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AN INITIAL EXPLORATION
OF THE
2005 IOWA RURAL INTERSTATE SPEED LIMIT INCREASE
USING
LINEAR REGRESSION

BY
THOMAS RYAN COOK

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Civil Engineering

South Dakota State University

2019

AN INITIAL EXPLORATION
OF THE
2005 IOWA RURAL INTERSTATE SPEED LIMIT INCREASE
USING LINEAR REGRESSION
THOMAS RYAN COOK

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the dissertation requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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This thesis is dedicated to those who have supported and sustained me through its creation. My fiancé, family, friends, and mentor have given me plenty of encouragement and laughter to create an environment in which to produce this effort. My sincere hope is that the information contained within provides a useful resource for future vehicle safety needs.

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Finally, I want to thank my wonderful fiancé Emily, my parents Dave and Julie, my brother Nick, my sister Sarah, my great family, my dear friends, and my Sigma Phi Epsilon brothers (the Rickys) for all of the endless love and support. They believed in me, offered words of affirmation, and took part in many memories over the years that empowered me to become a better student and person.

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ABSTRACT
AN INITIAL EXPLORATION
OF THE
2005 IOWA RURAL INTERSTATE SPEED LIMIT INCREASE
USING
LINEAR REGRESSION
THOMAS COOK
2019

Speed limit increases, particularly on interstates have been studied and researched many times over the course of the last 50 years in the United States. These research efforts began after the implementation of the National Maximum Speed Law (NMSL), which reduced all speed limits to a maximum of 55-mph. In the years that followed, this restriction was relaxed to 65-mph with the Surface Transportation and Uniform Relocation Assistance Act (STURAA) and ultimately repealed later by the National Highway System Designation Act (NHSDA). Since the repeal, states reacted in myriad of ways and many studies documented the changes of those reactions. While these efforts have investigated the changes in the fatality and crash rates before and after a speed limit increase, many additional crash data fields are available for research. The primary goal of the research detailed in this thesis was to consider available crash, road, and traffic data more broadly. The data used was obtained from the State of Iowa to observe the 2005 rural interstate speed limit increase from 65-mph to 70-mph.

CHAPTER 1. INTRODUCTION

Since the construction of the Interstate Highway System (IHS) across the United States, motorist safety has been studied and gradually improved over the last 5 decades. According to the Federal Highway Administration (FHWA), there were a total of 4,267 fatal crashes, 4,740 fatalities, and 0.79 and 0.48 fatalities per 100 million vehicle miles traveled (VMT) in 2017 for rural and urban interstates respectively (1). While those figures appear substantial, it should be noted that the fatality rates for rural and urban interstates have fallen by 0.33 and 0.08 since 2006 (1).

Despite this, great concern for safety exists as rural interstate speed limits continue to climb upward, in some cases to unprecedented levels. The following introduction will provide a brief summation of interstate speed limit history and regional characteristics that influence speed limits throughout the U.S.

U.S. Speed Limit History

During the aforementioned 50-year timeframe, speed limits in the United States on high speed roadways, primarily interstates, have fluctuated. Prior to the mid 1970s, states set interstate speed limits with little influence from the federal government (2, 3-7). Connecticut and New York first enacted speed laws in 1901 and by the early 1970s most states had rural interstate speed limits of 70 or 75 mph (3-7). Historically, these limits were set based primarily on the 85th percentile speed of all interstate drivers and the IHS design. This road design was meant to provide fast, safe travel by limiting access points and separating traffic flows (4, 7). These pre-federally mandated speed limits are shown in Figure 1.1.

