FINDING A NEW SAFETY PERFORMANCE FUNCTION FOR TWO-WAY, TWO-LANE HIGHWAYS IN RURAL AREAS

By

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Abstract

For over 30 years, crash prediction models (CPMs) have been created and analyzed, with the objective being to find the best way to predict where crashes will occur and how to prevent them in the future. This has recently become a popular discussion and reality since the release of the Highway Safety Manual (HSM) and its CPM in 2010. However, many are still hesitant to begin implementing these methods as the accuracy can vary. This is a study testing the original HSM's CPMs to state-specific calibrated CPMs, and new, independent CPMs to find the best model for rural, two-lane highways in Kansas.

Almost 300 miles of highway geometric data were collected to create these new models using negative binomial regression. The most significant variables in each model were found to consistently be lane width and roadside hazard rating. These models were compared against CPMs calibrated to be used on the HSM using nine validation segments. A difficulty to overcome was the large amount of animal-related crashes, as they account for 58.9 percent of crashes on Kansas highways. Removing those from the equation showed a large improvement in accuracy compared to other models created.

Acknowledgements

This thesis would not have been possible without the help and support of many people, who I would like to take the time to thank here. First of all I would like to thank Dr. Schrock for the support and guiding me throughout the whole process of my research. I would also like to thank my other two committee members, Dr. Mulinazzi and Dr. Parsons, for their support and input on this research.

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CHAPTER I - INTRODUCTION

In the past, engineers have relied on engineering judgment and design guidebooks, like A Policy on Geometric Design of Highways and Streets (the Green Book), to dictate what improvements to make when designing highways. This has improved the safety and led to a decline in fatal crashes over the last few decades with the current fatal and injury crash rate at 1.13 per 100 million vehicle miles traveled in 2009, which continues to decline in United States, and the fewest fatal crashes since the 1950s (*1*). Although safety has improved, engineers would like to be able to quantify how changes will impact the number of crashes on a segment of highway, and which changes will make a larger impact.

In 1999, engineers and professionals in the transportation field decided that the Highway Capacity Manual needed a supplement focusing on quantifying safety. With funding from both the Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP), the Highway Safety Manual (HSM) was developed, and in April of 2010, it was published by the American Association of State Highway and Transportation Officials (AASHTO).

The HSM provides a way to quantitatively measure safety in the planning, designing, constructing, and maintenance phases of highway design. It gives guidance in how to identify sites that need improvements, evaluate those sites, and provides possible improvements that would increase safety the most. It also provides a way to predict the number and severity of crashes using a crash prediction model (CPM) as well as guidance on the economic side of highway design, showing how to perform benefit/cost analyses using the newer concepts of crash prediction from the HSM and how to prioritize planned projects.

Problem Statement and Methodology

This thesis is meant to create an acceptable method that can be used by practicing engineers in Kansas to predict crashes for rural, two-way, two-lane highways in Kansas. The Kansas Department of Transportation (KDOT) has over 8600 miles of rural two-lane highways that it is in charge of maintaining. Road designers at KDOT have a simple template to follow when redesigning a section of highway, usually using the highest standards provided in the Green Book with ten foot shoulders, and 30 feet of clear zone, among other top design criteria when possible. Having an effective equation that will predict the number of crashes along a highway and show where the high crash locations will probably occur, would enable designers to create a safer road while saving money if it is found that eight foot shoulders would be just as beneficial as ten foot shoulders.

Research Objectives

The aim of this thesis is to create a safety performance function (SPF), an equation that can predict crashes along a segment of highway, which can be used for rural two-way, two-lane highways in Kansas. These types of rural roads make up 8600 miles of roadways maintained by KDOT, and although 64.5 percent of crashes occur in urban areas, 67.5 percent of fatal crashes occur on these two-lane rural roads (*2*). Due to the large proportion of fatal crashes occurring on these roads and the large amount of total mileage, creating a SPF for them is essiential.

The objective of this research is to find the best method for KDOT to use in predicting crashes, which in turn can affect the changes made when designing a segment of roadway. This objective will be met by the following:

- Creating a new SPF for Kansas;

- Comparing the SPF to previous methods used in Kansas; and

- Determining which methods would work best for engineers at KDOT.

Contribution to the State of the Art

As all current design books have gone through multiple iterations, each with new research refining methods, so too will the HSM as new methods are tested and used. Creating a new Kansas-specific SPF will be part of this process. It will help KDOT in more accurately predicting crashes and determining problem areas on Kansas highways. Using methods in the HSM can lead to more economical decisions on where the limited funds for highways would be most beneficial both economically and when concerning safety. The process will also provide an example and give guidance to other states or regions wanting to conduct the same task of analyzing their rural two-way, two-lane highways.

Thesis Organization

This thesis is organized into six chapters. Chapter I is the introduction and discusses what SPFs are and the present state of the world concerning them and provides a list of acronyms used throughout this thesis. Chapter II is the literature review, going over important research in the past concerning SPFs. Chapter III covers the methodology that will be followed to produce the new SPFs and how they will be analyzed. Chapter IV gives the detailed process of data collection to perform the analysis, which is discussed in Chapter V. The final chapter, Chapter VI, will give the findings of the analysis and give final recommendations to KDOT. Figure 1 is a chart showing the progression of this thesis.

| Literature Review | Methodology | Analysis | Findings and Recommendations |
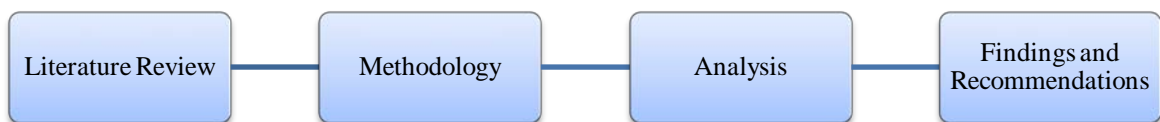
FIGURE 1 Outline of this thesis.

List of Acronyms

The following is a list of acronyms and their definitions used throughout this thesis.

- AADT – Annual Average Daily Traffic

- AASHTO – American Association of Highway Transportation Officials

- ADT – Average Daily Traffic

- ANN – Artificial Neural Network

- BIC – Bayesian Information Criterion

- CPM – Crash Prediction Model

- EB – Empirical-Bayes

- FHWA – Federal Highway Administration

- HSM – Highway Safety Manual

- IHSDM – Interactive Highway Safety Design Model

- KDOT – Kansas Department of Transportation

- KTA – Kansas Turnpike Association

- MAD – Mean Average Deviation

- MASD – Mean Absolute Scaled Deviation

- MPB – Mean Prediction Bias

- MQA - Maintenance Quality Assurance

- NCHRP – National Cooperative Highway Research Programs

- PDO – Property Damage Only

- RHR – Roadside Hazard Rating

- SPF – Safety Performance Function

- SPSS – Statistical Package for the Social Sciences

- TWLTL – Two-Way Left-Turn Lane

- TxDOT – Texas Department of Transportation

- ZIP – Zero-Inflated Poisson

CHAPTER II - LITERATURE REVIEW

The literature review was conducted to explore the history of SPFs and CPMs and the progression of their development to what we have today. Many different methods have been attempted through the years, but there has been one general methodology that has risen above the rest and is prominent today. Understanding what was tried in the past and worked as well as what did not work well is key in producing a functioning SPF for Kansas that can be used by future highway engineers.

The review of literature is ordered chronologically, starting with some of the first research in the relationship of geometric and surrounding features to crash type and moving on to the SPFs and CPMs that have evolved to what we have available to us today. It is not meant to include all CPM-related research, but to give a summary of the most critical sources that led to the development of the prominent methods used today and cover the more recent research of applications of CPMs.

The literature was found using various resources. These included the FHWA's online database of reports and Transportation Research Record, both in its online index and from the transportation library at the University of Kansas. The online access provided by the University of Kansas to online journals was also used, which allows use of several search engines including WorldCat.

Development of Crash Prediction Models

The HSM was published in 2010 and marked the culmination of decades of research attempting to quantify the relationship between roadway features and driver safety. Years of

research led up to this point. The following review of literature gives the important milestones in the research that led to the methods used today.

The Beginning of Predictive Models

The study of predicting the occurrence of crashes on a highway began with the study of how certain crash types related to roadway features. This was observed by looking at segments of roadway that had lanes and shoulders widened and seeing the reduction in crashes by looking at the before-and-after changes in crash volume. The first quantitative model created to predict crashes was included in a study by Zeeger et al. (*3*). Using data from previous studies in Ohio and Kentucky that studied the relationships between lane and shoulder widening as well as obstructions along the roadway, the following model was created using a weighted, least-squares fit method:

$$AR = 4.1501(0.8907)^L(0.9562)^S(1.0026)^{LS}(0.9403)^P(1.0040)^{LP} \qquad (1)$$

Where:

AR = number of run-off-road and opposite-direction crashes per million vehicle miles;

L = lane width (feet);

S = shoulder width including stabilized and unstabilized components (feet); and

P = stabilized component of the shoulder (feet).

Due to the fact that the data were from only two states and many assumptions were made to allow the creation of the equation, Zeeger et al. recognized that this was only a starting point for predictive models. The purpose of this equation was to work as an estimate of what the effect would be on the number of crashes if lane width, shoulder width and shoulder type were changed. The research recognized that there are many other elements that impact crashes beyond those investigated in this study.

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Zeeger et al. continued their study of predictive models, following up their initial predictive model with a more comprehensive study of roadway geometry and their effects on crashes (*4*). This study went more in-depth, looking at seven states – Alabama, Michigan, Montana, North Carolina, Utah, Washington, and West Virginia – which provided more variety in geographic characteristics like terrain type. Zeeger looked closely at the relationships between certain types of crashes and which roadway features would affect them, such as how lane and shoulder widening reduced run-off-road crashes. He tested multiple models with different combinations of 34 variables including number of railroad crossings, number of intersections, and type of development in the area. After studying the interactions of the variables and deducing which variables correlated well, they found the best-fit equation to be the following:

$$A = 0.0019(ADT)^{.8824}(0.8786)^{W}(0.9192)^{PA}(0.9316)^{UP}(1.2365)^{H}(0.8822)^{TER1}(1.3221)^{TER2} \quad (2)$$

Where:

A = number of crashes per mile per year;

ADT = average daily traffic;

W = lane width (feet);

PA = width of paved shoulder (feet);

UP = width of unpaved shoulder (feet);

H = average roadside hazard rating;

$TER1$ = 1 for flat terrain, 0 otherwise; and

$TER2$ = 1 for mountainous terrain, 0 otherwise.

The R^2 value for the model was 0.456, meaning that 45.6 percent of crashes in the study were explained by the model. Being some of the first research on predicting crashes, this was a good start, but not ready for practical application.

Development of Safety Performance Functions and Crash Prediction Models

As the relationship between road improvements and the reduction in crashes became clearer, and preliminary equations were developed to predict the number of crashes on a roadway with certain geometric characteristics, researchers began to explore and fine-tune these equations to more accurately predict crashes.

Miaou and Lum (*5*) created four different types of models to find the model of best fit to estimate the number of truck crashes along a segment of highway, although it can also be applied to other types of vehicles. Of the four models they tried – additive and multiplicative linear regression models and multiplicative Poisson regression with exponential rate function and nonexponential rate function - they found the Poisson regression models to work better as crashes are distinct, rare events and the crash counts are nonnegative numbers. The Poisson regression model is also closer to a probability model as compared to the multiple linear regression models. The best fit model is shown in equation 3.

$$P(y_i) = \frac{(\lambda_i v_i)^{y_i} e^{-\lambda_i v_i}}{y_i!} \qquad (3)$$

Where:

$P(y_i)$ = probability that y_i trucks will be involved in crashes;

λ_i = mean crash rate (number of trucks per million truck-miles) on the segment;

v_i = truck exposure (millions of truck-miles); and

y_i = number of trucks involved in crashes on the highway segment.

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λ_i is predicted using the following equation:

$$\lambda_i = \exp\ (0.0818 + 0.1022x_{1i} + 0.0949x_{2i} + 0.0426x_{3i} + 0.0341x_{4i} - 0.0263x_{5i}\ (4)$$

Where on the ith section:

x_{1i} = average daily traffic (ADT) per lane (in thousands of vehicles);

x_{2i} = horizontal curvature (in degrees per hundred feet);

$x_{3i} = x_{2i}$*horizontal curve length;

x_{4i} = deviation of stabilized outside shoulder width in each direction; and

x_{5i} = percent trucks.

However, the Poisson regression model does not account for overdispersion, or the variance to the mean. This is to be expected considering the relatively simple nature of the Poisson regression model compared to the high variability experienced in crash data. Miaou suggested using the negative binomial regression model to account for overdispersion as it allows for additional variance which can help account for variables that are not included when creating the equation. To test this theory, Miaou (*6*) followed up that study and compared Poisson regression, zero-inflated Poisson (ZIP) regression, and the negative binomial regression statistical methods in continuing his research in predicting truck crashes. In his investigation, he found that no model proved that it was better than the others and concluded that a Poisson regression be used to establish the relationship between highway geometrics and crashes. If the Poisson regression is found to have overdispersion, he suggested using either the ZIP regression, which accounts for the many segments of zero crashes that can be seen in data, or negative binomial regressions, which accounts for overdispersion.

A different approach was taken by Mountain, Fawaz, and Jarrett (*7*) in the UK, where they used the Poisson regression, two loglinear models (one with intersections included and the other with intersections separate) and the Empirical Bayes (EB) method to predict the number of crashes along a highway segment. They concluded that the EB method was superior to the predictive models as it appeared to be impartial to estimating crashes at segments considered to be high-risk. A similar study by Persaud (*8*) also looked at the effects of the EB method for predicting crashes on rural, two-way, two-lane roads in Canada. Noting that the EB method accounts not only for the traffic volume and geometric features of a highway, but also accounts for that segment's crash history, he predicted and confirmed that the EB method works well as a supplement to an equation formed using negative binomial regression.

Current Crash Prediction Models

As the previous studies established that Poisson and negative binomial regression models were the best for predicting crashes, the next step was to determine the best method to apply regression models to produce the most accurate CPMs, especially in the case of the HSM.

Highway Safety Manual Model

Vogt and Bared (*9*) made the first step to creating the base model, or SPF, that would be used in the HSM. They collected roadway geometry, as well as surrounding conditions, from the states of Washington and Minnesota for all rural, two-lane, two-way highways in both states. They used the Poisson regression model, negative binomial regression, and an extended negative binomial regression, which breaks segments into subsegments that were homogeneous. They chose the extended negative binomial regression technique as they preferred how it accounts for overdispersion, works well with the EB method when past crash data at a site are available, and every segment is homogeneous, regardless of the length. The R^2-value for the extended binomial

regression was also higher, as can be seen in Table 1. The R^2_P-value they used was a refined R^2-value that was the proportion of potentially explainable variation that could be expected from the many different factors. The R^2_K-value used with both forms of negative binomial regression is used by Miaou (*10*) and takes into account the overdispersion parameter.

TABLE 1 R^2 Values for the Different Statistical Methods

Test and R^2 Values	Washington	Minnesota	Combined
Poisson Regression (R^2, R^2_P)	0.7297, 0.8208	0.6279, 0.7716	0.6607, 0.7673
Negative Binomial Regression (R^2, R^2_K)	0.7251, 0.8609	0.6268, 0.8310	0.6669, 0.8354
Extended Negative Binomial Regression (R^2, R^2_K)	0.7246, 0.8575	0.5720, 0.8161	0.6547, 0.8291

Their preferred equation, created by using the extended negative binomial regression is:

$$N_{br} = EXPO * \exp(0.6409 + 0.1388 STATE - 0.0846 LW - 0.0591 SW + 0.0668 RHR +$$

$$0.0084 DD) \left(\sum WH_i \exp(0.0450 DEG_i)\right)\left(\sum WV_j \exp\left(0.4652 V_j\right)\right)\left(\sum WG_k \exp\left(0.1048 GR_k\right)\right) \quad (5)$$

Where:

N_{br} = predicted number of crashes along a highway segment;

$EXPO$ = exposure in million vehicle-miles of travel per year = $(ADT)(365)(L)(10^{-6})$;

ADT = average daily traffic volume (veh/day) on highway segment;

L = length of roadway segment (mi);

$STATE$ = which state the segment is in (0 = Minnesota, 1 = Washington);

LW = lane width (ft); averaged if different in each direction;

SW = shoulder width (ft); averaged if different in each direction;

RHR = roadside hazard rating; takes values from 1 to 7 and represents how hazardous the roadside can be (see Appendix A for definitions on how to determine the value);

DD = driveway density (driveways per miles) on highway segment;

WH_i = weight factor for the ith horizontal curve in the highway segment; proportion of total highway segment length represented by the portion of the ith horizontal curve that lies in the segment (the weights, WH_i, must sum to 1.0);

DEG_j = degree of curvature for the ith horizontal curve in the highway segment (degrees per 100 ft);

WV_j = weight factor for the jth crest vertical curve in the roadway segment; proportion of total highway segment length represented by the portion of the jth vertical curve that lies in the segment (the weights, WV_j, must sum to 1.0);

V_j = crest vertical curve grade rate for the jth crest vertical curve that lies within the segment in percent change in grade per 100 ft = $|g_{j2} - g_{j1}|/l_{j;}$

g_{j1}, g_{j2} = highway grades at the beginning and end of the jth vertical curve (percent);

l_j = length of jth vertical curve (in hundreds of feet);

WG_k = weight factor for the kth straight grade segment in the roadway segment; proportion of total highway segment length represented by the portion of the kth straight grade segment that lies in the segment (the weights, WG_k, must sum to 1.0); and

GR_k = absolute value of grade for the kth straight grade on the segment (percent).

To validate the model, a chi-squared test was used with the overdispersion parameter of the model included as well as looking at the mean absolute deviation (MAD) and the mean absolute scaled deviation (MASD). MAD and MASD are statistical measures that look at the average magnitude of variability of prediction. The measures are beneficial because they utilize absolute values, which prevent positive and negative errors from canceling each other out.

Refining the Crash Prediction Model

Estimates of safety based on statistical models, like that used by Vogt and Bared (9), can be very accurate for predicting crashes. However, statistical models can have an inverse or disproportionate weighting of variables that are not consistent with engineering principles. This can often be caused by variables serving as surrogates for other factors. In addition, the

statistical models do not necessarily show a cause and effect relationship, only a correlation. In order to more accurately account for the impact of various highway elements on safety, additional scrutiny of the model was desired.

To address this deficiency in Vogt and Bared's (*9*) base model, Harwood et al. (*11*) supplemented it with information from before-and-after studies, estimates from expert judgment, and estimates from historical data. In this study, Harwood et al. (*11*) gathered an expert panel to refine the crash modification factors (CMFs) developed by Hughes and Vogt (*9*). Separate expert panels were used to address CMFs for segments and intersections. The panel used their expert judgment along with published and unpublished research to evaluate a list of all the possible features that were known to impact safety and select a list of the most important features for which CMFs could be developed. The final list of CMFs for roadway segments developed by Harwood et al. (*11*) are:

- Lane width;
- Shoulder width;
- Shoulder type;
- Horizontal curve;
    - Length;
    - Radius;
    - Presence or absence of spiral transitions;
    - Superelevation;
- Grades;
- Driveway density;
- Two-way left-turn lanes (TWLTL);
- Passing lanes/short four-lane sections; and
- Roadside design.

This expert panel process was critiqued by Washington, Lord and Persaud (*12*). This critique pointed out ways that the expert panel process used by Harwood et al. (*11*) could be improved, but there was no definitive answer as to the accuracy and precision of the results of an expert panel process.

In addition to developing many of the CMFs published in the HSM, Harwood et al. (*11*) also developed the framework used in the HSM for applying the crash prediction model and using the EB procedure.

Once the list of CMFs was finalized, the following base conditions were determined and applied to the model developed by Vogt and Bared (*9*). These are the same base conditions used in the HSM (*13*) for rural, two-lane, two-way roads.

- Lane width (LW) = 12 feet;

- Shoulder width (SW) = 6 feet;

- Roadside hazard rating (RHR) = 3;

- Driveway density (DD) = 5 driveways per mile;

- Horizontal curvature (DEG) = none;

- TWLTL = none;

- Vertical curvature (V) = none; and

- Absolute grade level = 0%.

Using the base conditions, equation 6 was the final base equation used in the HSM:

$$N_{spf\,rs} = AADT \times L \times 365 \times 10^{-6} \times e^{-0.312} \tag{6}$$

Where:

$AADT =$ Annual average daily traffic; and

$L =$ length (mi).

Then, the CMFs are added as well as a calibration factor to account for any variations from the base conditions and to account for differences in the region being studied from the states used to create the base equation. The final equation used is as follows:

$$N_{predicted\ rs} = N_{spf\ rs} \times C_r \times (CMF_{1r} \times CMF_{2r} \times ... \times CMF_{12r}) \qquad (7)$$

Where:

$N_{predicted\ rs}$ = predicted average crash frequency for a roadway segment in one year;

$N_{spf\ rs}$ = predicted average crash frequency for base conditions for a roadway segment;

C_r = calibration factor for a roadway segment developed for a particular state or region; and

$CMF_{1r} ... CMF_{12r}$ = crash modification factors for rural two-lane, two-way roadway segments.

Each CMF has its own equation and process of determination, which can be explored more in the HSM (*13*) itself or in Lubliner's (*14*) study, which is discussed later in this chapter. This process may appear to be time consuming as each change in the segment would need another equation to be developed. To help with this problem, the Interactive Highway Safety Design Model (IHSDM), the CPM's software compliment, simplifies this work.

The HSM also has equations for rural multilane highways that are both undivided and divided, urban and suburban arterials, and signalized and unsignalized three- and four-leg intersections in all facility types.

HSM Calibration Procedures

Even though the HSM was published in 2010, the base equation, or SPF, given does not necessarily work well for every state or region as only two states data were used. To remedy this problem, the HSM strongly recommends first calibrating the model; this procedure should be performed every two to three years to account for newer vehicles and their new and constantly evolving safety features, as well as any other outside changes there may be. There are five steps listed in the HSM to correctly calibrating a model; the first step is to decide which type of roadway to perform the calibration on, such as a two-way, two-lane rural highways or three-leg urban signalized intersection. The second step is to select sites to perform the calibration, using a minimum sample size of 30 to 50 sites. They also suggest randomly choosing sites to prevent choosing only sites with large number of crashes and having about 100 crashes per year. However, recent research by Banihashemi (*15*) recommends that, at least for his test state, a calibration should contain at least 150 crashes per year to have the appropriate confidence level in the calibration value. Once the sites are established, the next step is to collect the total crash frequency for the years chosen to observe and obtain the site characteristics, like horizontal and vertical curvature. The fourth step is to use the predictive model, shown in equations 6 and 7, without a calibration factor and the EB method to get the expected crash frequency for the sites for the correct number of years. The final step is to compute the calibration factor using the following equation:

$$C_r = \frac{\sum_{all\ sites} observed\ crashes}{\sum_{all\ sites} predicted\ crashes} \qquad (8)$$

Since the SPF for two-lane rural roadways is a linear equation, the calibration factor is used to change the relative impact of AADT on predicted crashes for a given jurisdiction. If the calibration value is greater than one, then the AADT will have more weight on the total predicted

crashes. Similarly, if the calibration value is less than one, the AADT will have less weight on the predicted crashes. A visual representation of this is shown in Figure 2, with C_r factors from Oregon and Kansas, which are discussed in the following section.

SPF for Rural Two-Lane, Two-Way Segments
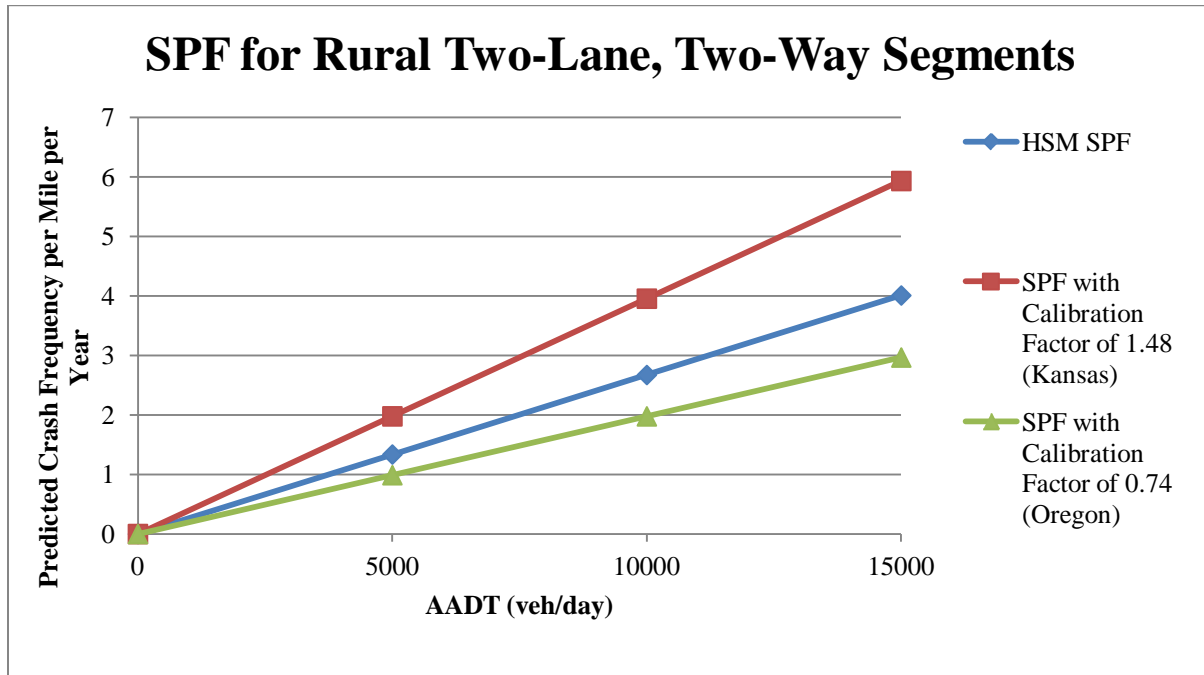
FIGURE 2 The base equation from the SPF with different calibration factors applied.
While calibrating the CPM should provide satisfactory results, more reliable estimates for a given jurisdiction may be obtained by developing a jurisdiction-specific SPF.

