Calibrating Highway Safety Manual for Rural Multilane Highways by Considering Fatal and Injury Crashes in Kansas

Syeda Rubaiyat Aziz
Sunanda Dissanayake, PhD, P.E.

2015 Mid-Continent Transportation Research Symposium
August 19, 2015

KANSAS STATE UNIVERSITY

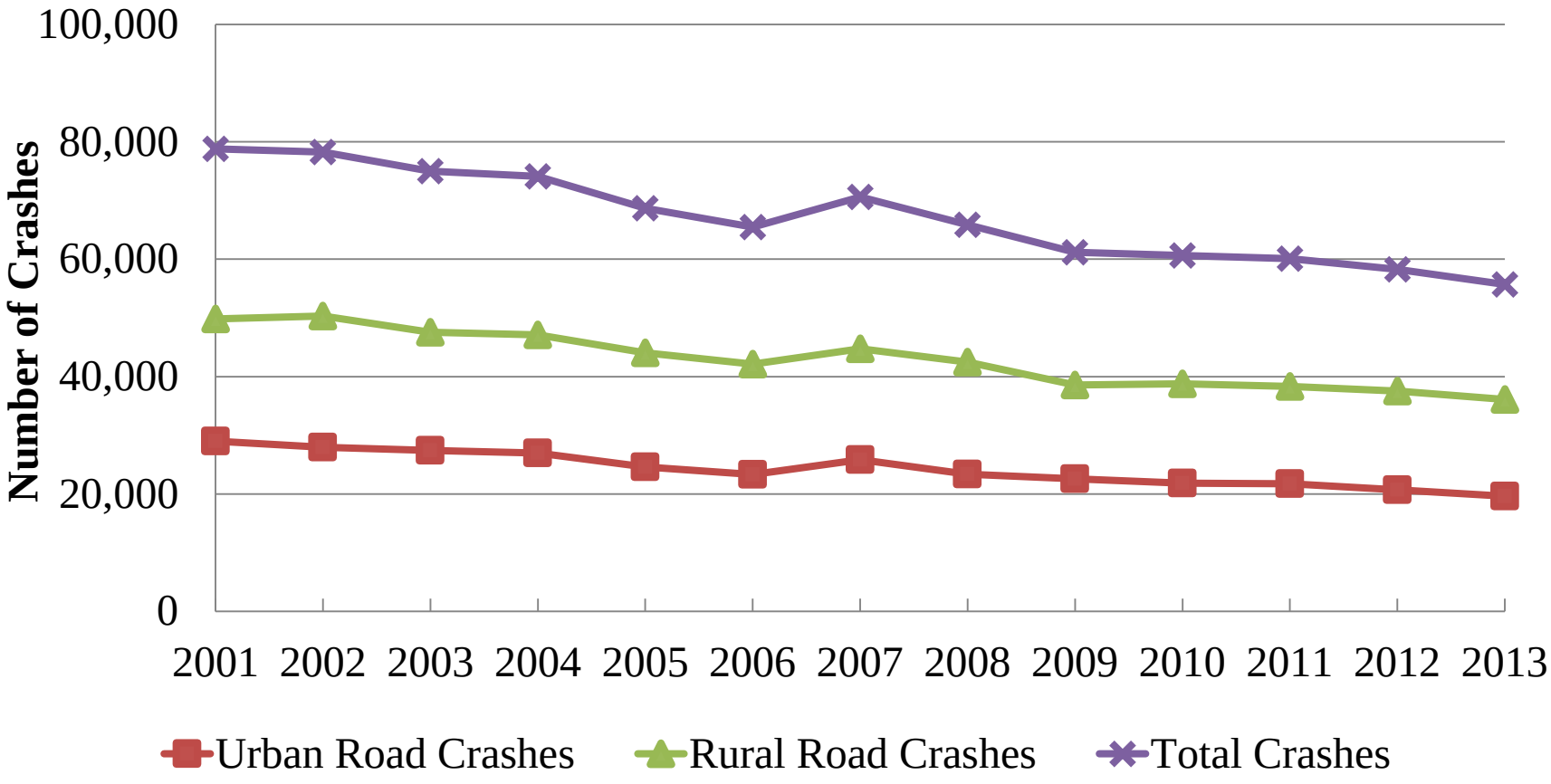
Outline

- Background
- Problem Statement
- Objectives
- Methodology
- Data
- Analysis & Results
- Acknowledgements

Background

- Highway fatal crashes 32,719 (2013) in US - FHWA
  - The number of fatalities increased by 2.5%
- Out of total 140,686 miles in Kansas, 90.7% rural roads.
- 2013, rural travel accounted for 47.8% of all vehicle miles (60% for state highways) in Kansas.

2001-2013 Kansas Crash Distribution



KANSAS STATE UNIVERSITY

Problem Statement

- Highway Safety Manual (2010) provides models and methodologies for prediction of crash frequency and analysis of safety
- Predictive methods in HSM developed based on national trends, statistics or using sample states throughout US.
- Limited use of methodologies.