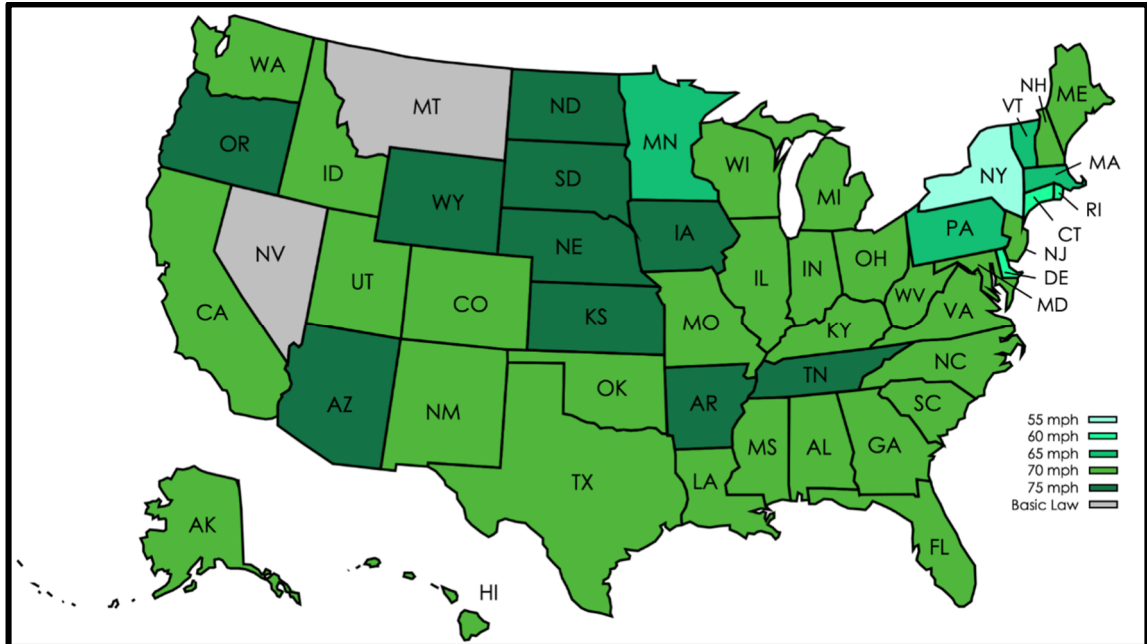


Figure 1.1: Pre-NMSL state rural, interstate speed limits (6).

National Maximum Speed Limit (NMSL)

In 1973, the Organization of Petroleum Exporting Countries (OPEC) imposed an oil embargo on the United States due to their military support for Israel in the Yom Kippur War (5, 8, 9). In response to this action, Congress passed the National Maximum Speed Limit (NMSL) as a part of the Emergency Highway Energy Conservation Act, which President Nixon signed into law on January 1st, 1974 (10). By March 4th, all states were in compliance with that mandate, mainly due to potential loss of federal highway funds (11, 12). Although early estimates of fuel conservation efforts predicted an annual savings of \$2 billion, most reviews concluded that the actual savings fell well short of that estimate (3, 4, 10, 11, 13, 14). One analysis determined a reduction of only 26.6 million barrels of oil out of the 5.9 billion barrels used (11). The United States Department of Transportation (US DOT) estimated that the reduced speed limits corresponded to just a 1 percent drop in fuel consumption (11). Despite the end of the

embargo, the law was permanently retained due to its observed traffic safety effects (6, 10, 12-14). Fatalities declined by 8,856 or 16% between 1973 and 1974 (13, 14).

While benefits were correlated to the NMSL, drivers became less compliant with the lower speed limits (6, 15). Studies noted that fatality reductions after the NMSL enactment were partially due to poor economic conditions and fuel conditions that reduced driving (6). In addition, highway design, vehicle characteristics, and emergency medical services improved which impacted fatality reductions (6).

Surface Transportation and Uniform Relocation Assistance Act (STURAA)

Federal limits from the NMSL were later relaxed upon the implementation of the Surface Transportation and Uniform Relocation Assistance Act (STURAA) in 1987 (2, 10, 16-25). This law allowed rural interstate speed limits of 65-mph (2, 10, 16-25). 38 states increased their speed limits in 1987, with two more states doing so in 1988 (18, 21, 26). Several other states raised speed limits through 1995, when only Delaware, New Jersey, Connecticut, Rhode Island, and Hawaii maintained the 55-mph limit (21). Speed limits in 1995 are shown in Figure 1.2.

