An evaluation of wrong-way driving crashes on Kansas freeways.

by

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Abstract

Transportation officials continuously seek to prevent and reduce wrong-way crashes on freeways in the United States. These crashes typically have a high probability of head-on vehicle crashes, resulting in fatalities or serious injuries due to excessive vehicle speeds, and decreased room to maneuver because of fixed barriers or rough shoulders. This research project studied wrong-way crashes on freeways in Kansas in order to determine what, if any, statistically significant variables contribute to wrong-way driving crashes. Although these crashes represented only 0.05 percent of all vehicle crashes in Kansas in 2015, wrong-way crashes were found to have a higher rate of fatalities and injuries. In Kansas, 22.6 percent of all crashes and 56 percent of all wrong-way crashes resulted in fatalities and injuries, even though typical vehicle crashes in Kansas occur at non-intersection locations in daylight or in the presence of streetlights without negative factors of adverse weather conditions or drivers influenced by alcohol or drugs. Using crash data provided by the Kansas Department of Transportation from the years 2005 to 2015, the research team examined 372 wrong-way crashes. A cumulative logit statistical model was developed to identify significant characteristics of variables associated with each wrong-way crash. Results showed that driver not under the influence of alcohol or drugs was a significant characteristic in fatal and injury wrong-way crashes. Additionally, certain days of the week were associated with decreased vehicle crash rates when compared to the reference category.

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1. INTRODUCTION

1.1 Background

The National Transportation Safety Board (NTSB) defines wrong-way driving as vehicular movement in or along a travel lane in a direction that is opposing the legal flow of traffic (NTSB, 2012 and Tamburri, 1965). This report's consideration will be limited to restricted-access highways with entrance and exit ramps. It does not consider wrong-way crashes that occur neither on roads with at-grade intersection access nor two-lane highways.
In the United States, NTSB analysis of FARS data shows anywhere from half to three-quarters of wrong-way drivers and nearly 60% of fatal crashes were impaired by alcohol. This number could be even higher since often alcohol information is missing from reports. Wrong-way crashes occur more often at night, with 78% of fatal crashes occurring between 6:00 p.m. and 6:00 a.m., with a significant number of these occurring on the weekend (NTSB, 2012). Within the state of Kansas from 2005 to 2015, 35% of wrong-way crashes involved alcohol or drugs, and 59% occurred between the hours or 6:00 p.m. and 6:00 a.m.

Wrong-way crashes can occur on divided highways or freeways, which are typically high-volume roads connecting major cities with each other and the rest of the United States. Freeways usually have two or more travel lanes in each direction with either a physical barrier between the lanes, such as a concrete barrier or guardrail, or a wide median separating each direction. Entrances to divided freeways are normally controlled by interchanges using signs or traffic control devices. Many different types of interchanges are currently in use throughout the United States such as diamond, cloverleaf, partial cloverleaf, single point interchange, and diverging diamond interchange. Although these interchanges are designed to limit access onto high-speed freeways and dictate the direction of travel onto the freeway, wrong-way incidents still occur on freeway.

1.2 Research Objectives

The primary objective of this research was to investigate the frequency and location of wrong-way driving crashes on Kansas freeways. This research was limited to access controlled divided freeways. Secondary objectives included investigating causes of each wrong-way driving crash using the Kansas Department of Transportation (KDOT) crash database, generating descriptive statistics of crash characteristics and creating a statistical model to determine crash severity.

1.3 Thesis Organization

This thesis is comprised of five chapters. Chapter 1 includes the background and research objectives. In Chapter 2, a review of the Manual of Uniform Traffic Control Devices (MUTCD) is presented along with a comprehensive review of literature. Chapter 3 explains the methodology and steps taken to investigate wrong-way driving crashes on freeways in Kansas using quantitative methods. Chapter 4 presents the methodology used to develop the statistical model to predict wrong-way crash severity. Chapter 5 includes a discussion of significant findings, limitations of this research project, recommendations for future research and contributions to highway safety.

2. LITERATURE REVIEW

A literature review was conducted to understand wrong-way crash characteristics and the state of wrong-way crash research. The review included investigation of the 2009 MUTCD, published by the Federal Highway Administration (FHWA), and an internet search for applicable wrong-way driving research. The literature was categorized as freeway ramps, driver characteristics, and countermeasures. Several states; Texas, California, Illinois, Alabama, and Florida, have current, ongoing research into wrong-way crashes. Extensive, relatively consistent research was found to quantify wrong-way crash characteristics.

2.1 MUTCD Review

The MUTCD provides uniform guidelines for traffic control devices (TCDs), pavement markings, highway and traffic signs (including size, dimensions, and height), retroreflectivity, and warrants for traffic signal installation on all roads open to the traveling public in the United States. The ninth edition of the MUTCD, published in 2009, has undergone two revisions, with the most recent revision published in May 2012. Potential technological improvements or new research into methods and practices have precipitated an amendment process for revising the MUTCD, but this process can take up to five years to complete.

The MUTCD was approved with Title 23, Code of Federal Regulations, Part 655.603 as the standard for designing, applying, and planning traffic control devices to improve roadway safety in the United States. Failure to adhere to the standards could result in loss of federal funding and an increased risk of liability for local agencies. A uniform standard for TCDs benefits all road users; lack of TCD standardization could cause driver confusion, especially in unfamiliar areas.

Section 2B.41 of the MUTCD specifically addresses wrong-way traffic control at interchange ramps, including a standards section with guidance and two optional sections with guidance. Standards for wrong-way traffic control consists of at least one ONE WAY sign for each direction of travel where an exit ramp intersects a crossroad. Additionally, at least one DO NOT ENTER sign must be placed near the downstream end of the exit ramp in full view of the driver mistakenly entering from the crossroad, and at least one WRONG WAY sign must be placed on the exit ramp facing a driver traveling in the wrong direction. Section 2B.41 provides further guidance for specific pavement markings under certain circumstances. As shown in **Figure 1**, freeway entrance signs or additional ONE WAY and WRONG WAY signs and wrong-way arrow pavement markings or lane-use arrow pavement markings could be added to supplement standard markings. Guidance for these additional markings suggests that additional ONE WAY signs should be used if the interchange design does not clearly indicate the direction of traffic, as shown in **Figure 2**. Another option allows interchange designers to use engineering judgment to identify if a special need exists and use warnings, devices, or prohibitive methods as necessary.

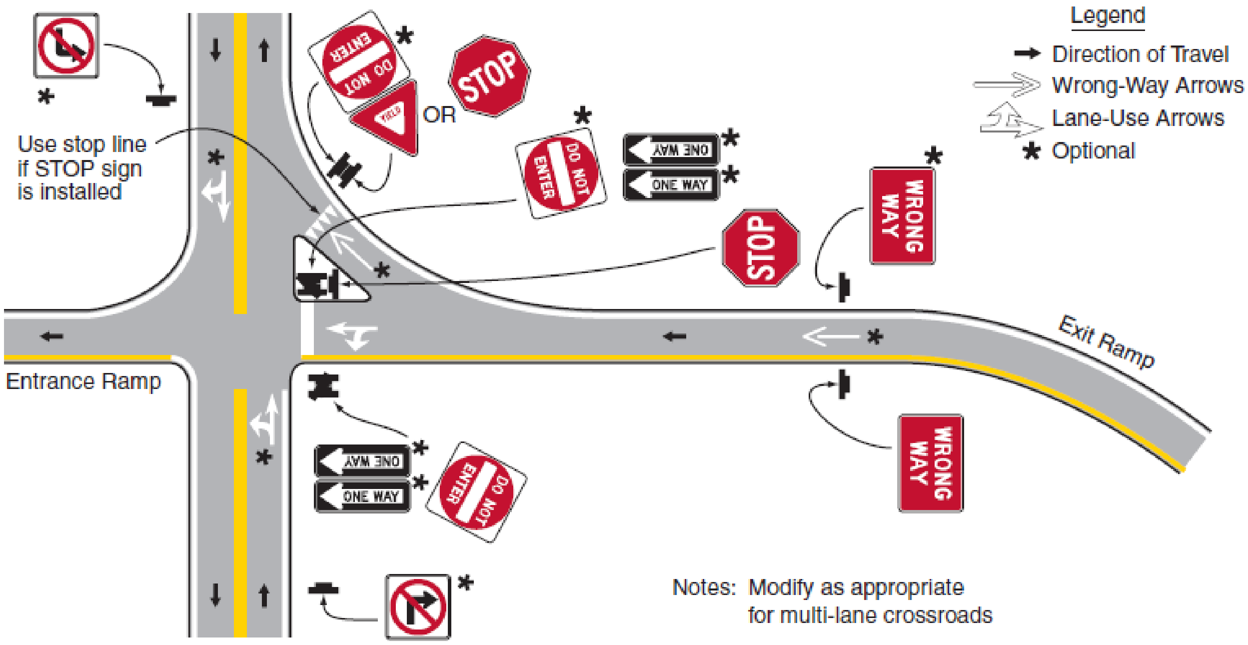


Figure 1: Application of Regulatory Signage and Pavement Markings at an Exit Ramp Termination to Deter Wrong-Way Entry (MUTCD, 2012).

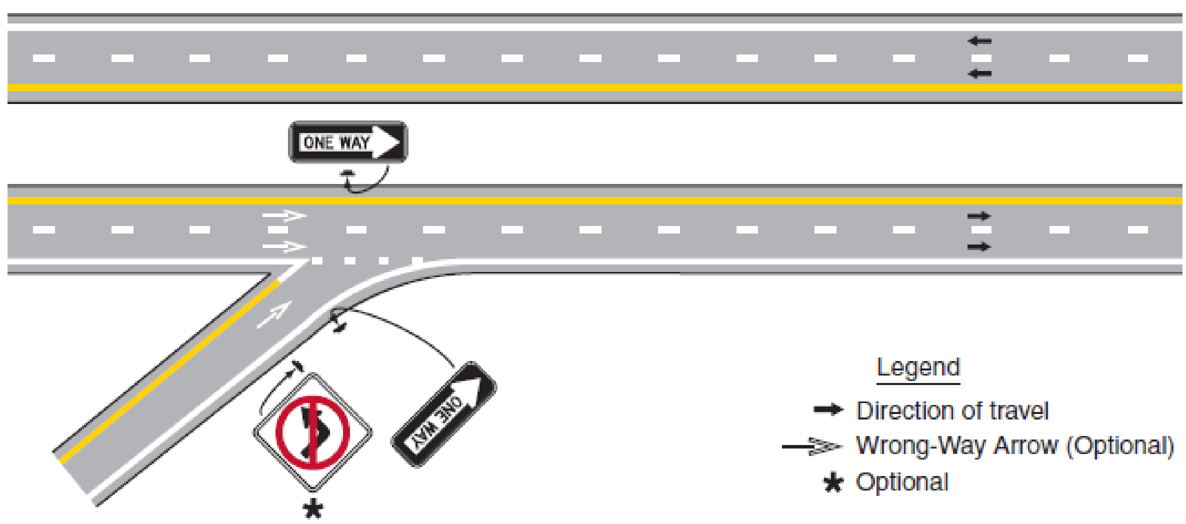


Figure 2: Signage and Pavement Markings at an Entrance Ramp Terminal Where the Design Does Not Clearly Indicate the Direction of Flow (MUTCD, 2012).

Section 2A.18 of the MUTCD identifies the minimum mounting height of primary signs along a roadway to be 5 ft. above the near edge of the pavement. If pedestrians, parked cars, or other obstructions are present, minimum sign height is fixed at 7 ft. However, section 2B.41 of the MUTCD allows the sign height to be lowered to a minimum of 3 ft. if no parked cars, pedestrians, or other obstructions are present along the ramps. Consequently, prior to implementation, an engineering study should be done to determine if this new minimum height would be effective.

Sections 2A.07 and 2A.08 of the MUTCD provide guidelines on sign illumination and retroreflectivity. Section 2A.07 specifies which parts of the sign should be illuminated and recommends types of retroreflectivity. This section asserts that illumination, not in the form of streetlights, or a minimum level of retroreflectivity must be maintained, and section 2A.08 provides the exact levels of retroreflectivity that must be maintained. Retroreflectivity levels are shown in **Table 1**. Several methods can be used to evaluate and maintain signs to ensure compliance with required retroreflective levels, including visual nighttime inspection by a trained sign inspector or measured sign retroreflectivity using a retroreflectometer. Signs can also be replaced based on their expected life or as part of a sign inventory system with specified replacement time periods. The life expectancy of a sign is determined based on retroreflectivity degradation of similar signs in one area. Sign life can vary by area, and control signs can be used to determine sign life expectancy. Signs erected in a controlled area in one geographical region can be monitored for retroreflectivity. When the control signs reach the minimum level, all signs that were emplaced at the same time, should be replaced. Other methods to determine sign replacement should be based on engineering studies. Additionally, within this section references are made to sections 2A.15 and 2A.21 of the MUTCD for methods to increase the noticeability of signs for drivers.

Table 1: Minimum Maintained Retroreflectivity Levels

Sign Color	Sheeting Type (ASTM D4956-04)				Additional Criteria
	Beaded Sheeting			Prismatic Sheeting	
	I	II	III	III, IV, VI, VII, VIII, IX, X	
White on Green	W*; G ≥ 7	W*; G ≥ 15	W*; G ≥ 25	W ≥ 250; G ≥ 25	Overhead
	W*; G ≥ 7	W ≥ 120; G ≥ 15			Post-mounted
Black on Yellow or Black on Orange	Y*; O*	Y ≥ 50; O ≥ 50			[2]
	Y*; O*	Y ≥ 75; O ≥ 75			[3]
White on Red	W ≥ 35; R ≥ 7				[4]
Black on White	W ≥ 50				–

[1] The minimum maintained retroreflectivity levels shown in this table are in units of cd/lx/m² measured at an observation angle of 0.2° and an entrance angle of -4.0°.
[2] For text and fine symbol signs measuring at least 48 inches and for all sizes of bold symbol signs
[3] For text and fine symbol signs measuring less than 48 inches
[4] Minimum sign contrast ratio ≥ 3:1 (white retroreflectivity ÷ red retroreflectivity)
* This sheeting type shall not be used for this color for this application.

Section 2A.15 of the MUTCD describes methods to enhance conspicuity for standard signs, including increasing the number of signs by adding an additional set of signs to the left-hand side of the road and increasing sign size. Red or orange flags can also be attached to the top of a sign to make it more noticeable, and LED lights can be added to a sign or border of a standard regulatory sign. Retroreflective tape can be used on signposts to enhance the conspicuity of the signs, but the tape must be at least 2 inches wide and cover the full length of the post from the sign to 2 feet above the roadway. The color of the retroreflective tape should match the color of the sign background, with the exception of DO NOT ENTER signs, which require red retroreflective tape.

Section 3B.14 of the MUTCD describes use of raised pavement markers to replace retroreflective pavement markings or internally illuminated lights. Guidance specifies spacing between markers depending on the line type being replaced. Raised pavement markers should mimic the marking pattern they are replacing, whether it is a directional arrow or a line, and raised markers should not be replaced with right edge lines unless an engineering study indicates that the benefits of the raised markers outweigh any impacts.

