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Safety Performance Functions for Rural Two-Way Stop-Controlled Intersections

--Manuscript Draft--

Full Title:	Safety Performance Functions for Rural Two-Way Stop-Controlled Intersections
Abstract:	Rural intersection safety continues to be a crucial issue throughout the United States. More than 20 percent of all traffic fatalities in the United States occur at intersections, and over 80 percent of intersection-related fatalities in rural areas occur at unsignalized intersections. The first edition of Highway Safety Manual (HSM) has already published the crash prediction models based on the intersection data from several states. Considering each state has unique situations, this paper introduces a safety model development for two-way stop-controlled intersections on rural two-lane highway. After a lenthy data verification process, totally 2,658 rural stop-controlled intersections including both three-leg (3T) and four-leg (4T) from all Parishes (counties) in Louisiana were used for the model development. A series of safety performance functions were developed with Zero-inflated Poisson (ZIP) models with the most recent five-year crash data. The results indicate thatgreater curve radiuses of major roads, greater curve lengths of major roads, greater lane widths of minor roads, and higher speed limits of major roads led to significantly smaller expected crash frenquencies for both 3ST and 4ST intersections. However, unlike 4ST intersections, exclusive right-turn lanes increase the likelihood of crashes at 3ST intersections. In addition to traffic volume,intersections located in the middle of curves led to significantly greater crash occurrences. The results of Louisiana specific models are different from that of HSM models and the difference varies by AADT. The data sources, sample size, modeling structure, and the direct variable selection could have contributed to the difference as well.
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ABSTRACT

Rural intersection safety continues to be a crucial issue throughout the United States. More than 20 percent of all traffic fatalities in the United States occur at intersections, and over 80 percent of intersection-related fatalities in rural areas occur at unsignalized intersections. The first edition of Highway Safety Manual (HSM) has already published the crash prediction models based on the intersection data from several states. Considering each state has unique situations, this paper introduces a safety model development for two-way stop-controlled intersections on rural two-lane highway. After a lenthy data verification process, totally 2,658 rural stop-controlled intersections including both three-leg (3T) and four-leg (4T) from all Parishes (counties) in Louisiana were used for the model development. A series of safety performance functions were developed with Zero-inflated Poisson (ZIP) models with the most recent five-year crash data. The results indicate that greater curve radiuses of major roads, greater curve lengths of major roads, greater lane widths of minor roads, and higher speed limits of major roads led to significantly smaller expected crash frenquencies for both 3ST and 4ST intersections. However, unlike 4ST intersections, exclusive right-turn lanes increase the likelihood of crashes at 3ST intersections. In addition to traffic volume, intersections located in the middle of curves led to significantly greater crash occurrences. The results of Louisiana specific models are different from that of HSM models and the difference varies by AADT. The data sources, sample size, modeling structure, and the direct variable selection could have contributed to the difference as well.

Keywords: Safety performance function, intersections, two-way stop-controlled, rural two-lane highway, 3ST, 4ST

INTRODUCTION

Rural roadway safety continues to be a crucial issue throughout the United States. More than 20 percent of all traffic fatalities in the United States occur at intersections, and over 80 percent of intersection-related fatalities in rural areas occur at unsignalized intersections (*1*). At such intersections, vehicles stopping or slowing to turn create speed differentials between vehicles traveling in the same direction. This is particularly problematic on two-lane highways (*2*). Having an intersection on a horizontal curve could double the crash risk, because of combined challenges. Although the AASHTO states that "an intersection on a sharp curve should be avoided or designed to compensate for reduced sight distance", in design practice, it is often allowed to have intersections on horizontal curves, if other solutions are prohibitively expensive (*3*). Many such intersections were constructed after, or long after, the major roadway was built, in order to provide accessibility to a minor street. There are many intersections on horizontal curves, located on state-owned and locally-owned roads in Louisiana, based on our preliminary investigation. **Figure 1** shows a collision that occurred at a T-intersection (a popular intersection type on rural, two-lane roadways controlled by a stop sign) between a right-turning vehicle and a run-off-road (ROR) vehicle, trying to negotiate the curve.