Contemporary Research

During the creation of the HSM, developers produced and distributed drafts of the document. While there are some minor variations between the final versions and these draft versions, the substance is nearly identical. Thanks to the availability of these draft manuals, there has already been a good deal of research that has been performed on the HSM even though it was only published in 2010. The following section aims to present a cross section of contemporary research both on efforts to calibrate and utilize the HSM and also on alternative CPMs developed for other transportation authorities.

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Highway Safety Manual Calibration

The calibration process described for the HSM has been performed and documented by a small number of entities already. The first study that calibrated the HSM's CPM for two-lane rural highway segments was performed in 2006 by Sun et al. (*16*) for highways in Louisiana. The CPM used was nearly identical to the one currently found in the HSM. The biggest difference was that the HSM had additional CMFs for rumble strips, lighting, and automated speed enforcement that were added subsequent to their research. In addition, the calibration procedure called for in the draft HSM and applied here differed from the one in the published HSM. The prime difference was that this procedure called for a stratification of calibration factors based on traffic volume. The factors were then averaged together for application.

The study by Sun et al. (*16*) utilized the same basic definition for rural two-lane highways. Due to lack of data, default values were used for several of the CMFs. The values provided for some of the data were not consistent with those experienced in Kansas. Ultimately through these data and calibration methodology, a calibration value of 1.63 was determined for the Louisiana highway system.

In addition to the calibration component, the Louisiana study also performed a validation of the CPM, which includes using the calibration factor and the EB procedure. The study showed the accuracy of the model when utilizing the calibration, in terms of percent difference between the observed and predicted crashes. The accuracy of the calibrated model, without utilizing the EB procedure, was a 5.22 percent difference. When the EB procedure was added, accuracy was improved to 3.06 percent difference. It is worth noting that these accuracies are provided for the aggregate of all the segments modeled in the validation study and do not show the individual segment accuracy in definable values.

In 2011, Xie et al.(*17*) performed a calibration of each of the three types of roadway facility considered by the HSM for the Oregon highway system. For rural, two-lane, two-way roads, their final calibration factor was found to be 0.74, using data from 2004-2006. They speculated it may be under 1.0 due to fewer property damage only (PDO) crashes being reported in Oregon, as those types of crashes were not required to be reported to authorities. They also found that accumulating the data was time consuming. A gap in their research exists as they did not validate the newly created calibration factors. Therefore, although they followed the steps given in the HSM, they did not go back to show how accurate the calibrated model was for predicting crashes.

One unique aspect of the Oregon study (*17*) is that they went through the effort of developing jurisdiction-specific crash distributions to replace the default values provided by the HSM. Their analysis showed that, on an aggregate level, using the jurisdiction specific distributions did not significantly impact the results as compared to using the HSM default values. This analysis did not include a quantification of this impact at the project level. It is also worth noting that, of the statistics provided, the Oregon-specific values did not vary notably from the default values provided in the HSM. Therefore, it is not surprising that no significant impact was found by using the Oregon-specific values in place of the default values.

Banihashemi compared calibrating the CPM to creating two new SPFs for the state of Washington (*15*).

$$N_{spf-1-rs} = 0.91705 \times AADT \times L \times 365 \times 10^{-6} \qquad (9)$$

$$N_{spf-2-rs} = 0.5782 \times AADT^{1.05} \times L \times 365 \times 10^{-6} \qquad (10)$$

Equation 9 had the same general form as the rural two-lane SPF found in the HSM. Equation 10 had a similar form except the *AADT* is raised to the power of 1.05. Four new state-specific CMFs were also produced for lane width, shoulder width, curve radius, and vertical grade, which were used with the new SPFs. In this study, it was found that the calibration for Washington state worked just as well as either of the new models, although the newer models may be preferred if more CMFs were created specifically for the state. However, since the original SPF was created using Washington and Minnesota data, the fact that it worked just as well as new SPFs is not entirely surprising. Similar to a number of previous studies, the models studied by Banihashemi (*15*) assumed default values for a number of the CMFs due to data limitations.

Two more major studies have been performed by Donnell (*18*) in Pennsylvania and Schneider and Fitzpatrick (*19*) in Texas. Donnell followed the calibration procedures in the HSM to determine the best way to calibrate for rural highways in Pennsylvania. He found a less-intensive data collection calibration to work just as well as the data-intensive calibration factor. However, these were only validated using two highway segments, which may not account for abnormalities. Schneider and Fitzpatrick also evaluated calibration factors, finding the best calibrations to come from using curve data individually instead of averaging curves together; they also found that calibrations varied across the state, determining that one state-wide calibration factor would not be sufficient.

Other Crash Prediction Models

Some transportation officials have taken the same principles used to develop the CPMs in the HSM and developed CPMs for their specific jurisdiction or a specific type of road. For example, Bonneson and McCoy (*20*) developed a model for predicting the number of crashes on an urban arterial street with specific median treatments including raised-curb, TWLTLs, and undivided

21

median. Their equations had different layouts from the HSM's although still using the negative binomial regression. A logarithmic link function related exposure measures and explanatory factors. The exposure measures, similar to those of the EXPO function used by the HSM, were ADT and segment length. The explanatory factors were also similar to those of the HSM's in driveway density, street density, and median treatment. Their model had the form of:

$$A = ADT^{b_1} Len^{b_2} e^{(linear\ terms)} \tag{11}$$

With the linear terms being:

$$linear\ terms = C_0 + C_1 x_1 + C_2 x_2 + \cdots + C_n x_n \tag{12}$$

Where:

A = annual crash frequency in crashes per segment per year;

ADT = average daily traffic demand;

Len = street segment length;

x_i = selected traffic and geometric characteristics; and

B_i, C_i = regression coefficients.

In another study, Mayora, Manzo, and Orive (*21*) developed a CPM for two-lane rural road segments on the Spanish National Network. The final version of their CPM contained some similar variables to the HSM's CPM, including vertical grade and access density. However, some variables were different, including reduction in design speed between adjacent segments and sight distance.

The most robust work to develop jurisdiction-specific CPMs has been performed for the Texas DOT (TxDOT). This included a six-year program for "(1) the development of safety design guidelines and evaluation tools to be used by TxDOT designers, and (2) the production of a plan for the incorporation of these guidelines and tools in the planning and design stages of the project development process (*22*)." The end product of this effort was the Roadways Safety Design Workbook (*22*) which includes safety prediction models for several facility types:

- Freeways;

- Rural highways (two and four lane);

- Urban and suburban arterials;

- Interchange ramps and frontage roads;

- Rural intersections; and

- Urban intersections.

The procedure used by TxDOT for rural highways is similar to that developed by Harwood et al.(*11*) with the primary exception that the TxDOT procedure predicts injury (plus fatal) crash frequency, as opposed to total crash frequency where property damage only (PDO) crashes would also be included. Similar to the HSM procedure, the TxDOT procedure has base conditions and then a series of CMFs to consider the individual attributes for a segment or intersection.

One relevant difference between the HSM and TxDOT procedures was found in the development of TxDOT's interchange ramp CPMs. Instead of creating a new CPM for interchange ramps, Lord and Bonneson (*23*) looked at calibrating existing SPFs for ramps based

on Texas data. One of the unique elements of this research was that it utilized a disaggregate approach based on the area type, ramp type, and ramp configuration. It was proposed in the research that this method would better fit the Texas data if certain attributes had a disproportionate affect on crashes than the state from which the original model was derived. However, no comparison could be found between the relative accuracy of a single calibration versus the disaggregate calibration.

The state of Utah (*24*) performed a study comparing a calibration model to four new negative binomial models (2 models, transformed AADT and no transformed variables at 75 percent and 95 percent significance each) and one model using hierarchical Bayesian techniques. They determined the negative binomial model with a transformed AADT to be the best model as it used fewer variables than the calibration model and had the lowest Bayesian information criterion (BIC) value of the four negative binomial models. Although this research is a good start, it is lacking in a validation study, especially in comparing the results of the calibration model to the new negative binomial models.

New research, released by Ibrahim and Sayed (*25*) in 2011, proposed the use of reliability-based risk measures to improve the performance of SPFs. Specifically, this research compared SPFs developed using typical negative binomial regression to ones using probability of non-compliance (P_{nc}) for horizontal curve locations on the Trans-Canada Highway. The comparison showed that the model for total crashes using P_{nc} outperformed the model without and was 10 percent significant using the likelihood reliability test. While this type of reliability measurement in highway safety shows promise, this research was limited to horizontal curves. Additional research is needed to confirm these findings and to investigate probability distributions of the design inputs as well as correlations between the variables (*25*).

SafetyAnalyst Prediction Models

SafetyAnalyst is a similar tool to the IHSDM, but it is associated with Part B of the HSM, which focuses on roadway safety management. It utilizes a SPF to predict crashes, but uses less geometric data and looks at an entire network with several different tools. These tools identify sites that could benefit from safety improvements, diagnose possible reasons for the safety problems, suggest what improvements could be made and at what cost, prioritizes which sites could benefit most with regard to cost estimates, and can perform before/after evaluations. To perform these analyses, the primary data needed includes the following:

- Segment length;

- Area type (rural/urban);

- Number of lanes;

- Median type;

- Access control; and

- Traffic Volume.

The base model for SafetyAnalyst is the following:

$$Crashes = e^a \times AADT^b \times SL \qquad (13)$$

Where:

$Crashes$ = predicted crashes per year;

$AADT$ = average annual daily traffic (veh/day);

SL = segment length (miles); and

a and b = regression parameters.

It can also be adjusted with a calibration factor that should be reevaluated on a yearly basis and a proportion factor if looking at only certain types of crashes. In supportive efforts, a

number of states have shared what they have learned and published research regarding their individual efforts to develop accurate methods for predicting crashes for network analysis. Many of these states have focused their research on development and calibration of SPFs used in SafetyAnalyst for their particular state, including Virginia (*26*) and Louisiana (*27*).

Research by Lyon et al. (*28*) recognized that there are some fundamental issues with statistical analysis of road safety. These include "site-selection bias, lack of experimental control of confounding variables, relatively small effects of some predictor variables, large crash variability, and omitted variable bias (*28*)."

Based on the network qualities and data availability, certain jurisdictions have chosen to deviate from the SafetyAnaylst method. In research performed by Qin and Wellner (*29*), jurisdiction-specific equations were developed for South Dakota. Direct comparison is difficult because this research developed equations for different roadway classifications than are presented in the HSM. One interesting finding is that the equations for South Dakota use some variables not found in the HSM, including percent trucks, vertical curve density, and a municipal funding category.

A similar study performed in Italy (*30*) developed jurisdiction-specific equations that used variables similar to those found in the HSM. Two primary differences are that the Italian equations predict only injury crashes and also use mean speed as a variable.

Kononov and Allery (*31*), of the Colorado Department of Transportation, developed a concept called Level of Safety Service (LOSS). LOSS is a screening model that compares the performance of similar roadways to determine problematic sections that have appreciably worse safety performance. This method uses SPFs to describe the overall performance of group of

similar road segments. A particular segment's LOSS is then measured as the deviation from that SPF.

Kansas Crash Prediction Research

Safety of the highway system is a paramount issue to KDOT. To improve the safety of its highway system, KDOT has commissioned numerous studies to address safety. Four of those contemporary studies address crash prediction on rural two-lane highway segments.

KDOT, like many other transportation organizations, has looked to research for more efficient ways to screen its robust system inventories and crash data for identifying relationships between highway features and safety. In 2009, Najjar and Mandavilli (*32*) used Artificial Neural Networks (ANN) to attempt to identify these relationships for Kansas highways. Their research covered the six major types of roadway network in Kansas: rural Kansas Turnpike Authority (KTA), rural two-lane, rural expressway, rural freeway, urban freeway, and urban expressway. The models evaluated not only the total crash rate but also the fatal, injury, and severe injury crash rates. For rural two-lane highways, Najjar and Mandavilli (*32*) identified eight different variables that were shown to impact crashes:

- Section length;
- Surface width;
- Route class;
- Shoulder width (outside);
- Shoulder type (outside);
- Average ADT;
- Average percent of heavy trucks; and

- Average speed limit.

The ANN models produced by Najjar and Mandavilli (*32*) were measured against training, testing, and validation data sets. The overall rural two-lane model produced a R^2 of 0.4655. The total crash rate model would be the most similar to the HSM model being investigated with this research. The R^2-value for the total crash rate ANN model was 0.173.

The research developed by Najjar and Mandavilli (*32*) was reported to be the "first in the nation to utilize the ANN mining approach to extract new and reliable traffic-crash correlations from historical databases." As such, it potentially provides a good framework for future applications of this methodology. However, some of the specific results for rural two-lane highways in Kansas seem inconsistent with engineering judgment, other research, and current practice. One such result was the safety performance of similar width shoulders with different pavement types. Due to these practical limitations the ANN model has not been implemented into practice by KDOT.

With a large deer population in the state, it is surprising that the only significant research done, to date, on animal crashes on highways in Kansas was performed by Meyer in 2006, as part of a research program sponsored by KDOT. The study, Assessing the Effectiveness of Deer Warning Signs (*33*), used multiple layer regression, logistic regression, and Principal Component Analysis to model the safety effectiveness of deer warning signs based on before-and-after data where signs had been installed. While this analysis did not produce a viable model to help predict the safety benefit of installing deer signs or being able to prioritize segments for installation of signs, there were several important statistical findings (*33*):

- The absence of the variable "presence of deer warning sign" suggests that there is little or no relationship between deer warning signs and crash rate.

- The most significant parameter was the amount of surrounding area that was wooded. Most likely, the amount of wooded area was acting in this data as a surrogate for deer population.

- The sole direct measure of deer population (harvest density) was only available at an extremely coarse geographical resolution for this application.

- Other than percent wooded area, the other parameters identified as having a significant influence on crash rate were traffic volume and speed, sight distance (indirectly implied by the curvature ratio and side slope), and clear width.

With the current guidance on how to perform statistically accurate before-and-after studies, it is possible that a model could be developed to better quantify factors impacting deer crashes. However, the findings of this research are still valid and can help to inform future consideration on the nature of animal crashes in Kansas.

The lack of measurable statistical benefit from the use of deer crossing signs was supported in a 2005 study, performed by Knapp (*34*), which synthesized available research on the safety benefits of deer crash countermeasures. This research summary showed that only exclusionary fencing and wildlife crossings showed positive safety analysis results for reducing deer-vehicle crashes.

In another study of roadway geometry features in 2010, Rhys et al. (*35*) performed a before-and-after analysis of the safety benefits of adding a centerline rumble strip to two different rural two-lane highways in Kansas. Utilizing the EB method, this study showed an 85

percent reduction in the targeted crash types, head-on and opposite sideswipe. They also showed a 33 percent reduction in total crashes. It is worth noting that this study defined total crashes as excluding animal crashes. The findings of this study state that "it can be assumed that overall results found in Kansas are comparable to results found by other states (*35*)." It is somewhat difficult to compare these results to the HSM because the CMF for centerline rumble strips also applies to one-half of run-off-the-road crashes. However, the value given for reduction of target crashes for the centerline CMF was 0.79 (21 percent reduction). Therefore, it is safe to say that the study by Rhys et al. (*35*) demonstrated a larger safety benefit for centerline rumble strips than what is shown in the HSM.

One additional noteworthy finding of the Rhys et al. (*35*) study was the creation of SPFs for roads similar to the two test sections analyzed. This was developed to isolate the safety benefit of the rumble strips. The equation they developed for similar rural two-way highways is:

$$ACC = e^{\beta_0} \times e^{\left(AADT_{before} \times \beta_1\right)} \tag{14}$$

Where:

ACC = expected number of crashes (per mile per year) in a section with the same characteristics to the section of interest;

$AADT_{before}$ = average AADT for the before period;

β_0 = -1.4019 (section A), -1.2229 (section B); and

β_1 = 0.0004 (section A), 0.0007 (section B).

An overdispersion factor was also calculated for the equation. It equaled -0.079 for section A and -0.148 for section B. The two sections cited in this report, A and B, reference the two different sections that were studied for crash reduction due to the addition of a centerline rumble

strip. Highways with similar traffic volumes, road geometry, and crash history were used to develop an SPF for each roadway type.

In the most recent research performed in Kansas, Lubliner (*14*) followed the calibration steps outlined by the HSM. In his research, he found problems with the HSM's definition of rural. In the HSM, they use the Federal Highway Administration's (FHWA's) definition of rural, where any city with a population under 5000 is considered rural; this does not work well for Kansas as many towns across the state have populations under 5000 but when a highway passes through the city, it has more urban features like curb-and-gutter, traffic signals and on-street parking. Like the study in Oregon (*17*), Lubliner also found the data collection process to be time consuming. There was also a unique problem as there were a large proportion of animal-related crashes, with 58.9 percent of crashes being animal-related in Kansas and the HSM's crash distribution having only 12.1 percent of crashes being animal-related. Several different variations of calibration factors were created to find one that would work best for Kansas. First, a statewide calibration was created with a calibration factor of 1.48. The next calibration factor broke the state down using the current KDOT districts and then combined districts that were adjacent to one another with similar calibration rates to meet the HSM standard of having at least 100 crashes per year. The third calibration factor looked only at crashes without animals and a calibration value of 0.557 was determined. The final calibrations looked at the animal crash rates of each individual segment and county, with the county, or variable, calibration factor working best, using the following equation 15.

$$C_{county} = 1.13 \times ACR_{county} + 0.635 \qquad\qquad (15)$$

Where:

C_{county}= calibration factor for a county; and

ACR_{county}= deer crash rate for a county.

C_{county} was found to work best, but he suggested further research be completed on creating a jurisdiction-specific SPF to see if it could predict crashes on rural Kansas highways better than calibrating the HSM's model.

Concluding Remarks

The prediction of crashes on a segment of roadway has had significant progression in the last 40 years. Predicting crashes will never be able to be exact as there will always be human factors that engineers cannot account for like distracted driving. However, improvements can still be made to today's highways to reduce the number of crashes. The research can also be used to make safer roads economically. The review of literature found the following findings to be significant:

- Negative binomial and Poisson regressions dominate the latest research and have been considered to be the better statistical methods in creating a SPF.
- Several equation forms have been used in predicting crashes, including Bonneson and McCoy's (*20*) equation and the form used in the HSM (*13*).

- There is a problem with animal crashes in Kansas, and these crashes are hard to predict as geometric features have little impact.

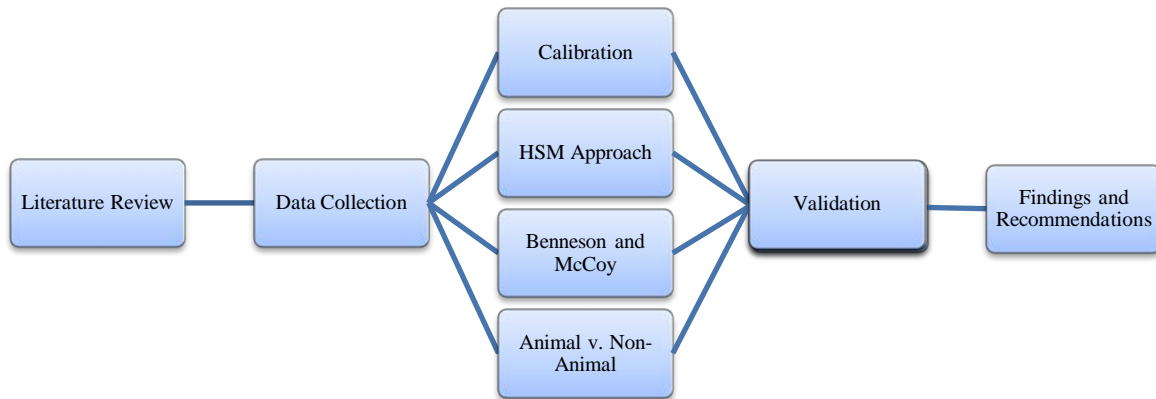With the literature review completed, Figure 3 shows the path the thesis will follow.

FIGURE 3 Path of research after the literature review.

CHAPTER III – METHODOLOGY

Introduction

Chapter II – Literature Review – gave guidance on how to best approach creating a SPF or CPM, and this chapter will outline the path this research will follow, derived from the literature. The objective of this thesis is to create a SPF that would ideally work with the HSM, but also to explore other options that may be superior methods for the state of Kansas.

This chapter will lay out the process of creating a new SPF for Kansas. First a brief overview of what data will be collected and where the data will come from will be covered. Next, the process of how the data will be used to create new SPFs will be discussed, and that will be followed by the validation process, which will use three statistical tests to pick the best model.

Data Collection

The first step in creating a SPF is collecting data. Many states that have conducted this type of research have been a part of the Highway Safety Information System (HSIS) system, where all roadway geometric features are available in a database. Unfortunately, Kansas is not a participant and the state does not have a comprehensive database of the roadway geometry, so the data needed to be collected manually. There are several variables that needed to be obtained in roadway geometry and surrounding conditions, including the following:

- Length of segment;

- AADT;

- Horizontal curve data;

- Vertical grade;

- Lane width;

- Shoulder width;

- Roadside Hazard Rating;

- Posted speed limit;

- Types of crashes; and

- Location of crashes.

There are multiple sources from which data needed to be collected. KDOT had the CANSYS database that contained some geometric features like lane and shoulder width, and they also had a crash database that contained all the crash data information. For additional geometric information, KDOT construction plans for the segments of highway selected were consulted, and the KDOT videolog and both Google Earth and Google Maps were used to determine the RHR as well as determine if there is any discrepancies between the plans and CANSYS database.

The data collection process was nearly identical to the process Lubliner (*14*) used in his analysis of calibration factors for Kansas, and all the data from his project were used along with new segments to increase the database available as the process has been noted to be time consuming. A more in-depth discussion of the data collection process is documented in Chapter IV – Data Collection.

Creating SPFs

As found in Chapter II – Literature Review, there are a variety of methods that have been used to create SPFs and CPMs. The first step to narrowing this down was determining which statistical method to use. There are several statistical methods that have been preferred for creating SPFs. An extensive discussion of these methods has been performed by Lord and Mannering (*36*). In their discussion of different models used, they found that some of the more

promising models are random-parameter models, finite mixture models along with the more traditional and widely used Poisson and negative binomial regression models. The random-parameter model allows each parameter of the model to vary across each observation in the set of data. They note that this is a complex process, and that the predictions may not be improved compared to more traditional models. The random-parameter model may also not be transferable to other datasets. The finite mixture models are used to examine heterogeneous populations, which would be an improvement to more common models which require homogeneous segments for best results.

The most popular methods as of late have been Poisson regression, ZIP regression, and negative binomial regression models. As Miaou noted (*6*), the different forms of regression create similar equations, and none of the methods are superior to any of the others. The HSM (*13*) requires use of the negative binomial regression procedure as it accounts for overdispersion. Overdispersion is when the variance is larger than the sample mean. This works well for predicting crashes as they can vary greatly from year to year and will sometimes go outside the normal variance. For these reasons, negative binomial regression was chosen as the statistical method to use.

The next step in creating an equation was to decide the format of the equations. As seen in the literature review, there were many equation variations created using negative binomial regression. The first equation form that was considered is one in a similar form of the HSM's base model in the CPM using the *EXPO* variable. The HSM has several requirements for making a jurisdiction-specific SPF along with using the negative binomial.