There is one confusing part of Section 2B.41 of the MUTCD, where it erroneously refers back to itself for signing guidance to avoid wrong-way movements at at-grade intersections. The correct section for at-grade intersections is 2B.42. In addition, figures for the at-grade intersections are located before section 2B.42 and in the middle of the explanation of section 2B.41, while figures for wrong-way traffic control at interchanges are located after section 2B.42, potentially confusing readers who are not familiar with sections of the MUTCD that relate to wrong-way driving. Additionally, **Figure 1** and **Figure 2** are the only two examples of interchanges shown, neither of which are the most common interchange types used in the United States. **Figure 1** and **Figure 2** mark optional signs with an asterisk, but all ONE WAY signs are marked with asterisks, even though the standard clearly states that one ONE WAY sign for each direction is required.

These MUTCD errors can cause confusion for agencies designing interchanges and allow opportunity for various interpretations by roadway designers, engineers, or local jurisdictions. Some states diligently utilize engineering studies to ensure proper placement of the maximum number of allowable signs, while other states barely comply with the MUTCD. With such a variety of interpretation, signage guidelines vary greatly between locales, leading to increased confusion among drivers on freeways.

2.2 Freeway Ramps

Only two research studies, both conducted in the 1980s, have considered wrong-way crashes on freeway ramps. Unlike other wrong-way research studies, these studies investigated possible relationships between crashes and ramp configuration. Using analyses, the research studies found possible safety concerns associated with certain ramp configurations. One study made recommendations for countermeasures.

Howard (1980) installed pneumatic tubes on interstate off-ramps in Virginia to detect vehicles traveling in the wrong direction and determine the number of subsequent wrong-way incidents. Eight ramps were investigated based on crash history and the potential for wrong-way events to occur. The study used a combination of road tubes and cameras to capture wrong-way event data over approximately 30 days. The camera verified that the incidents detected by the road tubes were actual wrong-way entries onto the interstate. Their findings indicated there were concerns with some of the ramps investigated, but this may have been skewed due to the nature of their selection process. Research results provided multiple countermeasure recommendations, including expansion of the use of road tubes and conducting studies at all ramps to determine if there are significant wrong-way incidents.

Campbell et al. (1988) studied interstate ramps in Georgia, focusing on the partial cloverleaf ramp design. Using pneumatic road tubes, the research team evaluated 17 partial cloverleaf ramps. At one particularly dangerous ramp identified by the research team, data collections were made using standard signs and then further data collections were made using different other mitigation methods to determine which one would be best. Results showed an increase in wrong-way events after changing interstate directional signs. Relocating the road tubes and adjusting the signs reduced the number of events, illustrating the need to exercise care in signing interchanges. Regarding side-by-side exit/entrance ramps in a partial cloverleaf, the study determined that removal of the barrier between the two ramps and utilization of a solid double yellow line and wrong-way signs reduced wrong-way events from 86.7 per month to 7.5

per month. The number of wrong-way incidents decreased even more after roadway users became familiar with the new geometry of the interchange. Researchers also recommended increased monitoring of all partial cloverleaf interchanges in Georgia in order to track wrong-way events.

Results of both studies showed several ramp types that seemed to have more wrong-way driving incidents than others, particularly ramps with left-hand entrances and side-by-side exit/entrance ramps. Both also recommended continued monitoring of ramps, especially long-term periodic monitoring of ramps with frequent wrong-way driving incidents and partial cloverleaf interchanges.

2.3 Characteristics of Wrong-Way Drivers

Several studies have evaluated characteristics of wrong-way drivers, and most of those studies have utilized historical crash data or meta-data reports that compile data to disseminate information about wrong-way drivers in a certain state or community. Effective implementation of countermeasures or intervention strategies, however, requires reasonable determination as to why drivers enter a freeway in the wrong direction.

Pour-Rouholamin et al. (2016) performed a comprehensive analysis of wrong-way crash data in Alabama. Using data provided by the Alabama Department of Transportation (ALDOT), the study identified 93 wrong-way crashes on Alabama interstates from 2009 to 2013. The purpose of this investigation was to use statistics to determine (at least a 95% confidence level)

Table 2: Final Firth's and Binary Model Results (Pour-Rouholamin, 2016)

Explanatory Variable	Firth's Model			Standard Binary Logistic Model		
	β	S.E.	OR (95% CI)	β	S.E.	OR (95% CI)
Month of the Year						
January	–	–	Reference	–	–	Reference
February	0.76	0.60	2.15 (0.66; 6.96)	0.82	0.63	2.27 (0.66; 7.81)
March	1.16*	0.56	3.19 (1.06; 9.65)	1.24*	0.59	3.47 (1.09; 11.06)
April	-0.27	0.73	0.76 (0.18; 3.19)	-0.32	0.78	0.73 (0.16; 3.38)
May	1.24*	0.56	3.47 (1.16; 10.37)	1.33*	0.59	3.80 (1.2; 11.96)
June	0.46	0.63	1.58 (0.46; 5.44)	0.49	0.66	1.64 (0.45; 6.03)
July	0.55	0.63	1.73 (0.5; 5.96)	0.59	0.66	1.80 (0.49; 6.59)
August	0.19	0.68	1.21 (0.32; 4.63)	0.19	0.72	1.21 (0.29; 5)
September	0.40	0.64	1.49 (0.43; 5.16)	0.44	0.67	1.55 (0.42; 5.72)
October	0.39	0.63	1.48 (0.43; 5.09)	0.43	0.66	1.53 (0.42; 5.63)
November	1.27*	0.56	3.56 (1.18; 10.74)	1.36*	0.59	3.88 (1.22; 12.35)
December	0.85	0.59	2.35 (0.74; 7.45)	0.92	0.62	2.51 (0.75; 8.42)
Time of the Day						
Morning (6-12)	–	–	Reference	–	–	Reference
Afternoon (12-18)	-0.79	0.47	0.45 (0.18; 1.13)	-0.82	0.48	0.44 (0.17; 1.13)
Evening (18-24)	1.05**	0.35	2.85 (1.43; 5.65)	1.08**	0.36	2.94 (1.46; 5.91)
Night (0-6)	1.70**	0.35	5.50 (2.75; 10.98)	1.74**	0.36	5.72 (2.83; 11.56)
Driver Age						
Less than 24	–	–	Reference	–	–	Reference
25 to 34 years	-0.07	0.31	0.93 (0.51; 1.71)	-0.07	0.31	0.93 (0.5; 1.72)
35 to 44 years	0.07	0.34	1.08 (0.55; 2.11)	0.06	0.35	1.06 (0.53; 2.11)
45 to 54 years	-0.02	0.41	0.98 (0.44; 2.18)	-0.07	0.42	0.94 (0.41; 2.14)
55 to 64 years	0.00	0.53	1.00 (0.36; 2.8)	-0.10	0.55	0.91 (0.31; 2.69)
65 years of over	2.21**	0.33	9.07 (4.8; 17.16)	2.24**	0.33	9.37 (4.91; 17.89)
Driver Condition						
Apparently Normal	–	–	Reference	–	–	Reference
DUI	2.16**	0.26	8.64 (5.21; 14.32)	2.18**	0.26	8.82 (5.29; 14.69)
Physical Impairment	4.03**	0.63	56.47 (16.56; 192.63)	4.00**	0.65	54.61 (15.14; 197)
Asleep/Fainted/Fatigued	-0.80	0.84	0.45 (0.09; 2.34)	-1.20	1.02	0.30 (0.04; 2.24)
Illness	1.46	0.87	4.30 (0.79; 23.44)	1.09	1.04	2.98 (0.39; 23)
Driver Residency Distance						
Less than 25 Miles	–	–	Reference	–	–	Reference
Greater than 25 Miles	-0.59*	0.24	0.55 (0.35; 0.88)	-0.61*	0.24	0.54 (0.34; 0.87)
Vehicle Age						
Less than 5 years	–	–	Reference	–	–	Reference
5 to 15 years	0.38	0.27	1.47 (0.87; 2.46)	0.40	0.27	1.49 (0.88; 2.52)
More than 15 years	0.76*	0.35	2.15 (1.09; 4.23)	0.77*	0.35	2.15 (1.08; 4.29)
Vehicle Damage						
Minor/None Visible	–	–	Reference	–	–	Reference
Major Not Disabled	0.27	0.39	1.31 (0.54; 3.28)	0.26	0.40	1.30 (0.55; 3.33)
Major and Disabled	1.51*	0.37	4.53 (2.25; 9.08)	1.50*	0.38	4.49 (2.26; 9.15)
Vehicle Towed?						
No	–	–	Reference	–	–	Reference
Yes	0.96*	0.41	2.61 (1.17; 5.83)	0.95*	0.42	2.58 (1.14; 5.83)

CU Driver Airbag Status						
Not Deployed	–	–	Reference	–	–	Reference
Deployed	1.09**	0.25	2.99 (1.83; 4.87)	1.11**	0.25	3.04 (1.86; 4.97)
Roadway Condition						
Dry	–	–	Reference	–	–	Reference
Wet	-0.98**	0.35	0.37 (0.19; 0.75)	-1.04**	0.36	0.35 (0.18; 0.72)
Intercept	-8.68**	0.68	–	-8.93**	0.71	–
Number of Observations:	57,132			57,132		
LL at Convergence:	-472.983			-506.042		
Wald χ^2 (31)	336.700			367.980		
Prob> χ^2	0.000			0.000		
AIC	1,009.97			1,076.08		
BIC	1,296.47			1,362.58		
Notes: ** Significant at the 99% confidence interval * Significant at the 95% confidence interval						

significant characteristics. Firth's penalized-likelihood logistic regression was used to analyze the data because, due to the small sample size, this method can handle any possible biases.

Table 2 shows results of Firth's logistic regression and a standard binary model. As shown in the table, the odds ratio (OR) was greater than 1, indicating wrong-way crashes are more likely to have defined characteristics. Identified characteristics included drivers 65 years or older, physically impaired drivers, drivers under the influence of drugs or alcohol, evening or dark driving conditions, and older vehicles. Wrong-way crashes typically resulted in airbag deployment and major damage to the primary vehicle, resulting in towing after the crash. In addition, wrong-way crashes most often occurred in March, May, or November on dry pavement.

Zhou et.al. (2012) investigated the contributing factors of wrong-way crashes on freeways in Illinois. The research team analyzed historical crash data collected from 2004 to 2009. Of 632 wrong-way crashes, the analysis identified 217 wrong-way crashes. Statistical analysis methods such as Casual Tables, Haddon Matrices, and significance tests to a 95% confidence level determined that factors such as alcohol and drug impairment, driver age, day of the week, month, time of the crash, and light conditions contributed significantly to wrong-way crashes. Results also showed that weather conditions were not significant. Factors such as alcohol, elderly drivers, male drivers, and nighttime crashes were overrepresented in wrong-way crashes compared to all crashes in Illinois. The research team selected twelve interchanges from the evaluated data (including information provided by Illinois state police) for further evaluation. Field investigation of each interchange included on-site identification of signs, including sign condition and location, the presence of pavement markings, pavement marking conditions, as well as geometric configurations and additional signage or markings needed due to those configurations. The research team developed a checklist for wrong-way crashes and a method to identify the most likely entry point for a wrong-way crash, as shown in **Figure 3**.

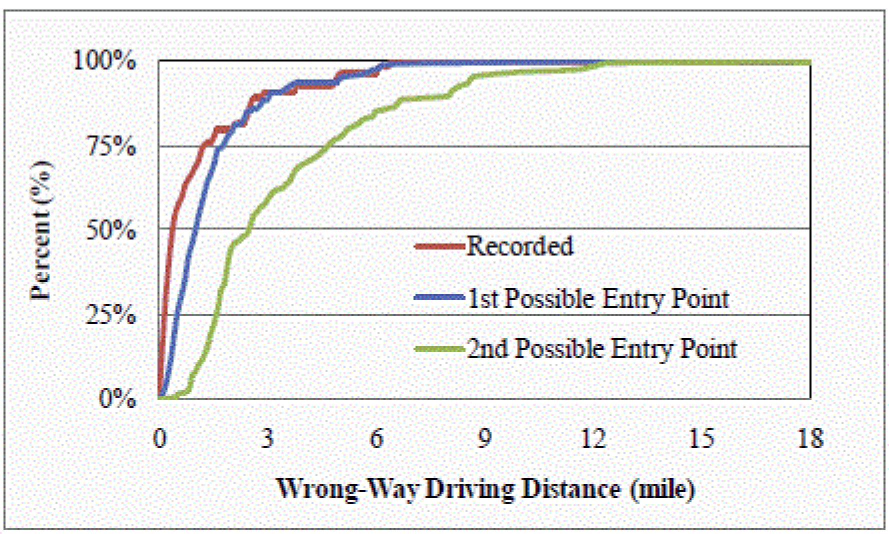


Figure 3: Accumulative distribution for wrong-way driving distance (Zhou, 2012)

Figure 3 illustrates the closest entry point and the second closest entry point for wrong-way crashes with no recorded entry point (ramp). Measuring the distance from the crash as specified by the crash report to the two entry points, researchers plotted the distance versus the percentage of vehicles driving that distance. They also graphed wrong-way crashes with recorded entry points on the same graph. Also shown in **Figure 3**, the recorded entries and estimations of the first possible entry were nearly identical. Using the mean distances between entry points, the recorded mean was found to be 1.2 miles and the mean for the first and second estimated entry points was 2.5 miles.

The NTSB (2012) provided several safety recommendations to prevent wrong-way crashes on interstates. These recommendations were based on the investigation of nine wrong-way crash studies in the United States. The first study, conducted in Baker, California, in 1968, involved 20 fatalities and 11 injuries. The second study, conducted in Dulles, Virginia, in 1970, involved two fatalities and 14 injuries, and the third study, conducted in Carrollton, Kentucky, in 1988, involved 27 fatalities and 35 injuries. All three studies involved passenger vehicles that struck buses, thereby accounting for the large number of fatalities and injuries. In addition to these studies, the NTSB investigated six studies that occurred during 2011 in Texas, Colorado, Wisconsin, Pennsylvania, and Nevada, with fatalities ranging from zero to three. They used the data collected to perform basic statistical analysis to determine wrong-way crash characteristics. The small sample size of nine crashes, however, prevented conclusion certainty with respect to percentages of alcohol-impaired drivers, time of day, and day of the week. One significant finding determined that, despite the small sample size, seven of nine crashes occurred in lanes closest to the median.

The Institute for Road Safety Research (SWOV) issued a fact sheet that summarizes data from wrong-way driving research in the Netherlands (2009). In 2004, the Ministry in charge of Road Accident Registration (VOR) changed their coding system to eliminate the designation of wrong-way driving, making determination of the exact number of wrong-way crashes more difficult. Using keywords to search for wrong-way crashes in years prior to 2004 revealed only approximately one-half of wrong-way driving crashes coded in VOR. Data from 1983 to 1998 showed that approximately 103 wrong-way crashes were analyzed with respect to age and driving under the influence. Research showed that younger drivers and older drivers were the highest at-risk groups for wrong-way driving, and younger drivers operating vehicles under the influence of alcohol was identified as a significant factor.

Kittelson & Associates Inc. (2015) conducted a wrong-way driving crash study for freeways and expressways in Florida. They used historical crash data to identify 6,300 potential wrong-way crashes that the research team analyzed and reduced to 280 actual wrong-way crashes from the years 2009 to 2013. Utilizing statistical analysis, the researchers identified several significant factors in wrong-way crashes, including alcohol and drug impairment, weekends and early mornings, and young and old drivers. They used a system to weight interchanges and assign a score for each wrong-way crash identified. Summing the scores for each crash by the type and location, they determined an overall score for each interchange design and interchange type. Results showed that diamond and/or partial diamond interchanges and partial cloverleaf interchanges had the highest scores, while the full cloverleaf interchange had the lowest score.

