Identify High Crash Risk Locations for Rural Roadways: A Systemic Approach to Reduce Severe and Fatal Traffic Crashes in Louisiana and Mississippi

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ABSTRACT

Louisiana is among the top crash and fatality overrepresented states with a much higher the national average crash and fatality rates. Traditional approach on high risk crash location identification does not work effectively on locations with low traffic volumes, such as rural and local roadways where bears low design standards. Systemic approach is a proactive way for critical crash location identification based on the roadway geometry and characteristics of locations. Rural two-lane roadways have much higher fatal crash rate than any other roadways. On Louisiana state-maintained rural two-lane roadways, most predominant crash types, “non-collision” single vehicle crashes (79%) on curves are more prevalent than on tangent sections and intersections. By using GIS and logistic regression model, this study investigate relationship between roadway geometric and driver characteristics and crash risk on rural two-lane curves. The analysis results reveal that the key crash contributing factors are alcohol involvement, surface condition, AADT, and radius of the curve.

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INTRODUCTION

Roadway safety is a major issue in Louisiana and Mississippi. For many years, the two states have been among the top in the country for crash and fatality rates. Both states' fatal crash rates have been much higher than the national average. According to NHTSA Safety reports, there were 29,989 fatal motor vehicle crashes in the United States in 2014 in which 32,675 deaths occurred. This resulted in 10.2 deaths per 100,000 people and 1.08 deaths per 100 million vehicle miles traveled (VMT). In the same year, 737 deaths occurred in 662 fatal crashes in Louisiana which resulted in 15.9 deaths per 100,000 people and 1.53 deaths per 100 million vehicle miles traveled.

With VMT continuously increasing, it is extremely challenging to reduce the number of crashes and fatalities. From 2010 to 2014, there was no significant reduction in number of fatal, injury, or PDO (Property Damage Only) crashes in Louisiana, as shown in Figure 1. The tall order of "Destination Zero Deaths", with a goal of reducing traffic fatalities and serious injuries by 50% by 2030, requires major changes in crash countermeasure selection procedures.

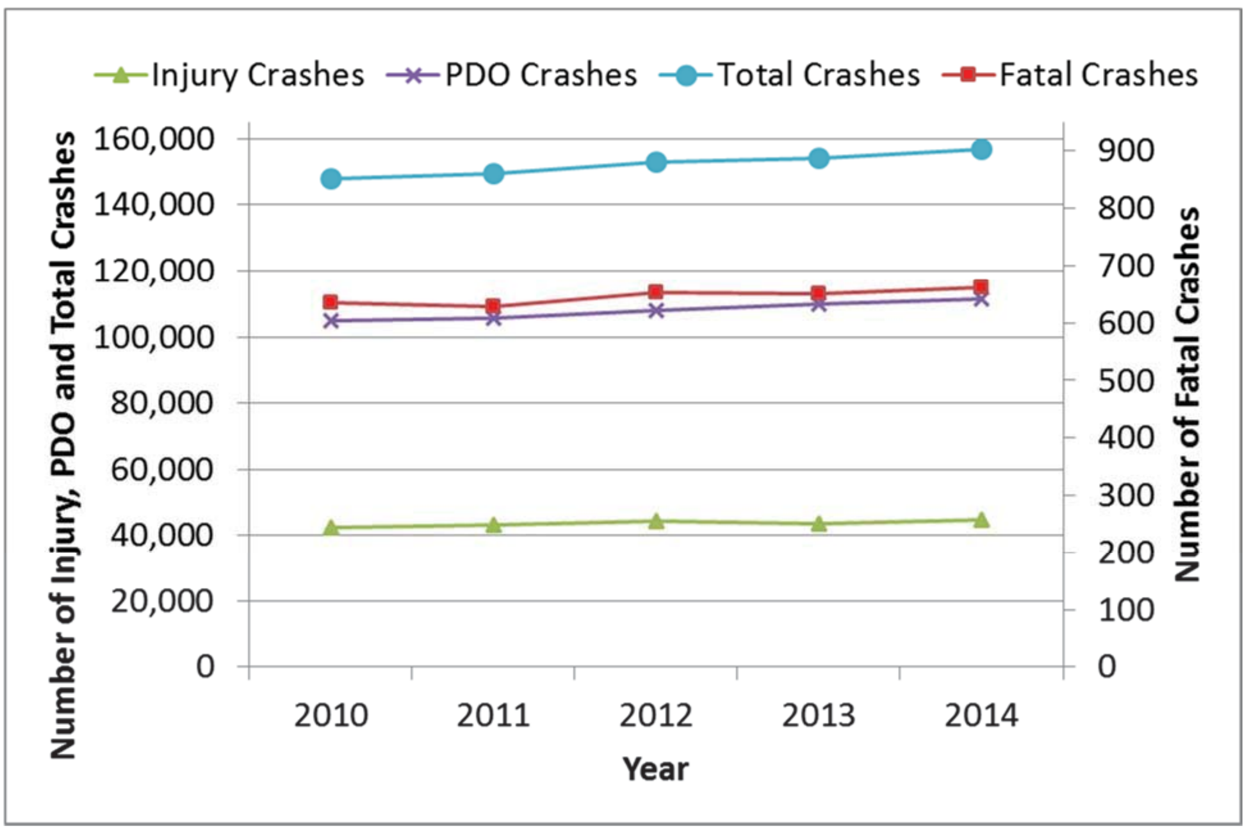

Figure 1 Crash trend by severity in Louisiana during 2010-2014

The traditional approach of addressing High Risk Locations (HRL) is primarily based on crash data. In this approach, crash countermeasure selections are triggered by high crash densities. This approach has been proven to be effective in preventing crashes in those high density locations, but crashes also occur at the locations with low AADT and low design standards. In 2014, two-thirds of the fatal crashes and more than half of injury crashes occurred on rural roadways (including non-state maintained roadways). This large number of crashes are not clustered or concentrated in some segments, they are scattered all over the network. For these rural roadways, a more effective approach to identify critical locations, or to screen high risk locations, is needed. On-going research in implementing a "systemic approach" for location identification tries to complement the traditional approach. A systemic approach involves identification of locations with similar risk characteristics. It involves application of countermeasures based on high-risk roadway features correlated with specific severe crash types to be addressed. Thus, affordable crash countermeasures can be selected for widespread implementation to prevent scattered crashes on rural roadways [1].

Lack of information is the major constraint of using a systemic approach. For example, locations with about 30% of fatal crashes and 40% of injury crashes occurred on non-state controlled local roadways that have no available information on geometric design features, and an annual average daily traffic (AADT). Even in state maintained roadways, the adequate information on significant features like clear zone width and operating speed are not available in crash databases. The role of human error in a majority of roadway crashes is undeniable. Both extrinsic characteristics, such as demographics (age, gender) and safety culture, and intrinsic characteristics such as distraction, inattentiveness, fatigue and etc., play a significant role in the occurrence and severity of crashes. There are numerous studies on role of human behavior on road crashes, but very few examples of identification of high risk locations using human factors exist. The use of human behavior in identification of HRL is also limited to the demographics who were involved in the crashes. Although most of the crashes are attributed to driver violations as a primary contributing factor, no studies included human behavior to identify high risk locations in Louisiana.

Identification of high risk locations requires not only a comprehensive study on the geometric features of the roadways and human behaviors related to the crashes, but also a statistical approach concerning pertinent roadway features and human behaviors. This report has documented investigation results of key contributing factors of crash risk on rural two-lane roadways in Louisiana. With many similarities between Louisiana and Mississippi, it is believed the results from this study are relatable to the state of Mississippi.

OBJECTIVE

The goal of this research project is to identify high crash risk locations of rural roadways. The current state-of-the-art approach suggests more advanced systemic approach in addition to traditional crash-based approach. Specifically, the project aimed to:

- Develop quantitative approach to crash risk based analysis and distinguish them from “black spot” or “site with promise” methods.
- Provide a review of existing methods and tools that can be used in systemic safety analysis.
- Produce a risk map for rural roadways
- Propose corresponding inexpensive crash countermeasures.

SCOPE

Rural roadways in Louisiana are primarily state-maintained rural roadways and non-state maintained local roadways. Geometric information and crash information are collected on state-controlled roadways; therefore, the scope of the project is limited to identification of high risk locations on rural roadways. For simplicity and homogeneity, the major share of crashes and scope of analysis were further reduced to rural two-lane roadways maintained by LADOTD. The analyses were performed on 2013-2014 crash data. The highway section information was obtained from 2014 database.

METHODOLOGY

Methodology section is divided basically into three parts: Information Review, Crash Risk Analysis, and Development of Risk Model. Information review consists of study of previous research related to identification of high risk location using different methods. Then crash risk analysis used the data from Louisiana rural two-lane roadways using LADOTD data of 2013-2014. A step by step crash analysis identified horizontal curves on as one of the vulnerable locations on rural two-lane roadways compared to other geometric configurations. Finally, a risk model is introduced to identify key crash contributing factors of fatal and injury crashes on rural two-lane curves.

