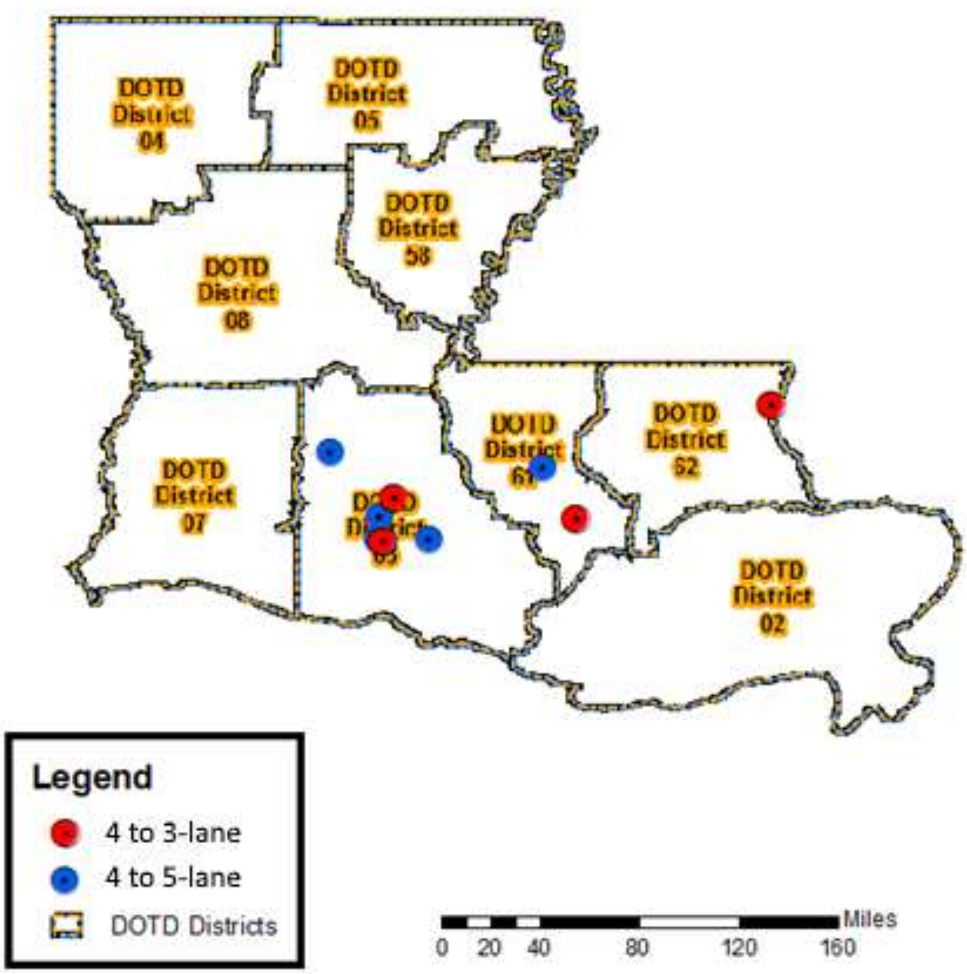


Figure 10
Lane conversion sites

Table 13
Lane conversion sites selected for analysis

Type of Conversion (Total Length)	Location	Control Section	Logmile from	Logmile to	Length (mile)	Conversion Year	Before years	After years	Access density (driveways/mile)
4U to 3T (3.92 miles)	N. Bertrand in Lafayette	828-38	1.52	2.04	0.52	2013	2010-12	2014-16	48
4U to 3T (3.92 miles)	LA 14 Charity in Abbeville	055-06	0.56	1.97	1.41	2011	2008-10	2012-14	68
4U to 3T (3.92 miles)	LA 3089 in Donaldsonville	426-01	0	0.62	0.62	2013	2010-12	2014-16	39
4U to 3T (3.92 miles)	LA 21 in Bogalusa	030-03	7.29	8.66	1.37	2008	2005-07	2009-11	36
4U to 5T (5.97 miles)	LA 14 in New Iberia	055-07	9.09	10.01	0.92	2007	2004-06	2008-10	37
4U to 5T (5.97 miles)	LA 14 (charity) in Abbeville	055-06	1.97	2.44	0.47	2011	2008-10	2012-14	66
4U to 5T (5.97 miles)	LA 14-Bypass in Abbeville	055-30	0.57	1.77	1.2	2011	2008-10	2012-14	45
4U to 5T (5.97 miles)	US 167 in Maurice	080-01	9	10.14	1.14	2012	2009-11	2013-15	43
4U to 5T (5.97 miles)	US 190 in Eunice	012-11	3.87	5.32	1.45	2012	2009-11	2013-15	59
4U to 5T (5.97 miles)	LA 42 in Baton Rouge	257-04	3.96	4.75	0.79	2013	2010-12	2014-16	44

Before/After Analysis

Table 14 lists three years before and three years after averaged AADT for both types of conversions. The AADT data was collected from yearly DOTD highway section database. It is noticeable that AADT decreases in some sites for both types of conversions. A 4U to 3T conversion in LA 21 in Bogalusa has a large reduction of AADT, considering the site includes multiple control sections with varied AADT and the overall AADT is the weighted AADT by length. The US 190 in Eunice, a site converted to five lanes, also experienced a considerable reduction in AADT.

Table 14
Change of AADT in lane conversion sites

Type of Conversion	Site	AADT before	AADT after	Percent change
4U to 3T	N. Bertrand (LA 3025) in Lafayette	9,867	9,833	-0.3%
4U to 3T	LA 14 Charity in Abbeville	8,333	9,200	10.4%
4U to 3T	LA 3089 in Donaldsonville	9,103	14,570	60.1%
4U to 3T	LA 21 in Bogalusa	13,900	9,533	-31.4%
4U to 5T	LA 14 in New Iberia	19,867	19,767	-0.5%

Type of Conversion	Site	AADT before	AADT after	Percent change
4U to 5T	LA 14 (charity) in Abbeville	6,800	7,860	15.6%
4U to 5T	LA 14-Bypass in Abbeville	15,271	17,097	12.0%
4U to 5T	US 167 in Maurice	18,748	20,098	7.2%
4U to 5T	US 190 in Eunice	22,141	19,194	-13.3%
4U to 5T	LA 42 in Baton Rouge	18,900	24,867	31.6%

Both segment + intersection and non-intersection crashes in three years before/after period have been extracted from the database. In the following analysis part of the report, the crash characteristics analysis for 4U to 3T will be presented first, analysis results for 4U to 5T will then follow. Each table and figure present three years before and/or after years of data. As mentioned in Part I: CLRS that intersection crashes in the analysis were identified as designated intersection crashes as identified in the police report and crashes occurred within 150 ft. of the intersections.

For 4U to 3T conversion, number of combined (segment + intersection) crashes did not increase, except for only one PDO crash increase in LA 3089 (Table 15). When only non-intersection crashes are considered, PDO crashes increased in two sites (Table 16).

Table 15
Segment + intersection crashes by severity before and after 4U to 3T conversion

Location	Total Crash			Fatal Crash		Injury Crash			PDO Crash		
	Before	After	Percent reduction	Before	After	Before	After	Percent reduction	Before	After	Percent reduction
N. Bertrand (LA 3025) in Lafayette	12	12	0%	0	0	1	1	0%	11	11	0%
LA 14 Charity in Abbeville	188	75	60.1%	0	0	64	26	59.4%	124	49	60.5%
LA 3089 in Donaldsonville	126	116	7.9%	0	1	42	30	28.6%	84	85	-1.2%
LA 21 in Bogalusa	53	41	22.6%	1	0	25	14	44%	27	27	0%
Total	**379**	**244**	**35.6%**	**1**	**1**	**132**	**71**	**46.2%**	**246**	**172**	**30.1%**

Table 16
Non-intersection crashes by severity before and after 4U to 3T conversion

Location	Total Crash			Fatal Crash		Injury Crash			PDO Crash		
	Before	After	Percent reduction	Before	After	Before	After	Percent reduction	Before	After	Percent reduction
N. Bertrand (LA 3025) in Lafayette	2	3	-50%	0	0	0	0	0%	2	3	-50%
LA 14 Charity in Abbeville	34	12	64.7%	0	0	13	4	69.2%	21	8	61.9%
LA 3089 in Donaldsonville	14	20	-42.9%	0	1	5	5	0%	9	14	-55.6%
LA 21 in Bogalusa	10	5	50%	1	0	2	0	100%	7	5	28.6%
Total	**60**	**40**	**33.3%**	**1**	**1**	**20**	**9**	**55.0%**	**39**	**30**	**23.1%**

The only fatal crash in the after period was observed in LA 3089 site (Figure 11). It was an early morning head-on crash, where the reason for careless operation was unknown. The report of the only fatal crash in the before period was unavailable.

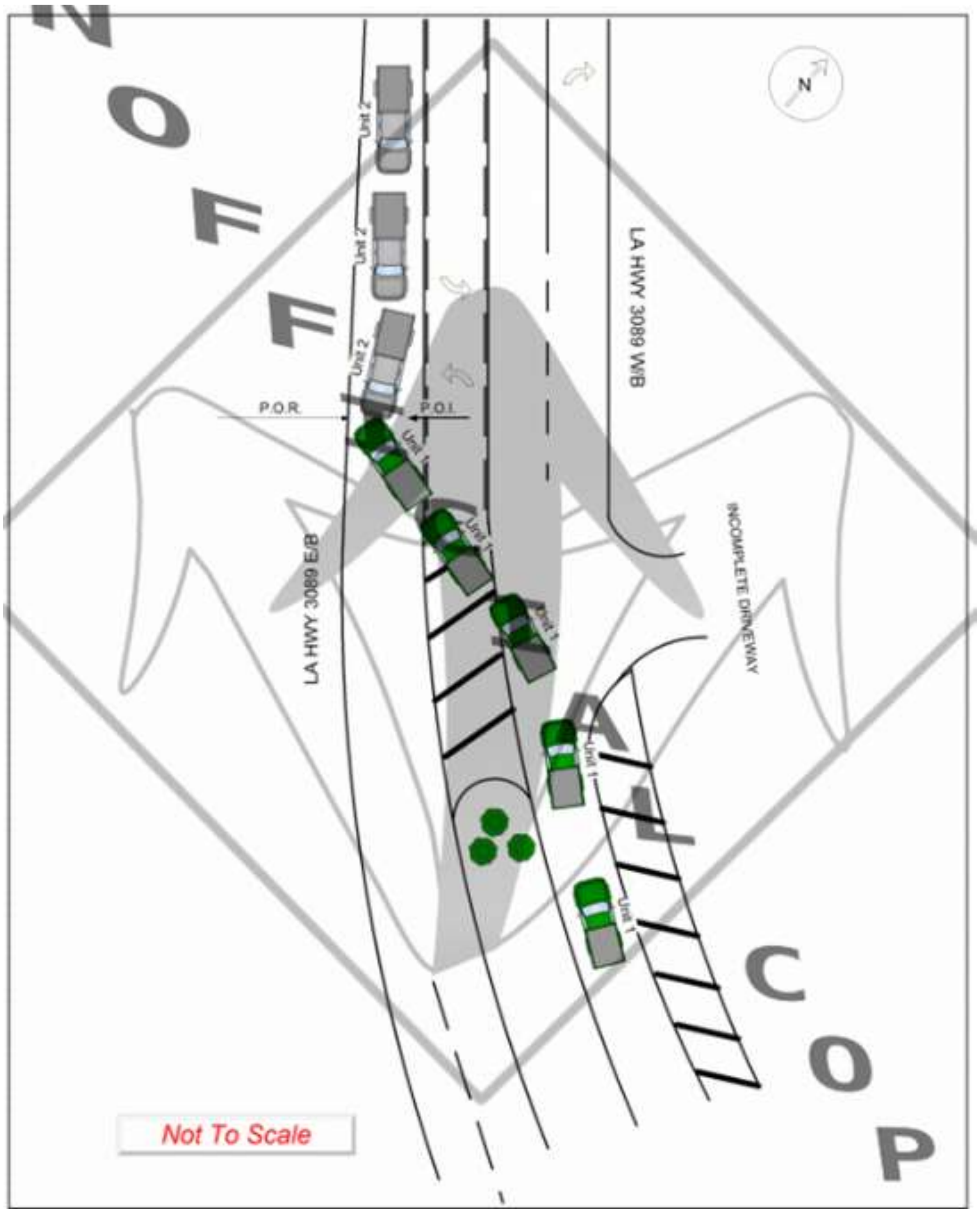


Figure 11
Head-on fatal crash on the LA 3089 section in the after period

For further insight into the crashes, analysis by manner of collision was also performed. Table 17 presents number of combined and non-intersection crashes by manner of collision. Number of crashes presented are total crashes for all four sites together. Site-by-site crash analysis is available in Appendix B.

Table 17
Crashes by manner of collision before and after 4U to 3T conversion

Manner of Collision	Combined (segment + intersection)			Non-intersection		
	Before	After	Percent Reduction	Before	After	Percent Reduction
Head-on	10	5	50%	2	1	50%
Left turn	73	24	67.1%	5	1	80%
Non-collision	11	10	9.1%	2	4	-100%
Rear-end	99	104	-5.1%	22	18	18.2%
Right turn	5	10	-100%	1	0	100%
Right angle	89	40	55.1%	5	1	80%
Sideswipe- OD	6	3	50%	2	0	100%
Sideswipe- SD	48	26	45.8%	11	10	9.1%
Other	38	22	42.1%	10	5	50%
Total	379	244	35.6%	60	40	33.3%

From Table 17, it is clear that rear-end and right turn crashes occurred mainly in intersections. 'Failure to yield' is one of the contributing factors for these two types of crashes. The LA 3089 in Donaldsonville site had increase in both types of crashes. Many rear-end crashes occurred due to failure of the following driver to maintain sufficient gap in front of intersections and private driveways (Figure 12). In addition to failure to yield, illegal maneuver caused right turn crashes (Figure 13). Failure to prioritize minor roadway movement at two way stop sign (Figure 13 - left) and illegal right turn from center lane (Figure 13 - right) caused the right turn crash incidents in the LA 3089 in Donaldsonville site.

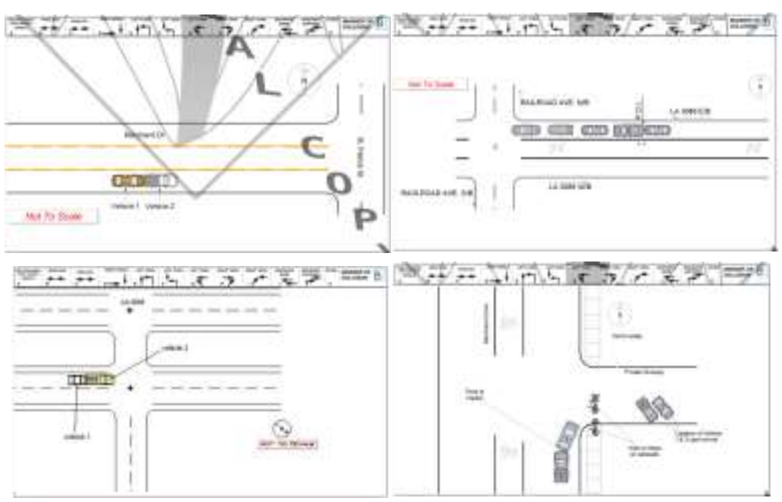


Figure 12

"Failure to yield" caused most of the rear-end crashes after 4U to 3T conversion

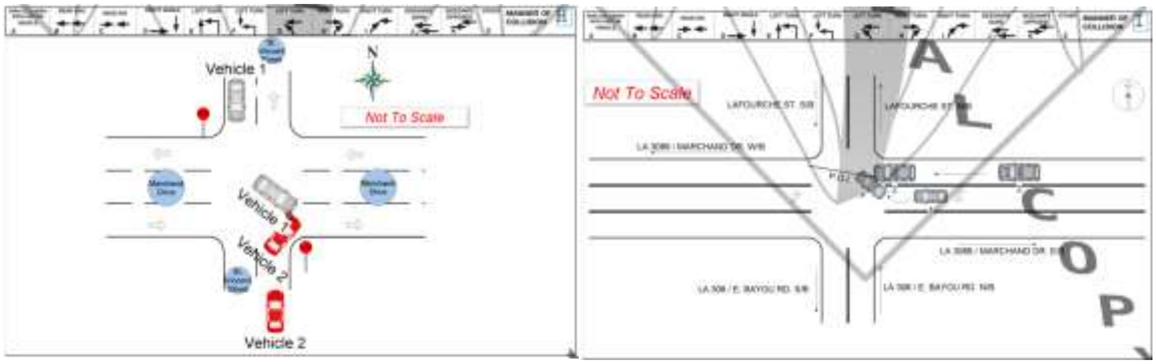


Figure 13
Illegal maneuver caused few right turn crashes to increase after three-lane conversion

Table 18 indicates that number of crashes from midnight to morning increased relative to number of crashes during other time, many sites included crashes when lighting condition was 'dark'. The number of alcohol-related crashes at intersections decreased in both types of conversions (Figure 14).

Table 18
Crashes by time of the day before and after 4U to 3T conversion

Time of the Day	Combined (segment + intersection)			Non-intersection		
	Before	After	Percent Reduction	Before	After	Percent Reduction
6 am - 12 pm	114	73	36.0%	17	18	-5.9%
12 pm - 6 pm	198	114	42.4%	33	12	63.6%
6 pm - 12 am	44	36	18.2%	5	4	20.0%
12 am - 6 am	18	21	-16.7%	4	6	-50.0%

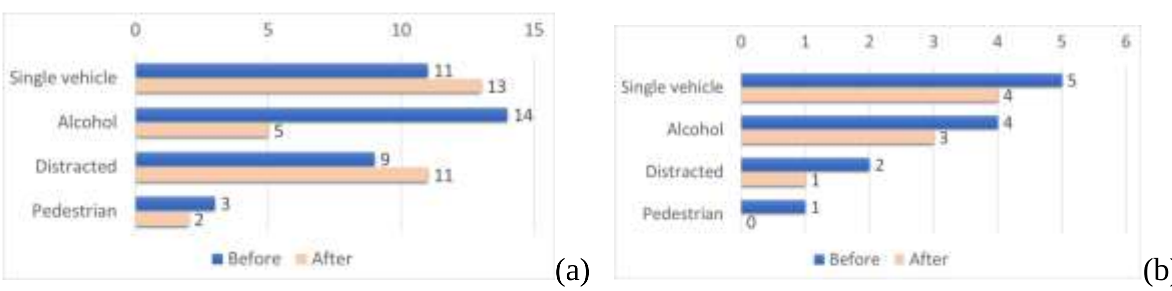


Figure 14
Number of single vehicle crashes, alcohol-related crashes, distracted driver crashes, and pedestrian-involved crashes for (a) segment + intersection (b) only segment before and after conversion to 4U to 3T

Table 19
Segment + intersection crashes by severity before and after 4U to 5T conversion

Location	Total Crash			Fatal Crash		Injury Crash			PDO Crash		
	Before	After	Percent reduction	Before	After	Before	After	Percent reduction	Before	After	Percent reduction
LA 14 in New Iberia	160	97	39.4%	0	0	50	24	52.0%	110	73	33.6%
LA 14 (charity) in Abbeville	39	20	48.7%	0	1	25	8	68.0%	14	11	21.4%
LA 14-Bypass in Abbeville	189	187	1.1%	0	0	73	53	27.4%	116	134	-15.5%
US 167 in Maurice	118	80	32.2%	0	0	28	24	14.3%	90	56	37.8%
US 190 in Eunice	293	233	20.5%	0	0	112	68	39.3%	181	165	8.8%
LA 42 in Baton Rouge	356	262	26.4%	0	0	70	43	38.6%	286	219	23.4%
Total	**1,155**	**879**	**23.9%**	**0**	**1**	**358**	**220**	**38.5%**	**797**	**658**	**17.4%**

Overall, there is a decrease in all types of severity crashes (Table 19). But only one fatal crash occurred on LA 14 (Charity) site, which is a nighttime pedestrian crash. There was no formal sidewalk available at the intersection (Figure 15). The number of PDO crashes increased at the LA 14 Bypass site. Details of the crash distribution by manner of collision can be seen in Appendix C. Table 20 presents severity distribution of non-intersection crashes. Number of non-intersection PDO crashes also increase at the LA 14 Bypass site, which contributes to total non-intersection crash increase in that site.

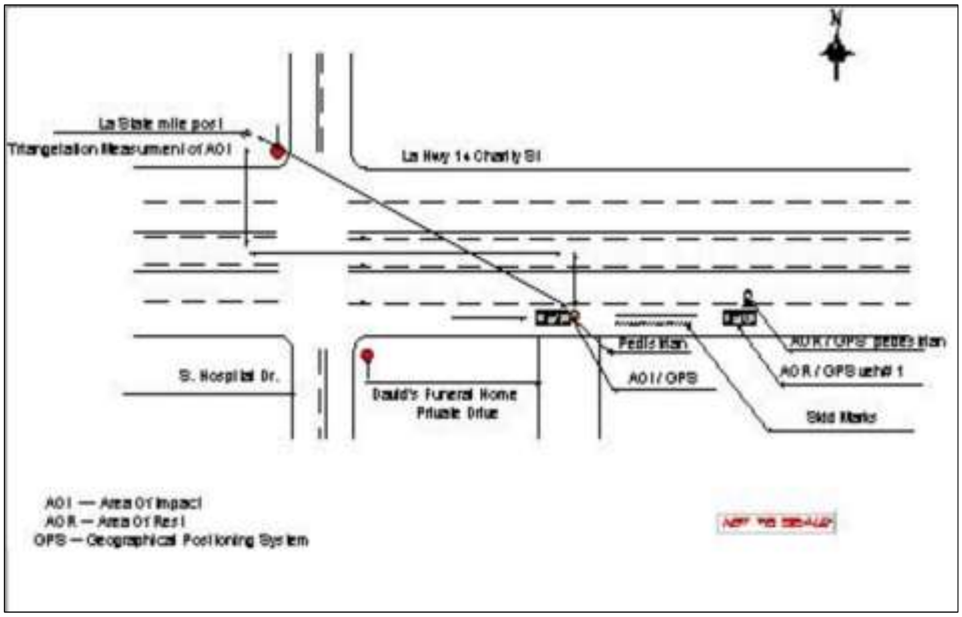


Figure 15
Fatal non-intersection nighttime pedestrian crash on LA 14 (charity) in Abbeville

Table 20
Non-intersection crashes by severity before and after 4U to 5T conversion

Location	Total Crash			Fatal Crash		Injury Crash			PDO Crash		
	Before	After	Percent reduction	Before	After	Before	After	Percent reduction	Before	After	Percent reduction
LA 14 in New Iberia	44	26	40.9%	0	0	11	8	27.3%	33	18	45.5%
LA 14 (charity) in Abbeville	10	4	60.0%	0	1	8	2	75.0%	2	1	50.0%
LA 14-Bypass in Abbeville	81	91	-12.3%	0	0	27	23	14.8%	54	68	-25.9%
US 167 in Maurice	42	15	64.3%	0	0	11	5	54.5%	31	10	67.7%
US 190 in Eunice	30	21	30.0%	0	0	11	7	36.4%	19	14	26.3%
LA 42 in Baton Rouge	68	50	26.5%	0	0	11	8	27.3%	57	42	26.3%
Total	**275**	**207**	**24.7%**	**0**	**1**	**79**	**53**	**32.9%**	**196**	**153**	**21.9%**

Analysis by manner of collision is presented for combined (segment + intersection) and non-intersection crashes in Table 21, total number of crashes in all four sites together. It is interesting to notice that although large reduction in left turn crashes and rear-end crashes was achieved, right turn crashes both at intersections and from driveways increased. Increase in sideswipe and head-on crashes at intersections is also noticeable.

Table 21
Crashes by manner of collision before and after 4U to 5T conversion

Manner of Collision	Combined (segment + intersection)			Non-intersection		
	Before	After	Percent Reduction	Before	After	Percent Reduction
Head-on	12	14	-16.7%	2	2	0%
Left turn	179	91	49.2%	23	16	30.4%
Non-collision	37	36	2.7%	15	15	0%
Rear-end	465	295	36.6%	130	68	47.7%
Right turn	20	29	-45%	5	7	-40%
Right angle	231	213	7.8%	38	29	23.7%
Sideswipe- OD	8	16	-100%	4	4	0%
Sideswipe- SD	104	130	-25%	37	50	-35.1%
Other	99	55	44.4%	21	16	23.8%
Total	**1,155**	**879**	**23.9%**	**275**	**207**	**24.7%**

From the after-period crash reports, it was found that head-on crashes in after period occurred mainly due to two reasons – failure to obey signal (Figure 16a) and failure to yield from driveways to opposite direction traffic (Figure 16b). Majority of the non-intersection right turn crashes in after years happened when driveway vehicles failed to yield while taking right turn (Figure 17). Many same direction sideswipe crashes resulted from lane changing. It is interesting to note that few opposite direction sideswipe crashes took place with vehicles waiting on the center lane to take left turn towards driveways (Figure 18). The FHWA suggests the increase in sideswipe crashes might be attributable to reduction of lane width, since the sites had at least one through lane width reduced to 9 to 9.5 ft. after reconfiguration to 5T *[40]*.

