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Four-Lane to Five-Lane Urban Roadway Conversions for Safety

XIAODUAN SUN,[1] SUBASISH DAS,[2] NICHOLAS FRUGE,[3]
RONALD L. BERTINOT,[3] AND DANIEL MAGRI[4]

[1]Civil Engineering Department, University of Louisiana at Lafayette, Lafayette, Louisiana, USA
[2]Civil Engineering, University of Louisiana at Lafayette, Lafayette, Louisiana, USA
[3]District 3, Louisiana Department of Transportation and Development, Lafayette, Louisiana, USA
[4]Safety Division, Louisiana Department of Transportation and Development, Baton Rouge, Louisiana, USA

Undivided roadways have consistently exhibited low safety performance, particularly in urban or suburban areas where roadside development is relatively intense. Changing a four-lane undivided road to a divided roadway by either building a boulevard cross-section or installing a physical barrier is a desirable option to improve safety performance of an undivided roadway, but it requires significant resources. This article introduces a crash countermeasure successfully implemented on two different segments of undivided roadways in Louisiana. This crash countermeasure is to change an undivided four-lane roadway to a five-lane roadway with a center lane for left turns by restriping pavement markings without increasing pavement width. Although the five-lane roadway is no longer an acceptable roadway type in Louisiana, the impressive crash reductions on both roadway segments demonstrate it is a feasible solution under constrained conditions. Based on the statistical analysis with 6 years of crash data (3 years before and 3 years after excluding the implementation year), the crash modification factors for both roadways are estimated to be less than 0.5 with a standard deviation less than 0.07. Although it is not surprising to see the biggest crash reduction comes from the rear-end collisions, the other types of collision are also reduced.

Keywords undivided roadways, safety analysis, crash countermeasure, crash modification factor (CMF)

1. Introduction

The Louisiana Strategic Highway Safety Plan is to reach Destination Zero Death on Louisiana roadways. This tall order calls for all feasible crash countermeasures to be implemented. A great number of crash countermeasures have been identified by various representative documents in recent years such as the *Highway Safety Manual* (*HSM*;

Address correspondence to Xiaoduan Sun, Civil Engineering Department, University of Louisiana at Lafayette, 104 University Circle, Lafayette, LA 70504, USA. E-mail: xsun@louisiana.edu

American Association of State Highway and Transportation Officials [AASHTO], 2010), *Countermeasures that Work* from the National Highway Transportation Safety Administration (National Highway Traffic Safety Administration [NHTSA], 2009), and the Crash Modification Factor Clearinghouse (CMF Clearing House, 2011). The effectiveness of many crash countermeasures have been quantified by scientific methodologies.

Undivided highways have consistently exhibited low safety performance, particularly in urban or suburban areas where driveway density is relatively high. Although rural two-lane highways experience the highest traffic fatality rate (fatalities per 100 million vehicle-mile-traveled [VMT]), undivided highways have the overall highest total crash rate (crashes per million VMT) and crash injury rate (crash injuries per million VMT) in the United States (Federal Highway Administration [FHWA], 2011). A high proportion of the crashes are rear-end collisions on this type of roadway. The undivided multilane roadway presents a common type of roadway in urban and rural areas. In Louisiana, there are 1,530 miles of undivided multilane roadways, and most of them are four-lane highways on the Louisiana Department of Transportation and Development System (LADOTD). Ninety-three percent of these roadways are in urban and suburban areas. Installing physical separation either by barrier or by green space (boulevard) has been the most recommended crash countermeasure for the problem. With sufficient pavement width, a four-lane undivided highway can also be easily changed to a five-lane roadway with the center lane for left turns, which expectedly reduces rear-end collisions. This option, even though it is the least expensive one, is less desirable based on past experiences with five-lane roadway operations in many urban and suburban areas. Louisiana has established policies discouraging five-lane roadway design in constructing new roads and seldom considers it as an option in reducing crashes on undivided multilane roadways.