Information Review

The first edition of Highway Safety Manual (HSM) provides Safety Performance Function (SPF) for estimating expected number of crashes by kind and severity for three types of roadways. The compatibility of SPFs in the HSM is uncertain since they are developed for base conditions. The unavailability of some factors relevant to local conditions causes severe biasness. It is also debatable that whether it is enough to calculate the expected number of crashes and then compare with the actual number. [2]

The systemic approaches have recently been used to identify potential high risk locations, which is not solely depends on the crash history, but considers characteristics of the locations with particular crash pattern and identifies sections with similar characteristics. FHWA has established a systematic tool with a step-by-step process for conducting systemic safety planning with considerations for determining a balance between spot and systemic safety improvements. The approach usually consists of four major objectives with specific goals. Firstly, identification of targeted crash types and corresponding risk factors by, selecting targeted facilities. Secondly, screening and prioritizing candidate locations by identifying network elements to analyze targeted crashes, conducting risk assessment and prioritizing targeted facility elements. Thirdly, selecting countermeasures by assembling comprehensive list actions, evaluating and screening countermeasures, and by selecting countermeasures for deployment. Fourthly, prioritizing projects for making a final decision process for countermeasure selection, developing safety projects, and prioritizing safety project implementation [3]. The FHWA tool provides a comprehensive generalized approach to provide options for state DOTs to find the project to be undertaken. But it is up to the states to determine how the risks would be assessed depending on the prioritized crash types.

Minnesota county roadway safety plan provides a guideline to identify high risk locations based on a customized star ranking procedure. Objective of the plan was to identify locations for and prioritize various safety measures to reduce the number of fatal and serious injury crashes. The major focus was on the use of crash data combined with safety surrogates to develop a star ranking system for roadway segments, horizontal cures, and stop-controlled intersections. In this approach, segments were defined by a consistency in speed limits, average daily traffic, and geometrics. Most significant crashes occurring on these segment were identified. Finally, segments identified were prioritized through the use of a five star ranking system related to the five safety risk factors. Although applied on county roadways, the approach clarifies its application procedures based on customized star ranking by the investigators [4].

The usRAP approach is rigorous approach which estimates risk along small roadway segments through previously established risk factors for four types of roadway users associated with approximately 50 roadway characteristics, mostly related with geometric factors and presence or absence of roadway features. Segments are assigned a star rating based on estimated risks. Countermeasures are proposed depending on the roadway types and presence and absence of a roadway feature that contributes to high risk. The known level of fatalities and injuries are usually allocated to each segment. The prioritization of the segments for improvement depends on the cost and crash reduction effectiveness of the countermeasures proposed in the form of benefit cost ratio. usRAP approach looks at the geometric features which are connected to most common crash types. It does not look for specific type of crashes, rather focuses on type of road users [5].

Studies on HRL identifications are also available outside United States. One study in European Union defines new procedures and criteria for identifying and ranking safety issues [6]. This method in the IASP project evaluates design consistency in terms of designs which have been demonstrated as effective in identifying hazardous road locations due to geometric road alignment. It uses theoretical-experimental models with basic concept of measuring safety index value by vulnerability, exposure, and magnitude. In order to measure the risk quantitatively, it evaluates many qualitative design aspects according to score assigned by expert opinions. However, this approach involves rigorous physical inspection along with available geometric and operational information. Applicability of the method to a large roadway network requires abundant resources including team of inspectors trained in the use of the IASP procedure.

Crash Analysis

Rural roadways and local roadways are characterized by low AADT and narrow lane width. It is abundantly clear that rural and local roadways share a high percentage of crashes according to Louisiana 2005-2014 crash data.

Table 1 Crash Severity distribution by road type (2005-2014)

Year	Road type	Crash Types		
		Fatal	Injury	Total
2005	Rural+local	65%	50%	51%
	Urban	35%	50%	49%
2006	Rural+local	58%	50%	52%
	Urban	42%	50%	48%
2007	Rural+local	64%	51%	52%
	Urban	36%	49%	48%
2008	Rural+local	63%	61%	62%
	Urban	37%	39%	38%
2009	Rural+local	61%	56%	58%
	Urban	39%	44%	42%
2010	Rural+local	62%	52%	53%
	Urban	38%	48%	47%
2011	Rural+local	63%	55%	55%
	Urban	37%	45%	45%
2012	Rural+local	60%	54%	55%
	Urban	40%	46%	45%
2013	Rural+local	64%	54%	55%
	Urban	36%	46%	45%
2014	Rural+local	67%	53%	55%
	Urban	33%	47%	45%

As mentioned previously, local roadways have no available information on geometric design features and AADT. Among the state-maintained rural roadways, rural two-lane roadways have the highest number of crashes and fatalities as shown in the 2014 crash database.

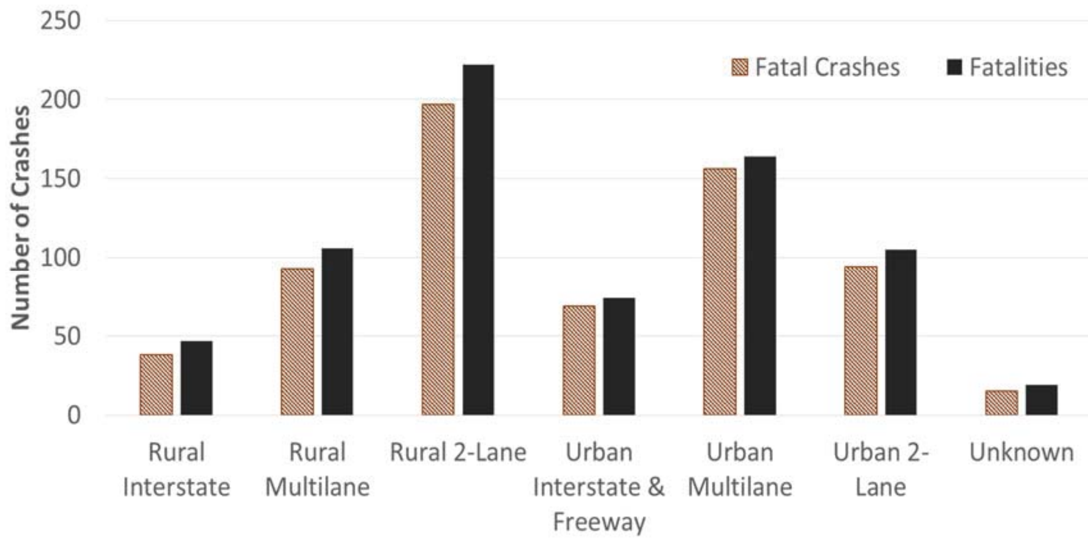

Figure 2. Fatal crashes and fatalities by highway functional class in Louisiana in 2014

In this study, crash report from the state database along with the highway database for 2013 and 2014 have been merged to study the crash patterns and the various features associated with the crashes. The two-years of data have been individually studied and then merged together to analyze the pattern of the crashes occurring in Louisiana. Crash characteristics on state and non-state roadways are classified into rural, urban, service and exits roadways. In total, 310,776 crashes were reported on Louisiana highways during 2013-2014. About 37% were on local roadways while the rest were reported on the state highway system. Further analysis indicates that 17% of those state highway crashes were on the rural roadways. Details can be seen in Figure 3.