Post-STURAA, the National Highway Traffic Safety Administration (NHTSA) reported that a 30% increase in rural freeway fatalities, resulting in 539 fatalities per year nationwide, were due to raised speed limits (27). Some researchers asserted that the increased speed limit actually saved lives, suggesting that while fatalities and crashes increased on interstates, the overall fatality or crash rates decreased (10, 17, 25). The assumption is that this decline is due to drivers shifting to interstate highways that are better engineered (2, 25).

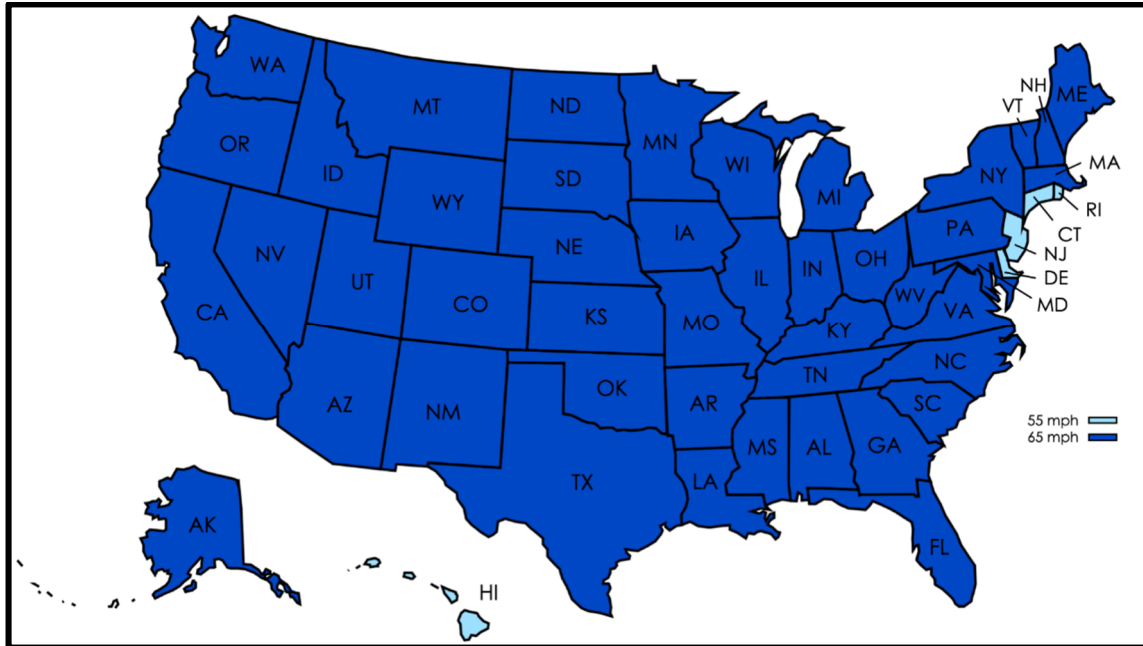


Figure 1.2: Post-STURAA state rural, interstate speed limits (18, 21, 26).

National Highway System Designation Act (NHSDA)

The final national change occurred when Congress repealed the NMSL in 1995 with the National Highway System Designation Act (NHSDA) (10, 11, 13, 28). NHSDA provided states full authority to set speed limits (10, 11, 13, 28). States reacted in diverse ways (10, 13). Hawaii maintained a rural interstate speed limit of 60-mph, 19 states remained at 65-mph, while 19 states increased to 70-mph, 10 states to 75-mph, and Montana went without a daytime speed limit (7, 9, 19). These changes are shown in Figure 1.3.

While the legislative branch discussed the NHSDA prior to passage, some safety advocates decried the abolishment of the NMSL (11). “Judith Stone, the president of the Advocates for Highway and Auto Safety predicted ‘6,400 added highway fatalities a year and millions of more injuries’” (11). Ralph Nader exclaimed after the repeal that “history will never forgive Congress for this assault on the sanctity of human life” (11). In spite of all the supposed danger, NHTSA reported that the traffic death rate fell to a record low

level in 1997 and that there were 66,000 fewer road injuries in 1997 compared to 1995 (11).