Braam (2006) investigated wrong-way crashes on freeways in North Carolina. This study was developed in response to a series of high-profile wrong-way crashes in Charlotte, North Carolina, during a six-month period. The purpose of the study was to identify characteristics of wrong-way crashes, determine the magnitude of the problem, highlight particular areas of concern, and recommend possible countermeasures. The study utilized data from crashes that occurred from 2000 to 2005, and statistical analyses were conducted to investigate significant factors. This study specifically investigated variables such as presence of alcohol, age, and race. Investigation of driver familiarity was attempted, but the research team found that variable difficult to quantify and did not present results in the study. The study also briefly investigated interchange type, but limited information was presented and information from another study in California was primarily cited (Copelan, 1989). When investigating North Carolina interchanges, however, the research team found that, in the nine counties with the most wrong-way crashes (101 out of 162 crashes), the interchanges in those counties were evenly split between full and half diamond and cloverleaf interchanges. Over 95% of wrong-way crashes in the rest of the counties occurred on interstates near diamond interchanges. Despite this disparity and because no information was available on the exact entry point, the conclusion was made that interchange geometry was not to blame for wrong-way crashes. The research team investigated wrong-way countermeasures based on crash analysis, including embedded sensors, video detectors, flashing lights, spikes, and other roadway barriers. However, the only countermeasures recommended enhanced the state's anti-drinking and driving program. Lastly, the study did not recommend countermeasures due to their high cost of installation and maintenance.

Although only limited statistical investigations have been conducted, impaired driving was a common characteristic among the studies, and several reports identified characteristics of weekends and nighttime/early mornings. Age was another significant variable in several studies, particularly old and young drivers. Although variables appeared to be similar between studies, there were studies performed in only three states. Further studies must be performed to investigate if these statistics were isolated or consistent throughout the United States.

2.4 Wrong-Way Driving Countermeasures

A majority of research on wrong-way crashes has centered on countermeasures, or actions taken to counter a dangerous situation. For wrong-way crashes, countermeasures can include changing sign size, location, and orientation or adding or changing pavement markings. Countermeasures can also include altering the layout or geometry of the interchange to help prevent wrong-way driving incidents. All these methods are discussed in the following literature review.

Zhou et al. (2014) summarized the proceedings from the first National Wrong-Way summit hosted by Southern Illinois University in 2013. The summit was an opportunity for transportation engineers from 23 states to exchange ideas, evaluate current countermeasures, and develop plans to reduce wrong-way driving incidents. The conference consisted of presenters from various states as well as the NTSB and the FHWA. Groups discussed implemented countermeasures and other issues pertaining to wrong-way crashes. A final presentation summarized groups' findings and organized a chart based on the 4 E's: engineering, education, enforcement, and emergency response.

Engineering recommendations were categorized as signing, pavement markings, roadway geometric improvement, and intelligent transportation systems (ITS). Signing improvements included lowering the sign height, installing oversized signs, using multiple signs on the same post, and using red retroreflective tape on the vertical posts of signs. Stop bars, wrong-way arrows, raised pavement markers, and dashed lane lines to delineate through turns were found to be effective pavement marking types. Alteration of highway ramp geometry, installation of longitudinal channelizer, entrance/exit ramp separation, and elevation of curb medians were effective geometric improvements. Effective ITS technologies included LED illuminated signs, dynamic message signs to warn other drivers, and use of existing GPS navigation technologies to provide wrong-way incident alerts. Targeted enforcement programs included DUI enforcement, dynamic message signs to warn drivers, and portable spike barriers to stop wrong-way drivers. Continued efforts to raise public awareness of basic road designs and interchanges as well as provide strategies for responding to a wrong-way driver were effective educational outreach strategies. The summit summary also suggested that countermeasures and targeted enforcement programs should focus on older drivers, young drivers, and drivers under the influence.

Pour-Rouholamin et al. (2015) used a survey conducted at the first National Wrong-way Driving Summit investigate wrong-way driving countermeasures. Ten countermeasures from five state highway agencies in the United States were reported. Using statistical analyses, the researchers determined trends, drew conclusions, and offered effective engineering solutions such as adding a second sign and increasing sign size. Lowering mounted signs resulted in an approximate 90% reduction in wrong-way driving incidents in California, and adding LEDs to WRONG WAY and DO NOT ENTER signs resulted in an approximate 30% reduction in wrong-way driving incidents in Texas. Pavement marking applications and improvements to problematic locations resulted in an approximate 40% reduction in wrong-way driving incidents in Texas.

Vaswani (1977) reviewed wrong-way incidents and crashes on Virginia highways between 1970 and 1976 using police reports to summarize crash information. These reports were sorted into six-month increments to show temporal trends and identify sections of highways and ramps for further investigation. Approximately 114 wrong-way crashes occurred along divided highways in Virginia, and 167 other crashes occurred during the same period at the studied locations. The Virginia Department of Transportation implemented engineering countermeasures to address wrong-way crashes, including reflectorized pavement arrows on ramps, stop lines on exit ramps, and continuation of pavement edge lines. During the study, wrong-way incidents decreased by approximately 50% on interstate highways and approximately 70% on non-interstate divided highways. The researchers found that the reduction in wrong-way incidents resulted from implemented engineering countermeasures, and they recommended expanding implementation of the countermeasures to other highway ramps.

Pour-Rouholamin et al. (2015) investigated traditional access management techniques to reduce wrong-way driving incidents. The investigation included reviewing interchange configurations, access control and geometric designs. Interchanges were evaluated for design consistency using the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets*, which presented several design configurations that were susceptible to wrong-way driving incidents, including the partial cloverleaf interchange, left-side exit ramps, exit ramps intersecting two-way frontage roads, and isolated exit ramps. Interchanges were evaluated for access management strategies and roadway geometric elements used to reduce potential wrong-way driving incidents. Countermeasures recommended in this study included raised medians for left-turning access exit ramps, channeled islands to narrow multilane exit ramps, and sufficient open-sight distances to help drivers distinguish exit ramps from entrance ramps.

Finley et al. (2014) investigated the effectiveness of wrong-way driving countermeasures and mitigation methods in Texas. Countermeasure effectiveness was evaluated using two closed-course driving studies to investigate how alcohol effects a drivers sign readability and where intoxicated drivers tend to glance when driving. The researchers evaluated 30 drivers using eye trackers to collect data of eye glances when signs were placed along the course. Each driver drove through the course on two separate occasions. Both studies were conducted at night with drivers with various blood alcohol content (BAC) levels. The first test was conducted with a BAC level of 0.00 g/dL, and on the next occasion the drivers went through the course three times with BAC levels of 0.12 g/dL, 0.08 g/dL and 0.04 g/dL, respectively. Study results showed that intoxicated drivers tend to glance towards the front and ground more than to the sides.

The second closed-course study evaluated physical features of the signs, including height, size, and red retroreflective tape variations on the pole of WRONG WAY signs and signs with and without LED illumination. Researchers also evaluated two types of arrows on pavement marked with red reflective raised markers. In addition to sign and arrow variations, other signs and arrows were installed in the closed course to distract drivers during the driving test. Results of the second study showed that the most noticeable signs were oversized or normal-sized with red retroreflective tape on the sign pole or signs with LED illumination. Results also showed that lowering the height of normal-sized signs was not as effective as other countermeasures.

Finally, data collected from before and after installation of the countermeasures were compared. Analysis results showed that a variety of countermeasures are needed to positively impact a driver and even multiple countermeasures may not influence intoxicated drivers. The researchers also recommended that wrong-way driving detection systems may be beneficial to traffic management centers to identify and respond quickly to wrong-way drivers.

Cooner et al. (2004) documented recommended guidelines for countermeasures on Texas highways. In order to recommend the most efficient countermeasures, researchers conducted a review of literature, surveys, and evaluations of countermeasures. They also analyzed wrong-way crashes on Texas freeways, and commonalities between areas of concern were determined and countermeasures were recommended based on a basic analysis. The researchers developed a checklist for reviewing interchanges and ramps for potential wrong-way driving. The checklist, developed specifically for suspected areas of concern or issues stemming from wrong-way incidents, covered topics such as the presence, condition and type of signs, as well as the visibility of the signs from interchange entrance, in both daytime and nighttime. Other notes on the interchanges included local businesses and geometry at the interchange.

Simpson et al. (2015) studied wrong-way crashes in Arizona using crash data from the years 2004 to 2014. Approximately 245 wrong-way crashes were identified during these years. Using statistical analyses, they identified significant characteristics of wrong-way crashes, determining that approximately 65% of wrong-way drivers in Arizona were impaired, a percentage similar to the national statistic of 60%. The study then investigated ways to detect wrong-way drivers and notify other drivers and alert authorities. This detection system incorporated three elements: detection, notification and monitoring, and driver information. Several methods of each element were discussed, and a program was developed to evaluate the various methods.

Pi-Sung et al. (2016) evaluated the effectiveness of red rectangular rapid flashing beacons (RRFB) at various sites in Florida. They analyzed 1173 wrong-way crashes from 2003 to 2014, with more than half of the crashes occurring at night or in the early morning. Since yellow flashing beacons have been shown to successfully alert drivers to pedestrians, they tested the effectiveness of red flashing beacons on WRONG WAY signs. The research team designed a scenario using nine combinations of signs and lights, four illumination levels, and two off-ramps. The scenarios were tested by closing the ramps and filming each setup at night. The scenario was explained to a total of 296 participants, evenly split between male and female with an age distribution similar to the age distribution in the area. The participants were shown the different videos, and then they were asked a series of questions about what they saw. The setup found to be most effective at gaining a driver's attention incorporated wrong-way signs on both sides of the road and RRFBs on the top and bottom of the signs with maximum illumination.

Zhou et al. (2014) developed a guide for state and local agencies in Illinois to implement countermeasures to reduce wrong-way driving incidents based on previous studies, current practices, and state-level design standards. In addition to published documents and standards, input from members who attended the National Wrong-Way Driving Summit in 2013 were included. The developed guide included tables and figures outlining general considerations and markings with specific guidelines. Each consideration was related to the impact on wrong-way driving, specifically characteristics to look for when considering each option and references to the MUTCD for implementation. The guide also included information for signs and pavement markings as well as the five most susceptible interchanges identified in previous research. These interchanges included partial cloverleafs, diamond interchanges with and without continuous frontage roads, single-point diamond interchanges, and freeway feeders. Interchange geometric designs and guidelines listed as susceptible to wrong-way driving incidents were also evaluated.

Zhou et al. (2015) developed a methodology to evaluate implemented wrong-way driving countermeasures using crash data from the years 2012 to 2013 in Illinois. Countermeasures were deployed at several of the most dangerous interchanges identified by a previous project in 2012. Data collected after placement of the countermeasures in 2013 were compared to data collected before the countermeasures were implemented in 2012. Simple before-and-after analysis of the data revealed an approximate 40% reduction in wrong-way crashes and approximate 13% reduction in fatal wrong-way crashes since implementation of the wrong-way driving countermeasures. Although these decreases are significant, complete implementation of the countermeasures were completed in 2014, so further study was recommended to increase understanding of any reductions.

Boot et al. (2015) used before-and-after analysis to explore the effectiveness of wrong-way crash countermeasures at 64 interchanges in Florida. A Kruskal-Wallis rank sum test was used to compare before-and-after crash data at each site to determine if certain countermeasures were more effective than others. The research team investigated wrong-way driving using a driving simulator with images of entrances and exits obtained from Google Street View and images of diamond and partial cloverleaf interchanges. These images were shown to participants, and they were asked if they were looking at an entrance or exit. While median accuracy for all images was 89.5%, entrance ramps scored higher than exit ramps. The range of accuracy varied greatly between entrance and exit ramps, with entrance ramps varying from 44% to 98% and exit ramps varying from 16% to 100% accuracy.

Vaswani (1975) conducted an effectiveness study of wrong-way driving countermeasures on divided highways in Virginia. Data were collected for 51 months, and the research team surveyed 78 wrong-way crashes and 205 wrong-way driving incidents. With the assistance of the Virginia state police, details of every wrong-way driving incident that occurred during this period were collected and analyzed. Statistical analysis was used to compare before-and-after crash data. The study found that the placement of arrows indicating direction of travel at entrance and exit ramps had a positive effect on crash prevention, particularly when the first arrow was within 5 feet of the stop line. The other countermeasure shown to have a positive impact on crash prevention was a second warning arrow, placed approximately 100 feet away from the first arrow. Continued pavement edge lines and stop lines were also found to be effective in preventing wrong-way driving. The researchers also recommended that placing signs so they are visible under certain conditions (e.g., low visibility/nighttime) may have a positive influence on wrong-way driving.

Copelan (1989) investigated crashes in California in response to a California senate bill requiring a study of wrong-way driving. This study investigated previous solutions (including countermeasures), results of camera surveillance studies, and a current wrong-way driving monitoring program. Researchers also surveyed traffic engineers in other states to determine if new solutions had been developed. The research team recommended ramps be evaluated for missing or worn signs and pavement markings, continuing edge lines, and potential addition of a second set of wrong-way signs and wide bars across off-ramps. Physical barriers were initially considered a countermeasure but later rejected as unsuitable due to ineffectiveness or lack of speed.

Vaswani (1973) conducted a study in Virginia to determine countermeasures to mitigate wrong-way driving on divided highways. Incident data were collected over a 25-month period, and statistical analyses were developed to determine if wrong-way crash incidents had higher percentages of fatal and serious injuries compared to other fatal and serious injury crashes. Several recommendations were developed that emphasized improvements to roadway geometry at interchanges, including elimination of flares on the left side of exit ramps and the addition of physical barriers to prevent right-hand turns onto exit ramps. Other recommendations included the locations of signs, the addition of pavement markings (e.g., stop lines, continued edge lines, and double yellow lines), and development of a method to evaluate ramps for signs and markings.

Messer et al. (1971) investigated wrong-way driving incidents in Texas by surveying engineers and law enforcement agencies. A total of 51 surveys were collected, including 32 from engineers and 19 from law enforcement agencies. Most questions pertained to an individual's response to wrong-way driving rather than an agency's response. A majority of survey results indicated that wrong-way driving is an issue, that the numbers of wrong-way driving incidents remain constant, and that most wrong-way driving incidents involve a driver under the influence. The survey also revealed that, when considering investment of safety funds, respondents were evenly split between engineering, education, and enforcement. A majority of respondents indicated that wrong-way driving incidents and crashes merited additional consideration. When respondents were asked about possible countermeasures, the research team received recommendations for interchange geometric improvements, pavement markings, maintenance and illumination of signage, as well as detection and warning devices.

Tamburri (1965) investigated the effectiveness of an automatic warning system for wrong-way drivers. This system, which was implemented on a single off-ramp on Highway 99 near Sacramento, California, consisted of a 5-foot by 3-foot red sign with white letters that was controlled by an inductive loop in the pavement. The message stated, "GO BACK – YOU ARE GOING – WRONG WAY." In addition to lights that were triggered by a vehicle traveling in the wrong direction, a horn sounded with one continuous blast and one pulsating blast. Finally, a camera captured the wrong-way event and logged the date and time. In addition to the warning system, directional and regulatory signs were modified at the exit point and preceding the off-ramp. The research team collected before-and-after data to determine system effectiveness. Modifying the signs reduced the number of wrong-way incidents by 54%, and the reduction in daylight wrong-way incidents was more than double the reduction in nighttime wrong-way incidents: 73% compared to 35%. Using the light and audio warning system, researchers observed 89% of the drivers stopped and turned around when the alarm sounded, and photos captured of vehicles traveling in the wrong direction allowed the research team to identify and interview several drivers.