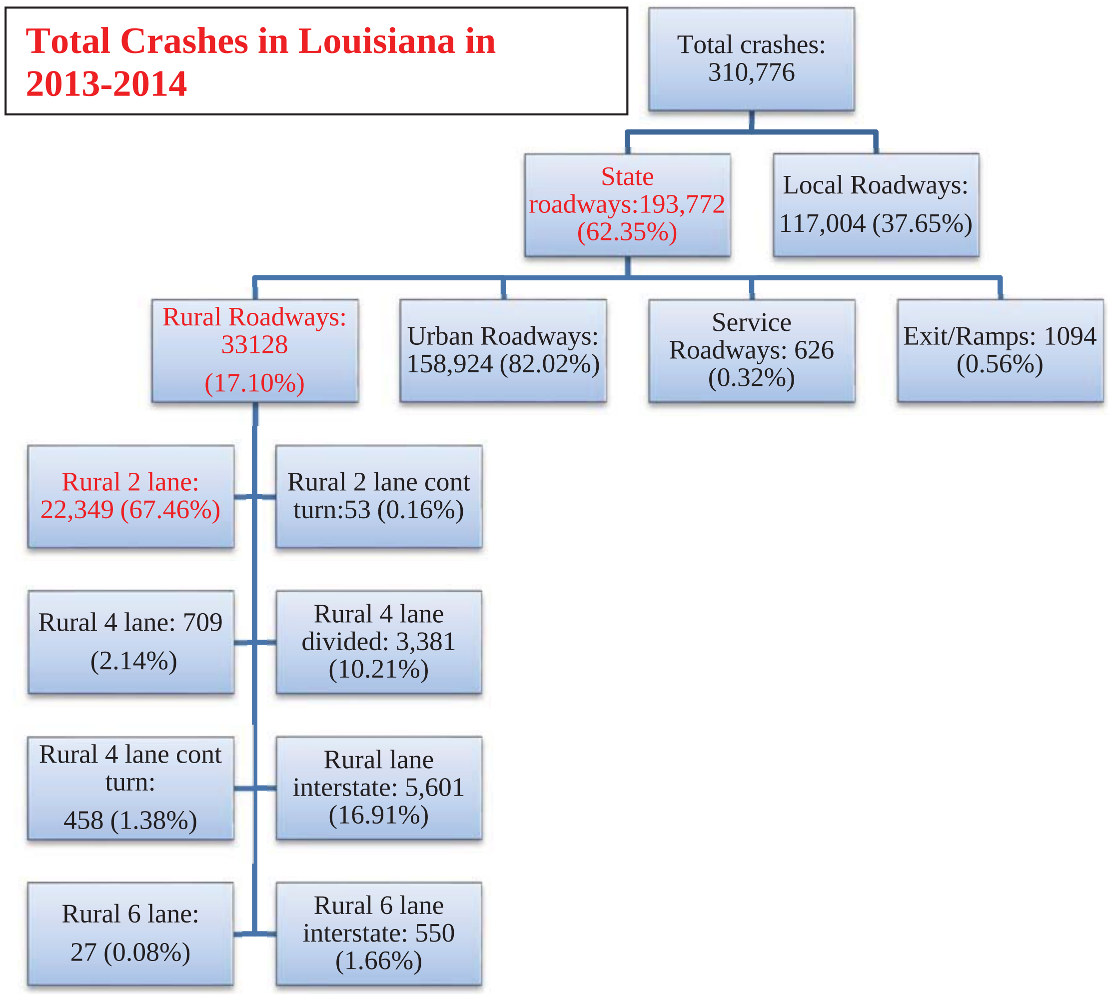

Figure 3 Crash distribution by road types in Louisiana in 2013-2014

LADOTD's highway sections data reveals that, 39% of rural two-lane state highways in Louisiana have lane widths of 10 ft. or less and 55% have shoulder widths of 4 ft. or less. More than 55% of rural two-lane highways have AADT less than 1500. The further investigation on the two-year crash data shows that pavement width between 22 and 24 ft. category possess the higher percentage of crashes because of high percentage of mileages in this category. Sections with pavement width of less than 20 ft. have relatively higher crash rate as shown in Figure 4.

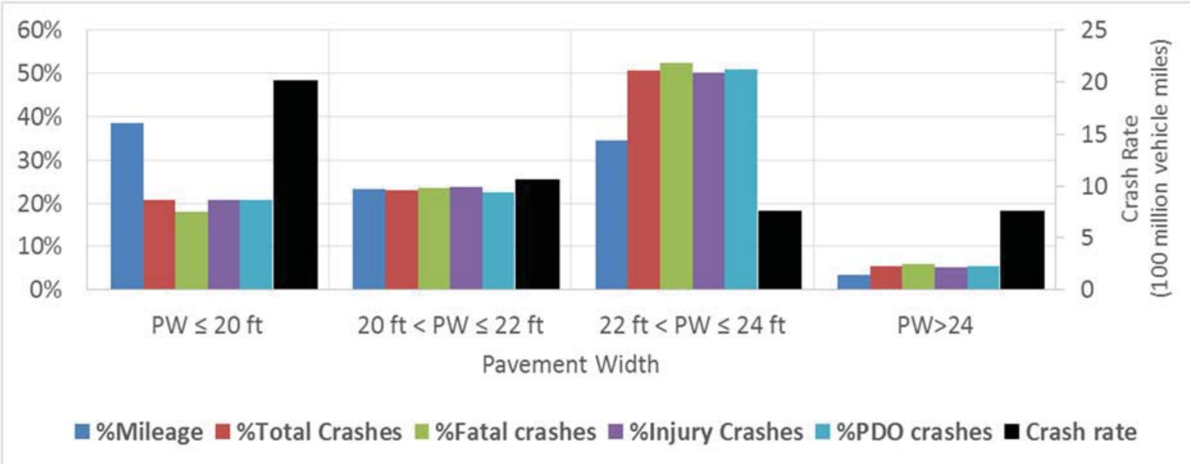

Figure 4 Mileage and crash severity distribution by pavement width on rural 2-lane

Similar trend is observed in the case of shoulder width. Shoulder width ranged from 2 to 4 ft. possess the highest mileage and therefore highest percentage of all types of crashes. But sections with less than 2 ft. shoulder width have the highest crash rate as shown in Figure 5.

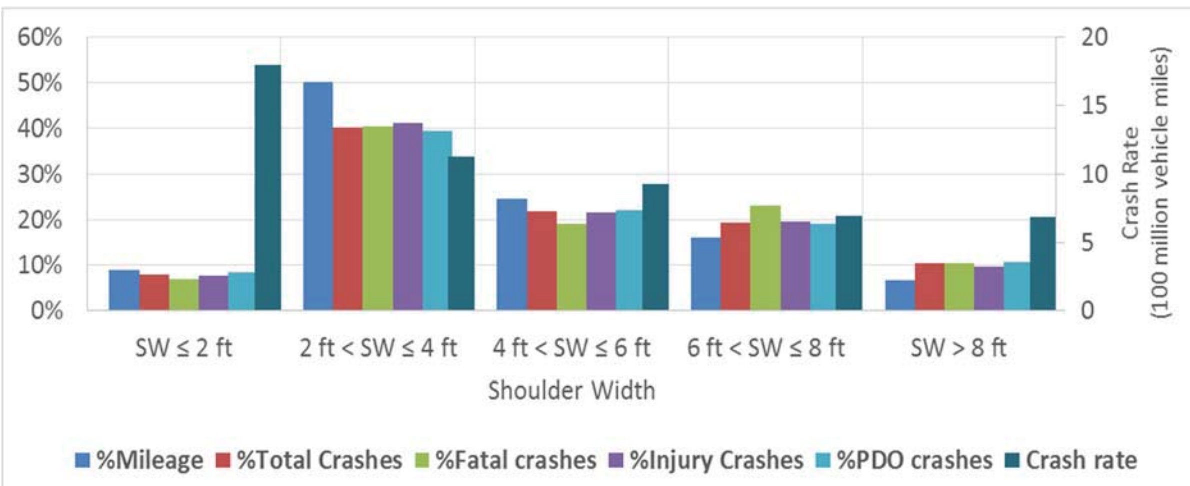

Figure 5 Mileage and crash severity distribution by shoulder width on rural 2-lane roadways

AADT distribution of all crashes shows that majority of crashes occur on roadways with for AADT between 800 and 1,600.

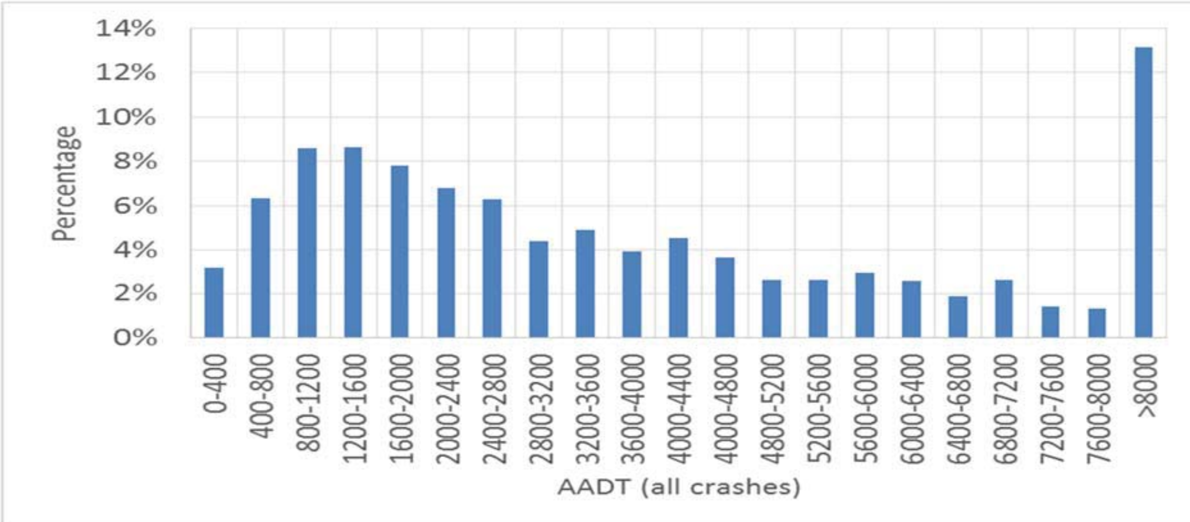

Figure 6 AADT distribution of all crashes in 2013-2014

Non-collision crashes (single vehicle crashes) is a major crash type on Louisiana highways, particularly on the curves (79%) as shown in Table 2.