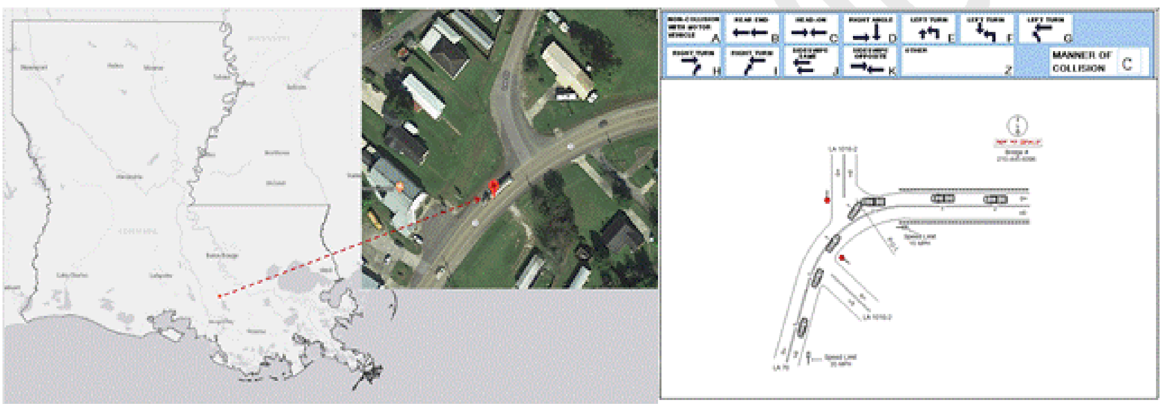

Figure 1 A typical example of an intersection on a curve

To get a better understanding of the influential factors on crash frequency and injuries, safety performance functions (SPFs) presented in the Highway Safety Manual (HSM) are useful tools to relate the number of crashes of different types or severities to site characteristics. These models always include traffic volume (Average Annual Daily Traffic, AADT), but also include site characteristics in the form of crash modification factors, such as lighting conditions and presence of turn lanes at intersections. It is recommended that these functions are either calibrated or re-estimated, using local data to improve their accuracy and precision (*4*). Several states, including Louisiana, have subsequently developed SPFs based on local data, which has revealed considerable, state-to-state variability in the accuracy of the HSM's SPFs. However, intersections on horizontal curves were not specifically investigated and considered in these models. Furthermore, the rural two-lane models were developed about 19 years ago (*5*). To fulfill the hefty goal established by Louisiana's Strategic Highway Safety Plan (SHSP) to reduce roadway departure, intersection, and non-motorized user fatalities and severe injuries by 50 percent by 2030, there is a clear need to further investigate intersection safety performance on rural, two-lane roads with geometric characteristics.

LITERATURE REVIEW

Safety performance of rural intersections has been conducted by many studies in the past. The HSM (2010) defines SPFs as regression models for estimating the predicted average crash frequency of individual roadway sections or intersections. In 2010, the AASHTO released a safety analysis software system, known as SafetyAnalyst. SafetyAnalyst is a cooperative effort by the Federal Highway Administration (FHWA), 27 participating states in the U.S., and interested local agencies. SafetyAnalyst "provides state-of-the-art analytical tools for use in the decision-making process to identify and manage a system-wide program of site-specific improvements to enhance highway safety by cost-effective means" (*6*). SafetyAnalyst uses a set of default SPFs developed using available data for four states, which include California, Minnesota, Ohio, and Washington. Considering different road characteristics across different jurisdictions, it is suggested to develop separate SPFs, based on the traffic and crash data of each state (*7*). To address issues associated with HSM model calibration, several states have developed their own intersection SPFs, including Illinois, Oregon, Virginia, Pennsylvania, and Michigan (*8*-*12*).

Various models were developed to study the relationship between crashes at rural intersections and contributing factors. Bauer and Harwood (*13*) applied multiple linear regression analysis in developing crash prediction models for at-grade intersections in California, using three years of crash data (1990 to 1992), as well as geometric design, traffic control, and traffic volume data. The multiple linear regression was used for urban four-leg stop-controlled (4ST) and signalized intersections, while Poisson and Negative Binomial (NB) regression were used for the remaining intersection types. Poisson and NB models have been used extensively in prior studies (*14*-*18*). The results indicated that roadway geometric, vehicular, and operational features had an effect on crash frequency. Therefore, those factors that significantly affect crashes should be given more attention in crash analyses at intersections (*19*).

The presence of horizontal curves adds complexity to intersections, and Kuciemba and Cirillo's studies have shown that safety is affected by the presence of horizontal curves in close vicinity of intersections (*20*). Vogt and Bared Vogt (1999) describes the development of a negative binomial regression model for three types of intersections on rural roads in California and Michigan, for the period of 1993 to 1995. The study involved 84 three-leg intersections (3ST), 72 four-leg intersections, and 49 signalized intersections. Degree of curve was found to increase the total number of crashes on three-leg intersections between four-lane major roads and two-lane stop-controlled minor roads (*15*). Savolainen and Tarko conducted a study for the Indiana Department of Transportation (INDOT) and found that curvature was a significant factor in the relative safety of intersections, where the intersection is two-lane two-way stop controlled, and the major road is a rural four-lane divided highway. NB models were developed to determine the statistical relationship between crash occurrence and intersection geometric characteristics. The same study stated that full curvature and superelevation increased crashes by 30 percent, in comparison to tangent intersections (*4*).

Recent rural intersection SPFs development in Pennsylvania also revealed the importance associated with roadway geometric characteristics for rural intersections. Donnell, Gayah, and Li developed SPF models for 3-leg and 4-leg rural intersections with minor street stop-controlled, all-way stop controlled, and signalized intersections. NB regression was used to develop these models. The SPFs included variables, such as major and minor AADTs, left and right shoulder width on the major and minor legs, paved width on major legs, and posted speed limits, among others. All of these studies show that calibrated SPFs based on the HSM predictive method, have considerably different precisions for different states (*11*).

There has been limited research using ZIP to model the expected crashes with large localized intersection database. In Louisiana, proximately one-third of total two-way stop-controlled (stop sign on minor roadway) intersections have zero crashes during the most recent five years. Consider that factor and the HSM model age, this research is aimed to develop a state-specific safety performance model to address the current need for safety improvement on rural two-lane highway intersections with stop sign on minor roadway.

DATA

Prior to the safety performance functions modeling, a huge effort was made to develop a comprehensive database based on the intersection crashes, traffic volume, and other relevant roadway characteristics for two-way stop-controlled intersections on Louisiana rural two-lane highways. The most recent five-year crash data (2013 to 2017) were used to reflect the latest highway safety conditions. As shown in **Figure 2,** there are several important steps in retrieving and merging different data files from Louisiana Department of Transportation and Development (LADOTD).