TABLE 2 Base Conditions

Variable	Base Condition
Lane Width	12 feet
Shoulder Width	6 feet
Roadside hazard rating (RHR)	3
Driveway Density (DD)	5 driveways per mile
Horizontal curvature	None
Vertical curvature	None
Centerline rumble strips	None
Passing Lanes	None
Two-way left-turn lanes	None
Lighting	None
Automated speed enforcement	None
Grade level	0%

It requires that the same base conditions must be used, which are listed in Table 2; not all of these variables were used as they were not prevalent on rural Kansas highways, like automated speed enforcement and lighting. It must also include AADT and segment length. The final base model to the equation is shown in equation 16:

$$N_{spf\,rs} = AADT \times L \times 365 \times 10^{-6} \times e^{-0.312} \tag{16}$$

where

$AADT$ = Average annual daily traffic; and

L = length (mi).

There were two different approaches to creating this equation. The first used the same approach the HSM used. The second worked in a reverse manner, with the CMFs and actual number of crashes known, the exponent on e, noted as X in equation 17, was found for each

segment, and then the negative binomial regression was run using only that exponent. One value was found, in the case of equation 6, -0.312.

$$X = ln\left(\frac{N_{known}}{EXPO \times CMF_{combined}}\right) \qquad (17)$$

Where

N_{known} = number of crashes known for the segment; and

$CMF_{combined}$ = All CMFs multiplied together.

The other main equation form that was considered is that of Bonneson and McCoy's (*20*), which gave an exponential function to both the AADT and length, as seen in equation 11, taken from the literature review. This allowed the predicted crashes to grow exponentially as the ADT increased.

$$A = ADT^{b_1}Len^{b_2}e^{(linear\ terms)} \qquad (11)$$

With

$$linear\ terms = C_0 + C_1 x_1 + C_2 x_2 + \cdots + C_n x_n \qquad (12)$$

Where

A = annual crash frequency in crashes per segment per year;

ADT = average daily traffic demand;

Len = street segment length;

x_i = selected traffic and geometric characteristics; and

B_i, C_i = regression coefficients.

This form of equation was created using the same reverse method that was used when making the HSM's CPM model.

These equations were created using Statistical Package for the Social Sciences (SPSS). The data collected were run through SPSS using negative binomial regression, and this output the exponents and coefficients needed to create the equations. If using the second model form, exponents were given to the AADT and length as well as an intercept and coefficients for the linear terms as in equation 11, which will be used in both equation forms. Each variable output also had a level of significance. The level of significance used was 0.05, meaning that it had a confidence level of 95 percent. A negative binomial regression was first run using all variables available, and then it will be run again only using variables that had a P-value of 0.05 or lower. This gave the final equations to be tested.

Other Equation Varieties

As noted in Lubliner's (*14*) and Meyer's (*33*) work discussed in the literature review, animal-related crashes account for a large portion of crashes in Kansas. These crashes cannot be predicted as they are random, and Meyer's work proved that roadway geometry had little effect on deer crash locations. Because of this, the crash type was separated between animal and non-animal crashes. It was predicted that eliminating animal-related crashes would produce a more accurate model.

Validation

Once the equations were created, they were tested using a validation set of roadway segments, which was from different segments from those used to create new SPFs. As there was

no set method in determining which equation works best, a variety of statistical methods were used along with engineering judgment to determine which equations were best to use. Each equation created was compared with the statewide and county-specific calibrations already created for Kansas by Lubliner (*14*) and the actual number of crashes in a certain time period. The following section covers the statistical tests that were used and the reasoning for each one and how they determined which methods work best.

Validation Statistics

The following statistical tests were run to determine which methods and equations were superior, and they were used along with engineering judgment so it could be observed if the results match with known guidelines. An example of engineering judgment would be when observing an equation, a positive coefficient for lane width goes against engineering judgment as it would indicate that an increase in lane width will result in an increase in crashes. The opposite has been proven true, and engineering judgment may be used to determine if other factors contributed to this.

T-Test

T-tests were performed for the predictions of each equation against the actual number of crashes on each validation segment using equation 18 to calculate the t statistic.

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$ (18)

Where

r = correlation coefficient; and

n = the number of segments.

The t statistic was used to find the p-value using the GraphPad Software website (*37*). The P-value evaluated if there was a significant difference between the actual and predicted crashes. A P-value less than 0.05 indicated a statistically significant difference, which would indicate that a model should not be used as there was a statistically significant difference between the actual crashes and predicted crashes.

Pearson's R

Pearson's R, a correlation coefficient, was also used to test which models worked best for predicting crashes. The closer to -1 or 1, the more correlation there is between the actual and predicted number of crashes. The following equation (19) was used to determine Pearson's R:

$$r = \frac{n \sum XY - (\sum X)(\sum Y)}{\sqrt{[n \sum X^2 - (\sum X)^2][n \sum Y^2 - (\sum Y)^2]}} \qquad (19)$$

Where:

X = actual number of crashes that occurred in a segment; and

Y = the predicted number of crashes.

The higher Pearson's R is, the higher correlation between the predicted crashes and actual crashes.

Bayesian Information Criterion

The BIC is often used in model selection. It is based on the likelihood function and accounts for the possibility of overfitting an equation by penalizing equations if there are too many variables used. The BIC is calculated and given when the negative binomial regression is run, and, therefore, none of the calibration methods will have this value because their CPM equation was already created. The lower BIC values indicate the better models.

Mean Prediction Bias (MPB)

The MPB was used to look for any overdispersion that may be present in each of the models, comparing the actual and predicted crashes, and is calculated using equation 20. A smaller number indicates less over or under prediction, and a positive MPB indicates overprediction where a negative MPB indicates underprediction.

$$MPB = \frac{\sum(Y_i - X_i)}{n}$$ (20)

With X_i being the actual number of crashes on a segment, Y_i being the predicted number of crashes on a segment, and n being the number of segments.

Mean Absolute Deviation (MAD)

The MAD was used to give a measure of the average magnitude of variability when each model is compared to the actual number of segments, and it is calculated using equation 21. The MAD's only difference from the MPB is that negative and positive differences are unable to cancel each other out, giving the total amount under or over predicted.

$$MAD = \frac{\sum|Y_i - X_i|}{n}$$ (21)

With the variables being the same as those used in equation 20.

Validation Process

These tests examined nine different KDOT projects that were completed between 2003 and 2006. The projects provided a substantial amount of data, allowing for the random nature of crashes and a better analysis of predicted crashes against the actual crashes. Once each test was run and a value found for the statistical tests mentioned in the section before were found, the different CPMs were compared to find the best model.

The first thing that was considered was the BIC value. As mentioned, a lower value indicated a better equation. However, as the BIC values were created using all the input information, it cannot be used to compare the equations to the calibration values used with the original HSM equations. Therefore, this will only help in determining the best new models. Next, the p-values were evaluated. Models with a p-value less than 0.05 will not be considered, and those close to 0.05, while not being entirely ruled out, will be noted that there is a likelihood that they may not work as well as other models. The next thing to consider will be Pearson's R; the higher the value, the more correlation there is between the predicted and actual crashes, so a higher Pearson's R value indicates a better fit model. Lastly, MPB and MAD are used to look for overdispersion, demonstrating if a model overpredicts or underpredicts, and provides another way to compare the models. No single test was used to pick the best model, but using these together with engineering judgment indicated which models worked best for the state of Kansas.

Summary

The objective of this thesis was met by following the steps determined after conducting the literature review. First data were collected, then new model equations were created, and those models went through a validation process, along with the previously determined calibration factors, to find which ones worked best for the state of Kansas. Figure 4 depicts the method that was followed.
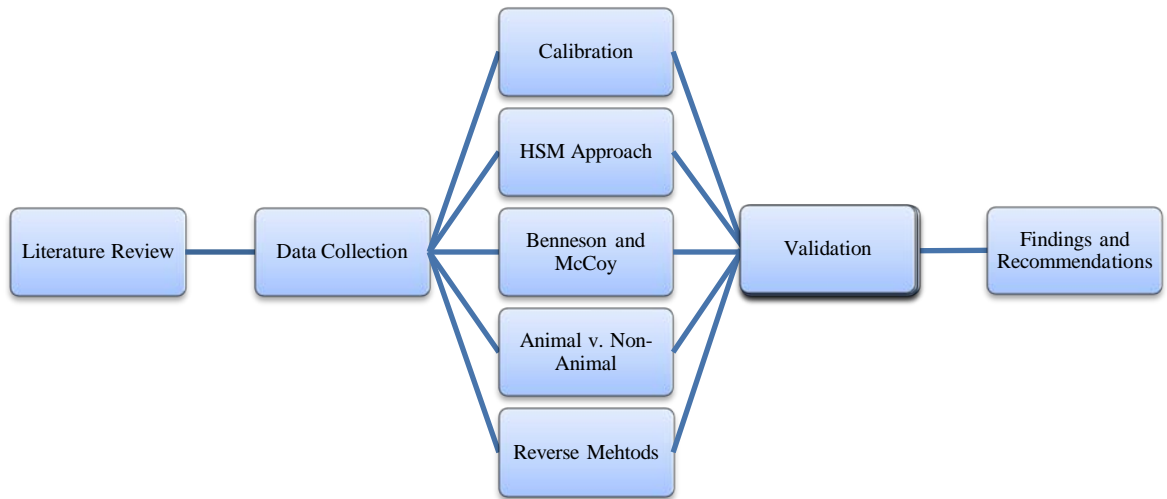
FIGURE 4 Layout of the methodology.

CHAPTER IV - DATA COLLECTION

Introduction

In this chapter, the method of collecting and processing data will be covered. The framework for the use of much of these data is presented in Chapter II - Literature Review. A portion of the data were first collected for Lubliner's study (*14*), and the same methodology was used for the remaining data that were collected. It is necessary to understand different data elements used in the process of creating a SPF. Naturally, problems similar to those encountered by Lubliner were also found in this study and are discussed throughout this chapter. In the following sections, the data sources and variables extracted from them are discussed in that order as well as data that helped sort out the rural data from urban data.

Data Sources

The following section covers the various databases and sources from where the data were be taken. Table 3 (see page 57) summarizes each variable, defines each variable, and provides the resources that were used in the data mining process.

CANSYS Database

The CANSYS database, maintained by KDOT computer staff, stores most roadway features in the Kansas highway system. The data were collected at random intervals and taken from different sources; this means the data may not be precise in matching existing field conditions and could be missing certain elements in certain areas. The CANSYS database is typically used for higher level analyses for network screening and trend evaluations. For this study, data were obtained for the entire state. The data were sorted by route name and county so that every mile is accounted for but also ensures none are counted twice. There were 45 specific

fields chosen to use in the analysis, which can be found in Appendix B; the following sections describe the most important attributes and how they were used.

District and County

Kansas is made up of 105 counties. As a county system is not practical for KDOT to use, they have divided the state into six districts, using county lines to separate them, a map of both the counties and districts can be seen in Figure 5. The districts were used to make sure that there was proper representation from each district when creating a SPF, and county maps in the KDOT system were also helpful when looking at the data.
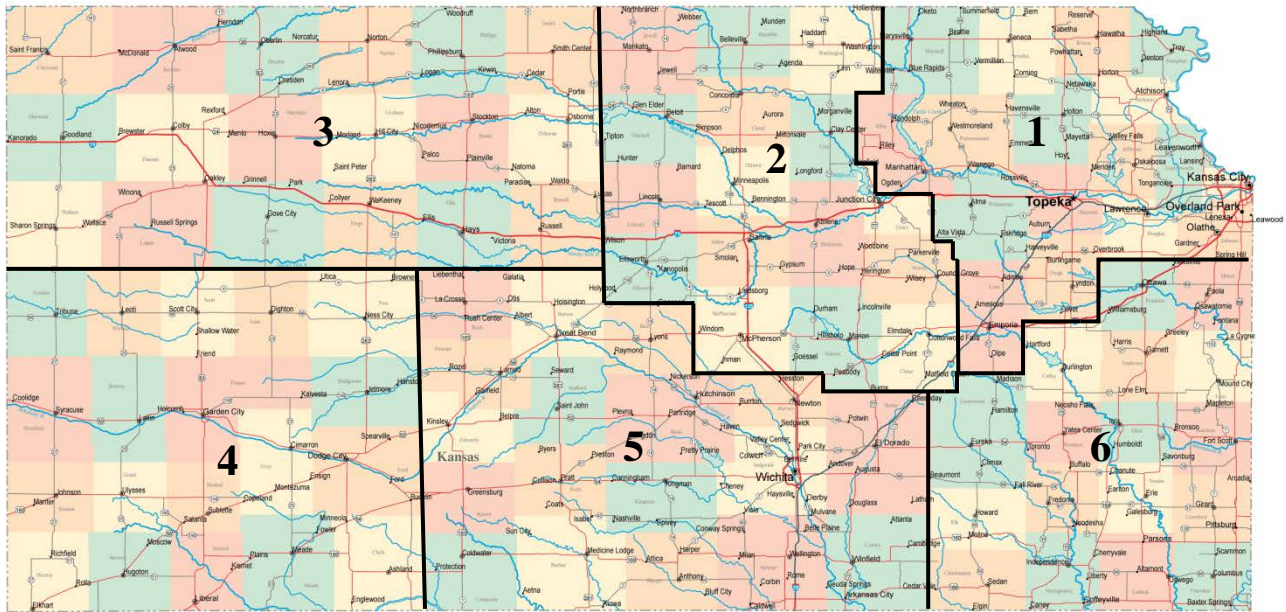
FIGURE 5 Kansas county and district map.

Begin and End Mile Post and Segment Length

Kansas has mileposts increasing from south to north for odd routes and west to east for even routes, as is custom in the United States. KDOT has both state mileposts and county mileposts, where the milepost can start at either the state line or county line. In the CANSYS database, the beginning and ending mileposts were defined by a crash report or an intersection.

Using the beginning and ending mileposts, a length was calculated. Having the milepost aided in converting miles to stationing and vice versa when looking at existing plans.

Intersections

Although intersection-related crashes are not being evaluated in this study, as they are usually calculated separately from predicting segment crashes due to different factors in the reason for intersection crashes, having the intersection name with the corresponding milepost was still useful. This information aided in confirming mileposts given in other documents to make sure the data were placed at the correct location.

Lane Class and City Code

Lane class identifies the type of highway facility present from undivided two-lane segments to divided eight-lane segments. For this specific study, segments classified as 1, which represent undivided two-lane segments, were filtered out; the remaining segments were not used. This does leave out some small segments that could otherwise be used as the HSM does allow for the occasional section with TWLTLs or short four-lane sections mainly found at intersections near more populated areas to be used when analyzing rural two-way, two-lane highways. However, the bias caused by this was considered small as those sections make up a small amount of the whole Kansas highway system.

The city code identification number dictates whether the segment is urban or rural. The number 999 represents a rural segment and a value of null means it is in an urban area. For this, the FHWA definition of urban is used, where urban is when a population is equal to or larger than 5000 people.

Accident Identification Number

The CANSYS database also has a field that identifies the location and specific identification number of each crash report. This does not give specific crash information, only the route, county, and milepost of each crash are given. These attributes were used to coordinate crash information from the Crash Report Database.

Crash Report Database

KDOT keeps a separate database of all crash reports filed for incidents on the Kansas highway system. This database is coded with reference to the Kansas Motor Vehicle Accident Report (KDOT Form 850A, see Appendix C) which is filled out for every incident that the Kansas Highway Patrol responds to or is made aware. Each of these incidents is given a specific crash identification number, and that number correlates with each crash's specific attributes.

For this study, all reports from 2005-2007 were gathered as 2007 was the most recent available data at the beginning of this study, and a minimum of three years of data were required as found in the literature. This is because a shorter time period would have too much variability due to the randomness of crashes, and a longer time period can create bias in changes of reporting standards or physical changes to highway features, and improvements in safety features in vehicles. The following sections are a list of fields used from the crash data and how each was used.

Location of Crash

There are multiple fields used to show where a crash took place. The main two that were used were the county milepost and the distance from a named intersection. As responders don't have precise positioning equipment, the milepost of where it is documented that the crash occurred can differ from where it actually was. All of the crashes were verified with proximity

to a named intersection to corroborate the location of the crash relative to the highway section being analyzed.

Accident Class

The accident class field identifies the type of crash that occurred. The most common in Kansas were found to be animal collisions, overturned crashes, collision with a motor vehicle in-transport, and collision with a fixed object. Additional fields identify the specific object or nature of crash if necessary.

Accident Severity

There are only three options for classifying the severity of the crash: fatal, injury, and PDO. If there were multiple vehicles involved in the crash, the most severe level from either vehicle was used.

Combined Database

The data collected from the CANSYS database and the crash data were combined into one spreadsheet using the VLOOKUP function in Microsoft Excel by matching up the crash identification numbers which was included in both databases. The crash identification numbers from each dataset were matched up, although crash identification numbers that included letters had to be matched manually. The main function was to match up the crashes to segments in the Kansas highway system.

Other Data Sources

The following data sources were used to obtain data that the combined CANSYS and crash report databases could not provide, but were needed to complete the data sets to create a new SPF.

Existing Plans

To suitably perform the creation of a new SPF for Kansas, more than the geometric data provided in the CANSYS database was needed. Plans for each segment were retrieved from the KDOT archive. KDOT's mileage log was used to determine the most recent highway grading project that had been performed on the selected segments of highway. Extra effort was used to combine elements of each project to get an accurate model of how the highway currently exists. Plan features like shoulder width were compared with the CANSYS data to ensure nothing had been more recently performed. The main information taken from the plans were the horizontal and vertical curve data.

KDOT Videolog and Aerial Photography

The data needed to determine the RHR and driveway density were not obtainable from any of the previous sources mentioned. To best estimate these, the KDOT Videolog, Google Maps, and Google Earth were used, where the videolog is similar to "street view" in both Google applications. The resolution is not particularly high in either of the Google applications, but it was useful in observing the number of driveways per mile. Google Earth's measuring tool was also used to estimate the amount of clear zone, and streetview in both Google applications aided in clear zone estimation and in determining the sideslope.

MQA Random Segment Generator

As part of a KDOT sponsored research project, Review and Analysis of the Kansas Department of Transportation Maintenance Quality Assurance Program (*38*), the University of Kansas developed a random segment generator to help with the Maintenance Quality Assurance (MQA) program. A modified version of this program was developed for Lubliner (*14*). It is still fed the same data used for the MQA program, but now allows the user to vary the length of a

random segment. Any method of randomly selecting segments can be used, but this was useful in that it looks at the entire Kansas highway system and makes adjustments if the segment happens to be at the end of the highway. However, it did require a manual screening of two-lane rural sections and also gives the data using the state milepost which had to be manually converted to the county milepost.

KDOT Maps

Several KDOT maps available on their website were used to collect data needed. Historical traffic count maps (*39*) provided the AADT for additional years as only AADT for 2007 was included in the CANSYS database.

KDOT also has a map identifying the speed of highway segments (*40*) that was used as the design speed in analysis. The county maps available on KDOT's website were also used in some cases to verify the current path of some of the 10-mile segments.

Variables

With the brief overview of each source used, now each variable taken will be discussed. As the data used to create new SPFs had already been input into the IHSDM for Lubliner's study, a crash prediction evaluation was run for each project; once an evaluation was run, there was an option to "Show Spreadsheet." The spreadsheet produced shows the AADTs for each year and divided the whole segment into homogeneous pieces. For example, if a horizontal curve or change in AADT was introduced, a new segment was started. These were then transferred to a spreadsheet so it would be able to be run through a statistical program, SPSS, to create the new SPF. The summary table at the end of this section, Table 3, on page 57, lists all the variables used and the source from which it was taken.

Segment Length

The length of segments used was initially determined by the IHSDM in the process mentioned where each section is homogeneous. If a segment was less than 0.1 mile, it was combined with one of the segments; this value was selected based on previous research by Vogt and Bared (*41*). Segments were kept as homogeneous as possible, but in some cases of consecutive small curves interspersed between short tangents, the curves and tangents were combined in a weighted average, which will be shown in the following sections where appropriate.

AADT

As mentioned before, the CANSYS database gave the AADTs for 2007, which vary across the segments. The AADTs were also taken from KDOT historical traffic flow maps for 2005 and 2006 using the 2007 map as reference to match up where the change in AADT occurred for consistency.

Exposure

The exposure variable is a function created using the segment length, AADT, and the time being evaluated. Instead of actually using the segment length and AADTs in creating the SPF, equation 22 is used.

$$EXPO = AADT \times L \times 365 \times 10^{-6} \tag{22}$$

Where

$EXPO$= exposure, in million vehicle miles per year;

$AADT$= average annual daily traffic; and

L= length in miles.

Horizontal Alignment

The CANSYS database does not contain the horizontal alignment information needed to create a SPF. This information includes the length of horizontal curves and tangents and the radii of horizontal curves. These data were taken from the plan and profile sheets of the segments. In the case of the 10-mile segments, much research and cross referencing needed to be done to ensure that plans were the most recent, and in the case of some of the older plans, the close attention had to be paid to route numbers as some have changed over the years. The plans had all the information needed, and it was assumed that the current alignment was the same as the original grading. As mentioned earlier, some of the horizontal curves needed to be combined. Equation 23 was used, weighting the curves using the lengths of the segment and the curve.

$$Horizontal\ Curve = \ \Sigma\left(R_i \times \frac{l_i}{l_{total}}\right) \qquad (23)$$

Where

R_i = radius of the ith curve;

l_i = length of the ith curve; and

l_{total} = length of the total section.

Vertical Grade

The vertical grades were also taken from the same plans as the horizontal alignments. Only the grades and points of intersection were needed to determine the length of the segment. Most of the plans stated the grade, but some needed to be approximated using the existing profile drafted in the plans. Because the grade changed often, it was impractical to let this determine

segment length.   Therefore, the grades were also combined using a weighted average using equation 24.

$$Average\ Vertical\ Grade = \sum \left(G_j \times \frac{l_j}{l_{total}} \right) \qquad (24)$$

Where

G_j = grade of jth segment;

l_j = length of the jth curve; and

l_{total} = length of the total section.

Cross Section Elements

The cross section elements needed were available in the CANSYS database.   These include the following:

- Lane width;

- Shoulder width;

- Shoulder type;

- Presence of passing lane;

- Presence of short four-lane section; and

- Presence of center two-way left-turn lane.

These elements were compared to the typical sections in existing plans to make sure they matched. If they did not, aerial photography was used to determine which value to use.

Roadside Hazard Rating

The RHR is determined based on many factors including sideslope, clear zone, and if a car would be able to recover if it departed the roadway as advised by Zeeger (*11*) (Appendix A).

The CANSYS database has approximated values for the sideslope of the road, and this was compared with data from the KDOT roadviewer and Google Streetview. Because Kansas is a fairly flat state, the RHR did not vary much along segments or among different the different segments, and usually there was a RHR in the range of 1-4.

Crashes

Crashes were taken from the combined database and paired up with the segment where they occurred, converting the mileposts to stationing. All intersection-related crashes were filtered out, as intersection crashes are currently predicted separately in the HSM.

Speed

Speed was another factor considered in creating a new SPF. Most of the segments had posted speeds of 65 mph. The speeds were taken from a KDOT 2008 map with the speeds of all state highways, which can be found in Appendix D.

Other Variables

There were other factors considered in CPMs. Although not all of them were available, if they were they were put into initial consideration of the variables. These elements were not included in the CANSYS database, and they were determined using both the KDOT videolog and aerial photography.

Driveway density, a CMF and factor in the HSM's CPM, is an easy to determine element using aerial photography in the Google applications. Driveways onto the highway were counted and considered on a per mile basis. Field entrances were disregarded as they are not used on a daily basis. Few segments had more than five driveways per mile, which is the threshold for the

CMF used for driveway density in the HSM's CPM. This means at least five driveways are present to show a significant increase in crashes.

Other elements also considered include lighting, centerline rumble strips, and automated speed enforcement. Kansas does not use automated speed enforcement on their highways, and lighting is a rarity in rural areas. There was also only one segment of highway with centerline rumble strips; although the data for it were collected, it was decided more segments with centerline rumblestrips would need to be in the database before using them in the analysis.

TABLE 3 Summary Table of Variables Used and Their Source

Variable	Definition	Source
DIST	District	CANSYS Database
RTE	Route Number	CANSYS Database
AADT	Average daily traffic (vehicles/day)	CANSYS Database, KDOT Maps
LogAADT	Natural log (ln) of AADT	
L	Length of segment (mi)	CANSYS Database
LogL	Natural log (ln) of L	
EXPO	Exposure, or the amount of cars that have a chance of being involved in a crash	Equation 24
LogEXPO	Natural log (ln) of EXPO	
LW	Lane width (ft)	CANSYS Database, Plans
SW	Shoulder width (ft)	CANSYS Database, Plans
RHR	Roadside Hazard Rating (see Zeeger, Appendix A)	Google Earth, Google Maps
DrPerMi	Driveways per mile	Google Earth, Google Maps
SpdLmt	Posted speed limit (mph)	KDOT Map
Radius	Radius of curve (ft)	Plans
DegCur(i)	Degree of horizontal curve (degrees per 100 ft)	Plans
HorzCurL	Length of horizontal curve (mi)	Plans
HorzCurWeight	Weight for each horizontal curve	Included in equation 25
AvgHorzCurDeg	Average horizontal curve degrees	Equation 25
GradeL	Length of homogeneous vertical curve segment (mi)	Plans
Grade	Grade of segment (Percent grade per 100 ft)	Plans
VertGrWeight	Weight for each vertical grade	Included in equation 26
AvgGrade	Average grade of segment	Equation 26
NonAnimalAcc	Crashes not involving animals	Crash Database
AnimalAcc	Crashes involving animals	Crash Database
TOT_ACC	Total crashes within the segment	Crash Database

Table 3 gives the complete list of variables, their definitions, and sources. Some variables

needed to be manipulated to correctly run the negative binomial regression. To do this, the

natural log needed to be taken of the variables that would be in the base of the equation. These

would be AADT, length, and EXPO. It is a custom seen throughout the research for these to be denoted with Log as a prefix instead of LN – LogAADT, LogL, and LogEXPO.