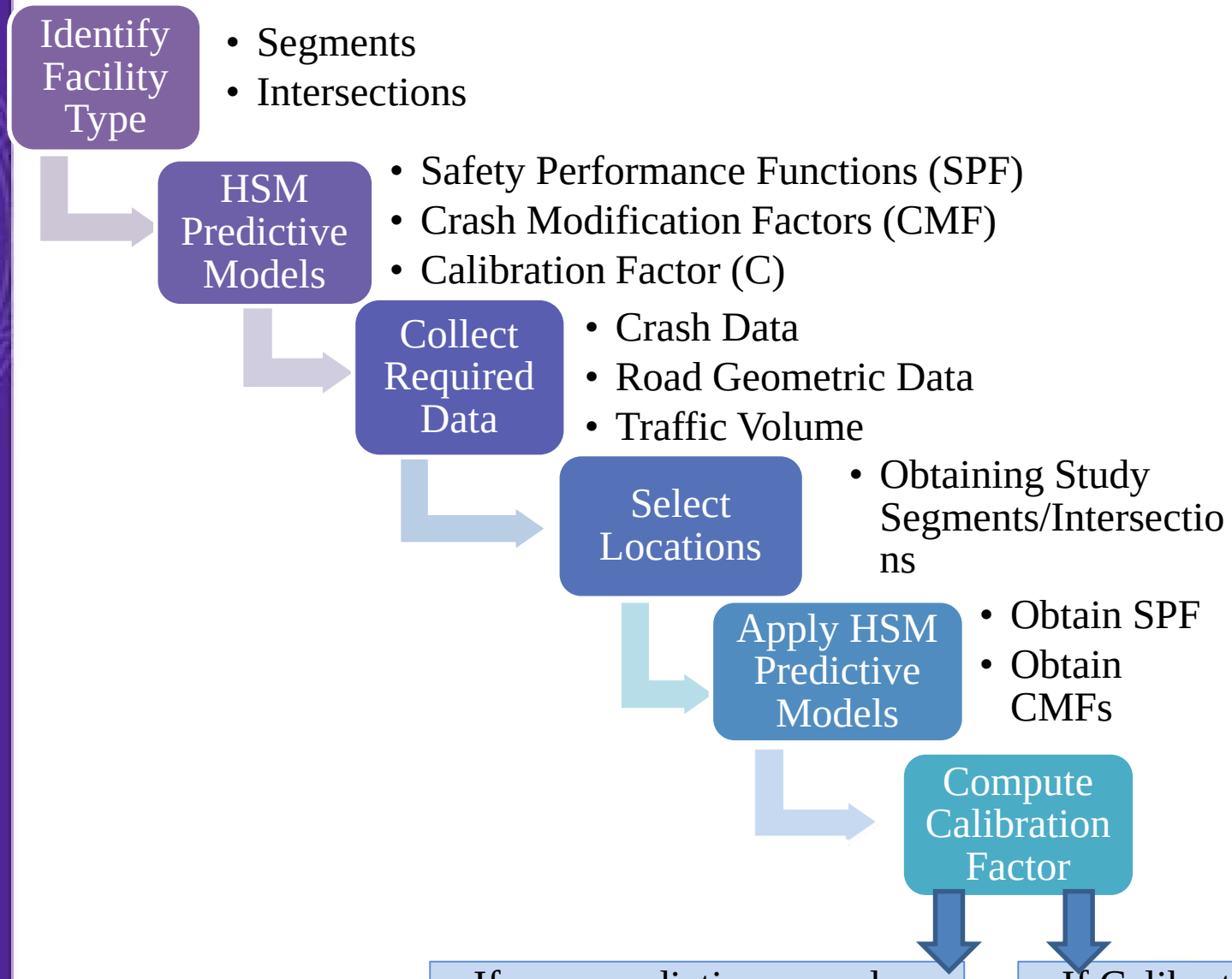
Objectives

- Calibration of HSM for rural multilane highways considering the Fatal and Injury crashes in Kansas.

- If the HSM methodology fails to predict crashes at rural segments and intersections accurately, new models or safety performance functions (SPFs) will be developed. (not shown in this presentation)

Methodology & Required Data

The standard HSM calibration



HSM Predictive Methodology

- Safety Performance Function (SPF)
- Crash Modification Factors (CMF)
- Calibration Factor

Safety Performance Function (SPF)

SPFs are regression equations that calculate the dependent variable, predicted crash frequency, based on independent variables.

$$N_{spf} = e^{[a + b \times \ln(AADT) + \ln(L)]}$$

Where,

N_{spf} = Base total expected average crash frequency for the rural segment,

AADT = AADT on the highway segment,

L = Length of highway segment (miles), and

a, b = regression coefficients.

KANSAS STATE UNIVERSITY

Crash Modification Factors (CMF)

The SPF is multiplied by CMF for each independent variable.

$$N_{Predicted} = N_{spf} * (CMF_1 * CMF_2 * \ldots\ldots\ldots CMF_i)$$

Where,

$N_{Predicted}$ = Adjusted number of predicted crash frequency,
N_{spf} = Total predicted crash frequency under base condition,
CMF_i = Crash modification factors

A CMF > 1.0 → increase in crashes, countermeasure decreases safety

A CMF < 1.0 → reduction in crashes, countermeasure increases safety

KANSAS STATE UNIVERSITY

CMFs for 4D & 4U

For rural multi-lane highways, five CMFs for 4D segments and five CMFs for 4U segments

4D		4U	
Variable	Base Condition	Variable	Base Condition
Lane width	12 feet	Lane width	12 feet
Right shoulder width	8 feet	Shoulder width and type	6 feet, paved
Median Width	30 feet	Side-slope	1:7 or flatter
Lighting	None	Lighting	None
Automated Speed Enforcement	None	Automated Speed Enforcement	None