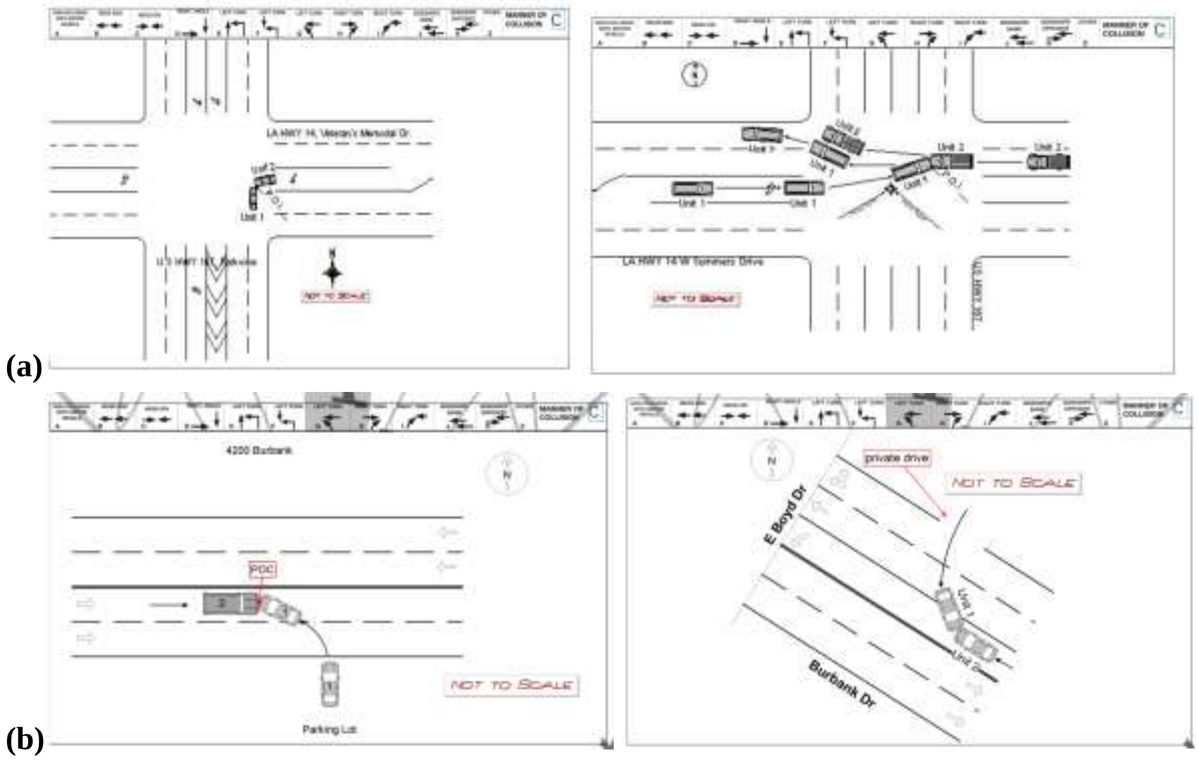


Figure 16
Post five-lane conversion head-on crashes resulted from (a) failure to obey signal, (b) failure to yield while taking left turn from driveways

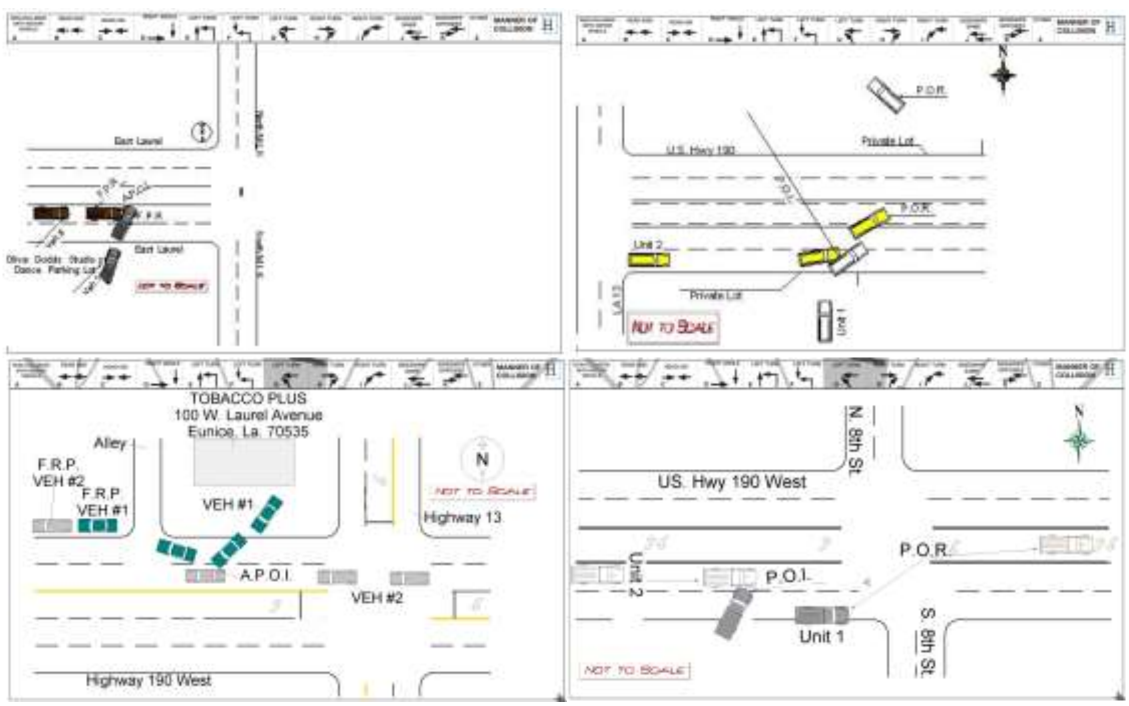


Figure 17
Examples of post five-lane conversion right turn crashes due to failure to yield from driveways

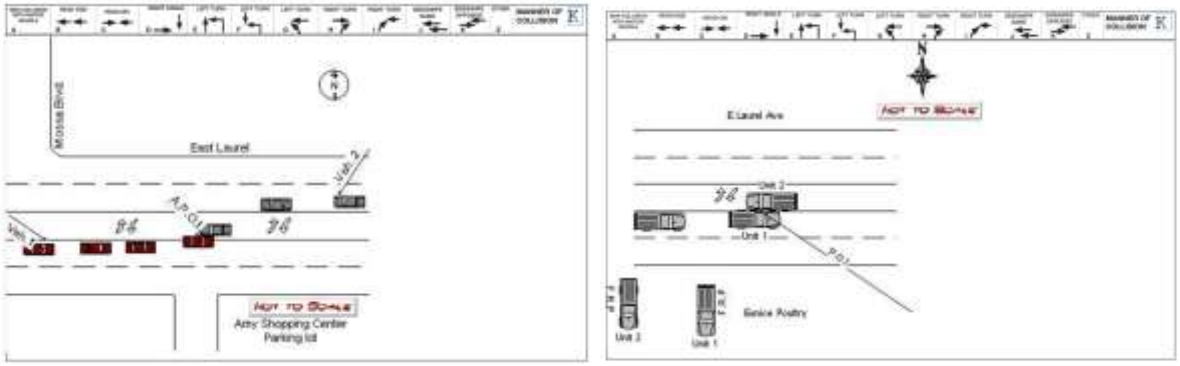
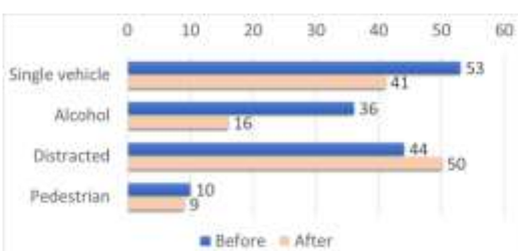


Figure 18
Post five-lane conversion opposite direction sideswipe crashes with the vehicles on the left turn lane

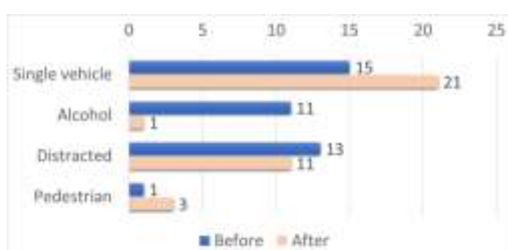
For 4U to 5T, number of crashes decreased for all four quarters of the day. This happens for both combined crashes and non-intersection crashes (Table 22). However, it should be mentioned that in the crash report, few number of crashes had no established time of the incidence. Reduction in alcohol-related crashes can be seen in Figure 19.

Table 22
Crashes by time of the day before and after 4U to 5T conversion

Time of the Day	Combined (segment + intersection)			Non-intersection		
	Before	After	Percent Reduction	Before	After	Percent Reduction
6 am - 12 pm	351	304	13.4%	83	74	10.8%
12 pm - 6 pm	575	429	25.4%	137	104	24.1%
6 pm - 12 am	166	103	38.0%	35	20	42.9%
12 am - 6 am	59	42	28.8%	20	9	55.0%



(a)



(b)

Figure 19
Number of single vehicle crashes, alcohol-related crashes, distracted driver crashes, and pedestrian-involved crashes for (a) segment + intersection (b) only segment before and after 4U to 5T conversion

CMF Development

The Improved Prediction method is a four-step method which considers the traffic flow change in the facilities for the before and after year of study. This method estimates the unbiased crash changes in absence of a safety performance function. Since safety performance function is developed for non-intersection segment, Improved Prediction method has been utilized to check the safety effectiveness of combined (segment + intersection) crashes in terms of CMF. The steps involved in this process are explained as follows. Further details of this method can be found in Hauer *[26]*.

Step 1: Estimating the safety if countermeasures were not installed in the after years (π) and the safety estimation with the countermeasures (λ).

$$\lambda = N \tag{13}$$

$$\pi = r_{tf}K \tag{14}$$

where,

λ = Estimated expected number of crashes in the after period with countermeasure

N= Observed annual crashes in the facility in the after period with countermeasure

π = Estimated expected number of crashes in the after period without countermeasure

K= Observed annual crashes in the facility in the before period without countermeasure

r_{tf} =Traffic flow correction factor

$$r_{tf} = \frac{\hat{A}_{avg}}{\hat{B}_{avg}} \tag{15}$$

A_{avg} = Average traffic flow during the after period

B_{avg} = Average traffic flow during the before period

Step 2: Estimating the variance $var(\lambda)$ and $var(\pi)$

$$var(\lambda) = \lambda \tag{16}$$

$$var(r_{tf}) = (r_{tf})^2[v^2(A_{avg}) + v^2(B_{avg})] \tag{17}$$

$$var(\pi) = (r_d)^2[(r_{tf})^2K + K^2var(r_{tf})] \tag{18}$$

where,

$var(\lambda)$ = Estimated variance of λ

$var(\pi)$ = Estimated variance of π

r_d= Ratio of time duration of after period to time duration of before period

$v =$ Percent coefficient of variance for AADT estimates

$$v = \left(1 + \frac{7.7}{number\ of\ counts - days} + \frac{1650}{AADT^{0.82}}\right) * 0.01 \quad (19)$$

Step 3: Estimating the crash difference δ and the ratio θ

$$\delta = \pi - \lambda \quad (20)$$

$$\theta = \frac{\frac{\lambda}{\pi}}{[1 + \frac{var(\pi)}{\pi^2}]} \quad (21)$$

where,

δ = Estimated safety impact of countermeasure

θ = Estimated unbiased expected crash modification factor

Step 4: Estimating the standard deviation of δ and θ

$$\sigma(\delta) = \sqrt{var(\lambda) + var(\pi)} \quad (22)$$

$$\sigma(\theta) = \frac{\theta\sqrt{\frac{var(\lambda)}{\lambda^2} + \frac{var(\pi)}{\pi^2}}}{1 + \frac{var(\pi)}{\pi^2}} \quad (23)$$

Results of this method are presented in Table 23 and Table 24. All the combined segments have been impacted positively with the adjustment of AADT. For 4U to 3T conversion (Table 23), CMF varies from 0.398 to 0.973, which means individual sites achieved 2.7% to 60.2% total crash reduction. However, overall CMF is 0.688 with standard deviation as low as 0.051. For 4U to 5T conversion (Table 24), CMF varies from 0.507 to 0.987, which means individual sites achieved 1.3% to 49.3% total crash reduction. However, overall CMF is 0.758 with standard deviation as low as 0.033.

Table 23
4U to 3T Improved Prediction results

Project	Section Length (mile)	Total Crash (Before)	Total Crash (After)	CMF/ Safety Effectiveness (θ)	Standard Deviation σ(θ)
N. Bertrand (LA 3025) in Lafayette	0.52	12	12	0.973	0.316
LA 14 Charity in Abbeville	1.41	188	75	0.398	0.050
LA 3089 in Donaldsonville	0.62	126	116	0.913	0.116
LA 21 in Bogalusa	1.37	53	41	0.771	0.128
Total	**3.92**	**379**	**244**	**0.688**	**0.051**

Table 24
4U to 5T Improved Prediction results

Project	Section Length (mile)	Total Crash (Before)	Total Crash (After)	CMF/ Safety Effectiveness (θ)	Standard Deviation σ(θ)
LA 14 in New Iberia	0.92	160	97	0.605	0.068
LA 14 (charity) in Abbevile	0.47	39	20	0.507	0.125
LA 14-Bypass in Abbeville	1.20	189	187	0.987	0.088
US 167 in Maurice	1.14	118	80	0.675	0.086
US 190 in Eunice	1.45	293	233	0.794	0.058
LA 42 in Baton Rouge	0.79	356	262	0.734	0.057
Total	**5.97**	**1,155**	**879**	**0.758**	**0.033**

Safety performance function for undivided four-lane highway has been developed by DOTD. Hence, it was utilized to estimate safety effectiveness of non-intersection crashes. Same steps were followed as it has been described in the analysis of CLRS (Part I of the report). Results are presented in Table 25 and Table 26. For 4U to 3T conversion (Table 25), the individual CMF was as low as 0.352 to up to 0.94, which means crash reduction from 6% to as large as 64.8% in non-intersection crashes in individual site can be achievable. Overall, CMF was 0.613 (indicates 38.7% crash reduction), with a standard deviation of 0.125. In 4U to 5T conversion (Table 26), one site (LA 14 Bypass) shows slight increase in non-intersection crashes. The individual CMF was as low as 0.333, which means up to 66.7% reduction of non-intersection crashes in individual site can be achievable. Overall, CMF was 0.701 (indicates 29.9% crash reduction), with very low standard deviation of 0.065.

Table 25
4U to 3T EB results

Project	**After period count, O_a**	**EB Estimate, E_a**	**var(E_a)**	**CMF/ Safety Effectiveness (θ)**	**Standard Deviation σ(θ)**
N. Bertrand (LA 3025) in Lafayette	3	2.9	2.88	0.772	0.473
LA 14 Charity in Abbeville	12	33.1	35.79	0.352	0.116
LA 3089 in Donaldsonville	20	19.7	30.13	0.940	0.311
LA 21 in Bogalusa	5	8.4	5.97	0.550	0.271
Total	**40**	**64.1**	**74.78**	**0.613**	**0.125**

Table 26
4U to 5T EB results

Project	**After Period count, O_a**	**EB Estimate, E_a**	**var(E_a)**	**CMF/ Safety Effectiveness (θ)**	**Standard Deviation, σ(θ)**
LA 14 in New Iberia	26	41.9	41.70	0.606	0.147
LA 14 (charity) in Abbeville	4	10.0	11.13	0.361	0.195
LA 14-Bypass in Abbeville	91	83.4	93.91	1.076	0.166
US 167 in Maurice	15	44.0	47.65	0.333	0.098
US 190 in Eunice	21	26.1	21.99	0.780	0.214
LA 42 in Baton Rouge	50	88.8	124.50	0.554	0.103
Total	**207**	**294.2**	**340.88**	**0.701**	**0.065**

DISCUSSION OF RESULTS

Summary of Analysis

The recent lane conversion projects in Louisiana are, again, successful in crash reduction. The overall crashes decreased 36% for 4U to 3T and 24% for 4U to 5T. Excluding intersections, crash reductions are 33% and 25% for 4U to 3T and 4U to 5T respectively. As with the previous study, the biggest drop, 47%, occurred on rear-end collisions for four- to five-lane conversions. The four- to three-lane conversions yield crash reduction in all crash types except single-vehicle crashes which increased from 2 to 5. The injury crashes reduced 36% and 38% for 4U to 3T and 4U to 5T conversions. Because of short segments' length, fatal crash is a very rare event: one fatal crash in before and one in after periods. The before fatality happened on a segment before converted to three-lane, and one fatal crash occurred on a segment converted from four- to five-lane that had nothing to do with the project (pedestrian crossing street away from the intersection).

The CMFs estimated by the improved method and EB method are listed in Tables 27 and 28 for the three-lane and five-lane conversions. The estimated CMF is 0.61 with certainty for positive safety results on four- to three- lane cases and 0.70 with certainty for positive safety results on four- to five-lane case when only segments (non-intersections) are considered.

Table 27
4U to 3T comparison of CMF results of combined sections and non-intersection crashes

Location	**Segment + Intersection crashes (Improve Prediction Method)**			**Non-intersection crashes (Empirical Bayes method)**		
	θ	θ -3σ	θ +3σ	θ	θ -3σ	θ +3σ
N. Bertrand (LA 3025) in Lafayette	0.973	0.025	1.920	0.772	0	2.191
LA 14 Charity in Abbeville	0.398	0.247	0.549	0.352	0.004	0.699
LA 3089 in Donaldsonville	0.913	0.564	1.262	0.940	0.006	1.874
LA 21 in Bogalusa	0.771	0.388	1.154	0.550	0	1.362
Total	**0.688**	**0.534**	**0.842**	**0.613**	**0.238**	**0.989**

Table 28
4U to 5T comparison of CMF results of combined sections and non-intersection crashes

Location	Segment + Intersection crashes (Improved Prediction Method)			Non-intersection crashes (Empirical Bayes method)		
	θ	θ -3σ	θ +3σ	θ	θ -3σ	θ +3σ
LA 14 in New Iberia	0.605	0.401	0.809	0.606	0.163	1.048
LA 14 (Charity) in Abbeville	0.507	0.132	0.881	0.361	0	0.946
LA 14-Bypass in Abbeville	0.987	0.722	1.251	1.076	0.578	1.575
US 167 in Maurice	0.675	0.419	0.932	0.333	0.038	0.627
US 190 in Eunice	0.794	0.619	0.970	0.780	0.139	1.421
LA 42 in Baton Rouge	0.734	0.563	0.905	0.554	0.245	0.864
Total	**0.758**	**0.659**	**0.857**	**0.701**	**0.505**	**0.897**

The scatterplot of AADT and driveway density with CMF shows that, overall, the lane reconfiguration works well with a combination of relatively low AADT and high driveway density and a combination of high AADT and relatively low driveway density (Figure 20). However, the result is limited to only ten converted segments only. Results from more data points would deliver more confident results.

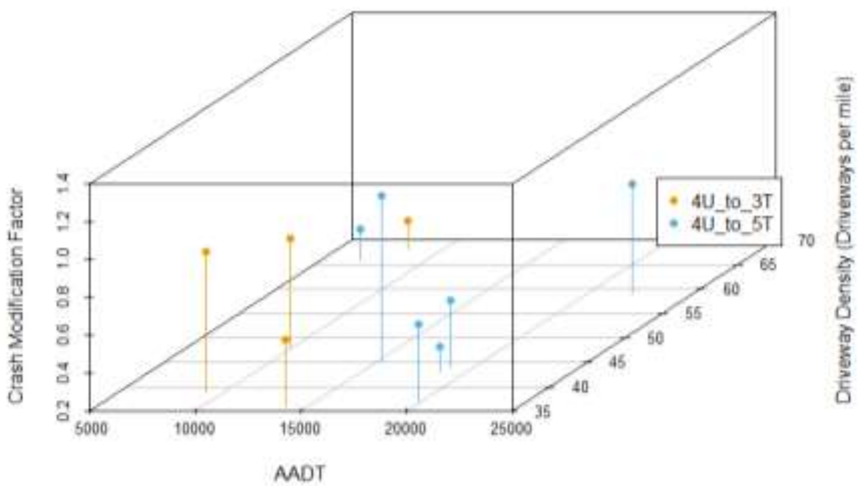


Figure 20
Scatterplot of CMF vs AADT and driveway density

Safety Benefit Cost Analysis

Benefit was estimated according to the latest crash cost by different injury types from DOTD. The cost of restriping is $11,450 per mile based on the data from the previous study. The cost of re-striping per mile including both materials and labor is $11,450 per mile by outside contract. It would cost significantly less if it is done in-house, by the District maintenance crew. The benefit estimations based on the observed crash reduction for both combined (segment + intersection) and non-intersection crashes are listed in Tables 29 and

30. Both types of conversions yield high safety benefit cost ratio with or without considering intersection crashes.

Table 29
Benefit cost analysis for 4U to 3T conversion

Combined (segment + intersection)				Non-intersection			
Injury Type	**Crash Reduction**	**Crash Cost**	**Benefit**	**Injury Type**	**Crash Reduction**	**Crash Cost**	**Benefit**
Fatal	0	$1,710,561	$0	Fatal	0	$1,710,561	$0
Severe	-1	$489,446	-($489,446)	Severe	0	$489,446	$0
Moderate	32	$173,578	$5,554,496	Moderate	9	$173,578	$1,562,202
Complaint	30	$58,636	$1,759,080	Complaint	2	$58,636	$117,272
None	74	$24,982	$1,848,668	None	9	$24,982	$224,838
Total safety benefit			**$8,672,798**	**Total safety benefit**			**$1,904,312**
Total construction cost ($11,450 per mile)			**$44,873**	**Total construction cost ($11,450 per mile)**			**$44,873**
Safety benefit cost ratio			**193**	**Safety benefit cost ratio**			**42**

Table 30
Benefit cost analysis for 4U to 5T conversion

Combined (segment + intersection)				Non-intersection			
Injury Type	**Crash Reduction**	**Crash Cost**	**Benefit**	**Injury Type**	**Crash Reduction**	**Crash Cost**	**Benefit**
Fatal	-1	$1,710,561	-($1,710,561)	Fatal	-1	$1,710,561	-($1,710,561)
Severe	6	$489,446	$2,936,676	Severe	4	$489,446	$1,957,784
Moderate	19	$173,578	$3,297,982	Moderate	9	$173,578	$1,562,202
Complaint	113	$58,636	$6,625,868	Complaint	13	$58,636	$762,268
None	139	$24,982	$3,472,498	None	43	$24,982	$1,074,226
Total Benefit			**$14,622,463**	**Total Benefit**			**$3,645,919**
Total construction cost ($11,450 per mile)			**$68,448**	**Total construction cost ($11,450 per mile)**			**$68,448**
Safety benefit cost ratio			**214**	**Safety benefit cost ratio**			**53**

PART III: RCUT (RESTRICTED CROSSING U-TURN) OR J-TURN

INTRODUCTION

The safety of intersections on the divided high-speed highways is always a concern because of the complicated high-risk maneuvers. Majority of the intersection crashes are right angle collisions with a high percentage of fatalities and injuries. For example, at a stop-sign controlled approach intersecting with a high-speed highway, the major crash type is a crash involving a vehicle entering the intersection from the stop approach and a vehicle traveling high speed on the through approach, usually on the far side of the intersection from the right. The crash typically occurs after the vehicle from the stop approach has entered the divided median portion of the intersection and is attempting either to cross or turn left onto the far side of the arterial. While sign and marking countermeasures may impact this problem, they are not considered as effective as eliminating the through and left turn movement from the minor street. For a signalized intersection, an exclusive left turn signal phase does promote safety, but it often results in a lower intersection capacity and the excessive delay during rush hours.

One relatively new countermeasure at such locations is called Restricted Crossing U-Turn (RCUT), or simply J-turn, has gained lots of attraction. For an RCUT intersection, the minor road vehicles with the intention to either make a left turn or drive through are forced to turn right, follow the major road some distance, then merging to the left lane to make a U-turn at a designated U-turn facility. After the U-turn, the vehicle can make the desired maneuver. Figure 21 illustrates how RCUT works for crossing vehicles (Path A) and left turn vehicles (Path B).

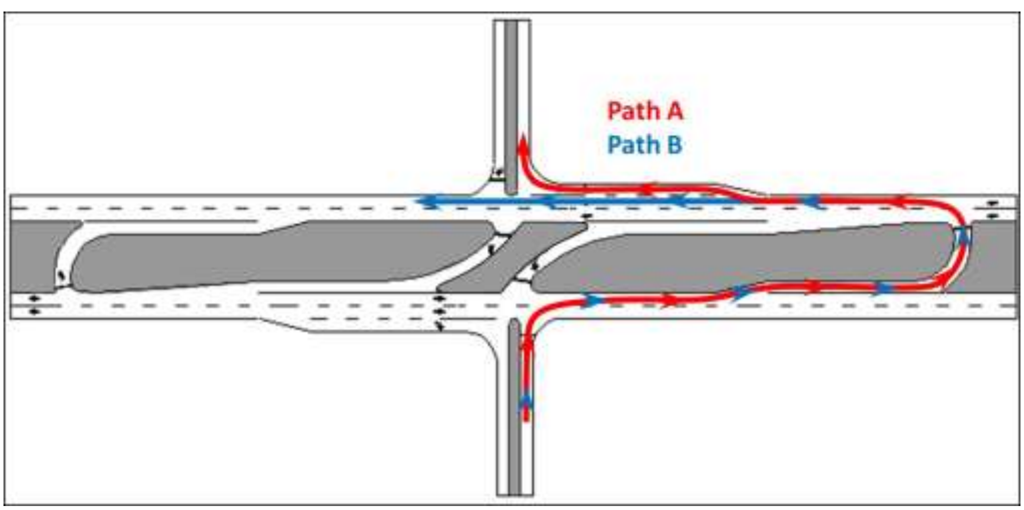


Figure 21
RCUT Intersection diagram (Reproduced from FHWA website *[41]*)

Because of the relatively short history of RCUT application in the United States, there are very limited studies available on the safety effectiveness of such intersection treatment. The NCHRP 650 titled “Median Intersection Design for Rural High-Speed Divided Highways” describes common safety issues at median intersections on rural divided highways and presents innovative geometric and operational treatments for addressing those issues, which also included recommendations for modifications to the AASHTO A Policy on Geometric Design of Highways and Streets (Green Book) and the Manual on Uniform Traffic Control Devices (MUTCD) *[42]*. One study analyzed five RCUTs in Missouri with the Empirical Bayes (EB) method and concluded that RCUT can reduce total crashes 34.8%, fatal and injury crashes 53.7%, right angle crashes 80%, and totally eliminate the left turn crashes *[43]*. The Maryland study observes 92% reduction in total crashes and 100% reductions in fatal and injury crashes, while its EB analysis yields a 44% reduction in total crashes *[44]*. Similarly, a 57% reduction of total crashes with a 97% reduction in right angle crashes and total elimination of left turn crashes were observed by the North Carolina study *[45]*. The North Carolina and Missouri studies have been documented in Restricted Crossing U-turn Intersection Informational Guide by FHWA *[46]*.

To solve the intersection crash problems along the high-speed highways, DOTD has installed close to a dozen of RCUTs in last several years. This part of the report presents the study on the safety effectiveness of ten RCUTs in Louisiana. In previous studies, Restricted Crossing U-Turn has been addressed as “Superstreet,” “J-turn,” “Right turn U-Turn” or “Reduced Conflict Intersection.” In this report, the term “RCUT” and “J-turn” will be used interchangeably.

OBJECTIVE

The purpose of this part of the project was to evaluate the safety benefit of RCUT in Louisiana. The specific objectives were to:

- Perform a before/after crash characteristics analysis.
- Develop the crash modification factor of RCUT intersections utilizing the EB method and Improved Prediction Method
- Estimate overall safety benefit-cost ratio of RCUT installation.

SCOPE

The scope of the study was limited to the 10 RCUTs (one in rural area and nine in urban areas) on four divided multiple-lane highways with a speed limit higher than or equal to 55 mph. Due to the difference in design, three types of RCUT were evaluated: complete RCUT, partial RCUT with two minor streets, and partial RCUT with one minor street.

METHODODLOGY

Data Collection and Verification

A total of 11 RCUT intersections were identified in Louisiana with the help of the DOTD. Google maps were used to verify the locations and construction years of each RCUT intersection for selection of RCUTs with at least three years in operation by 2016. Ten out of 11 RCUTs were selected for analysis. The RCUT at the intersection of Chemin Metairie and LA 3073 is on a new roadway with no before year crashes to compare to and was therefore excluded from the study. Louisiana RCUTs were grouped into three different types of RCUT – Complete RCUT (J), RCUT with access to two minor roads at each U-turn (JJ), and RCUT only with access to one minor road at U-turn (JJJ). Illustrations of all three types of RCUT are given in Figure 22. The number in parenthesis indicates the number of RCUT intersections in each type for this study.

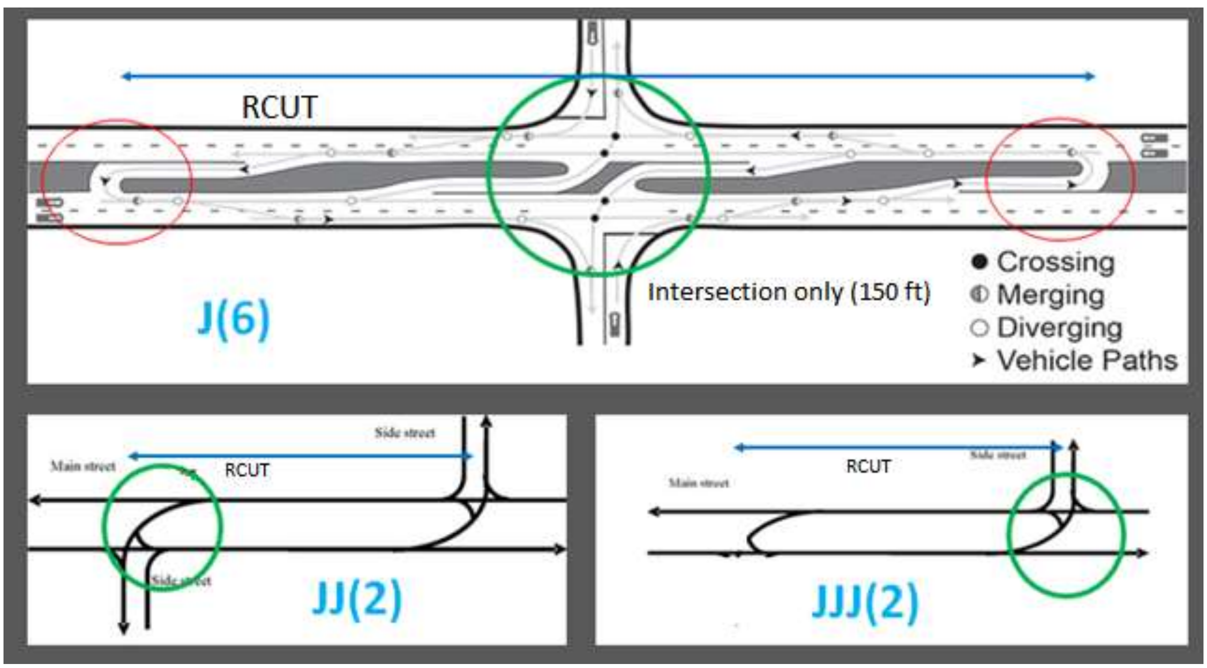


Figure 22
Different RCUT intersection design in Louisiana

The control section and logmile information were obtained from DOTD online tool that converts the geographic coordinates (latitude and longitude) to control section ID. The crashes, retrieved from the DOTD database, were populated to each control section *[1]*. Some of the crash reports, maintained by the state police, were obtained from the access provided by the "Thinkstream website" *[47]*. Crashes within the 150-ft. radius from the intersection was considered as intersection only crashes, whereas the RCUT crashes were crashes that occurred between two U-turns as shown in the Figure 22. Figure 23 illustrates the locations of the 10 RCUTs in the state.