2. Literature Review

Under exactly the same conditions such as traffic volume, driveway type and density, lighting and parking, which roadway (four-lane undivided vs. five-lane roadway) is safer? Although roadway users generally prefer five-lane layout to four-lane undivided roadway for convenience, the answer to the question should come from crash data analysis. However, there is no CMF listed in the first edition of the *HSM* (AASHTO, 2010) for converting four-lane undivided urban roadway to five-lane roadway, and to our knowledge no before-and-after studies have been conducted in the last decade on the impact of such conversions.

However, there are some design documents concerning four-lane to five-lane options. The *Minnesota Statewide Urban Design and Specifications* (2010) lists the crash rate of 6.75 for four-lane undivided roadway and 4.01 for five-lane with center turn lane. A National Cooperative Highway Research Program (NCHRP) report published 25 years ago stated that conversion from a four-lane undivided cross section to a five-lane two way left turn lane (TWLTL) cross section with narrower lanes reduced accident rates, on the average, by 45% (Harwood, 1986).

Although little documentation was found on four-lane to five-lane conversion, there have been lots of projects throughout the United States converting four-lane to three-lane roadway (one lane in each direction with a center turn lane) for many years in the past for the benefits of safety particularly the safety of pedestrians and cyclists on urban and suburban areas. This conversion is also called "road diet." As mentioned in several documentations, this conversion is suitable for annual average daily traffic (AADT) less than 20,000 (FHWA, 2010) or for peak-hour traffic volume less than 1,750 (Iowa Department of Transportation,

2012). The case studies summarized by Knapp et al. (2003) show a consistent improvement on highway safety from 21 roadways in seven states with AADT from 8,400 to 24,000. Another important factor in consideration is access density or access spacing. As pointed out by a Minnesota study, three-lane roadway is suitable for high access density under AADT less than 20,000 (Byers & Drager, 2011).

FHWA CMF clearinghouse has one CMF for adding TWLTL to the major approach of an unsignalized three-leg intersection but does not have CMF for roadway segment conversion (CMF Clearing House, 2012).

3. Study Objects

South College Road, part of a state route named LA3025, experienced the typical safety problems of undivided multilane roadways. It is located inside the city of Lafayette and is functioning as an arterial street. With an annual average daily traffic (AADT) around 28,000 in 2009, the majority of vehicles on the segment are through traffic. There are more than 30 driveways connecting to doctor offices and small residential areas. Three signalized intersections are located within this segment. The two signalized intersections in the middle of the segment are only 150 feet apart, and their signal timing is designed in tandem, functioning as one signalized intersection, whereas the other is a T-intersection with a constant green indication for westbound through vehicles on South College and a ban on left turns from the side street onto South College. The total length of this segment is about 1.3 miles. The crash rates computed as crashes per million VMT for this roadway segment in the 3 years prior to the restriping project were 8.49, 9.90, and 11.74,
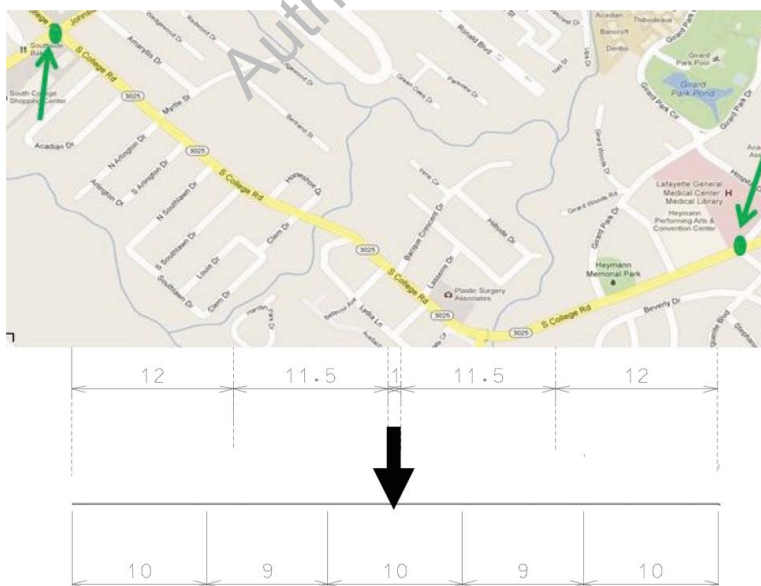

Figure 1. South College Road layout and lane configuration before and after the project (dimensions in feet). (Color figure available online.)

respectively. The high number of crashes on this road segment had been a problem for some time.