Friebele et al. (1971) evaluated the feasibility of a detection and communication system to alert drivers of approaching wrong-way drivers. They studied various methods of mitigating wrong-way crashes used throughout the United States, and they gathered historical crash data on different ramp types to determine locations and designs most susceptible to wrong-way incidents. They concluded that further research into ramp geometry and methods to reduce the numbers of impaired drivers were needed. They also recommended that electronic sensors and warning devices, while occasionally problematic, could be used to warn drivers of impending wrong-way incidents and that technological advances should be monitored to determine if improvements in their performance warrants future implementation.

Simpson (2013) evaluated the effectiveness of wrong-way detection devices on highway ramps by testing six sensors: microwave, two Doppler radars, video imaging, thermal sensors, and magnetic sensors. Each type of sensor was placed on a ramp, for a total of six ramp sites. Vendors installed each sensor and ran the control tests to ensure each sensor was operating properly prior to data collection. After several months of operation, control tests were executed at each ramp to determine the effectiveness of each sensor under varying conditions. Testing recreated typical driver actions, such as driving straight in lanes, and impaired driver actions, such as weaving back and forth across the lanes. Each sensor was rated based on its ability to detect wrong-way movements, notify authorities, video record each incident for verification, and visibly warn drivers of a potential wrong-way entry. The sensors were also evaluated during 14 test runs for their ability to detect false positives. The researchers affirmed the effectiveness of systems that detect and warn wrong-way drivers and recommended steps to ensure the most appropriate system is used for each interchange.

Parsonson (1979) used cameras to evaluate wrong-way traffic incidents on 44 freeway ramps in Atlanta, Georgia. They concentrated on ramps known to have wrong-way incidents, including half diamonds, partial cloverleafs (parclo), and parclo AB loop ramps. The research team concluded that considerable effort should be spent on roadway signage, lighting, geometric design improvements, and pavement markings to warn drivers if they are traveling in the wrong direction. The research team recommended inexpensive and effective countermeasures such as using trailblazer signs, lowering the height of WRONG WAY and DO NOT ENTER signs, and adding stop lines to exit ramps and arrows to off-ramps. They also concluded that half-diamonds, parclos, and parclo AB loop ramps may be more susceptible to wrong-way driving incidents than other interchanges. They chose eight ramps for further testing with countermeasures. Countermeasures such as the addition of signs, pavement markings, and stop lines were phased in over a period of one year. Only one of the eight ramps failed to show improvement.

Scifres (1974) investigated wrong-way crashes on rural divided highways in Indiana. Data from Indiana state police records yielded 96 wrong-way crashes from 1970 to 1972. Based on the collected data, the researcher conducted field investigations to determine the most probable entry point for wrong-way drivers. A statistical analysis showed that wrong-way crashes typically occurred on weekends and in areas and times of day with low visibility. The results showed a significant number of intoxicated drivers at the time of the crashes. The researcher concluded that diamond and parclo interchanges could be targeted for countermeasure installation or enhancement to reduce the number of wrong-way driving incidents.

Tamburri et al. (1965) conducted follow-up research for the study “Wrong-Way Driving Incidents on Limited Access Divided Highways” (Gay, 1963). Reports of approximately 1200 wrong-way driving incidents from the California highway patrol revealed that incidents of wrong-way driving increased after the installation of enhanced signing and pavement markings implemented in the study by Gay (1963). The exception was that wrong-way driving incidents decreased during daylight hours at off-ramps and at-grade intersections where large directional arrows were installed. Physical barriers were tested and found to be ineffective or inadequate. To be effective, physical barriers should totally disable the vehicle in a safe manner or remove it from the road.

The California Department of Transportation (Caltrans) (2016) submitted research study results to the California state legislature on the prevention of wrong-way crashes. This report provided data updates for the wrong-way driving report, “Prevention of Wrong-Way Accidents on Freeways” (Copelan, 1989). Data collected since the 1989 report showed a reduction of fatal wrong-way crashes from 0.4 fatal crashes per billion vehicles miles traveled (BVMT), to 0.13 fatal crashes per BMVT. This works out to an average of 35 fatal crashes per year in 1989 year reduced to an average of 23 fatal crashes per year in 2013. Data analyzed on wrong-way crashes from 1989 to 2015 showed a steady downward trend of wrong-way crashes, while vehicle miles traveled (VMT) increased by 26%.

Rogers et al. (2014) investigated wrong-way crashes on the Central Florida toll road network. Data were collected from hard copy crash reports from 2003 to 2012, wrong-way driving citation data from 2010 to 2012, 911 call center data, and a toll road customer survey. A statistical model was developed to establish a ranking system for various roads based on number of crashes, severity of crashes, 911 calls, and police citations. The research team concluded that a further investigation was needed to evaluate countermeasures.

Estep (1972) investigated wrong-way driving crashes from 1961 to 1972 and summarized current state-of-practice countermeasures such as signing changes, automatic warning signs, lights, and a horn. Data were collected from all California wrong-way crashes in 1971 and statistically compared to previous data. The ramp surveillance program was noted as one of the most successful programs. Using pneumatic road tubes, the study investigated approximately 800 ramps in California. Data analysis showed that over 60% of the ramps registered no wrong-way incidents and 6% reported greater than 6 incidents per month, allowing Caltrans to target wrong-way countermeasures at high-risk ramps. The study also provided wrong-way crash prevention recommendations such as periodic inspections of all ramps in daytime and nighttime conditions, maintenance of traffic control devices, and camera surveillance at high-risk locations.

Overall, there was a large breadth of research on wrong-way driving. The first research was conducted in the 1960's and has increased in the last decade. There was limited research conducted on ramps and interchanges as well as limited research into the causes of wrong-way driving. There are also a limited number of states, less than 25% that have conducted any research into wrong-way crashes. Almost all of the research available is on the effectiveness of countermeasures. While research is limited on vehicle detection, this is mostly due to the limited technology available. The breadth of the research that has been conducted on intervention countermeasures such as signs, pavement markings and sign illumination.

3. METHODOLOGY

3.1 Wrong-Way Crash Data

Wrong-way crash data from the Kansas Crash and Analysis Reporting System (KCARS) were uploaded from physical accident reports completed by law enforcement personnel for the Kansas Law Enforcement Reporting (KLER) system. Law enforcement personnel currently use KDOT Form 850A Rev 1-2009, and **Figure 4** illustrates the heading and part of the information entered at the crash site.

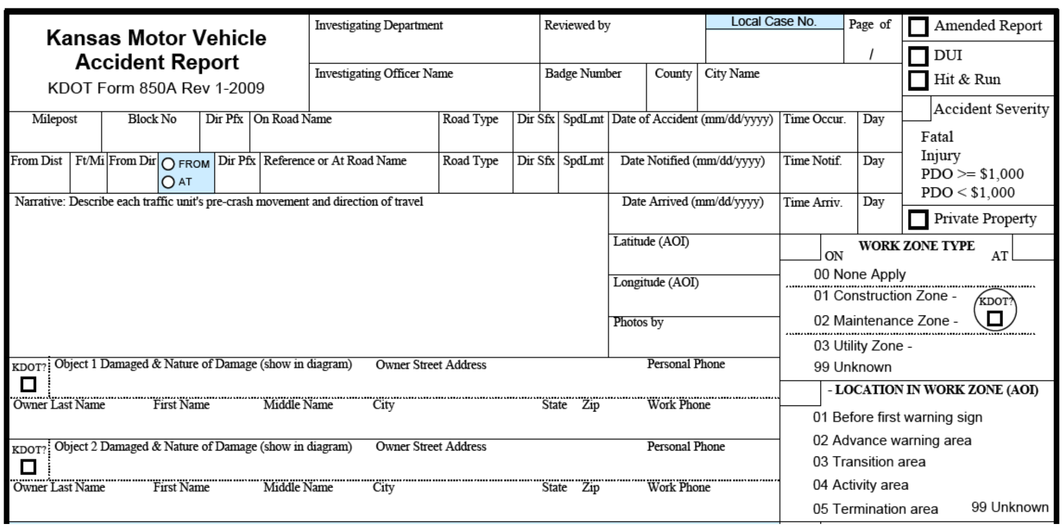
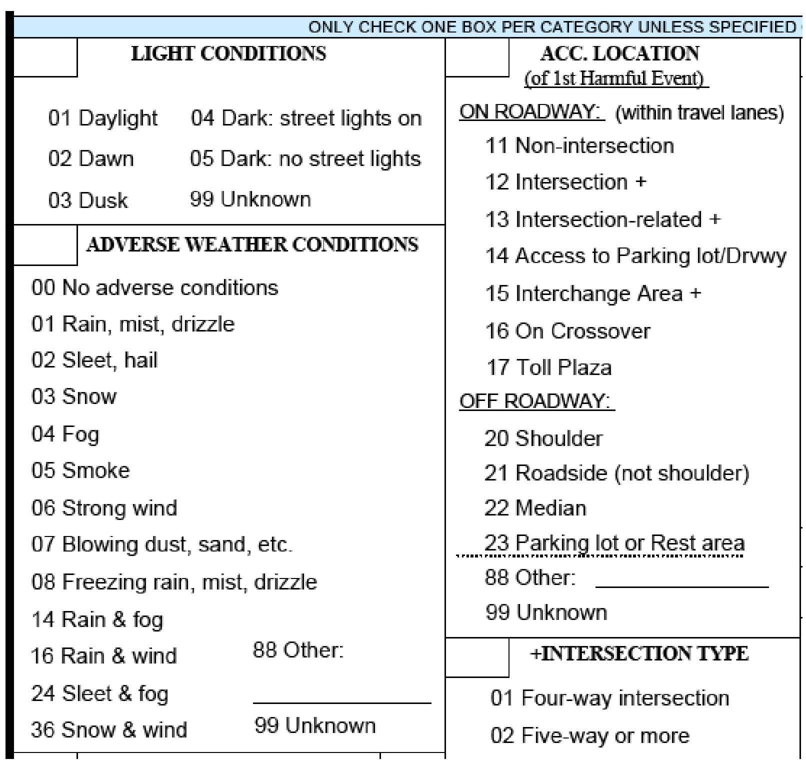

Kansas Motor Vehicle Accident Report
KDOT Form 850A Rev 1-2009
Investigating Department | Reviewed by | Local Case No. | Page of /
Amended Report
Investigating Officer Name | Badge Number | County | City Name
DUI
Hit & Run
Milepost | Block No | Dir Pfx | On Road Name | Road Type | Dir Sfx | SpdLmt | Date of Accident (mm/dd/yyyy) | Time Occur. | Day
Accident Severity
Fatal
Injury
PDO >= $1,000
PDO < $1,000
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
Private Property
Latitude (AOI)
Longitude (AOI)
Photos by
ON | WORK ZONE TYPE | AT
00 None Apply
01 Construction Zone -
02 Maintenance Zone -
03 Utility Zone -
99 Unknown
KDOT?
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
- 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
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

Figure 4: Kansas Motor Vehicle Accident Report

The entire accident report form consists of twelve pages of selectable options, drawings, and crash information. Recorded data describes occupants of all vehicles involved in the crash, extensive information about each vehicle, and relevant environmental and external conditions. Crash reports are updated once tests are performed and information becomes available. The accident report is then converted to an Excel/Access file for ease of sorting. Conversion from handwritten notes to electronic format is performed by personnel within the Kansas prison system, allowing opportunity for possible interpretation discrepancies even if care is taken to avoid mistakes.

A coding manual with explanations and illustrations for possible crash scenarios attempts to standardize how law enforcement officers complete the crash form. For each section of the report officers are instructed to select the option that best applies at the time of the crash, often relying on the officer's judgment. **Figure 5** illustrates options for three categories used in this study. Although the options for light conditions are self-explanatory, definitions for adverse weather conditions are included in the coding manual. **Figure 5** also shows seven combinations of precipitation depending on outdoor temperature. Possible inconsistencies may arise as each police officer may view similar weather conditions differently. For example, the option of "strong winds" requires officer judgment since determination of actual wind speed at the time of the crash is impossible and no set value determines strong wind.


ONLY CHECK ONE BOX PER CATEGORY UNLESS SPECIFIED

LIGHT CONDITIONS

01 Daylight
02 Dawn
03 Dusk
04 Dark: street lights on
05 Dark: no street lights
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
24 Sleet & fog
36 Snow & wind
88 Other:
99 Unknown

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

Figure 5: Codes for Light Conditions, Adverse Weather Conditions and Accident Location

Crash location has an extensive listing in the coding manual, including diagrams of example situations. For example, diagrams illustrate the boundaries of an intersection and interchange. The manual also helps define “intersection-related,” although that term is also based on police officer judgment to determine if traffic flow through an intersection was related to the crash. The manual also includes descriptions for crashes in or near parking lots, driveways, and toll plazas. Interchanges are restricted to entrances with various grades for the highway and crossroads, specifically excluding at-grade intersections. A crossover, defined as a small section

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

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
- 13 Mirrors
- 14 Unattended or driverless in motion
- 15 Unattended or driverless not in motion

Figure 6: Accident Code Sheet Contributing Circumstances

of paved road linking two directions of a divided highway that does not have an at-grade intersection, is often coded incorrectly when areas where one highway passes over another are included. **Figure 6** shows the section for coding contributing circumstances for crashes. The section "Driver action at the time of crash" is enlarged in **Figure 7.**

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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

Figure 7: Driver's actions at time of crash

Crashes coded as "47" in **Figure 7** are considered wrong-way crashes in Kansas, but this option could also be selected for crashes that are not wrong-way crashes. A vehicle that is involved in a crash on the wrong side of the road is not necessarily traveling in the wrong direction.

A preliminary study revealed a significant number (over 50%) of wrong-way driving crashes on state highways that lack a median or barrier between travel lanes. Wrong-way driving crashes on two-lane non-divided highways typically occur when a vehicle drifts over the centerline, begins a passing maneuver, or other events not related to traveling in the wrong direction on a highway. This research investigated only crash data from freeways to eliminate the influence of these driver errors as they relate to vehicle crashes. An initial scan of three years of crash data indicated a limited number of crashes on freeways, so additional data were extracted and a final data set was developed for years 2005 to 2015. Initial investigation of the final dataset also found crashes that occurred on divided highways with at-grade intersections and as well as those with ramps and interchanges. Divided highways with at-grade intersection entrances were a small subset of the data, so at-grade wrong-way crashes on divided highways were not included because these intersections have differing geometric characteristics and operations than divided highways with ramps and interchanges.

Crash data were uploaded to ArcMap in order to spatially locate and visualize each crash and determine visually if natural spatial patterns occurred in the data. **Figure 8** shows a map of Kansas with spatially located wrong-way crashes; **Figure 9** shows fatal and injury wrong-way driving crashes in Kansas, with a single dot (or data point) representing one crash record. As shown in both figures, the largest percentage of wrong-way crashes occurred in clusters in the southern and eastern portions of Kansas in large metropolitan areas, specifically Kansas City and Wichita, the two most populated urban areas in the state. Smaller clusters of wrong-way driving crashes were also evident west of the Kansas City metropolitan area near Topeka, Manhattan, and Salina (moving east to west in both figures). The figures also clearly illuminate the high number of wrong-way crashes along Interstate 70, the main east-west interstate across Kansas. Other interstates in Kansas with reported wrong-way driving crashes include Interstates 35 and 335, which connect Kansas City and Topeka to Wichita, and Interstate 135, which runs north-south from Wichita through Salina. Less than 20 wrong-way crashes were identified outside of these interstate routes.