Table 2 Crashes on road type (tangent vs. horizontal curve) by manner of collision

Manner of collision	Straight segment	On Curve	Intersection	Curve and intersection	Others
NON-COLLISION	52%	79%	18%	44%	51%
REAR END	22%	4%	26%	15%	16%
HEAD-ON	2%	2%	2%	3%	5%
RIGHT ANGLE	5%	1%	24%	11%	3%
LEFT TURN	6%	2%	13%	11%	0%
RIGHT TURN	0%	0%	2%	1%	0%
SIDESWIPE	7%	6%	7%	6%	5%
OTHER	6%	5%	8%	9%	19%
TOTAL	100%	100%	100%	100%	100%

More comprehensive analysis by crash type shows that significant percentages of those fatal, injuries and the PDO crashes occur on the curves in the rural two-lane roadways as shown in Figure 7. 43.28% of the fatal crashes on curves indicate that curves on rural two-lane roadways are the most prominent locations for crashes. This is also true for other crash types which can be seen from the percentage distribution of injury crashes (28.34%) and PDO crashes (22.59%). Curves on rural two-lane roadways are significantly possess more risk than other straight segments and intersections.

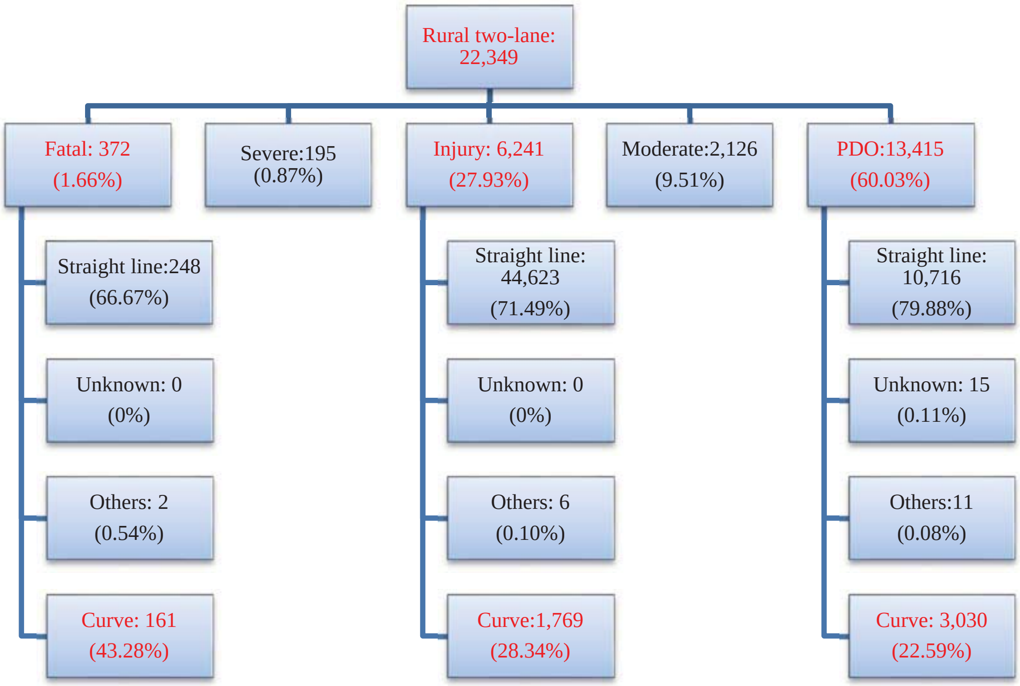

Figure 7 Distrbution of crash types by alignment of rural two-lane road

It is clear that horizontal curves must be a location of interest for safety improvement on rural two-lane roadways. It is observed that more than 63% of the fatal crashes, 69% of injury crashes, and 63% of PDO crashes have been recorded to have "violation" as the primary contributing factor. The study also found that violation, movement prior to crash and condition of driver cover almost 85% of the total fatal, injury and PDO crashes which are thus considered as the three most prominent primary crash contributing factors for horizontal curves of rural two lane roadways. The other category includes the road surface, roadway condition, lightning, weather, traffic control and land use. Less than 2% of each type of crashes are reported due to vehicle condition as the primary factor as shown in Figure 8.

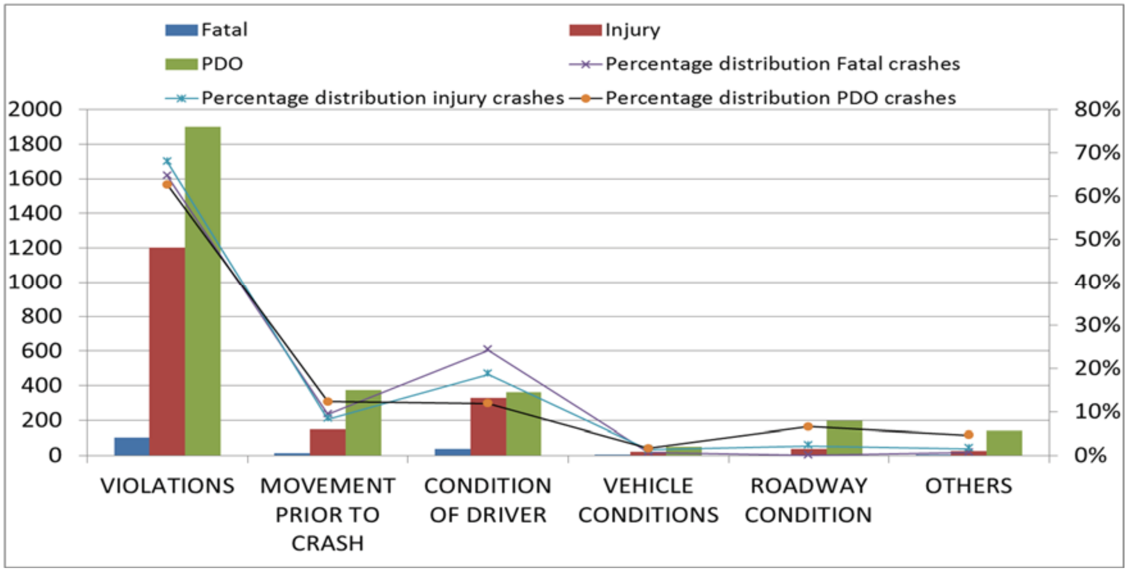

Figure 8 Primary contributing factors on rural two-lane curve by severity

As the study showed that violation is the main primary contributing factor for crashes, it was further analyzed. “Careless operation” is found to be the main reason for violation. Though a smaller percentage is owned by the rest of the causes for violation but for the fatal crashes, “driver condition” and “moving to the left lane” were significant causes followed by careless operation as shown in Figure 9. Therefore, the study identifies “driver carelessness” as the prime cause of violation during crashes in the curves on rural two- lane roadways.

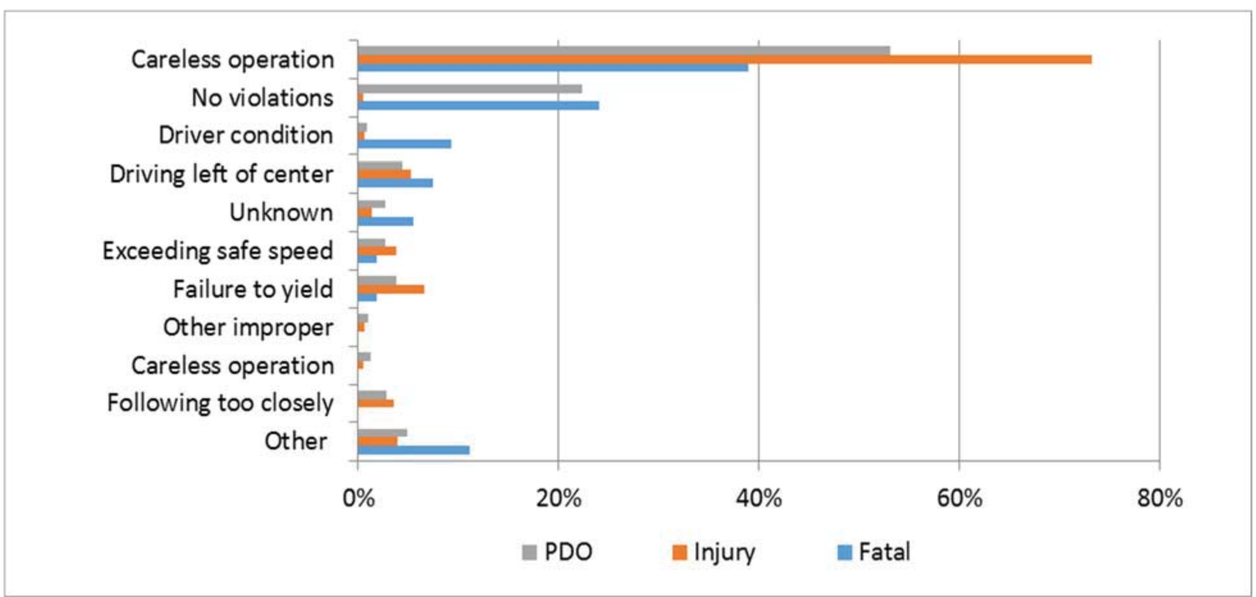

Figure 9 Distribution of reasons for violations of rural two-lane curve crashes

The secondary contributing factors for curves on the rural two-lane highways are shown in Figures 10, 11 and 12.