In 2003, instead of waiting for available funds to implement the desirable solutions, The LADOTD District 3 office restriped this segment of LA3025, changing it from the four-lane undivided roadway to the five-lane roadway with center lane for left-turning vehicles. The layout of the segment and lane configurations before and after the project are shown in Figure 1.

Encouraged by the huge crash reduction on S. College Road 3 years after the restriping project, the district office of LADOTD applied the exact same solution on LA182 in 2007. This one-mile segment on LA182 is located in Opelousas, a small city about 20 miles north of Lafayette. Passing through a suburban area with low population density, this segment is under a slightly different environment with AADT around 22,000 in 2009, about 28% smaller than the one on S. College Road but with the same safety problems. There are more than 50 driveways connecting to various businesses, such as small retail stores, fast food restaurants, a gas station, and residential areas. Two signalized intersections are located within this segment. The crash rates for this roadway segment in the 3 years prior to the restriping project were 8.08, 9.69, and 6.62, respectively. The layout and lane configuration before and after the restriping project are shown in Figure 2.

The number of crashes and crash rates before and after the restriping projects are listed in Table 1. These crashes occurred between the two ends of the segments. The speed limit remained the same on S. College road before and after the project implementation. However, the speed limit on the 0.44 miles of roadway on the south end of LA 182 segment (44% of the segment) was reduced from 50 mph to 45 mph after the restriping project.

The similar and very impressive results from both roadways deserve a further analysis to quantify the safety impact with reliable statistical methods and to investigate the crash
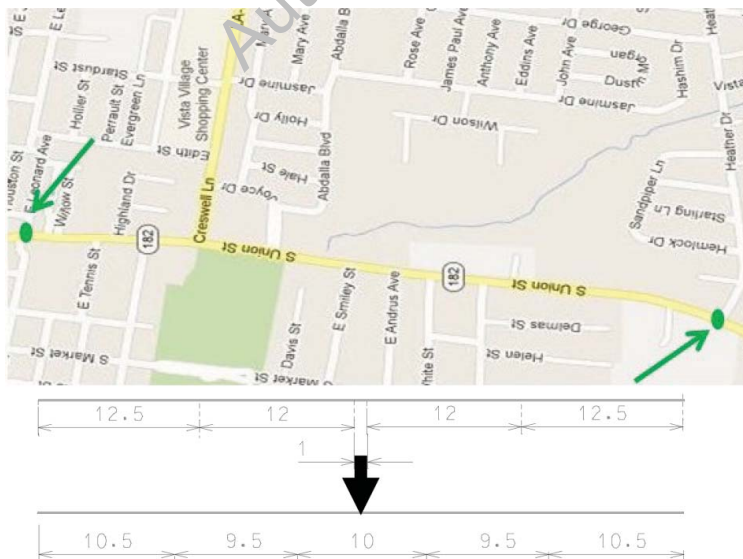

Figure 2. LA 182 layout and lane configuration before and after the project (dimensions in feet). (Color figure available online.)

Table 1

Crash reduction summary

	Before 2000–2002 for LA 3025; 2004–2006 for LA 182		After 2004–2006 for LA 3025; 2008–2010 for LA 182		Percentage Change	
	Crashes	Average Crash Rate of 3 years	Crashes	Average[a] Crash Rate of 3 years	Crashes	Crash Rate
LA 3025	358	10.05	147	4.59	–59%	–54.3%
LA 182	178	8.12	85	3.53	–52%	–51.3%

[a]Calculated as total number of crashes per million vehicle-mile-traveled.

characteristics before and after the projects because many other sites have been identified to have the same treatment. The crash data used are from the state crash reporting system at LADOTD. After careful evaluation of the data, it was determined to use the total crashes for the analysis, including crashes identified as intersection crashes because driveway-related crashes are coded as intersection crashes by police. The inconsistent crash location coding makes it hard to accurately separate the signalized intersection crashes from the driveway crashes. This coding practice exists in the before-and-after database. The unavailability of all detailed individual crash reports (close to 800), particularly from the early years before LADOTD starting to scan all crash reports, made the intersection crash separation infeasible.