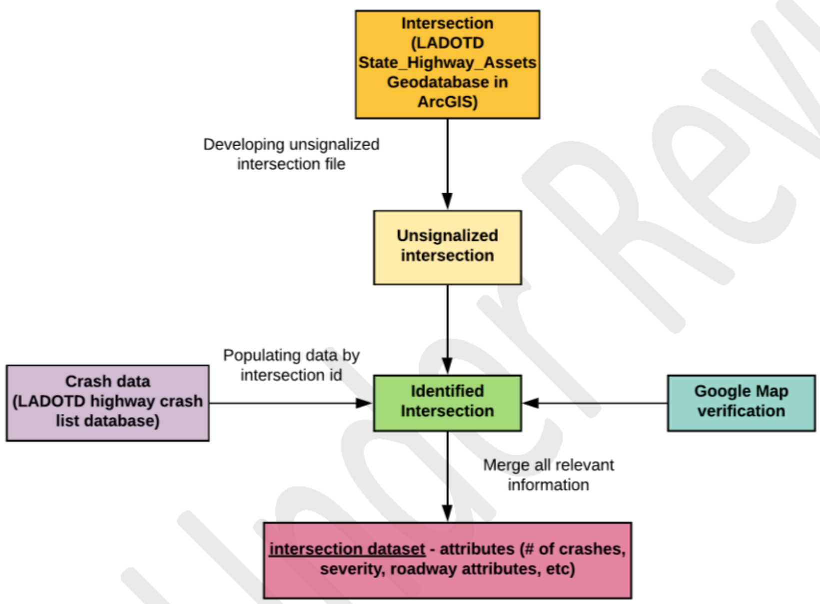

Figure 2 Database development flow chart

To assure the data accuracy, a significant effort was made to verify and correct the information presented in the data files shown in **Figure 2**. The shapfiles from the LADOTD *State_Highway_Assets Geodatabase* in ArcGIS format provide the spatial basis for gathering the necessary roadway attributes for the intersections, such as horizontal curve radius for major and minor roads, lane widths, number of intersection legs, speed limits, etc. The AADT data was obtained system-wide, for each rural intersection, from the LADOTD roadway inventory file. Satellite imagery and street-level imagery in Google Maps were utilized to exam the data accuracy intersection by intersection such as turning radiuses and type of traffic control. Further, additional information that was not otherwise included in the existing datasets, was manually collected, which includes the presence of left- and right-turn lane, and intersection locations (beginning of curve, or middle of curve). The LADOTD's crash database uses the ABCDE scale to describe severity level of crashes. ‘A’ indicates fatal injury, ‘B’, ‘C’, and ‘D’ indicate incapacitating or severe injury, non-incapacitating or moderate injury, and possible or compliant injury, respectively. ‘E’ represents that no injuries occurred in the crash. In this study, A, B, C, and D levels of severity were combined as fatal and injury crashes. The end product from the process illustrated in **Figure 2** is a comprehensive database containing information on intersection, roadway, and crash characteristics. The data process was facilitated by the intersection identification number and intersection name, used in the LADOTD system, which allowed data from different sources to be identified. Incomplete and, obviously, incorrect data (such as AADT entered as zero or blank) were removed. **Table 1** gives an overview of descriptive statistics of the intersections used in the model development.

Table 1 Overview of Rural Intersections

	Stop Sign on Minor Road (3T) (2,151 intersections)				**Stop Sign on Minor Road (4T) (507 intersections)**			
Variable	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
AADT								
Major road	2,616	2,463	55	22,000	2,757	2,362	91	18,600
Minor road	542	995	10	20,500	712	952	8	7,200
Curve Radius (ft.)								
Major road	520.0	725.3	0	3,222.0	356.8	690.4	0	2,483.1
Minor road	27.5	175	0	2,438.8	33.3	208.9	0	2,263.1
Curve length (ft.)								
Major road	187.7	396.2	0	2,701.7	93.1	268.7	0	1,822.5
Minor road	16.5	110.3	0	2,388.2	15.1	102.5	0	1,640.1
Lane width (ft.)								
Major road	11.6	0.8	8	16	11.6	0.7	10	16
Minor road	9.3	1.8	6	14	9.9	1.9	6	14
Speed limit (mph)								
Major road	49.5	8.4	25	55	47.2	9.9	25	65
Minor road	33.1	14.1	5	55	37.2	14.3	10	55
Intersection location (0 for tangent, 1 for intersection at beginning of a curve, 2 on middle of a curve)								
	0.660	0.796	0	2	0.408	0.704	0	2
Left-turn lane presence (0 for no, 1 for yes)								
	0.012	0.107	0	1	0.018	0.132	0	1
Right-turn lane presence (0 for no, 1 for yes)								
	0.007	0.086	0	1	0.014	0.117	0	1
Total crashes	1.200	2.556	0	47	2.50	4.064	0	37
Fatal and injury crashes	0.500	1.085	0	16	1.060	1.911	0	20
Property damage only crashes	0.767	1.753	0	31	1.418	2.473	0	21

METHODOLOGY

Given the nature of random, discrete, and non-negative crash data, the Poisson distribution has been shown to provide a better fit and has been used widely to model crash frequency data (*15, 16, 21-23*). The probability of y_i crashes occurring at a given intersection i, $P(y_i|\lambda_i)$, is shown in **Equation 1**:

$$P(y_i|\lambda_i) = \frac{e^{-\lambda_i}\lambda_i^{y_i}}{y_i!};\ y_i = 0,1,2,3\ldots \quad (1)$$

The relationship between the number of crashes at intersection i and the q parameter (X_{i1}, X_{i2},

X_{iq}) is shown in **Equation 2**:

$$\lambda_i = \exp\left(\beta_0 + \sum_{j=1}^{q} X_{ij}\beta_j\right) \quad (2)$$

Where, $\lambda_i =$ expected number of crashes per year at intersection i, X_i is the independent variables at intersection i, and β_j is a vector of estimable regression coefficients.