New Model Data

To create a new model, the data and variables needed to be collected for specific roadway segments to create new SPFs. The next section will detail the process of segment selection for the initial and validation sets and any problems encountered.

Selection of Highway Segments

29 segments of roadway design plans had already been entered into the IHSDM for Lubliner (*14*) to calibrate the HSM's CPM and then to validate the calibration, with 19 and 10 sets of plans for each, respectively. Both groups of data were selected in different manners and were used to create a new SPF because having more data is required in creating an equation.

For the calibration set, an original 50, 10-mile long random sections of highway were initially selected using the MQA program. 10-mile segments were selected as there would be a variety of projects in different areas while also having a suitable number of crashes on each segment. Nine of the fifty segments randomly selected by the MQA program had to be thrown out as they did not meet the two-lane, two-way rural standards.

For the validation set of the initial calibration, the projects were selected differently. Only projects that were in construction between 1999 and 2003 were considered as this would have enough crash data after completion to compare what the model produced and what the actual number of crashes were. KDOT's project management system (WinCPMS) was used to select projects using the program category of "modernization-safety & shoulder improvements" so that only those projects were returned. Then these plans were manually screened for two-lane

rural highways with project lengths more than 2.5 miles long. The first 10 projects remaining in the list were then chosen as the validation plans for calibration in Lubliner's study (*14*). However, for the purpose of his study, Lubliner skipped some segments so that there was at least one project from each district represented in his validation since district-specific calibrations were used. The remaining nine validation segments were then used for the validation set to test the new SPFs and Lubliner's calibrations for this research. Figure 6 shows the location of each segment throughout Kansas.

Once all the segments were finalized, there were modifications to the segments used if the project went through a town, as it was found that the FHWA's definition of rural did not work well in Kansas. The final segments used for creating the new models can be seen in Table 4, with the route, district, county and mileposts; these segments also account for 290.7 miles of rural two-lane highways in Kansas.

TABLE 4 New Model Segments

Segment Number	Route	District	County of First Section	County Milepost Begin	End	County of Second Section	County Milepost Begin	End
1	K-25	6	Grant	23.78	24.7	Kearny	0	9.08
2	US-400	5	Greenwood	6.59	16.59			
3	K-4	6	Lane	12.97	22.97			
4	K-150	2	Marion	6.7	8.01	Chase	0	8.49
5	K-25	6	Kearny	32.48	39.03	Wichita	0	3.45
6	K-177	2	Chase	32.35	33.08	Morris	0	9.28
7	K-25	6	Kearny (Part 1)	12.88	16.15	Kearny (Part 2)	16.95	23.68
8	US-59	4	Labette	14.16	24.16			
9	US-169	4	Neosho (Part 1)	1.96	6.96	Neosho (Part 2)	8.27	13.27
10	K-181	3	Smith	2.4	12.4			
11	US-160	5	Cowley (E/W)	12.4	22.4			
12	K-2	5	Harper (E/W)	10.23	17.23	Harper (N/S)	18.07	21.07
13	US-83	3	Logan	19.12	29.12			
14	US-36	3	Smith	2.78	12.78			
15	K-99	1	Wabaunsee	31.01	41.01			
16	US-400	4	Labette	22.56	25.55	Cherokee	0	7.02
17	US-36	2	Republic	17.97	27.97			
18	US-75	1	Brown	0	10.0			
19	K-116	1	Atchison	0.99	10.99			
20	K-383	3	Norton	0	13.62			
21	US-50	2	Chase	20.67	28.49			
22	US-56	2	Marion	32.05	39.82			
23	US-77	5	Butler	0	12.71			
24	US-283	6	Ness	13.94	30.20			
25	US-73	1	Atchison	0	4.14			
26	K-47	4	Wilson	5.57	7.75			
27	US-36	3	Rawlins	28.47	36.39			
28	K-156	5	Barton	18.61	35.81			
29	US-50	6	Hamilton	17.21	28.50			

*Second sections are when a segment crossed a county line or were split into two due to a town being in the middle of the segment.
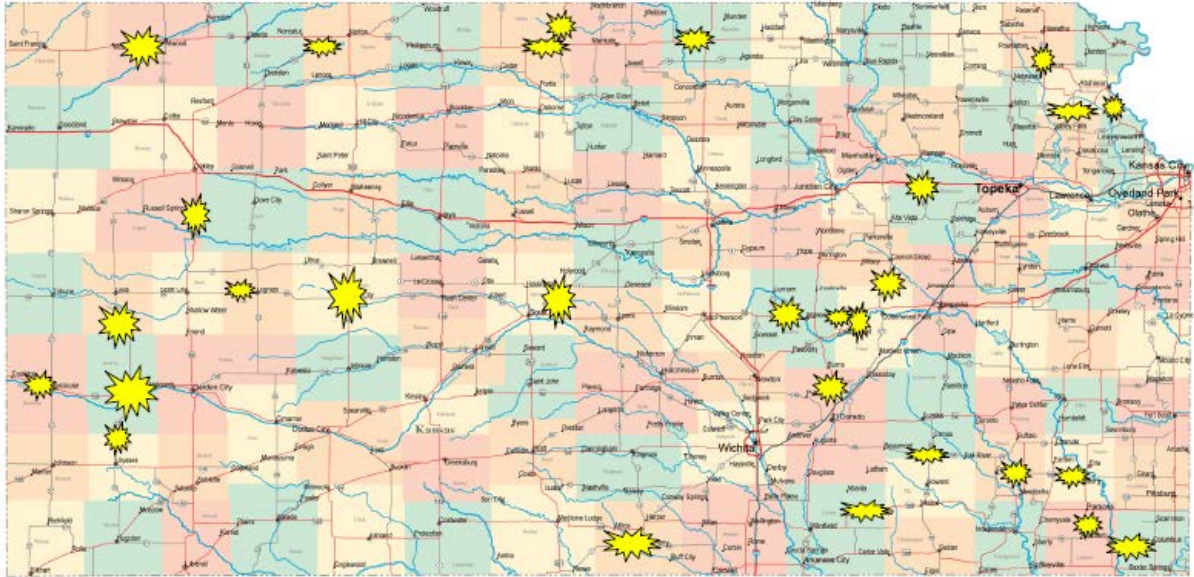
FIGURE 6 Map of where segments for SPF creation are located.

Definition of Rural

As mentioned in the Lubliner's work (*14*), the HSM uses the FHWA's definition of rural where a town with a population equal to or less than 5000 is considered rural. In Kansas, there are 41 cities with a population of 5000 or greater. In the first screening of data for Lubliner (*14*), this definition of rural was used, but when the process had moved on and these specific types of areas were getting a closer look, it was found that many of the highway segments passed through a city of less than 5000, the city still had more of what would be considered urban roadway design. These segments could have curb and gutter, storm sewers, on-street parking, sidewalks, and downtown-style development. As with Lubliner, these segments were excluded from the data that were used to create a new SPF and in the validation process.

A local example of the rural scenarios can be seen in Figures 7-10, which are from US-56 from the intersection of US-56 and US-59, in Douglas County, KS, east to Edgerton, KS. Figure 7 shows the highway in a rural setting, facing west, and is west of Baldwin. Figure 8 was taken

in Baldwin, KS; you can see a traffic signal and curb-and-gutter instead of shoulders along the side of the highway. These features are more urban, although Baldwin's population is 4202, which according to the FHWA is rural. Figure 9 shows the highway between Baldwin and Edgerton, again with the typical rural features expected. Figure 10 shows the busiest area along US-56 that runs through Edgerton, population 1788. The shoulders and highway design are still rural. This is not necessarily because of the smaller population, but because of the position of the highway to Edgerton. US-56 ran through the middle of Baldwin, as can be seen more clearly in the inset map. Although the majority of Baldwin is south of the highway, there is part of it to the north side of the highway as well. In the case of Edgerton, the entire town is south of the highway. Sites like this would still be included in the study as the highway features have remained rural.

FIGURE 7 Photo of US-56, 1 mile west of Baldwin City.

FIGURE 8 Photo of US-56 in Baldwin City, KS.

FIGURE 9 Photo of US-56 between Baldwin City and Edgerton, KS.

FIGURE 10 Photo of US-56 in Edgerton, KS.

Validation Sets

The validation sets were the nine remaining projects from the validation list used by Lubliner that met the rural, two-way, two-lane and length requirements. Table 5 gives a list of these projects, with a total of 70.5 miles being represented from the Kansas rural highway system; the same data extraction process and sources were used for the validation set as in the original set. These projects are from the three of six KDOT districts, and a few are located in the same county. This provides the opportunity to look closely at a segment while the AADT changes, but the highway geometrics and surrounding environments remain similar. K-27 in Sherman was designed and constructed in two different parts, so they were treated as separate segments in this study. Figure 11 shows where the segments are located in Kansas.

TABLE 5 Validation Projects

Segment Number	Project Number	Primary Route	District	Primary County	Length	Time Period after Construction
1	K-6777-01	K-150	2	Marion	8.0	2003-2009
2	K-5754-01	US-36	3	Rawlins	8.4	2003-2009
3	K-6372-01	US-24	3	Osborne	6.9	2006-2009
4	K-5768-01	US-77	2	Marion	6.7	2005-2009
5	K-5748-01	US-75	4	Wilson	10.9	2006-2009
6	K-5385-01	US-50	2	Marion	4.0	2003-2009
7	K-5752-01	US-283	3	Norton	11.3	2004-2009
8	K-5740-01	K-27	3	Sherman pt.2	10.2	2004-2009
9	K-5738-01	K-27	3	Sherman	4.1	2004-2009
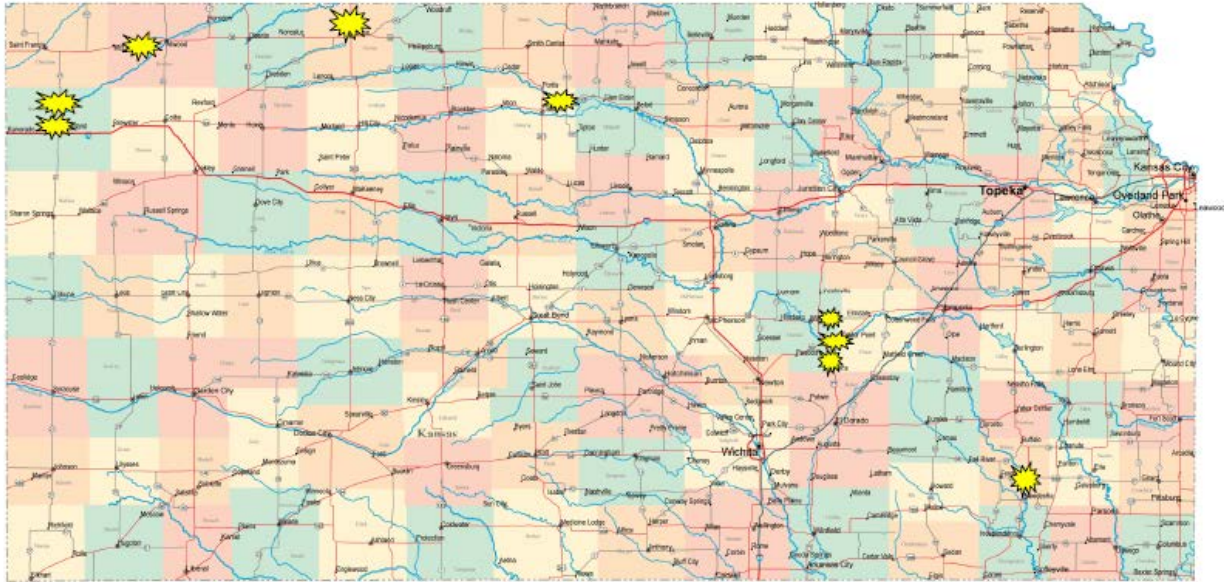
FIGURE 11 Location of validation projects.

Crash Data

Extra crash data were needed beyond the 2005-2007 crash data originally collected to verify the accuracy of the new SPF. Crashes were requested from 1999 to 2009 for the validation segments, to be able to compare the accuracy of the new SPF. Any data from before the new highway was built were removed. The years of construction were also removed from the evaluation, even if construction had only been going on for part of the year, to remove any possible bias that would come from traveling through a construction zone.

Summary

The accuracy of the data collected is essential for the process of creating a new SPF for an optimum equation.

- All of the data mentioned in this chapter were collected for both the set of data used in creation of the new SPFs and in the validation process.

- Validation sections were selected in the same way KDOT would select their projects.

- Any section of highway that went through a small town, no matter the size of the town, was eliminated from the datasets. This is more limiting than the HSM definition that follows the guidance of the FHWA with any segment in a city with a population of 5000 or less considered to be rural.

- As already established by Xie in Oregon (*17*) and Lubliner (*14*), the data collection process was time consuming. A total of 361.2 miles were used in this study.

Figure 12 below shows the progression of this thesis.
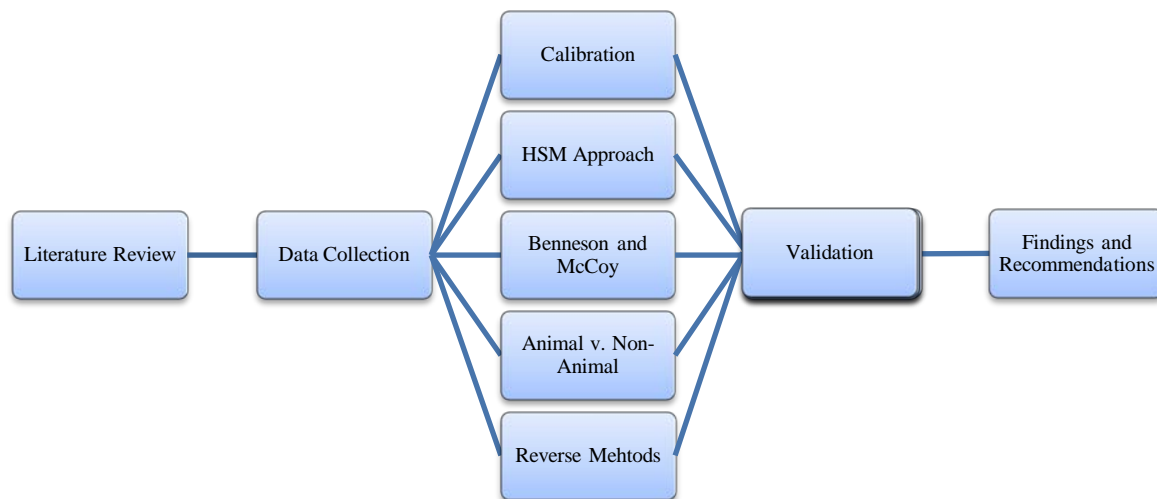
FIGURE 12 Thesis progression.

CHAPTER V – ANALYSIS

Introduction

This chapter will cover the actual process of creating equations and then validating them. First, a study of the data collected was conducted to look for any anomalies within the data. Once a thorough study of the data was completed, the data were run in SPSS to create new SPFs. Following this, the new equations were tested in a validation procedure, using both the new equations and calibration factors from Lubliner (*14*). Several analyses were run on these to aid in determining which methods will work best for the state of Kansas.

Creating New SPFs

This section will go over the process detailed in the methodology used to create new SPFs. First the data were analyzed, and then the data were run through SPSS to create equations.

Data Analysis

Data were first observed by themselves, and then in a correlation analysis to see how they interacted with one another. This was done before the equations were created to ensure that any variables with a high correlation were not in the same equation, as a high correlation indicates a high relationship to the types of crashes they are related to. The Summary statistics in Table 6 show the range and average of values in the variables collected. Kansas rural highways were similar, no matter which part of the state they were located, as the topography is generally similar throughout the state, with the speed limit of most highways being 65 mph, an average grade of 1.11 percent, and an average RHR of 1.7. A special interest was also taken into the number of animal crashes, as they had been noted in Lubliner's (*14*) work to be problematic in predicting crashes and were not considered to be related to geometric improvements (*33*).

TABLE 6 Summary Statistics

	Range	Minimum	Maximum	Mean
ADT	5265	365	5630	2216
L (mi)	8.2	0.1	8.3	0.8
LW (ft)	1.1	11.0	12.1	12.1
SW (ft)	11.8	1	12.8	7.1
RHR	3	1	4	1.7
Driveways per Mile	4.5	0.5	5	1.2
Avgerage Horizontal Curve Degree (degrees per 100 ft)	6.6	0	6.6	0.4
Average Vertical Grade (% per 100 ft)	5.2	0	5.2	1.1
Speed Limit (mph)	10	55	65	64.3
Total Crashes	7	0	7	0.6
Animal Only Crashes	7	0	7	0.4
Non-Animal Crashes	5	0	5	0.2

Table 7 contains the correlation study, looking at the correlation of the variables to the non-animal crashes, animal crashes, and total crashes. A positive correlation indicates that as the variable increases, the amount of crashes will increase, and a negative correlation indicates that as the variable increases, the number of crashes will decrease. If a correlation is found to be significant, it indicates a strong relationship between the data. Using a level of significance of 0.05, EXPO, AADT, length, RHR, driveways per mile and the average horizontal curve degree were found to have a significant correlation in each crash category. It should be noted that although correlation studies can show insight to the relationship between geometric features and crashes, it does not indicate cause and effect and can sometimes be misleading. For example, driveways per mile has a negative correlation with all types of crashes. This indicates that as the number of driveways increase, the number of crashes decrease, but most would expect an increase of driveways in a mile to increase in crashes. Therefore, this relationship could have a confounding factor impacting the correlation.

TABLE 7 Correlation of Variables to Crashes

		Non-Animal Crashes	Animal Crashes	Total Crashes
SpdLmt	Pearson's R	0.017	0.080	0.070
	P-value	0.587	0.010*	0.023*
EXPO	Pearson's R	0.434	0.499	0.609
	P-value	< 0.001*	< 0.001*	< 0.001*
AADT	Pearson's R	0.170	0.132	0.188
	P-value	< 0.001*	< 0.001*	< 0.001*
L	Pearson's R	0.342	0.496	0.557
	P-value	< 0.001*	< 0.001*	< 0.001*
LW	Pearson's R	-0.034	0.017	-0.004
	P-value	0.274	0.583	0.898
SW	Pearson's R	0.039	0.094	0.093
	P-value	0.213	0.002*	0.003*
RHR	Pearson's R	0.111	0.076	0.113
	P-value	< 0.001*	0.015*	< 0.001*
DrPerMi	Pearson's R	-0.062	-0.067	-0.083
	P-value	0.047*	0.032*	0.008*
AvgHorzDeg	Pearson's R	-0.118	-0.147	-0.173
	P-value	< 0.001*	< 0.001*	< 0.001*
AvgVertGrade	Pearson's R	0.059	0.002	0.032
	P-value	0.056	0.936	0.310

*Indicates significance at the 0.05 level.

Equations

With the initial data observations completed, the next step was to use the data to create the equations. First, the data were entered into SPSS via an Excel file and then code was run to produce the factors in the equation (an example of which can be found in Appendix E). First, it was run using all variables, and then anything with a level of significance over 0.05 was discarded and the code was run again with the remaining variables. The following are the final equation models to be tested.

Kansas (KS) CPM

The first negative binomial model, the KS CPM, was created with the variable LogEXPO so it could be used with the HSM's CPM and its CMFs. Table 8 shows the coefficients of all the variables run with their significance level, and Table 9 shows the coefficients when only the significant variables are run.

TABLE 8 KS CPM with All Variables

Variable	Coefficients	P-value
Intercept	-3.35	0.079
SpdLmt	0.03	0.387
SW	-0.02	0.344
AvgHorzCurDeg	0.03	0.763
RHR	0.33	< 0.001
AvgGrade	0.07	0.188

TABLE 9 KS CPM with Only Significant Variables

Variable	Coefficients	P-value
Intercept	-1.72	< 0.001
RHR	0.38	< 0.001

The final equation then is seen in equation 25, with an overdispersion factor (K) of 0.052.

$$N_{KSCPM} = EXPO \times e^{(-1.76+0.38 \times RHR)} \times CMF_{combined} \tag{25}$$

Where

$CMF_{combined}$ = All CMFs multiplied together.

And when applying the base values noted in Table 2 in Chapter 3 to use with the HSM and IHSDM, the equation is reduced to the following:

$$N_{KSCPM} = EXPO \times e^{(-0.56)} \times CMF_{Combined} \tag{26}$$

Reverse CPM

The next model was created by taking the known number of crashes in the data. Equation 27 was used to create the equations and solve for the exponent of e, with X representing the exponent. Equation 28 was the final transformed equation to solve for the new exponents. This was an attempt to see if working backwards from a high-quality model and CMFs would create a better fit with our data.

$$N = EXPO \times e^{X} \times CMF_{combined} \tag{27}$$

$$X = ln\left(\frac{N_{known}}{EXPO \times CMF_{combined}}\right) \tag{28}$$

Where

N_{known} = number of crashes known for the segment; and

X = new exponent values.

Table 10 shows the intercept and X values along with their significance.

TABLE 10 Coefficients for Reverse CPM Method

Variable	Coefficients	P-value
Intercept	-1.583	< 0.001
X	1.287	< 0.001

The X produced for each segment was then used in the negative binomial regression operation to create the exponent shown in equation 29, the reverse CPM with a K-value of 6.172E-8 which is so small that it could also be considered a Poisson regression.

$$N_{RevCPM} = EXPO \times e^{-0.30} \times CMF_{combined} \tag{29}$$

KS Model

The next model, the KS model, applied the Bonneson and McCoy (*20*) model using the negative binomial regression, with LogAADT and LogL so that they both have exponents. Table 11 and Table 12 show the significance of each variable when all were used for an equation and just the significant variables, respectively.

TABLE 11 KS Model with All Variables

Variable	Coefficients	P-value
Intercept	-9.00	< 0.001
LogADT	0.79	< 0.001
LogLength	0.86	< 0.001
SpdLmt	0.03	0.310
SW	0.00	0.969
AvgHorzCur	-0.08	0.408
RHR	0.40	< 0.001
AvgGrade	0.07	0.127

TABLE 12 KS Model with Significant Variables

Variable	Coefficients	P-value
Intercept	-7.16	< 0.001
LogADT	0.82	< 0.001
LogLength	0.87	< 0.001
RHR	0.40	< 0.001

The final model is equation 30, with an overdispersion factor of 0.058.

$$N_{KSMod} = AADT^{0.82} L^{0.87} e^{(-7.16+0.40 \times RHR)} \qquad (30)$$

Reverse KS Model

To create the Reverse KS Model used the same reverse process was performed to obtain the *X*-value in equation 28, but then the negative binomial regression was run so that the equation would come out similar to that of the KS Model. Table 13 shows the exponents with their corresponding significance.

TABLE 13 Reverse KS Model Coefficients and P-values

Variable	Coefficient	P-value
Intercept	-11.80	< 0.001
LogADT	1.39	< 0.001
LogL	1.42	< 0.001
X	1.68	< 0.001

Equation 31 is the Reverse KS Model, and the exponent on the *e* comes from adding the intercept and *X* coefficients, it has an overdispersion factor of < 0.001.

$$N_{RevKSMod} = AADT^{1.39} L^{1.42} e^{-10.12} \qquad (31)$$

Animal and No Animal Models

For the final models, the animal crashes were separated from the total crashes to create equations that predict animal and non-animal related crashes separately. The first model looked at crashes involving only animals with all the coefficients in Table 14, the significant coefficients only in Table 15, and in equation format in equation 32. It had an overdispersion factor of 0.212.

TABLE 14 Animal Crashes Only with All Coefficients

Variable	Coefficients	Significance
Intercept	-10.54	< 0.001
SW	0.02	0.471
RHR	0.36	< 0.001
AvgHorzCurDeg	-0.05	0.675
AvgGrade	0.05	0.779
LogADT	0.65	< 0.001
LogL	0.87	< 0.001

TABLE 15 Animal Crashes Only with Significant Coefficients

Variable	Coefficients	Significance
Intercept	-6.82	< 0.001
RHR	0.31	< 0.001
LogADT	0.74	< 0.001
LogL	0.87	< 0.001

The next equation was created by removing all animal-related crashes, and had an overdispersion factor of 0.236. Table 16 and Table 17 show the initial variables and their significance in the initial run and final run with only significant variables, respectively, and equation 33 is the final model.