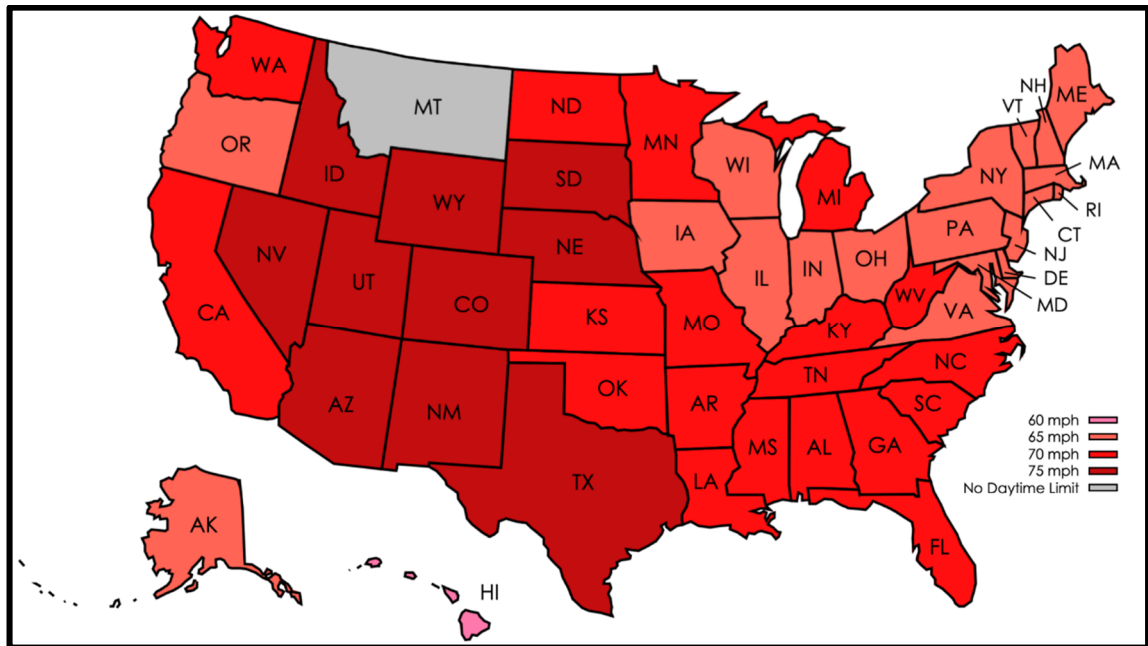


Figure 1.3: State rural, interstate speed limits immediately following the NHSDA (7, 9, 19).

Since the NMSL repeal, the rural interstate speed limits of states have continued to rise (10, 19, 29-35). Many of the Plains and Rocky Mountain states have raised some or all segments of their rural interstates to 80-mph and Texas has even set a limit of 85-mph on certain sections of interstate corridors (19). Current rural interstate speed limits are pictured in Figure 1.4.