3.1. Estimating Safety Effectiveness

Because simply comparing crash frequencies before and after a crash countermeasure implementation does not account for the changes in traffic volume and, most importantly, the stochastic nature of crashes, the analysis was conducted based on the principle that the true impact of a crash countermeasure should be the difference between the predicted safety after the crash countermeasure implementation and the predicted safety in the after period if the crash countermeasure were not implemented. Ideally, the predicted expected safety should be calculated by the empirical Bayes (EB) method with a rigorously developed and carefully calibrated safety performance function. Because the models in Chapter 12 of the *HSM* (AASHTO, 2010) for the two types of roadways are not calibrated with Louisiana data, the following "four-step" procedure introduced by Hauer (2002) was used to estimate a crash modification factor for the restriping projects assuming crashes following Poisson probability distribution. For this analysis, the actual number of crashes was used for the "predicted" crashes after the crash countermeasure implementation. The details of the safety estimation are summarized as follows:

Step 1: Estimating the safety if the restriping were not installed during the after period and the safety with the restriping project,

$$\hat{\lambda} = N$$

$$\hat{\pi} = \hat{r}_{tf} K$$

where,

$\hat{\lambda}$: estimated expected number of crashes in the after period with the project
N: observed annual crashes after the project implementation

Table 2

Results from the first step

	$\hat{\lambda}$	$\hat{A}_{avg}$	$\hat{B}_{avg}$	$\hat{r}_{tf}$	$\hat{\pi}$
LA 3025	147	23,888	26,580	0.90	322
LA 182	85	21,947	20,067	1.09	195

$\hat{\pi}$: estimated expected number of crashes in the after period without the project

K: observed crashes before the project implementation

$\hat{r}_{tf}$: traffic flow correction factor $\hat{r}_{tf} = \hat{A}_{avg}/\hat{B}_{avg}$

$\hat{A}_{avg}$: average traffic flow during the after period

$\hat{B}_{avg}$: average flows during the before period.

The results of this application for both roadways are listed in Table 2.

Step Two: Estimating the variance

$$V\hat{A}R\{\hat{\lambda}\} = N$$

$$V\hat{A}R\{\hat{\pi}\} = (r_d)^2[(\hat{r}_{tf})^2 K + K^2 V\hat{A}R\{\hat{r}_{tf}\}]$$

$$V\hat{A}R\{\hat{r}_{tf}\} = (\hat{r}_{tf})^2(v^2\{\hat{A}_{avg}\} + v^2\{\hat{B}_{avg}\})$$

where,

$V\hat{A}R\{\hat{\lambda}\}$: estimated variance of estimated expected number of crashes in the after period with the project

$V\hat{A}R\{\hat{\pi}\}$: estimated variance of estimated expected number of crashes in the after period without the project

r_d: duration of after period/duration of before period

v: the percent coefficient of variance for AADT estimates

v: $= 1 + 7.7/(\text{number of count} - \text{days}) + 1650/\text{AADT}^{0.82}$

The results of this application for both roadways are listed in Table 3.

Step Three: Estimating the crash difference and the ratio

Table 3

Results from the second step

	$V\hat{A}R\{\hat{\lambda}\}$	$V\hat{A}R\{\hat{\pi}\}$	$v\{\hat{A}_{avg}\}$	$v\{\hat{B}_{avg}\}$	$V\hat{A}R\{\hat{r}_{tf}\}$
LA 3025	147	616	0.0398	0.0395	0.0025
LA 182	85	337	0.0430	0.0425	0.0039

Table 4
Results from the third step

	$\hat{\delta}$	$\hat{\theta}$
LA 3025	175	0.45
LA 182	110	0.43

$$\hat{\delta} = \hat{\pi} - \hat{\lambda}$$

$$\hat{\theta} = (\hat{\lambda}/\hat{\pi})/[1 + V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2]$$

where,

$\hat{\delta}$: estimated safety impact of the project
$\hat{\theta}$: estimated unbiased expected crash modification factor.

The results of this application for both roadways are listed in Table 4.