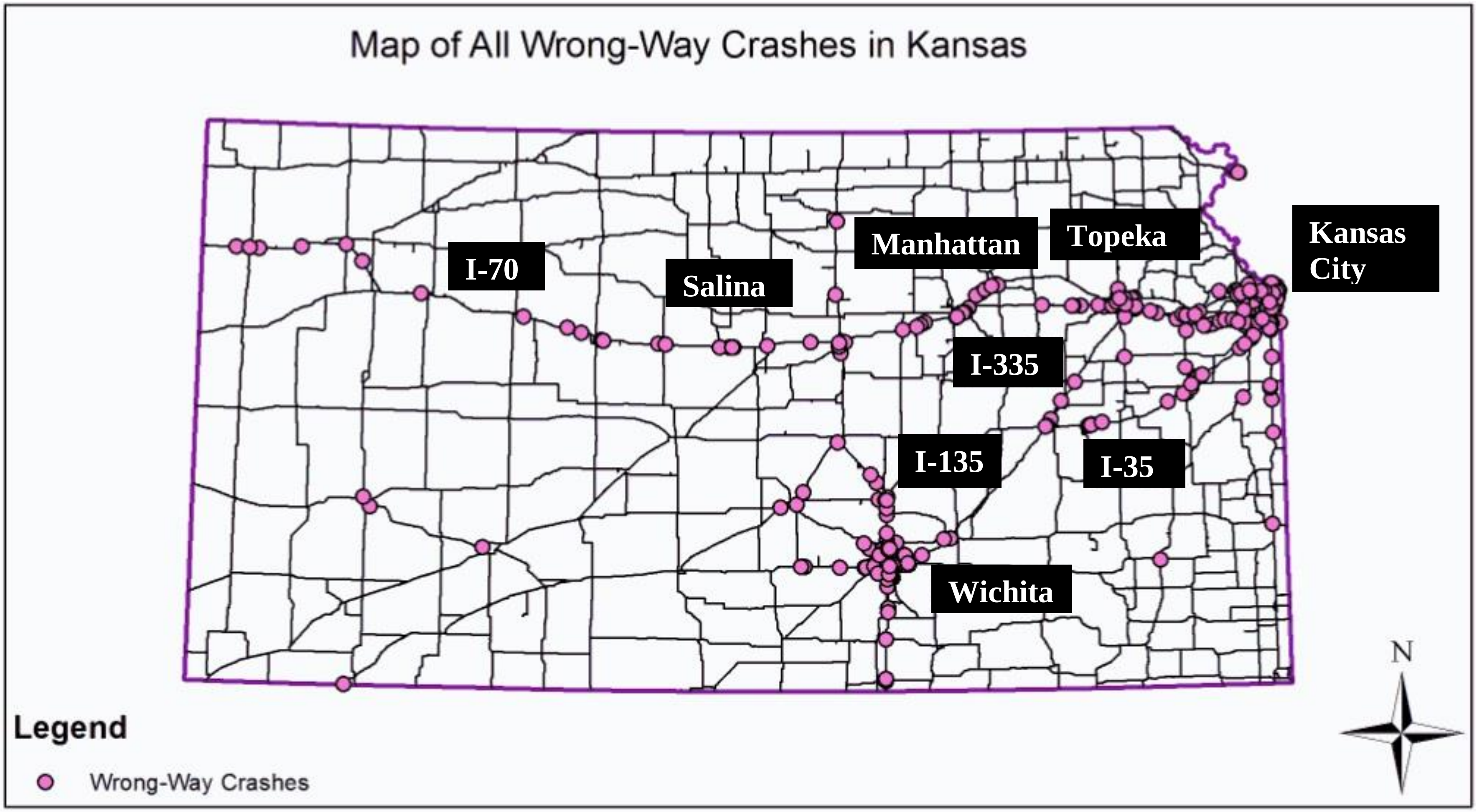


Figure 8: Map of all Wrong-Way Crashes

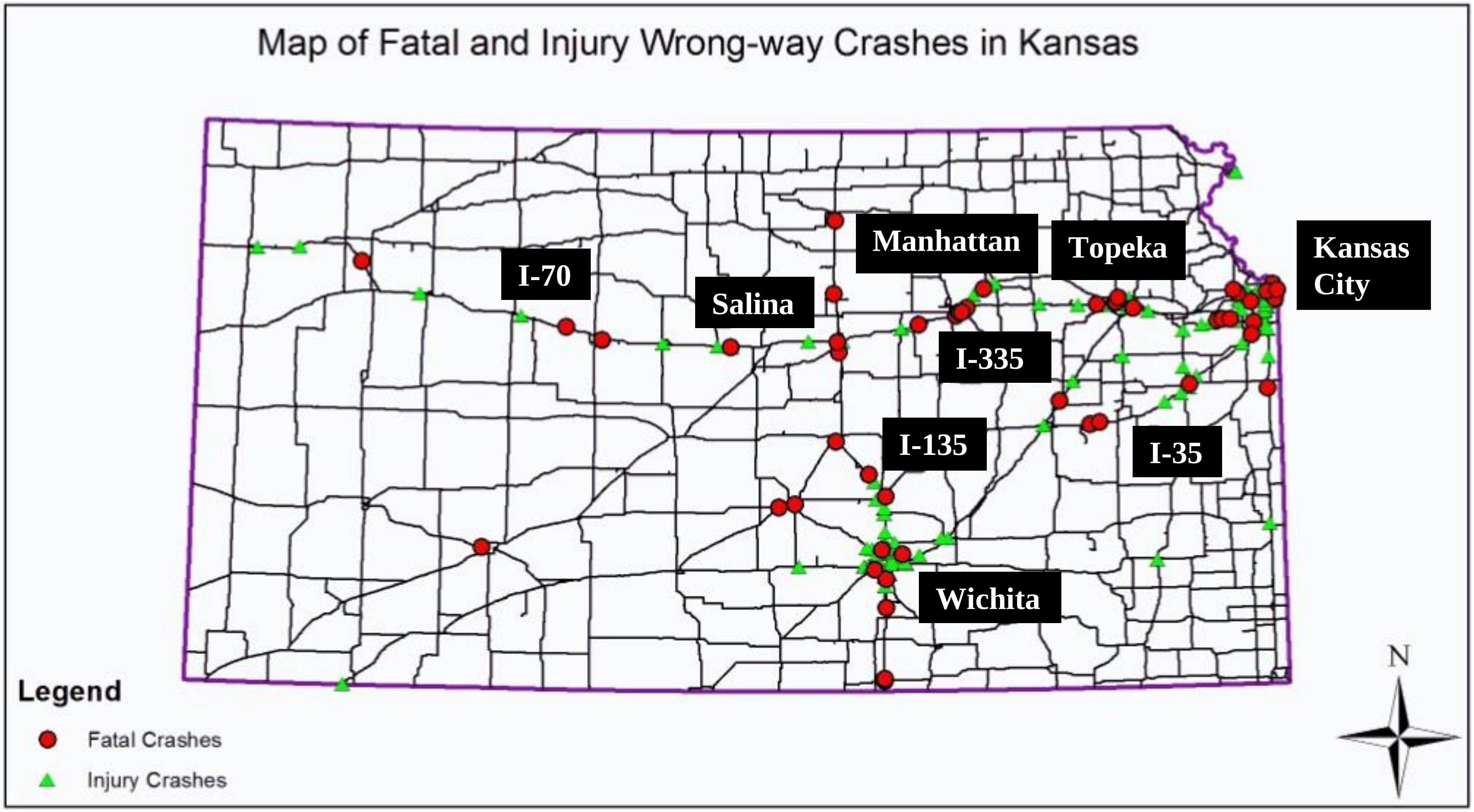
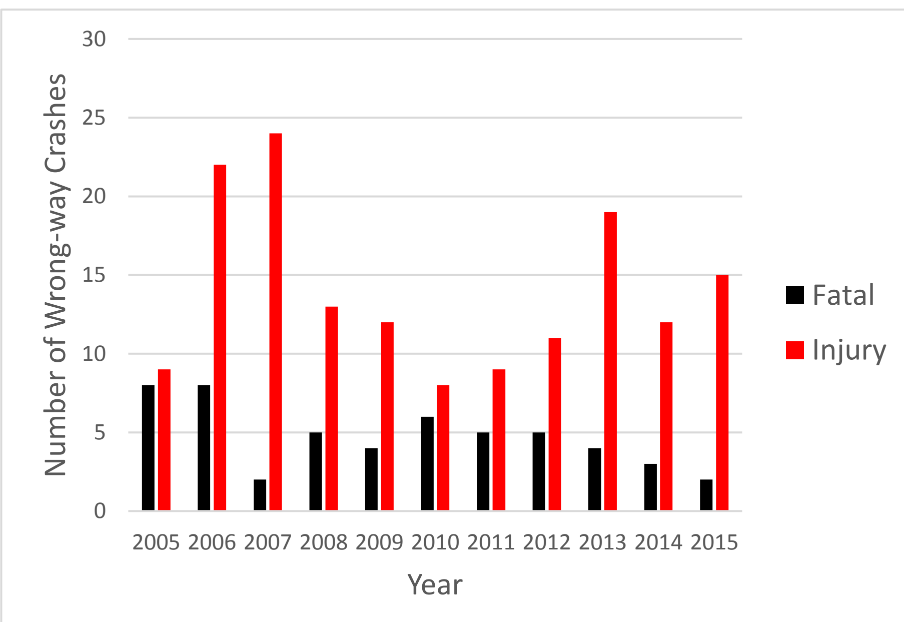


Figure 9: Map of all Fatal and Injury Crashes

3.2 Descriptive Statistics

A final dataset of wrong-way driving crashes on divided highways in Kansas included 372 crashes that occurred between 2005 and 2015. Initial data evaluation showed that the total number of crashes was comprised of approximately 52 fatal crashes (13.9%), 154 injury crashes (41.3%), and 166 property damage only (PDO) crashes (44.6%). Approximately 55% of the wrong-way driving crashes investigated resulted in a fatality or serious injury. Fatal and serious injury crashes accounted for approximately 22% of all crashes in Kansas (Kansas, 2015) and approximately 27% of all crashes in the United States (NHTSA, 2014), meaning that, although wrong-way driving crashes are less common than other types of crashes, consequences of wrong-way driving crashes can be more serious than other crashes. **Figure 10** shows the relationship between fatal and injury crashes and the total number of serious crashes in Kansas between 2005 and 2015.



Year	Total No. Wrong-way Crashes
2005	47
2006	56
2007	48
2008	39
2009	33
2010	21
2011	25
2012	24
2013	30
2014	22
2015	27

Figure 10: Fatal and Serious Injury Wrong-way Crashes and Total Wrong-way Crashes by year

As shown on the left side of **Figure 10**, temporal trends of fatal and serious injury wrong-way crashes demonstrate an overall decrease in the number of crashes. In the figure, however, when fatal crashes reach a minimum, serious injury crashes reach a maximum, and as fatal crashes increase to the maximum, serious injury crashes decrease, reaching a low point for serious crashes while reaching a maximum point for fatal crashes. Fatal crashes then decline again, but serious injury crashes climb. Despite the increase and decrease of fatal and serious injury wrong-way driving crashes, the total number of serious crashes remained somewhat constant between 2005 and 2015, ranging from a minimum of 14 crashes to a maximum of 30 crashes. The overall average number of serious injury crashes was approximately 19 crashes per year, and the average number of wrong-way driving crashes was 34 crashes per year.

According to the National Highway Traffic Safety Administration (NHTSA), since 1996 the percentage of serious crashes has decreased nationally from approximately 33% to 28% (NHTSA, 2104). The overall trend of wrong-way crashes in Kansas was similar to the overall NHTSA trend, with an overall decrease in wrong-way driving crashes declining from 47 wrong-way driving crashes in 2005 to 27 wrong-way driving crashes in 2015.

Additional descriptive statistics of the wrong-way driving crash dataset from 2005 to 2015 are shown in **Figure 11**. **Figure 11(a)** shows weather conditions during each wrong-way driving crash. As shown, most wrong-way driving crashes in Kansas, 324 crashes or 87%, occurred under no adverse weather conditions. Although the absence of adverse weather conditions for this high percentage of wrong-way driving crashes may seem implausible since adverse weather such as fog, rain, or snow may hinder driver visibility of ramps or traffic controls, crash data from Kansas agrees with NHTSA findings that state that approximately 86% of wrong-way driving crashes occurred under no adverse weather conditions (NHTSA, 2014).

Figure 11(b) shows the roadway location of each crash, indicating that approximately 60% of wrong-way driving crashes occurred at non-intersections or a location not in proximity to entrance or exit ramps, thereby proving that drivers involved in wrong-way driving crashes pass existing ramp regulatory signs and travel the wrong direction on the freeway away from the interchange. Unfortunately, the further a driver operates a vehicle in the wrong direction, the greater the chance of encountering an opposing vehicle and the more time and distance required for police and/or Emergency Medical Services (EMS) to intersect the vehicle or respond to a serious crash. Although it often cannot be quantified, many drivers could have realized they were traveling in the wrong direction, corrected the direction of the vehicle, and proceeded safely on the freeway in the correct direction without incident. As stated in the literature review, wrong-way driving detection is essential in order to identify potential ramps and interchanges for countermeasure deployment.

Figure 11(c) shows the crash data light condition observed by the police officer at the crash site. Due to the limited crash data set size, “dawn, dusk, and unknown” light conditions were combined into one category, as displayed on the far-right bar of the graph. As shown, the numbers of crashes for each lighting condition were nearly identical; however, the number of fatal and serious injury crashes were also similar for light conditions of “daylight,” “dark: streetlights on,” and “dark: no streetlights.” In contrast, the total number of wrong-way driving crashes decreased from “daylight” to “dark: streetlights on” to “dark: no streetlights.” As the amount of light available decreased, the number of wrong-way driving crashes also decreased; however, the percentage of fatal and serious injury crashes during daylight hours was 46.9%.