- CMF = 1 indicates variable at base condition
- Deviation from base condition changes the factor

KANSAS STATE UNIVERSITY

CMFs from HSM (4D)

Table 11-16. CMF for Collision Types Related to Lane Width (CMF_{RA})

	Annual Average Daily Traffic (AADT) (vehicles/day)		
Lane Width	**< 400**	**400 to 2000**	**> 2000**
9 ft	1.03	$1.03 + 1.38 \times 10^{-4}(AADT - 400)$	1.25
10 ft	1.01	$1.01 + 8.75 \times 10^{-5}(AADT - 400)$	1.15
11 ft	1.01	$1.01 + 1.25 \times 10^{-5}(AADT - 400)$	1.03
12 ft	1.00	1.00	1.00

Table 11-17. CMF for Right Shoulder Width on Divided Roadway Segments (CMF_{2nd})

Average Shoulder Width (ft)				
0	**2**	**4**	**6**	**8 or more**
1.18	1.13	1.09	1.04	1.00

Table 11-18. CMFs for Median Width on Divided Roadway Segments without a Median Barrier (CMF_{3rd})

Median Width (ft)	CMF
10	1.04
20	1.02
30	1.00
40	0.99
50	0.97
60	0.96
70	0.96
80	0.95
90	0.94
100	0.94

CMFs from HSM (4U)

Table 11-11. CMF_{RA} for Collision Types Related to Lane Width

	Average Annual Daily Traffic (AADT) (vehicles per day)		
Lane Width	**< 400**	**400 to 2000**	**> 2000**
9 ft or less	1.04	$1.04 + 2.13 \times 10^{-4}(AADT - 400)$	1.38
10 ft	1.02	$1.02 + 1.31 \times 10^{-4}(AADT - 400)$	1.23
11 ft	1.01	$1.01 + 1.88 \times 10^{-5}(AADT - 400)$	1.04
12 ft or more	1.00	1.00	1.00

Table 11-12. CMF for Collision Types Related to Shoulder Width (CMF_{WRA})

	Annual Average Daily Traffic (AADT) (vehicles per day)		
Shoulder Width	**< 400**	**400 to 2000**	**> 2000**
0 ft	1.10	$1.10 + 2.5 \times 10^{-4}(AADT - 400)$	1.50
2 ft	1.07	$1.07 + 1.43 \times 10^{-4}(AADT - 400)$	1.30
4 ft	1.02	$1.02 + 8.125 \times 10^{-5}(AADT - 400)$	1.15
6 ft	1.00	1.00	1.00
8 ft or more	0.98	$0.98 - 6.875 \times 10^{-5}(AADT - 400)$	0.87

Table 11-13. CMF for Collision Types Related to Shoulder Type and Shoulder Width (CMF_{TRA})

	Shoulder Width (ft)						
Shoulder Type	**0**	**1**	**2**	**3**	**4**	**6**	**8**
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11

Table 11-14. CMF for Sideslope on Undivided Roadway Segments (CMF_{3ru})

1:2 or Steeper	1:3	1:4	1:5	1:6	1:7 or Flatter
1.18	1.15	1.12	1.09	1.05	1.00

CMF for Presence of Lighting (4D/4U)

$$CMF_{lighting} = 1 - [(1 - 0.72 * P_{inr} - 0.83 * P_{pnr}) * P_{nr}]$$

Where,

P_{inr} = Proportion of nighttime crashes for unlighted segments that involve fatality or injury,

P_{pnr} = Proportion of nighttime crashes for unlighted segments that involve PDO crashes, and

P_{nr} = Proportion of total crashes for unlighted segments that occur at night.

Base Condition = No Lighting = 1.00

Calibration Factor

Total predicted crashes = N_{SPF} * (CMF_1*CMF_2*CMF_3….)

Calibration factor (C)

$$C = \frac{\sum \text{Total observed crashes}}{\sum \text{Total predicted crashes}}$$

C < 1 → overprediction of crash frequencies. multiplying the factor lowers the predictions to match observed frequencies on average.

C > 1 → underprediction of crash frequencies, multiplying the factor increases the predictions to match the observed frequencies.

Data

In order to obtain the SPF, data collected from:

- Highway crash data → Kansas Crash and Analysis Reporting System (KCARS) database

- Geometric properties data → the state's highway inventory database Control Section Analysis System (CANSYS)
  - study duration was determined to be 2011 - 2013