TABLE 16 Non-Animal Crashes with All Coefficients

Variable	Coefficients	P-value
Intercept	-9.61	0.001
SW	-0.05	0.204
RHR	0.46	< 0.001
DDdrivemile	0.15	0.439
AvgHorzCurDeg	-0.13	0.399
AvgGrade	0.12	0.122
LogADT	1.17	< 0.001
LogL	0.84	< 0.001

TABLE 17 Non-Animal Crashes with Significant Coefficients

Variable	Coefficients	P-value
Intercept	-10.07	< 0.001
RHR	0.58	< 0.001
LogADT	1.01	< 0.001
LogL	0.85	< 0.001

These equations were added together to see if there was an improvement in the total number of crashes predicted, shown in equation 34.

In looking at the first three models, equations 32, 33, and 34 and their comparison to the actual crashes and overall crash history in Kansas, it was found that animal-related crashes made a large impact on the accuracy of the models as they did with the calibrations formed.

$$N_{pred-an} = AADT^{0.74} L^{0.87} e^{(-6.82+0.31 \times RHR)} \tag{32}$$

$$N_{pred-no-an} = AADT^{1.01} L^{0.85} e^{(-10.07+0.58 \times RHR)} \tag{33}$$

$$N_{total} = N_{pred-an} + N_{pred-no-an} \tag{34}$$

Where

$N_{pred-an}$= the predicted number of crashes only involving animals; and

$N_{pred-no-an}$ = the predicted number of crashes not involving animals.

Validation

Validation was conducted using nine different rural highway segments, and the process of selecting the segments and data collection were discussed in detail in Chapter IV - Data Collection. Each segment was split into homogeneous sections, and the variables from Table 3 were used in each equation except for the calibrated models and KS CPM. For the KS CPM the base values assigned by the HSM for each variable were used, and the CMFs were used to account for any changes in the segment from the base conditions, as would be done when using the HSM's CPM and IHSDM.

Table 18 is a list of the segments used in the validation. There are two separate sections for K-27 in Sherman County; this is because they were conducted as two separate projects at KDOT. Also of notice in Table 18, is the validation data that animal-related crashes accounted for a majority of crashes, especially on US-24 in Osborne County, with 41 of 43 crashes involving animals.

TABLE 18 Crash Breakdown of the Nine Validation Segments

Segment Number	Route	County	Length (mi)	Number of Years	Actual Crashes	Crashes with animals	Crashes without animals
1	K-150	Marion	8.0	7	17	11	6
2	US-36	Rawlins	8.4	7	17	13	4
3	US-24	Osborne	6.9	4	43	41	2
4	US-77	Marion	6.7	5	12	9	3
5	US-75	Wilson	10.9	4	35	26	9
6	US-50	Marion	4.0	7	30	22	8
7	US-283	Norton	11.3	6	18	16	2
8	K-27	Sherman (2)	10.2	6	6	6	0
9	K-27	Sherman (1)	4.1	6	8	3	5

Once the validation segments were entered, each equation and calibration was run for each segment, which gave the total number of crashes per year for each segment, which are

shown in the following section, Statistical Analysis. Once the crashes were run for each segment, the t-statistic, P-value, and Pearson's r were calculated using Excel and GraphPad (*37*) software. The BIC values were also taken from the statistical outputs of the new equations, which came from the data produced when running SPSS. The following section will be a discussion of the statistical analysis.

Statistical Analysis

Two analyses were run as US-24 in Osborne County had an unusually large amount of animal crashes compared to the other counties. The Osborne County case is not considered to be an outlier, but seeing how the equations performed with and without it can give insight to how strong the equations are. Each analysis will be discussed and followed by a discussion on what both the analyses indicate.

Analysis with US-24 in Osborne County

As shown in Table 19, both the KS CPM and Reverse CPM have low P-values, still higher than 0.05, but the low values indicate the models may not work as well. If a significance level of 0.10 had been chosen, they would have been found significant. When looking at Pearson's R, the variable calibration had the highest value in the group of 0.734. The Reverse KS Model had one of the better fits of the new models with the lowest BIC of 1128, out of the three new total crash prediction models. The MPB indicated that the KS CPM and Reverse CPM underpredicted the number of crashes the most of all the models, and having the same value of the MPB, but positive value for the MAD confirmed that they underpredicted the number of crashes in each segment. The KS Model consistently overpredicted, but the MAD increased which indicates that the model also underpredicted on some segments. The calibrations had the

lower MPBs and MADs of the models in Table 19, and the CPM Default fell between the calibrations and new models.

TABLE 19 Comparison of Actual Crashes to Predicted Crash Models

Segment Number	Actual Crashes (Crashes /yr)	CPM Default (Crashes /yr)	State Calib. (Crashes /yr)	Variable Calib. (Crashes /yr)	KS CPM (Crashes /yr)	KS Model (Crashes /yr)	Reverse CPM (Crashes /yr)	Reverse KS Model (Crashes /yr)
1	2.43	2.67	3.94	3.25	2.09	3.30	2.72	10.28
2	2.43	1.72	2.54	2.21	1.35	2.28	1.75	4.61
3	10.75	2.02	2.93	3.92	1.55	2.42	2.02	7.38
4	2.40	1.93	2.85	2.35	1.51	2.55	1.96	5.08
5	8.75	5.15	7.59	7.71	3.96	10.74	5.52	12.57
6	4.29	3.03	4.47	3.69	2.37	3.78	1.68	4.85
7	3.00	1.81	2.67	3.70	1.39	3.13	1.22	2.56
8	1.00	2.60	2.56	2.02	1.35	2.30	1.24	3.17
9	1.33	1.74	3.84	1.35	2.04	2.89	1.78	7.91
Pearson's R		0.461	0.464	0.734	0.461	0.499	0.547	0.482
P-value		0.174	0.751	0.417	0.079	0.758	0.095	0.065
BIC		N/A[A]	N/A[A]	N/A[A]	1826	1787	1228	1128
MPB		- 1.52	- 0.33	- 0.69	- 3.57	2.55	- 3.23	2.45
MAD		2.02	1.74	1.25	3.57	3.58	3.23	3.30

[A]*Do not have access to the BIC values for the CPM default equation.*

Taking a visual look at the differences in Figure 13, many of the equations appear to have predictions close to the actual number of crashes per year. Segment three has large discrepancies, which can be expected due to the large volume of animal-related crashes that occurred. Segment five also has a larger range of values, with the variable calibration model being the closest.
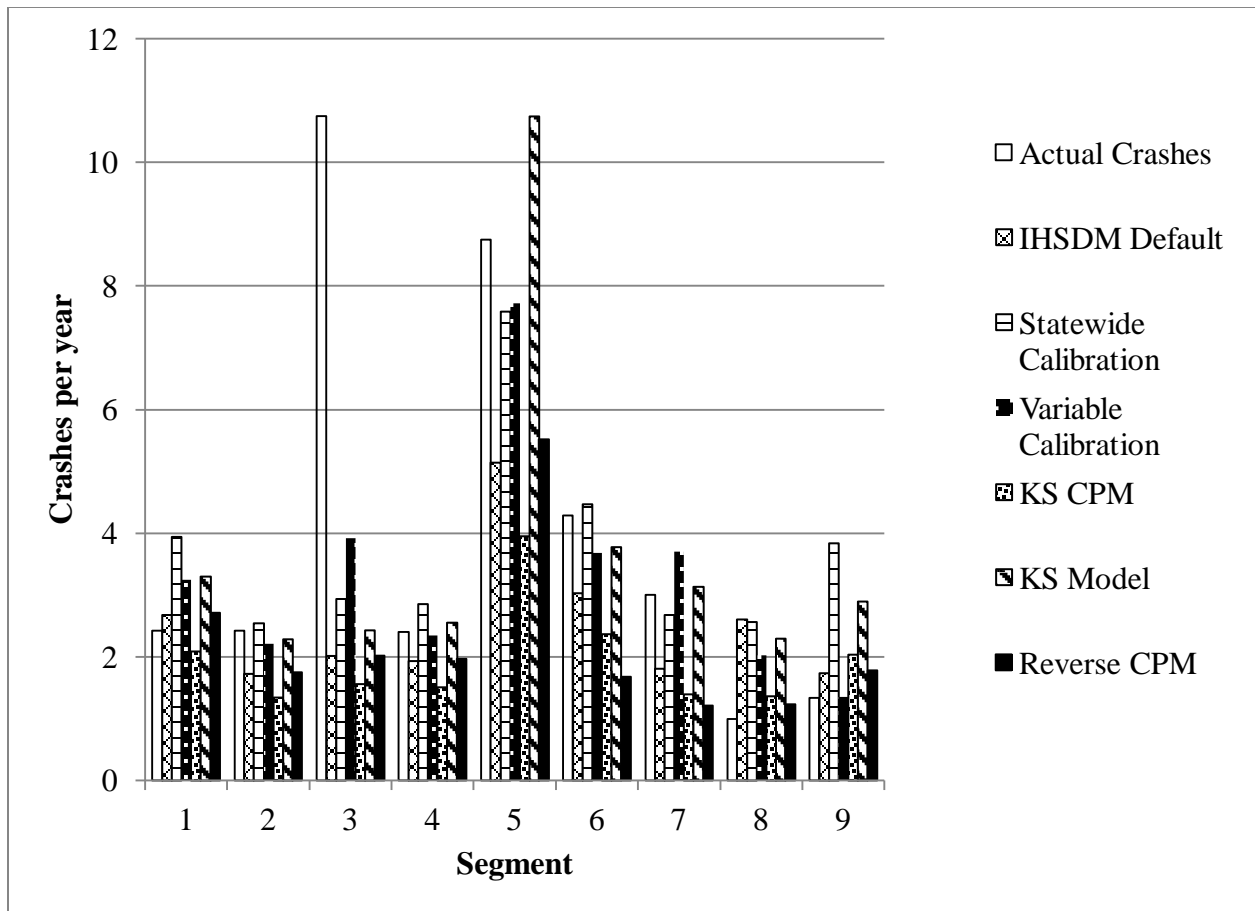
FIGURE 13 Graph comparing the actual crashes per year to the predicted models.

An interest was taken in finding a way to better predict crashes without animal involvement. Table 20 shows the average crashes per year for crash types without animals, with animals, and the two models combined. Looking first at the P-values, there was no statistical significance between the actual crashes and predicted crashes in any of the models. Pearson's R has a wide range with the animal crash model having the lowest correlation; this can be expected as animal crashes were difficult to predict as there is no evidence of a correlation between animal crashes and geometric features. The model looking only at the crashes without animal involvement had the highest Pearson's R and BIC out of all the calibrations and models tested, and the combination of the two equations had a Pearson's R that fell between the two equations. The MPB is low for both the first two equations, but when combined, the MPB and MAD

become much larger. This is due to the large variation in the animal crashes, which is seen in the larger MAD value for the animal crashes model. The crashes without animals performed well with one of the lowest MPBs among all the models and had the lowest MAD.

TABLE 20 Actual Crashes Compared to Predicted, Looking at Animal, Non-Animal, and the Combination of Them

Segment Number	Actual Animal Crashes (Crashes /yr)	Predicted Animal Crashes (Crashes /yr)	Actual Crashes Without Animals (Crashes /yr)	Predicted Crashes Without Animals (Crashes /yr)	Total Crashes (Crashes /yr)	Predicted Animal + Without Animal (Crashes /yr)
1	1.57	2.79	0.86	0.89	2.43	3.67
2	1.86	1.97	0.57	0.55	2.43	2.52
3	10.25	2.06	0.50	0.61	10.75	2.67
4	1.80	2.14	0.60	0.64	2.40	2.79
5	6.50	9.14	2.25	3.73	8.75	12.87
6	3.14	2.90	1.14	0.62	4.29	3.52
7	2.67	2.90	0.33	0.54	3.00	3.44
8	1.00	1.91	0.00	0.41	1.00	2.33
9	0.50	2.52	0.83	0.47	1.33	2.99
Pearson's R		0.340		0.886		0.508
P-value		0.698		0.448		0.811
BIC		1480		973		N/A[A]
MPB		- 0.40		- 0.45		- 3.55
MAD		1.51		0.73		3.62

[A] *The BIC value cannot be calculated when adding two separate equations together.*

Looking at Figure 14, the animal crashes were still hard to predict as segments three and five continuing to not be as close as other segments. The crashes without animal involvement were close in Figure 15 with an exception of segment five, which had a difference of 1.48 crashes per year. Figure 16 shows the combined equations, with the same discrepancies still showing in segments three and five.
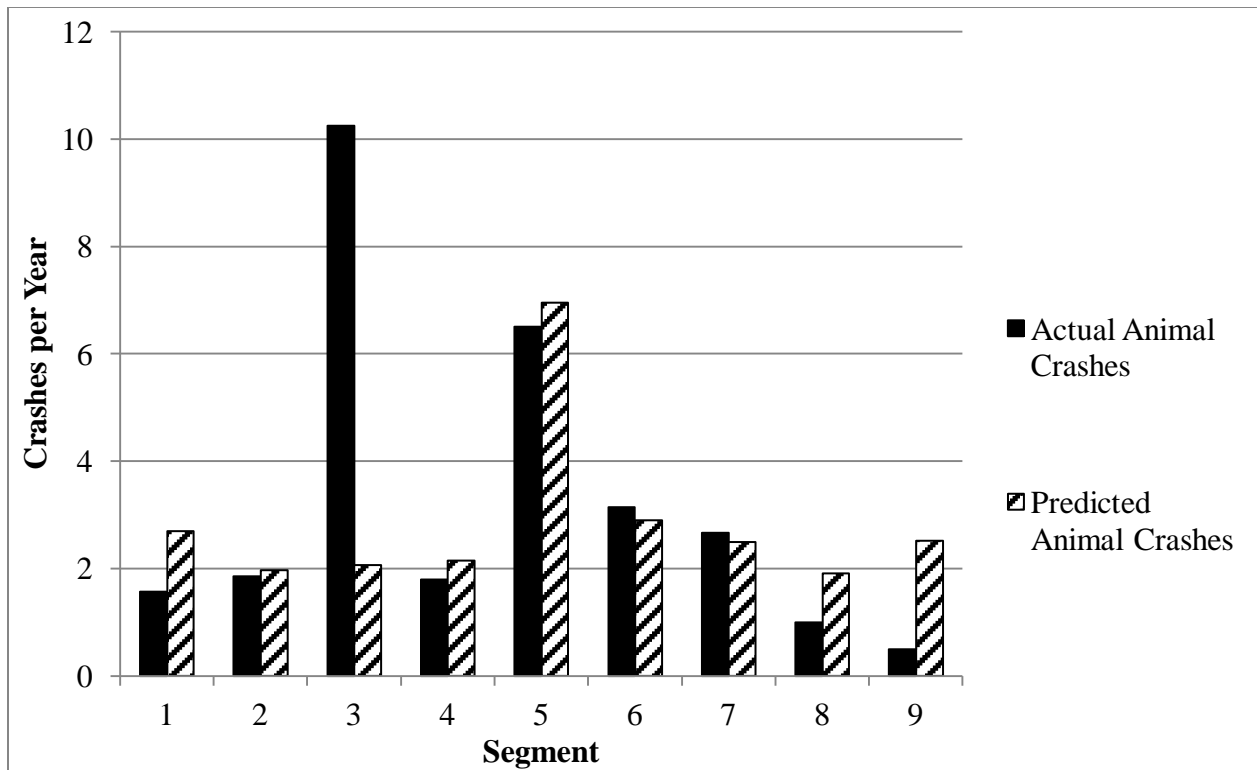
FIGURE 14 Crashes with animals, predicted and actual.
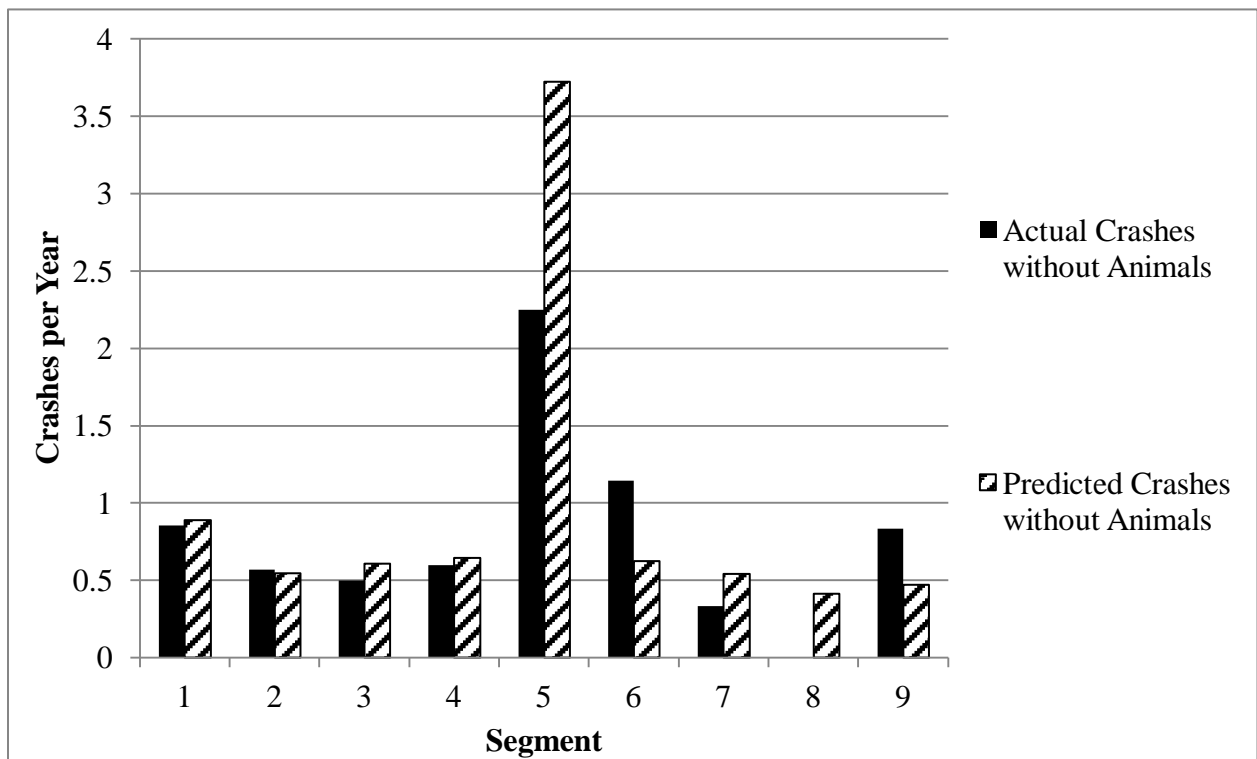
FIGURE 15 Crashes without animals, predicted and actual.
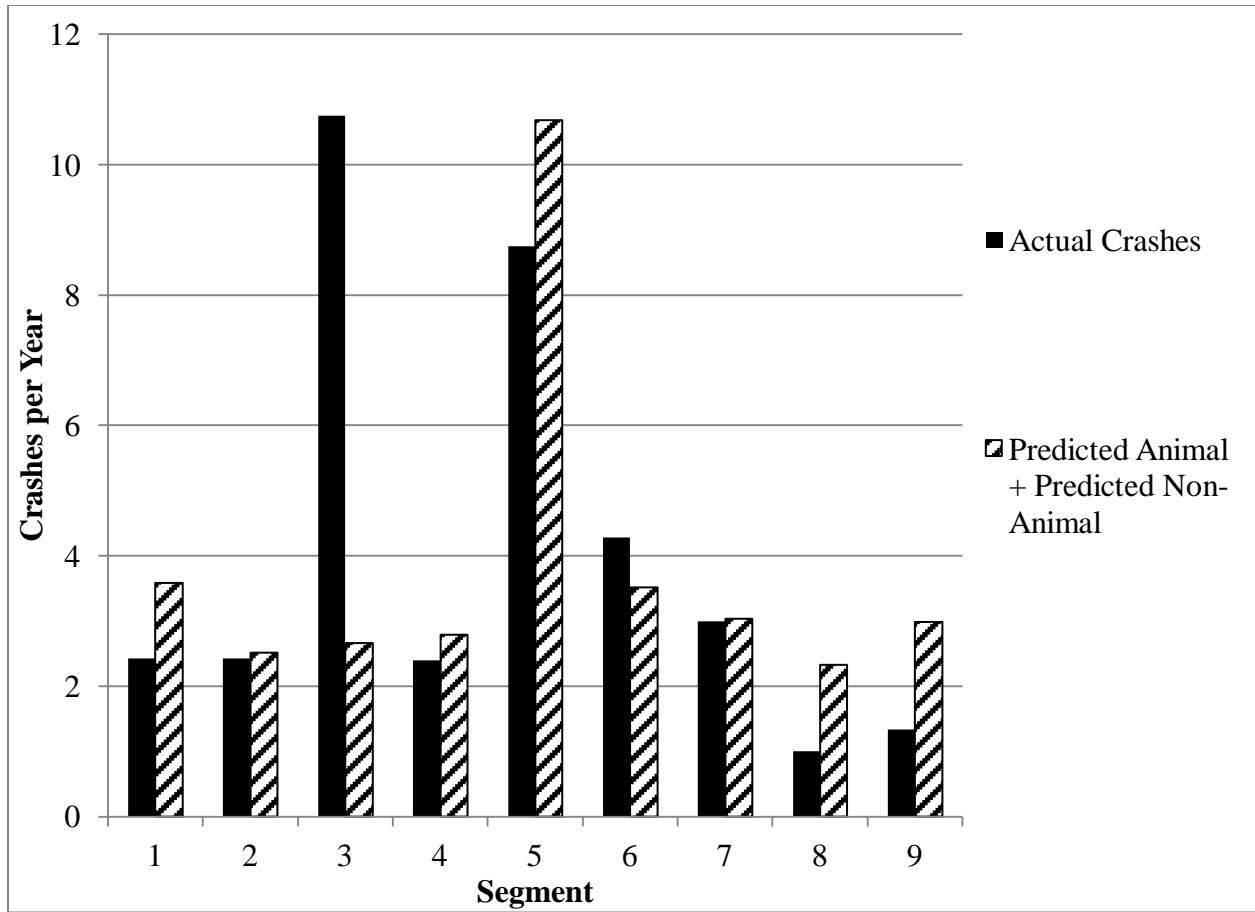
FIGURE 16 Comparison of actual crashes against predicted for the combined animal and non-animal crashes.

Analysis without US-24

The analysis without US-24 showed a large improvement in all models but the non-animal model as could be expected. The variable calibration performed the best of all the models with a correlation of 0.970, but the other models also showed improvement, especially with the KS Model, as can be seen in Table 21. However, although the Pearson's R improved for the KS Model, the P-value is at 0.071, which still does not indicate a significant difference between the actual and predicted crashes, but is a large decrease from the analysis with US-24. The Reverse KS Model also has a lower P-value indicating a significant difference between the actual and predicted crashes, and although the Pearson's R increased with US-24 removed, it still

has a lower correlation than the other models. The drop in P-values is thought to happen with these two models because each significantly over-predicted crashes on segment five. This offset their under-prediction for segment three, averaging out the differences. The MPB improves on all but the State Calibration model, which went from -0.33 to 0.54, but still a small number and the MAD for State Calibration improved overall from 1.74 to 0.87. The improvement of all models with the MPB and MAD tests can be expected as US-24 was underpredicted by all models.

TABLE 21 Validation Results without Segment Three

Segment Number	Actual Crashes (Crashes /yr)	CPM Default (Crashes /yr)	State Calib. (Crashes /yr)	Variable Calib. (Crashes /yr)	KS CPM (Crashes /yr)	KS Model (Crashes /yr)	Reverse CPM (Crashes /yr)	Reverse KS Model (Crashes /yr)
1	2.43	2.67	3.94	3.25	2.09	3.30	2.72	10.28
2	2.43	1.72	2.54	2.21	1.35	2.28	1.75	4.61
4	2.40	1.93	2.85	2.35	1.51	2.55	1.96	5.08
5	8.75	5.15	7.59	7.71	3.96	10.74	5.52	12.57
6	4.29	3.03	4.47	3.69	2.37	3.78	1.68	4.85
7	3.00	1.81	2.67	3.70	1.39	3.14	1.22	2.56
8	1.00	2.60	2.56	2.02	1.36	2.30	1.24	3.17
9	1.33	1.74	3.84	1.35	2.03	2.89	1.78	7.91
Pearson's R		0.887	0.901	0.970	0.897	0.952	0.872	0.608
P-value		0.289	0.191	0.756	0.088	0.071	0.092	0.016
MPB		-0.55	0.54	0.07	-2.47	0.59	-0.86	2.82
MAD		1.05	0.87	0.50	2.47	0.74	1.08	2.92

The equations with animal crashes alone and the combination of animal crashes and non-animal crashes also improved remarkably with Pearson's R over 0.9 as can be seen in Table 22. The equation that eliminated animal crashes performed almost exactly the same with a difference in the Pearson's R of 0.001. The significance of the predicted animal crashes also changed, with

a P-value of 0.071. Although there are still no significant differences, it is a dramatic drop from 0.698. As with the other models, the MPB and MAD improved, although the model without animal crashes changed the least, but also continued to have the lowest MPB behind Variable Calibration and have the third lowest MAD behind Variable Calibration and the Animal Crashes model.