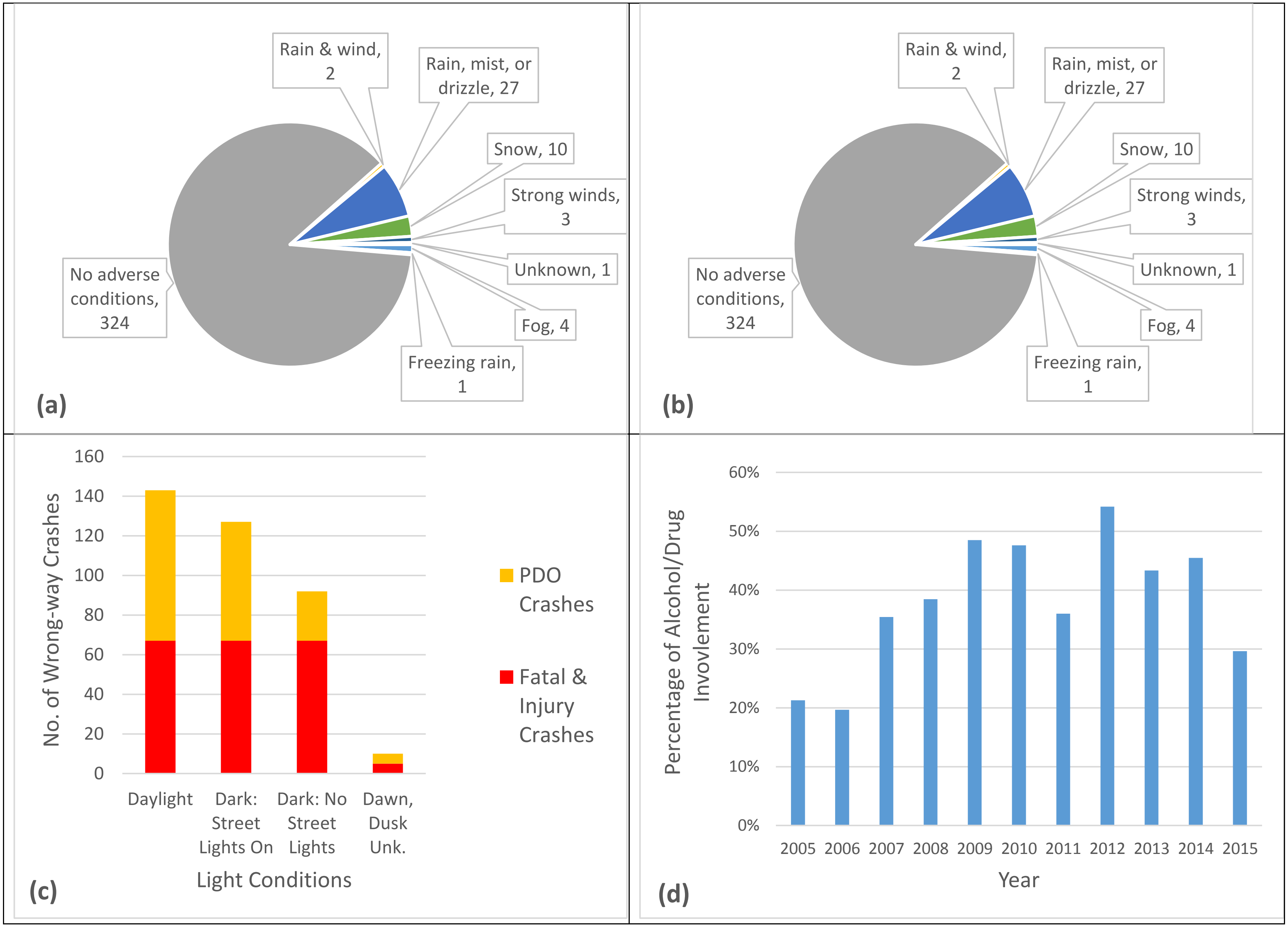


Figure 11: (a) Wrong-way Crashes by Weather Conditions; (b) Wrong-way Crashes by Location; (c) Crash Severity by Light Conditions; (d) Percentage of Wrong-way Crashes with Alcohol/Drug Involvement by Year.

When the light condition was "dark: streetlights on," the percentage of wrong-way driving crashes (fatal or serious injury) increased to 52.8%. When the light condition was "dark: no streetlights," the percentage of wrong-way crashes resulting in a fatality or serious injury increased to 72.8%. In other words, nearly 3 of every 4 wrong-way driving crashes occurred at night with no streetlights present.

Figure 11(d) shows the percentage of wrong-way driving crashes involving a driver under the influence of alcohol or drugs, demonstrating that crashes involving impaired drivers increased from approximately 20% in 2006 to approximately 54% in 2012. The highest value for Kansas was relatively close to the 60% national percentage reported by NHTSA. Based on crash data from 2005 to 2015, 2012 was the only year in which over 50% of wrong-way driving crashes involved an impaired driver, although percentages decreased to 30% in 2015. Overall, in the ten years of crash data, 35.5% of wrong-way crashes, or an average of 12 crashes per year, involved a driver impaired by alcohol and/or drugs. Twelve crashes represented only a small percentage of the total number of crashes reported in Kansas (approximately 60,000) and impaired driving crashes (approximately 2,300). Additional variables were also investigated in the wrong-way driving crash data set (**Figure 12**).

Figure 12(a) shows the relationship between driver impairment (alcohol and/or drug use), non-impaired drivers, and crash severity. As shown, fatal and serious injury crashes demonstrated approximately the same amount of impaired and non-impaired drivers, but PDO crashes occurred significantly more frequently with non-impaired drivers, indicating drivers may have been more alert and able to take corrective actions, thus reducing crash severity.

Figure 12(b) shows the total number of wrong-way driving crashes with impaired drivers by days of the week. As shown, Friday and Saturday correlated to the highest number of crashes.

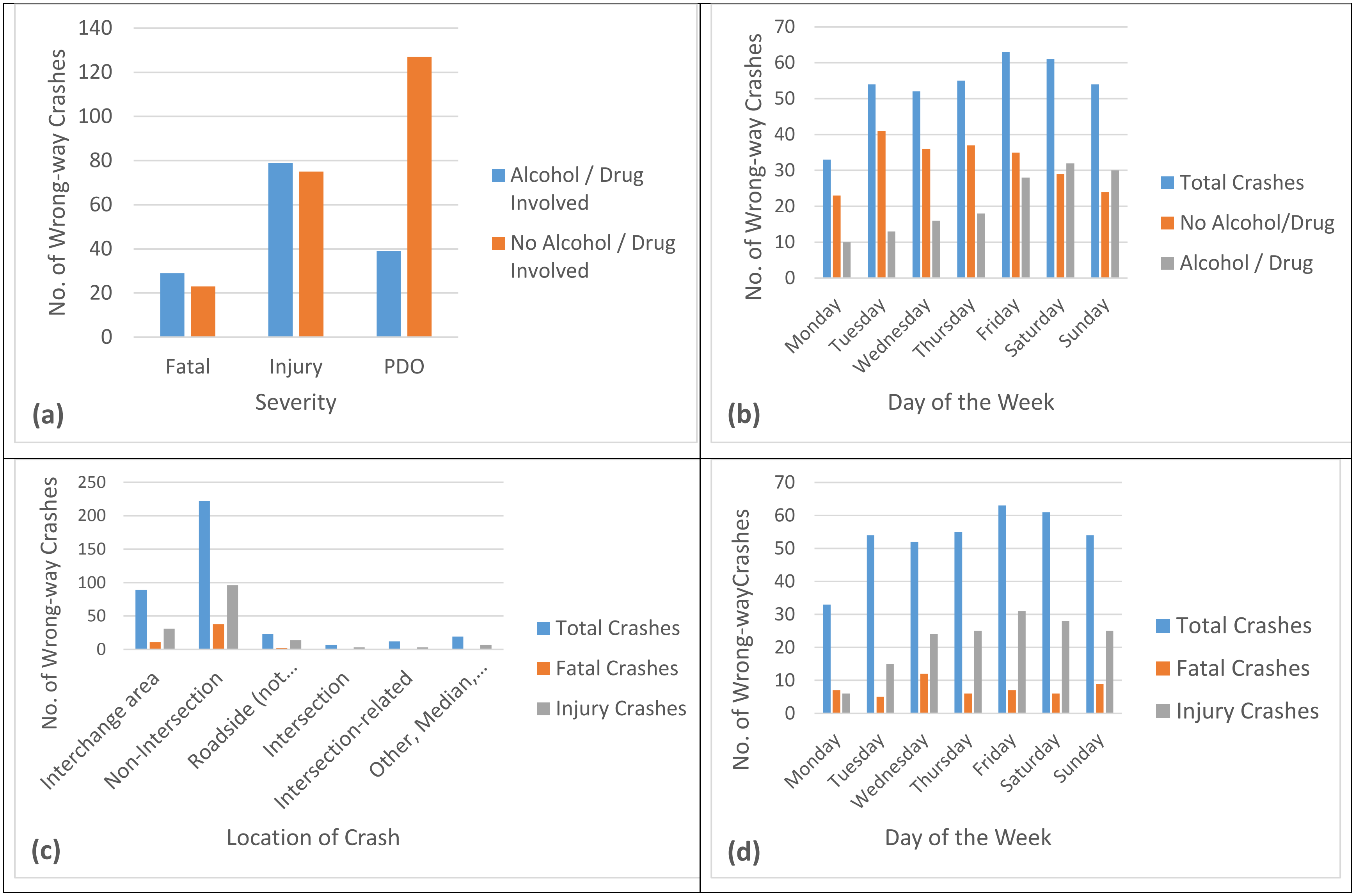


Figure 12: (a) Alcohol/Drug Involved Wrong-way Crashes by Severity; (b) Wrong-way Crashes by Day of the Week & Alcohol/Drug; (c) Location of Wrong-way Crashes by severity; (d) Wrong-way Crash Severity by Day of the Week

Previous literature reported that 60% of wrong-way crashes involved an impaired driver, with 78% of all wrong-way crashes occurring from 6:00 p.m. to 6:00 a.m. (NTSB, 2014), reinforcing the increased number of crashes on Fridays and Saturdays since drinking establishments are typically busiest on weekend nights. **Figure 12(b)** also shows the upward trend in impaired driving crashes, which peaks on Saturday, with more than 20 impaired driving crashes occurring on Friday, Saturday, and Sunday. The figure also shows that an average of 30 non-impaired wrong-way driving crashes occurred each day of the week, while impaired driving crashes averaged just over 14 each day from Monday thru Thursday. Friday, Saturday and Sunday averaged 30 impaired wrong-way crashes per day, over double the average for the rest of the week. The peak for no alcohol/drug crashes occurred on Tuesday and decreased throughout the rest of the week and Monday. Minimum alcohol/drug involvement began on Monday and reached the maximum on Saturday.

The location of wrong-way driving crashes and crash severities are graphed in **Figure 12(c)**, with six possible roadway locations considered. Results showed that almost all fatal and serious injury crashes occurred at interchanges and non-intersection areas. A crash that occurred at an "Interchange Area" is defined as the part of a roadway that is near, but not directly in the interchange or intersection. In addition, the cause of a wrong-way driving crash should not be related to, or a direct impact of the geometric design or location of the interchange. If the crash occurred on the freeway away from the immediate interchange area, it was a "Non-Intersection" crash.

Figure 12(d) correlates wrong-way driving crash severity and days of the week. Less than 50 wrong-way crashes occurred on Mondays, while the rest of the days of the week ranged from 52 to 63 wrong-way driving crashes. A slight peak in crashes occurred on Friday, affirming previous research studies that investigated wrong-way crashes and days of the week (Zhou et al., 2012; NTSB, 2012; Kittelson & Associates, 2015). However, **Figure 12(d)** shows that fatal wrong-way driving crashes most often occurred on Saturday (9 fatal crashes) and Wednesday (12 fatal crashes). Crash distribution was similar for the remaining five days of the week, varying from 5 to 7 fatal wrong-way driving crashes each day.

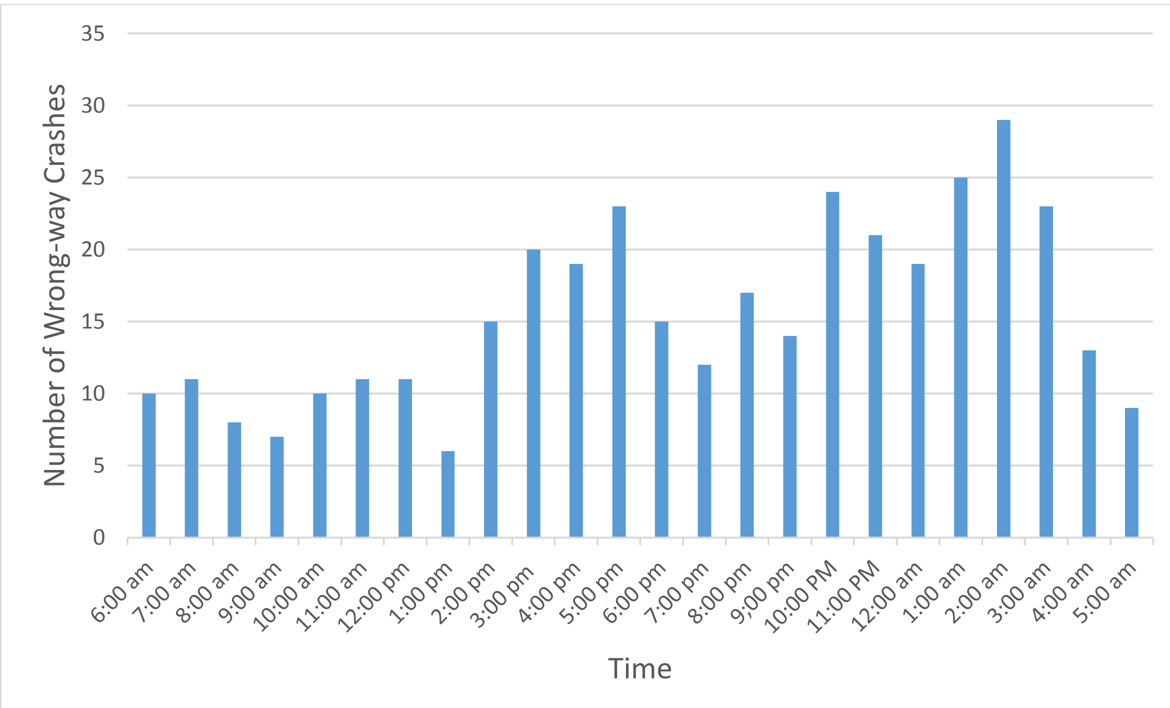


Figure 13: Wrong-Way Crashes by Hour

Figure 13 illustrates two distinct peaks of wrong-way crash data when the number of crashes are plotted against time of day. The first peak occurred between 2:00 p.m. and 5:00 p.m., and the second peak occurred between 10:00 p.m. and 2:00 a.m. However, national trends have shown that wrong-way driving crashes typically occur between 6:00 p.m. and 6:00 a.m. (NTSB, 2012). Although the Kansas data affirmed national trends, the number of wrong-way driving crashes decreased to less than half of the maximum number of crashes at certain times of the day, specifically 6:00 p.m. to 9:00 p.m. and 3:00 a.m. to 2:00 p.m. **Figure 13** shows that most wrong-way driving crashes occurred between 1:00 a.m. and 3:00 a.m., which corresponds to closing times for drinking establishments and subsequent travel by impaired drivers on roadways.

4. STATISTICAL ANALYSIS

4.1 Initial Model Selection

Crash variables for the 372 wrong-way crashes in Kansas were analyzed for statistically significant characteristics at the 95% confidence level. Crashes were analyzed based on crash type: fatal crash, injury crash, and PDO. Since the response variable had three categories (fatal, injury, PDO), the cumulative logit model was chosen to fit the data, allowing the model to simultaneously compare fatal crashes to PDO crashes and injury crashes to PDO crashes. Utilizing the statistical software package SAS for analysis, which uses "proc logistic", a "logit link" was added to ensure that the link function in the model was the log link. The basic model was:

$$log(\hat{y}) = \hat{\beta}_0 + \hat{\beta}_1 X_1 + \hat{\beta}_2 X_2 + \cdots + \hat{\beta}_k X_k \quad \textbf{Eq. 1}$$

Where: $\hat{y}$ = *response fatal or injury crash*

$\hat{\beta}_k$ = *estimates*

X = *parameters*

k = *number of parameters*

The method of model selection used was backward selection. The first step in backward selection, the method used for model selection, was to run the model using all possible parameters of a wrong-way crash. Time of day was one of the available parameters, and since time is a cycle, the term "time squared" was added to better fit the model. After initial analysis, parameters were removed from the model, starting with the parameter with the largest p-value greater than the chosen level of $\alpha = 0.05$. The model was rerun, and the parameter with the largest p-value greater than $\alpha = 0.05$ was removed. This procedure continued until all parameters were lower than the chosen p-value.