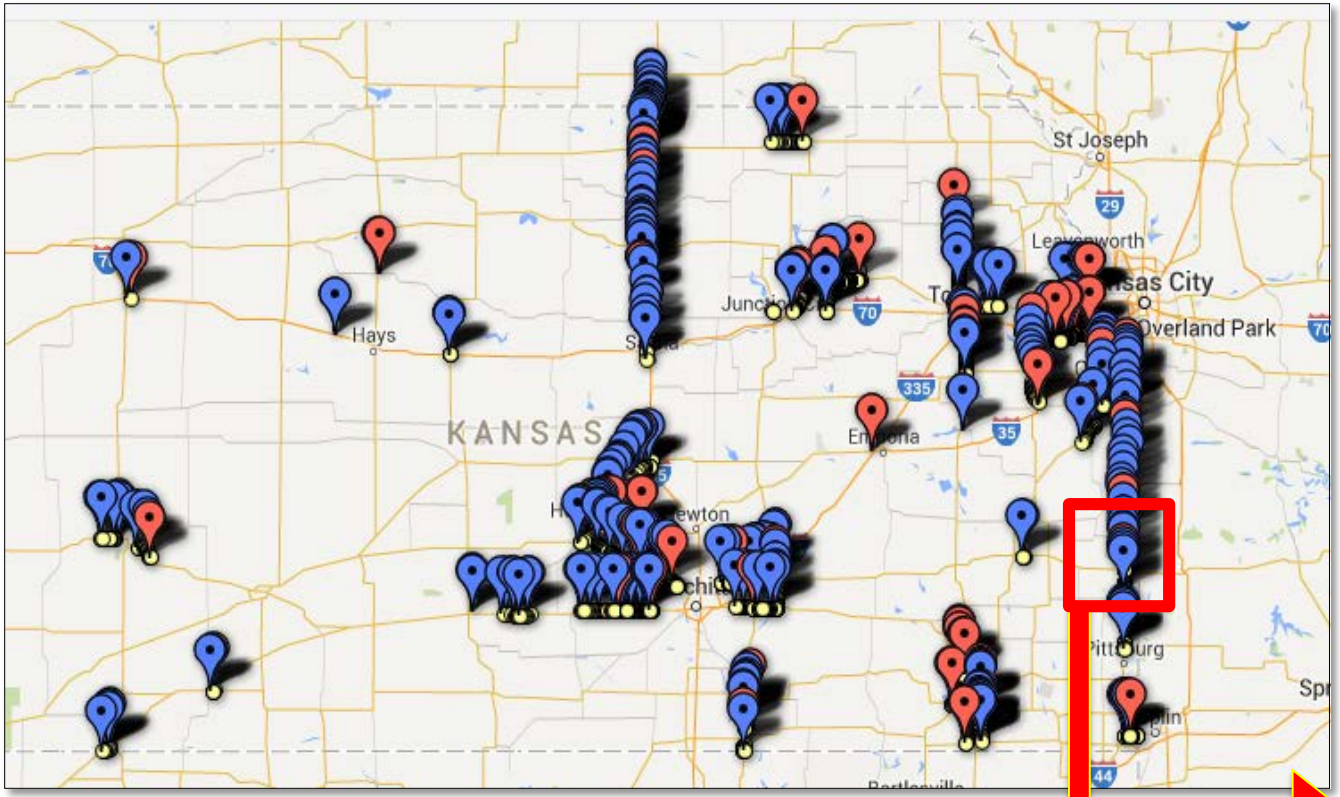
Required Data & Their Sources For Rural Four-lane Segments

Data Description	Source
AADT	Control Section Analysis System (CANSYS)
Lane Width	Control Section Analysis System (CANSYS)
Median Width	Control Section Analysis System (CANSYS)
Shoulder Width	Control Section Analysis System (CANSYS)
Side Slope	Control Section Analysis System (CANSYS)
Presence of Lighting	Google Maps
Number of Crashes	KCARS
Presence of Speed Enforcement	Not Applicable for Kansas
Segment locations	Control Section Analysis System (CANSYS)

Segment Selection

- HSM recommends minimum segment length 0.1 mile.
- Segments obtained from CANSYS database identified by beginning and ending of mile post.
- No. of 4D Segments: 283
- No. of 4U Segments: 83