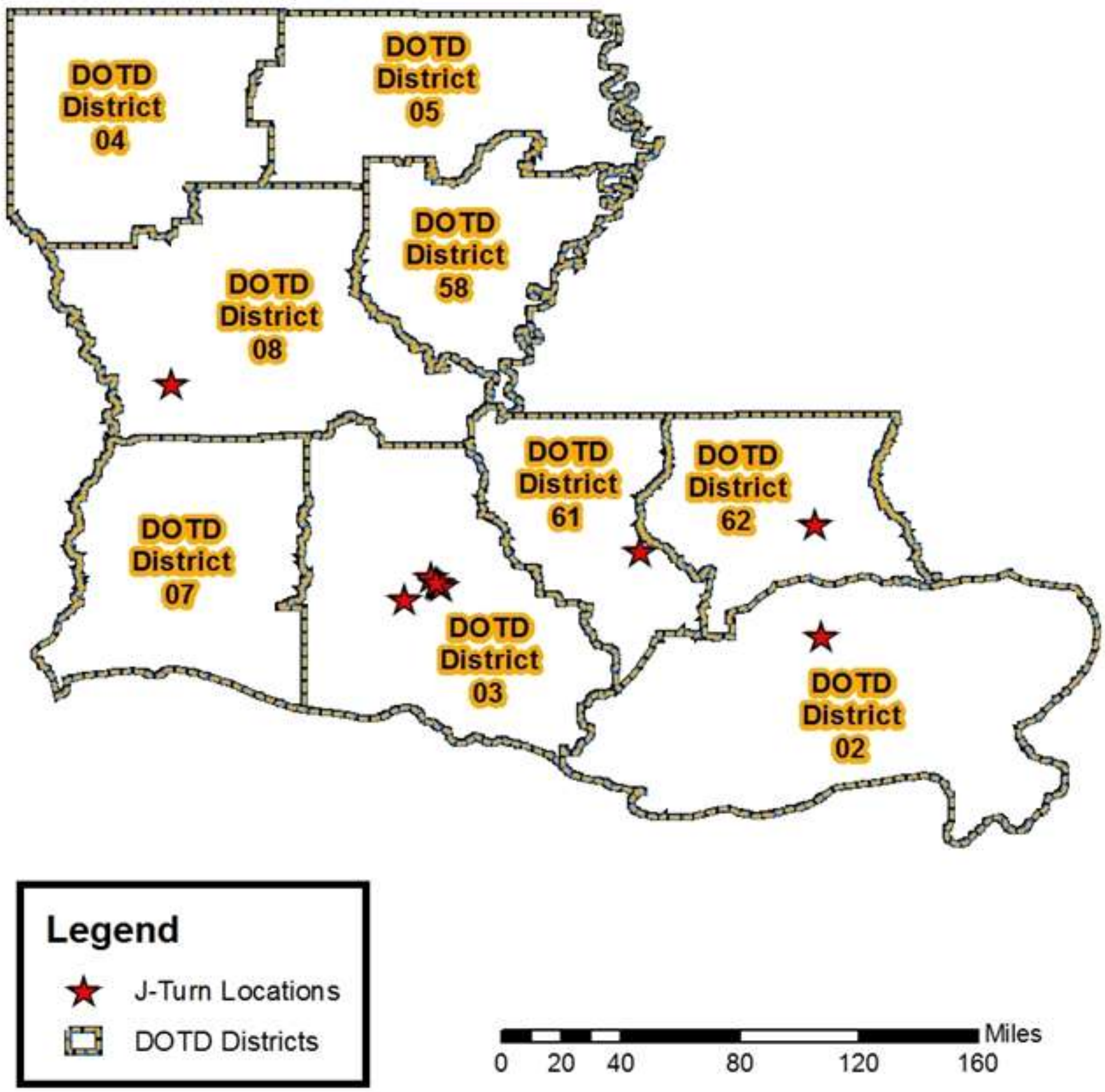


Figure 23
RCUT locations in Louisiana

Six RCUTs in this study are from DOTD District 3 and five of the six are located along the Highway 90 between East University Avenue and Albertsons Parkway intersections. Table 31 lists the general information of those locations.

Table 31
General information of RCUT intersections

RCUT Type	Location	District	Location setting and Highway Type in After Period	Intersection Type	Year of Construction	AADT	
						Before	After
J	**US 167 at LA 699**	**3**	Rural 4-lane divided	2ST	2012	17,100	19,133
J	**LA 21 at Zinnia Rd.**	**62**	Urban 4-lane divided	2ST	2012	24,900	24,200
J	**Kurthwood Rd. at Alexandria Highway**	**8**	Urban 4-lane divided	2ST	2011	7,067	9,367
J	**LA 45 at 10th street**	**2**	Urban 6-lane divided	2ST	2013	38,233	35,900
J	**US 61 at LA 42**	**61**	Urban 4-lane divided	4SG	2013	41,900	41,900
J	**US 90 at Morgan Ave**	**3**	Urban 6-lane divided	4SG	2012	59,833	55,967
JJ	**US 90 at Perimeter Road**	**3**	Urban 6-lane divided	1ST	2012	59,833	55,967
JJ	**US 90 at Park Centre Rd**	**3**	Urban 6-lane divided	1ST	2012	59,833	55,967
JJJ	**US 90 at Kol Drive**	**3**	Urban 6-lane divided	1ST	2012	59,833	55,967
JJJ	**US 90 at Girouard Drive**	**3**	Urban 6-lane divided	1ST	2012	36,367	36,233

2ST: Two way stop-sign controlled intersection equivalent to 4ST in HSM
1ST: One way stop-sign controlled T intersection equivalent to 3ST in HSM
4SG: Two-way signalized intersection

Crash Characteristics Analysis

The crash analysis was done by crash severity, manner of collision, user type, time of the day, alcohol involvement, and distracted driver condition. There are two units specified in the analysis, RCUT section (including U-turns) and intersection only, as illustrated in Figure 22. Table 32 presents the crash distribution by severity in all RCUTs before and after the installation, which shows total fatal crashes reduced from two to zero, total injury crashes 191 to 169, and total PDO crashes 447 to 387, but there are variations in crash changes.

Table 32
Crashes by severity in RCUT

RCUT	Year of construction	Total crashes		Fatal crashes		Injury crashes		PDO crashes	
		Before	After	Before	After	Before	After	Before	After
US 167 at LA 699 (J)	2012	23	32	1	0	14	10	8	22
LA 21 at Zinnia Road (J)	2012	49	35	0	0	17	7	32	28
Kurthwood Rd. at Alexandria Highway (J)	2011	18	13	1	0	7	7	10	6
LA 45 at 10th street (J)	2013	73	42	0	0	21	7	52	35
US 61 at LA 42 (J)	2013	118	140	0	0	27	39	91	101
US 90 at Morgan Avenue (J)	2012	132	96	0	0	47	46	85	50
US 90 at Perimeter Road (JJ)	2012	64	73	0	0	16	22	48	51
US 90 at Park Centre Road (JJ)	2012	13	9	0	0	2	2	11	7

US 90 at Kol Drive (JJJ)	2012	136	85	0	0	37	22	99	63
US 90 at Girouard Drive (JJJ)	2012	14	31	0	0	3	7	11	24
Overall crashes		**640**	**556**	**2**	**0**	**191**	**169**	**447**	**387**
Change in number of crashes		**-84**		**-2**		**-22**		**-60**	

Table 33 shows the changes by type of crashes. The large reduction in the targeted crashes, right angle and left turn (58.8% and 37.0%, respectively), are very encouraging. Again, the detailed information is given in Appendix D.

Table 33
Crashes by manner of collision in RCUT

RCUT Location	**Non-collision**		**Rear-end**		**Right angle**		**Left turn**		**Right Turn**		**Sideswipe**	
	Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
US 167 at LA 699 (J)	3	11	2	9	10	5	5	1	0	1	1	5
LA 21 at Zinnia Road (J)	1	1	20	18	11	3	11	5	3	3	3	4
Kurthwood Rd. at Alexandria Highway (J)	2	4	9	6	5	2	0	0	2	1	0	0
LA 45 at 10th street (J)	3	2	33	26	19	2	6	1	3	5	9	5
US 61 at LA 42 (J)	6	11	53	69	14	8	14	10	6	7	21	29
US 90 at Morgan Avenue (J)	2	13	89	44	15	9	11	5	5	11	8	11
US 90 at Perimeter Road (JJ)	6	7	47	38	2	5	1	3	0	0	6	16
US 90 at Park Centre Road (JJ)	0	1	4	2	6	0	1	1	0	2	1	3
US 90 at Kol Drive (JJJ)	8	11	86	36	17	7	4	5	5	8	14	16
US 90 at Girouard Drive (JJJ)	1	6	7	15	3	1	1	3	0	0	0	5
Overall crashes	**32**	**67**	**350**	**263**	**102**	**42**	**54**	**34**	**24**	**38**	**63**	**94**
Change in number of crashes	**35**		**-87**		**-60**		**-20**		**14**		**31**	

Pedestrian and bicyclist safety are a major concern at intersections, particularly in the era of green transportation. The analysis shows no pedestrian crashes and only two crashes involved with bicyclists in RCUT intersections. Table 34 lists the number of before/after crashes by number of vehicles involved in crashes, as well as driver alcohol impairment and distraction. There is an increase in single vehicle and alcohol involvement crashes.

Table 34
RCUT Crash distribution by number of vehicles, alcohol, and distraction involvement

RCUT Location	Single vehicle		Multiple vehicle		Alcohol Involved		Distraction	
	Before	After	Before	After	Before	After	Before	After
US 167 at LA 699 (J)	3	11	20	21	4	6	0	0
LA 21 at Zinnia Road (J)	1	1	48	34	0	1	4	4
Kurthwood Rd. at Alexandria Highway (J)	2	4	16	9	0	1	0	1
LA 45 at 10th street (J)	3	2	70	40	4	0	0	0
US 61 at LA 42 (J)	6	11	112	129	1	8	13	4
US 90 at Morgan Avenue (J)	2	13	130	83	0	0	5	0
US 90 at Perimeter Road (JJ)	6	7	58	66	1	0	6	1
US 90 at Park Centre Road (JJ)	0	1	13	8	1	5	1	0
US 90 at Kol Drive (JJJ)	8	11	128	74	1	1	9	2
US 90 at Girouard Drive (JJJ)	1	6	13	25	0	1	0	1
Total	**32**	**67**	**608**	**489**	**12**	**23**	**38**	**13**

Table 35 shows the crashes by time of day for RCUT, where most of the crashes are in the afternoon period. Crashes decreased all quarters of the day except between midnight and 6 am.

Table 35
Crashes by time of the day in RCUT

RCUT Location	6 am - 12 pm		12 pm - 6 pm		6 pm - 12 am		12 am - 6 am	
	Before	After	Before	After	Before	After	Before	After
US 167 at LA 699 (J)	8	10	9	13	3	8	3	1
LA 21 at Zinnia Road (J)	13	8	31	25	2	1	3	1
Kurthwood Rd. at Alexandria Highway (J)	3	2	6	4	8	6	1	1
LA 45 at 10th street (J)	1	0	25	25	41	16	6	1
US 61 at LA 42 (J)	42	42	51	62	18	27	7	9
US 90 at Morgan Avenue (J)	62	34	53	38	7	12	10	12
US 90 at Perimeter Road (JJ)	23	16	33	38	2	7	6	12
US 90 at Park Centre Road (JJ)	1	2	8	3	3	3	1	1
US 90 at Kol Drive (JJJ)	63	33	51	31	10	11	12	10
US 90 at Girouard Drive (JJJ)	3	13	7	11	4	3	0	4
Total	**219**	**160**	**274**	**250**	**98**	**94**	**49**	**52**

Table 36 presents the changes in crash frequencies by severity for RCUT intersection only. The crash reductions are significant in all three crash severity levels while reduction in total crashes is 31.1%. The crash reduction is observed in most of the intersections except one location (US 167 at LA 699) where a minor design deficiency is identified and US 90 at Kol Drive also experienced an increase in total crashes resulting from increase in PDO crashes.

Table 36
Crash severities in the before and after period of RCUT intersection

RCUT Intersection Location	Total Crashes		Fatal Crashes		Injury Crashes		PDO Crashes	
	Before	After	Before	After	Before	After	Before	After
US 167 at LA 699 (J)	17	26	1	0	11	8	5	18
LA 21 at Zinnia Road (J)	39	10	0	0	15	1	24	9
Kurthwood Rd. at Alexandria Highway (J)	15	7	1	0	5	4	9	3
LA 45 at 10th street (J)	73	42	0	0	21	7	52	35
US 61 at LA 42 (J)	76	59	0	0	13	10	63	49
US 90 at Morgan Ave. (J)	70	57	0	0	17	15	53	42
US 90 at Perimeter Road (JJ)	11	4	0	0	1	1	10	3
US 90 at Park Centre Road (JJ)	10	4	0	0	2	2	8	2
US 90 at Kol Drive (JJJ)	11	12	0	0	5	3	6	9
US 90 at Girouard Drive (JJJ)	6	5	0	0	1	2	5	3
Total	**328**	**226**	**2**	**0**	**91**	**53**	**235**	**173**

Table 37 presents the changes in intersection only crashes by manner of collision before and after RCUT. The impressive crash reductions are manifested in all targeted crash types. Left turn crashes decreased by 61.5%, right angle by 68.1%, and rear-end by 35.2%. However, the non-collisions, i.e., single vehicle crashes, increased by 80.0%.

Table 37
RCUT Intersection crashes by manner of collision

RCUT Intersections Location	Manner of Collision									
	Left Turn		Right angle		Non-Collision (single vehicle)		Rear-end		Right Turn	
	Before	After	Before	After	Before	After	Before	After	Before	After
US 167 at LA 699 (J)	4	1	9	5	1	6	1	8	0	1
LA 21 at Zinnia Road (J)	11	3	11	1	0	1	12	4	3	0
Kurthwood Rd. at Alexandria Highway (J)	0	0	5	2	1	1	8	3	1	1
LA 45 at 10th street (J)	6	1	19	2	3	2	33	26	3	5
US 61 at LA 42 (J)	6	6	8	4	3	3	47	31	3	3
US 90 at Morgan Ave. (J)	8	0	10	8	0	5	44	24	3	9
US 90 at Perimeter Road (JJ)	1	1	0	0	0	0	9	2	0	0
US 90 at Park Centre Road (JJ)	1	1	5	0	0	0	2	0	0	1
US 90 at Kol Drive (JJJ)	1	0	3	0	2	0	4	6	0	0
US 90 at Girouard Drive (JJJ)	1	2	2	1	0	0	2	1	0	0
Total Crash counts	**39**	**15**	**72**	**23**	**10**	**18**	**162**	**105**	**13**	**20**
Change in crashes	**-24**		**-49**		**8**		**-57**		**7**	

Table 38 lists changes in crashes by number of vehicles involved, drivers' alcohol impairment and distraction. While distracted driver-related crashes and multiple-vehicle crashes reduced by 68.2% and 34.6%, respectively, the single vehicle crashes increased 80%.

Table 38
Intersection crashes by number of vehicles, alcohol, and distraction

Intersections	Single vehicle		Multiple vehicle		Alcohol		Distraction	
	Before	After	Before	After	Before	After	Before	After
US 167 at LA 699 (J)	1	6	16	20	0	0	0	0
LA 21 at Zinnia Road (J)	0	1	39	9	0	0	3	0
Kurthwood Rd. at Alexandria Highway(J)	1	1	14	6	0	0	0	1
LA 45 at 10th street (J)	3	2	70	40	4	0	0	0
US 61 at LA 42 (J)	3	3	73	56	1	4	11	4
US 90 at Morgan Ave (J)	0	5	70	52	0	0	5	0
US 90 at Perimeter Road (JJ)	0	0	11	4	1	0	1	0
US 90 at Park Centre Road (JJ)	0	0	10	4	1	0	1	0
US 90 at Kol Drive (JJJ)	2	0	9	12	1	0	1	1
US 90 at Girouard Drive (JJJ)	0	0	6	5	0	1	0	1
Total	**10**	**18**	**318**	**208**	**8**	**5**	**22**	**7**

Table 39 shows that crashes were reduced across all time periods with the largest percentage reduction on the 6-am to 12-pm time interval followed by the 6-pm to 12-am time interval.

Table 39
Intersection crashes by time of day

Intersections	6 am – 12 pm		12 pm – 6 pm		6 pm – 12 am		12 am - 6 am	
	Before	After	Before	After	Before	After	Before	After
US 167 at LA 699 (J)	7	7	8	12	2	6	0	1
LA 21 at Zinnia Road (J)	11	4	25	4	2	1	1	1
Kurthwood Rd. at Alexandria Highway(J)	0	0	6	1	8	6	1	0
LA 45 at 10th street(J)	1	0	25	25	41	16	6	1
US 61 at LA 42(J)	31	12	27	24	13	17	5	6
US 90 at Morgan Avenue (J)	32	20	29	21	5	8	4	8
US 90 at Perimeter Road (JJ)	1	1	5	2	3	1	2	0
US 90 at Park Centre Road (JJ)	1	1	6	3	3	0	0	0
US 90 at Kol Drive (JJJ)	4	4	5	7	1	0	1	1
US 90 at Girouard Drive (JJJ)	3	2	1	1	2	2	0	0
Total	**91**	**51**	**137**	**100**	**80**	**57**	**20**	**18**

To explain why the intersection, US 167 at LA699, exibits an increase in total crashes, secifically in rear-end crashes (from one to eight) in three years, researchers conducted furthur investigations on this intersection layout design. By reviewing all original crash reports, researchers found that the increased rear-end collisions were concentrated on one minor road approach (Figure 25). As shown Figure 24, by replacing stop-sign with yield sign on that approach, vehicles move much closer to US 167 through the channelized right turn lane, which gives driver in the following vehicle almost the same view distance as the leading vehicle. Rear-end crash could happen if a very conservative driver is in the leading vehicle and a very aggressive driver in the following. This problem can be resolved by changing angle of channelized lane (to reduce view distance of the following vehicle).

Figure 24
Location experiencing increase in rear-end collisions

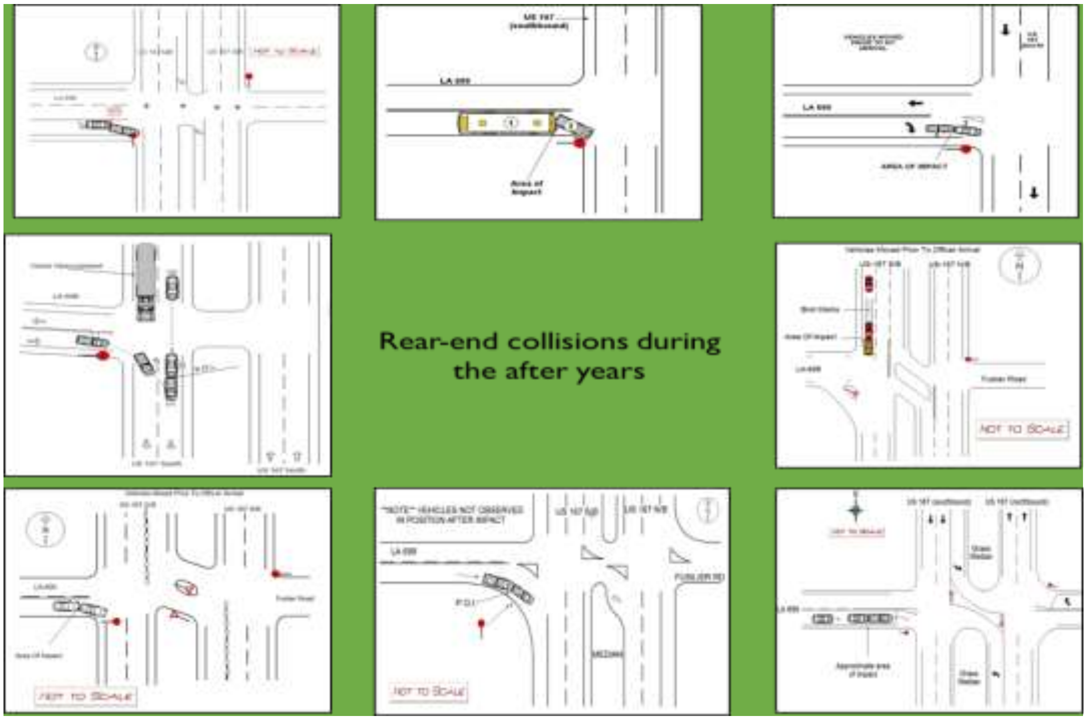


Figure 25
Crash diagram of rear-end collisions at US 167 at LA 699 RCUT facility in the after period

Another in-depth investigation was conducted at the intersection of US 90 and Morgan Avenue to review the increase in non-collision crashes. Review of crash reports revealed that the crash increases were related to drivers' carelessness. RCUT intersection design features were not responsible for the crashes. Figure 26 presents non-collision crash diagrams at the intersection. The description of the crashes is presented clockwise from the diagram at top left.

1. The driver made left turn into no-turn section (section from where the traffic from other direction make turns) and crashed with the island.
2. While making a left turn, a large truck's tail crashed into an electric pole.
3. A vehicle struck a box that fell off from the leading vehicle on the road
4. A vehicle struck the curb while trying to make a right turn into the driveway that is very close to the intersection

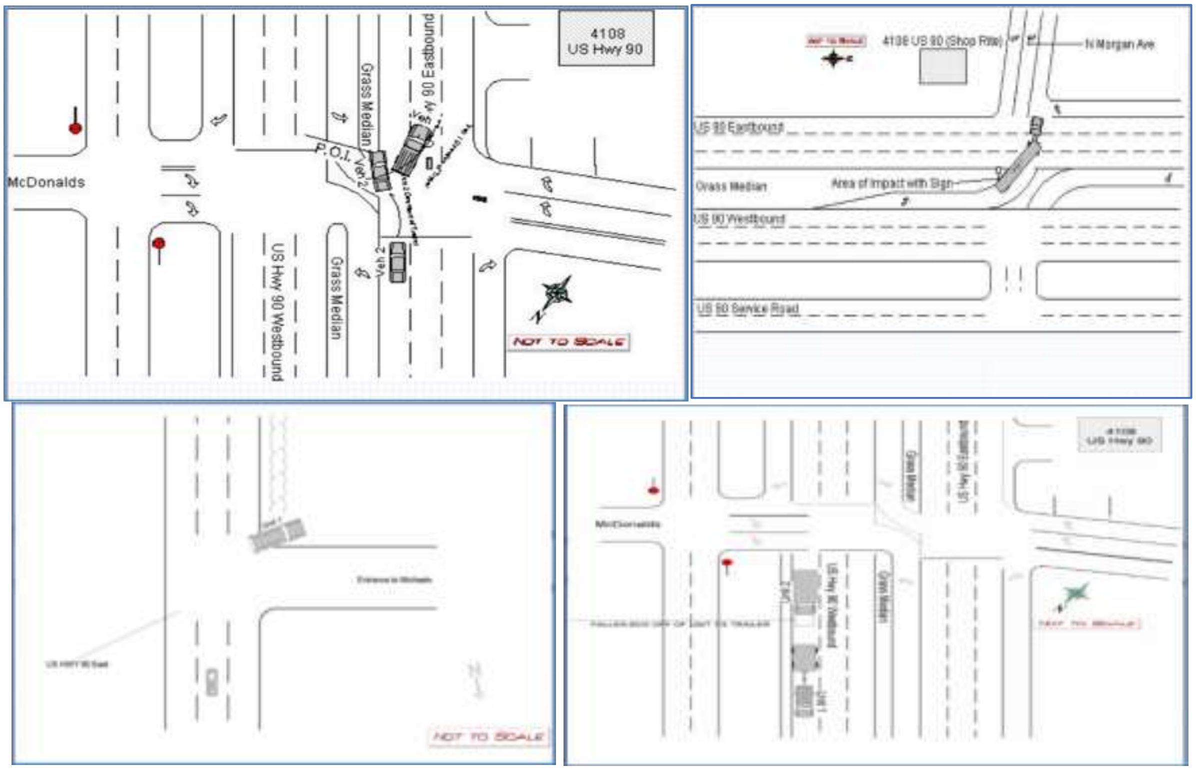


Figure 26
Non-collision crashes at US 90 at Morgan Avenue intersection

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CMF Development

Improved Prediction Method

The improved prediction method is a four-step method that evaluates safety by accounting for changes in traffic in the before/after period. Steps of the method have been described in methodology section in "Part II: Lane Conversion." The Improved Prediction method was used in the analysis for both RCUT and intersection only. The expected crash reduction is 85 (14%) for RCUTs, which leads to a CMF of 0.86. Table 40 gives not only an estimated CMF and its standard deviation. It is clear the crash reduction is almost certain with the 95% confidence. However, it should be mentioned that 4 intersections [US 90 at Morgan Ave (J), US 90 at Perimeter Road (JJ), US 90 at Kol Drive (JJJ), US 90 at Park Centre Road (JJ)] were converted from four lanes to six lanes in addition to constructed RCUTs.

Table 40
CMF by the improved prediction method for RCUT

Intersections	θ	σ(θ)
US 167 at LA 699 (J and stop sign)	1.37	0.297
LA 21 at Zinnia Road (J and stop)	0.71	0.132
Kurthwood Rd. at Alexandria Highway (J, stop sign)	0.67	0.209
LA 45 at 10th street (J, stop sign)	0.57	0.096
US 61 at LA 42(J, stop sign)	1.18	0.120
US 90 at Morgan Avenue (J and signal)	0.73	0.082
US 90 at Perimeter Road (JJ)	1.14	0.154
US 90 at Park Centre Road (JJ)	0.68	0.242
US 90 at Kol Drive (JJJ)	0.62	0.074
US 90 at Girouard Drive (JJJ)	2.16	0.501
Overall	**0.86**	**0.040**

The CMF estimated by the improved prediction method for the intersections is shown in Table 41.

Table 41
Result of Improved prediction method for only intersection crashes

Intersections	θ	σ(θ)
US 167 at LA 699 (J)	1.49	0.364
LA 21 at Zinnia Road (J)	0.25	0.083
Kurthwood Rd. at Alexandria Highway(J)	0.45	0.184
LA 45 at 10th street(J)	0.57	0.096
US 61 at LA 42(J)	0.77	0.113
US 90 at Morgan Ave (J)	0.81	0.120
US 90 at Perimeter Road (JJ)	0.35	0.181
US 90 at Park Centre Road (JJ)	0.79	0.378
US 90 at Kol Drive (JJJ)	1.06	0.343
US 90 at Girouard Drive (JJJ)	0.39	0.200
Overall	**0.69**	**0.050**

The CMF was also estimated by RCUT intersection type, which is presented in Table 42. The partial RCUT with two minor streets (JJ) outperforms complete RCUT (J) and partial RCUT with one minor street (JJJ). It should be noted that there are a fewer number of partial

RCUTs with two minor streets (2) and partial RCUT with one minor street (2) compared with complete RCUTs (6).

Table 42
CMF by Improved prediction method

RCUT type	RCUT				Intersection only			
	θ	σ(θ)	θ-2σ	θ+2σ	Θ	σ(θ)	θ-2σ	θ+2σ
Complete RCUT (J)	0.87	0.054	0.758	0.974	0.69	0.055	0.581	0.803
Partial RCUT with two minor streets (JJ)	1.06	0.135	0.791	1.330	0.38	0.138	0.099	0.652
Partial RCUT with one minor street (JJJ)	0.77	0.081	0.610	0.933	0.98	0.268	0.446	1.518

Empirical Bayes Method

The EB method has been recommended by the first edition of Highway Safety Manual (HSM). A safety performance function (SPF) is needed for applying this method. Since no SPF for six-lane divided highways exists, only intersection CMF was estimated by the EB method in this study.

There are different SPFs for different intersection controls. The HSM has the SPFs for intersections on urban arterials: 3ST (one-way stop sign controlled T-intersection), 3SG (signalized T-Intersection), 4ST (all-way stop sign controlled cross intersection), and 4SG (signalized cross intersection). To predict the expected total crashes per year, four types of collision have been defined:

- Multiple-vehicle collisions
- Single-vehicle collisions
- Vehicle-pedestrian collision
- Vehicle-bicycle collision

The equations of the first step, estimation of predicted crashes according to HSM 2010, are described below. However, estimation of expected crashes (second step) and safety effectiveness (third step) remain the same. Those two steps can be found in "Part I: CLRS". Their equations are described below:

Multiple-Vehicle Collision

$$N_{bimv} = \exp[a + b * \ln(AADT_{maj}) + c * \ln(AADT_{min})] \quad (24)$$

where,

N_{bimv} = Predicted number of multiple vehicle crashes

$AADT_{maj}$= Annual average daily traffic for major road approaches
$AADT_{min}$= Annual average daily traffic for minor road approaches
a, b, c = Regression coefficients (Refer Table 12-10, HSM)

Single-Vehicle Collision

$$N_{simv} = \exp[a + b * \ln(AADT_{maj}) + c * \ln(AADT_{min})] \quad (25)$$

where,
N_{simv} = Predicted number of single vehicle crashes
$AADT_{maj}$ = Annual average daily traffic for major road approaches
$AADT_{min}$ = Annual average daily traffic for minor road approaches
a, b, c = Regression coefficients (Refer Table 12-12, HSM)

Vehicle-Pedestrian Collision

For signalized intersection:

$$Npedi = Npedbase * \ CMF \quad (26)$$

where,
N_{pedi} = Predicted number of vehicle-pedestrian crashes
$N_{pedbase}$ = Predicted number of vehicle-pedestrian collisions per year for base condition at signalized intersection

$$N_{pedbase} = \exp[a + b * \ln(AADT_{total}) + c * \ln\left(\frac{AADT_{min}}{AADT_{maj}}\right) + d * \ln(PedVol) + e * n_{lanesx}] \quad (27)$$

where,
$AADT_{total}$= Sum of AADT for major and minor roads
PedVol= Sum of daily pedestrian volumes crossing all the intersection lanes
n_{lanesx} = Maximum number of lanes crossed by pedestrian in any crossing maneuver
a, b, c, d, e = Regression coefficients (Refer Table 12-14, HSM)

SPF for stop-controlled intersection:

$$N_{pedi} = N_{bi} * \ f_{pedi} \quad (28)$$

where,
f_{pedi} = pedestrian adjustment factor (Refer Table 12-16, HSM)
The value for N_{bi} is determined by the equation 12-6 given in the HSM.