The Poisson regression model assumes that the mean of crash counts is equal to its variance (equal-dispersion). However, in much of the crash data, the variance is greater than the mean, well known as over-dispersion. For these cases, applying a Poisson regression model for intersection crash data would result in underestimation of the standard error of the regression parameters, which can, ultimately, lead to a biased selection of covariates. In some cases, excess zeros in crash data exist, considered to be a result of over-dispersion. In this study, 1,008 intersections had zero crashes during 2013 to 2017. The Poisson model cannot be used for these cases, as it cannot handle the over-dispersion, due to these high amount of zeros. To address this challenge, the ZIP model can be alternatively used. The ZIP model serves as a dual-state method for modeling data, characterized by a significant amount of zeros, or more zeros than one would expect in a traditional Poisson distribution. The ZIP model assumes that all zero counts come from two different processes: (i) the process generating excess zero count (zero-crash state) derived from a binary model and (ii) the process generating non-negative counts for intersection crashes including zero values, which estimated from the Poisson distribution (*22*). Suppose π_i is the probability that intersection i will exist in the zero-crash state, and $1 - \pi_i$ is the probability that crash counts are generated according to a Poisson model. Therefore, the probability distribution of the ZIP random variable is shown in **Equation 3**:

$$P(Y = y_i) = \begin{cases} \pi_i + (1-\pi_i)e^{-\lambda_i}; & y_i = 0 \\ (1-\pi_i)\frac{e^{-\lambda_i}{\lambda_i}^{y_i}}{y_i!}; & y_i > 0 \end{cases} \quad (3)$$

The probability of being in the zero-crash state, P_i, is often fitted using the losgistic regression model, as follows in **Equation 4**:

$$logit(P_i) = ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \sum_{j=1}^{q} Z_{ij}\beta_j \quad (4)$$

Where Z_{ij} is a function of intersection i, and β_j is a vector of estimable regression coefficients. The mean and variance of ZIP are given as follows in **Equation 5 and 6**:

$$E(Y) = \lambda_i(1-\pi_i) \quad (5)$$

$$Var(Y) = \lambda_i(1-\pi_i)(1+\lambda_i\pi_i) \quad (6)$$

RESULTS

The variable selection is based on extensive literature review and preliminary analysis of the data. Three models with same structure for three different crash severity levels, total, fatal and injury, and property damage only (PDO) crashes, are established for 3ST and 4ST intersections, respectively. NCSS data analysis statistical software was used for ZIP model estimation.

Three-Leg Two-Way Stop-Controlled Rural Intersections (3ST)

The ZIP model estimation results for total, fatal and injury, and PDO crashes occurring at 3ST rural intersections are shown in **Table 2**. Logarithm of ADT (Ln(ADT)) of major and minor roads, curve radius of major roads, curve length of major roads, lane width of minor roads, speed limit of major and minor roads, intersection location, and right-turn lane presence were found to be statistically significant with p value less than 5 percent . Out of these variables, Ln(ADT) of major and minor roads, speed limit of minor roads, intersection locations, and right-turn lane presence are positively related to intersection crashes. On the contrary, curve radius of major roads, curve length of major roads, lane width of minor roads, and speed limit of major roads have negative association with the expected intersection crashes.

Intersection crashes increase as traffic flow increases in all three different traffic severity levels, as expected. The results show that intersections with higher speed limits on minor roads tend to have higher probability of crashes occurring. However, higher speed limits on major roads are negatively related to expected fatal and injury crashes. Considering higher speed limit is always associated with higher AADT, the high speed limits should not be interpreted as a measure to reduce fatal and injury intersection crashes. Intersections on the middle of a curve had 11 percent more total crashes compared to intersections on a tangent. The expected total and PDO crashes decrease as curve radius and curve length on major roads increase, as well as lane widths of minor roads. The 3T intersections with right-turn lanes on major highway were found to have six percent more total crashes, 18 percent fatal and injury crashes, and five percent PDO crashes, relative to the intersections without right-turn lanes.

Four-Leg Two-Way Stop-Controlled Rural Intersections (4ST)

Table 3 summarizes the ZIP model results for total, fatal and injury, and PDO crashes at four-leg two-way stop-controlled rural intersections. Similar to three-leg intersections, intersection crashes increase as traffic flow increases in all three different traffic severity levels. The probability of having total and PDO crashes decreases as curve radius on major roads increases, and the probability of having total and fatal and injury crashes decreases as curve length on major roads and minor road lane widths increase. The results show that intersections with higher speed limits on major roads tend to have lower probability of occurring fatal and injury crashes. 4ST intersections with right-turn lanes were found to have 45 percent smaller total crashes and 44 percent smaller PDO crashes, relative to intersections without right-turn lanes. Intersection locations were not found to significantly affect crash frequency, except for PDO crashes.