Rural Four-Lane Divided Segments and Crash Location Map



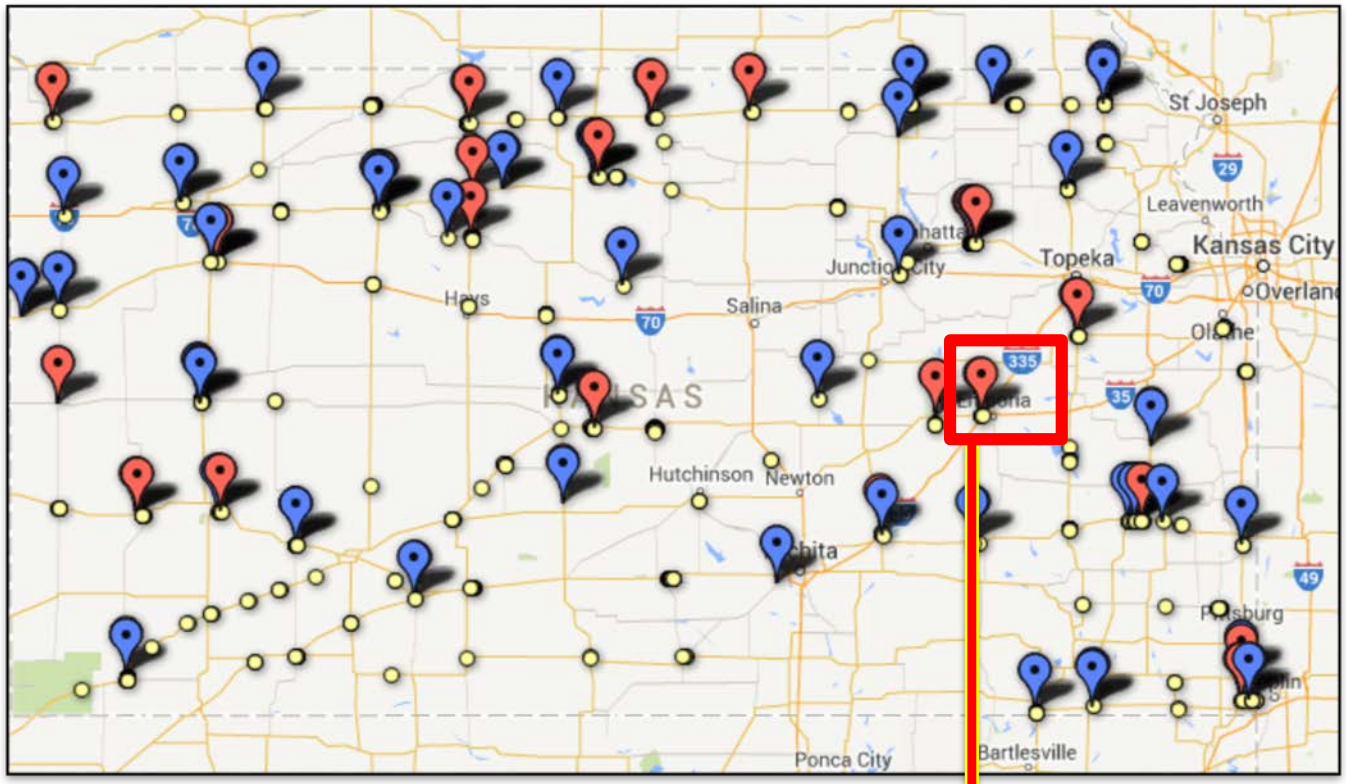
Total Crashes on Segments = 910 / year

Legends:

- Beginning of Segment
- End of Segment
- Location of Crash

KANSAS STATE UNIVERSITY

Rural Four-Lane Undivided Segments and Crash Location Map



Total Crashes on Segments = 44 / year

Legends:

- Beginning of Segment
- End of Segment
- Location of Crash

KANSAS STATE UNIVERSITY

Presence of Lighting

Google Maps and Google Earth ® used to identify presence of lighting at segments

KANSAS STATE UNIVERSITY

Analysis & Results

Preliminary Crash Analysis

Crash Percentages by Crash Severity Level for Rural Four-lane Highways in Kansas

Crash Severity Level	Year					
	2011		2012		2013	
	Count	Percent	Count	Percent	Count	Percent
Fatal	27	1.5	21	1.4	17	1.5
Incapacitating (disabled) Injuries	49	2.7	37	2.4	29	2.5
Non-incapacitating Injuries	157	8.7	132	8.5	119	9.9
Possible Injuries	96	5.3	80	5.2	65	5.4
Property Damage Only	1,479	81.7	1,285	82.5	969	80.7
Total	1,808	100.0	1,550	100.0	1,199	100.0

Preliminary Crash Analysis

Crash Severity Level vs Collision Type for Rural Four-lane Highways in Kansas

Collision Type	2011			2012			2013		
	F (%)	I (%)	PDO (%)	F (%)	I (%)	PDO (%)	F (%)	I (%)	PDO (%)
Head-On	20.0	5.4	3.0	20.0	3.9	0.5	23.1	3.0	0.0
Rear End	20.0	45.9	38.1	0.0	46.7	41.6	15.4	50.3	47.3
Angle - Side Impact	55.0	38.4	16.8	70.0	35.6	16.3	61.5	28.4	15.9
Sideswipe - Opposite Direction	5.0	1.6	1.1	0.0	1.7	0.8	0.0	2.0	0.2
Sideswipe – Same Direction	0.0	8.1	33.0	10.0	11.7	32.6	0.0	13.2	29.8
Backed Into	0.0	0.0	1.5	0.0	0.0	1.6	0.0	0.0	0.9
Other	0.0	0.5	6.4	0.0	0.6	5.7	0.0	2.0	5.5
Unknown	0.0	0.0	0.2	0.0	0.0	1.0	0.0	1.0	0.2

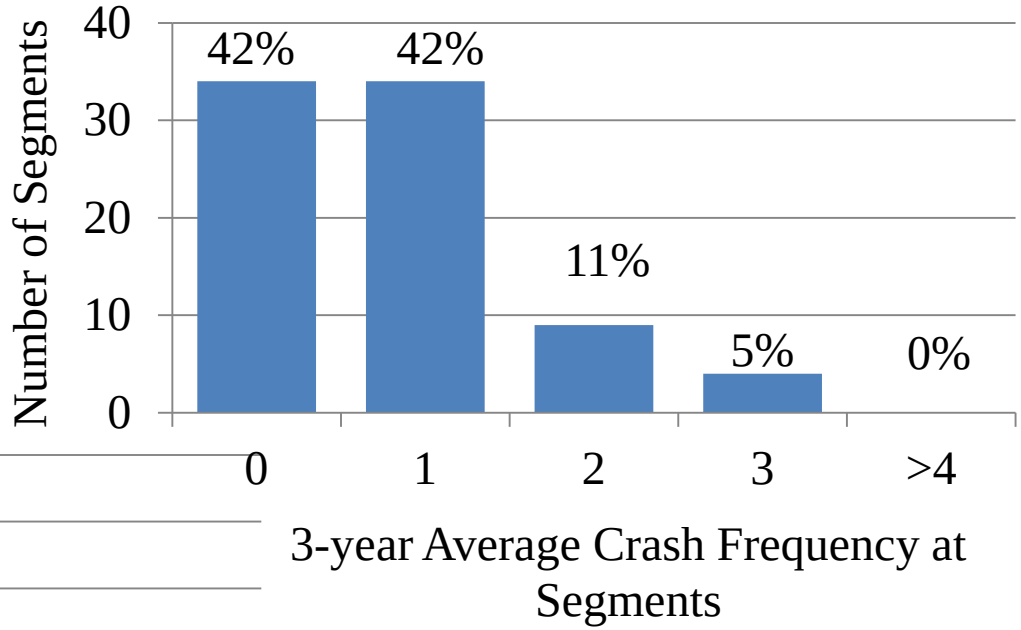
Crash Proportion by Lighting Condition over Study Period