Vehicle-bicycle collisions:

$$N_{bikei} = N_{bi} * f_{bikei} \qquad (29)$$

where,

f_{bikei} = bicycle crash adjustment factor (Refer Table 12-17, HSM)

The results of the calculations are listed in Table 43.

Table 43
Results of SPF calculation for urban intersections

Intersections	N_{bimv}	N_{simv}	N_{pedi}	N_{bikei}	$N_{spf,total}$
LA 21 at Zinnia Road (J	5.209	0.713	0.130	0.107	6.159
Kurthwood Rd. At Alexandria Hwy.	4.592	0.725	0.117	0.096	5.530
LA 45 at 10th street	7.402	0.821	0.181	0.148	8.552
US 61 at LA 42	44.908	2.303	0.021	0.708	47.941
US 90 at Morgan Avenue	18.861	0.678	0.004	0.293	19.836
US 90 at Perimeter Road	6.272	0.201	0.136	0.104	6.712
US 90 at Kol Drive	6.272	0.201	0.136	0.104	6.712
US 90 at Park Centre Road	6.272	0.201	0.136	0.104	6.712
US 90 at Girouard Drive	3.609	0.186	0.080	0.061	3.935

The result of EB method for the intersection crashes is shown in Table 44. The estimated CMF is 0.80, which means that the overall intersection crashes at the ten facilities decreased by 20% after the RCUT installation. The standard deviation of the estimation is 0.068.

Table 44
Result of EB Method for intersection crashes

Intersections	**θ**	**σ**
US 167 at LA 699 (J)	1.38	0.395
LA 21 at Zinnia Road (J)	0.35	0.119
Kurthwood Rd. at Alexandria Highway (J)	0.45	0.189
LA 45 at 10th street (J)	0.74	0.141
US 61 at LA 42 (J)	0.78	0.133
US 90 at Morgan Ave. (J)	0.97	0.168
US 90 at Perimeter Road (JJ)	0.38	0.205
US 90 at Kol Drive (JJJ)	1.15	0.433
US 90 at Park Centre Road (JJ)	0.81	0.413
US 90 at Girouard Drive (JJJ)	0.42	0.222
Overall	**0.80**	**0.068**

The estimated CMF by RCUT intersection type using EB method (Table 45) is similar to the results of Improved Prediction method results.

Table 45
CMF for Intersection only

Type of Intersection	θ	σ	θ-2σ	θ+2σ
Complete RCUT (J)	0.80	0.073	0.65	0.95
Partial RCUT with two minor streets (JJ)	0.42	0.163	0.09	0.75
Partial RCUT with one minor street (JJJ)	1.07	0.339	0.39	1.75

DISCUSSION OF RESULTS

Summary of Analysis

The safety benefit of RCUT is significant. For RCUT project, the crash reductions are 13%, 11% and 100% for total crashes, injury and fatal crashes, respectively. For only intersections, total crashes, injury, and fatal crashes reduced by 31.1%, 41.8%, and 100%, respectively. The crash severity reduction for intersection only comes from the decreasing right angle and left turn crashes at 68.1% and 61.5%, respectively. Table 46 presents the summary of observed crash changes.

Table 46
Summary of observed crash changes

Crash type		RCUT			Intersection only		
		Before	**After**	**Percent reduction**	**Before**	**After**	**Percent reduction**
Total crashes		640	556	13.1%	328	226	31.1%
Crashes by severity	Fatal	2	0	100%	2	0	100%
	Injury	191	169	11.5%	91	53	41.8%
	PDO	447	387	13.4%	235	173	26.4%
Targeted crashes	Right angle	102	42	58.8%	72	23	68.1%
	Left turn	54	34	37.04%	39	15	61.5%

Table 47 summarizes the CMFs estimated by the EB and Improved Prediction method for six complete RCUT intersections only at the selected confidence level.

Table 47
CMF with 95% confidence interval

Improved prediction method						Empirical Bayes method		
RCUT			**Main intersection only**			**Main intersection only**		
θ (CMF)	**θ-2σ**	**θ+2σ**	**θ (CMF)**	**θ-2σ**	**θ+2σ**	**θ (CMF)**	**θ-2σ**	**θ+2σ**
0.86	0.78	0.94	0.69	0.59	0.79	0.80	0.66	0.93

Safety Benefit-Cost Analysis

Since the DOTD website has no details about the construction cost of a RCUT facility, the project team relied on the limited cost information from a few purposed RCUT facilities that include non-RCUT improvements. The range of cost varies from $300,000 to $1,000,000 with RCUT and non-RCUT roadway improvement features. The estimated average construction cost for each RCUT according to the DOTD District representative is $300,000. Similarly, the safety benefits of RCUT are computed by crash reduction and economic loss of crashes as shown in Table 48.

Table 48
Estimation of total safety benefit

Injury type	Crash reduction	Economic loss per crash	Benefit
Fatal	2	$1,710,561	$3,421,122
Severe	2	$489,446	$978,892
Moderate	1	$173,578	$173,578
Complaint	35	$58,636	$2,052,260
PDO	62	$24,982	$1,548,884
Total Benefit			**$8,174,736**

Table 49 shows the safety benefit-cost ratio for each individual intersection including reduction in crashes by injury type. The overall safety benefit cost ratio is estimated as 2.72. The safety benefit cost ratio would be 1.63 if average cost of RCUT is conservatively estimated at a half million dollars.

Table 49
Benefit cost ratio analysis

Location	Reduction in Crashes by Injury Type					Total Safety Benefit	Total Construction Cost	Safety Benefit/cost
	Fatal	Severe	Moderate	Complaint	PDO			
US 167 at LA 699	1	1	0	2	-13	$1,992,513	$300,000	6.64
LA 21 at Zinnia Rd.	0	0	4	10	15	$1,655,402	$300,000	5.52
Kurthwood Rd. at Alexandria Hwy.	1	0	-1	2	6	$1,804,147	$300,000	6.01
LA 45 at 10th street	0	0	1	13	17	$1,360,540	$300,000	4.54
US 61 at LA 42	0	1	1	1	14	$1,071,408	$300,000	3.57
US 90 at Morgan Ave	0	0	-4	6	11	-$67,694	$300,000	-0.23
US 90 at Perimeter Road	0	0	0	0	7	$174,874	$300,000	0.58
US 90 at Kol Drive	0	0	0	2	-3	$42,326	$300,000	0.14
US 90 at Park Centre Road	0	0	0	0	6	$149,892	$300,000	0.50
US 90 at Girouard Drive	0	0	0	-1	2	-$8,672	$300,000	-0.03
Overall	**2**	**2**	**1**	**35**	**62**	**$8,174,736**	**$3,000,000**	**2.72**

PART IV: ROUNDABOUT

INTRODUCTION

Since the first roundabout was introduced to Lafayette 18 years ago, state-wide support has grown for this intersection type. There are more than 30 roundabouts in operation statewide and around 100 roundabouts in the planning and design stage. Figure 27 shows the roundabout locations in Louisiana. The benefits of a roundabout are twofold: improving traffic flow and reducing crashes, particularly injury and fatal crashes. Properly designed, a roundabout can guide all vehicles operating at a lower speed while negotiating the circle for the intended exit approach. By giving more maneuvering freedom to drivers, i.e., letting drivers decide when to enter an intersection, human factor plays a bigger role in roundabout operation than in other types of intersection traffic control. Considering the state's goals for "Destination Zero Deaths" 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.

Roundabout performance in the U.S and elsewhere in the world has been well documented. One of the notable studies comes from NCHRP in 2007 *[48]*. The NCHRP study collected 310 sets of roundabout data from previous research conducted between 1997 and 2007 in the U.S., which contained 6% roundabouts in rural areas and 94% in urban and suburban areas, with 9% signalized intersections, 51% one-way or two-way stop intersections, 10% all-way stop intersections, and a remaining 30% newly constructed roundabout intersections. The study also selected 55 roundabouts that had complete design and AADT information as well as a sufficient amount of 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 previous traffic control types. By utilizing the EB before/after analysis method, the study shows the expected reductions in total crash and injury crash is 45% and 76%, respectively, for signalized intersection and a 44.2% and 81.8% reduction, respectively, for stop 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 HSM uses the results of this NCHRP study in roundabout CMF as 0.56 for total crashes and 0.18 for injury and fatal crashes for a roundabout with minor road stop control before. For signalized intersections, CMF from the HSM is 0.52 for total crashes and 0.22 for injury and fatal crashes. For all-way stop intersections, CMF from HSM is 1.03 for total crashes *[20]*.

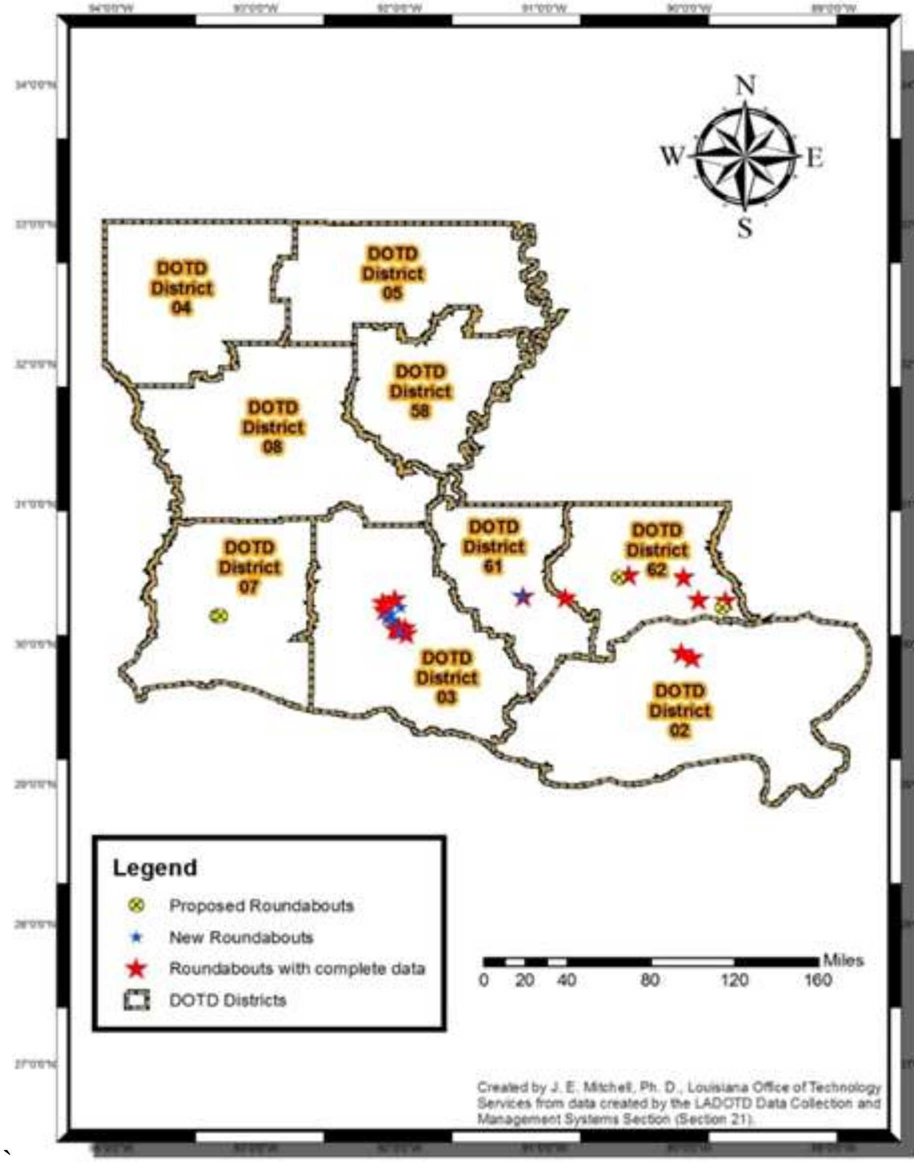

Figure 27
Roundabout locations in Louisiana

Because of the variances in design, local safety culture and road user behavior, not all roundabout studies yield similar results. The Wisconsin roundabout studies published in 2011 and 2013 indicated that roundabouts significantly reduced the severity of crashes from more than 50 roundabouts selected *[49, 50]*. The studies found a 38% reduction in injury and fatal crashes. However, the changes in PDO crashes varied by location, which resulted in a 12% increase in total crashes. The intersections with stop signs on minor road 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 increased 5.5% and 23.5%, respectively.

Two follow-up Wisconsin studies investigated the roundabout impacts on type of crashes. Published in 2016, B. Burdett, et al. examined the manner of collisions at roundabouts and non-roundabout intersections in Wisconsin with a focus on the rear-end collision and single-vehicle crashes *[51]*. The rear-end collisions and single-vehicle crashes, the two most common type of crashes at roundabouts, consists of 20% and 29% respectively, of the total crashes – a big increase in roundabout single vehicle crashes compared to crashes occurring at non-roundabout intersections. Burdett's study results indicate that younger drivers, aged between 16 to 24 years old, have a 50% higher probability to be involved in rear-end and single-vehicle crashes in roundabout than mid-aged and aged drivers do. Additionally, the research concludes that the proper pavement marking at approaching lane might significantly reduce the number of rear-end collisions, and the landscaped central island has a positive impact on reducing single vehicle crashes and severity.

Based on the review of the literature, it is clear that the safety benefits of a roundabout vary significantly with the previous type of traffic control and the study location. There are inconsistent results between the different intersection traffic control types and the land use setting. Roundabouts have been recognized as the most complex intersection design, which requires special design expertise and operation experiences. Very few of the previous studies mention 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 apparent.

OBJECTIVE

This fourth part of the project was to conduct a comprehensive crash analysis on roundabout. The specific objectives were to:

- Investigate the safety impact of roundabout safety through before- and after-crash characteristics analysis
- Develop a crash modification factor
- Estimate overall safety benefit-cost ratio of roundabouts.

SCOPE

The roundabouts selected for this research project had been in operation for at least 3 years prior to 2016, when this research was initiated. The roundabouts on a new highway were excluded from the analysis because there was no before crash data to compare. It is understood that some intersections were converted to roundabout for capacity purposes, which means that the conversions were not motivated by the need for safety improvement. Since the original plan was to evaluate roundabout safety benefit without purposely excluding the capacity motivated roundabout implementation, the team did not exclude any roundabout with at least three-years in operation.

METHODOLOGY

Data Collection and Verification

To minimize the effect of regression-to-the-mean, 18 intersections that have been in operation for at least three years were selected for the analysis. Table 50 lists the basic information. All the roundabouts are single lane roundabouts. All the 18 roundabouts are currently located in urban areas according to the roadway information. Based on the Google Maps, few roundabouts are in suburban areas. However, the DOTD database does not separate the suburban from urban probably because of the dynamic nature of suburban areas. To accurately identify intersection crashes, the team did not just rely on the indicator of the crash database (1 for intersection and 0 for non-intersection). To capture intersection-related crashes, the research team investigated all crashes within a 500-ft. radius of the intersections. For a few intersections with high AADT, crashes occurring half a mile away from the intersections were also investigated considering potential traffic queues at the intersections.

All crashes within 500-ft. radius were examined by reviewing the crash narratives from original crash reports to see if they were intersection related or not. The radius even went to 3,000 feet for one intersection that experiences severe peak-hour traffic congestion. Original crash reports are a great source of information, which provide more details on what and how the crash happened as well as the driver (or road user) and environmental conditions before, during and after the crash. Altogether about 1,000 crash reports were reviewed for the roundabout analyses.

The crash analyses also let the team identify coding errors. For example, many roundabout crashes were wrongly coded at the scene by police officers as “left turn crashes.” By reading the crash narratives, it was discovered that these crashes are not left turn crashes. Thus, it is recommended that the crash report needs to be modified and the law enforcement officers need to be further informed on appropriate coding for roundabout-related crashes.

Table 50

Intersection	Prior Traffic Control Type	AADT	
		Before	After
LA 59 @ LA 36	Signalized (4-way)	23,400	25,267
LA 1091 @ Brownswitch Rd	Signalized (4-way)	29,800	29,700
LA 431 @ LA 42	Stop on minor road (T)	18,367	17,733
US 190 @ LA 434	Stop on minor road (T)	24,833	18,300
LA 93 @ St Mary/LA 3168	Stop on minor road (4-way)	11,617	12,100
LA 428 at Mardi Gras	Stop on minor road (4-way)	6,133	6,000
E Milton/LA 92 @ Bonin	Stop on minor road (4-way)	9,433	9,500
Lafayette/LA 89 @ Iberia/LA 92	Stop on minor road (T to 4-way)	18,300	22,833
Hector Connoly @ E Angelle	Stop on minor road (T to 4-way)	13,000	13,500
E Fairfield @ S Morgan	Stop on minor road (T to 4-way)	6,555	6,997
A 327 River Rd. @ LA 327 Gardere	Stop on minor road (T to 4-way)	6,897	7,900
E Milton/LA 92 @ Chemin Metairie	Stop on minor road (T to 4-way)	10,702	11,469
Chemin Metairie @ Viaulet	Stop on minor road (T to 4-way)	800	800
E Milton/LA 92 @ Verot School/LA 339	All way stop (4-way)	40,533	35,033
Gloria Switch/LA 98 @ LA 93	All way stop (4-way)	22,400	23,767
Bonin @ Fortune	All way stop (4-way)	7,277	7,277
LA 3158 @ Old Covington Rd	All way stop(4-way)	8,333	9,300
LA 406 @ LA 407	All way stop(T)	20,833	22,500

Summary of eighteen roundabouts

Crash Characteristics Analysis

The observed crash-severities for each location before and after a roundabout project are listed in Table 51.

Table 51
Observed before and after crashes by severity

Intersection	Year of Construction	Fatal crash		Injury crash		PDO crash	
		Before	After	Before	After	Before	After
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 Crashes		**1**	**2**	**81**	**35**	**156**	**157**

Overall there is a significant reduction (57%) in injury crashes but a small increase in PDO crashes. The number of fatal crashes increased from 1 to 2; however, all 3 crashes occurred at different locations with different crash characteristics. The fatal crashes occurred at two different roundabouts involving a motorcycle running-off-roadway (ROR); while the one fatal crash occurred before roundabout installation was right angle collision. By categorizing the 18 intersections into three groups according to the previous traffic control type, Table 52 shows some patterns in changes of crashes.

Table 52
Change of crashes by prior traffic control type

Roundabout	Type of Prior Traffic Control	Year of Implementation	Changes in Total Crashes	% Change by Group
1	*Signalized (4-way)*	2007	-5	+2(+6%)
2	*Signalized (4-way)*	2012	+7	
3	*Stop on minor road (T)*	2012	-17	-62 (-46%)
4	*Stop on minor road (T)*	2013	-4	
5	*Stop on minor road (4-way)*	2013	-25	
6	*Stop on minor road (4-way)*	2013	-39	
7	*Stop on minor road (4-way)*	2011	-2	
8	*Stop on minor road (T to 4-way)*	2012	+2	
9	*Stop on minor road (T to 4-way)*	2012	+5	
10	*Stop on minor road (T to 4-way)*	2007	+3	
11	*Stop on minor road (T to 4-way)*	2011	-3	
12	*Stop on minor road (T to 4-way)*	2008	+18	
13	*Stop on minor road (T to 4-way)*	2013	0	
14	*All way stop (4-way)*	2011	+3	+16 (+24%)
15	*All way stop (4-way)*	2011	-4	
16	*All way stop (4-way)*	2011	+2	
17	*All way stop (4-way)*	2010	+15	
18	*All way stop (T)*	2010	0	
Total Change			**-44**	

The 11 roundabouts with a stop sign on the minor road before roundabout conversion experienced the largest crash reduction, 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. Table 53 gives the changes in crash severity by group.

Table 53
Changes in crash severity by group

Previous Traffic Control	Number of Intersections	Fatal Crash		Injury Crash		PDO Crash		Total Crash	
		Before	After	Before	After	Before	After	Before	After
Signalized	2	0	0	11	5	23	31	34	36
Stop on Minor road (No layout change)	5	0	0	46	10	78	27	124	37
Stop on Minor road (Layout change)	6	0	1	4	5	8	31	12	37
All way Stop	5	1	1	20	15	47	68	68	84
Ovaerall	**18**	**1**	**2**	**81**	**35**	**156**	**157**	**238**	**194**

Again, it is clear that all groups have injury crash reduction and the greatest reduction occurs in the group of intersections with stop-sign on the minor road. Another interesting result is the change in the type of crashes by manner of collision as shown in Table 54.

Table 54
Changes by type of crashes

Previous Traffic Control	Number of Intersections	Angle Crash*		Rear-end		Single vehicle	
		Before	After	Before	After	Before	After
Signalized	2	19	27	12	7	3	2
Stop on Minor road (No layout change)	5	83	11	29	16	12	10
Stop on Minor road (Layout change)	6	6	11	2	12	4	12
All way Stop	5	25	18	31	39	10	27
Overall	**18**	**133**	**67**	**74**	**74**	**29**	**51**

"Angle Crash" includes right angle crashes, right turn crashes, and sideswipe crashes.

To investigate why the significant number of single vehicle crashes increased, researchers looked at crashes by lighting condition. As shown in Table 55, single vehicle running off roadway (ROR) crashes overall increased 117% and more so for the signalized and all way stop groups. 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. Clearly, there is a problem at night for the ROR crashes for the roundabouts converted from all way stop sign-controlled intersections, in which all five roundabouts have no street lights. One typical example is shown in Figure 28, where LA 3158 intersects the Old Covington Road. This is a roundabout converted from all way stop sign-controlled intersection with the AADT less than 10,000. In addition to having all required signs and pavement markings, the flashing lights on LA 3158 are installed to warn drivers approaching the roundabout (only roundabout with the flash warning light). The number of crashes at this roundabout increased 188% while the traffic volume only increased by 12%, and the ROR crashes increased from zero to nine in the first three years, and to eight including one fatal motorcycle crash between the fourth and the sixth year in operation (see Appendix E). It was found that all 17 (nine plus eight in the six roundabout operation years) ROR crashes occurred at night, which is suggests a poor visibility problem. It is possible that before roundabout, a few careless or aggressive drivers did not stop at night when passing through the intersection crashes due to the low traffic volume. The roundabout has somewhat punished the bad driving behavior at this intersection. The sufficient lighting could most likely help those drivers to avoid ROR crashes. 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.

Table 55
Changes in Crashes by lighting conditions

Previous Traffic control	**Daylight**		**Dark**		**Single vehicle ROR**				**Street Light Installed (Yes / No)**
					Daylight		**Dark**		
	Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	
Signalized	20	22	14	14	0	1	0	1	All Yes
Stop on Minor road (No layout change)	90	23	34	14	5	4	7	6	3 Yes; 2 No
Stop on Minor road (Layout change)	9	16	3	21	0	1	2	10	3 Yes; 3 No
All way Stop	48	44	20	40	5	5	4	22	All No
Overall	**167**	**105**	**71**	**89**	**10**	**11**	**13**	**39**	**8 Yes; 10 No**

Figure 28
LA 3158 at Old Covington Rd.

For intersections with the number of approaches increasing from three to four with stop-sign controlled (on minor road) before roundabout, the observed crash reduction is not as big as 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 number of conflicting points could, to a certain degree, explain the difference among four groups in crash reduction or increasing. Table 56 lists the changes in the number of conflicting points and their control mechanism at each intersection before and after the roundabout conversion.

Table 56
Number of Conflicting Points and Control Mechanism Before and After

Roundabout	Before		After	
	Number of conflicting points	**Controlled by**	**Number of conflicting points**	**Controlled by**
1	Diverging: 8	Traffic signal with LT phase	Diverging: 4	Yield sign control at entrance
	Merging: 8		Merging: 4	
	Crossing: 16		Crossing: 0	
	Total: 32		**Total: 8**	
2	Diverging: 8	Traffic signal with LT phase	Diverging: 7	
	Merging: 8		Merging: 8	
	Crossing: 16		Crossing: 0	
	Total: 32		**Total: 15**	
3, 4, 5 (T-intersection before and cross after)	Diverging: 3	Stop sign on minor road	Diverging: 3	
	Merging: 3		Merging: 3	
	Crossing: 3		Crossing: 0	
	Total: 9		**Total: 6**	
6,7 (cross intersection before and after)	Diverging: 8	Stop sign on minor road	Diverging: 4	
	Merging: 8		Merging: 4	
	Crossing: 16		Crossing: 0	
	Total: 32		**Total: 8**	
8, 9, 10, 11, 12, 13 (T-intersection before and cross after)	Diverging: 3	Stop sign on minor road	Diverging: 4	
	Merging: 3		Merging: 4	
	Crossing: 3		Crossing: 0	
	Total: 9		**Total: 8**	
14,15, 16, 17,	Diverging: 8	All-way stop	Diverging: 4	
	Merging: 8		Merging: 4	
	Crossing: 16		Crossing: 0	
	Total: 32		**Total: 8**	
18 (T-intersection before and after)	Diverging: 3	All-way-stop	Diverging: 3	
	Merging: 3		Merging: 3	
	Crossing: 3		Crossing: 0	
	Total: 9		**Total: 6**	

Roundabouts generally reduce 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 reduces from nine to eight) as shown in Figure 29.

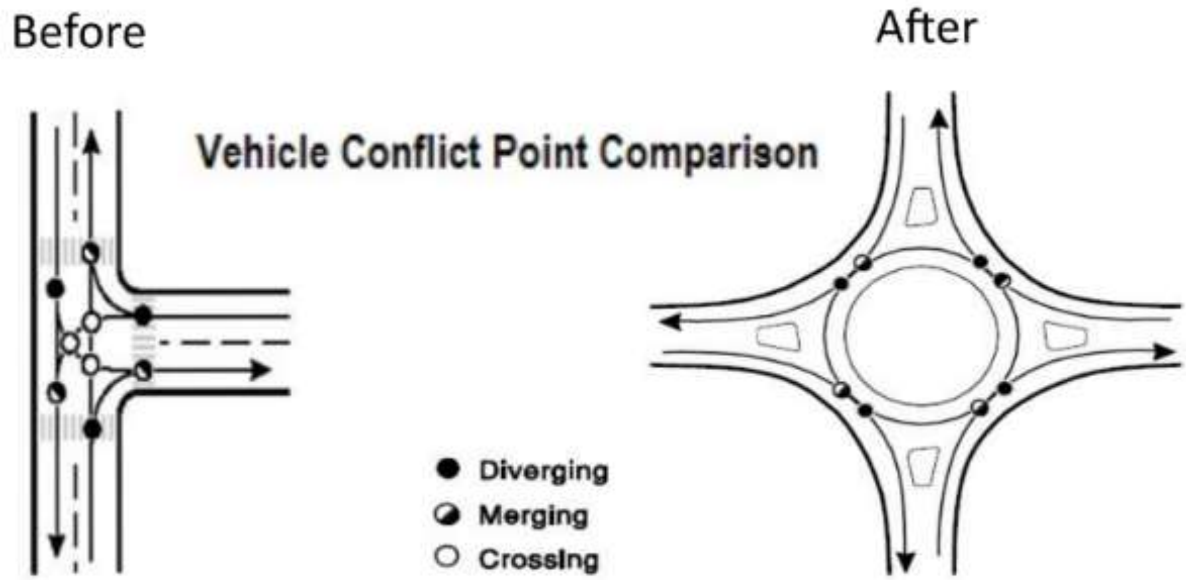

Figure 29
Change of Conflicting Points at Intersections with Layout Change

Another reason that might have contributed to the increase in crashes is the land use change before and after the roundabout installation. The intersection of LA 92 and Chemin Metairie Road experienced the largest crash increase among the roundabout group that were converted from the stop sign on minor road control with the number of approaches increased from three to four. Due to the significant change in land use surrounding this location, the roundabout had an increase in the number of approaches, from three to four. The southbound extension of the minor roadway made the intersection an important gateway to a rapidly growing community at the time of roundabout construction. After the roundabout construction, this minor road also becomes a major connector linking the newly developed township (beyond the scope of picture showing in Figure 30) to a major metropolitan highway (Ambassador Caffery Parkway). The crashes increase from one to nineteen in the first three years of roundabout operation while the official AADT only increase 15%. The most alarming fact is the crashes occurred at nighttime kept increasing between the first and second three years' period of roundabout operation. This roundabout has no street light. It is highly possible that the actual AADT on Chemin Metairie Road is much higher that the official AADT obtained. It is reasonable to assume the changes in land use and road functionality are mainly responsible for the crash increase. But without accurate traffic count, it is hard to quantify the impact. For further details, see Appendix E.