TABLE 2 Coefficients for 3ST Rural Intersection Model

Variable	Total Crashes				Fatal and Injury Crashes				PDO Crashes			
	Coefficient	Std. Error	Z Value	p-value	Coefficient	Std. Error	Z Value	p-value	Coefficient	Std. Error	Z Value	p-value
Non-zero crash probability state as Poisson function												
(Intercept)	-6.02700	0.43135	-13.97	0.0000	-6.44061	0.89932	-7.16	0.0000	-6.48233	0.62053	-10.45	0.0000
Ln(ADT)												
Major road	0.48200	0.03343	14.42	**0.0000**	0.47977	0.06462	7.43	**0.0000**	0.52604	0.04993	10.54	**0.0000**
Minor road	0.33848	0.02484	13.62	**0.0000**	0.34262	0.04734	7.24	**0.0000**	0.35287	0.03581	9.85	**0.0000**
Radius												
Major road	-0.00019	0.00005	-3.60	**0.0003**	-0.00006	0.00009	-0.61	0.5389	-0.00017	0.00008	-2.10	**0.0354**
Minor road	-0.00001	0.00014	-0.07	0.9475	-0.00003	0.00029	-0.12	0.9038	-0.00007	0.00018	-0.42	0.6716
Curve length												
Major road	-0.00023	0.00008	-2.84	**0.0046**	-0.00018	0.00014	-1.33	0.1820	-0.00006	0.00014	-0.41	0.6813
Minor road	-0.00008	0.00026	-0.31	0.7567	-0.00030	0.00049	-0.61	0.5412	-0.00015	0.00031	-0.47	0.6376
Lane width												
Major road	-0.00497	0.03300	-0.15	0.8802	-0.08383	0.06920	-1.21	0.2257	-0.02967	0.04617	-0.64	0.5204
Minor road	-0.06709	0.02344	-2.86	**0.0042**	-0.01339	0.03839	-0.35	0.7273	-0.06878	0.03290	-2.09	**0.0365**
Speed limit												
Major road	-0.00069	0.00321	-0.22	0.8292	-0.01326	0.00576	-2.30	**0.0213**	-0.00086	0.00451	-0.19	0.8490
Minor road	0.00636	0.00259	2.46	**0.0140**	0.00625	0.00502	1.24	0.2133	0.00374	0.00367	1.02	0.3082
Intersection location	0.10881	0.04556	2.39	**0.0169**	0.15270	0.09069	1.68	0.0922	0.10445	0.06813	1.53	0.1252
Left-turn lane presence	0.05230	0.10172	0.51	0.6072	0.30268	0.19140	1.58	0.1138	0.13930	0.12556	1.11	0.2672
Right-turn lane presence	0.63741	0.12976	4.91	**0.0000**	0.98269	0.20261	4.85	**0.0000**	0.41414	0.18179	2.28	**0.0227**
Zero crash probability state as logistic function												
(Intercept)	6.25941	1.33161	4.70	**0.0000**	5.97884	2.15012	2.78	0.0054	5.30141	1.62498	3.26	0.0011
Ln(ADT)												
Major road	-0.23091	0.10347	-2.23	**0.0256**	-0.15316	0.17459	-0.88	0.3803	-0.07414	0.14325	-0.52	0.6048
Minor road	-0.05159	0.08163	-0.63	0.5273	0.06353	0.12806	0.50	0.6198	-0.06124	0.09891	-0.62	0.5358
Radius												
Major road	-0.00023	0.00019	-1.17	0.2425	0.00007	0.00025	0.26	0.7927	-0.00010	0.00026	-0.38	0.7029
Minor road	0.00056	0.00050	1.12	0.2606	0.00085	0.00086	0.99	0.3214	0.00001	0.00057	0.02	0.9806
Curve length												
Major road	0.00012	0.00028	0.42	0.6749	-0.00166	0.00092	-1.79	0.0734	-0.00062	0.00066	-0.95	0.3444
Minor road	-0.00033	0.00082	-0.40	0.6861	-0.00144	0.00164	-0.88	0.3803	0.00048	0.00083	0.58	0.5611
Lane width												
Major road	-0.28892	0.10922	-2.65	**0.0082**	-0.17739	0.17185	-1.03	0.3020	-0.20373	0.12835	-1.59	0.1124
Minor road	-0.01170	0.06794	-0.17	0.8633	-0.09914	0.08951	-1.11	0.2680	-0.07793	0.08526	-0.91	0.3607

Speed limit												
Major road	-0.01600	0.00953	-1.68	0.0932	-0.03836	0.01315	-2.92	**0.0035**	-0.01725	0.01130	-1.53	0.1267
Minor road	-0.02083	0.00830	-2.51	**0.0121**	-0.02156	0.01305	-1.65	0.0985	-0.02421	0.01031	-2.35	**0.0188**
Intersection location	-0.03657	0.14902	-0.25	0.8061	0.12539	0.25968	0.48	0.6292	-0.06851	0.21051	-0.33	0.7448
Left-turn lane presence	-0.90651	0.74719	-1.21	0.2250	-1.30725	0.96186	-1.36	0.1741	-1.07121	0.79116	-1.35	0.1757
Right-turn lane presence	1.17109	0.68024	1.72	0.0851	0.75055	0.77424	0.97	0.3323	1.58476	0.74182	2.14	**0.0327**
Log-likelihood	-3,090.3465				-1,833.8146				-2,304.4858			
AIC	6,236.6931				3,723.6292				4,664.9717			