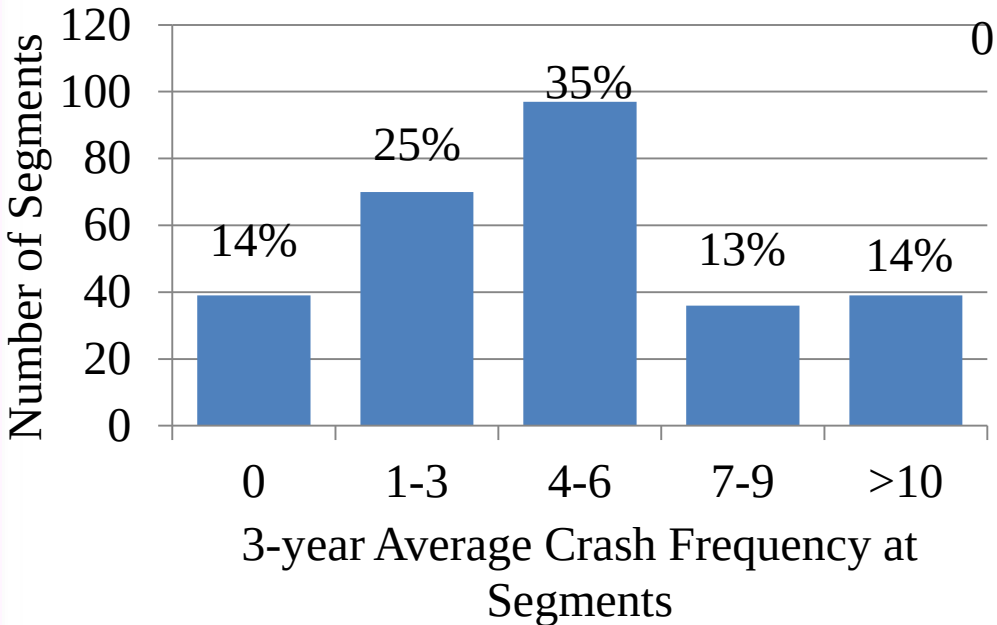
Roadway Type	Nighttime Crash Proportions	Kansas Four-lane Highways	HSM Given Default
4D	P_{inr}	0.599	0.426
	P_{pnr}	0.124	0.323
	P_{nr}	0.876	0.677
4U	P_{inr}	0.477	0.255
	P_{pnr}	0.127	0.361
	P_{nr}	0.873	0.639

P_{inr} = Proportion of nighttime crashes for unlighted segments that involve fatality or injury,
P_{pnr} = Proportion of nighttime crashes for unlighted segments that involve PDO crashes,
P_{nr} = Proportion of total crashes for unlighted segments that occur at night.

Number of Crashes at Segments

4U →





← 4D

KANSAS STATE UNIVERSITY

Descriptive Statistics for Rural Four-lane Segments

Roadway Type	Description	Average	Minimum	Maximum	Std. Dev.
4D	Length (mile)	1.53	0.1	8.63	1.55
	AADT (2013)	8,000	490	31,000	4657
	Left lane width (ft)	12.06	10.99	20.99	0.59
	Right lane width (ft)	12.06	10.99	20.99	0.59
	Left paved shoulder width (ft)	5.68	0	9.84	1.43
	Right paved shoulder width (ft)	9.35	0	9.84	1.84
	Median width (ft)	30.65	4.92	152.00	15.79
	Number of crashes	9.72	0	98.0	11.90
4U	Length (mile)	0.28	0.1	0.86	0.16
	AADT (2013)	4,114	460	12,600	2919
	Left lane width (ft)	12.45	10.00	22.51	1.33
	Right lane width (ft)	12.45	10.00	22.51	1.33
	Left paved shoulder width (ft)	5.05	0	10.00	4.68
	Right paved shoulder width (ft)	4.83	0	10.00	4.66
	Side Slope	-	1:2	1:6	-
	Number of crashes	1.59	0	11.0	2.14