TABLE 22 Results without Segment Three, Animal and Non-Animal Models

Segment Number	Actual Animal Crashes	Predicted Animal Crashes	Actual Crashes without Animals	Predicted Crashes without Animals	Total Crashes	Predicted Animal + Predicted Non-Animal
	(Crashes /yr)	(Crashes /yr)	(Crashes /yr)	(Crashes /yr)	(Crashes /yr)	(Crashes /yr)
1	1.57	2.70	0.86	0.89	2.43	3.58
2	1.86	1.97	0.57	0.55	2.43	2.52
4	1.80	2.14	0.60	0.64	2.40	2.79
5	6.50	6.96	2.25	3.73	8.75	10.68
6	3.14	2.90	1.14	0.62	4.29	3.52
7	2.67	2.50	0.33	0.54	3.00	3.04
8	1.00	1.91	0.00	0.41	1.00	2.33
9	0.50	2.52	0.83	0.47	1.33	2.99
Pearson's R		0.914		0.885		0.953
P -value		0.071		0.488		0.063
MPB		0.51		-0.39		-2.44
MAD		0.60		0.67		2.51

Comparison of Analyses

The second analysis was helpful in seeing how the models reacted when an extreme case was not present. Pearson's R showed improvement when an extreme case was removed in most of the models. The Non-Animal Model showed the least improvement, with Pearson's R and P-values remaining almost the same at 0.885; this shows the number of animal crashes did not affect the Non-Animal Model. The Variable Calibration also showed an improvement from a

Pearson's R of 0.734 to 0.97. Although there was a large difference, it was the smallest difference seen among the other models that include animal related crashes. This indicated that although the results when Variable Calibration did improve when segment three was removed, it was one of the least affected by the large amount of deer crashes.

Model Evaluation

With the analysis complete, Table 23 was created, which lists the pros and cons for each model in order to select the best model. Accuracy was based on the statistical methods used when segment three was included. If a method changed significantly with segment three removed, it was also considered.

TABLE 23 Pros and Cons of Methods

Model	Pros	Cons
Statewide Calibration	• Easy to use with one calibration number	• Has moderate accuracy • Needs all the variables to input into the IHSDM
Variable Calibration	• High accuracy by using a calibration factor based on county animal crash rates • Performed exceptionally well when segment three was removed from analysis	• Needs all the variables to input into the IHSDM
KS CPM	• Based on the HSM's CPM • Will work with the IHSDM and CMFs	• Has moderate accuracy • Needs all the variables to input into the IHSDM
Reverse CPM	• Easy to recreate by just using one variable with the negative binomial	• Moderate accuracy, but declined when segment three was removed • Would have a significant difference if a level of 0.10 was used
KS Model	• Used only one variable • Needed less data collected	• Moderate accuracy
Reverse KS Model	• Promising model with exponents allowing a curved line	• Low accuracy and it declined when segment three was removed
Animal Only Model	• Easy to use	• Low accuracy • Large discrepancies in some segments • As animal related crashes are not related to road geometry, would not be considered to be that accurate
Without Animal Model	• High accuracy and lowest BIC • Only needed one variable • Performed the same when segment three was removed	• Using only one variable limits the possible geometric improvements that could be observed with the HSM
Animal Only and No Animal Models Combined	• Needed only one variable	• Moderate accuracy • Same problem with the Animal Only model regarding animal crashes and road geometry

Two of the models stand out as the best – the Non-Animal Model and Variable Calibration. The final model selection and other findings will be discussed in Chapter VI – Findings and Recommendations.

Summary

Several different models were created in an attempt to find the model that would work best for the state of Kansas. The biggest problem with the models was the large amount of deer crashes, as previous work has shown. Two models, both using methods to deal with animal crashes, appeared to work significantly better than the others, those being Lubliner's Variable Calibration, equation 15, and the Non-Animal Model, equation 33. Either model should work well in engineering practice.

CHAPTER VI – FINDINGS AND RECOMMENDATIONS

This chapter will summarize the key conclusions drawn from the analysis and give final thoughts on what the research found. It will also give recommendations for future researchers to consider when continuing research on CPMs.

Findings

Using the analysis in Chapter V – Analysis, and engineering judgment, the different models and calibrations were analyzed. Table 23 in Chapter V, gives an analysis of each model and calibration method tested, listing the pros and cons of each model tested. Each statistical method used in the validation process was considered.

From the analysis, it appears that there are two models that would work best for the state of Kansas. The Variable Calibration method, where crashes are predicted using the HSM's CPM and a calibration based on animal crash rates on a county basis had a high correlation using Pearson's R. The Variable Calibration method also took individual county animal crash statistics into consideration which helped in accounting for the animal crashes. It was run using the HSM's CPM method and IHSDM, which required in-depth data mining in collecting all the variables. The equation for the calibration factor, C_{county}, is restated below in equation 15, and it will be used in the HSM's equation, shown as equation 7.

$$C_{county} = 1.13 \times ACR_{county} + 0.635 \qquad (15)$$

$$N_{predicted\ rs} = N_{spf\ rs} \times C_r \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{12r}) \qquad (7)$$

The Non-Animal Model, restated below in equation 33, was a new SPF created using only crashes that did not involve an animal. This model had a high correlation and low BIC, making it a good candidate. Eliminating animal-related crashes, which were generally out of an engineer's control, made for an improved SPF. It also only requires RHR, AADT, and the length

of the segment, reducing the number of variables needed, which would result in less effort collecting data when being applied.

$$N_{pred-no-an} = AADT^{1.01} L^{0.85} e^{(-10.07+0.58 \times RHR)} \hspace{4cm} (33)$$

Recommendations

The two models listed in the Findings section of this chapter would work well for KDOT at the present time. Although the crashes without animals model would work well and needs less data collected, it was created using only 3.4 percent of rural highways throughout Kansas. Although a wide range of variables were collected, they may not be properly represented in the model, especially as there were many variables found to have significant correlations with crash types, but were not represented in the final models. After speaking with KDOT, the Variable Calibration by Lubliner will be given as the preferred model.

Future Research

The database of highway segments should continue to be added upon until the whole Kansas highway system's geometric features are in a database. As more data are collected, the methods in this thesis would work well in producing a viable SPF. This would also continue to improve the models and create more possible variables such as centerline rumblestrips, which have proven to work effectively in reducing crashes, and others that had significant correlations but did not appear significant in the equations.

To follow this research, a study of the models with the segments that can be used by the EB method should be studied. The EB method has been shown to improve the accuracy of crash predictions by taking past crashes along a segment into account, but is also more difficult to perform by hand. The IHSDM does use this feature if the "before" plans are put in, but if the

geometrics of the segment change too much, like when a realignment is being performed, the EB method cannot be used. Kansas is also in the process of developing jurisdiction-specific CMFs for shoulder width and shoulder type. Nationally, other states may follow creating new SPFs if facing similar problems with animal-related crashes or another variable that may be different from the HSM states of Washington and Minnesota.

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APPENDIX A - ROADSIDE HAZARD RATING GUIDE

The data collected for the crash prediction models used the following RHR guide created by Zegeer, et al. (*3*) to characterize the crash potential for roadside designs found on two-lane highways. Roadside hazard was ranked on a seven-point scale from 1 (best) to 7 (worst). The seven categories of roadside hazard rating are defined as follows and can be found also in the report by Harwood et al. (*11*):

Rating = 1

- Wide clear zones greater than or equal to 9 m (30 ft) from the pavement edgeline.
- Sideslope flatter than 1:4.
- Recoverable.

Rating = 2

- Clear zone between 6 and 7.5 m (20 and 25 ft) from pavement edgeline.
- Sideslope about 1:4.
- Recoverable.

Rating = 3

- Clear zone about 3 m (10 ft) from pavement edgeline.
- Sideslope about 1:3 or 1:4.
- Rough roadside surface.
- Marginally recoverable.

Rating = 4

- Clear zone between 1.5 and 3 m (5 to 10 ft) from pavement edgeline.
- Sideslope about 1:3 or 1:4.
- May have guardrail (1.5 to 2 m [5 to 6.5 ft] from pavement edgeline).
- May have exposed trees, poles, or other objects (about 3 m or 10 ft from pavement edgeline).
- Marginally forgiving, but increased chance of a reportable roadside collision.

Rating = 5

- Clear zone between 1.5 and 3 m (5 to 10 ft) from pavement edgeline.
- Sideslope about 1:3.
- May have guardrail (0 to 1.5 m [0 to 5 ft] from pavement edgeline).
- May have rigid obstacles or embankment within 2 to 3 m (6.5 to 10 ft) of pavement edgeline.
- Virtually non-recoverable.

Rating = 6

- Clear zone less than or equal to 1.5 m (5 ft).
- Sideslope about 1:2.
- No guardrail.
- Exposed rigid obstacles within 0 to 2 m (0 to 6.5 ft) of the pavement edgeline.
- Non-recoverable.

Rating = 7

- Clear zone less than or equal to 1.5 m (5 ft).
- Sideslope 1:2 or steeper.
- Cliff or vertical rock cut.
- No guardrail.
- Non-recoverable with high likelihood of severe injuries from roadside collision.

Figures 8 through 14 present photographs illustrating the seven roadside hazard rating categories.

Figure 8. Typical Roadway with Roadside Hazard Rating Equal to 1.

Figure 9. Typical Roadway with Roadside Hazard Rating Equal to 2.

Figure 10. Typical Roadway with Roadside Hazard Rating Equal to 3.

Figure 11. Typical Roadway with Roadside Hazard Rating Equal to 4.

Figure 12. Typical Roadway with Roadside Hazard Rating Equal to 5.

Figure 13. Typical Roadway with Roadside Hazard Rating Equal to 6.

Figure 14. Typical Roadway with Roadside Hazard Rating Equal to 7.

APPENDIX B - ORIGINIAL CANSYS DATA FIELDS

- RSE_DISTRICT
  - KDOT District, 1-6
- RSE_COUNTY
  - Kansas County, numbered by alphabetical order by county, 1-105
- FROM_LRS
  - LRS is the Linear Reference System used for internal highway system tracking.
- TO_LRS
  - LRS is the Linear Reference System used for internal highway system tracking.
- NE_GROUP
  - NE is the Number Element field used for internal highway system tracking.
- BOUND_GROUP
  - The bound group field is a code used for internal cataloging of the highway system.
- FROM_SECT
  - The section field is used for internal highway system tracking.
- TO_SECT
  - The section field is used for internal highway system tracking.
- RSE_BEGIN_DESCR
  - Written description of the beginning of the LRS Section
- RSE_END_DESCR
  - Text description of the end of the LRS Section
- BEGIN_COUNTY_MP
  - County milepost of the beginning of the LRS Section
- END_COUNTY_MP
  - County milepost of the end of the LRS Section
- NE_LENGTH
  - Length of the LRS section (miles), END_COUNTY_MP - BEGIN_COUNTY_MP
- NMS_MRG_JOB_ID
- NMS_MRG_SECTION_ID
- SECT_NETWORK_DIRECTION
  - Direction of highway, Eastbound (EB) or Northbound (NB)
- SECT_NE_SUB_TYPE
  - This field indicates whether the route is divided (D) or undivided (U)
- SECT_ROUTE
  - The section field is used for internal highway system tracking.
- INTR_INTRSCTN_NAME
  - Name of intersecting roadway, field was found to be incomplete
- INTR_ON_STATE_NONSTATE
  - Type of intersecting roadway, State highway (S) or other roadway (N)
- INTR_TFO_IND
  - TFO Indicator
- INTR_INTRSCTN_DESC
  - Text description of interesting roadway
- INTR_LEFT_TURN_LN
  - Type of left turn lane, values below, field was found to be incomplete
    - 0 - N/A, rural section, not permitted, or no intersections exist on section.
    - 1 - Turns permitted, mult. exclusive turning lanes exist.   No through

- ▪ 2 - Turns permitted, cont. exclusive turn lane. (Chicken Ln) No through.
- ▪ 3 - Turns Permitted, single exclusive turn lane.
- ▪ 4 - Turns permitted, no exclusive turn lane.
- ▪ 5 - No turn permitted during peak period.
- INTR_RIGHT_TURN_LANE
  - o Type of right turn lane, values same as left turn lane, field was found to be incomplete
- INTR_NMBR_LGS
  - o Number of total legs in intersection, field was found to be incomplete
- INTR_INTERSECTION_CONTROL
  - o Type of intersection control, values below, field was found to be incomplete
    - ▪ 0 - N/A, rural section
    - ▪ 1 - Signal, uncoordinated fixed time
    - ▪ 2 - Signal, traffic actuated
    - ▪ 3 - Signal, progressive (cordinated signal through several intersections)
    - ▪ 4 - Stop sign
    - ▪ 5 - Other or No control
    - ▪ 6 - Roundabout
    - ▪ 7 - Interchange
- INTR_INTRSCTN_ID
  - o ID number individual to each intersection in system
- LNCL_LNCL_CLS_ID
  - o Lane Class, values below
    - ▪ 1 - 2LU - Two lane, undivided.
    - ▪ 10 - 1L1 - One lane, one way.
    - ▪ 11 - 2L1 - Two lane, one way.
    - ▪ 12 - 3L1 - Three lane, one way.
    - ▪ 13 - 4L1 - Four lane, one way.
    - ▪ 14 - 2LD - Two lane, divided
    - ▪ 2 - 4LU - Four lane, undivided.
    - ▪ 3 - 4LD - Four lane, divided.
    - ▪ 4 - 6LU - Six lane, undivided.
    - ▪ 5 - 6LD - Six lane, divided.
    - ▪ 6 - 8LU - Eight lane, undivided.
    - ▪ 7 - 8LD - Eight lane, divided.
    - ▪ 8 - 3L - Three lane.
    - ▪ 9 - 5L - Five lane.
- UAB_CITY_CODE
  - o Urban area code, Rural (999)
- A007_AADT_CNT
  - o 2007 AADT Value
- SHLD_SHOR_SHLDR_ID
  - o Type of right shoulder
    - ▪ 1 - None - Non-State shoulder code
    - ▪ 10 - ASSC - ABS with B.S.T. and curb and gutter
    - ▪ 11 - BC - Bituminous base.
    - ▪ 12 - BCGU - Bituminous base and gutter
    - ▪ 13 - BCCG - Bituminous base curb and gutter
    - ▪ 14 - GUTT - Gutter
    - ▪ 15 - GUTU - Gutter and turf
    - ▪ 16 - GUAS - Gutter and ABS

- 17 - GASS - Gutter and ABS (with B.S.T.)
- 18 - GUBC - Gutter and bituminous base
- 19 - CG - Curb and gutter
- 2 - TURF - Turf.
- 20 - CGTU - Curb and gutter and turf
- 21 - CGAS - Curb and gutter and ABS
- 22 - CASS - Curb and gutter and ABS (with B.S.T.)
- 23 - CGBC - Curb and gutter and bituminous base
- 24 - SEAG - Seeded aggregate base.
- 25 - AISM - Agg. 1 with CACL2 (3R), LT 6".
- 26 - CGMT - Mountable village curb and gutter
- 27 - PCCBO - PCCP Shoulder w/ Bituminous Overlay
- 28 - WEDG - Wedge <= 2' aggregate/bituminous filler.
- 29 - PCC - Portland cement concrete shoulder.
- 3 - TUGU - Turf and gutter
- 30 - AC - Asphaltic concrete shoulder.
- 31 - 1'BT - One foot bituminous with remainder turf.
- 32 - 2'BT - Two feet bituminous with remainder turf.
- 33 - 3'BT - Three feet bituminous with remainder turf.
- 34 - 4'BT - Four feet bituminous with remainder turf.
- 35 - 5'BT - Five feet bituminous with remainder turf.
- 36 - 6'BT - Six feet bituminous with remainder turf.
- 37 - 7'BT - Seven feet bituminous with remainder turf.
- 38 - 8'BT - Eight feet bituminous with remainder turf.
- 4 - TUCG - Turf and curb and gutter
- 41 - 1'BA - One foot bituminous with remainder aggregate.
- 42 - 2'BA - Two feet bituminous with remainder aggregate.
- 43 - 3'BA - Three feet bituminous with remainder aggregate.
- 44 - 4'BA - Four feet bituminous with remainder aggregate.
- 45 - 5'BA - Five feet bituminous with remainder aggregate.
- 46 - 6'BA - Six feet bituminous with remainder aggregate.
- 47 - 7'BA - Seven feet bituminous with remainder aggregate.
- 48 - 8'BA - Eight feet bituminous with remainder aggregate.
- 5 - AS - Aggregate base stabilized, (CACL2), full design thickness.
- 51 - 1'AT - One foot aggregate with remainder turf.
- 52 - 2'AT - Two feet aggregate with remainder
- 53 - 3'AT - Three feet aggregate with remainder
- 54 - 4'AT - Four feet aggregate with remainder
- 55 - 5'AT - Five feet aggregate with remainder
- 56 - 6'AT - Six feet aggregate with remainder
- 57 - 7'AT - Seven feet aggregate with remainder
- 58 - 8'AT - Eight feet aggregate with remainder
- 6 - ASGU - Aggregate base stabilized and
- 60 - 3'CA - Three feet PCC with remainder
- 68 - PCA1C - PCCP with remainder AS1C
- 7 - ASCG - Aggregate base stabilized and
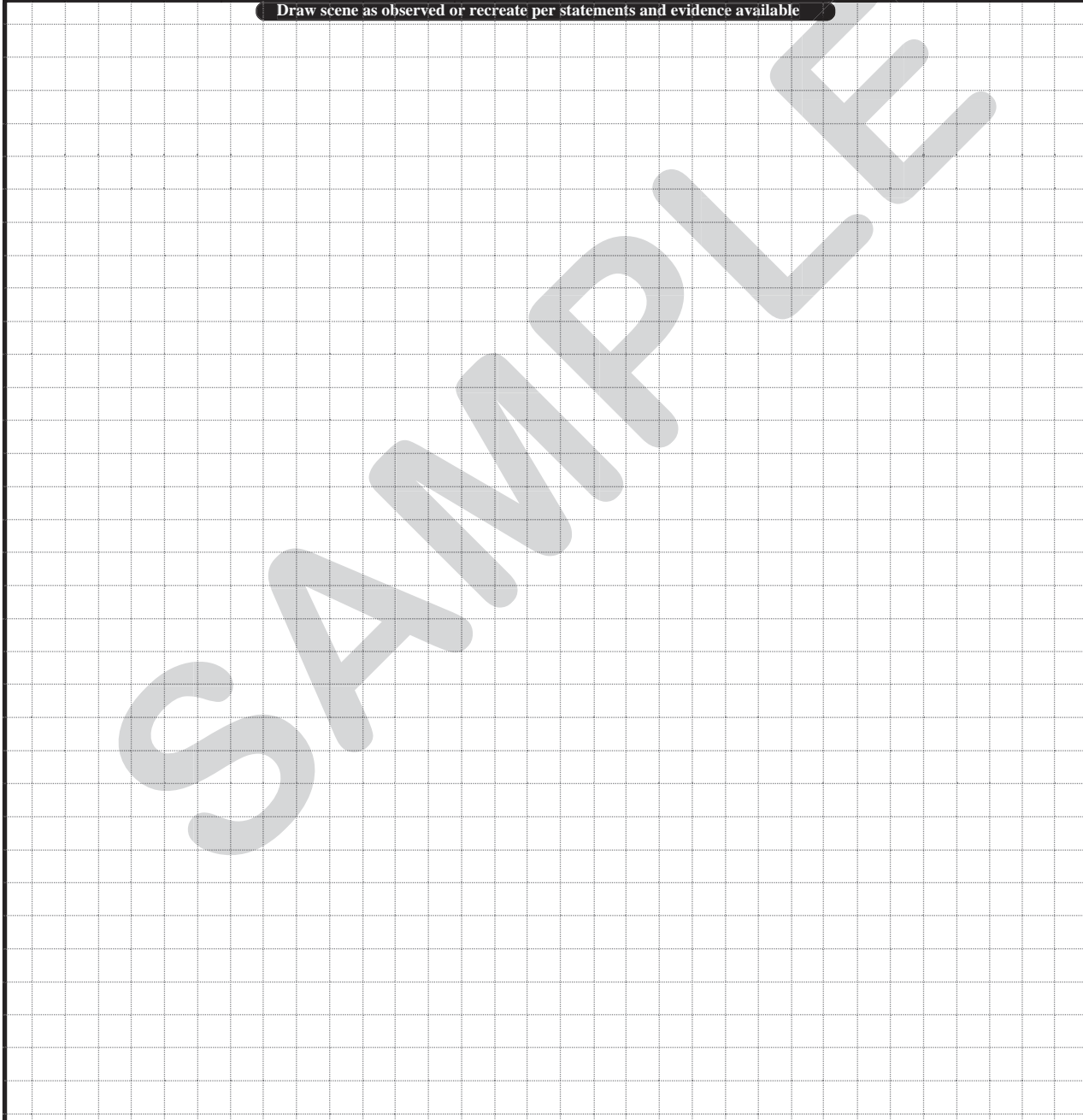
- ▪ 70 - PCBT - PCCP remainder bituminous.
- ▪ 71 - STABILIZED - Non-State code for Stabilized
- ▪ 72 - COMBINATION - Non-State code for
- ▪ 8 - ASSE - ABS with B.S.T.
- ▪ 9 - ASSG - ABS with B.S.T. and gutter
- SHLD_SHOR_SHLDR_WDTH
  - o Width of right shoulder (meters)
- SHLD_SHOL_SHLDR_ID
  - o Left shoulder type
    - ▪ Coding same as right shoulder type
- SHLD_SHOL_SHLDR_WDTH
  - o Width of left shoulder (meters)
- LANE_LN1R_LN_ID
  - o Type of first right lane, values below
    - ▪ 1 - THRU - Through lane
    - ▪ 10 - CREEPER - Creeper lane (grade associated)
    - ▪ 11 - DEAD - Dead lane for special situations
    - ▪ 12 - CONT LEFT TURN - Continuous left turn lane
    - ▪ 13 - CUT PARA PRK- Cut parallel parking (approx. 5 ft)
    - ▪ 14 - CUT DIAG PRK - Cut diagonal parking (approx. 17 ft)
    - ▪ 3 - LEFT TURN - Left turn lane
    - ▪ 4 - RIGHT TURN - Right turn lane
    - ▪ 5 - PASSING - Passing lane IAW "New Guideline" construction
    - ▪ 6 - ACCEL/DECEL -Acceleration lane
    - ▪ 7 - PARALLEL PRK - Parallel parking (approx. 8 FEET)
    - ▪ 8 - DIAGONAL PRK - Diagonal parking (approx. 17 feet)
    - ▪ 9 - CENTER PRK - Center parking
- LANE_LN1R_LN_WDTH
  - o Width of first right lane (meters)
- LANE_LN2R_LN_ID
  - o Type of second right lane (if present), values same as first right lane
- LANE_LN2R_LN_WDTH
  - o Width of second right lane (if present) (meters)
- LANE_LN1L_LN_ID
  - o Type of first left lane, values same as first right lane
- LANE_LN1L_LN_WDTH
  - o Width of first left lane (meters)
- LANE_LN2L_LN_ID
  - o Type of second left lane (if present), values same as first right lane
- LANE_LN2L_LN_WDTH
  - o Width of second left lane (if present) (meters)
- ACCL_SMRY_ACC_ID
  - o Accident ID number, distinct for each reported accident
- ACCL_SMRY_ACC_TYPE_ID
  - o Accident type
    - ▪ 1 - F - Includes a fatality.
    - ▪ 2 - D - No fatalities, highest severity is disabling injury.
    - ▪ 3 - N - No fatalities, highest severity is non-incapacitating injury.
    - ▪ 4 - I - No fatalities, highest severity is possible injury.