TABLE 3 Coefficients for 4ST Rural Intersection Model

Variable	Total Crashes				Fatal and Injury Crashes				PDO Crashes			
	Coefficient	Std. Error	Z Value	p-value	Coefficient	Std. Error	Z Value	p-value	Coefficient	Std. Error	Z Value	p-value
Non-zero crash probability state as Poisson function												
(Intercept)	-4.71083	0.61632	-7.64	0.0000	-7.10434	1.06554	-6.67	0.0000	-4.42287	0.83828	-5.28	0.0000
Ln(ADT)												
Major road	0.28316	0.04601	6.15	**0.0000**	0.20040	0.07661	2.62	**0.0089**	0.27922	0.06977	4.00	**0.0001**
Minor road	0.37274	0.03417	10.91	**0.0000**	0.38992	0.05783	6.74	**0.0000**	0.38042	0.05080	7.49	**0.0000**
Radius												
Major road	-0.00021	0.00008	-2.60	**0.0094**	-0.00022	0.00013	-1.68	0.0923	-0.00034	0.00011	-2.97	**0.0029**
Minor road	-0.00011	0.00020	-0.52	0.6038	-0.00012	0.00037	-0.32	0.7489	-0.00060	0.00032	-1.87	0.0616
Curve length												
Major road	-0.00054	0.00013	-4.31	**0.0000**	-0.00053	0.00019	-2.72	**0.0065**	-0.00036	0.00019	-1.93	0.0532
Minor road	-0.00060	0.00047	-1.26	0.2087	-0.00006	0.00107	-0.06	0.9552	-0.00060	0.00070	-0.86	0.3881
Lane width												
Major road	-0.00757	0.04586	-0.17	0.8689	-0.02519	0.08012	-0.31	0.7532	-0.01759	0.06818	-0.26	0.7965
Minor road	-0.07827	0.02748	-2.85	**0.0044**	-0.17690	0.04401	-4.02	**0.0001**	-0.06195	0.03981	-1.56	0.1196
Speed limit												
Major road	-0.00537	0.00466	-1.15	0.2498	-0.03300	0.00915	-3.60	**0.0003**	-0.00347	0.00626	-0.55	0.5791
Minor road	0.00523	0.00367	1.43	0.1536	0.00566	0.00603	0.94	0.3484	0.00905	0.00507	1.78	0.0743
Intersection location	0.00511	0.07506	0.07	0.9458	0.14084	0.13014	1.08	0.2791	0.24328	0.10198	2.39	**0.0171**
Left-turn lane presence	-0.07035	0.17213	-0.41	0.6828	0.07607	0.23820	0.32	0.7495	-0.34861	0.31291	-1.11	0.2652
Right-turn lane presence	-0.57965	0.23252	-2.49	**0.0127**	-0.02317	0.39044	-0.06	0.9527	-0.59859	0.30193	-1.98	**0.0474**
Zero crash probability state as logistic function												
(Intercept)	13.51852	2.48407	5.44	0.0000	8.28804	3.59763	2.30	0.0212	9.68895	2.49190	3.89	0.0001
Ln(ADT)												
Major road	-0.93510	0.20190	-4.63	**0.0000**	-1.23330	0.30392	-4.06	**0.0000**	-0.60282	0.20462	-2.95	**0.0032**
Minor road	-0.35130	0.15142	-2.32	**0.0203**	-0.08403	0.23205	-0.36	0.7173	-0.33251	0.15422	-2.16	**0.0311**
Radius												
Major road	-0.00075	0.00043	-1.75	0.0803	-0.00167	0.00101	-1.65	0.0987	-0.00097	0.00048	-2.02	**0.0435**
Minor road	-0.02160	17.14584	0.00	1.0000	-0.14353	19.79092	-0.01	0.9942	-0.00222	19.81604	0.00	0.9999
Curve length												
Major road	0.00029	0.00079	0.37	0.7101	0.00073	0.00122	0.60	0.5487	-0.00127	0.00109	-1.17	0.2426
Minor road	-0.07723	9.17844	0.00	1.0000	0.12136	8.29528	0.01	0.9947	-0.09394	9.23429	0.00	0.9981
Lane width												

Major road	-0.45614	0.19982	-2.28	**0.0224**	-0.23119	0.29717	-0.78	0.4366	-0.47857	0.21278	-2.25	**0.0245**
Minor road	0.21179	0.11165	1.90	0.0578	0.40681	0.19116	2.13	**0.0333**	0.25338	0.12251	2.07	**0.0386**
Speed limit												
Major road	-0.01269	0.01768	-0.72	0.4729	0.04049	0.04138	0.98	0.3278	0.00972	0.01923	0.51	0.6132
Minor road	-0.04166	0.01674	-2.49	**0.0128**	-0.07233	0.02829	-2.56	**0.0106**	-0.02731	0.01646	-1.66	0.0971
Intersection location	0.36016	0.34755	1.04	0.3001	0.57928	0.65642	0.88	0.3775	0.99896	0.38746	2.58	**0.0099**
Left-turn lane presence	-14.43705	7.30381	-0.01	0.9954	-19.08350	5.90132	0.00	0.9981	-0.25646	3.62518	-0.07	0.9436
Right-turn lane presence	-15.92645	6.69988	-0.01	0.9956	-3.19380	1.54574	-2.07	**0.0388**	-19.18249	8.27459	-0.00	0.9986
Log-likelihood	-1,080.7159				-651.8427				-768.7804			
AIC	2,217.4318				1,359.6854				1,593.5607			

One way to assess the quality of SPFs is to use goodness of fit tests such as Cumulative Residual (CURE) plots. In the CURE method, the cumulative residuals (the difference between the observed and predicted values for each site) are plotted in increasing order for each covariate separately. Also plotted are graphs of the 95 percent confidence limits. If there is no bias in the model, the plot of cumulative residuals should stay inside of these limits. CURE plots for the SPFs for major road AADT versus total crashes on 3ST and 4ST intersections are provided in **Figure 3** and **Figure 4**, respectively. The results show that the overall fit is good for this covariate in that the cumulative residuals oscillate around the value of zero and lie between the two standard deviation boundaries, except for AADT equals to 2,200 (3ST) and AADT between 7,000 and 8,000 (4ST).