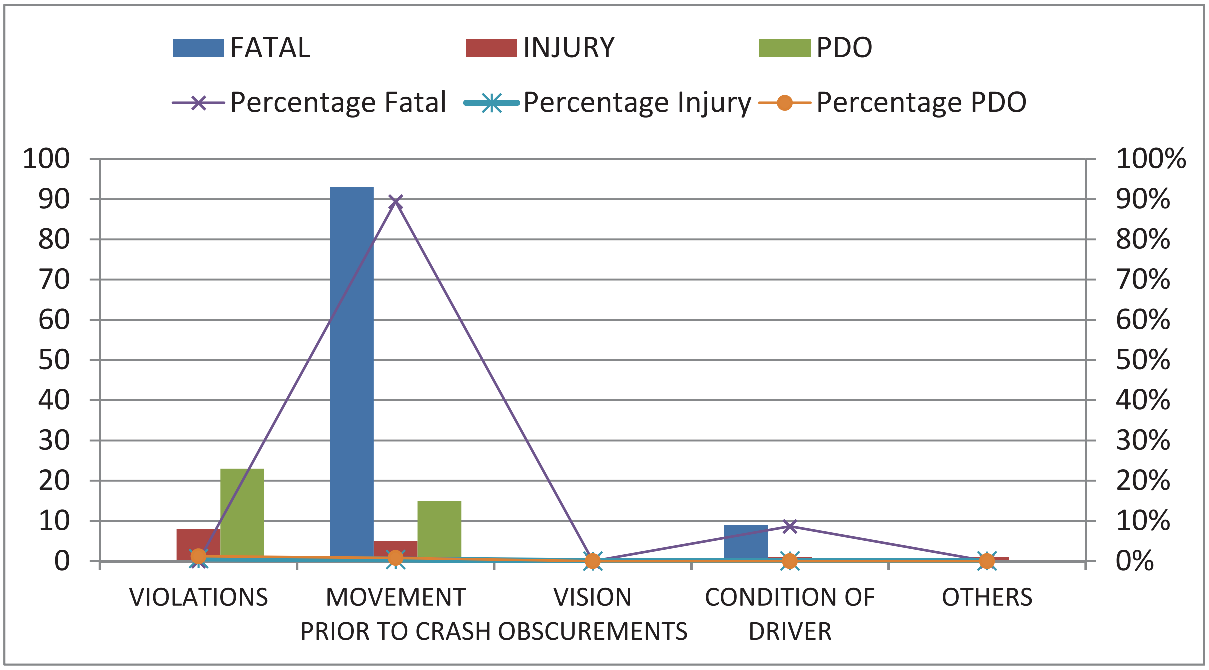

Figure 10 Distribution of secondary factors of rural two-lane curve crashes with primary contributing factor as violation

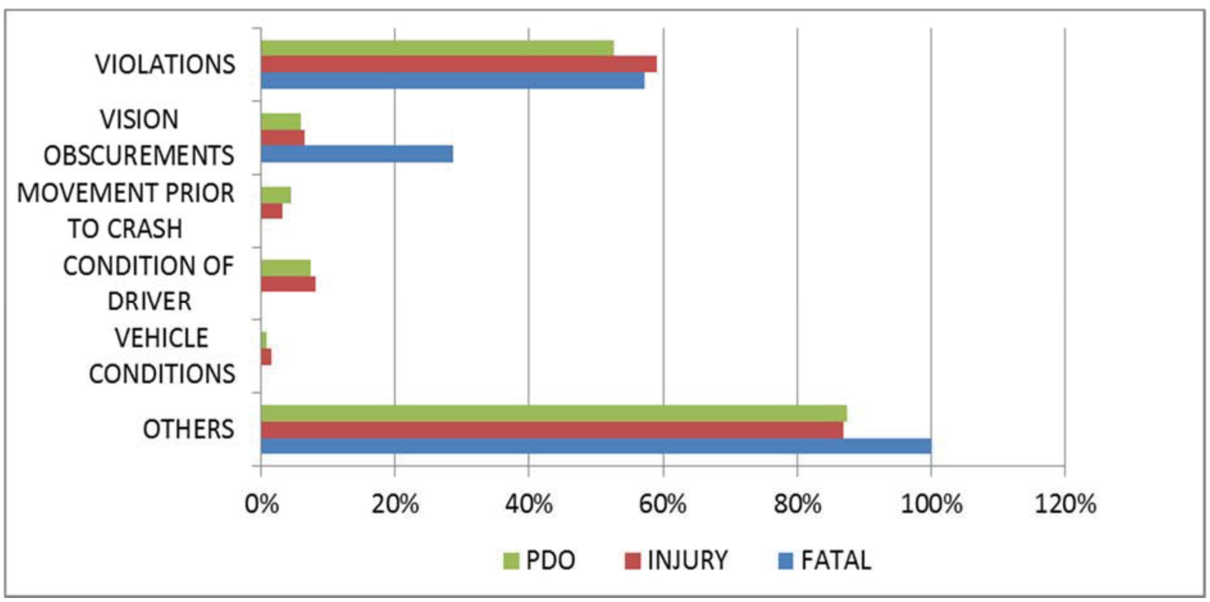

Figure 11 Distribution of secondary factors of rural two-lane curve crashes with primary contributing factor as movement prior to crash

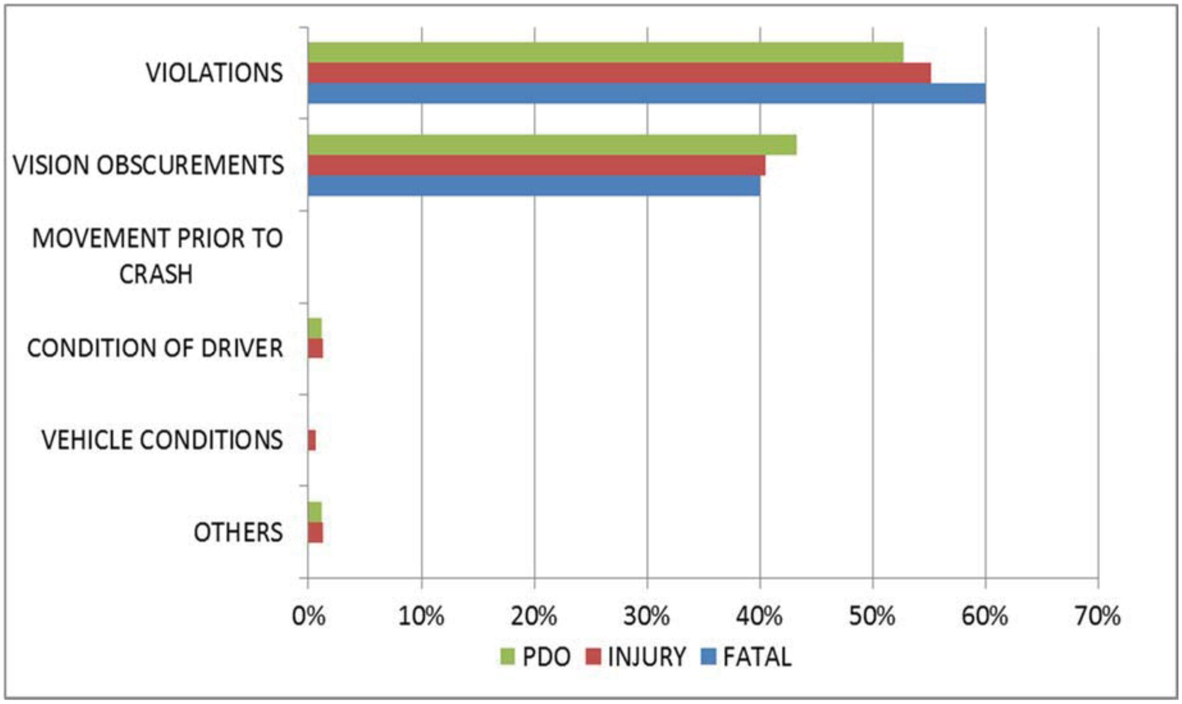

Figure 12 Distribution of secondary factors of rural two-lane curve crashes with primary contributing factor as driver condition

An ArcGIS map was developed to display the fatal crashes on curves of rural two-lane highways as shown in Figure 13, which shows 171 total fatal curve crashes in 2013 and 2014, respectively. The magnitude of curve radius is an important indicator of curve crashes. Radius of each curve where crashes occurred were identified through Curve Calculator [7] in ArcGIS. A demonstration of radius estimation through Curve calculator is shown in Figure 14.