- - - 5 - P - No fatalities or injuries, property damage only.
- ACCL_SMRY_ACC_DT
  - Date of accident

APPENDIX C - KANSAS CRASH REPORT FORM

KDOT FORM 850A REV 1-2009

Kansas Motor Vehicle Accident Report
KDOT Form 850A Rev 1-2009

Investigating Department	Reviewed by	Local Case No.	Page of /

☐ Amended Report
☐ DUI
☐ Hit & Run

Investigating Officer Name	Badge Number	County	City Name

○ Fatal
○ Injury
○ PDO >=$1,000
○ PDO < $1,000
☐ Private Property

Milepost	Block No	Dir Pfx	On Road Name	Road Type	Dir Sfx	SpdLmt	Date of Accident (mm/dd/yyyy)	Time Occur.	Day

From Dist	Ft/Mi	From Dir	○ FROM ○ AT	Dir Pfx	Reference or At Road Name	Road Type	Dir Sfx	SpdLmt	Date Notified (mm/dd/yyyy)	Time Notif.	Day

Narrative: Describe each traffic unit's pre-crash movement and direction of travel

Date Arrived (mm/dd/yyyy) | Time Arriv. | Day

Latitude (AOI)

Longitude (AOI)

Photos by

WORK ZONE TYPE
O / A
○ ○ 00 None Apply
○ ○ 01 Construction Zone - KDOT? ☐
○ ○ 02 Maintenance Zone -
○ ○ 03 Utility Zone -
○ ○ 99 Unknown

KDOT? ☐ | Object 1 Damaged & Nature of Damage (show in diagram) | Owner Street Address | Personal Phone

Owner Last Name | First Name | Middle Name | City | State | Zip | Work Phone

KDOT? ☐ | Object 2 Damaged & Nature of Damage (show in diagram) | Owner Street Address | Personal Phone

Owner Last Name | First Name | Middle Name | City | State | Zip | Work Phone

- LOCATION IN WORK ZONE (AOI)
○ 01 Before first warning sign
○ 02 Advance warning area
○ 03 Transition area
○ 04 Activity area
○ 05 Termination area   ○ 99 Unknown

ONLY CHECK ONE BOX PER CATEGORY UNLESS SPECIFIED OTHERWISE

- WORK ZONE CATEGORY
○ 01 Lane closure
○ 02 Lane shift / crossover
○ 03 Work on shoulder / median
○ 04 Intermittent or moving vehicle
○ 88 Other: _____
○ 99 Unknown

LIGHT CONDITIONS
○ 01 Daylight   ○ 04 Dark: street lights on
○ 02 Dawn   ○ 05 Dark: no street lights
○ 03 Dusk   ○ 99 Unknown

ADVERSE WEATHER CONDITIONS
○ 00 No adverse conditions
○ 01 Rain, mist, drizzle
○ 02 Sleet, hail
○ 03 Snow
○ 04 Fog
○ 05 Smoke
○ 06 Strong wind
○ 07 Blowing dust, sand, etc.
○ 08 Freezing rain, mist, drizzle
○ 14 Rain & fog
○ 16 Rain & wind   ○ 88 Other: _____
○ 24 Sleet & fog
○ 36 Snow & wind   ○ 99 Unknown

SURFACE TYPE
O / A   O / A
○ ○ 01 Concrete
○ ○ 02 Blacktop (Asphalt)
○ ○ 03 Gravel   ○ ○ 88 Other: _____
○ ○ 04 Dirt
○ ○ 05 Brick   ○ ○ 99 Unknown

SURFACE CONDITIONS
O / A   O / A
○ ○ 01 Dry   ○ ○ 88 Other: _____
○ ○ 02 Wet
○ ○ 03 Snow   ○ ○ 99 Unknown
○ ○ 04 Ice
○ ○ 05 Mud/dirt/sand
○ ○ 06 Debris (oil, etc.)
○ ○ 07 Standing/ moving water
○ ○ 08 Slush

ACC. LOCATION
(of 1st Harmful Event)
ON ROADWAY: (within travel lanes)
○ 11 Non-intersection
○ 12 Intersection +
○ 13 Intersection-related +
○ 14 Access to Parking lot/Drvwy
○ 15 Interchange Area +
○ 16 On Crossover
○ 17 Toll Plaza
OFF ROADWAY:
○ 20 Shoulder
○ 21 Roadside (not shoulder)
○ 22 Median
○ 23 Parking lot or Rest area
○ 88 Other: _____
○ 99 Unknown

+INTERSECTION TYPE
○ 01 Four-way intersection
○ 02 Five-way or more
○ 03 T - intersection
○ 04 Y - intersection
○ 05 L - intersection
○ 06 Roundabout (See Manual for Definitions)
○ 07 Traffic Circle
○ 08 Part of an interchange
○ 99 Unknown

ROAD SPECIAL FEATURES (up to 3)
☐ 00 None
☐ 01 Bridge
☐ 02 Bridge Overhead
☐ 03 Railroad Bridge
☐ 04 RRXING
☐ 05 Interchange
☐ 06 Ramp
☐ 99 Unknown

ACCIDENT CLASS
(mark 1 box per side)

1st Harmful Event		Most Harmful Event
○ 00 Other non-collision		○
○ 01 Overturned/Rollover		○

COLLISION WITH:
○ 02 Pedestrian	○
○ 03 Motor vehicle in-transport*	○
○ 04 Legally Parked Vehicle	○
○ 05 Railway train	○
○ 06 Pedal cyclist	○
○ 07 Animal Type: _____	○
○ 08 Fixed object**	○
○ 09 Other object: _____	○
○ 99 Unknown	○

**FIXED OBJECT TYPE
(mark 1 box per side if applicable)

1st Harmful Event	Most Harmful Event
○ 01 Bridge structure	○
○ 02 Bridge rail	○
○ 03 Crash cush./Impact attenuator	○
○ 04 Divider, median barrier	○
○ 05 Overhead sign support	○
○ 06 Utility devices: pole,meter,etc	○
○ 07 Other post or pole	○
○ 08 Building	○
○ 09 Guardrail	○
○ 10 Sign post	○
○ 11 Culvert	○
○ 12 Curb	○
○ 13 Fence/Gate	○
○ 14 Hydrant	○
○ 15 Barricade	○
○ 16 Mailbox	○
○ 17 Ditch	○
○ 18 Embankment	○
○ 19 Wall	○
○ 20 Tree	○
○ 21 RRXING fixtures	○
○ 88 Other: _____	○
○ 99 Unknown	○

*COLLISION WITH VEHICLE
(mark 1 box per side if applicable)

1st Harmful Event	Most Harmful Event
○ 01 Head on	○
○ 02 Rear end	○
○ 03 Angle - side impact	○
○ 04 Sideswipe: opposite direction	○
○ 05 Sideswipe: Same direction	○
○ 06 Backed into	○
○ 88 Other: _____	○
○ 99 Unknown	○

TRAFFIC CONTROLS
(On / At Road) O/A
Type Present   OK/NF
00 None
01 Officer, flagger
02 Traffic signal
03 Stop sign
04 Flasher
05 Yield sign
06 RR gates / signal
07 RR crossing signs
08 No passing zone
09 Center/Edge lines
10 Warning signs
11 School zone signs
12 Parking lines
88 Other: _____
99 Unknown

1		1		1
2		2		2
3		3		3
4		4		4
5		5		5

Accident Diagram 850A continued	SPECIAL EVENT	SPECIAL DATA	Local Case No.	Page of /

ROADWAY
NUMBER OF LANES

O / A
- O O 01 One
- O O 02 Two
- O O 03 Three
- O O 04 Four to Six
- O O 05 Seven or more
- O O 88 Other: _____
- O O 99 Unknown

ROAD CHARACTER

O / A
- O O 01 Straight & Level
- O O 02 Straight on grade/slope
- O O 03 Straight on hillcrest
- O O 04 Curved & level
- O O 05 Curved on grade/slope
- O O 06 Curved on hillcrest
- O O 88 Other: _____
- O O 99 Unknown

SPECIAL JURISDICTION
- O 00 Normal Jurisdiction (Not Special)
- O 01 National Park Service
- O 02 Military
- O 03 Indian Reservation
- O 04 College / University Campus
- O 05 Other Federal property
- O 88 Other: _____
- O 99 Unknown

A basic diagram is required for all state reportable accidents showing movements, direction, and positions of all traffic units in relationship to the trafficway. Identify (label) the street(s) and traffic unit(s) along with the area of impact (AOI) where possible. Refer to vehicles and pedestrians by unique numbers assigned in this report.

Indicate North Direction

Draw scene as observed or recreate per statements and evidence available

Note: The above line scale is 1"=20'; 5 feet squares. If another scale is used, please specify.

Occupants & Vehicles
KDOT Form 850B Rev. 1-2009

DRIVER & PASSENGER INFORMATION
(record pedestrians on supplemental form 854)

Investigating Officer / Badge No. | Local Case No. | Page of /

TU#	VIOLATIONS CHARGED	CITATION#	TU#	VIOLATIONS CHARGED	More violations in narrative ☐	CITATION#

OFFICER'S OPINION OF APPARENT CONTRIBUTING CIRCUMSTANCES - ENTER AS MANY AS APPLY TO THIS ACCIDENT (FACTOR TYPE, TU#, CC CODE)

Unit #	DRIVER Last Name	Middle Name	DRIVER ADDRESS (Number, Street, Suffix, etc.)		Personal Phone Number	Gender	SE Used	Inj Severity	Transpt Unit
Seat Type	DRIVER First Name	Date of Birth	City	State Zip	Work Phone Number	Age	Eject/Trap	Eject Path	Extrication?
TU		MN		New address? ☐ Personal					
ST		DOB		Work					☐
TU		MN		New address? ☐ Personal					
ST		DOB		Work					☐

TRAFFIC UNIT# ____ (01, 03, N3, X3, etc)

DL State	Driver's License Number	DL Class	Driving for Employer? ☐	CDL? ☐

DR LICENSE COMPLY
- ○ 00 Not licensed
- ○ 01 Valid License
- ○ 02 Suspended
- ○ 03 Revoked
- ○ 04 Expired
- ○ 05 Cancld or Denied
- ○ 06 Disqualified
- ○ 07 Restricted
- ○ 99 Unknown

RESTRICT COMPLY

Restrictions? Y ○ N ○

Driver's Lic Restrictions	Complied? Y N
1 ____	○ ○
2 ____	○ ○
3 ____	○ ○
4 ____	○ ○

COMMERCIAL ENDORSEMENTS
- ☐ Z - None
- ☐ T - Double/Triple Trailer
- ☐ P - Passenger Vehicle
- ☐ N - Tank Vehicle
- ☐ H - Placarded Haz. Material
- ☐ X - Combination Tank/HazMat
- ☐ S - School Bus
- ☐ U - Unknown

TRAFFIC UNIT# ____ (02, 04, N2, X4, etc)

DL State	Driver's License Number	DL Class	Driving for Employer? ☐	CDL? ☐

DR LICENSE COMPLY
- ○ 00 Not licensed
- ○ 01 Valid License
- ○ 02 Suspended
- ○ 03 Revoked
- ○ 04 Expired
- ○ 05 Cancld or Denied
- ○ 06 Disqualified
- ○ 07 Restricted
- ○ 99 Unknown

RESTRICT COMPLY

Restrictions? Y ○ N ○

Driver's Lic Restrictions	Complied? Y N
1 ____	○ ○
2 ____	○ ○
3 ____	○ ○
4 ____	○ ○

COMMERCIAL ENDORSEMENTS
- ☐ Z - None
- ☐ T - Double/Triple Trailer
- ☐ P - Passenger Vehicle
- ☐ N - Tank Vehicle
- ☐ H - Placarded Haz. Material
- ☐ X - Combination Tank/HazMat
- ☐ S - School Bus
- ☐ U - Unknown

SUBSTANCE USE (mark all that apply)
- ☐ AP - Alcohol ingested
- ☐ AC - Alcohol contributed
- ☐ DP - Illegal drugs ingested
- ☐ DC - Illegal drugs contributed
- ☐ MP - Medication ingested
- ☐ MC - Medication contributed

METHOD OF DETERMINATION (mark all that apply)

ALCOHOL / DRUGS
- ☐ 00 No evidence of impairment ☐
- ☐ 01 Evidential Test (Breath,Blood,etc) ☐
- ☐ 02 Preliminary Breath Test PBT ☐
- ☐ 03 Behavioral
  Tests: HGN, walk-and-turn, one leg stand, etc.
- ☐ 04 Passive Alcohol Sensor ☐
  (detects alcohol from driver's mouth)
- ☐ 05 Observed ☐
  (Odor, staggering, slurred speech, etc)
- ☐ 06 Other (e.g. saliva test) ☐

IMPAIRMENT TEST (mark all that apply)
- ☐ NG - No Test given
- ☐ TR - Test Refused (Alcohol/Drug)
- ☐ PT - Prelim Positive Test (PBT)
- ☐ TG - Evidentiary Test given
- ☐ RP - Results pending

ALCOHOL
- ☐ Evidentiary Breath 0._____ | ☐ Eye Fluid 0._____
- ☐ Blood (BAC) 0._____ | ☐ Other 0._____
- ☐ Drug screen result ○ Pos ○ Neg

SUBSTANCE USE (mark all that apply)
- ☐ AP - Alcohol ingested
- ☐ AC - Alcohol contributed
- ☐ DP - Illegal drugs ingested
- ☐ DC - Illegal drugs contributed
- ☐ MP - Medication ingested
- ☐ MC - Medication contributed

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- ☐ 01 Evidential Test (Breath,Blood,etc) ☐
- ☐ 02 Preliminary Breath Test PBT ☐
- ☐ 03 Behavioral
  Tests: HGN, walk-and-turn, one leg stand, etc.
- ☐ 04 Passive Alcohol Sensor ☐
  (detects alcohol from driver's mouth)
- ☐ 05 Observed ☐
  (Odor, staggering, slurred speech, etc)
- ☐ 06 Other (e.g. saliva test) ☐

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- ☐ NG - No Test given
- ☐ TR - Test Refused (Alcohol/Drug)
- ☐ PT - Prelim Positive Test (PBT)
- ☐ TG - Evidentiary Test given
- ☐ RP - Results pending

ALCOHOL
- ☐ Evidentiary Breath 0._____ | ☐ Eye Fluid 0._____
- ☐ Blood (BAC) 0._____ | ☐ Other 0._____
- ☐ Drug screen result ○ Pos ○ Neg

Unit #	PASSENGER Last Name	Middle Name	PASSENGER ADDRESS (Number, Street, Sfx, etc.)		Personal Phone Number	Gender	SE Used	Inj Severity	Transpt Unit
Seat Type	PASSENGER First Name	Date of Birth	City	State Zip	Work Phone Number	Age	Eject/Trap	Eject Path	Extrication?
TU		MN		New address? ☐ Personal					
ST		DOB		Work					☐
TU		MN		New address? ☐ Personal					
ST		DOB		Work					☐
TU		MN		New address? ☐ Personal					
ST		DOB		Work					☐
TU		MN		New address? ☐ Personal					
ST		DOB		Work					☐

Transport Unit	EMS Time Notified	Injured taken by:	Transport Unit	EMS Time Notified	Injured taken by:
EMS Arrived	EMS Time@Hosp	Injured taken to:	EMS Arrived	EMS Time@Hosp	Injured taken to:

Transport Units: A, B, C, ..., N

Occupants & Vehicles
850B Continued

VEHICLE#		SPECIAL DATA	VEHICLE#		SPECIAL DATA		Local Case No.	Page of
(01, 03, N3, X3, etc)			(02, 04, N2, X4, etc)					/

OWNER Last Name ("Same" if Driver)	OWNER First Name	Middle Name	OWNER Last Name ("Same" if Driver)	OWNER First Name	Middle Name

OWNER ADDRESS (Number, Street)	New address? ☐	Personal Phone	OWNER ADDRESS (Number, Street)	New address? ☐	Personal Phone

CITY	ST	ZIP	Work Phone	CITY	ST	ZIP	Work Phone

COLOR	YEAR	MAKE	MODEL	BODY STYLE	ST	COLOR	YEAR	MAKE	MODEL	BODY STYLE	ST

LICENSE PLATE #	County	Exp YR	Removed by:	MC CCs	LICENSE PLATE #	County	Exp YR	Removed by:	MC CCs

VEHICLE IDENTIFICATION NUMBER	Dir of Travel	# Occupants	VEHICLE IDENTIFICATION NUMBER	Dir of Travel	# Occupants

Insurance Company	Policy Number	Insurance Company	Policy Number

SPECIAL CONDITIONS FOR TRAFFIC UNITS

Odometer	Fire? ☐

☐ 1 Hit & Run ☐ 2 Non-Contact ☐ 3 Stolen
☐ 4 Legally Parked ☐ 5 Pursued by LE ☐ 6 Driverless
☐ 7 Towed away due to damage

SPECIAL CONDITIONS FOR TRAFFIC UNITS

Odometer	Fire? ☐

☐ 1 Hit & Run ☐ 2 Non-Contact ☐ 3 Stolen
☐ 4 Legally Parked ☐ 5 Pursued by LE ☐ 6 Driverless
☐ 7 Towed away due to damage

VEHICLE BODY TYPE / LARGE / HEAVY VEHICLE (GCVWR over 10,000lbs)

Vehicle 1

- ○ 01 Automobile
- ○ 02 Motorcycle
- ○ 03 Motor scooter or Moped
- ○ 04 Van
- ○ 05 Pickup truck <10,001 lbs
- ○ 06 Sport utility veh - SUV
- ○ 07 Camper or RV
- ○ 08 Farm machinery
- ○ 09 All-terrain vehicle - ATV

- ○ 10 Single heavy truck >10,000 lbs
- ○ 11 Truck & trailer(s)
- ○ 12 Tractor-trailer(s)
- ○ 13 Cross country bus
- ○ 14 School bus
- ○ 15 Transit (city) bus
- ○ 16 Other bus
- ○ 25 Train
- ○ 88 Other:

Calculated speed at impact
Bus Seat Capacity ____
(○ Fuel ○ Hybrid ○ Electric)
○ 99 Unknown

Vehicle 2

- ○ 01 Automobile
- ○ 02 Motorcycle
- ○ 03 Motor scooter or Moped
- ○ 04 Van
- ○ 05 Pickup truck <10,001 lbs
- ○ 06 Sport utility veh - SUV
- ○ 07 Camper or RV
- ○ 08 Farm machinery
- ○ 09 All-terrain vehicle - ATV

- ○ 10 Single heavy truck >10,000 lbs
- ○ 11 Truck & trailer(s)
- ○ 12 Tractor-trailer(s)
- ○ 13 Cross country bus
- ○ 14 School bus
- ○ 15 Transit (city) bus
- ○ 16 Other bus
- ○ 25 Train
- ○ 88 Other:

Calculated speed at impact
Bus Seat Capacity ____
(○ Fuel ○ Hybrid ○ Electric)
○ 99 Unknown

VEHICLE USE (Vehicle 1)

- ○ 01 No special use
- ○ 02 Taxi / Limo
- ○ 03 School bus
- ○ 04 Other bus
- ○ 05 Military
- ○ 06 Police
- ○ 07 Ambulance
- ○ 08 Fire
- ○ 09 Mail/Parcel
- ○ 99 Unknown

VEHICLE DAMAGE (Vehicle 1)

- ○ 00 None
- ○ 01 Damage (minor)
- ○ 02 Functional
- ○ 03 Disabling
- ○ 04 Destroyed
- ○ 88 Other:
- ○ 99 Unknown

VEHICLE USE (Vehicle 2)

- ○ 01 No special use
- ○ 02 Taxi / Limo
- ○ 03 School bus
- ○ 04 Other bus
- ○ 05 Military
- ○ 06 Police
- ○ 07 Ambulance
- ○ 08 Fire
- ○ 09 Mail/Parcel
- ○ 99 Unknown

VEHICLE DAMAGE (Vehicle 2)

- ○ 00 None
- ○ 01 Damage (minor)
- ○ 02 Functional
- ○ 03 Disabling
- ○ 04 Destroyed
- ○ 88 Other:
- ○ 99 Unknown

DAMAGE LOCATION AREA (Vehicle 1)

First Impact ____ Major Impact ____

FRONT
1 2 3A 3B 4 5
12B 12C 13 6A
12A 6B
11 10 9B 9A 8 7

☐ 14 Undercarriage ☐ 15 Windshield
☐ 16 Other windows ☐ 99 Unknown
☐ 17 Entire vehicle damaged
☐ 88 Other: ____

Trailer? ○ Present ○ Damaged

VEH. MANU. BEFORE UNSTAB. SIT. (Vehicle 1)

- ○ 01 Straight/following road
- ○ 02 Left Turn
- ○ 03 Right Turn
- ○ 04 U Turn
- ○ 05 Passing
- ○ 06 Changing lanes
- ○ 07 Avoidance man.
- ○ 08 Merging
- ○ 09 Parking
- ○ 10 Backing
- ○ 11 Stopped awaiting turn
- ○ 12 Stopped in traf
- ○ 13 Illegally parked
- ○ 14 Disabled in roadway
- ○ 15 Slowing or stopping
- ○ 16 Negotiating a curve
- ○ 88 Other:
- ○ 99 Unknown

DAMAGE LOCATION AREA (Vehicle 2)

First Impact ____ Major Impact ____

FRONT
1 2 3A 3B 4 5
12B 12C 13 6A
12A 6B
11 10 9B 9A 8 7

☐ 14 Undercarriage ☐ 15 Windshield
☐ 16 Other windows ☐ 99 Unknown
☐ 17 Entire vehicle damaged
☐ 88 Other: ____

Trailer? ○ Present ○ Damaged

VEH. MANU. BEFORE UNSTAB. SIT. (Vehicle 2)

- ○ 01 Straight/following road
- ○ 02 Left Turn
- ○ 03 Right Turn
- ○ 04 U Turn
- ○ 05 Passing
- ○ 06 Changing lanes
- ○ 07 Avoidance man.
- ○ 08 Merging
- ○ 09 Parking
- ○ 10 Backing
- ○ 11 Stopped awaiting turn
- ○ 12 Stopped in traf
- ○ 13 Illegally parked
- ○ 14 Disabled in roadway
- ○ 15 Slowing or stopping
- ○ 16 Negotiating a curve
- ○ 88 Other:
- ○ 99 Unknown

VEHICLE SEQUENCE OF EVENTS (List up to 4 per unit in the order of occurence)

| 1 | 2 | 3 | 4 | ☐ The exact sequence is unknown

NON-COLLISION (Vehicle 1)

- 01 Ran off road right
- 02 Ran off road left
- 03 Crossed centerline
- 04 Overturn/Rollover
- 05 Crossed median
- 06 Fell/Jumped from veh
- 07 Thrown or falling object
- 08 Cargo loss or shift
- 09 Equipment failure (tire, brakes, etc.)
- 10 Downhill runaway
- 11 Trailer swing
- 12 Seperation of units
- 13 Jackknife
- 14 Fire
- 15 Explosion
- 16 Immersion in water
- 88 Other event:
- 98 Unknown non-coll.

COLLISION WITH (Vehicle 1)

- 21 Pedestrian
- 22 Motor veh in-transport
- 23 Legally Parked Vehicle
- 24 Train
- 25 Pedal cycle (bike, etc)
- 26 Animal
- 27 Fixed Object
- 28 Other moveable object
- 99 Unknown object

VEHICLE SEQUENCE OF EVENTS (List up to 4 per unit in the order of occurence)

| 1 | 2 | 3 | 4 | ☐ The exact sequence is unknown

NON-COLLISION (Vehicle 2)

- 01 Ran off road right
- 02 Ran off road left
- 03 Crossed centerline
- 04 Overturn/Rollover
- 05 Crossed median
- 06 Fell/Jumped from veh
- 07 Thrown or falling object
- 08 Cargo loss or shift
- 09 Equipment failure (tire, brakes, etc.)
- 10 Downhill runaway
- 11 Trailer swing
- 12 Seperation of units
- 13 Jackknife
- 14 Fire
- 15 Explosion
- 16 Immersion in water
- 88 Other event:
- 98 Unknown non-coll.