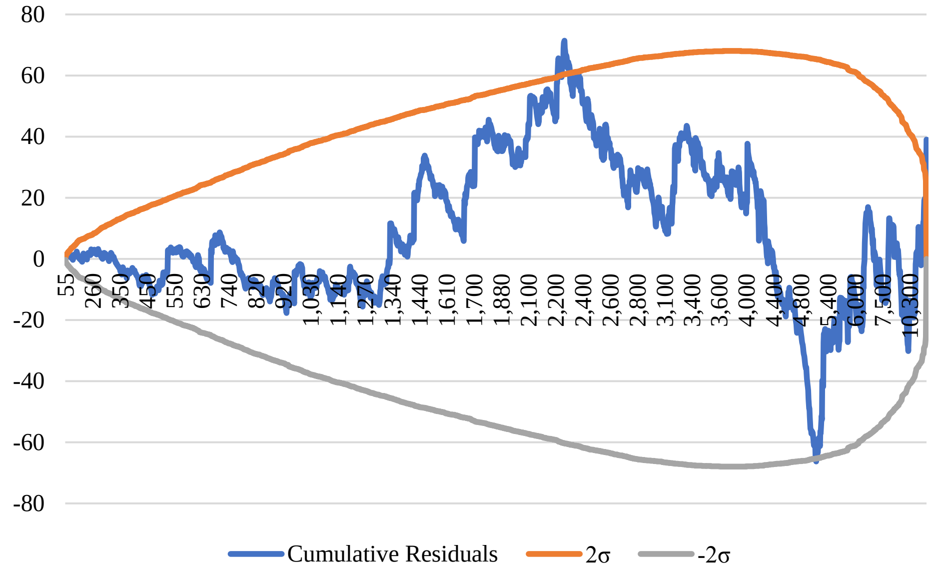

Figure 3 CURE Plot major roadway AADT vs total crashes on 3ST intersections

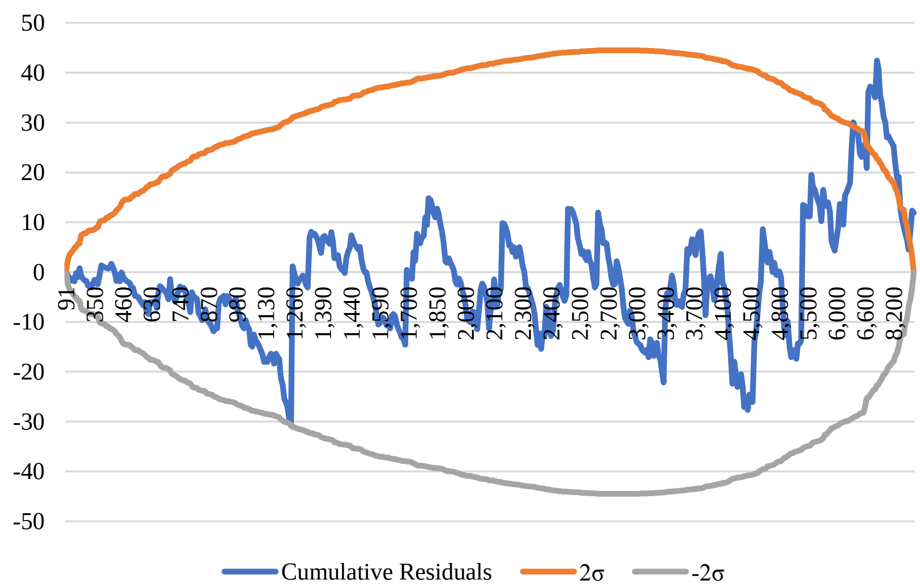

Figure 4 CURE Plot major roadway AADT vs total crashes on 4ST intersections

Comparison to HSM Models

A graphical representation of both the Louisiana-specific modeld for total crashes are shown in **Figure 5** and **Figure 6** along with the respective HSM base models. The comparison is made for minor roadway AADT at 500 and 1,000, respectively. For 3ST intersections, the expected crashes from the HSM model are smaller than that of the Louisiana model at lower major roadway volumes, but begins to top the results of the Louisiana model when the major roadway AADT exceeds 12,000 (minor road AADT=500) and 8,200 (minor road AADT=1,000). For the 4ST intersection, the expected crashes from the HSM models is higher than that of the Louisiana specific model when the AADT on major roadway exceed 2,200 (minor road AADT=500) and 1,000 (minor road AADT=1,000). At the low end of major road volumes (AADT 400), the HSM underpredicts 4ST crashes by approximately 15 percent, compared to the Louisiana-specific model. At higher volumes (7,000 AADT), the HSM's results are much higher than that of the Louisiana model.