Figure 30
The Land Use Development around Intersection of LA 92 and Chemin Metairie Rd. before and after roundabout

For all 18 roundabouts, the total heavy vehicle at fault crashes increased in the first three years as shown in Table 57 particularly at all-way stop sign-controlled intersections (300% crash increase). No bicycle rider at fault crash was found. There were slight increases in the crashes involving distracted or alcohol/drug impaired drivers.

Table 57
Changes by at fault type of road users

Previous Traffic Control	Heavy Truck		Motorcycle		Pedestrian	
	Before	After	Before	After	Before	After
Signalized	1	0	0	1	0	0
Stop on Minor road (No layout change)	6	5	1	0	0	0
Stop on Minor road (Layout change)	2	1	0	4	0	0
All way Stop	2	8	3	5	1	0
Overall	**11**	**14**	**4**	**10**	**1**	**0**

Table 58
Changes by impaired driving behavior

Previous Traffic Control	Distraction		Alcohol / Drug	
	Before	After	Before	After
Signalized	1	1	1	1
Stop on Minor road (No layout change)	4	3	7	6
Stop on Minor road (Layout change)	0	3	0	4
All way Stop	7	9	5	10
Overall	**12**	**16**	**13**	**21**

In Table 58, considering the impaired driving behaviors, such as distracted driving or impaired driving, the reduction in the number of crashes could only be seen at the roundabouts converted from the stop sign on minor road intersections without layout change, while in other groups the number of crashes increased or remained the same.

To investigate whether the length of roundabout operation had any impact on the intersection safety, this study also analyzed the crashes for roundabout being in operation for six years. Table 59 shows the changes in the AADT and crashes at 10 intersections that had crash increase in the first three years of the roundabout operation. The results indicate that while the fatal and injury crashes continuously decreased, 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, which means the crash reduction is sustainable.

Table 59
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 second after Three Year time Period (the 4^{th} and 6^{th} year)
AADT	+0%	-8%
Total Crashes	+28%	+119%
Fatal Crashes	0%	0%
Injury Crashes	-15%	+4%
PDO Crashes	+46%	+166%
Single-Vehicle	+112%	+159%
Rear-End	+55%	+82%
Angle	-18%	+148%
Day time	-2%	+97%
Night time	+93%	+167%

All 18 roundabout details are given in Appendix E.

CMF Development

Both the Improved Prediction method and the EB method were used to develop the CMF. The result from the EB method is more accurate and recommended to be used for the engineers when analyzing the roundabouts of similar previous traffic control. Both Improved Prediction and EB method steps can be found in previous parts of the report.

The CMF (θ) and standard deviation (σ) of all 11 roundabouts converted from stop sign on minor road controlled intersections using the Improved Prediction method are listed in Table 60 and the CMF derived through the EB method can be found in Table 61. All the eleven roundabouts are single lane roundabouts. The CMF for the rest seven roundabouts from the other two groups (signal controlled and all way stop controlled) was not estimated, since there are apparently contributing factors to the crashes increase in the other two groups.

As shown in Table 60, CMFs derived from the eleven roundabouts converted from the stop sign on minor road controlled intersection is 0.53 by Improved Prediction Method, the expected crash reduction in this group can be 47%. The estimated CMF for those eleven roundabouts by EB method is 0.51 (Table 61), the expected crash reduction is 49%.

Table 60
CMF for all eleven roundabouts converted from stop sign on minor road controlled intersections by Improved Prediction method

Roundabout	θ	σ(θ)	θ±3σ
LA 431 @ LA 42	0.34	0.119	(0, 0.70)
Chemin Metairie Rd.@ Viaulet Rd.	0.86	0.598	(0, 2.65)
US 190 @ LA 434	0.59	0.249	(0, 1.34)
LA 93 @ St Mary/LA 3168	0.28	0.093	(0, 0.56)
LA 428 @ Mardi Gras Blvd.	0.09	0.047	(0, 0.23)
E. Milton Rd. /LA 92 @ Bonin Rd.	0.77	0.298	(0, 1.67)
Lafayette Rd./LA 89 @ Iberia Rd./LA 92	1.23	0.520	(0, 2.79)
Hector Connoly Rd.@ E. Angelle Rd.	13.87	0.730	(11.7, 16.1)
E. Fairfield Rd.@ S. Morgan Rd.	7.88	0.403	(6.67, 9.09)
E. Milton Rd./LA 92 @ Chemin Metairie Rd.	13.74	6.556	(0, 33.4)
LA 327/ River Rd. @ LA 327/ Gardere Rd.	0	0.009	(0, 0.03)
Overall	**0.53**	**0.068**	**(0.33, 0.73)**

Table 61
CMF for all eleven roundabouts converted from stop sign on minor road controlled intersections by EB method

Roundabout	θ	σ(θ)	θ±3σ
LA 431 @ LA 42	0.39	0.144	(0, 0.82)
Chemin Metairie Rd.@ Viaulet Rd.	2.57	1.758	(0, 7.84)
US 190 @ LA 434	0.83	0.384	(0, 1.98)
LA 93 @ St Mary/LA 3168	0.20	0.069	(0, 0.41)
LA 428 @ Mardi Gras Blvd.	0.21	0.105	(0, 0.53)
E. Milton Rd. /LA 92 @ Bonin Rd.	0.23	0.096	(0, 0.52)
Lafayette Rd./LA 89 @ Iberia Rd./LA 92	0.84	0.378	(0, 1.97)
Hector Connoly Rd.@ E. Angelle Rd.	2.44	1.365	(0, 6.54)
E. Fairfield Rd.@ S. Morgan Rd.	1.86	1.135	(0, 5.27)
E. Milton Rd./LA 92 @ Chemin Metairie Rd.	7.41	3.550	(0, 18.06)
LA 327/ River Rd. @ LA 327/ Gardere Rd.	0.00	0.002	(0, 0.01)
Overall	**0.51**	**0.075**	**(0.28, 0.73)**

Five of the roundabouts were converted from the intersections controlled by stop sign on minor road without the layout change, therefore having much smaller variances. The results are presented in Table 62 and Table 63. The estimated CMF of these five roundabouts is 0.32 by the Improved Prediction method and 0.28 by the EB method.

When specifically considering the five roundabouts without the layout change in this group, as can be figured out from Table 63, the expected crash reduction is 72% (CMF is 0.28 by EB method), which is much higher than that found in the NCHRP study. The higher CMF value indicates the roundabouts in Louisiana, that converted from the intersections with stop sign on minor road before, perform better than the statewide roundabouts in terms of improving intersection safety effectiveness.

Table 62
CMF by Improved Prediction method for five roundabouts converted from stop sign on minor road controlled intersections without layout change

Roundabout	θ	σ(θ)	θ±3σ
LA 431 @ LA 42	0.34	0.119	(0, 0.70)
US 190 @ LA 434	0.59	0.249	(0, 1.34)
LA 93 @ St Mary/LA 3168	0.28	0.093	(0, 0.56)
LA 428 @ Mardi Gras Blvd.	0.09	0.047	(0, 0.23)
E. Milton Rd. /LA 92 @ Bonin Rd.	0.77	0.298	(0, 1.67)
Overall	**0.32**	**0.055**	**(0.15, 0.48)**

Table 63
CMF by EB method for five roundabouts converted from stop sign on minor road controlled intersections without layout change

Roundabout	θ	σ(θ)	θ±3σ
LA 431 @ LA 42	0.39	0.144	(0, 0.82)
US 190 @ LA 434	0.83	0.384	(0, 1.98)
LA 93 @ St Mary/LA 3168	0.20	0.069	(0, 0.41)
LA 428 @ Mardi Gras Blvd.	0.21	0.105	(0, 0.53)
E. Milton Rd. /LA 92 @ Bonin Rd.	0.23	0.096	(0, 0.52)
Overall	**0.28**	**0.054**	**(0.12, 0.45)**

DISCUSSION OF RESULTS

Summary

Regardless of prior traffic control type and motivation for roundabouts, 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 the 49% crash reduction was observed (CMF is 0.51 by EB method). The crash characteristics analysis revealed the following:

- Roundabout reduces overall injury crashes significantly by eliminating left turn and head-on collisions and reducing right angle and sideswipe collisions.
- Single vehicle running off roadway crashes increase, including two fatal ROR crashes.
- The prior traffic control makes a big difference in changes of crashes.
- Roundabouts, with stop sign on minor road before, gain the biggest safety benefit, 70% crash reduction for the intersections with the same number of approaches before and after.

Since more roundabouts being proposed in Louisiana roadways, it is important for DOTD to know the issues discussed in this project for future roundabout constructions. Details have been discussed in Appendix E.

Table 64
Summary of potential compounding factors

Roundabout	Change in Total Crashes	Potential Compounding Factors for Changes
Converted from Signalized Intersection		
2	+7	It should be a two-lane roundabout with higher than 25,000 AADT. Design alignment (intersecting angle) is not desirable
Converted from Stop Sign on Minor Road without Layout Change Intersection		
6	-39	Merging two-lanes in each direction into one-lane road before the roundabout serves very well for this roundabout
Converted from Stop Sign on Minor Road with Layout Change Intersection		
8	+2	One street connection within 150 feet
9	+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)
10	+3	Inside a new subdivision with substandard sign and pavement marking
11	-3	With excellent lighting (inside a Casino area)
12	+18	Huge land use change
Converted from All Way Stop Controlled Intersection		
14	+3	Due to the ROW limit, this roundabout is limited to a one-lane with AADT higher than

Roundabout	Change in Total Crashes	Potential Compounding Factors for Changes
		35,000, three driveways within 150 feet including a car dealer right by the circle.
17	+15	Lack of lighting

Safety Benefit Cost Analysis

Similar to other three crash countermeasures, the cost and benefit for roundabouts are computed by the available data. The design-construction cost of a roundabout varies between $450,000 and $1.2 million dollars based on the data from DOTD and other local government agencies. Table 65 lists the injury crashes by injury level used in Louisiana crash report. The benefit calculation is the same as with other countermeasures studied in this project.

Table 65
Changes in number of crashes by injuries

Previous Traffic Control	Severe injuries		Moderate injuries		Complaint injuries		Total	
	Before	After	Before	After	Before	After	Before	After
Signalized	0	0	2	2	9	3	11	5
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**	**8**	**7**	**72**	**28**	**81**	**35**

The benefit-cost ratio is listed in Table 66 by group and in Table 67 by intersection. The B/C is less than one for other groups (0.06 and 0.91 for all way stop and stop on minor road, respectively). However, the long-term B/C ratio will be bigger than one 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 66
Benefit-cost ratio estimation by different control type

Previous Traffic Control	Benefit from crash reduction	Cost of Project	Benefit/Cost
Signalized	$151,960	$1,812,000	0.08
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 67
Safety benefit-cost ratio estimation of each individual roundabout

Intersection	Severe Injuries	Moderate Injuries	Complaint Injuries	Benefit from injury crash reduction	PDO	Benefit from reduction in PDO crashes	Cost of Project	Benefit /Cost
	+/-	+/-	+/-		+/-			
LA 59 @ LA 36	0	+1	-1	-$114,942	-5	$124,910	$842,000	0.01
LA 1091 @ Brownswitch Rd.	0	-1	-5	$466,758	+13	-$324,766	$970,000	0.14
LA 431 @ LA 42	0	0	-7	$410,452	-10	$249,820	$1,200,000	0.55
US 190 @ LA 434	0	0	-2	$117,272	-2	$49,964	$1,000,000	0.17
LA 93 @ St Mary/LA 3168	0	-1	-5	$466,758	-19	$474,658	$550,000	1.71
LA 428 @ Mardi Gras Blvd.	0	-2	-18	$1,402,604	-19	$474,658	$793,127	2.37
E. Milton Rd. /LA 92 @ Bonin Rd.	0	0	-1	$58,636	-1	$24,982	$560,000	0.15
Lafayette Rd./LA 89 @ Iberia Rd./LA 92	0	0	-1	$58,636	+3	-$74,946	$800,000	0
Hector Connoly Rd.@ E. Angelle Rd.	0	0	1	-$58,636	+3	-$74,946	$850,000	0
E. Fairfield Rd.@ S. Morgan Rd.	0	0	0	$0	+3	-$74,946	$550,000	0
LA 327/ River Rd. @ LA 327/ Gardere Rd.	0	0	-1	$58,636	-2	$49,964	$700,000	0.16
E. Milton Rd./LA 92 @ Chemin Metairie Rd.	0	+2	+1	-$405,792	+15	-$374,730	$450,000	0
Chemin Metairie Rd.@ Viaulet Rd.	0	0	-1	$58,636	+1	-$24,982	$550,000	0.06
E. Milton/LA 92 @ Verot School Rd.	0	0	0	$0	+3	-$74,946	$1,100,000	0
Gloria Switch Rd. /LA 98 @ LA 93	0	0	-2	$117,272	-3	$74,946	$579,000	0.33
Bonin Rd. @ Fortune Rd.	0	-1	-2	$290,850	+5	-$124,910	$539,000	0.31
LA 3158 @ Old Covington Rd.	0	+1	-2	-$56,306	+17	-$424,694	$556,000	0
LA 406 @ LA 407	-1	0	+2	$372,174	-1	$24,982	$750,000	0.53

CONCLUSIONS

Each crash countermeasure evaluated in this project aims to reduce crashes by number and severity as well as targeted types of crashes for a particular roadway facility. The specific conclusions for the four countermeasures are:

1. CLRS is an effective measure for rural two-lane highways. The observed reduction is 15.1%, 31.2% and 22.1% for total, fatal and injury crashes, respectively. Targeted crashes (head-on and opposite direction sideswipe crashes) are reduced by 36.7%. The CMF derived by EB method with the state developed SPF is 0.831. The higher than nine B/C ratio indicates that CLRS is an economically justified crash countermeasure for two-lane roadways with minimum lane width 11 ft. and speed limit of 55 mph or higher.

2. Based on the small sample size evaluated in this study, the results indicate that lane conversions could be an effective and low-cost crash countermeasure for urban and suburban four-lane undivided roadways with driveway density higher than 36 (studied sections have driveway density varies from 36 to 68 driveways per mile). The 4U to 5T is not a perfect solution but an effective alternative for crash reduction under the budgetary constraint. For 4U to 3T, the observed crash reductions are 35.6% for total and 46.2% for injury crashes including intersections, i.e., roadway segment plus intersection because of added turning lane at some intersections; excluding intersections, the reductions are 33% for total and 55% for injury crashes. For 4U to 5T, the observed reductions are 23.9% for total and 38.5% for injury crashes with intersections; excluding intersections, the reductions are 24.7% for total and 33% for injury crashes. The fatal crashes for 4U to 3T remained two before and after the lane conversion. For 4U to 5T, fatal crash increases from zero to one but the crash was occurred because of a pedestrian improperly crossing street (jaywalking) which has nothing to do with lane conversion project. For 4U to 3T, the estimated CMF (with 4 sites) is 0.69 for segment plus intersection by Improved Prediction method and is 0.61 for segment only (without intersection) by EB method. For 4U to 5T, the estimated CMF (with 6 sites) is 0.76 for segment plus intersection by Improved Prediction method and is 0.70 for segment only (without intersection) by EB method. Providing space for non-motorized travel modes is another benefit for 4U to 3T conversion. The very high B/C ratio, between 42 and 53, indicates that the lane conversion is a very cost-effective crash countermeasure.

3. This study concentrated only on the main intersection of a RCUT. Since, the surrounding intersections are usually modified along with the main intersection this report is recommending further research be performed on the entire RCUT system before reaching any conclusions. Based on the small sample size evaluated in this study, the results indicate that RCUTs can improve safety on four- or six-lane divided highways. The observed total crash reductions are 13.1%, fatal crashes 100% and injury crashes 11.5% for the RCUT section. For intersection only, the observed reductions in total, fatal and injury crashes are 31.1%, 100%, and 41.8% respectively. The targeted right angle and left turn crashes reduced by 58.8% and 37% for RCUT section, and for intersection only, they are 68.1% and 61.5%. The CMF derived from the six complete RCUTs (J type) is 0.86 and 0.69 for the RCUT section and intersection only by the Improved Prediction Method. With the EB Method, the estimated CMF is 0.80 for only intersection, using the SPF available in Highway Safety Manual. The B/C ratio of 1.63 to 2.72 (estimated only by three after years' crash reduction data) suggests that RCUTs are an economically justified crash countermeasure for intersections on four- or six-lane divided highways.

4. While the roundabouts (18 total) evaluated in this study were installed for either the purpose of reducing congestion or reducing crash severity, this report only evaluates the effects on crash severity. The observed injury crash reduced by 57% based on the aggregated crash statistics for all 18 roundabouts. Based on limited sample size for each group in this study, the intersections with stop control on the minor street (without layout change) harvested the highest safety benefits from roundabouts because of the biggest reduction in the number of conflicting points. The observed reductions in this group are 70%, 78% and 65% for total, injury and PDO crashes, respectively. The estimated CMF with EB for this top performance group is 0.51. For other groups, the crash frequency changes between before and after roundabout are not consistent. The inconsistency could come from the lack of intersection lighting at some roundabouts, unavailable or inaccurate AADT data for capacity motivated roundabouts, small sample size, and change in the design guidelines. Based on the small sample size it wasn't possible to draw any safety conclusions. What needs to be addressed for future analysis is that the crash reports had right angle crashes for roundabouts which is not a possibility. This report is recommending that Louisiana trains its law enforcement agencies on roundabouts and roundabout crashes. Also, lighting levels should be studied to determine at what lighting level deficiencies do crashes increase.

RECOMMENDATIONS

Based on the results, the project recommends that the state:

1. Continue to implement CLRS on the state and non-state two-lane highways where head-on and sideswipe crash rate is higher than the state average.
2. Investigate/study additional locations to convert the urban and suburban undivided four-lane roadway segments that have high driveway density (higher than or equal to 36 driveways per mile based on the current and prior lane conversion studies) into five or three-lane roadways depending on the AADT (less than 20,000 for 3T and more than 20,000 for 5T).
3. Investigate/study additional locations to convert into RCUT where the crossing roadway has low AADT and is in lower functional classification.
4. Consider/investigate converting signalized/unsignalized intersections where fatal and injury crash rate is higher than the state average into roundabout. The priority may be given to intersections with stop control on minor street.
5. The crash type coding at roundabout needs to be better defined through training and communication with the law enforcement officers and traffic record coordinating committee (TRCC).

Recommendations for future research:

1. More research is warranted for all the countermeasures once more projects are constructed. Sample size was limited.
2. Investigate the crashes of the entire RCUT system.
3. Investigate the lighting level at roundabouts that cause deficiencies.
4. Investigate ROR and cross-centerline crashes on rural two-lane roadways on the CLRS. The current study identified the crash reductions in head-on collisions and sideswipe in opposite-direction crashes, which are the targeted crash type in this study and by other previous studies. The detailed analysis on non-collision (single vehicle), crossing-center line crashes is missing in this project.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

3T	Three-Lane Highway with a Left Turn Lane
4U	Four Lane Undivided Highway
5T	Five-Lane Highway with a Left Turn Lane
AADT	Annual Average Daily Traffic
B/C	Benefit/Cost
CLRS	Center Line Rumble Strips
CMF	Crash Modification Factor
DOTD	Louisiana Department of Transportation and Development
EB	Empirical Bayes
FHWA	Federal Highway Administration
HSIS	Highway Safety Information System
HSM	Highway Safety Manual
IIHS	Insurance Institute for Highway Safety
LTRC	Louisiana Transportation Research Center
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
PDO	Property Damage Only
RCUT	Restricted Crossing U-Turn
RTM	Regression to the Mean
SOMR	Stop on Minor Road
SPF	Safety Performance Function
TWLTL	Two Way Left Turn Lane
TWSC	Two Way Stop Control
VMT	Vehicle Miles travelled

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APPENDIX

Appendix A Design of centerline rumble strips
Appendix B Four-lane to three-lane individual site analysis
Appendix C Four-lane to five-lane individual site analysis
Appendix D RCUT individual site analysis
Appendix E Roundabout individual site analysis

APPENDIX A

Design of Centerline Rumble Strips

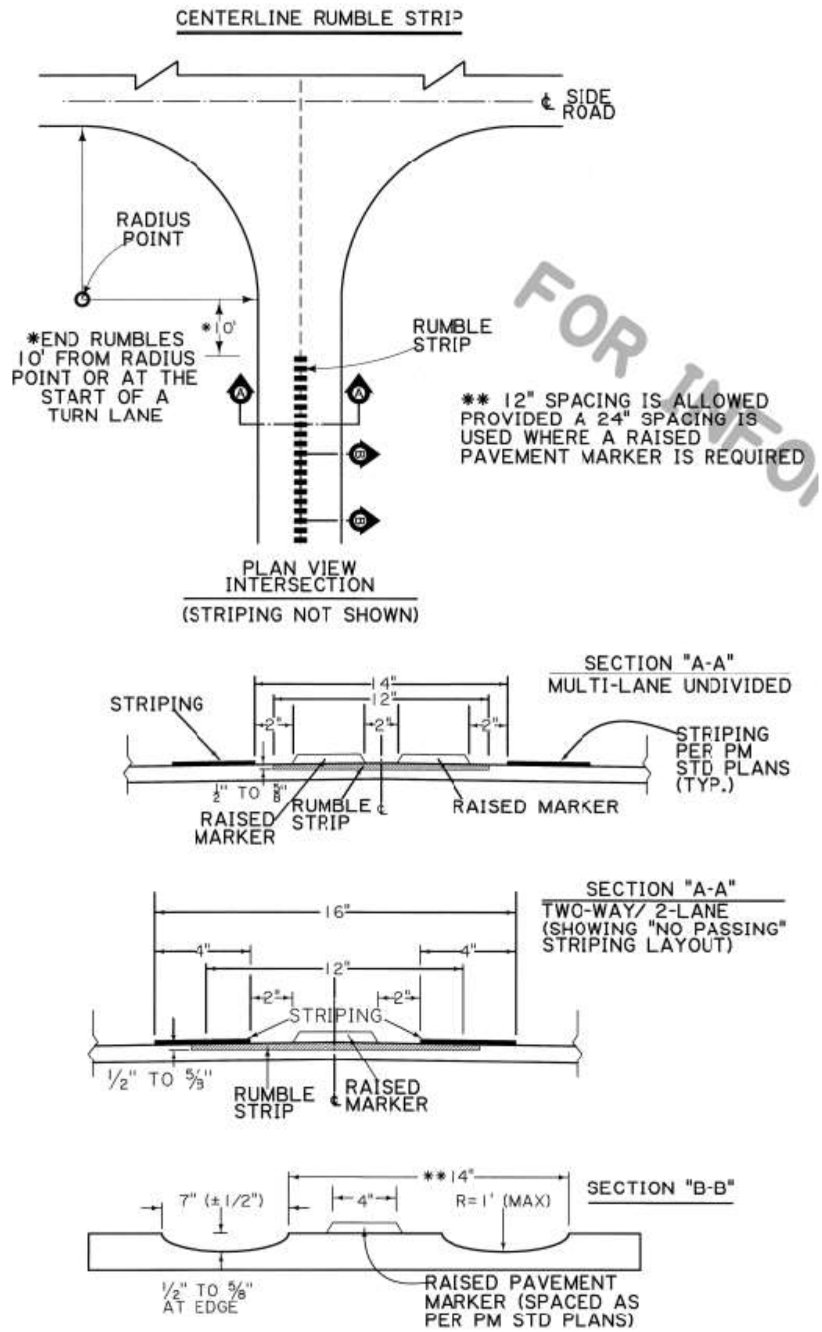

Figure A1

Plan and section views of rumble strips and raised pavement marker (not to scale and reproduced from DOTD website)

APPENDIX B

Four-lane to Three-lane Individual Site Analysis

Site 1: N. Bertrand in Lafayette

N. Bertrand Drive on LA 3025 highway is a half-mile segment in Lafayette stretched from Eraste Landry St. to Cameron St. [US 90]. This four-lane highway section was converted to three-lane in 2013. Twenty out of 25 driveways in this section are connected to minor commercial establishments. The wider through lanes after restriping (each around 15 ft.) was not utilized for any bicycle lane or sidewalk. Over the years of before/after conversion of this segment, AADT did not significantly change. Total number of crashes in before/after period in this section remained unchanged. Although number of right angle crashes reduced, but there was increase in rear-end crashes especially at the intersections.

Figure B1

Before (top) after (bottom) image of site 1 - N. Bertrand in Lafayette

Table B1.1

Length, AADT, and access information of site 1 - N. Bertrand in Lafayette

Variable		Number
Length (mile)		**0.52**
Average AADT (Before)		**9,867**
Average AADT (After)		**9,833**
Driveway	Minor Commercial	20
	Major Residential	2
	Minor Residential	3
Intersection	1ST	2
	2ST	2

Table B1.2

Crash information of site 1 - N. Bertrand in Lafayette

Crash Type		Segment + Intersection		Non-Intersection	
		Before	After	Before	After
Total Crash		12	12	2	3
Severity	Fatal	0	0	0	0
	Injury	1	1	0	0
	PDO	11	11	2	3
Manner of collision	Head-on	0	0	0	0
	Left turn	1	1	0	1
	Non-collision	1	0	0	0
	Rear-end	1	8	1	1
	Right turn	0	1	0	0
	Right angle	6	0	0	0
	Sideswipe- OD	0	0	0	0
	Sideswipe- SD	3	0	1	0
	Other	0	2	0	1
Time of the day	6 am - 12 pm	8	5	1	2
	12 pm - 6 pm	4	6	1	0
	6 pm - 12 am	0	1	0	1
	12 am - 6 am	0	0	0	0
Single vehicle		0	0	0	0
Alcohol		0	0	0	0
Distracted driver		0	1	0	1
Pedestrian		0	0	0	0

Site 2: LA 14 Charity in Abbeville

The second site was on highway LA 14E, from St Charles Street to Viola Street. This 1.4-mile highly accessible section was converted to three-lane in 2011. This section includes 96 driveways — majority are minor commercial driveways and minor residential household driveways. About 40 ft. wide four-lane pavement was restriped to three 12 ft. lanes. After conversion to three-lane, this site experienced large reduction left turn, rear-end, right angle, and sideswipe crashes.

Figure B2

Before (top) after (bottom) image of site 2 - LA 14 Charity in Abbeville

Table B2.1
Length, AADT, and access information of site 2: LA 14 Charity in Abbeville

Variable		**Number**
Length (mile)		**1.41**
Average AADT (Before)		**8,333**
Average AADT (After)		**9,200**
Driveway	Major Commercial	2
	Minor Commercial	66
	Major Residential	1
	Minor Residential	28
Intersection	1ST	2
	2ST	2

Table B2.2
Crash information of Site 2: LA 14 Charity in Abbeville

Crash Type		**Segment + Intersection**		**Non-Intersection**	
		Before	**After**	**Before**	**After**
Total Crash		188	75	34	12
Severity	Fatal	0	0	0	0
	Injury	64	26	13	4
	PDO	124	49	21	8
Manner of collision	Head-on	4	1	1	0
	Left turn	45	8	1	0
	Non-collision	5	3	1	2
	Rear-end	48	29	15	5
	Right turn	2	0	1	0
	Right angle	40	22	3	0
	Sideswipe- OD	3	0	1	0
	Sideswipe- SD	19	9	4	4
	Other	22	3	7	1
Time of the day	6 am - 12 pm	68	22	13	4
	12 pm - 6 pm	99	36	17	4
	6 pm - 12 am	16	11	2	2
	12 am - 6 am	4	6	1	2
Single vehicle		7	2	3	1
Alcohol		8	1	2	1
Distracted driver		4	4	0	0
Pedestrian		2	1	0	0

Site 3: LA 3089 in Donaldsonville

The site 3, part of both Marchand Drive and Albert Street, is on LA 3089 in Donaldsonville. It starts from Bayou Road (LA 1) and ends at 245 ft. southeast of Church Street. Although 0.62 miles long, the site has a total of 10 intersections and additional two intersections with flashing lights. Four 11.5 ft.-wide lane sections were restriped to two 12-ft. through lanes and a 14-ft. center lane in 2013. With a 60% increase in AADT, the site experiences reduction in right angle and sideswipe crashes and increase in non-collision and rear-end crashes.