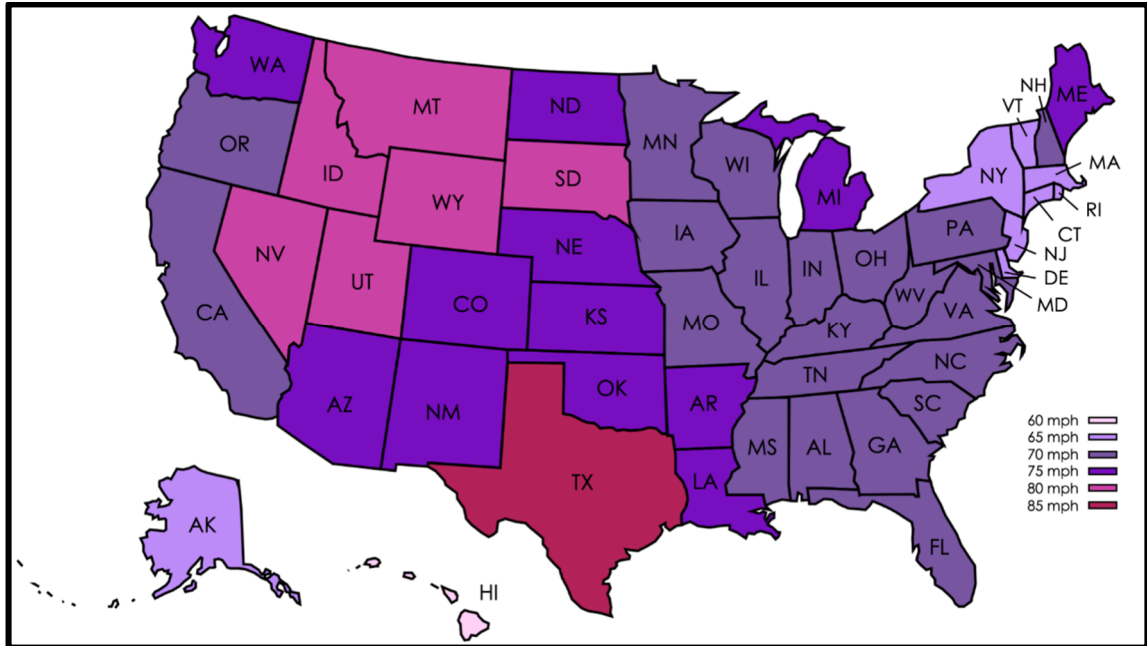


Figure 1.4: Current state rural, interstate speed limits (10, 19, 29-35).

State and Regional Speed Limits

When considering safety impact analyses of rural interstate speed limit increases, regional characteristics can also be a consideration, at least from a comparative, historical perspective. For example, geographical features such as the proximity to bodies of water or the presence of mountainous terrain often dictate slower speeds. Additionally, population density another factor. Figure 1.5 presents states in a regional format and Tables 1.1 through 1.7 list the rural interstate speed limits for individual states and geographic considerations for each region.

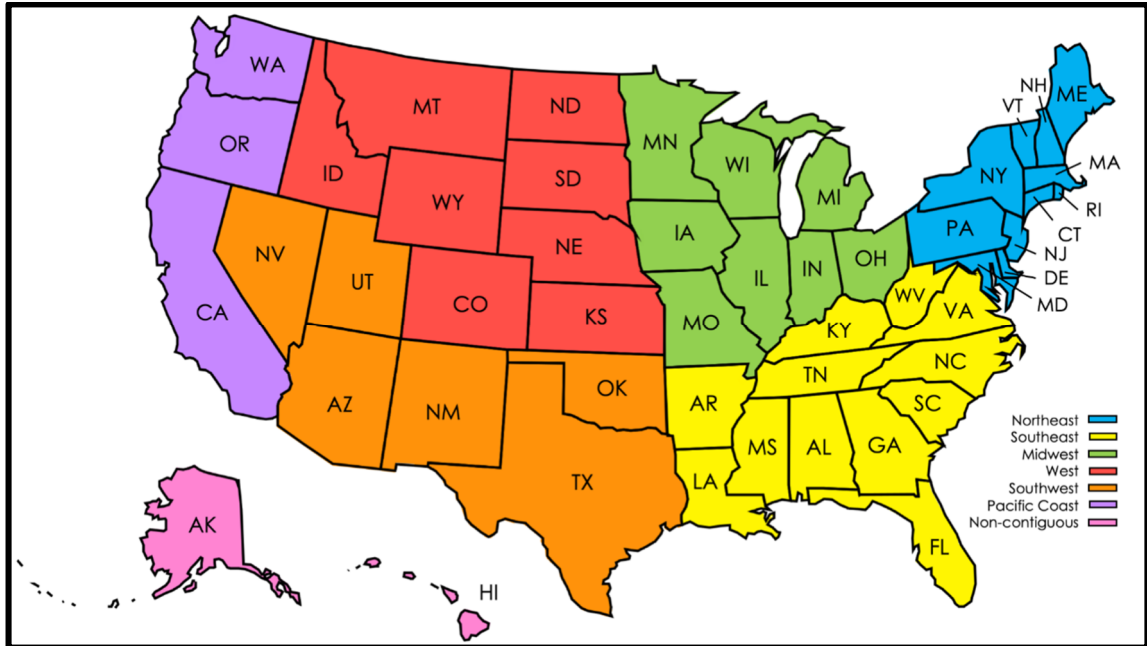


Figure 1.5: Regional map of the United States.