Calibration Worksheet 4D

	ID	BEGIN CO MP	END CO MP	Segement Length (mile)	MED TYPE DESCR	SHOR DESC	AADT SMRY AADT CNT	MED WDTH (feet)	CMF (Median)	SHOR SHLDR WDTH	SHOR SHLDR WDTH (feet)	CMF (Shoulder)	SHLD SHIN SHLDR WDTH	SHLD SHIN SHLDR WDTH (feet)	LN1R LN WDTH (feet)	CMF (Lane Width)	LN2R LN WDTH
2	163	10.357	11.161	0.804	) - Depressilized, (CAC		2275	7.87	1.04	3	9.84	1	1.2	3.94	12.01	1.00	3.66
3	498	6.009	6.93	0.921	) - Depress3ituminous		2695	29.86	1.00	3	9.84	1	1.8	5.91	12.01	1.00	3.66
4	499	6.93	8.097	1.167	) - Depress3ituminous		3420	29.86	1.00	3	9.84	1	1.8	5.91	12.01	1.00	3.66
5	500	8.097	9.067	0.97	) - Depress3ituminous		3950		1.00	3	9.84	1	1.8	5.91	12.01	1.00	3.66
6	513	12.715	13.155	0.44	) - Depress3ituminous		2830		1.00	3	9.84	1	1.8	5.91	12.01	1.00	3.66
7	514	13.155	15.235	2.08	) - Depressement cor		2830		1.00	3	9.84	1	1.8	5.91	12.01	1.00	3.66
8	515	15.235	18.273	3.038	) - Depressement cor		2685		1.00	3	9.84	1	1.8	5.91	12.01	1.00	3.66
9	516	18.273	22.323	4.05	) - Depressement cor		2545		1.00	3	9.84	1	1.8	5.91	12.01	1.00	3.66
10	517	22.323	25.356	3.033	) - Depressement cor		2420		1.00	3	9.84	1	1.8	5.91	12.01	1.00	3.66

Sample Analysis:
Segment ID: 499
Segment Length: 1.167 mile
Median Type: Depressed
Median Width: 29.86 ft
CMF (Median): *Using HSM Table 11-18* : 1.00
Shoulder Type: Bituminous
Right Shoulder Width: 9.84 ft
CMF (Shoulder): *Using HSM Table 11-17* : 1.00
Lane Width: 12.01 ft
CMF (Lane): *Using HSM Table 11-16* : 1.00
Contd….

KANSAS STATE UNIVERSITY

Calibration Worksheet 4D

1	LANE LN2R LN WDTH (feet)	Presence of Lighting	CMF (Lighting)	No. of Fatal Crash	No. of Injury Crash	No. of Property Damage Crash	Total (F+I+PO)	No. of Daytime Crashes	No. of Nighttime Crashes	Night time Fatal Crash	Night time Injury Crash	Night time PDO Crash	N (spf) [Total Crash]	AADT 2013	N (spf) [Fatal/Injury Crash]	Predicted Total Crashes	Predicted Fatal/Injury Crashes
2	12.01	n	1.00	0	1	5	6	3	3	0	0	3	0.665	4550	0.373	2.08	1.16
3	12.01	n	1.00	0	1	6	7	5	2	0	0	2	0.910	5390	0.503	2.73	1.51
4	12.01	n	1.00	0	0	5	5	1	4	0	0	4	1.481	6840	0.800	4.44	2.40
5	12.01	n	1.00	0	2	4	6	1	5	0	2	3	1.432	7900	0.764	4.30	2.29
6	12.01	n	1.00	0	0	7	7	0	7	0		7	0.458	5660	0.252	1.37	0.75
7	12.01	n	1.00	0	0	13	13	3	10	0		10	2.164	5660	1.190	6.49	3.57
8	12.01	n	1.00	0	3	20	23	8	15	0		14	2.991	5370	1.652	8.97	4.96
9	12.01	n	1.00	0	2	18	20	13	7	0		7	3.770	5090	2.092	11.31	6.28
10	12.01	n	1.00	0	0	12	12	8	4	0		4	2.678	4840	1.493	8.03	4.48

Presence of Lighting: No
CMF (Lighting): 1.00
No. of Fatal Crashes: 0
No. of Injury Crashes:0
No. of PDO Crashes: 5
Total Crashes: 5
AADT: 6,840

N_{spf} (F/I Crash): *Using HSM SPF for rural 4D*: $N_{spf} = e^{[a + b \times \ln(AADT) + \ln(L)]} =$ **0.80**

Predicted F/I Crashes: N_{spf} (F/I Crash)*CMF(ln.)*CMF(Sh.)*CMF(Md.)*CMF(Lt)=**2.4**

KANSAS STATE UNIVERSITY

4D Segments Calibration Factor Calculation

No. of Fatal Crashes	No. of Injury Crashes	Total (Fatal / Injury) Crashes	No. of Property Damage Crashes	Total (Fatal + Injury + Personal Damage Only)	No. of Daytime Crashes	No. of Nighttime Crashes	Nighttime Fatal Crash	Nighttime Injury Crash	Nighttime PDO Crash	No. of Total Nighttime Crashes	Predicted Total Crashes	Predicted Fatal / Injury Crashes
45	483	528	2202	2730	1087	1636	18	185	1433	1636	1901.6	1007.7

$$\textbf{Fatal and Injury Crash, } C_r = \frac{\text{Total Observed Crashes}}{\text{Total Predicted Crashes}} = \frac{528}{1007.7} = \mathbf{0.524}$$