4.2 Results

The initial model did not show many significant variables. Results of the initial model are shown in **Table 3**.

Table 3: Results of Initial Statistical Model

Type 3 Analysis of Effects			
Effect	**DF**	**Wald Chi-Square**	**Pr > ChiSq**
DUI	2	18.7817	<.0001
Day of the Week	12	22.0945	0.0365
Month	22	15.9680	0.8175
UOM	4	4.9231	0.2953
Accident_Class	10	5.8562	0.8272
Accident_Location	10	12.0161	0.2840
Time	2	2.8264	0.2434
time2	2	3.0290	0.2199
Weather	10	4.3874	0.9282
Light_Condition	10	6.5035	0.7713
DESCRIP	4	8.7846	0.0667

Two parameters significant to the 95^{th} percentile were DUI and day of the week. The parameter DUI represents the combined categories of drug and alcohol involvement, which are tracked separately by KDOT. DESCRIP was close to being significant to the 95^{th} percentile, with a p-value of 0.0667. Accident location, light condition, and weather were noteworthy parameters that were not significant even though the descriptive statistics were noteworthy. The degrees of freedom were doubled because response *y* had three levels and the model conditioned on two cases: fatal versus PDO and injury versus PDO.

After several iterations in which the parameter that was not significant was removed, the final model contained variables DUI and day of the week as significant parameters (**Table 4**).

Table 4: Final model

Type 3 Analysis of Effects			
Effect	**DF**	**Wald Chi-Square**	**Pr > ChiSq**
DUI	2	29.2711	<.0001
Day of the Week	12	21.7019	0.0410

The final model for the data is:

$$log(\hat{y}) = \hat{\beta}_0 + \hat{\beta}_1 X_1 + \hat{\beta}_2 X_2 \quad \textbf{Eq. 2}$$

Where: $\hat{y}$ = *fatal or injury crash*

$\hat{\beta}_0$ = *intercept*

$\hat{\beta}_k$ = *estimate for k parameter*

X_1 = *alcohol/drug involvement (DUI)*

X_2 = *day of the week as a qualitative parameter (DayoftheWeek)*

Parameter DUI stayed at a p-value of <0.0001 throughout the selection process, indicating the parameter was significant regardless which other parameters were present. DESCRIP, which became less significant as the selection process continued, was eliminated from the final model. Reference conditions for the model were alcohol involvement for DUI and Wednesday for day of the week.

Significant characteristics were not identical for injury and fatal crashes. While alcohol/drug involvement was significant for both types of crashes, the only day that was significant was Tuesday. As shown in **Table 5**, Monday was also significant for injury crashes.

What is of interest was the estimation of odds ratio. For those with insignificant maximum likelihood estimation, it would conclude it showed no difference.

Table 5: Individual Parameter Estimates and Odds Ratios for Injury Crashes

Analysis of Maximum Likelihood Estimates				Odds Ratio Estimates		
Parameter	Estimate	Standard Error	Pr > Chi Sq	Point Estimate	95% Wald Confidence Limits	
Intercept	1.3263	0.3865	0.0006			
DUI 0 vs 1	**-1.2100**	**0.2543**	**<.0001**	**0.298**	**0.181**	**0.491**
Day of the Week Friday vs Wednesday	-0.3874	0.4341	0.3721	0.679	0.290	1.589
Day of the Week Monday vs Wednesday	**-1.6884**	**0.5799**	**0.0036**	**0.185**	**0.059**	**0.576**
Day of the Week Saturday vs Wednesday	-0.6868	0.4394	0.1181	0.503	0.213	1.191
Day of the Week Sunday vs Wednesday	-0.5071	0.4593	0.2695	0.602	0.245	1.481
Day of the Week Thursday vs Wednesday	-0.4308	0.4427	0.3305	0.650	0.273	1.548
Day of the Week Tuesday vs Wednesday	**-1.2396**	**0.4588**	**0.0069**	**0.289**	**0.118**	**0.711**

Table 6 shows that Friday, Saturday, and Thursday were significant for fatal crashes. For each of these characteristics, significance was based on the parameters relationship to the reference category: alcohol involved for DUI and Wednesday for day of the week. Interpretation of results highlighted the importance of comparing the two cases. For the DUI parameter, not under influence vs under influence; and the parameters of injury and PDO, the ratio for "not under influence" was 29.8%, while the ratio decreased to 22.2% for the parameters of fatal and PDO, indicating that driving under the influence causes more direct fatalities than not under the influence. In other words, if a driver impaired by alcohol or drugs proceeds to drive, the crash would likely be severe and potentially be fatal.

Table 6: Individual Parameter Estimates and Odds Ratios for Fatal Crashes

Analysis of Maximum Likelihood Estimates				Odds Ratio Estimates		
Parameter	Estimate	Standard Error	Pr > Chi Sq	Point Estimate	95% Wald Confidence Limits	
Intercept	0.8114	0.4630	0.0796			
DUI 0 vs 1	**-1.5035**	**0.3493**	**<.0001**	**0.222**	**0.112**	**0.441**
Day of the Week Friday vs Wednesday	**-1.2387**	**0.5927**	**0.0366**	**0.290**	**0.091**	**0.926**
Day of the Week Monday vs Wednesday	-0.8655	0.6038	0.1517	0.421	0.129	1.374
Day of the Week Saturday vs Wednesday	**-1.6187**	**0.6163**	**0.0086**	**0.198**	**0.059**	**0.663**
Day of the Week Sunday vs Wednesday	-0.9217	0.5806	0.1124	0.398	0.127	1.241
Day of the Week Thursday vs Wednesday	**-1.1854**	**0.6102**	**0.0521**	**0.306**	**0.092**	**1.011**
Day of the Week Tuesday vs Wednesday	**-1.6502**	**0.6271**	**0.0085**	**0.192**	**0.056**	**0.656**

As shown in

Table 6, the odds ratio for injury and PDO were almost identical for Friday and Wednesday, but for the parameters of fatal and PDO, the ratio for Friday showed a 29% chance of being more fatal than Wednesday. Similarly, when Monday is compared to Wednesday, the ratio was 18.5% with injury and PDO, and for the conditions of fatal and PDO, no difference was observed. These comparisons all relate to one-case significance, allowing for no straightforward conclusions. The only conclusive comparison was Tuesday and Wednesday, where in the case of injury and PDO, the ratio was 28.9% for fatal and 19.2% for PDO, leading to the conclusion that Tuesday was less severe than Wednesday. Similarly, when comparing the descriptive statistics to the statistical model, Wednesday also had the largest number of fatal crashes.

5.DISCUSSION OF SIGNIFICANT FINDINGS

Transportation officials continuously seek to prevent and reduce vehicle crashes on freeways. With every vehicle crash, loss of life, serious medical injuries, or damage to property results in substantial economic losses. Although thousands of vehicles crash every day, an infrequent but high-profile crash type is wrong-way driving crashes, which often involve one or more fatalities. However, understanding how and why wrong-way crashes occur can be difficult, even for police officers at the crash site, since many wrong-way crashes result in one or more fatalities and verifying where the driver entered the freeway or if he or she was impaired are challenging factors to determine. However, the literature review proved that wrong-way crashes tend to have similar factors and characteristics.

A literature review was conducted to increase understanding of prevalent wrong-way crash research. The following conclusions were made:

- Overall there was a large breadth of research
- Limited research was found on freeway ramps and interchanges
- Limited research was also found which discussed causes of wrong-way crashes
- A limited number of research has been conducted wrong-way crash analyses for states
- Almost all research conducted has focused on effectiveness of wrong-way driving countermeasures
- Additionally research studies have focused on intervention strategies and vehicle detection technology

Wrong-way crash data from years 2005 through 2015 were obtained from KDOT via KCARS to study wrong-way crashes in Kansas. Only crashes that occurred on divided highways with ramps and interchanges were selected for review; crashes with at-grade intersections were removed from the data. The data were sorted by characteristics, descriptive statistics were created, and the data were input into ArcMap using provided latitude and longitude values for each crash. Two large crash clusters were observed near Kansas City and Wichita, and two other small groups of crashes were centered on Topeka, with smaller clusters around Manhattan and Salina. Wrong-way crash clusters were also observed along Interstate 70, the main east-west interstate in Kansas, and along interstates I-135, I-35, and I-335. The only other road that had multiple wrong-way crashes was US-69.

Fatal and injury crashes were shown to comprise 55% of all wrong-way crashes in Kansas. Research showed that, during the years 2005 to 2015, 60% of total wrong-way crashes occurred at non-intersection locations, while 87% occurred with no adverse weather conditions at the time of the crash. According to the data, wrong-way crashes occurred in daylight 38% of the time, and 35% of crashes occurred with active streetlights in darkness. Overall, alcohol and/or drugs were involved in 40% of wrong-way crashes, resulting in an increased number of fatal and injury crashes compared to crashes with no alcohol or drug involvement. However, these statistics for Kansas are not in line with national statistics; less wrong-way crashes involving alcohol and less crashes at night occurred in Kansas compared to the national statistics.

The cumulative logit model was chosen for this study because the response variable had three categories: fatal, injury and PDO. The backwards selection method was used to achieve the final model. The only factors found to be significant to the 95% confidence level were DUI and day of the week for fatal and injury crashes. The ratio for “not under the influence” indicated that driving under the influence causes more direct fatalities. All days of the week were compared to Wednesday. Although prevalent days differ for injury and fatal crashes, both fatal and injury crashes are similar in that Wednesday has greater odds of having a more severe crash than any other day of the week.

5.1 Contributions to Highway Safety

Reduction of wrong-way crashes is becoming a priority of transportation agencies throughout the United States, but no previous published research has emphasized wrong-way driving in Kansas. The first step to reducing wrong-way crashes is to determine crash causes, specifically identifying significant characteristics to determine the causes and reduce the number of wrong-way crashes. Unfortunately, however, minimal research has been conducted on wrong-way driving characteristics in the United States. In fact, statistical studies have been done in only three states. Additional statistical information on wrong-way driving will add to the body of knowledge available on a national scale.

5.2 Study Limitations

This research project had several limitations. First, this project was strictly a statistical study of historical crash data; it lacked in-depth research into each crash to identify relative circumstances. Second, because only a limited number of crashes occur each year, the study was extended over a longer time period than would have been preferred in order to obtain a feasible number of crashes.

5.3 Future Research

Further research should focus on identifying most commonly used interchanges in wrong-way crashes, thereby allowing determination of effective countermeasures for reducing the number of crashes. Future study should include monitoring select interchanges using road tubes to identify areas with high incidence rates, allowing for targeted implementation of countermeasures.

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Appendix A - Initial Statistical Analysis Results

Type 3 Analysis of Effects			
Effect	**DF**	**Wald Chi-Square**	**Pr > ChiSq**
DUI	2	18.7817	<.0001
DayoftheWeek	12	22.0945	0.0365
Month	22	15.9680	0.8175
UOM	4	4.9231	0.2953
Accident_Class	10	5.8562	0.8272
Accident_Location	10	12.0161	0.2840
Time	2	2.8264	0.2434
time2	2	3.0290	0.2199
Weather	10	4.3874	0.9282
Light_Condition	10	6.5035	0.7713
DESCRIP	4	8.7846	0.0667

Analysis of Maximum Likelihood Estimates							
Parameter		**y**	**DF**	**Estimate**	**Standard Error**	**Wald Chi-Square**	**Pr > ChiSq**
Intercept		**1**	1	-9.8920	202.2	0.0024	0.9610
Intercept		**2**	1	-32.8965	377.2	0.0076	0.9305
DUI	**0**	**1**	1	-1.2576	0.3373	13.9053	0.0002
DUI	**0**	**2**	1	-1.8028	0.5005	12.9755	0.0003
DayoftheWeek	**Friday**	**1**	1	-0.3551	0.5020	0.5003	0.4794
DayoftheWeek	**Friday**	**2**	1	-1.7734	0.7497	5.5961	0.0180
DayoftheWeek	**Monday**	**1**	1	-1.6162	0.6368	6.4402	0.0112
DayoftheWeek	**Monday**	**2**	1	-1.2216	0.7710	2.5105	0.1131

Analysis of Maximum Likelihood Estimates							
Parameter		**y**	**DF**	**Estimate**	**Standard Error**	**Wald Chi-Square**	**Pr > ChiSq**
DayoftheWeek	**Saturday**	**1**	1	-0.7575	0.5015	2.2817	0.1309
DayoftheWeek	**Saturday**	**2**	1	-1.7863	0.7578	5.5565	0.0184
DayoftheWeek	**Sunday**	**1**	1	-0.4605	0.5432	0.7189	0.3965
DayoftheWeek	**Sunday**	**2**	1	-0.6209	0.7681	0.6534	0.4189
DayoftheWeek	**Thursday**	**1**	1	-0.6075	0.5128	1.4034	0.2362
DayoftheWeek	**Thursday**	**2**	1	-1.7218	0.7434	5.3648	0.0205
DayoftheWeek	**Tuesday**	**1**	1	-1.3653	0.5235	6.8010	0.0091
DayoftheWeek	**Tuesday**	**2**	1	-2.1886	0.7750	7.9750	0.0047
Month	**1**	**1**	1	0.7816	0.7859	0.9892	0.3199
Month	**1**	**2**	1	-0.5672	1.0937	0.2689	0.6040
Month	**10**	**1**	1	0.2603	0.7546	0.1190	0.7301
Month	**10**	**2**	1	-0.1403	0.9026	0.0242	0.8765
Month	**11**	**1**	1	0.3690	0.7228	0.2607	0.6097
Month	**11**	**2**	1	-2.2165	1.3281	2.7852	0.0951
Month	**12**	**1**	1	0.5237	0.7745	0.4572	0.4989
Month	**12**	**2**	1	0.5632	0.9455	0.3548	0.5514
Month	**2**	**1**	1	0.6775	0.7678	0.7787	0.3775
Month	**2**	**2**	1	-0.2324	1.0514	0.0488	0.8251
Month	**3**	**1**	1	0.0265	0.7448	0.0013	0.9716
Month	**3**	**2**	1	-0.0764	0.9080	0.0071	0.9329
Month	**4**	**1**	1	0.1931	0.7238	0.0712	0.7896
Month	**4**	**2**	1	-0.7437	0.9975	0.5559	0.4559
Month	**5**	**1**	1	0.5512	0.7456	0.5466	0.4597
Month	**5**	**2**	1	0.1433	0.9343	0.0235	0.8781
Month	**6**	**1**	1	0.2824	0.7352	0.1475	0.7009
Month	**6**	**2**	1	-2.1448	1.3322	2.5922	0.1074
Month	**7**	**1**	1	0.5293	0.7836	0.4563	0.4993