Step Four: Estimating the standard deviation

$$\hat{\sigma}\{\hat{\delta}\} = \sqrt{V\hat{A}R\{\hat{\pi}\} + V\hat{A}R\{\hat{\lambda}\}}$$

$$\hat{\sigma}\{\hat{\theta}\} = \frac{\hat{\theta}\sqrt{V\hat{A}R\{\hat{\lambda}\}/\hat{\lambda}^2) + (V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2)}}{(1 + V\hat{A}R\{\hat{\pi}\}/\hat{\pi}^2)}$$

The results of this application for both roadways are listed in Table 5.

Based on the above calculations, the estimated expected crash reduction for LA 3025 is 175 with a standard deviation of 27.62; and it is 110 for LA 182 with a standard deviation of 20.53. The estimated expected CMF is 0.45 and 0.43 (or crash reduction factor of 0.55 and 0.57) with the standard deviation 0.051 and 0.062 for the two roadway segments, respectively.

4. Crash Characteristics

The biggest concern over this restriping type project was whether it increases other types of crashes while reducing the number of rear-end collisions. Based on the distribution of crash types shown in Figure 3, rear-end crashes did decrease 82% on LA 3025 and 44% on

Table 5
Results from the fourth step

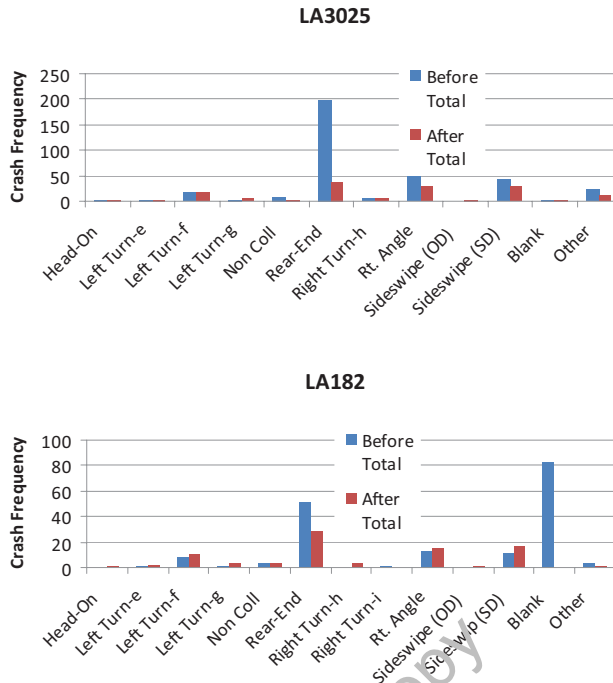|	$\hat{\sigma}\{\hat{\delta}\} = \sqrt{variance}$	$\hat{\sigma}\{\hat{\theta}\} = \sqrt{variance}$
LA 3025	27.62	0.051
LA 182	20.53	0.062

LA3025

LA182

Figure 3. Distribution of crash types. (Color figure available online.)

LA 182. On LA 3025, the crash reductions are also evident on all major types of crashes, particularly sideswipe (both types) and right-angle. However, on LA 182, there are slight increases in right-angle, left-turn-f, and sideswipe (same direction) crashes; however, there are 82 crashes with no information on the type of collision from the before time period, which somewhat affects the comparison.

The crashes by pavement surface conditions and time of day were also investigated from the before and after periods. As shown in Figure 4, though crash reduction is consistent
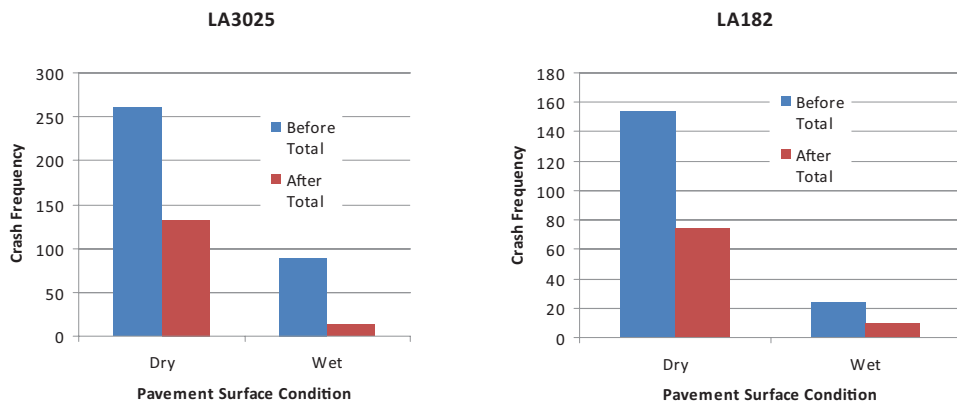
LA3025

LA182

Figure 4. Crash reductions under pavement surface conditions. (Color figure available online.)