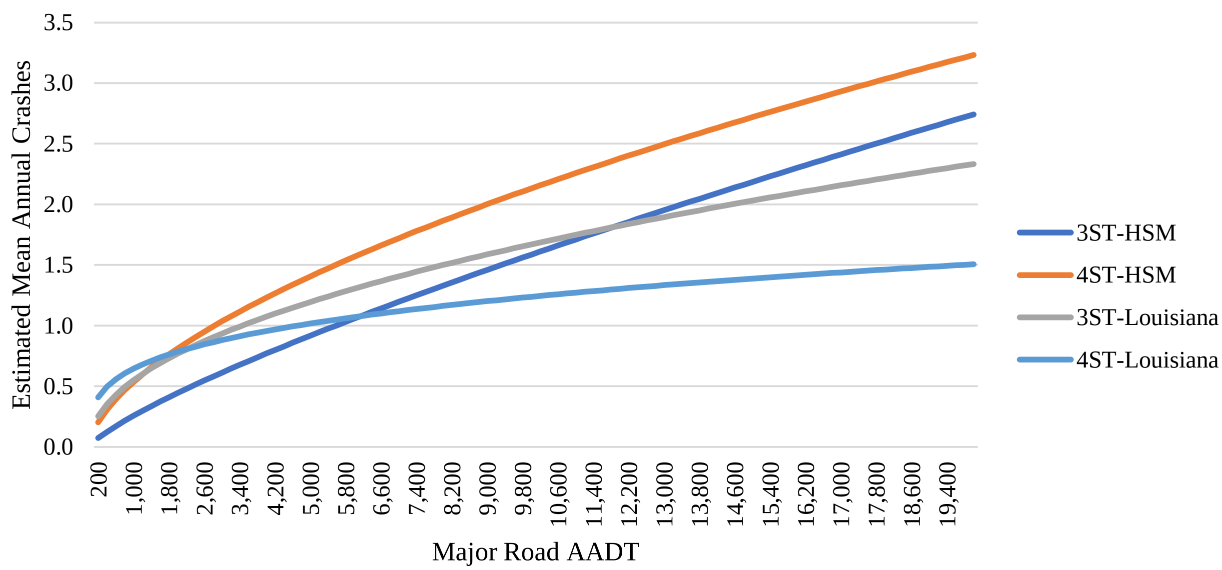

Figure 5 Model results for total crashes on 3ST and 4ST intersections for minor roadway AADT=500

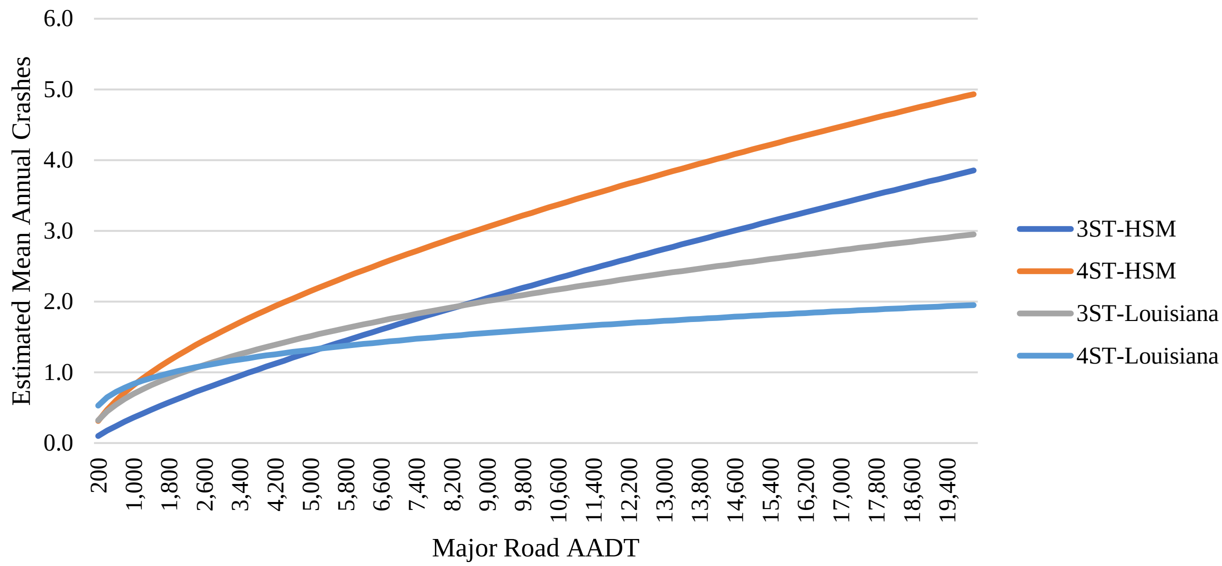

Figure 6 Model results for total crashes on 3ST and 4ST intersections for minor roadway AADT=1,000

DISCUSSIONS

The results from ZIP modes show that in addtion to AADTs, curve radius and length, lane width of minor roadway and speed limit have impact on the intersection safety. The greater curve radius and length of major roads, and wider lane width of minor road, lead to smaller expected crash frequencies for both 3ST and 4ST intersections. However, right-turn lane presence unexpectedly increases the likelihood of crashes at 3T intersections, on contrary to the results of 4ST. It is also surpise to see intersections located in the middle of a curve results a higher expected crash for both 3ST and 4ST intersections. Another surprising result is speed limit; the higher speed limit on minor roadway is detrimental to safety but is not on major highways.

There are several potential causes for the difference between the results from the Louisiana-specific models and the results from the uncalibrated HSM base models. The HSM models were developed long time ago, thus may not present the current roadway safety situation, since lots of effort and funding have been invested into crash reduction, particularly on rural two-lane highways that has been long recognized as the type of roadway with the highest traffic fatality rate. The data sources, sample size, modeling structure, and the direct variable selection could have contributed to the difference as well. The HSM models did not consider excess zeros existance in crash data. There are more than one-third of total two-way stop-controlled (stop sign on minor roadway) intersections having zero crashes in the five-year study period. It is believed that the Louisiana-specific models work better than uncalibrated HSM base models.

FUTURE WORK

Following the discoveries presented in this paper, the research team will continuously examine the validality of the model and explore the potential interrelationship between the selected varibles, such as investigating the impact of right-lane presences and speed limitss on the expected crashes at different AADT level for both major and minor roadways.

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception: Ming Sun and Xiaoduan Sun; methodology: Ming Sun; data collection: Ming Sun and Mousumy Akter; analysis and interpretation of results: Ming Sun and Ashifur Rahman; draft manuscript preparation: Ming Sun, Xiaoduan Sun and Subasish Das. All authors reviewed the results and approved the final version of the manuscript.

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