Figure B3

Before (top) after (bottom) image of site 3 - LA 3089 in Donaldsonville

Table B3.1

Length, AADT, and access information of site 3 - N. Bertrand in Lafayette

Variable		Number
Length (mile)		**0.62**
Average AADT (Before)		**9,103**
Average AADT (After)		**14,570**
Driveway	Minor Commercial	22
	Minor Residential	2
Intersection	1ST	2
	2ST	4
	4SG	4

Table B3.2

Crash information of site 3 - LA 3089 in Donaldsonville

Crash Type		Segment + Intersection		Non-Intersection	
		Before	After	Before	After
Total Crash		126	116	14	20
Severity	Fatal	0	1	0	1
	Injury	42	30	5	5
	PDO	84	85	9	14
Manner of collision	Head-on	5	3	1	1
	Left turn	17	14	0	0
	Non-collision	5	6	1	2
	Rear-end	39	56	4	9
	Right turn	3	7	0	0
	Right angle	30	7	2	1
	Sideswipe- OD	3	2	1	0
	Sideswipe- SD	16	14	5	4
	Other	8	7	0	3
Time of the day	6 am - 12 pm	28	30	1	8
	12 pm - 6 pm	67	54	9	7
	6 pm - 12 am	19	19	2	1
	12 am - 6 am	9	13	2	4
Single vehicle		3	8	1	3
Alcohol		5	3	2	2
Distracted driver		4	5	1	0
Pedestrian		0	1	0	0

Site 4: LA 21 in Bogalusa

The site 4 is a 1.37-mile segment on LA 21 in Bogalusa stretched from East 2nd St to 230 ft. west of Rosa Pearl Lane. The accesses in the site are mainly minor residential driveways and two-way stop sign controlled intersections. This four-lane segment was restriped to three-lane in 2008. Although the AADT reduced by 29%, the site experienced reduction in injury crashes, especially left turn crashes.

Figure B4
Before (top) after (bottom) image of site 4 - LA 21 in Bogalusa

Table B4.1
Length, AADT, and access information of site 4 - LA 21 in Bogalusa

Variable		Number
Length (mile)		**1.37**
Average AADT (Before)		**13,500**
Average AADT (After)		**9,533**
Driveway	Minor Commercial	11
	Minor Residential	38
Intersection	1ST	2
	2ST	19

Table B4.2
Crash information of site 4 - LA 21 in Bogalusa

Crash Type		Segment + Intersection		Non-Intersection	
		Before	After	Before	After
Total Crash		53	41	10	5
Severity	Fatal	1	0	1	0
	Injury	25	14	2	0
	PDO	27	27	7	5
Manner of collision	Head-on	1	1	0	0
	Left turn	10	1	4	0
	Non-collision	0	1	0	0
	Rear-end	11	11	2	3
	Right turn	0	2	0	0
	Right angle	13	11	0	0
	Sideswipe- OD	0	1	0	0
	Sideswipe- SD	10	3	1	2
	Other	8	10	3	0
Time of the day	6 am - 12 pm	10	16	2	4
	12 pm - 6 pm	28	18	6	1
	6 pm - 12 am	9	5	1	0
	12 am - 6 am	5	2	1	0
Single vehicle		1	3	1	0
Alcohol		1	1	0	0
Distracted driver		1	1	1	0
Pedestrian		1	0	1	0

APPENDIX C

Four-lane to Five-lane Individual Site Analysis

Site 1: LA 14 in New Iberia

This segment is part of the LA 14 highway known as Center Street, located at the entrance of New Iberia. It was converted to five-lane highway in 2007. There are many minor commercial establishments on the southern side of the segment. This segment experiences reduction of all type of crashes along with small reduction in AADT after conversion to five-lane highway. Google street view image before conversion was not available.

Figure C1
After image of site 1 - LA 14 in New Iberia

Table C1.1
Length, AADT, and access information of site 1 - LA 14 in New Iberia

Variable		Number
Length (mile)		**0.92**
Average AADT (Before)		**19,867**
Average AADT (After)		**19,767**
Driveway	Major Commercial	2
	Minor Commercial	29
	Minor Residential	1
	Minor Industrial	2
Intersection	1ST	6
	3SG	2

Table C1.2

Crash information of site 1 - LA 14 in New Iberia

Crash Type		Segment + Intersection		Non-Intersection	
		Before	**After**	**Before**	**After**
Total Crash		160	97	44	26
Severity	Fatal	0	0	0	0
	Injury	50	24	11	8
	PDO	110	73	33	18
Manner of collision	Head-on	4	2	0	1
	Left turn	26	17	8	4
	Non-collision	10	4	4	1
	Rear-end	48	39	11	9
	Right turn	4	4	1	1
	Right angle	36	12	10	3
	Sideswipe- OD	1	0	0	0
	Sideswipe- SD	8	10	2	3
	Other	23	9	8	4
Time of the day	6 am - 12 pm	57	26	20	10
	12 pm - 6 pm	65	58	17	15
	6 pm - 12 am	28	6	5	1
	12 am - 6 am	10	6	2	0
Single vehicle		12	4	5	1
Alcohol		8	3	3	0
Distracted driver		6	6	1	2
Pedestrian		1	2	1	1

Site 2: LA 14 (charity) in Abbeville

This segment is also on LA 14 highway. It is known as Charity Street and located in the city of Abbeville. This four-lane segment was converted to five-lane in 2011. There are many minor commercial establishments on the southern side of the segment. This segment experiences reduction of all type of crashes after conversion to five lane highway by narrowing down the lane width to 10 feet. Reduction of left turn, rear-end, and right angle crashes both in whole segment and intersection was observed. Most of the same direction sideswipe crashes in the after years occurred due to the issue of lane change in the same direction.

Figure C2

Before (top) after (bottom) image of site 2 - LA 14 (charity) in Abbeville

Table C2.1

Length, AADT, and access information of site 2 - LA 14 (charity) in Abbeville

Variable		Number
Length (mile)		**0.47**
Average AADT (Before)		**6,800**
Average AADT (After)		**7,860**
Driveway	Major Commercial	1
	Minor Commercial	21
	Minor Residential	9
Intersection	1ST	3
	2ST	2

Table C2.2

Crash information of site 2 - LA 14 (charity) in Abbeville

Crash Type		Segment + Intersection		Non-Intersection	
		Before	After	Before	After
Total Crash		39	20	10	4
Severity	Fatal	0	1	0	1
	Injury	25	8	8	2
	PDO	14	11	2	1
Manner of collision	Head-on	1	0	1	0
	Left turn	10	4	3	0
	Non-collision	3	2	0	1
	Rear-end	7	1	3	1
	Right turn	0	2	0	0
	Right angle	14	4	3	0
	Sideswipe- OD	0	0	0	0
	Sideswipe- SD	1	5	0	2
	Other	3	2	0	0
Time of the day	6 am - 12 pm	11	10	6	0
	12 pm - 6 pm	19	6	3	2
	6 pm - 12 am	7	3	1	2
	12 am - 6 am	1	1	0	0
Single vehicle		2	1	0	1
Alcohol		2	0	0	0
Distracted driver		2	0	1	0
Pedestrian		0	1	0	1

Site 3: LA 14-Bypass in Abbeville

This third site is on LA 14 bypass highway. Converted in 2011, this segment has many minor commercial establishments. The segment has two major intersections with LA 82 and US 167. Around 400 ft. of these intersections, the segment becomes divided highways with many U-turn accesses. A number of crashes occurred around these two intersections. Although total number of crashes remain unchanged, non-intersection crashes do increase. Also, many non-collision crashes occurred along the whole segment in the after years. Eight out of 12 non-collision crashes are related to light truck, truck-trailer, or SUV.

Figure C3

Before (top) after (bottom) image of site 3 - LA 14-Bypass in Abbeville

Table C3.1
Length, AADT, and access information of Site 3 -LA 14-Bypass in Abbeville

Variable		Number
Length (mile)		**1.2**
Average AADT (Before)		**15,271**
Average AADT (After)		**17,097**
Driveway	Major Commercial	1
	Minor Commercial	45
	Minor Residential	7
	Minor Industrial	1
Intersection	1ST	1
	2ST	1
	4SG	2

Table C3.2
Crash information of site 3 - LA 14-Bypass in Abbeville

Crash Type		Segment + Intersection		Non-Intersection	
		Before	After	Before	After
Total Crash		189	187	81	91
Severity	Fatal	0	0	0	0
	Injury	73	53	27	23
	PDO	116	134	54	68
Manner of collision	Head-on	1	4	1	0
	Left turn	16	12	3	5
	Non-collision	3	12	3	9
	Rear-end	104	88	48	35
	Right turn	5	2	2	1
	Right angle	26	25	10	11
	Sideswipe- OD	2	4	2	2
	Sideswipe- SD	20	31	8	23
	Other	12	9	4	5
Time of the day	6 am - 12 pm	55	69	18	31
	12 pm - 6 pm	97	93	47	51
	6 pm - 12 am	29	16	12	4
	12 am - 6 am	8	9	4	5
Single vehicle		4	15	2	12
Alcohol		9	4	5	0
Distracted driver		5	11	4	5
Pedestrian		2	0	0	0

Site 4: US 167 in Maurice

This segment is located on US 167, known as Maurice Avenue, in Maurice. This four-lane segment was converted to five-lane in 2012. The high volume of AADT along with minor commercial and residential accesses around the segment justifies the attempt to convert to five-lane. Large number of rear-end crashes were reduced after restriping to five-lane.

Figure C4
Before (top) after (bottom) image of site 4 - US 167 in Maurice

Table C4.1
Length, AADT, and access information of site 4 - US 167 in Maurice

Variable		Number
Length (mile)		**1.14**
Average AADT (Before)		**18,748**
Average AADT (After)		**20,098**
Driveway	Minor Commercial	35
	Minor Residential	14
Intersection	1ST	1
	2ST	9
	3SG	3
	4SG	1

Table C4.2
Crash information of site 4 - US 167 in Maurice

Crash Type		Segment + Intersection		Non-Intersection	
		Before	After	Before	After
Total Crash		118	80	42	15
Severity	Fatal	0	0	0	0
	Injury	28	24	11	5
	PDO	90	56	31	10
Manner of collision	Head-on	3	3	0	0
	Left turn	5	5	0	0
	Non-collision	1	4	0	2
	Rear-end	64	31	23	3
	Right turn	2	2	1	1
	Right angle	17	9	5	0
	Sideswipe- OD	1	3	1	1
	Sideswipe- SD	12	11	7	4
	Other	13	12	5	4
Time of the day	6 am - 12 pm	41	29	15	5
	12 pm - 6 pm	69	41	22	7
	6 pm - 12 am	3	4	2	0
	12 am - 6 am	5	6	3	3
Single vehicle		7	6	2	5
Alcohol		1	1	1	0
Distracted driver		9	4	3	1
Pedestrian		0	0	0	0

Site 5: US 190 in Eunice

This 1.45-mile segment is located on US 190, known as West Laurel Avenue in the city of Eunice. On this segment, the high AADT in before period reduces in after period, by 13%. Although right angle crashes from large number of commercial driveways increased after the conversion, overall the number of crashes reduced along with the large reduction in left turn and rear-end crashes.

Figure C5
Before (top) after (bottom) image of site 5 - US 190 in Eunice

Table C5.1

Length, AADT, and access information of site 5 - US 190 in Eunice

Variable		Number
Length (mile)		**1.45**
Average AADT (Before)		**22,141**
Average AADT (After)		**19,194**
Driveway	Major Commercial	1
	Minor Commercial	85
Intersection	1ST	1
	2ST	14
	3SG	2
	4SG	4

Table C5.2

Crash information of site 5 - US 190 in Eunice

Crash Type		Segment + Intersection		Non-Intersection	
		Before	After	Before	After
Total Crash		293	233	30	21
Severity	Fatal	0	0	0	0
	Injury	112	68	11	7
	PDO	181	165	19	14
Manner of collision	Head-on	2	2	0	0
	Left turn	49	21	2	2
	Non-collision	4	7	1	1
	Rear-end	137	63	17	6
	Right turn	6	12	1	1
	Right angle	42	69	1	4
	Sideswipe- OD	1	9	0	1
	Sideswipe- SD	25	41	6	6
	Other	27	9	2	0
Time of the day	6 am - 12 pm	111	82	11	12
	12 pm - 6 pm	147	120	16	4
	6 pm - 12 am	24	24	2	4
	12 am - 6 am	8	7	1	1
Single vehicle		9	9	1	1
Alcohol		10	6	0	1
Distracted driver		12	13	2	1
Pedestrian		5	3	0	1

Site 6: LA 42 in Baton Rouge

This 0.8-mile long segment, located on the outskirts of Baton Rouge, was converted to five-lane in 2013. Majority of the driveways are from residential areas. Safety is improved with significant reduction in left turn and rear-end crashes after conversion.

Figure C6

Before (top) after (bottom) image of site 6 - LA 42 in Baton Rouge

Table C6.1

Length, AADT, and access information of site 6 - LA 42 in Baton Rouge

Variable		Number
Length (mile)		**0.798**
Average AADT (Before)		**18,900**
Average AADT (After)		**24,867**
Driveway	Major Residential	2
	Minor Residential	23
	Minor Commercial	10
Intersection	1ST	2
	4SG	3

Table C6.2

Crash information of site 6 - LA 42 in Baton Rouge

Crash Type		Segment + Intersection		Non-Intersection	
		Before	**After**	**Before**	**After**
Total Crash		356	262	68	50
Severity	Fatal	0	0	0	0
	Injury	70	43	11	8
	PDO	286	219	57	42
Manner of collision	Head-on	1	3	0	1
	Left turn	73	32	7	5
	Non-collision	16	7	7	1
	Rear-end	105	73	28	14
	Right turn	3	7	0	3
	Right angle	96	94	9	11
	Sideswipe- OD	3	0	1	0
	Sideswipe- SD	38	32	14	12
	Other	17	14	2	3
Time of the day	6 am - 12 pm	76	88	13	16
	12 pm - 6 pm	178	111	32	25
	6 pm - 12 am	75	50	13	9
	12 am - 6 am	27	13	10	0
Single vehicle		19	6	5	1
Alcohol		6	2	2	0
Distracted driver		10	16	2	2
Pedestrian		2	3	0	0

APPENDIX D

RCUT Individual Site Analysis

Site 1: US 167 at LA 699 RCUT Intersection

US 167 at LA 699 intersection is a four-legged complete RCUT intersection with stop-control on minor road. This RCUT was constructed in 2012 from two-way stop sign controlled intersection with flashing lights. The RCUT previously had three two way median openings which has then been modified into U-turns one on either side of the intersections. The U-turn to the north is 1,964 ft. and the U-turn to the south is at 1,305 ft. from the minor road. The AADT increased by 11.9%, from 17,100 to 19,133 in this RCUT segment. This RCUT experienced the increase in total number of crashes after the installation compared to the period before. This facility also experienced the increase in AADT in the after period. However, there were no fatal crash in the three years after the construction of RCUT. No pedestrian nor bicycle crashes were experienced at this intersection. Detailed investigation of the increase in total crashes has been presented in Part III of the report.

Figure D1

US 167 at LA 699 RCUT facility

Table D1

Crash information of US 167 at LA 699 RCUT

Crash Type		RCUT		Intersection	
		Before	After	Before	After
Total Crash		23	32	17	26
Severity	Fatal	1	0	1	0
	Injury	14	10	11	8
	PDO	8	22	5	18
Manner of collision	Non-collision	3	11	1	6
	Rear-end	2	9	1	8
	Head-on	2	0	1	0
	Right angle	10	5	9	5
	Left turn	5	1	4	1
	Right turn	0	1	0	1
	Sideswipe	1	5	1	5
Time of the day	6 am - 12 pm	8	10	7	7
	12 pm - 6 pm	9	13	8	12
	6 pm - 12 am	3	8	2	6
	12 am - 6 am	3	1	0	1
Single vehicle		3	11	1	6
Multiple vehicle		20	21	16	20
Alcohol		4	6	0	0

Site 2: LA 21 at Zinnia Road RCUT Intersection

It is a four-legged, two-way stop-controlled intersection that has looped U-turns on either end of the intersection. The U-turn to the north-east is at 525 feet and the U-turn to the south-west is at 600 feet from the minor road. It was installed in 2012. This intersection is in a small market area serving few markets on the southbound whereas the northbound has no access on the right side but there is go through. The intersection also has a median. The intersection serves driveways between two U-turns and both U-turns have bulb-out loops to accommodate large vehicles. The minor road opens to a dense residential area on the northern side. The AADT decreased by 2.8%, from 24,900 to 24,200 in this RCUT segment. This RCUT experienced decrease in total number of crashes after the installation compared to the period before. No fatal crashes occurred in this facility during the period of analysis.

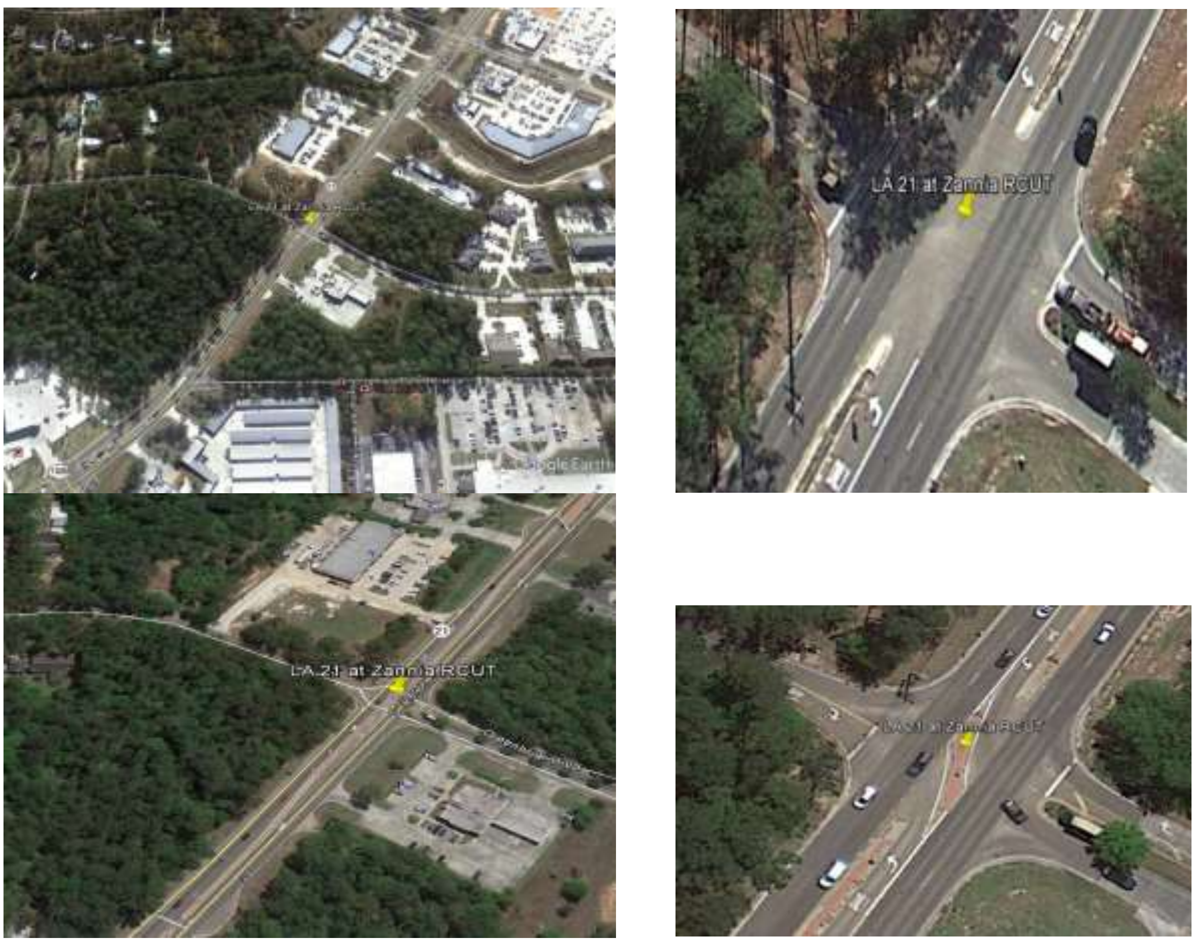

Figure D2

LA 21 at Zinnia Road RCUT

Table D2

Crash information of LA 21 at Zinnia Road RCUT

Crash Type		RCUT		Intersection	
		Before	After	Before	After
Total Crash		49	35	39	10
Severity	Fatal	0	0	0	0
	Injury	17	7	15	1
	PDO	32	28	24	9
Manner of collision	Non-collision	1	1	0	1
	Rear-end	20	18	12	4
	Head-on	0	1	0	0
	Right angle	11	3	11	1
	Left turn	11	5	11	3
	Right turn	3	3	3	0
	Sideswipe	3	4	2	1
Time of the day	6 am - 12 pm	13	8	11	4
	12 pm - 6 pm	31	25	25	4
	6 pm - 12 am	2	1	2	1
	12 am - 6 am	3	1	1	1
Single vehicle		1	1	0	1
Multiple vehicle		48	34	39	9
Alcohol		0	1	0	0
Distraction		4	4	3	0

Site 3: Kurthwood Road and Alexandria highway RCUT Intersection

This facility is a four-legged stop signed complete RCUT intersection with two U-turns. The U-turn to the east is at 1,500 feet and the U-turn to the west is at 1,700 ft. from the minor road. This was constructed in 2011. There are only two driveways in between the two U-turns. The westbound U-turn is near to a roundabout which has access to a newly built Market place. This RCUT experienced decrease in total number of crashes after the installation compared to the period before. This facility also experienced 32% increase in AADT in the after period (from 7,100 to 9,367). However, this facility experienced the total elimination of fatal crash and decrease in injury crash.

Figure D3

Kurthwood Road and Alexandria highway RCUT

Table D3

Crash information of Kurthwood Road and Alexandria highway RCUT

Crash Type		RCUT		Intersection	
		Before	**After**	**Before**	**After**
Total Crash		18	13	15	7
Severity	Fatal	1	0	1	0
	Injury	7	7	5	4
	PDO	10	6	9	3
Manner of collision	Non-collision	2	4	1	1
	Rear-end	9	6	8	3
	Right angle	5	2	5	2
	Right Turn	2	1	1	1
Time of the day	6 am - 12 pm	3	2	0	0
	12 pm - 6 pm	6	4	6	1
	6 pm - 12 am	8	6	8	6
	12 am - 6 am	1	1	1	0
Single vehicle		2	4	1	1
Multiple vehicle		16	9	14	6
Alcohol		0	1	0	0
Distraction		0	1	0	1

Site 4: LA 45 at 10th street RCUT Intersection

This RCUT is on LA 45 at 10th street in St. Charles Parish, which was constructed in 2013. This RCUT has raised island at the intersection restricting the left turn and go through from 10th street. This intersection does not have U-turns on either side of the intersection but is connected to another intersection. The intersection to the north of the RCUT is at 400 feet and the U-turn to the south is at 940 feet. The intersection is close to different schools and institutes on the southern side from the intersection including a school for the disabled and deaf. Large number of pedestrians are expected in this area during school hours. The drive through fast food restaurant right at the intersection was started after the construction of the RCUT. The intersection on the northern side of the RCUT is very busy. It was very difficult to determine the U-turn position at the intersections. Only the 150-ft. intersection has been considered for the analysis. This RCUT facility experienced overall 6.1% decrease in AADT in the after period, but reduction in total crashes including rear-end, right angle, left turn, and sideswipe crashes. The facility experienced no pedestrian and bicycle crashes.

Figure D4

LA 45 at 10th street RCUT

Table D4

Crash information of LA 45 at 10th street RCUT

Crash Type		Intersection Crashes	
		Before	After
Total Crash		73	42
Severity	Fatal	0	0
	Injury	21	7
	PDO	52	35
Manner of collision	Non- collision	3	2
	Rear-end	33	26
	Head-on	0	1
	Right angle	19	2
	Left turn	6	1
	Right Turn	3	5
	Side Swipe	9	5
Time of the day	6 am - 12 pm	1	0
	12 pm - 6 pm	25	25
	6 pm - 12 am	41	16
	12 am - 6 am	6	1
Single vehicle		3	2
Multiple vehicle		70	40
Alcohol		4	0

Site 5: US 61 at LA 42 RCUT Intersection

This RCUT at the intersection of US 61 and LA 42 is in Ascension Parish. The RCUT was installed in 2013. This is a signalized intersection with two left turn lanes from south bound major road to the minor road. The RCUT has two U-turns with one storage bays one on either side of the intersection. The U-turn to the north is at 1,275 ft. and to the south is at 1,400 ft. The minor road has access to a residential opening. This RCUT has 13 driveways on the northern bound and 11 on the southern bound of US 61 between the two U-turns. Bulb-out loops are provided on the southern U-turn. Deceleration lane on each bound are provided at almost half the spacing. There was increase and decrease of AADT, but no change on average AADT (41,900). The RCUT experienced reduction on right angle crashes. The investigation on the increase of total crashes in the segment has been explained in Part III of the report.

Figure D5

US 61 at LA 42 RCUT

Table D5

Crash information of US 61 at LA 42 RCUT

Crash Type		RCUT		Intersection	
		Before	After	Before	After
Total Crash		118	140	76	59
Severity	Fatal	0	0	0	0
	Injury	27	39	13	10
	PDO	91	101	63	49
Manner of collision	Non- collision	6	11	3	3
	Rear-end	53	69	47	31
	Head-on	4	6	3	3
	Right angle	14	8	8	4
	Left turn	14	10	6	6
	Right Turn	6	7	3	3
	Side Swipe	21	29	6	9
Time of the day	6 am - 12 pm	42	42	31	12
	12 pm - 6 pm	51	62	27	24
	6 pm - 12 am	18	27	13	17
	12 am - 6 am	7	9	5	6
Single vehicle		6	11	3	3
Multiple vehicle		112	129	73	56
Alcohol		1	8	1	4
Distraction		13	4	11	4

RCUT intersections on Highway 90

In 2012, on the highway section between West Pinhook Road and Albertson's Parkway on US 90, 16 unsignalized full access median openings and 13 one-directional partial median openings were installed which formed five RCUT intersections. The project reduced the signal phases at Morgan Avenue. Along with the installation of the RCUTs, third lane was constructed on either direction to form an urban divided six-lane highway. Among the five RCUTs on the section, only one is a complete RCUT, two are JJ and rest two are JJJ RCUT intersections (see "Methodology" in Part III of the report for the type of RCUT intersections).

Site 6: US 90 at Morgan Avenue RCUT Intersection

This facility is a four-legged signalized complete RCUT intersection with two U-turns. There is a median opening to allow left turns from the major road to turn at the intersection on the six-lane highway. The U-turn to the east is at 1,150 ft. and the U-turn to the west is at 1,025 ft. from the intersection. The minor road has access to a small residential area. There are four driveways in between the two U-turns. Although AADT increased in the before years (average was 59,833), but 6.5% reduction was observed in the after years (average was 55,967). This RCUT experienced a reduction in total number of crashes after the installation compared to the period before. In this RCUT, rear-end, right angle, and left turn crashes are decreased, but non-collision, head-on, right turn, and sideswipe crashes increased. In the intersection, left turn crashes were eliminated and right angle crashes were also reduced.

Figure D6
US 90 at Morgan Avenue RCUT

Table D6
Crash information of US 90 at Morgan Avenue RCUT

Crash Type		RCUT		Intersection	
		Before	After	Before	After
Total Crash		132	96	70	57
Severity	Fatal	0	0	0	0
	Injury	47	46	17	15
	PDO	85	50	53	42
Manner of collision	Non-collision	2	13	0	5
	Rear-end	89	44	44	24
	Head-on	2	3	0	3
	Right angle	15	9	10	8
	Left turn	11	5	8	0
	Right turn	5	11	3	9
	Sideswipe	8	11	5	8
Time of the day	6 am - 12 pm	62	34	32	20
	12 pm - 6 pm	53	38	29	21
	6 pm - 12 am	7	12	5	8
	12 am - 6 am	10	12	4	8
Single vehicle		2	13	0	5
Multiple vehicle		130	83	70	52
Alcohol		0	0	0	0
Distraction		5	0	5	0

Site 7: US 90 at Perimeter Road RCUT Intersection

This RCUT facility is a six-lane US 90 highway has two U-turn accesses from major road into the minor road. The distance between the two U-turns is 2,670 ft. This intersection is in between the two main signalized intersections – Verot school at US 90 and Kaliste Saloom Road at US 90. The minor road opens to the DOTD office on one end and to residential opening on the other side. There are no driveways in between the two U-turns. For the intersection crash analysis, the access to the DOTD is taken into consideration because it had high flow of traffic during the peak hours. This RCUT segment experienced an increase in total number of crashes after the installation compared to the period before, but reduction was observed in total crashes in the intersection especially in rear-end crashes. Left turn and sideswipe crashes in the intersection remain unchanged.