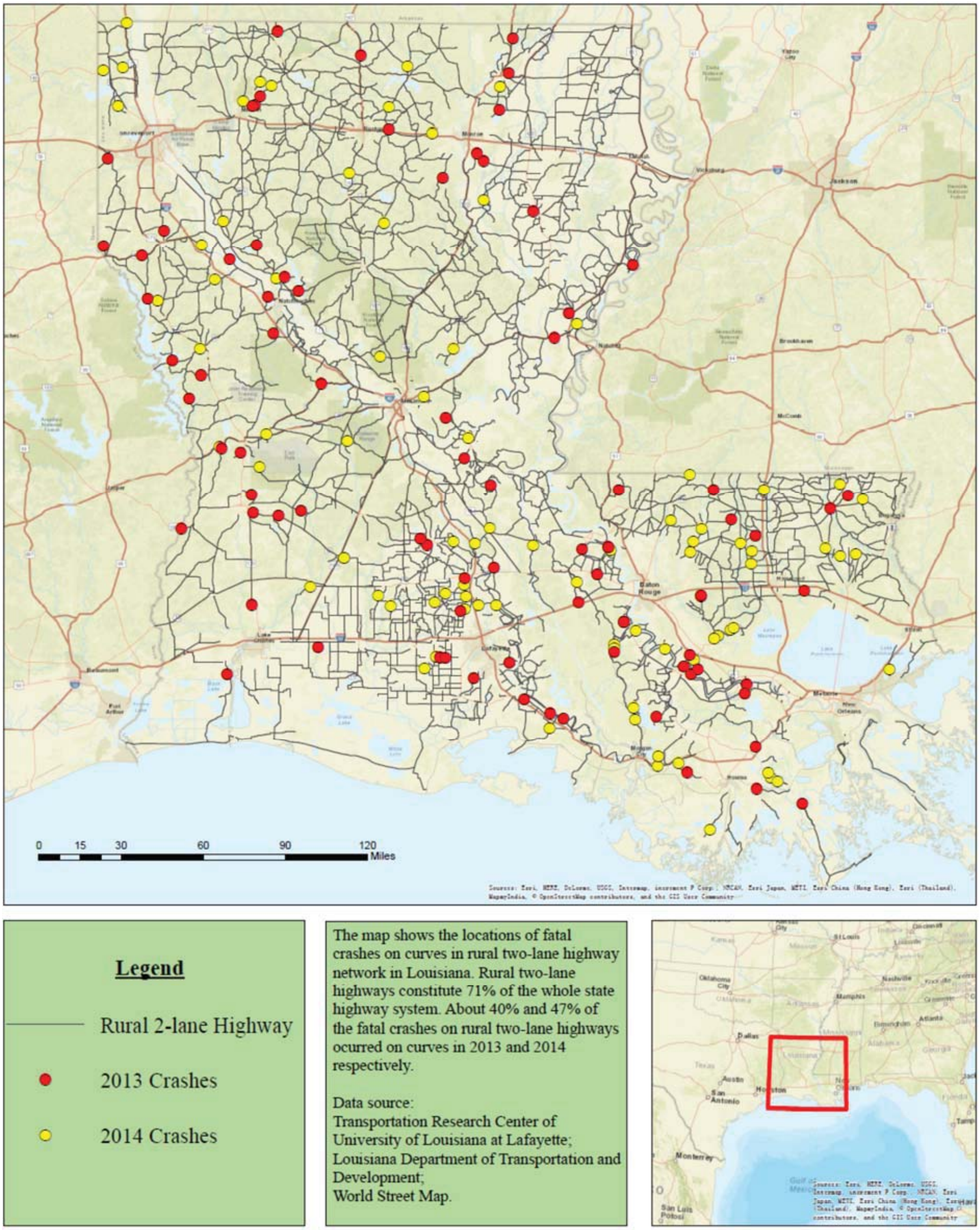

Figure 13 Fatal Crashes on Rural Two-Lane Curves in Louisiana in 2013-2014

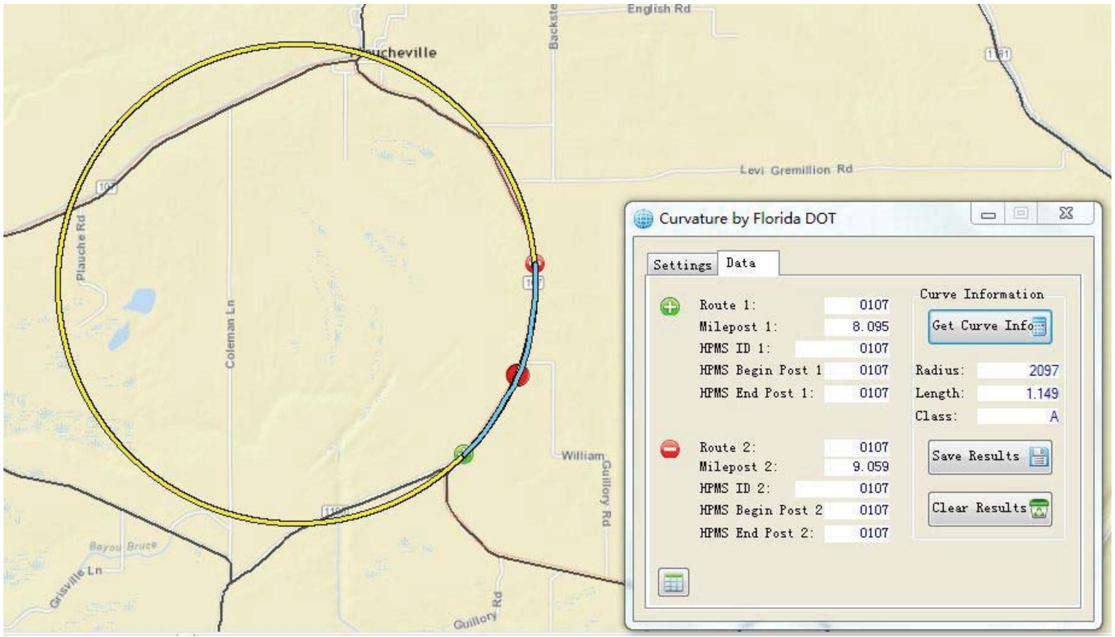

Figure 14 A demonstration of radius estimation through Curve calculator

From the horizontal curve radius distribution of fatal crashes, it is seen that more fatal crashes happened on the curve with smaller radius than that on large radius curves. The analysis shows that about 45% fatal curve crashes happened on curve with radius smaller than 800 feet as shown in Figure 15.

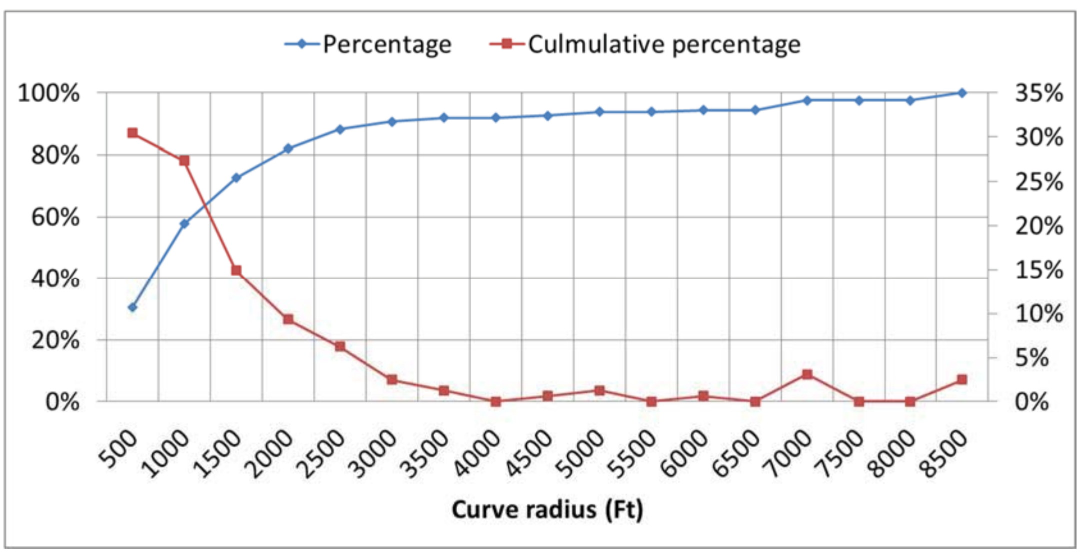

Figure 15 Percentage of radius distribution of fatal crashes on rural two-lane curves (2013-2014)

Logistic Regression Model

Many studies can be found on identification and evaluation safety on rural two-lane curves [8] [9] [10] [11]. Some studies also quantify safety effects on horizontal curves on rural two-lane roadways [12] [13]. This study uses logistic regression model to identify the contributing factors for the crash risk on rural two-lane curves. One of the major advantages of logistic regression model is that it can be applied with both qualitative and quantitative variables with the condition of a resulting dichotomous response variable.

Logistic regression is a method for modeling in situations usually expressed by a binary response variable. Predictor variables can be numerical or categorical (including binary). In order to identify risk of being involved in a fatal or serious injury crash on rural two-lane curves, 2013-14 rural two-lane curve crash data were used. The binary response variable in the model, Y can be denoted as 1, if the crash is fatal or injury crash; it can be denoted as 0, if the crash is neither fatal nor injury crash. Typically, 1 denotes “yes” or “true”, and 0 denotes “no” or “false” in dichotomous response.

Letting Y be the binary response variable, it is assumed that $P(Y=1)$ is possibly dependent on $\vec{x}$, a vector of predictor values. The goal is to model

$$p(\vec{x}) \equiv P(Y=1 \mid \vec{x}) .$$

Since Y is binary, modeling $p(\vec{x})$ is in fact modeling $E(Y \mid \vec{x})$, which is similarly done in OLS regression, with a numerical response.