Analysis of Maximum Likelihood Estimates							
Parameter		**y**	**DF**	**Estimate**	**Standard Error**	**Wald Chi-Square**	**Pr > ChiSq**
Month	**7**	**2**	1	-0.2606	1.0484	0.0618	0.8037
Month	**8**	**1**	1	-0.0784	0.7468	0.0110	0.9164
Month	**8**	**2**	1	-1.5807	1.0383	2.3177	0.1279
UOM	**F**	**1**	1	-0.0879	1.0357	0.0072	0.9324
UOM	**F**	**2**	1	7.8503	47.6042	0.0272	0.8690
UOM	**M**	**1**	1	-0.1505	1.0803	0.0194	0.8892
UOM	**M**	**2**	1	9.0556	47.6072	0.0362	0.8491
Accident_Class	**FixedObj**	**1**	1	8.9596	116.4	0.0059	0.9386
Accident_Class	**FixedObj**	**2**	1	8.1198	200.3	0.0016	0.9677
Accident_Class	**OtherMot**	**1**	1	9.8954	116.4	0.0072	0.9323
Accident_Class	**OtherMot**	**2**	1	9.0779	200.3	0.0021	0.9639
Accident_Class	**OtherNon**	**1**	1	0.0945	133.9	0.0000	0.9994
Accident_Class	**OtherNon**	**2**	1	-0.4918	224.1	0.0000	0.9982
Accident_Class	**OtherObj**	**1**	1	8.9862	116.4	0.0060	0.9385
Accident_Class	**OtherObj**	**2**	1	-0.2577	210.0	0.0000	0.9990
Accident_Class	**Overturn**	**1**	1	10.0474	116.4	0.0074	0.9312
Accident_Class	**Overturn**	**2**	1	8.2149	200.3	0.0017	0.9673
Accident_Location	**Intercha**	**1**	1	-1.2174	0.6790	3.2140	0.0730
Accident_Location	**Intercha**	**2**	1	0.8669	1.1744	0.5449	0.4604
Accident_Location	**Intersec**	**1**	1	-1.8434	0.9305	3.9243	0.0476
Accident_Location	**Intersec**	**2**	1	-0.1933	1.6582	0.0136	0.9072
Accident_Location	**Median**	**1**	1	0.3166	1.0364	0.0933	0.7600
Accident_Location	**Median**	**2**	1	-6.0434	50.9036	0.0141	0.9055
Accident_Location	**Non-Inte**	**1**	1	-0.9269	0.6872	1.8192	0.1774
Accident_Location	**Non-Inte**	**2**	1	0.4101	1.1661	0.1237	0.7251
Accident_Location	**Other**	**1**	1	-2.2078	1.0812	4.1695	0.0412
Accident_Location	**Other**	**2**	1	-8.4476	44.5253	0.0360	0.8495

Analysis of Maximum Likelihood Estimates							
Parameter		**y**	**DF**	**Estimate**	**Standard Error**	**Wald Chi-Square**	**Pr > ChiSq**
Time		**1**	1	-0.1889	0.1215	2.4168	0.1200
Time		**2**	1	-0.2410	0.1981	1.4793	0.2239
time2		**1**	1	0.00776	0.00515	2.2717	0.1318
time2		**2**	1	0.0117	0.00827	1.9861	0.1588
Weather	**Fog**	**1**	1	18.9352	125.5	0.0228	0.8800
Weather	**Fog**	**2**	1	18.7599	205.7	0.0083	0.9273
Weather	**Noadvers**	**1**	1	10.9920	116.4	0.0089	0.9248
Weather	**Noadvers**	**2**	1	12.0463	200.3	0.0036	0.9520
Weather	**Rain,mis**	**1**	1	10.5440	116.4	0.0082	0.9278
Weather	**Rain,mis**	**2**	1	10.6001	200.3	0.0028	0.9578
Weather	**Snow**	**1**	1	11.8130	116.4	0.0103	0.9192
Weather	**Snow**	**2**	1	11.9200	200.3	0.0035	0.9526
Weather	**Strongwi**	**1**	1	2.5951	131.0	0.0004	0.9842
Weather	**Strongwi**	**2**	1	12.3800	200.3	0.0038	0.9507
Light_Condition	**Dark:NoS**	**1**	1	-8.7894	117.4	0.0056	0.9403
Light_Condition	**Dark:NoS**	**2**	1	-3.1702	240.3	0.0002	0.9895
Light_Condition	**Dark:Str**	**1**	1	-9.2273	117.4	0.0062	0.9373
Light_Condition	**Dark:Str**	**2**	1	-4.1625	240.3	0.0003	0.9862
Light_Condition	**Dawn**	**1**	1	-17.3203	129.2	0.0180	0.8934
Light_Condition	**Dawn**	**2**	1	-12.5655	255.0	0.0024	0.9607
Light_Condition	**Daylight**	**1**	1	-8.6086	117.4	0.0054	0.9415
Light_Condition	**Daylight**	**2**	1	-2.7296	240.3	0.0001	0.9909
Light_Condition	**Dusk**	**1**	1	-7.1209	117.4	0.0037	0.9516
Light_Condition	**Dusk**	**2**	1	-1.2287	240.3	0.0000	0.9959
DESCRIP	**4LDIV**	**1**	1	1.1106	0.8373	1.7592	0.1847
DESCRIP	**4LDIV**	**2**	1	8.7467	44.8543	0.0380	0.8454
DESCRIP	**6LDIV**	**1**	1	0.7713	0.8494	0.8245	0.3639

Analysis of Maximum Likelihood Estimates							
Parameter		**y**	**DF**	**Estimate**	**Standard Error**	**Wald Chi-Square**	**Pr > ChiSq**
DESCRIP	**6LDIV**	**2**	1	7.1482	44.8562	0.0254	0.8734

Odds Ratio Estimates				
Effect	**y**	**Point Estimate**	**95% Wald Confidence Limits**	
DUI 0 vs 1	**1**	0.284	0.147	0.551
DUI 0 vs 1	**2**	0.165	0.062	0.440
DayoftheWeek Friday vs Wednesda	**1**	0.701	0.262	1.876
DayoftheWeek Friday vs Wednesda	**2**	0.170	0.039	0.738
DayoftheWeek Monday vs Wednesda	**1**	0.199	0.057	0.692
DayoftheWeek Monday vs Wednesda	**2**	0.295	0.065	1.336
DayoftheWeek Saturday vs Wednesda	**1**	0.469	0.175	1.253
DayoftheWeek Saturday vs Wednesda	**2**	0.168	0.038	0.740
DayoftheWeek Sunday vs Wednesda	**1**	0.631	0.218	1.829
DayoftheWeek Sunday vs Wednesda	**2**	0.537	0.119	2.422
DayoftheWeek Thursday vs Wednesda	**1**	0.545	0.199	1.488
DayoftheWeek Thursday vs Wednesda	**2**	0.179	0.042	0.767
DayoftheWeek Tuesday vs Wednesda	**1**	0.255	0.092	0.712
DayoftheWeek Tuesday vs Wednesda	**2**	0.112	0.025	0.512
Month 1 vs 9	**1**	2.185	0.468	10.196
Month 1 vs 9	**2**	0.567	0.066	4.838
Month 10 vs 9	**1**	1.297	0.296	5.693
Month 10 vs 9	**2**	0.869	0.148	5.098
Month 11 vs 9	**1**	1.446	0.351	5.963
Month 11 vs 9	**2**	0.109	0.008	1.472
Month 12 vs 9	**1**	1.688	0.370	7.703

Odds Ratio Estimates				
Effect	**y**	**Point Estimate**	**95% Wald Confidence Limits**	
Month 12 vs 9	**2**	1.756	0.275	11.204
Month 2 vs 9	**1**	1.969	0.437	8.867
Month 2 vs 9	**2**	0.793	0.101	6.224
Month 3 vs 9	**1**	1.027	0.239	4.420
Month 3 vs 9	**2**	0.926	0.156	5.492
Month 4 vs 9	**1**	1.213	0.294	5.011
Month 4 vs 9	**2**	0.475	0.067	3.358
Month 5 vs 9	**1**	1.735	0.403	7.482
Month 5 vs 9	**2**	1.154	0.185	7.203
Month 6 vs 9	**1**	1.326	0.314	5.603
Month 6 vs 9	**2**	0.117	0.009	1.594
Month 7 vs 9	**1**	1.698	0.366	7.887
Month 7 vs 9	**2**	0.771	0.099	6.015
Month 8 vs 9	**1**	0.925	0.214	3.996
Month 8 vs 9	**2**	0.206	0.027	1.575
UOM F vs MF	**1**	0.916	0.120	6.973
UOM F vs MF	**2**	>999.999	<0.001	>999.999
UOM M vs MF	**1**	0.860	0.104	7.149
UOM M vs MF	**2**	>999.999	<0.001	>999.999
Accident_Class FixedObj vs Unknown	**1**	>999.999	<0.001	>999.999
Accident_Class FixedObj vs Unknown	**2**	>999.999	<0.001	>999.999
Accident_Class OtherMot vs Unknown	**1**	>999.999	<0.001	>999.999
Accident_Class OtherMot vs Unknown	**2**	>999.999	<0.001	>999.999
Accident_Class OtherNon vs Unknown	**1**	1.099	<0.001	>999.999
Accident_Class OtherNon vs Unknown	**2**	0.612	<0.001	>999.999
Accident_Class OtherObj vs Unknown	**1**	>999.999	<0.001	>999.999
Accident_Class OtherObj vs Unknown	**2**	0.773	<0.001	>999.999

Odds Ratio Estimates				
Effect	**y**	**Point Estimate**	**95% Wald Confidence Limits**	
Accident_Class Overturn vs Unknown	**1**	>999.999	<0.001	>999.999
Accident_Class Overturn vs Unknown	**2**	>999.999	<0.001	>999.999
Accident_Location Intercha vs Roadside	**1**	0.296	0.078	1.120
Accident_Location Intercha vs Roadside	**2**	2.380	0.238	23.779
Accident_Location Intersec vs Roadside	**1**	0.158	0.026	0.981
Accident_Location Intersec vs Roadside	**2**	0.824	0.032	21.258
Accident_Location Median vs Roadside	**1**	1.372	0.180	10.463
Accident_Location Median vs Roadside	**2**	0.002	<0.001	>999.999
Accident_Location Non-Inte vs Roadside	**1**	0.396	0.103	1.522
Accident_Location Non-Inte vs Roadside	**2**	1.507	0.153	14.816
Accident_Location Other vs Roadside	**1**	0.110	0.013	0.915
Accident_Location Other vs Roadside	**2**	<0.001	<0.001	>999.999
Time	**1**	0.828	0.652	1.051
Time	**2**	0.786	0.533	1.159
time2	**1**	1.008	0.998	1.018
time2	**2**	1.012	0.995	1.028
Weather Fog vs Unknown	**1**	>999.999	<0.001	>999.999
Weather Fog vs Unknown	**2**	>999.999	<0.001	>999.999
Weather Noadvers vs Unknown	**1**	>999.999	<0.001	>999.999
Weather Noadvers vs Unknown	**2**	>999.999	<0.001	>999.999
Weather Rain,mis vs Unknown	**1**	>999.999	<0.001	>999.999
Weather Rain,mis vs Unknown	**2**	>999.999	<0.001	>999.999
Weather Snow vs Unknown	**1**	>999.999	<0.001	>999.999
Weather Snow vs Unknown	**2**	>999.999	<0.001	>999.999
Weather Strongwi vs Unknown	**1**	13.398	<0.001	>999.999
Weather Strongwi vs Unknown	**2**	>999.999	<0.001	>999.999
Light_Condition Dark:NoS vs Unknown	**1**	<0.001	<0.001	>999.999

Odds Ratio Estimates				
Effect	**y**	**Point Estimate**	**95% Wald Confidence Limits**	
Light_Condition Dark:NoS vs Unknown	**2**	0.042	<0.001	>999.999
Light_Condition Dark:Str vs Unknown	**1**	<0.001	<0.001	>999.999
Light_Condition Dark:Str vs Unknown	**2**	0.016	<0.001	>999.999
Light_Condition Dawn vs Unknown	**1**	<0.001	<0.001	>999.999
Light_Condition Dawn vs Unknown	**2**	<0.001	<0.001	>999.999
Light_Condition Daylight vs Unknown	**1**	<0.001	<0.001	>999.999
Light_Condition Daylight vs Unknown	**2**	0.065	<0.001	>999.999
Light_Condition Dusk vs Unknown	**1**	<0.001	<0.001	>999.999
Light_Condition Dusk vs Unknown	**2**	0.293	<0.001	>999.999
DESCRIP 4LDIV vs 8LDIV	**1**	3.036	0.588	15.670
DESCRIP 4LDIV vs 8LDIV	**2**	>999.999	<0.001	>999.999
DESCRIP 6LDIV vs 8LDIV	**1**	2.163	0.409	11.430
DESCRIP 6LDIV vs 8LDIV	**2**	>999.999	<0.001	>999.999

Appendix B – Final Statistical Model

Type 3 Analysis of Effects			
Effect	**DF**	**Wald Chi-Square**	**Pr > ChiSq**
DUI	2	29.2711	<.0001
Day of the Week	12	21.7019	0.0410

Analysis of Maximum Likelihood Estimates							
Parameter		**y**	**DF**	**Estimate**	**Standard Error**	**Wald Chi-Square**	**Pr > ChiSq**
Intercept		**1**	1	1.3263	0.3865	11.7729	0.0006
Intercept		**2**	1	0.8114	0.4630	3.0720	0.0796
DUI	**0**	**1**	1	-1.2100	0.2543	22.6468	<.0001
DUI	**0**	**2**	1	-1.5035	0.3493	18.5263	<.0001
DayoftheWeek	**Friday**	**1**	1	-0.3874	0.4341	0.7966	0.3721
DayoftheWeek	**Friday**	**2**	1	-1.2387	0.5927	4.3682	0.0366
DayoftheWeek	**Monday**	**1**	1	-1.6884	0.5799	8.4762	0.0036
DayoftheWeek	**Monday**	**2**	1	-0.8655	0.6038	2.0549	0.1517
DayoftheWeek	**Saturday**	**1**	1	-0.6868	0.4394	2.4426	0.1181
DayoftheWeek	**Saturday**	**2**	1	-1.6187	0.6163	6.8991	0.0086
DayoftheWeek	**Sunday**	**1**	1	-0.5071	0.4593	1.2192	0.2695
DayoftheWeek	**Sunday**	**2**	1	-0.9217	0.5806	2.5204	0.1124
DayoftheWeek	**Thursday**	**1**	1	-0.4308	0.4427	0.9470	0.3305
DayoftheWeek	**Thursday**	**2**	1	-1.1854	0.6102	3.7739	0.0521
DayoftheWeek	**Tuesday**	**1**	1	-1.2396	0.4588	7.3002	0.0069
DayoftheWeek	**Tuesday**	**2**	1	-1.6502	0.6271	6.9256	0.0085

Odds Ratio Estimates				
Effect	**y**	**Point Estimate**	**95% Wald Confidence Limits**	
DUI 0 vs 1	**1**	0.298	0.181	0.491
DUI 0 vs 1	**2**	0.222	0.112	0.441
DayoftheWeek Friday vs Wednesda	**1**	0.679	0.290	1.589
DayoftheWeek Friday vs Wednesda	**2**	0.290	0.091	0.926
DayoftheWeek Monday vs Wednesda	**1**	0.185	0.059	0.576
DayoftheWeek Monday vs Wednesda	**2**	0.421	0.129	1.374
DayoftheWeek Saturday vs Wednesda	**1**	0.503	0.213	1.191
DayoftheWeek Saturday vs Wednesda	**2**	0.198	0.059	0.663
DayoftheWeek Sunday vs Wednesda	**1**	0.602	0.245	1.481
DayoftheWeek Sunday vs Wednesda	**2**	0.398	0.127	1.241
DayoftheWeek Thursday vs Wednesda	**1**	0.650	0.273	1.548
DayoftheWeek Thursday vs Wednesda	**2**	0.306	0.092	1.011
DayoftheWeek Tuesday vs Wednesda	**1**	0.289	0.118	0.711
DayoftheWeek Tuesday vs Wednesda	**2**	0.192	0.056	0.656