Figure D7
US 90 at Perimeter Road RCUT

Table D7
Crash information of US 90 at Perimeter Road RCUT

Crash Type		RCUT		Intersection	
		Before	After	Before	After
Total Crash		64	73	11	4
Severity	Fatal	0	0	0	0
	Injury	16	22	1	1
	PDO	48	51	10	3
Manner of collision	Non-collision	6	7	0	0
	Rear-end	47	38	9	2
	Head-on	2	4	0	0
	Right angle	2	5	0	0
	Left turn	1	3	1	1
	Right turn	0	0	0	0
	Sideswipe	6	16	1	1
Time of the day	6 am - 12 pm	23	16	1	1
	12 pm - 6 pm	33	38	5	2
	6 pm - 12 am	2	7	3	1
	12 am - 6 am	6	12	2	0
Single vehicle		6	7	0	0
Multiple vehicle		58	66	11	4
Alcohol		1	0	1	0
Distraction		6	1	1	0

Site 8: US 90 at Kol drive RCUT Intersection

This RCUT on US 90 has U-turn accesses from major road into the minor road. The distance between the two U-turns is 790 ft. Kol Drive provides access to a residential area with five residential buildings. The intersection experiences reduction in both left turn and right angle crashes.

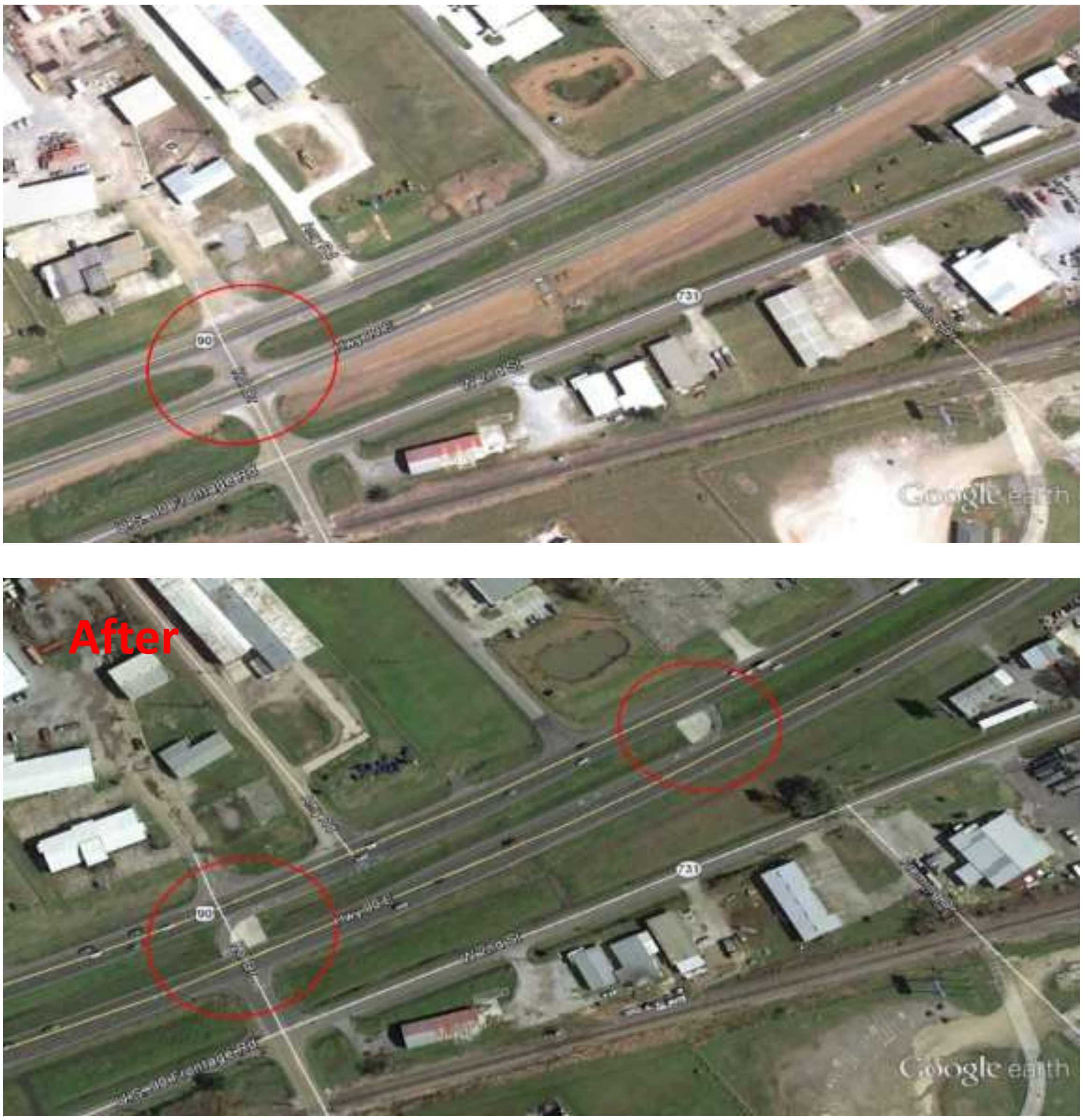

Figure D8
US 90 at Kol drive RCUT

Table D8
Crash information of US 90 at Kol Drive RCUT

Crash Type		RCUT		Intersection	
		Before	After	Before	After
Total Crash		136	85	11	12
Severity	Fatal	0	0	0	0
	Injury	37	22	5	3
	PDO	99	63	6	9
Manner of collision	Non-collision	8	11	2	0
	Rear-end	86	36	4	6
	Head-on	2	2	1	1
	Right angle	17	7	3	0
	Left turn	4	5	1	0
	Right turn	5	8	0	0
	Sideswipe	14	16	0	5
Time of the day	6 am - 12 pm	63	33	4	4
	12 pm - 6 pm	51	31	5	7
	6 pm - 12 am	10	11	1	0
	12 am - 6 am	12	10	1	1
Single vehicle		8	11	2	0
Multiple vehicle		128	74	9	12
Alcohol		1	1	1	0
Distraction		9	2	1	1

Site 9: US 90 at Park Centre Road RCUT Intersection

This RCUT on US 90 is one of the five RCUTs installed in a series. This RCUT has only two U-turn accesses from major road into the minor road. Both U-turns are connected to three-leg stop controlled intersections. The distance between the two U-turns is 622 ft. The park center road has access to residential area followed by an industrial area. The AADT increased by a very small margin (0.37%), from 36,333 to 36467. This RCUT experiences no right angle crashes in the after period whereas six right angle crashes occurred in the section in the before period.

Figure D9
US 90 at Park Centre Road RCUT

Table D9

Crash information of US 90 at Park Centre Road RCUT

Crash Type		RCUT		Intersection	
		Before	After	Before	After
Total Crash		13	9	10	4
Severity	Fatal	0	0	0	0
	Injury	2	2	2	2
	PDO	11	7	8	2
Manner of collision	Non-collision	0	1	0	0
	Rear-end	4	2	2	0
	Head-on	1	0	1	0
	Right angle	6	0	5	0
	Left turn	1	1	1	1
	Right turn	0	2	0	1
	Sideswipe	1	3	1	2
Time of the day	6 am - 12 pm	1	2	1	1
	12 pm - 6 pm	8	3	6	3
	6 pm - 12 am	3	3	3	0
	12 am - 6 am	1	1	0	0
Single vehicle		0	1	0	0
Multiple vehicle		13	8	10	4
Alcohol		1	5	1	0
Distraction		1	0	1	0

Site 10: US 90 at Girouard Drive RCUT Intersection

This RCUT is also a combination of two U-turns. Among the two U-turns, only one has an access from major road into the minor road. This facility is on a horizontal curve next to Morgan Avenue RCUT segment on one side and near to Albertson's Parkway on the other side. The distance between the two U-turns is 2,150 ft. This segment experiences 6.9% increase in AADT, from 56,067 to 59,933. In this RCUT, total number of crashes increase but reduction in head on and right angle crashes is observed.

Figure D10
US 90 at Girouard Drive RCUT

Table D10
Crash information of US 90 at Girouard Drive RCUT

Crash Type		**RCUT**		**Intersection**	
		Before	**After**	**Before**	**After**
Total Crash		14	31	6	5
Severity	Fatal	0	0	0	0
	Injury	3	7	1	2
	PDO	11	24	5	3
Manner of collision	Non-collision	1	6	0	0
	Rear-end	7	15	2	1
	Head-on	2	1	1	0
	Right angle	3	1	2	1
	Left turn	1	3	1	2
	Right turn	0	0	0	0
	Sideswipe	0	5	0	1
Time of the day	6 am - 12 pm	3	13	3	2
	12 pm - 6 pm	7	11	1	1
	6 pm - 12 am	4	3	2	2
	12 am - 6 am	0	4	0	0
Single vehicle		1	6	0	0
Multiple vehicle		13	25	6	5
Alcohol		0	1	0	1
Distraction		0	1	0	1

APPENDIX E

Roundabout Individual Site Analysis

Roundabout 1: LA 59 at LA 36
Previous control type: Signalized
Speed limit: 20 mph
Number of approaches: 4 before, 4 after
Roadway Speed limit: 35 mph on LA 59 and 30 mph on LA 36
Roundabout lighting condition: Yes

Figure E1.1
Before/after images of LA 59 at LA 36 roundabout

Table E1
Before/after crashes at intersection of LA 59 at LA 36 roundabout

Crash Type		Intersection Crashes	
		Before	After
Total Crash		14	9
Severity	Fatal	0	0
	Injury	3	3
	PDO	11	6
Manner of collision	Single Vehicle	3	1
	Rear-end	1	1
	Head-on	0	0
	Angle Crash	10	7
Lighting condition	Daytime	9	7
	Dark	5	2
Heavy Vehicle		1	0
Motorcycle		0	0
Alcohol/Drug		1	0
Distracted Driver		1	0

The total number of crashes decreased from 14 to 9, with an increase traffic volume (from 23,400 to 25,267 vehicles per day) as shown in Table E1. The number of injury crashes remain the same, and the PDO crashes decreased from 11 to 6. All manner of collisions shows a decreasing trend or remains the same. Noticeably, this roundabout has traffic light, as shown in Figure E1.2. It can be seen in Table E1 that less crashes were caused by bad lighting condition at night.

Figure E1.2

Traffic light condition in LA 59 at LA 36 roundabout

Roundabout 2: LA 1091 at Brownswitch Rd.

Previous control type: Signalized
Speed limit: 15 mph
Number of approaches: 4 before, 4 after
Roadway Speed limit: 40 mph on LA 1091 and 30 mph on Brownswich Rd.
Roundabout lighting condition: Yes

Figure E2.1

Before/after images of LA 1091 at Brownswitch Rd. roundabout

Table E2

Before/after crash information of LA 1091 at Brownswitch Rd. roundabout

Crash Type		**Intersection Crashes**	
		Before	**After**
Total Crash		20	27
Severity	Fatal	0	0
	Injury	8	2
	PDO	12	25
Manner of collision	Single Vehicle	0	1
	Rear-end	11	6
	Head-on	0	0
	Angle Crash	9	20
Lighting condition	Daytime	11	15
	Dark	9	12
Heavy Vehicle		0	0
Motorcycle		0	1
Alcohol/Drug		0	1
Distracted Driver		0	1

The traffic volume varied from 29,800 to 29,700 vehicles per day after roundabout construction. From Table E2, it can be figured out the crash severity decreased with the number of injury crashes decreased from 8 to 2. However, the PDO crashes increased sharply from 12 to 25.

Police officers cited 78% crashes occurred at exiting or entering roundabout as “fail to yield.” According to the FHWA research (*Roundabouts: an information guide*), the inappropriate alignment offset (in Figure E2.2) fail to help the road users to slow down before roundabout. The right-side office cannot perform the roundabout function of calming down the traffic and slowing down the operation speed. Additionally, the distance between right turn lane and roundabout lane is too small (in Figure E2.3), which induces more conflicting points. This geometric design and yield line installation makes the approaching right turn drivers hard to merge with the traffic existing in the roundabout.

With adequate illumination (shown in Figure E2.4), the proportion of crashes occurred at dark remain the same before and after the roundabout installation (45% to 44.4%).

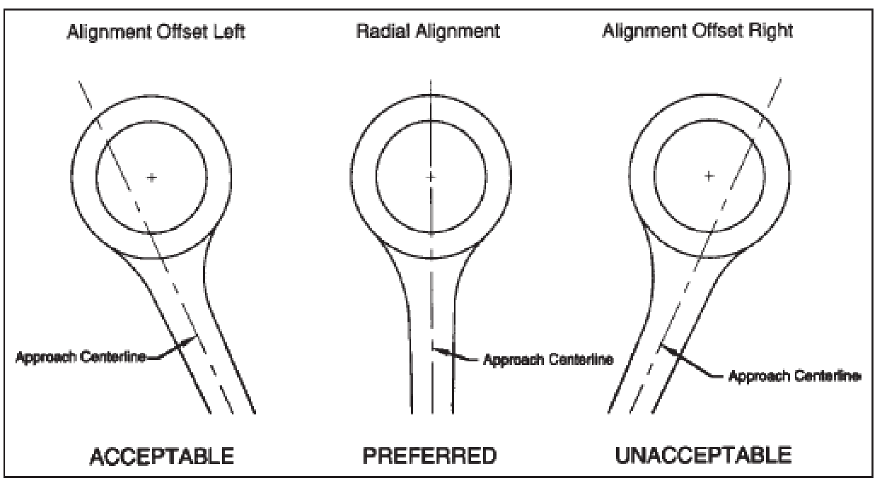

Figure E2.2

Offset design of approaching lane in a roundabout

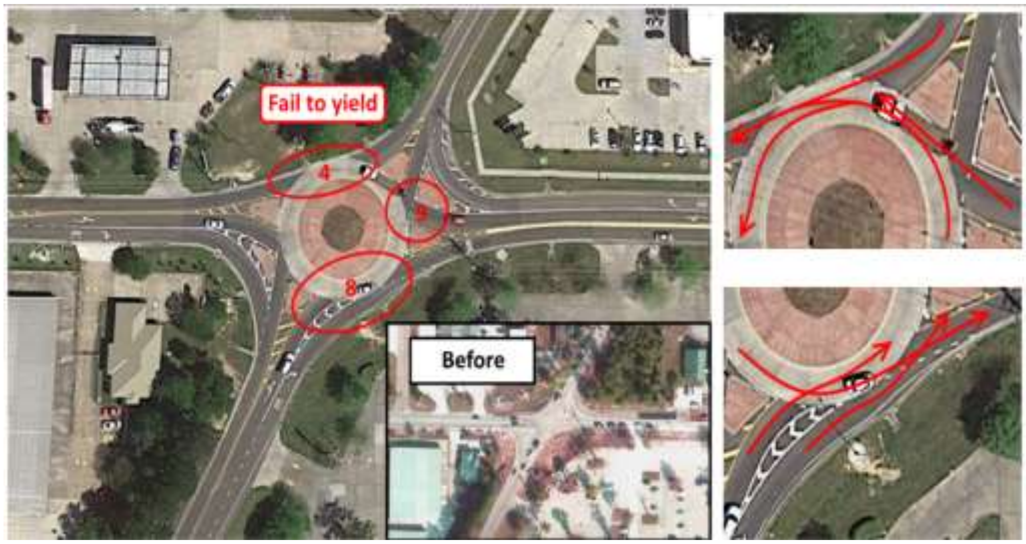

Figure E2.3

Conflicting when merge with alignment of LA 1091 at Brownswitch Rd. roundabout

Figure E2.4

Traffic light condition in LA 1091 at Brownswitch Rd. roundabout

Roundabout 3: LA 431 at LA 42

Previous control type: Stop on minor road
Speed limit: 15 mph
Number of approaches: 3 before, 3 after
Roadway Speed limit: 55 mph on LA 431 and 25 mph on LA 42.
Roundabout lighting condition: Yes

Figure E3.1

Before/after images of LA 431 at LA 42 roundabout

Table E3

Before/after crash information of LA 431 at LA 42 roundabout

Crash Type		**Intersection Crashes**	
		Before	**After**
Total Crash		26	9
Severity	Fatal	0	0
	Injury	8	1
	PDO	18	8
Manner of collision	Single Vehicle	7	2
	Rear-end	10	6
	Head-on	0	0
	Angle Crash	9	1
Lighting condition	Daytime	16	7
	Dark	10	2
Heavy Vehicle		0	1
Motorcycle		0	0
Alcohol/Drug		3	1
Distracted Driver		2	1

The safety of this intersection was improved after conversion to roundabout, with a small decrease in traffic volume (From 18,367 to 17,733 vehicles per day). From Table E3, the total crashes decreased sharply from 26 to 9 and the injury crashes also decreased from 8 to 1. All manner of collisions shows a decreasing trend. The traffic light was identified being installed very recently from Google Earth after 2016. With adequate illumination, the proportion of crashes occurred at dark not change.

Figure E3.2

Traffic light condition LA 431 at LA 42 roundabout

Roundabout 4: US 190 at LA 434

Previous control type: Stop on minor road
Speed limit: 15 mph
Number of approaches: 3 before, 3 after
Roadway Speed limit: 45 mph on US 190 and 45 mph on LA 434
Roundabout lighting condition: No

Figure E4.1

Before/after images of US 190 at LA 434 roundabout

Table E4

Before/after crash information of US 190 at LA 434 roundabout

Crash Type		**Intersection Crashes**	
		Before	**After**
Total Crash		10	6
Severity	Fatal	0	0
	Injury	2	0
	PDO	8	6
Manner of collision	Single Vehicle	0	3
	Rear-end	8	1
	Head-on	0	0
	Angle Crash	2	2
Lighting condition	Daytime	10	2
	Dark	0	4
Heavy Vehicle		0	1
Motorcycle		0	0
Alcohol/Drug		1	2
Distracted Driver		0	1

The safety of this intersection was improved after conversion to roundabout, with a 26% reduction in traffic volume (from 24,833 to 18,300 vehicles per day). The total crashes decreased from 10 to 6 and the injury crashes was eliminated as shown in Table E4. As no traffic light installed (in Figure E4.2), before roundabout construction, all 10 crashes occurred during daytime, but in after years 67% crashes occurred at dark. All the three single vehicle crashes at roundabout occurred at dark.

Figure E4.2

Traffic light condition in US 190 at LA 434 roundabout

Roundabout 5: LA 93 at St. Mary St. /LA 3168

Previous control type: Stop on minor road
Speed limit: 15 mph
Number of approaches: 4 before, 4 after
Roadway Speed limit: 45 mph on LA 93 and 40 mph on St. Mary St.
Roundabout lighting condition: Yes

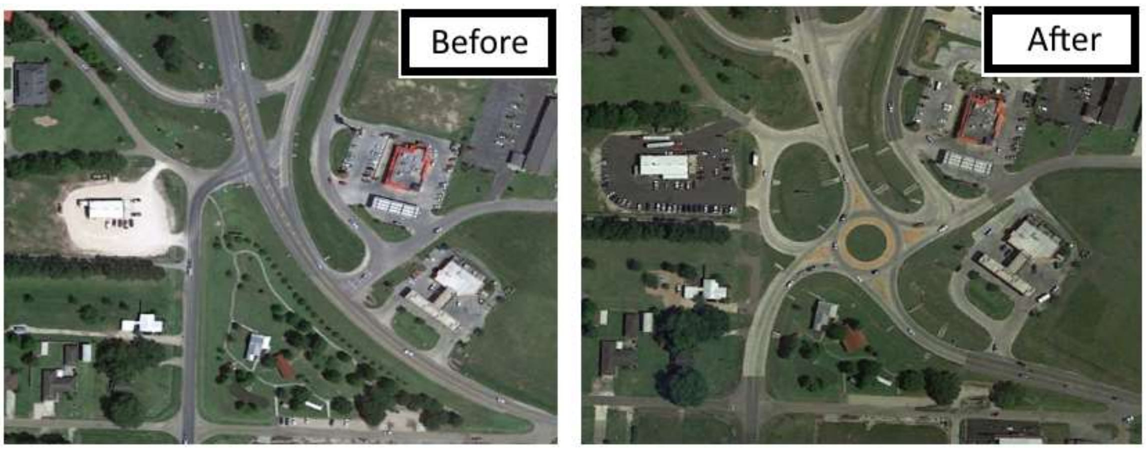

Figure E5.1

Before/after images of LA 93 at St. Mary St./LA 3168 roundabout

Table E5

Before/after crash information of LA 93 at St. Mary St./LA 3168 roundabout

Crash Type		**Intersection Crashes**	
		Before	**After**
Total Crash		35	10
Severity	Fatal	0	0
	Injury	9	3
	PDO	26	7
Manner of collision	Single Vehicle	3	2
	Rear-end	9	4
	Head-on	0	0
	Angle Crash	23	4
Lighting condition	Daytime	29	7
	Dark	6	3
Heavy Vehicle		5	3
Motorcycle		1	0
Alcohol/Drug		1	2
Distracted Driver		1	0

There was a small increase in traffic volume (from 11,617 to 12,100 vehicles per day). The total crashes decreased from 35 to 10 and the injury crash decreased from 9 to 3 as shown in

Table E5. In all type of crashes, it can be figured out a reducing trend. This roundabout has traffic light (in Figure E5.2), less crashes occurred at bad lighting condition were observed.

Figure E5.2

Traffic light condition in LA 93 at St. Mary St./LA 3168 roundabout

Roundabout 6: LA 428 at Mardi Gras Blvd.

Previous control type: Stop on minor road
Speed limit: 35 mph
Number of approaches: 4 before, 4 after
Roadway Speed limit: 35 mph on LA 428 and 15 mph on Mardi Gras Blvd.
Roundabout lighting condition: No

Figure E6.1

Before/after images of LA 428 at Mardi Gras Blvd. roundabout

Table E6

Before/after crash information of LA 428 at Mardi Gras Blvd. roundabout

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

The safety of this intersection was greatly improved. The traffic volume slightly decreased from 6,133 to 6,000 vehicles day. In Table E6, it shows the total crashes decreased from 43 to 4, with a sharply reduction of injury crashes from 24 to 4. The only single vehicle crash occurred at dark; all other manner of collisions meets a reduction. It can also be seen from Table E6 that the angle crash decreased from 42 to 2. This intersection used to be a quite wide intersection due to the boulevard, which can produce more angle crash. However, after converting to roundabout intersection, at about 300 feet before entering the roundabout from northbound and south bound on LA 428, the number of lanes merged from two to one (in Figure 6.2). This merge lane avoids constructing a multiple lane roundabout and significantly reduced the number of conflicting points in this intersection.

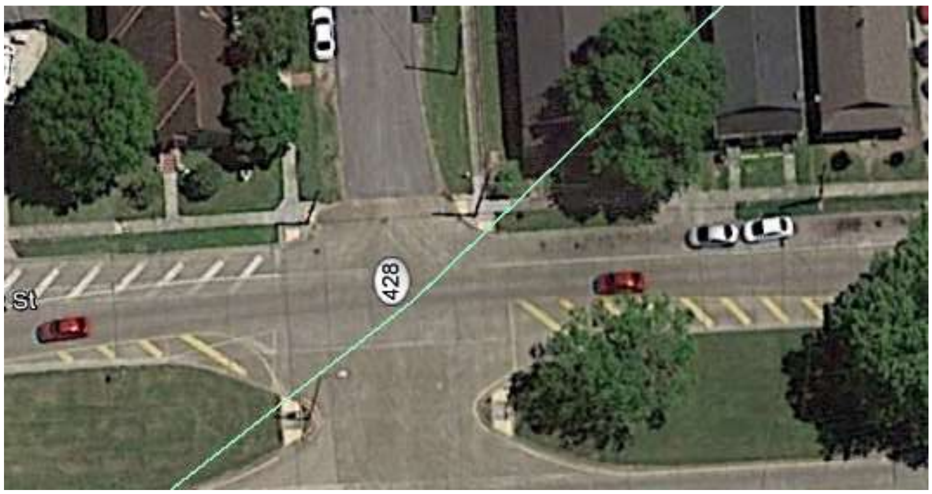

Figure E6.2

Lane merged before entering LA 428 at Mardi Gras Blvd. roundabout

In this intersection, there is no illumination facility for roundabout, but the approaches have continuous traffic light (in Figure E6.3). In the FHWA research, the guide book also mentions the illumination requirement in roundabout. To ensure the road users can be able to perceive the general layout and operation condition in the intersections, and they have enough to make appropriate maneuvers, adequate lighting should be provided at all roundabouts. However, for different land use, the requirement varies. For intersections in suburban area, if one or more approaches are illuminated, or an illuminated vicinity might make the road users distracted, the adequate lighting is necessary.

Figure E6.3

Traffic light condition in LA 428 at Mardi Gras Blvd. roundabout

Roundabout 7: E. Milton Ave. at Bonin Rd.

Previous control type: Stop on minor road
Assigned speed limit: 15 mph
Number of approaches: 4 before, 4 after
Roadway Speed limit: 45 mph on E. Milton Ave. and 45 mph on Bonin Rd.
Roundabout lighting condition: Yes

Figure E7.1

Before/after images of E. Milton Ave. at Bonin Rd. roundabout

Table E7

Before/after crash information of E. Milton Ave. at Bonin Rd. roundabout

Crash Type		Intersection Crashes	
		Before	After
Total Crash		10	8
Severity	Fatal	0	0
	Injury	3	2
	PDO	7	6
Manner of collision	Single Vehicle	2	2
	Rear-end	1	4
	Head-on	0	0
	Angle Crash	7	2
Lighting condition	Daytime	7	5
	Dark	3	3
Heavy Vehicle		0	0
Motorcycle		0	0
Alcohol/Drug		1	1
Distracted Driver		0	1

Total crash reduction from 10 to 8 was observed in this roundabout. There was a small increase in AADT (9,433 to 9,500 vehicles per day). It can be figured out from Figure E7.1 that the access management is much better after construction of roundabout. A new access road was built connecting the roundabout and nearest community area. This action redistributed the traffic volume on E. Milton Ave. and helped to diminishing the radius of curve in the previous intersection. However, after converting to roundabout, the road user of E. Milton Ave. need to yield if there exists traffic in the intersection. The following vehicle might not have this attention, because the drivers did not need to slow down in previous years. This can be the reason of increased rear-end collision. With adequate illumination (in Figure E7.2), no increasing of crash occurred at dark is observed.

Figure E7.2

Traffic light condition in LA 428 at E. Milton Ave. at Bonin Rd. roundabout

Roundabout 8: Lafayette St./LA 89 at Iberia St./LA 92

Previous control type: Stop on minor road
Speed limit: 15 mph
Number of approaches: 3 before, 4 after
Roadway Speed limit: 45 mph on LA 92 and 20 mph on LA 89
Roundabout lighting condition: Yes

Figure E8.1

Before/after images of Lafayette St./LA 89 at Iberia St./LA 92 roundabout

Table E8

Before/after crash information of Lafayette St./LA 89 at Iberia St./LA 92 roundabout

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

The total crashes rose from 6 to 8 in this roundabout, but the injury crash was eliminated. There was a 25% increase in traffic volume (from 18,300 to 22,833 vehicles per day). More crashes occurred at bad lighting condition were observed, and all the three single vehicle crashes happened at dark. However, as identified from the latest Google Earth street view (Feb. 2017), new traffic light has already installed in this location as shown in Figure E8.2.

Figure E8.2

Traffic light condition in Lafayette St./LA 89 at Iberia St./LA 92 roundabout

Roundabout 9: Hector Connoly Rd. @ E. Angelle St.

Previous control type: Stop on minor road
Speed limit: 15 mph
Number of approaches: 3 before, 4 after
Roadway Speed limit: 35 mph on Hector Connoly Rd.
Roundabout lighting condition: Yes

Figure E9.1

Before/after images of Hector Connoly Rd. at E. Angelle St. roundabout

Table E9

Before/after crash information of Hector Connoly Rd. @ E. Angelle Rd. roundabout

Crash Type		**Intersection Crashes**	
		Before	**After**
Total Crash		0	5
Severity	Fatal	0	1
	Injury	0	1
	PDO	0	3
Manner of collision	Single Vehicle	0	1
	Rear-end	0	2
	Head-on	0	2
	Angle Crash	0	0
Lighting condition	Daytime	0	3
	Dark	0	2
Heavy Vehicle		0	0
Motorcycle		0	1
Alcohol/Drug		0	1
Distracted Driver		0	1

In this location, roundabout was installed in 2012, accompanied with a new shopping center construction in the same year, which caused an increase in AADT (from 13,000 to 13,500 vehicles per day). Five crashes were observed after roundabout construction. One fatal crash occurred after converting to roundabout, motorcycle run out of road and occurred at dark (See crash diagram Figure E9.2). This roundabout has adequate illumination (in Figure E9.4)

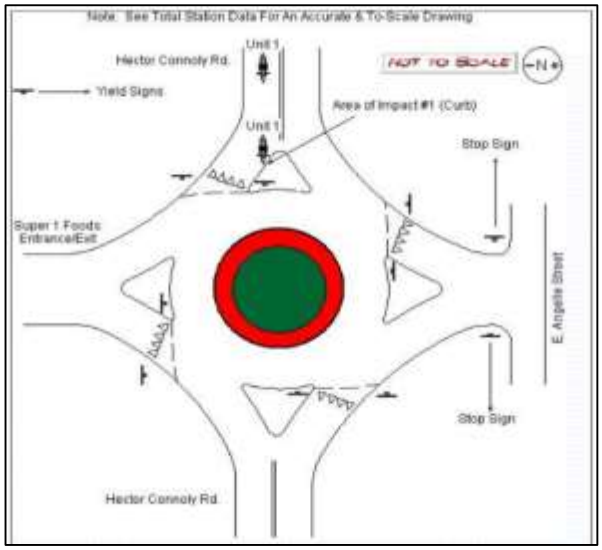

Figure E9.2

Crash diagram of fatal motorcycle crash in after years at Hector Connoly Rd. at E. Angelle St. roundabout

The deep skid marks show in Figure E9.3 on the eastbound indicates the inappropriate alignment design for right turn road users on Hector Connoly Road. A project was undergoing to narrow the flare at the eastbound and westbound entrance of this roundabout.