If $p(\vec{x})$ is modeled as a linear function of predictor variables, e.g.,

$$\beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p ,$$

Then the fitted model can result in estimated probabilities which are outside of [0,1]. What tends to work better is to assume that

$$p(\vec{x}) = \frac{\exp(\beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p)}{1 + \exp(\beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p)},$$

where $x_1, \ldots, x_p$ may be the original set of explanatory or contributing variables.

Therefore,

$$\log\left(\frac{p(\vec{x})}{1 - p(\vec{x})}\right) = \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p .$$

$\log\left(p(\vec{x}) / [1 - p(\vec{x})]\right)$ is called the *logit*. The estimate of $p(\vec{x})$ will be between 0 and 1, irrespective of the value of $\hat{\beta}_0 + \hat{\beta}_1 x_1 + \ldots + \hat{\beta}_p x_p$ .The unknown parameters (the coefficients, $\beta_0, \beta_1, \ldots, \beta_p$) are typically estimated by maximizing the likelihood,

$$\prod_{i=1}^{n} \left\{ p(\vec{x})^{\,y_i} \left[1 - p(\vec{x}_i)\right]^{1-y_i} \right\},$$

Which can also be expressed as $P(Y_1 = y_1, \ldots, Y_n = y_n \mid \vec{x}_1, \ldots, \vec{x}_n)$.

It is assumed that the errors are normally distributed in the model.

Data collection and preparation

The data used in this study was obtained from Louisiana Department of Transportation and Development (LADOTD). The database is basically comprised of crash information, highway section information, and vehicle information. The analyses were performed on 2013-2014 crash data. The highway section information was obtained from 2014 database.

Curve crashes were identified by using an index match function in MS Excel 2016, where curve location logmiles were compared with crash location logmiles. Then, a total of 9 explanatory variables were selected to identify the key contributing factors among the variables. Both categorical and numerical variables were used. Categorical variables are:

- Surface condition (Dry or Wet)
- Alcohol involvement (Yes or No)
- Driver's gender (male or Female)
- Time (Daytime or Nighttime)

The numerical variables used in the model are:

- Driver's age
- AADT
- Curve radius (ft)
- Lane width (ft)
- Shoulder width (ft)

Since not all the contributing factors were categorical in nature, no dummy variables were used to represent each of these factors.

Figure 7 suggests that number of crashes on rural two-lane curves during 2013-2014 is close to 5,000. However, these identifications were made by office on the crash spot. With each crash GIS location, about 9,000 crashes are identified on rural two-lane roadway curves during 2013 and 2014. These 9,093 crashes were used in the logistic regression model.

Crash database contains significant number of missing values, especially driver's age and gender information. The model was prepared using R x64 3.1.2 version which accounts for few missing values in small scale, when fitting a generalized linear model by setting a parameter inside the fitting function. It is, however, preferable to replace the missing values manually. A typical approach is to replace the missing values with the average, the median, or the mode of the existing one depending on the type and nature of the data. Utilizing the R-code, 403 missing data points (out of 9,093) of driver's age variable were replaced by average. Missing 403 driver's gender information was populated by the mode value "Male". Coding details can be found in Appendix A. List of all 171 fatal crashes with the contributing factors have been tabulated in Appendix B.

DISCUSSION OF RESULTS

Results from crash analysis:

From simple crash analysis, followings statements can be asserted:

- Rural two-lane roadways have more fatal crashes than any other type roadways do.
- The most predominant type of crash on rural two-lane roadways is “non-collision” crashes (or single vehicle crashes), which consistes 79% on curves.
- Sections with pavement width of less than 20 ft. and shoulder width less than 2 ft. are more vulnerable ro KI crashes on curves.
- About 45% of curvature fatal crashes happened on curve with radius under 800 feet.

Results from logistic regression model:

Logistic regression model results are summarized in Table 3.

Table 3 Summary of results from logistic regression model

	Estimate	Std. Error	z Value	Pr(>|z|)	Odds Ratio
(Intercept)	-3.03E-01	1.52E-01	-1.997	0.0458	0.7383144
surf_dry	2.20E-01	5.41E-02	4.06	4.90E-05	1.2456535
alcohol	1.20E+00	7.20E-02	16.682	< 2e-16	3.3220822
age	-1.97E-03	9.80E-04	-2.007	0.0447	
gender_male	-2.32E-01	4.61E-02	-5.026	5.01E-07	0.7933247
nighttime	-2.80E-01	4.58E-02	-6.108	1.01E-09	0.7557937
AADT	-1.53E-05	7.23E-06	-2.121	0.0339	
radius	-7.30E-06	4.10E-06	-1.779	0.0752	
lane_width	4.44E-03	1.29E-02	0.345	0.73	
shoulder_width	6.60E-03	9.53E-03	0.692	0.489	

Estimate of coefficients represent how likely the factor will contribute to a rural two-lane curve crash as a fatal or injury crash than a simple property damage only crash. A positive coefficient indicates that the corresponding variable increases the likelihood of fatality or injury in rural two-lane curve crash rather than property damage crash, whereas a negative estimated coefficient indicates the reverse. The p-value (in the form of Pr(>|z|)) estimates the strength of the result. Odds ratio quantifies how strongly the presence or absence of the factor is associated with the presence or absence of its opposite factor in the risk of being involved in fatal or injury crash than PDO crash on rural two-lane curves. Odds ratio is only applicable for dichotomous variable, not to continuous variables like AADT or curve radius.

From Table 3, these following points on interpreting the results and their implications can be made:

- It is evident that alcohol involvement contributes to the likelihood of a crash being fatal or injury on rural two-lane curve. Although only 1,040 crashes were recorded as involved with alcohol, high odds ratio suggests that KI (killed and injury) crashes are closely related to drinking and driving.

- On rural two-lane curves, female drivers are more likely to involve in KI crash than a PDO crash. Male drivers are predominantly involved in total crashes, but when a crash occurs on curve, a female driver is more likely to be involved with KI crashes than male.

- Interestingly, nighttime crashes are less likely to involve a fatality or injury when it comes to rural two-lane curve crashes.

- The older a driver is the less likely for a KI crash on curves. Younger drivers are prone to KI crashes on rural two-lane curves.

- AADT doesn’t have a close relationship with KI crashes on curves, which maybe partially explained by low AADT on two-lane roadways analyzed here.

- Lane width and shoulder width are not contributory factors to the risk of having a KI crash on rural two-lane curve. Wider lane and shoulder are supposedly to reduce the risk of having a severe curve crash, which is not revealed in this study.

CONCLUSIONS

Rural two-lane roadways have more fatal crashes than any other type of roadways in Louisiana. The 79% of total curve crashes on rural two-lane roadways are single vehicle crashes. Curves on rural two-lane roadways significantly possess more crash risk than tangent segments and intersections do. About 45% of curvature fatal crashes happened on curve with radius under 800 feet. To reduce fatalities, attentions must be paid on crash countermeasures for curves on rural two-lane roadways. Many countermeasures, such as chevron signs, shoulder and centerline rumble strips have been approved effective, since visibity has been identified as a signifcant issue in the crash risk analysis. Location-specific actions may be needed on individual curve analysis.

RECOMMENDATIONS

This research demonstrates how vulnerable crash locations can be identified through filtering process depending on the crash types in focus. A method is recommeded to be developed to take into account of all these factors with focus on roadway design. The roadway features might include not only geometric elements but also forgiving roadwayside design elements, such as available clear zone, barrier design, drainage design, sign post breakaway design. Many low cost crash countermeasures can be developed for Louisiana roadways by the research team in the past. Information related to cost of proposed low cost countermeasures and expected number of crashes are required to estimate the feasibility of the countermeasures. A statistical model can also be developed to differntiate the potential risk of identified high risk locations comparing with typical low risk locations.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AADT	Annual Average Daily Traffic
DOT	Department of Transportation
FHWA	Federal Highway Administration
HRL	High Risk Location
HSM	Highway Safety Manual
IASP	Identification of Hazard Locations and Ranking of Measures to Improve Safety on Local Rural Roadways (Italian acronym IASP)
KI	Killed or Injury
LADOTD	Louisiana Department of Transportation and Development
usRAP	United States Road Assessment Program

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Appendix A: R-Code for The Logistic Regression Model to Identify Contributing Factors of Curve Crashes

```
# start

# reading the csv file which contains the data

try.lott <- read.csv('C:/Users/Ashifur/Documents/R/curve
info_4.csv',header=T,na.strings=c(""))

# checking the data for blank cells
sapply(try.lott,function(x) sum(is.na(x)))

# checking the data for number of unique data for each variable
sapply(try.lott, function(x) length(unique(x)))

# using a library to take care of missing values
# installing the package Amelia
library(Amelia)

# taking a look at missing value summary on a chart
missmap(try.lott, main = "Missing values vs observed")

# selecting the range of data to be analyzed from the csv file
data <- subset(try.lott,select=c(26,28,29,30,31,32,34,35,36,37))

# populating the missing ages of drivers by the mean
data$age[is.na(data$age)] <- mean(data$age,na.rm=T)

test <- data

# using the logit model
model <- glm(KSI ~.,family=binomial(link='logit'),data=test)
summary(model) # shows summary of the results

# showing the odds radio and interval of the ratio
exp(cbind(Odds_and_OR=coef(model), confint(model)))
```