Northeast: Northeast states consist of Connecticut (CT), Delaware (DE), Maine (ME), Maryland (MD), Massachusetts (MA), New Hampshire (NH), New Jersey (NJ), New York (NY), Pennsylvania (PA), Rhode Island (RI), and Vermont (VT). Rural interstate speed limits in northeastern states are lower than most western states, with a majority set at 65-mph. This is likely due to greater urbanization of land than other regions, large percentages of forest-use land, and the proximity to the Atlantic Ocean (36). Higher population density and longer settlement history for these states have also constrained high speed roadways. Climate for the region is divided between the colder, more snow prone Pennsylvania, New York, and New England states (CT, MA, ME, NH, RI, VT) and the warmer coastal states (37). Speed limits for rural interstates in northeast states are outlined in Table 1.1.

Table 1.1: Rural Interstate Speed Limits for Northeast states (38).

| Rural Interstate Speed Limit | States |
|------------------------------|----------------------------|
| 65 mph | CT, DE, MA, NJ, NY, RI, VT |
| 70 mph | DC, MD, NH, PA |
| 75 mph | ME |

Southeast: Southeast states consist of Alabama (AL), Arizona (AZ), Florida (FL), Georgia (GA), Kentucky (KY), Louisiana (LA), Mississippi (MS), North Carolina (NC), South Carolina (SC), Tennessee (TN), Virginia (VA), and West Virginia (WV). Rural interstate speed limits in southeastern states are 70-mph, except in Arkansas and Louisiana where rural limits are 75-mph. Geography varies from the Appalachian Mountains with forests in the eastern section of the region to the Florida Everglades and Louisiana swamplands in the southeastern and southwestern sections (37). Additionally, the Mississippi River is a major waterway and defines the borders of several southeastern states. Predominantly, southeast states have a humid subtropical climate, but some southern areas of Florida do experience tropical temperatures and limited winter impacts (37). Rainfall is a major concern, especially during summer months when hurricanes start to form (37). The forests and swampland areas have restricted interstate development, but nearby surrounding plains made the geometric design for higher interstate speeds possible (37). Speed limits for rural interstates in southeast states are outlined in Table 1.2.

Table 1.2: Rural Interstate Speed Limits for Southeast states (38).

| Rural Interstate Speed Limit | States |
|------------------------------|--|
| 70 mph | AL, FL, GA, KY, MS, NC, SC, TN, VA, WV |
| 75 mph | AR, LA |

Midwest: Midwest states consist of Iowa (IA), Illinois (IL), Indiana (IN), Michigan (MI), Minnesota (MN), Missouri (MO), Ohio (OH), and Wisconsin (WI). Rural interstate speed limits for a majority of this region are 70-mph, except for Michigan with 75-mph limits. The northernmost states border Canada and the Great Lakes of Superior, Michigan, Huron, and Erie (39). The Mississippi and Missouri Rivers run through the area and form several borders of mid-western states as well (39). Overall, the region

ranges from flat plains on the west to more sloping land on the east with some forests in the north (39). Climate for this region is temperate, where all four seasons occur, but some areas experience harsh winters (39). Interstates are more frequent near the big cities of Chicago, Minneapolis, Kansas City, Detroit, and Indianapolis and sparser in the plains area due to lower population density. Speed limits for rural interstates in Midwest states are outlined in Table 1.3.