KANSAS STATE UNIVERSITY

Calibration Worksheet 4U

1	ID	BEGIN CO MP	END CO MP	Length of segment	SHOR DESC	AADT 2013	SHLD SHOR FORESLOPE	CMF (Foreslope)	TRA	Shoulder width (ft)	WRA	CMF (Shoulder width)	Lane Width (ft)	CMF (RA)	CMF (Lane Width)	BEG LON	BEG LAT	END LON	END LAT
2	78	18.647	18.873	0.226	uminous	2880	6:01	1.05	1	9.84	0.87	0.96	12.01	1	1	-95.24	38.266	-95.238	38.269
3	151	7.666	8.171	0.505	ituminous	7910	6:01	1.05	1	9.19	0.87	0.96	13.48	1	1	-95.38	37.922	-95.37	37.922
4	152	8.171	8.649	0.478	Curb and g	7910	0	1	1	0.00	1.50	1.14	13.48	1	1	-95.37	37.922	-95.362	37.922
5	153	8.649	9.046	0.397	ized, (CA(	7910	6:01	1.05	1	9.84	0.87	0.96	13.48	1	1	-95.36	37.922	-95.354	37.922
6	161	10.004	10.109	0.105	ized, (CA(	4420	6:01	1.05	1	9.84	0.87	0.96	13.48	1	1	-95.34	37.922	-95.335	37.922
7	162	10.109	10.357	0.248	ized, (CA(	4550	6:01	1.05	1	9.84		0.96	13.48	1	1	-95.33	37.922	-95.33	37.922
8	164	11.161	11.415	0.254	ized, (CA(	4550	6:01	1.05	1	9.84		0.96	12.01	1	1	-95.32	37.922	-95.311	37.922
9	168	12.059	12.29	0.231	Curb and g	2740	0	1	1	0.00		1.14	12.01	1	1	-95.3	37.922	-95.295	37.922
10	169	12.29	12.56	0.27	ized, (CA(	2740	6:01	1.05	1	9.84		0.96	12.01	1	1	-95.29	37.922	-95.29	37.922

Sample Analysis:
Segment ID: 161
Segment Length: 0.105 mile
Shoulder Type: Aggregate base stabilized
AADT: 4,420
Side Slope: 1:6
CMF (Side Slope): *Using HSM Table 11-14* : 1.05
Shoulder Width: 9.84 ft
CMF (Shoulder): *Using HSM Table 11-12 & 11-13* : 0.96
Lane Width: 13.48 ft
CMF (Lane): *Using HSM Table 11-11* : 1.00
Contd….

KANSAS STATE UNIVERSITY

Calibration Worksheet 4U

	Presence of Lighting	CMF (lighting)	No. of Fatal Crash	No. of Injury Crash	No. of Property Damage Crash	Total (F+I+PO)	No. of Daytime Crashes	No. of Nighttime Crashes	Night time Fatal Crash	Night time Injury Crash	Night time PDO Crash	No. of Nighttime Crashes	N (spf) [Total Crash]	N (spf) [Fatal/Injury Crash]	Predicted Total Crashes	Predicted Fatal/Injury Crashes
1																
2	y	0.912197	0	0	0	0	0	0	0	0	0	0	0.17	0.11	0.47	0.31
3	y	0.912197	0	1	10	11	5	6	0	0	6	6	1.25	0.76	3.45	2.11
4	y	0.912197	0	0	1	1	0	1	0	0	1	1	1.18	0.72	3.66	2.24
5	n	1	0	0	2	2	0	2	0	0	2	2	0.98	0.60	2.98	1.82
6	n	1	0	0	0	0	0	0	0	0	0	0	0.13	0.08	0.40	0.25
7	n	1	0	0	0	0	0	0	0		0	0	0.32	0.20	0.97	0.62
8	n	1	0	0	0	0	0	0	0		0	0	0.33	0.21	0.99	0.64
9	n	1	0	1	0	1	0	1	0		0	1	0.16	0.11	0.56	0.37
10	n	1	0	0	1	1	1	0	0		0	0	0.19	0.13	0.58	0.39

Presence of Lighting: No
CMF (Lighting): 1.00
No. of Fatal Crashes: 0
No. of Injury Crashes:0
No. of PDO Crashes: 0
Total Crashes: 0

N_{spf} (F/I Crash): *Using HSM SPF for rural 4U*: $N_{spf} = e^{[a + b \times \ln(AADT) + \ln(L)]} = \mathbf{0.08}$

Predicted F/I Crashes: N_{spf} (F/I Crash)*CMF(ln.)*CMF(Sh.)*CMF(Slp.)*CMF(Lt)=**0.25**

KANSAS STATE UNIVERSITY

4U Segments Calibration Factor Calculation

No. of Fatal Crash	No. of Injury Crashes	Total (Fatal / Injury) Crashes	No. of Property Damage Crashes	Total (Fatal + Injury + PDO Crashes	No. of Daytime Crashes	No. of Nighttime Crashes	Nighttime Fatal Crashes	Nighttime Injury Crashes	Nighttime PDO Crashes	No. of Total Nighttime Crashes	Predicted Total Crashes	Predicted Fatal / Injury Crashes
0	20	20	112	132	69	63	0	8	55	63	88.28	55.68

Fatal and Injury Crash, $C_r = \frac{\text{Total Observed Crashes}}{\text{Total Predicted Crashes}} = \frac{20}{55.68} = \mathbf{0.359}$

KANSAS STATE UNIVERSITY

Conclusion

- C= 0.524 (4D), 0.359 (4U) over predicts fatal and injury crashes combined.
- For more accurate prediction, jurisdiction-specific SPFs should be developed.

Applications of HSM Calibration

- Facilitate private, county, state, and federal government agencies to identify possible factors that may influence rural crash occurrence.
- Finally, the calibration will assist in reducing fatalities experienced on rural roadways in Kansas.

Acknowledgements

Kansas Department of Transportation

Dr. Howard Lubliner

Mr. Steven Buckley

Ms Elsit Mandal

Mr. Rex McCommon

Mr. Leif Holliday

KANSAS STATE UNIVERSITY

Thank You.

KANSAS STATE
UNIVERSITY