COLLISION WITH (Vehicle 2)

- 21 Pedestrian
- 22 Motor veh in-transport
- 23 Legally Parked Vehicle
- 24 Train
- 25 Pedal cycle (bike, etc)
- 26 Animal
- 27 Fixed Object
- 28 Other moveable object
- 99 Unknown object

| **Accident Narrative**
KDOT Form 851 Rev. 1-2009 | **Officer Observations**
Description of Events | **Witness Statements**
Additional Information | Investigating Officer / Badge No. | Local Case No. | Page of
/ |

Accident Narrative 851 Continued	Officer Observations Description of Events	Witness Statements Additional Information	Local Case No.	Page of /

☐ Completed Post Crash Inspection

HEAVY VEHICLE & HAZMAT Supplement
KDOT Form 852 Rev. 1-2009

INFORMATION ON HEAVY VEHICLES / BUSES / HAZARDOUS MATERIALS

Investigating Officer / Badge No.	Local Case No.	Page of
		/

MOTOR CARRIER INFORMATION

TU # _____

Carrier Name _____ Carrier Street Address (P.O. Box only if no street address) _____ City _____

State _____ Zip _____ Phone _____ Carrier Country _____

CARRIER IDENTIFICATION NUMBER(S)

_____ USDOT# _____ MC/MX# ☐ NONE

CARRIER TYPE

○ 0 - Intrastate ○ 1 - Interstate ○ 2 - Not in Commerce - Other Truck or Bus ○ 3 - Not in Commerce - Government Veh ○ 4 - Other / Not Specified

AT THE TIME OF CRASH, THIS VEHICLE WAS:
- ○ 01 Operating on a trafficway open to the public (In-Transport)
- ○ 02 Parked on or off the trafficway
- ○ 88 Other: _____
- ○ 99 Unknown

GVWR/GCWR
- ○ 01 10,000 lbs or less
- ○ 02 10,001-26,000 lbs
- ○ 03 More than 26,000 lbs
- ○ 99 Unknown

ACTUAL WEIGHT _____ lbs

SOURCE OF CARRIER NAME
- ○ 01 Side of vehicle
- ○ 02 Shipping papers or manifest
- ○ 03 Driver
- ○ 04 Logbook

PERMITS (Issuer and Permit Number)
1. _____
2. _____
3. _____

VEHICLE INFORMATION

HAZMAT / ROADWAY INFORMATION

TRAILER DIMENSIONS
WIDTH (in) LENGTH (ft)

	WIDTH (in)	LENGTH (ft)
Trailer 1		
Trailer 2		
Trailer 3		

TRAILER(s) DAMAGED?
- ☐ None
- ☐ Trailer 1
- ☐ Trailer 2
- ☐ Trailer 3

OVERSIZED LOAD
- ☐ Height
- ☐ Weight
- ☐ Width

HAZARDOUS MATERIALS INVOLVEMENT

Did the vehicle have a Hazardous Materials Placard? Yes ○ No ○

If Yes, Include The Following Information From The Placard:

HazMat 4-digit # from the diamond center box: _____

HazMat Class # from the bottom of diamond: _____

1090 / 3

HazMat Weight (lbs) _____

Was HazMat released (spilled) from THIS vehicle's cargo? Yes ○ No ○

TRUCK AND TRAILER TOTALS

Vehicle Length (include trailer(s)) _____ ft No. of Trailers _____ No. of Axles _____

TRAILER 1 - IDENTIFICATION NUMBER _____

TRAILER 2 - IDENTIFICATION NUMBER _____

TRAILER 3 - IDENTIFICATION NUMBER _____

ON-ROAD LANE TYPE
- ○ 00 Two-way traffic - Undivided roadway
- ○ 01 One-way traffic - Undivided roadway
- ○ 02 Two-way traffic - Median strip w/o barrier
- ○ 03 Two-way traffic - Median strip w/ barrier
- ○ 04 Two-way traffic - Undivided with a continuous left turn lane
- ○ 99 Unknown

VEHICLE ACCESS CONTROL TO ROADWAYS
- ○ 00 No access control (Unlimited access - Roads with no interchanges)
- ○ 01 Partial access control (mix of interchanges and "at-grade" intersections)
- ○ 02 Full access control (entry/exit only by interchange ramps)
- ○ 99 Unknown

SEE BACK OF THIS FORM FOR EXAMPLES OF VEHICLE CONFIGURATIONS AND CARGO TYPES

VEHICLE CONFIGURATION
- ○ 00 Bus 9-15 passengers, including driver
- ○ 01 Bus more than 15 passengers
- ○ 02 Single-unit truck (2-axles)
- ○ 03 Single-unit truck (3 or more axles)
- ○ 04 Single-unit truck with trailer(s)
- ○ 05 Truck Tractor only (bobtail)
- ○ 06 Truck Tractor and semi-trailer
- ○ 07 Truck Tractor and two trailers
- ○ 08 Truck Tractor and three trailers
- ○ 09 Heavy truck > 10,000 lbs cannot classify
- ○ 10 Vehicles less than 10,000 lbs carrying hazardous materials
- ○ 88 Other: _____
- ○ 99 Unknown

CAB TYPE
- ○ 01 Cab behind engine
- ○ 02 Cab over engine
- 99 Unknown

CARGO BODY TYPE
- ○ 00 Not applicable/No cargo body
- ○ 01 Van or Enclosed box
- ○ 02 Hopper (e.g. Grain, Chips, Gravel)
- ○ 03 Cargo tank (liquid, powder, etc)
- ○ 04 Flatbed
- ○ 05 Dump
- ○ 06 Concrete mixer
- ○ 07 Vehicle transporter
- ○ 08 Garbage or refuse
- ○ 09 Bus 9-15 people, including driver
- ○ 10 Bus more than 15 people
- ○ 11 Pole
- ○ 12 Vehicle towing another motor vehicle
- ○ 13 Intermodal chassis
- ○ 14 Logging
- ○ 88 Other: _____
- ○ 99 Unknown

CARGO TYPE
- ○ 00 None
- ○ 01 Drive away or Tow away
- ○ 02 Explosives
- ○ 03 Animals: farm or other
- ○ 04 Farm products
- ○ 05 Gases
- ○ 06 General freight (packages)
- ○ 07 Heavy machinery, objects
- ○ 08 Household goods
- ○ 09 Liquids (bulk)
- ○ 10 Logs, poles, lumber
- ○ 11 Metal (coils, sheets, etc)
- ○ 12 Mobile / Modular home
- ○ 13 Motor vehicles
- ○ 14 Refrigerated foods
- ○ 15 Solids (bulk)
- ○ 16 Rock, sand, gravel, salt
- ○ 17 Other food products
- ○ 18 Plastic products
- ○ 19 People
- ○ 20 Garbage / refuse
- ○ 21 Pavement mixture: concrete, asphalt, etc.
- ○ 88 Other: _____
- ○ 99 Unknown

SPECIAL DATA

852 cont'd	REPORTING CRITERIA FOR HEAVY VEHICLES AND/OR HAZARDOUS MATERIALS

COMPLETE THIS SUPPLEMENT FOR EACH OF THE FOLLOWING VEHICLES INVOLVED WHERE AT LEAST ONE MOTOR VEHICLE IN-TRANSPORT WAS ON A TRAFFICWAY OPEN TO THE PUBLIC:

>10,000 lbs — Any truck having a gross vehicle weight rating (GVWR) of more than 10,000 pounds or a gross combination weight rating (GCWR) over 10,000 pounds used on public trafficways, OR...

BUS — Any motor vehicle with seats to transport nine (9) or more people, including the driver OR...

HAZMAT — Any vehicle, regardless of weight, carrying placardable hazardous materials or displaying a hazardous materials placard.

AND

IF THIS ACCIDENT INCLUDES:

A FATALITY: — Any person(s) killed in or outside of any vehicle (truck, bus, car, etc.) involved in the crash or who dies within 30 days of the crash as a result of an injury sustained in the crash, OR...

AN INJURY: — Any person(s) injured as a result of the crash who immediately receives medical treatment away from the crash scene, OR...
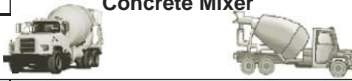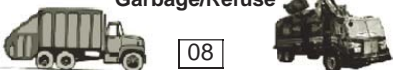
TOW-AWAY: — Any motor vehicle (truck combination, bus, car, etc.) disabled as a result of the crash and transported away from the scene by a tow truck or other vehicle.

Vehicle Configuration

00 Bus (9-15 Seats, Including Driver)	**04** Truck/Trailer (Single-Unit Truck Pulling a Trailer)
01 Bus (16 or More Seats, Including Driver)	**05** Truck Tractor (Bobtail)
02 Single-Unit (2 Axles, 6 Tires)	**06** Tractor/Semi Trailer (One Trailer)
03 Single-Unit (3 or More Axles)	**07** Truck Tractor/Double (Two Trailers)
	08 Truck Tractor/Triple (Three Trailers)

Revised 06/05

Cargo Body Type

09 Bus (9-15 Seats, Including Driver)	**05** Dump	**11** Pole
10 Bus (16 or More Seats, Including Driver)	**06** Concrete Mixer	**14** Log
01 Van/Enclosed Box	**07** Auto Transporter	**13** Intermodal Chassis
03 Cargo Tank	**08** Garbage/Refuse	**12** Vehicle Towing Motor Vehicle
04 Flat Bed	**02** Grain, Chips, Gravel	**00** No Cargo Body

Federal Motor Carrier Safety Administration

U.S. Department of Transportation
www.fmcsa.dot.gov

Passengers & Pedestrians
KDOT Form 854 Rev. 1-2009

LIST ADDITIONAL PASSENGERS BY TRAFFIC UNIT

Investigating Officer / Badge No.

Local Case No.

Page of /

Unit # / Seat Type	PASSENGER Last Name / PASSENGER First Name	Middle Name / Date of Birth	PASSENGER ADDRESS (Number, Street, Sfx, etc.) / City State Zip	Personal Phone Number / Work Phone Number	Gender / Age	SE Used / Eject/Trap	Inj Severity / Eject Path	Transpt Unit / Extrication?
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐
TU		MN	New address? ☐	Personal				
ST		DOB		Work				☐

Transport Unit ___	EMS Time Notified	Injured taken by:		**Transport Unit** ___	EMS Time Notified	Injured taken by:
EMS Arrived	EMS Time@Hosp	Injured taken to:		EMS Arrived	EMS Time@Hosp	Injured taken to:
Transport Unit ___	EMS Time Notified	Injured taken by:		**Transport Unit** ___	EMS Time Notified	Injured taken by:
EMS Arrived	EMS Time@Hosp	Injured taken to:		EMS Arrived	EMS Time@Hosp	Injured taken to:

Transport Units: A, B, C, ..., N

Passengers & Pedestrians	PEDESTRIAN INFORMATION	Investigating Officer / Badge No.	Local Case No.	Page of
854 continued				/

Unit #	PEDESTRIAN Last Name	Middle Name	PEDESTRIAN ADDRESS (Number, Street, Sfx, etc.)		Personal Phone Number	Gender	SE Used	Inj Severity	Transpt Unit
Ped Type	PEDESTRIAN First Name	Date of Birth	City	State Zip	Work Phone Number	Age	Eject/Trap	Eject Path	Extrication?
TU		MN		New address? ☐	Personal				
PT		DOB			Work				☐
TU		MN		New address? ☐	Personal				
PT		DOB			Work				☐

Transport Unit ___	EMS Time Notified	Injured taken by:		**Transport Unit** ___	EMS Time Notified	Injured taken by:
EMS Arrived	EMS Time@Hosp	Injured taken to:		EMS Arrived	EMS Time@Hosp	Injured taken to:

TU#	DirTrvl	DL State	Driver's License Number	Special Data	TU#	DirTrvl	DL State	Driver's License Number	Special Data

PEDESTRIAN ROADWAY LOCATION BEFORE IMPACT

○ 00 NOT in roadway (driving lanes)

IN or AT INTERSECTION
- ○ 01 In crosswalk or bikeway
- ○ 02 NOT in crosswalk or bikeway
- ○ 03 In intersection without a crosswalk or bikeway

NOT IN or AT INTERSECTION
- ○ 11 In crosswalk or bikeway
- ○ 12 NOT in crosswalk or bikeway
- ○ 13 In area without a crosswalk or bikeway

○ 88 Other: _____   ○ 99 Unknown

PEDESTRIAN ROADWAY LOCATION BEFORE IMPACT

○ 00 NOT in roadway (driving lanes)

IN or AT INTERSECTION
- ○ 01 In crosswalk or bikeway
- ○ 02 NOT in crosswalk or bikeway
- ○ 03 In intersection without a crosswalk or bikeway

NOT IN or AT INTERSECTION
- ○ 11 In crosswalk or bikeway
- ○ 12 NOT in crosswalk or bikeway
- ○ 13 In area without a crosswalk or bikeway

○ 88 Other: _____   ○ 99 Unknown

OTHER PEDESTRIAN LOCATION (Not in Driving Lanes)

- ○ 01 Within a work zone
- ○ 02 In median (not shoulder)
- ○ 03 On Island
- ○ 04 Road shoulder (not ditch or median)
- ○ 05 Roadside (not on shoulder)
- ○ 06 Sidewalk
- ○ 07 Outside trafficway
- ○ 08 Driveway access crosswalk
- ○ 09 Dedicated bike lane
- ○ 10 Shared-use path or trails
- ○ 11 Inside building
- ○ 12 In legally parked vehicle
- ○ 88 Other: _____
- ○ 99 Unknown

OTHER PEDESTRIAN LOCATION (Not in Driving Lanes)

- ○ 01 Within a work zone
- ○ 02 In median (not shoulder)
- ○ 03 On Island
- ○ 04 Road shoulder (not ditch or median)
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- ○ 09 Dedicated bike lane
- ○ 10 Shared-use path or trails
- ○ 11 Inside building
- ○ 12 In legally parked vehicle
- ○ 88 Other: _____
- ○ 99 Unknown

PEDESTRIAN ACTION BEFORE CRASH

- ○ 01 Walking / cycling to or from school
- ○ 02 Approaching or leaving bus
- ○ 03 Approaching or leaving vehicle
- ○ 04 Working (not on vehicle)
- ○ 05 Working on vehicle
- ○ 06 Pushing motor vehicle
- ○ 07 Standing, sitting, or lying
- ○ 08 Playing, running, walking
- ○ 09 Cycling
- ○ 10 Entering or crossing
- ○ 88 Other: _____
- ○ 99 Unknown

PEDESTRIAN ACTION BEFORE CRASH

- ○ 01 Walking / cycling to or from school
- ○ 02 Approaching or leaving bus
- ○ 03 Approaching or leaving vehicle
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- ○ 07 Standing, sitting, or lying
- ○ 08 Playing, running, walking
- ○ 09 Cycling
- ○ 10 Entering or crossing
- ○ 88 Other: _____
- ○ 99 Unknown

PEDESTRIAN OBEDIENCE TO TRAFFIC SIGNAL

- ○ 00 No pedestrian signal
- ○ 01 Obeyed pedestrian signal
- ○ 02 Disobeyed pedestrian signal
- ○ 03 Ped signal malfunction
- ○ 04 Not applicable
- ○ 99 Unknown

PEDESTRIAN OBEDIENCE TO TRAFFIC SIGNAL

- ○ 00 No pedestrian signal
- ○ 01 Obeyed pedestrian signal
- ○ 02 Disobeyed pedestrian signal
- ○ 03 Ped signal malfunction
- ○ 04 Not applicable
- ○ 99 Unknown

SUBSTANCE USE (mark all that apply)
- ☐ AP - Alcohol ingested
- ☐ AC - Alcohol contributed
- ☐ DP - Illegal drugs ingested
- ☐ DC - Illegal drugs contributed
- ☐ MP - Medication ingested
- ☐ MC - Medication contributed

SUBSTANCE USE (mark all that apply)
- ☐ AP - Alcohol ingested
- ☐ AC - Alcohol contributed
- ☐ DP - Illegal drugs ingested
- ☐ DC - Illegal drugs contributed
- ☐ MP - Medication ingested
- ☐ MC - Medication contributed

METHOD OF DETERMINATION (mark all that apply)

ALCOHOL   DRUGS
- ☐ 00 No evidence of impairment ☐
- ☐ 01 Evidential Test (Breath,Blood,etc) ☐
- ☐ 02 Preliminary Breath Test PBT ☐
- ☐ 03 Behavioral
  Tests: HGN, walk-and-turn, one leg stand, etc.
- ☐ 04 Passive Alcohol Sensor
  (detects alcohol from driver's mouth)
- ☐ 05 Observed ☐
  (Odor, staggering, slurred speech, etc)
- ☐ 06 Other (e.g. saliva test) ☐

IMPAIRMENT TEST (mark all that apply)
- ☐ NG - No Test given
- ☐ TR - Test Refused (Alcohol/Drug)
- ☐ PT - Prelim Positive Test (PBT)
- ☐ TG - Evidentiary Test given
- ☐ RP - Results pending

ALCOHOL:
- ☐ Evidentiary Breath   ☐ Eye Fluid
  0. _____   0. _____
- ☐ Blood (BAC)   ☐ Other
  0. _____   0. _____
- ☐ Drug screen ○ Pos ○ Neg

METHOD OF DETERMINATION (mark all that apply)

ALCOHOL   DRUGS
- ☐ 00 No evidence of impairment ☐
- ☐ 01 Evidential Test (Breath,Blood,etc) ☐
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- ☐ RP - Results pending

ALCOHOL:
- ☐ Evidentiary Breath   ☐ Eye Fluid
  0. _____   0. _____
- ☐ Blood (BAC)   ☐ Other
  0. _____   0. _____
- ☐ Drug screen ○ Pos ○ Neg

Transport Units: A, B, C, ..., N

Accident Code Sheet
KDOT Form 855 Rev. 1-2009

CONTRIBUTING CIRCUMSTANCES (LIST IN ORDER OF SIGNIFICANCE)

Example: |D1|42|OR|02 Interpretation: Driver 1 made an improper turn on icy or slushy roadway

DRIVER CCs   (D + TU# = D1)

00 No driver contributing circumstance evident

DRIVER CONDITION AT THE TIME OF CRASH
01 Under the influence of illegal Drugs
02 Under the influence of Alcohol
03 Under the influence of medication
04 Ill or Medical condition
05 Fell asleep or fatigued
06 Emotional: Angry, depressed, upset, impatient, etc.

DRIVER DISTRACTED BY
20 Mobile (cell) phone
21 Other electronic devices
22 Other distraction in or on vehicle
23 An item or action NOT in or on vehicle
24 Inattention (general sense)

DRIVER ACTIONS AT THE TIME OF CRASH
30 Failed to yield the right of way
31 Disregarded traffic signs, signals, or markings
32 Red light running (disregarded traffic signal)
33 Followed too closely
34 Exceeded posted speed limit
35 Too fast for conditions
36 Impeding or Too slow for traffic
37 Avoidance or Evasive action
38 Over correction / Over steering
39 Reckless / Careless driving
40 Aggressive / Antagonistic driving
41 Improper lane change
42 Made improper turn
43 Improper backing
44 Improper passing
45 Improper or No turn signal
46 Improper parking
47 Wrong side or wrong way
48 Did not comply with license restrictions

ENVIRONMENT   (code E, no TU#)

01 Animal: domestic or wild

WEATHER RELATED
02 Rain, mist, or drizzle
03 Sleet, hail, or freezing rain
04 Falling or Blowing snow
05 Strong winds
06 Fog, smoke, or smog
07 Blowing sand, soil, or dirt
08 Reduced visibility due to cloudy skies

VISION OBSTRUCTIONS
15 Building, vehicles, object made by humans
16 Vegetation: trees, shrubs, etc.
17 Glare from sun, headlights, or other lights

PEDESTRIAN CCs   (P + TU# = P1)

00 No pedestrian contributing circumstance evident

NON-MOTORIST CONDITION AT THE TIME OF CRASH
01 Under the influence of illegal drugs
02 Under the influence of Alcohol
03 Under the influence of medication
04 Ill or Medical condition
05 Fell asleep or fatigued
06 Emotional: Angry, depressed, upset, impatient, etc.

NON-MOTORIST DISTRACTED BY
15 Mobile (cell) phone
16 Other electronic devices
17 Inattention (general sense)

NON-MOTORIST ACTIONS AT THE TIME OF CRASH
25 Failed to yield the right of way
26 Disregarded traffic control signs, signals, officer, etc.
27 Improper crossing
28 In Roadway (standing, lying, etc)
29 Darting
30 Wrong side of roadway
31 Not visible (dark clothing)
32 Pedal cycle violation(s)

VEHICLE CCs   (V + TU# = V1)

PROBLEMS WITH OR LOSS OF...
01 Brakes
02 Tires
03 Wheel(s)
04 Trailer coupling, hitch, or safety chains
05 Cargo
06 Window or windshield; ice on windshield, tinting, etc
07 Wipers
08 Lights: Front (head), tail, signals, etc
09 Steering
10 Power Train: engine, driveshaft, transmission, differential
11 Exhaust
12 Suspension
13 Mirrors
14 Unattended or driverless in motion
15 Unattended or driverless not in motion

ROAD CCs (On/At)   (code OR or AR, no TU#)
01 Wet surface, standing or moving water
02 Icy or slushy
03 Snow accumulation or snow packed
04 Debris or obstruction
05 Road construction or maintenance
06 Ruts, holes, bumps
07 Traffic control device inoperative or missing
08 Shoulders: none, low, soft, or high
09 Worn, travel-polished surface
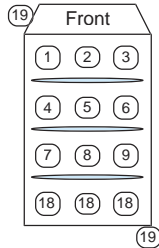
Codes 88 and 99 apply to Other and Unknown

VARIOUS CODE LISTS

OCCUPANT SEAT POSITION

FRONT ROW
01 Driver
02 Center
03 Right

SECOND ROW
04 Left
05 Center
06 Right

THIRD ROW
07 Left
08 Center
09 Right

10 Motorcycle passenger

11 Extra person on driver's seat or lap

12-17 Extra person on passenger lap

18 Other seat position IN vehicle

19 Other position ON or Outside vehicle

27 Enclosed cargo area

28 Unenclosed cargo area (pickup bed, etc)

29 Sleeper section of truck cab

30 Trailing unit (auto, boat, camper)

99 Unknown position IN or On vehicle

PEDESTRIAN TYPES (non-motorist)

21 Walking, standing, running, etc
22 Pedal cyclist
23 Rider of animal
24 Occupant of animal-drawn vehicle
25 In vehicle NOT IN TRANSPORT (legally parked veh)
26 Machine operator or passenger   (Working Vehicles...
    ...snow plows, emergency veh, paving machines, etc)
88 Other   99 Unknown

TRAIN OCCUPANT SEAT TYPES

31 Train crew (list all in control whether injured
   or not)

32 Train passengers (list if injured)

GENDER

M Male

F Female

U Unknown

SAFETY EQUIPMENT USE

S Shoulder & Lap belt

X Shoulder belt only

L Lap belt only

I Infant seat/restraint system (rear facing)

C Child seat/restraint system (front facing)

T "Booster" seat/restraint system (see manual)

P Airbag deployed only (Passive system)

R Airbag deployed - Shoulder & Lap belt

J Airbag deployed - Shoulder belt only

W Airbag deployed - Lap belt only

F Airbag deployed - Infant seat (rear facing)

D Airbag deployed - Child seat (front facing)

K Airbag deployed - "Booster" seat

B Both Motorcyclist helmet & eye protection

E Motorcyclist eye protection

H Motorcyclist helmet

Q Pedestrian helmet or protective pads   V Reflective clothing

N None used   U Unknown

EJECTED / TRAPPED

N Not ejected or trapped
E Ejected (totally)
P Partially ejected
T Trapped in vehicle
U Unknown

INJURY SEVERITY

N Not injured
P Possible injury (complaint of pain)
I Injury - not incapacitating
D Injury - incapacitating (disabling)
F Fatal injury   U Unknown

EJECTION PATH

01 Side door	06 Roof - sunroof/convertible top down)
02 Side window	07 Roof - convertible top up
03 Windshield	08 Other path (pickup bed)
04 Back window	99 Unknown
05 Back door/Tailgate	

ANIMAL TYPES

01 Deer	03 Cow	05 Horse
02 Other wild animal: bobcat, coyote, etc	04 Other domestic animal: cat, dog, etc	

KS LIC CLASS
(see manual)

A - GCWR>26,000

B - GVWR>26,000

C - GVWR<26,001

M - Motorcycle

(Class+) P - Permit

ID - Identification #

U - Unknown

KANSAS LICENSE RESTRICTIONS

B Corrective lenses	K Intrastate only	J04 25 Mi. from Home
C Mechanical aid (devices)	L Without Air-brakes	J05 Within City Limits
D Prosthetic aid (devices)	M No CDL - A Bus	J06 Licensed Driver Front Seat
E Automatic Transmission	N No CDL - A/B Bus	J07 Moped
F Outside mirror	O No Tractor-Trailer	J08 Seasonal CDL
G Daylight only	J01 Outside business area	J09 Farm Permit
H Employment only	J02 Under Age Sixteen	U Unknown
I Limited - Other	J03 No Freeway driving	

HAZARDOUS MATERIAL CLASS CODES

1 Explosives
2 Gases
3 Flammable/combustible liquid
4 Flammable/combustible solid
5 Oxidizers & organic peroxides
6 Poisonous/infectious substance
7 Radioactive material
8 Corrosive material
9 Misc. HazMat

KANSAS

Speed Limits On Rural Highways

Speed_2011.gws
8/8/11

75

60

65

45

70

50

75

55

APPENDIX E - SPSS CODE EXAMPLE

```
GENLIN TOT_ACC WITH LogAADT LogL LW SW RHR DrPerMi SpdLmt AvgHorzCurDeg
AvgGrade
  /MODEL LogAADT LogL LW SW RHR DrPerMi SpdLmt AvgHorzCurDeg AvgGrade
INTERCEPT=YES
 DISTRIBUTION=NEGBIN(MLE) LINK=LOG
  /CRITERIA METHOD=NEWTON SCALE=1 COVB=MODEL MAXITERATIONS=100
MAXSTEPHALVING=30 PCONVERGE=1E-006(ABSOLUTE) SINGULAR=1E-012
ANALYSISTYPE=3(WALD) CILEVEL=95 CITYPE=WALD LIKELIHOOD=FULL
  /MISSING CLASSMISSING=EXCLUDE
  /PRINT CPS DESCRIPTIVES MODELINFO FIT SUMMARY SOLUTION CORB
/SAVE RESID (R).
```