Table 1.3: Rural Interstate Speed Limits for Midwest states (38).

| Rural Interstate Speed Limit | States |
|------------------------------|----------------------------|
| 70-mph | IA, IL, IN, MN, MO, OH, WI |
| 75-mph | MI |

West: West states consist of Colorado (CO), Idaho (ID), Montana (MT), North Dakota (ND), Nebraska (NE), South Dakota (SD), and Wyoming (WY). Rural interstate speed limits for western states range between 75 and 80-mph, due to the abundant open plains land (36). The eastern states of this region are mostly plains with only the Missouri River as a major waterway presence (36). In the western section, the main geographic feature is the Rocky Mountains which limit interstate development (36). The few interstate segments that do traverse the mountainous section have reduced speed limits due to the physical terrain (36). Western state climate varies from the more temperate seasons of the plains sub-region to the heavy snowfall alpine climate of the Rocky Mountain states (36). States in the western U.S. have generally been early adopters of higher rural interstate speed limits due to the large areas of open land and fewer large cities. Speed limits for rural interstates in West states are outlined in Table 1.4.

Table 1.4: Rural Interstate Speed Limits for West states (38).

| Rural Interstate Speed Limit | States |
|------------------------------|----------------|
| 75 mph | CO, ND, NE |
| 80 mph | ID, MT, SD, WY |

Southwest: Southwest states consist of Arizona (AZ), New Mexico (NM), Nevada (NV), Oklahoma (OK), Texas (TX), and Utah (UT). Rural speed limits range between 75-mph and 85-mph for interstates in this region. These states have an arid climate with deserts that encompass thousands of square miles (40). While Texas and Oklahoma have dryer land sections, their climate also includes humid subtropical weather due to their location in relation to the Gulf of Mexico (40). These states are similar to the West states because there are vast amounts of land that are suitable for high speed interstate roadways (40). Arizona and New Mexico are limited by rockier terrain because of nearby mountains and other physical attributes like the Grand Canyon (40). Speed limits for rural interstates in Southwest states are outlined in Table 1.5.

Table 1.5: Rural Interstate Speed Limits for Southwest states (38).

| Rural Interstate Speed Limit | States |
|------------------------------|------------|
| 75 mph | AZ, NM, OK |
| 80 mph | NV, UT |
| 85 mph | TX |

Pacific Coast: Pacific Coast states consist of California (CA), Oregon (OR), and Washington (WA). Rural interstate speed limits are set at 70-mph and 75 mph for Washington. The Pacific Northwest sub-region contains several mountain ranges, coastline, and dry plains (36). The climate varies from a Mediterranean setting on the west to semi-arid on the east. Interstates in this area follow large cities near the coast and avoid mountainous terrain (36). This allows for some stretches of higher speed roadways with some constraints (36). California experiences climate of alpine in the north, temperate in the middle portion, and subtropical in the south (36). Physical attributes include the Sierra Nevada mountain range, deserts in the south, and coastline (36). Similar to the Pacific Northwest, California has areas that allow for higher speed

interstates, but mountainous sections and more urbanized cities restrict these speeds (36).

Speed limits for rural interstates in Pacific Coast states are outlined in Table 1.6.

Table 1.6: Rural Interstate Speed Limits for Pacific Coast states (38).

| Rural Interstate Speed Limit | States |
|------------------------------|--------|
| 70 mph | CA, OR |
| 75 mph | WA |

Non-Contiguous: Non-Contiguous states consist of Alaska (AK) and Hawaii (HI). Rural interstate speed limits are much lower than mainland states, with a 60-mph limit in Hawaii and a 65-mph limit in Alaska. These slower speeds are due to the unique and atypical physical characteristics of the region. Hawaii consists of 8 main tropical islands which vary in size from about 4,000 to 45 square miles and are home to several volcanoes (41). Honolulu is the only island to carry an interstate, which runs from city centers to tourist attractions like beaches, parks and visitor centers (41). Alaska is the largest state in the union with a climate that varies from oceanic on the south to sub-arctic and tundra in the northern section (42). Due to a low population density, Alaska has very few roadways (42). The four interstate roads that do exist link major population areas together, as well as provide a route to enter Canada (42). Speed limits for rural interstates in Non-Contiguous states are outlined in Table 1.7.