Table 6
Crash severities before and after the project

Crashes by Severity	LA 3025			LA 182		
	Before	After	% Change	Before	After	% Change
Total crashes	358	147	–58.9	178	85	–52.3
Property-damage-only crashes	277	105	–62.1	124	63	–49.2
Injury crashes	81	40	–50.6	54	22	–59.3
Fatal crashes	0	2	increase	0	0	0

under both pavement surface conditions, the percentage of reduction is higher under wet pavement conditions than that under dry conditions. Under wet pavement condition, the reduction is 82% for LA 3025 and 58% for LA 182.

It is also interesting to note that the crash reduction is also consistent during different time periods on both roadway segments as shown in Figure 5. Lastly, the distribution of crash severity before and after the restriping projects is examined. As shown in Table 6, frequencies decrease for property-damage-only (PDO) crashes and injury crashes except on the LA 3025 segment where fatal crashes increased from zero to two. To investigate the cause of these two fatal crashes, the detailed crash reports were obtained. The reports from the local police show that one fatal crash occurred in 2006 involving a single vehicle running out-of-control and colliding with a utility pole, and the other fatal crash occurred in 2005 at the T-intersection involving a vehicle on S. College that turned left on a permissive green ball in front of an opposing through vehicle. Neither fatal crash was related to the change of the roadway. There were no fatal crashes in 2007, 2008, 2009, and 2010, 4 years after the study time period on this segment.

5. Cost–Benefit Ratio

The cost of restriping a roadway per mile covering materials and labor is about $7,105 by the maintenance crew of the LADOTD District Office or $11,450 by outside contract.
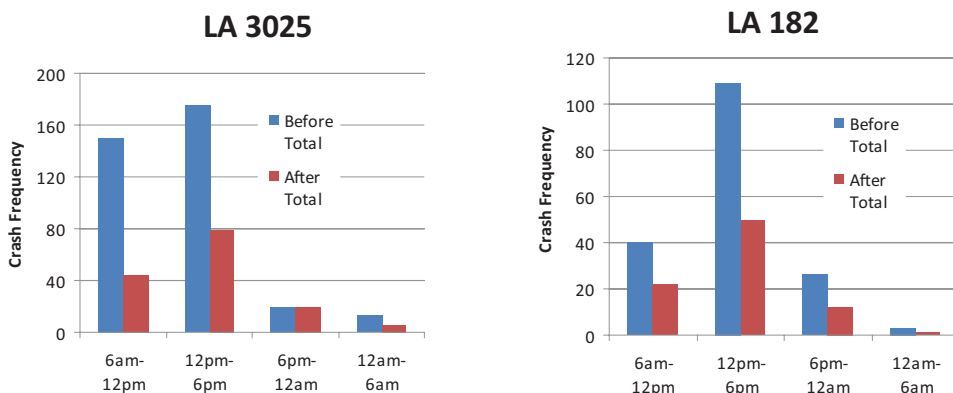

Figure 5. Crash distributions by time of the day. (Color figure available online.)
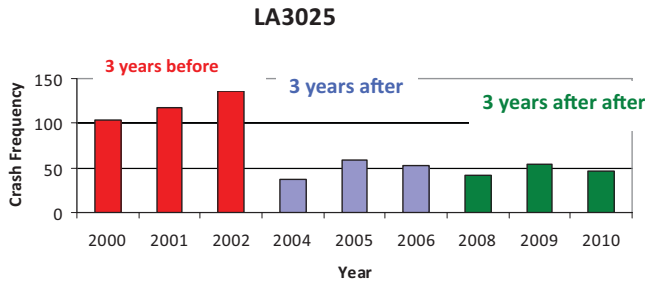
LA3025

Figure 6. Crashes by year on LA 3025. (Color figure available online.)