Figure E9.3

Skid marks on eastbound Hector Connoly Rd. at E. Angelle St. roundabout

Figure E9.4

Traffic light condition in Hector Connoly Rd. at E. Angelle St. roundabout

Roundabout 10: E. Fairfield Dr. at S. Morgan Ave.

Previous control type: Stop on minor road
Speed limit: 15 mph
Number of approaches: 3 before, 4 after
Roadway Speed limit: 45 mph on E. Fairfield Drive and 40 mph on S. Morgan Avenue
Roundabout lighting condition: No

Figure E10.1

Before/after images of E. Fairfield Dr. at S. Morgan Ave. roundabout

Table E10

Before/after crash information of E. Fairfield Dr. at S. Morgan Ave. roundabout

Crash Type		**Intersection Crashes**	
		Before	**After**
Total Crash		0	3
Severity	Fatal	0	0
	Injury	0	0
	PDO	0	3
Manner of collision	Single Vehicle	0	2
	Rear-end	0	0
	Head-on	0	0
	Angle Crash	0	1
Lighting condition	Daytime	0	0
	Dark	0	3
Heavy Vehicle		0	0
Motorcycle		0	0
Alcohol/Drug		0	1
Distracted Driver		0	0

This is a roundabout locating in a residential community area. The traffic volume is relatively low; it increased from 6,555 to 6,997 vehicles per day. Three crashes observed after roundabout installation. The below-standard traffic sign and pavement markings (Figure E10.2) presumably contributed to the increase in PDO crashes. All three increased crashes occurred at dark, as no traffic light installed in the location (in Figure E10.3).

Figure E10.2

Below standard signs and absence of pavement marking at E. Fairfield Dr. at S. Morgan Ave. roundabout

Figure E10.3

Traffic light condition in E. Fairfield Dr. at S. Morgan Ave. roundabout

Roundabout 11: LA 327/ River Rd. at LA 327/ Gardere Rd.

Previous control type: Stop on minor road
Speed limit: 15 mph
Number of approaches: 3 before, 4 after
Roadway Speed limit: 45 mph on Gardere Rd. and 30 mph on River Rd.
Roundabout lighting condition: Yes

Figure E11.1

Before/after images of LA 327/ River Rd. at LA 327/ Gardere Rd. roundabout

This roundabout eliminates all three crashes before installation. The traffic volume increased 14.5% (from 6,897 to 7,900 vehicles per day). This roundabout is close to the L'Auberge Casino and Hotel, which is normally open until midnight, and the traffic lights were installed as shown in Figure E11.2. No crash occurred at night after converting to roundabout in three years.

Table E11

Before/after crash information of LA 327/ River Rd. at LA 327/ Gardere Rd. roundabout

Crash Type		Intersection Crashes	
		Before	After
Total Crash		3	0
Severity	Fatal	0	0
	Injury	1	0
	PDO	2	0
Manner of collision	Single Vehicle	2	0
	Rear-end	0	0
	Head-on	0	0
	Angle Crash	1	0
Lighting condition	Daytime	1	0
	Dark	2	0
Heavy Vehicle		0	0
Motorcycle		0	0
Alcohol/Drug		0	0
Distracted Driver		0	0

Figure E11.2

Traffic light condition in LA 327/ River Rd. at LA 327/ Gardere Rd. roundabout

Roundabout 12: E. Milton Ave./LA 92 @ Chemin Metairie Rd.

Previous control type: Stop on minor road
Speed limit: 15 mph (East/West bound); 25 mph (North/South bound)
Number of approaches: 3 before, 4 after
Roadway Speed limit: 35 mph on E. Milton Avenue and 35 mph on Chemin Metairie Road
Roundabout lighting condition: No

Figure E12.1

Before/after images of E. Milton Ave./LA 92 at Chemin Metairie Rd. roundabout

Table E12

Before/after crash information of E. Milton Ave./LA 92 at Chemin Metairie Rd. roundabout

Crash Type		Intersection Crashes	
		Before	After
Total Crash		1	19
Severity	Fatal	0	0
	Injury	0	3
	PDO	1	16
Manner of collision	Single Vehicle	0	4
	Rear-end	0	7
	Head-on	0	0
	Angle Crash	1	8
Lighting condition	Daytime	1	9
	Dark	0	10
Heavy Vehicle		0	0
Motorcycle		0	3
Alcohol/Drug		0	2
Distracted Driver		0	2

This roundabout was built when the Chemin Meterie extension to the south was constructed. It was not built for a crash countermeasure. This roundabout serves as a major gateway to Youngsville that was a very upcoming town at the time of the extension project and has been booming since then. The land use surrounding the intersection underwent a huge transformation—from a rural area with lots of open fields to a suburban area with packed residential and commercial development as show in Figure E12.2. The AADT on LA 92 increased from 10,702 to 11,469, there is no reliable data on the traffic volume on Chemin Meterie that has been changed from a minor roadway to a collector linking Youngsville to a new major arterial roadway in Lafayette. The area transformation, the AADT increase and intersection layout change are mainly responsible for the crashes increase (from 1 to 19 in the first 3 years.) As mentioned by an engineer in District 3, this roundabout was not installed as a countermeasure to fix the crash problem.

In Table E12, crashes occurred at the dark increased from 0 to 10, including 4 single vehicle crashes, with no traffic light installed (in Figure E12.4). The enormous land use change can also contribute to the increase of crashes. The city has extended its urban scale, and also the population increased 103% from 2000 to 2010 [11]. Prior to the conversion of this three-leg intersection to roundabout, this location was a rural two-lane road intersected with a local road surrounded by sugarcane farms, which had very limited traffic volume. A new shopping area constructed at the same year with roundabout. Because the different speed limit before entering the roundabout at east/west bound is different from north/south bound, the road users heading east/west bound was identified to be responsible for 14 crashes, and figure E12.3 shows 13 of 14 east/west bound road users at fault crashes (1 crash report is not available).

Figure E12.2

Before/after comparison at E Milton Ave./LA 92 at Chemin Metairie Rd. roundabout

Figure E12.3

East/west bound road user at fault crashes at E Milton Ave./LA 92 at Chemin Metairie Rd. roundabout

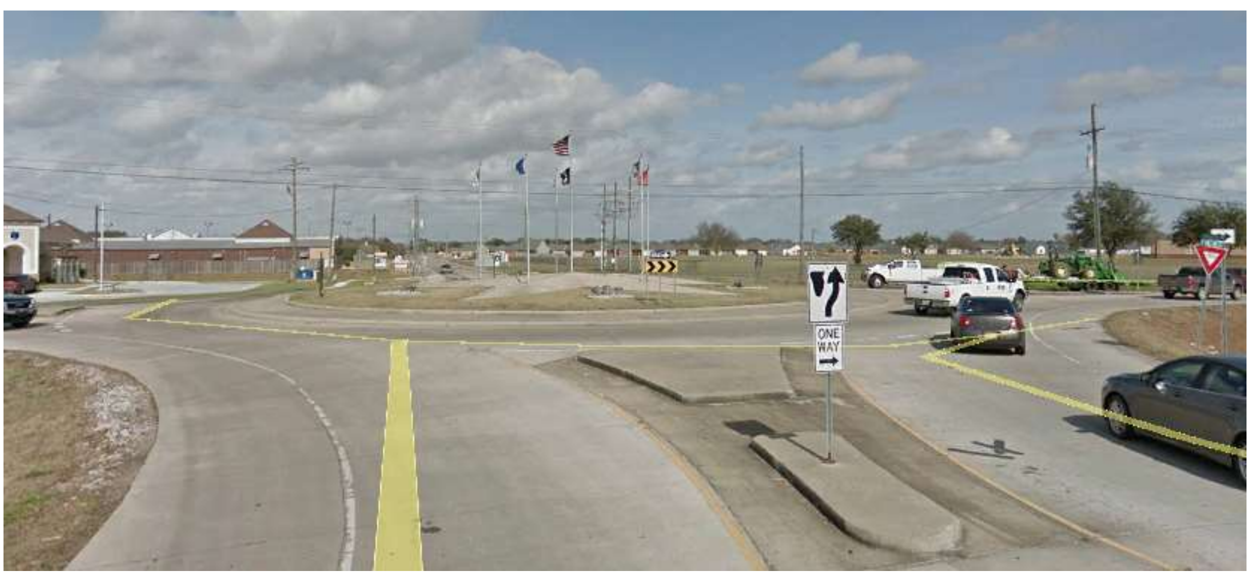

Figure E12.4

Traffic light condition in E Milton Ave./LA 92 at Chemin Metairie Rd. roundabout

Roundabout 13: Chemin Metairie Pkwy. at Viaulet Rd.

Previous control type: Stop on minor road
Speed limit: 15 mph
Number of approaches: 3 before, 4 after
Roadway Speed limit: 40 mph on Viaulet Rd.
Roundabout lighting condition: No

Figure E13.1

Before/after images of Chemin Metairie Pkwy. at Viaulet Rd. roundabout

Table E13

Before/after crash information of Chemin Metairie Pkwy. at Viaulet Rd. roundabout

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

This roundabout is located in a very rural area, with really low traffic volume (800 vehicles per day). The crash severity decreased after construction of roundabout.

Roundabout 14: E. Milton Ave./LA 92 at Verot School Rd./LA 339
Previous control type: All way stop
Speed limit: 15 mph
Number of approaches: 4 before, 4 after
Roadway Speed limit: 45 mph on E. Milton Ave. and 45 mph on Verot School Rd.
Roundabout lighting condition: No

Figure E14.1

Before/after images of E. Milton Ave./LA 92 at Verot School Rd./LA 339 roundabout

Table E14

Before/after crash information of E. Milton Ave./LA 92 at Verot School Rd./LA 339 roundabout

Crash Type		**Intersection Crashes**		
		Before	**After**	**After-after**
Total Crash		34	37	28
Severity	Fatal	0	0	0
	Injury	8	8	1
	PDO	26	29	27
Manner of collision	Single Vehicle	4	6	5
	Rear-end	18	24	18
	Head-on	0	0	0
	Angle Crash	12	7	5
Lighting condition	Daytime	24	19	22
	Dark	10	18	6
Heavy Vehicle		1	6	0
Motorcycle		0	2	0
Alcohol/Drug		2	4	0
Distracted Driver		2	5	2

This intersection has the highest traffic volume, which reduced from 40,533 to 35,033 vehicles per day after converting to roundabout. As a result of low traffic capacity in this intersection, the queue length in this intersection is much longer than in any other roundabouts. One project, started from November 2015 (Project No. H.005508.6), is undergoing to change Verot School Road from two-lane to four-lane. In this case, researchers boarded the radius from 500 feet to 2,000 ft. for searching all crash reports, and found several crashes more than 1,000 ft. distance away from the roundabout center, but still related to the roundabout. From Table E14, the total crashes slightly increased to 37. Crashes occurred at dark increased from 10 to 18, whereas single vehicle crashes increased from 4 to 6. In after-after years (2015-2016), the crashes reduced to 28. As the ongoing project, the traffic was slow down and controlled manually. Less proportion of crashes occurred at dark though this roundabout has no traffic light installed (in Figure E14.3).

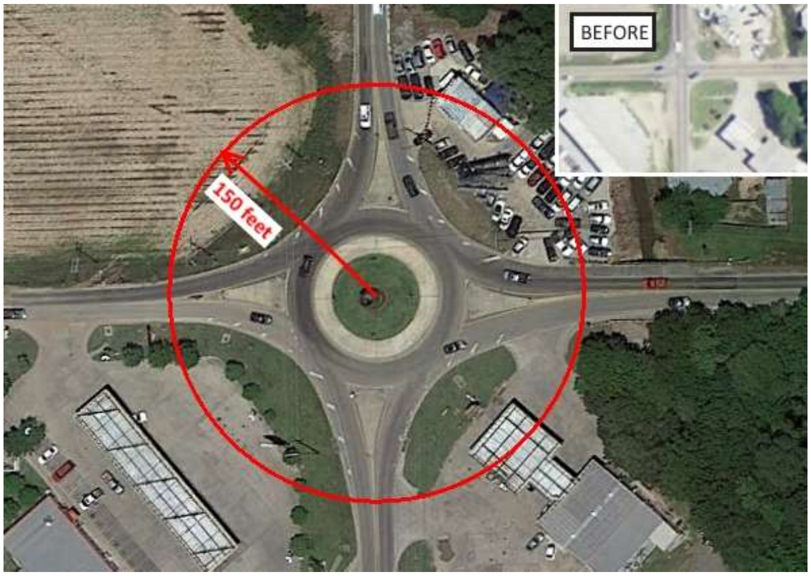

Figure E14.2

All accesses are within 150 ft. from center of E. Milton Ave./LA 92 at Verot School Rd./LA 339 roundabout

A number of accesses were found within 150 feet from center of roundabout (Figure E14.2). In total, 11 heavy vehicle drivers were involved in crashes occurred in this location, and 6 of them were responsible for the crashes. Figure E14.4 presents the 11 heavy vehicle involved crashes, 5 are large vehicles crashed on small vehicles; 5 are small vehicles crashed on large vehicles; 1 is between large vehicles. Among the 6 heavy vehicle driver at fault crashes, 1 is angle crash and 5 are rear-end collision.

Figure E14.3

Traffic light condition in E. Milton Ave./LA 92 at Verot School Rd./LA 339 roundabout

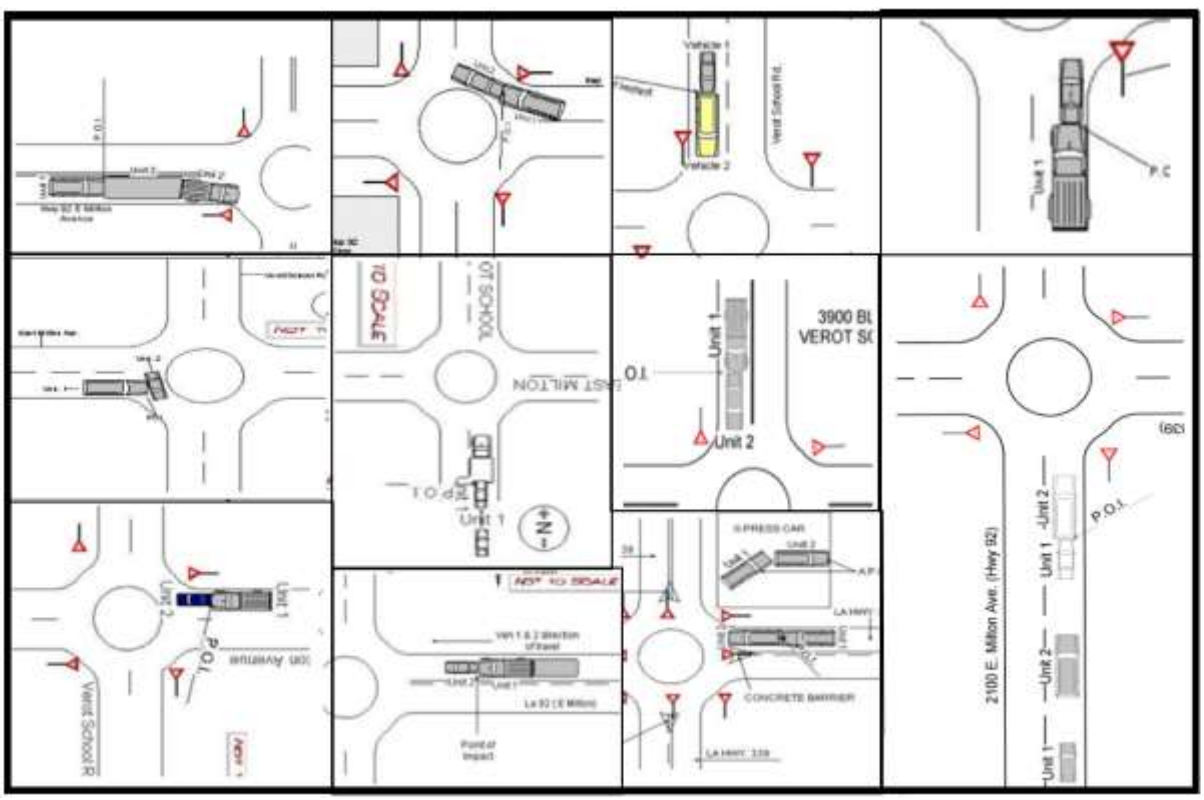

Figure E14.4

Heavy vehicles involved crash during after years E. Milton Ave./LA 92 at Verot School Rd./LA 339 roundabout

Roundabout 15: Gloria Switch Rd./LA 98 @ LA 93

Previous control type: All way stop
Assigned speed limit: 15 mph
Number of approaches: 4 before, 4 after
Roadway Speed limit: 45 mph on Gloria Switch Rd. and 40 mph on LA 93
Roundabout lighting condition: No

Figure E15.1

Before/after images of Gloria Switch Rd./LA 98 @ LA 93 roundabout

Table E15

Before/after crash information of Gloria Switch Rd./LA 98 @ LA 93 roundabout

Crash Type		Intersection Crashes	
		Before	After
Total Crash		18	14
Severity	Fatal	0	1
	Injury	5	3
	PDO	13	10
Manner of collision	Single Vehicle	5	10
	Rear-end	5	3
	Head-on	1	0
	Angle Crash	7	1
Lighting condition	Daytime	13	7
	Dark	5	7
Heavy Vehicle		1	0
Motorcycle		1	2
Alcohol/Drug		2	3
Distracted Driver		4	2

The traffic volume increased from 22,400 to 23,767 vehicles per day. The injury crashes reduced from 5 to 3, and one fatal crash observed after this intersection converted to roundabout. This fatal crash is one motorcycle running out of roadway and crash with the central island. This fatal crash occurred at dark. This intersection does not have any traffic light (in Figure E15.3) and the approaching tangent on Gloria Switch Road is as long as 5 miles, which potentially result in single vehicle crash at bad lighting condition. The proportion of crashes occurred at dark increased from 28% to 50%, and proportion of single vehicle crashes increased from 28% to 71%, with 8 out of 10 single vehicle crashes occurred at dark in total (listed in Figure E15.2).

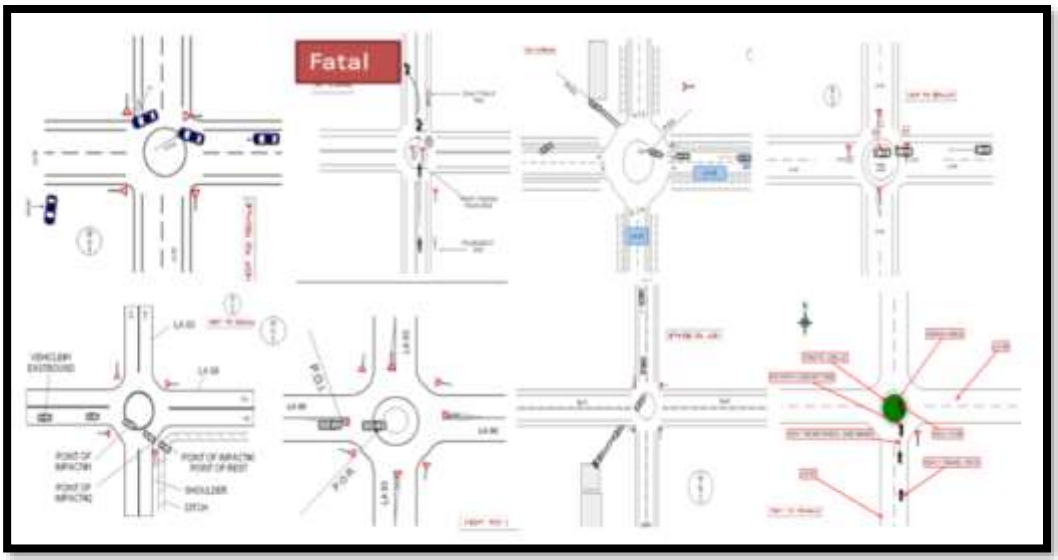

Figure E15.2

Nighttime single vehicle crashes at Gloria Switch/LA 98 @ LA 93 roundabout (including one fatal crash)

Figure E15.3

Traffic light condition in Gloria Switch/LA 98 @ LA 93 roundabout

Roundabout 16: Bonin Rd. at Fortune Rd.

Previous control type: All way stop
Speed limit: 25 mph
Number of approaches: 4 before, 4 after
Roadway Speed limit: 45 mph on Fortune Rd. and 40 mph on Bonin Rd.
Roundabout lighting condition: No

Figure E16.1

Before/after images of Bonin Rd. at Fortune Rd. roundabout

Table E16

Before/after crash information of Bonin Rd. at Fortune Rd. roundabout

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

The traffic volume (7,277 vehicles per day) did not change before and after installation of roundabout. The total crashes increased from 6 to 8 (from Table E16), but the injury crashes were eliminated after converting to roundabout. Without traffic light (shown in Figure

E16.2), the proportion of bad lighting condition related crashes rose from 33% to 50%. The inappropriate access management (shown in Figure E16.3) also considered to be the reason for increased angle crashes from 3 to 5.

Figure E16.2

Traffic light condition in Bonin Rd. at Fortune Rd. roundabout

Figure E16.3

Accesses within 150 ft. from center of Bonin Rd. at Fortune Rd. roundabout

Roundabout 17: LA 3158 at Old Covington Hwy.

Previous control type: All way stop
Speed limit: 25 mph
Number of approaches: 4 before, 4 after
Roadway Speed limit: 55 mph on LA 3158 and 45 mph on Old Covington Hwy.
Roundabout lighting condition: No

Figure E17.1

Before/after images of LA 3158 at Old Covington Hwy. roundabout

Table E17

Before/after crash information of LA 3158 at Old Covington Hwy. roundabout

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. In Table E17, the total crashes increased from 8 to 23 after converted to roundabout. The fatal crash was eliminated in the first three years (2011-2013) operation of roundabout, but observed again during after-after years' period (from 2014 to 2016). The injury crashes show the continue 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).
Without traffic light installment (shown in Figure 17.2), the proportion of crashes occurred at dark increased sharply from the proportion of crashes occurred at dark keep increasing from 38% to 39% to 60%.

In FHWA roundabout guild book, in the rural area, illumination is not mandatory since if no power supply nearby, the provision of lighting is unnecessary costly. However, in this case, the roundabout should be well signed to provide precise information at night. In the guide book, Section 7.3.1.3, it says "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." The flashing warning light was installed (in Figure E17.5), and this is the only intersection that installed flashing warning light before approaching roundabout. But it still not enough for reducing the bad lighting condition related crashes, due to the crash data before and after roundabout construction.

All the 9 single vehicle crashes occurred at dark during 2011 to 2013, as listed in Figure 17.3. The fatal crash observed during 2014 to 2016 shown in Figure E17.4, where a motorcycle run out of roadway and crash on the roundabout central island, occurred at dark. Exclude the fatal crash, other 7 crashes occurred at dark during after-after years.

Figure E17.2

Traffic light condition at LA 3158 at Old Covington Hwy. roundabout

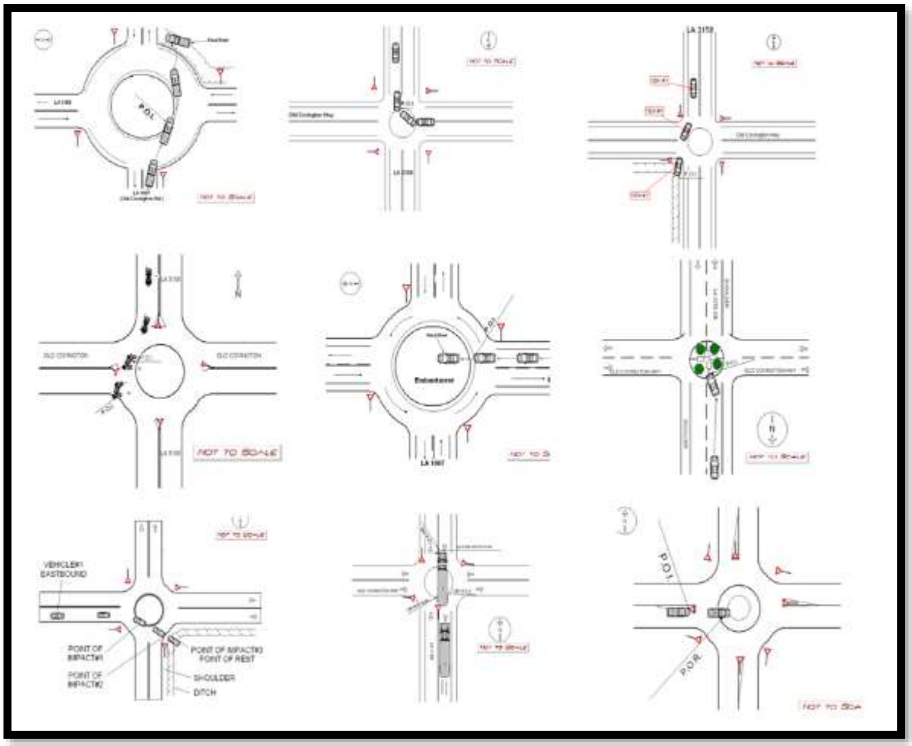

Figure E17.3

Nine single vehicle crashes at LA 3158 at Old Covington Hwy. roundabout during 2011 to 2013

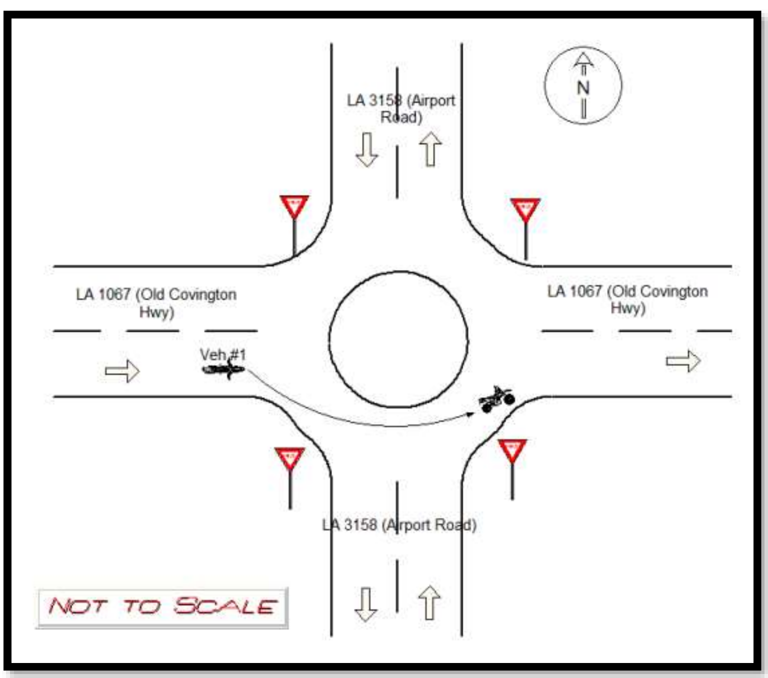

Figure E17.4

Fatal single vehicle crashes in 2015 at LA 3158 at Old Covington Hwy. roundabout

Figure E17.5

Flashing warning light in LA 3158 at Old Covington Hwy.

Roundabout 18: LA 406 at LA 407

Previous control type: All way stop
Speed limit: 15 mph
Number of approaches: 3 before, 3 after
Roadway Speed limit: 45 mph on LA 406 and 45 mph on LA 407
Roundabout lighting condition: No

Figure E18.1

Before/after images of LA 406 at LA 407 roundabout

Table E18

Before/after crash information of LA 406 at LA 407 roundabout

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

The traffic volume increased from 20,833 to 22,500 after converted to roundabout. The total crashes did not change, and one more injury crash was observed after converted to roundabout.

The traffic light was only installed for road user on LA 407 when entering and exiting the roundabout, however, for road users on LA 406, no traffic light was installed yet (Figure E18.2). The two at dark crashes all occurred at LA 406. However, according to the FWHA research, for the intersection in suburban area, if one or more approaches are illuminated, or an illuminated vicinity might make the road users distracted, the adequate lighting is necessary.

Figure E18.2

Traffic light condition in LA 406 at LA 407 roundabout

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