APPENDIX B: Fatal Crashes on Rural Two-Lane Curves

Table 4 Fatal crashes on rural two-lane curves with the contributing factors analyzed

surf_dry	alcohol	age	gender	nighttime	AADT	radius	lane_width	shoulder_width
0	1	44	1	0	7000	844	13	3
1	1	33	1	1	5000	13771	12	8
1	0	50	1	1	2500	18857	12	10
1	1	21	1	1	1250	4744	12	3
1	1	31	1	0	12100	1254	12	4
1	1	49	1	1	1790	2455	12	4
0	0	31	1	1	3400	5610	10	6
1	1	38	0	1	3600	1088	11	4
1	1	33	1	0	4200	3465	12	4
1	0	38	1	1	800	5079	10	4
1	0	34	1	1	3800	3975	12	4
0	1	42	0	0	2400	22307	12	10
1	1	26	1	1	7700	8988	12	8
1	0	38	1	1	4200	707	11	4
1	1	61	1	1	2300	2146	12	3
0	1	31	1	0	2100	2408	10	4
1	1	46	0	1	800	4530	11	5
1	0	86	1	0	1310	6945	14	1
1	0	70	1	0	1230	1211	10	3
1	1	69	1	1	3700	2040	12	10
1	0	80	1	0	3800	2302	10	3
1	0	61	1	0	1280	13669	11	3
1	1	44	1	1	10700	2227	12	8
1	1	18	0	1	3700	2053	12	2
1	0	36	1	1	6100	2857	11	4
1	1	27	0	1	4600	6095	12	3
1	1	38	0	1	460	134	10	5
1	0	39	1	0	4300	757	11	8
1	0	25	1	1	3600	5576	12	5
1	0	45	1	0	790	292	10	2
1	0	23	1	1	2500	2867	12	10
1	1	27	1	1	4600	2287	12	3
1	0	90	1	0	1980	1653	11	5
1	1	45	1	1	250	117	9	4
1	0	40	0	1	2800	3132	11	2

surf_dry	alcohol	age	gender	nighttime	AADT	radius	lane_width	shoulder_width
1	0	35	1	0	2800	4133	13	5
1	1	52	1	1	1810	1042	11	4
1	1	29	1	0	2200	1154	11	8
1	1	33	1	0	230	273	10	4
1	1		1	1	1450	4161	24	6
1	0	15	1	1	1100	1333	10	6
0	0	22	1	0	1400	1614	12	4
0	0	18	1	1	1200	2275	10	2
1	1	49	1	0	6300	1486	12	6
1	1	20	1	1	2800	3384	11	3
1	1	18	0	0	11200	8557	12	2
1	0	20	1	0	3100	2585	12	4
1	1	33	0	0	2800	594	11	3
1	1	19	1	1	840	1655	11	4
1	0	51	0	1	1230	3026	10	3
1	1	32	1	0	5500	1022	11	4
1	1	22	1	0	1850	1141	12	4
1	0	44	1	0	2200	533	11	3
1	0	18	1	1	790	522	11	2
1	1	27	1	1	5200	898	11	4
0	0	53	1	0	4400	26126	12	4
1	1	20	0	0	3000	15471	10	4
0	1	33	1	1	4600	3184	11	8
1	1	36	1	0	8000	6014	12	8
0	0	54	0	0	1490	3076	10	3
1	0	25	1	1	750	2915	10	2
1	0	43	1	1	5500	5847	12	10
1	1	52	1	1	1100	1804	12	4
1	1	43	1	0	9000	7285	12	8
1	1	50	0	1	590	1541	10	4
1	1	31	1	1	410	1547	10	5
1	0	24	0	0	3100	2008	12	5
1	0	34	1	0	4100	14143	11	5
1	1	30	1	1	430	1038	10	2
0	1	31	0	0	1900	1319	10	5
0	1	51	1	1	4900	12785	12	9
1	1	46	0	1	16500	5793	12	10
0	0	19	1	1	7200	30769	12	8
1	1	47	1	1	1800	866	10	5
0	1	35	1	1	8800	1164	12	10

surf_dry	alcohol	age	gender	nighttime	AADT	radius	lane_width	shoulder_width
1	1	24	1	0	5000	16615	12	7
1	1	44	1	1	5100	12639	12	8
1	0	32	1	1	4700	2023	12	7
1	0	48	1	1	4600	18329	12	10
1	0	20	0	0	5200	838	12	6
1	1	23	1	1	1580	740	13	4
0	1	29	1	1	600	718	10	4
1	1	59	1	1	5000	3936	12	8
1	1	51	1	1	520	12513	11	3
1	1	28	1	1	3500	1172	12	6
1	0	70	1	0	7700	10238	12	8
1	1	40	0	1	1390	1166	12	5
1	0	19	1	1	1640	1203	10	3
1	0	43	1	0	5000	24064	12	8
1	0	54	1	1	6100	6577	13	4
1	1	20	1	0	3100	3133	11	4
0	0	54	1	1	2000	4603	11	6
0	0	34	1	1	4500	11515	12	10
1	0	53	1	1	1090	1950	12	5
1	1	20	1	0	1140	723	10	7
1	1	25	1	1	1890	2299	11	0
1	0	30	1	1	1910	3267	10	3
1	1	45	1	0	8300	284	13	4
1	1	20	1	1	1340	4487	11	5
1	1	25	0	1	7200	5839	12	8
1	1	27	0	1	4500	1642	12	8
1	1	52	1	0	5900	911	10	3
1	0	56	0	0	7200	29112	12	6
1	0	22	1	0	2600	998	11	2
1	1	22	0	0	820	944	10	4
1	1	48	1	1	1590	1265	12	4
1	0	54	0	1	4900	1295	12	8
1	1	34	1	0	450	404	11	5
1	1	49	1	1	8400	2333	12	6
1	0	77	1	1	900	771	10	4
1	1	68	1	1	3100	914	12	5
1	1	65	1	0	2000	18411	12	5
1	1	62	1	1	4500	592	11	5
1	0	16	1	1	1810	2908	12	8
1	1	48	1	1	11700	1049	13	5

surf_dry	alcohol	age	gender	nighttime	AADT	radius	lane_width	shoulder_width
1	1	15	1	1	1970	606	11	3
0	1	20	1	1	9000	3576	12	8
1	1	22	1	1	2200	344	11	2
0	0	23	1	1	2100	1293	12	3
1	1	34	1	1	2600	9406	12	10
1	1	72	0	0	1390	1166	12	5
1	0	52	1	1	700	3602	10	4
1	1	44	1	1	800	98	10	3
1	1	56	1	0	1340	4581	12	3
1	0	47	0	0	1300	1743	10	3
1	1	21	1	1	4500	928	10	4
1	0	35	1	0	14000	894	12	6
1	0	42	1	0	3200	2210	11	8
1	1	31	0	0	1000	1679	12	7
1	1	24	1	1	820	1091	11	3
1	1	72	0	0	3400	7696	12	8
1	1	35	1	1	2800	14915	10	5
1	0	86	1	0	2500	2277	12	8
1	1	64	1	1	2800	1499	11	2
0	1	31	0	1	3700	1357	10	3
1	1	41	1	1	1890	4549	12	6
1	1	22	1	1	1270	5923	10	4
0	1	47	1	1	440	905	10	4
1	1	34	1	1	1300	1062	12	5
1	1	19	0	0	5700	11048	12	8
1	1	50	1	1	1580	1461	11	4
1	0	72	1	0	3000	7419	12	4
1	0	74	0	0	5100	5859	12	6
0	0	45	1	1	5100	2332	12	8
1	1	56	1	0	1440	793	12	5
1	1	53	1	0	4200	3516	13	3
1	0	23	1	1	8800	6806	12	10
1	1	35	1	1	2000	1959	10	4
1	1	30	1	1	2000	1005	10	3
1	1	21	1	0	19800	6938	12	5
1	0	32	1	0	490	3186	11	2
1	1	57	1	0	2200	853	10	4
0	0	13	0	1	2300	8226	11	3
1	0	23	1	1	1110	19839	10	1
1	1	36	1	1	250	689	11	2

surf_dry	alcohol	age	gender	nighttime	AADT	radius	lane_width	shoulder_width
1	1	46	1	1	4200	982	13	3
1	1	28	1	1	1480	17630	11	4
1	1		1	1	6800	1210	11	4
1	1	53	0	0	171	11826	10	3
1	1	33	1	1	3700	895	13	5
1	1	39	1	1	1820	1413	11	3
1	0	22	0	0	4700	5442	12	2
1	0	44	1	1	9000	2952	12	8
0	0	26	0	1	5600	1479	11	4
1	0	20	0	0	1540	808	12	3
1	1	37	0	1	5300	1416	11	7
1	1	22	0	1	2600	9406	12	10
1	0	50	1	1	5700	2202	12	8
1	1	43	1	1	1110	2157	12	5
1	1	22	1	1	970	11379	11	7
1	1	24	1	1	7200	844	13	3