Based on the FHWA estimation (2011), the average cost for an injury crash is $24,390, and for a PDO is $3,730; this yields a benefit-to-cost (B/C) ratio of 88 for the LA 182 segment if using an outside contract (assuming the paint lasts about 3 years). This is the most conservative B/C ratio: it would be larger if maintenance crew costs were used for the LA 182 project and much larger if the LA 3025 crash data were used.

6. Discussion

The crash modification factors derived from the before and-after crashes analysis of the restriping projects is striking. Crash countermeasures as listed in the first edition of the *HSM* (AASHTO, 2010), seldom yield CMF values smaller than 0.5. The estimated CMF and standard deviation on both roadway segments indicate a certainty that a restriping project reduces crashes since the estimated CMF plus the three standard deviations is still much less than one (0.60 for LA 3025 and 0.62 for LA 182). As shown in Figure 6, the annual crashes on LA 3025 in 2008, 2009, and 2010 further confirm the sustainable effectiveness of the crash countermeasure even though the segment experienced a 10 percent increase in the average AADT from the 2004 to 2006 period to 2008 to 2010.

Although all the signalized intersection crashes are not excluded from the analysis, the impact of the restriping project should not be overestimated because the configurations of all signalized intersections remain the same before and after the restriping projects. It is believed that the effect of including crashes related to signalized intersections is minimized if not totally canceled because it exists consistently before and after the project. Following this argument, the analysis results may even be conservative.

Although nothing was changed except the lane configuration on LA 3025, there was a speed limit reduction (from 50 mph to 45 mph) on 44% of LA 182 segment after the restriping project. Without collecting speed data before and after the restriping project and not having speeding enforcement cameras on this segment, the impact of speed limit change on operating speed is not clear. However, the numerous past studies on speed have shown that operating speed is seldom controlled by speed limit unless enforcement is present; and speed change has no statistically significant effect on crash frequency but does associate with crash severity. It is possible that the higher percentage of injury reduction on LA 182 (comparing to the one on LA 3025) shown in Table 6 could be somewhat associated with the speed limit change.

The repeated success on these two roadway segments demonstrates the need for flexibility in selecting the best safety improvement project under the existing constraints (financial or otherwise). For each specific traffic crash problem, there are always a set of crash

countermeasures ranking from the highest to the lowest in crash reduction capability and B/C ratio. When the most desirable options are restricted in immediate application due to funding or other issues, finding a timely solution is still critical. Leaving infrastructure in unsafe conditions will only lead to more costly crash problems. Although banned in new construction, five-lane roadway type remains an effective crash countermeasure for the existing, problematic four-lane undivided roadway segment in urban areas.

If and when funds do become available and sufficient right-of-way (ROW) can be obtained, these two five-lane roadway segments can be converted to a boulevard roadway type, a concept very much promoted today in urban and suburban areas in Louisiana. However, in reality, it is not easy to purchase additional ROW due to strong reluctance from established businesses along a roadway, and it can be very costly if utilities have to be relocated. It takes considerable time and sometimes a strong political will to plan and design the roadway conversion, which is why existing roadways are seldom converted to four-lane divided roadway with a boulevard cross section.

Examining these two successful crash reduction cases, it is important to note that one-size-fits-all solutions do not always prevail in highway safety. Although this study shows impressive results, caution must be taken when applying this crash countermeasure in other locations. Particular attention must be made to not only the number of driveways but also the type and size of traffic generators along the roadway and existence of other travel modes. Along the LA 3025 segment, there are no retail types of business. Thus, traffic volumes to and from these driveways are relatively small. The biggest difference between these two segments is that there are 25 small retail businesses, such as fast food restaurants, a gas station, and small stores along the LA 182 segment. With sufficient segments (samples), it would be interesting to investigate whether the presence and size of retail business make a difference in the magnitude of the CMF. Also noted that both roadway segments are not major bus corridors and do not have noticeable bicycle and heavy truck traffic, which makes the lane conversion possible.

Acknowledgments

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