Table 1.7: Rural Interstate Speed Limits for Non-Contiguous states (38).

| Rural Interstate Speed Limit | States |
|------------------------------|--------|
| 60 mph | HI |
| 65 mph | AK |

Thesis Organization

The remainder of this thesis is organized in the following manner:

Chapter 2 provides a literature review that covers the research conducted throughout the history of the interstate highway system and specifically the State of Iowa's interstates and the thesis motivation and objectives.

Chapter 3 details the methodology of the data collection. The computer programs used to collect and develop the data for analysis will be discussed as well as the specific methods to used filter the desired crash and road data.

Chapter 4 explains linear regression modeling using qualitative variables, the statistical analysis process utilized for this thesis. The fundamental aspects of this statistical method will be discussed, as well as specific model elements related to this research.

Chapter 5 examines the results of the linear regression modeling on the selected variables.

Chapter 6 summarizes the results and presents recommendations for future research efforts.

CHAPTER 2. LITERATURE REVIEW

Many traffic safety research efforts have studied the frequency, severity, and crash type occurring on interstate road systems (2, 3, 8, 10, 11, 13, 14, 16-18, 28, 43, 44). Crash occurrence is categorized depending on each analysis but generally involves determining the frequency, density, or crash rate on a roadway or roadway system (10). Some analyses focus on crash frequencies but these may fail to account for impact of distance. Others consider crash density with the addition of a mileage factor (e.g., crashes/mile), while several study crash rates by including both volume and mileage (e.g., crashes/vehicle-miles travelled (VMT)). Crash severity identifies the seriousness of injury related to each crash, with crashes often categorized as fatal injury, major injury, minor injury, possible/unknown injury, and property damage only (PDO) (10). Crash type analysis differentiates crashes by various categories including, vehicle (e.g., vehicle configuration and type), driver (e.g., driver age and gender), roadway (e.g., roadway system and number of lanes), and environmental (e.g., lightning and weather conditions), among other fields.

The following literature review will discuss studies conducted for the various changes in interstate speed limits in the U.S. to provide historical context to understand how researchers have approached this subject in the past. In addition, previous research in the state of Iowa regarding its interstate crash history is examined as Iowa is the focus of this thesis.

Analytical History

National Maximum Speed Limit (NMSL)

Prior to the era of federal speed limit control, most states had a rural interstate speed limit at or above 70 mph. Iowa had an established rural interstate speed limit of 75 mph (9). In the wake of the 1973 oil embargo, the federal government passed the National Maximum Speed Limit (NMSL) which reduced maximum speed limits to 55 mph (7, 10, 13, 45, 46). The measure failed to deliver significant fuel conservation savings but was maintained due to observed positive traffic safety impacts (10). During the following decade, researchers explored whether the 55-mph speed limit resulted in these crash severity reductions. In 1976, Burritt studied the crash counts and rates following the authorization of the NMSL and noticed a decline in all crash severity rates linked to reduced speeds and speed variations (10, 47). Further research also concluded that the 55-mph speed limit helped provide the observed safety benefits, other than a study by Labrum and Weckesser et al. that could not make any distinct conclusions from the available data (10, 48-54).

While fuel shortages initially encouraged compliance in the 1970s, drivers began ignoring the 55 mph speed limits when the concern dissipated during the 1980s (15). Forester et al. examined NMSL impacts from the perspectives of cost-benefits and safety. They determined that the NMSL-induced speed variation reduction was the most significant reason for decline in fatalities but recommended a discontinuation of the law due to the travel time increases (53). A more comprehensive research effort conducted by the Transportation Research Board (TRB) noted reductions of 2,000 to 4,000 annual fatalities, fuel consumption savings of roughly 2%, and \$65 million in annual tax payer

savings, as well as noted dis-benefits (6, 9). Dis-benefits included an estimated 1 billion additional driving hours and additional enforcement costs of about \$118 million annually (6, 9). Despite that, TRB recommended maintaining the NMSL at 55-mph and cautioned that there would be trade-offs for higher speeds if the law was altered (9).

Surface Transportation and Uniform Relocation Assistance Act (STURAA)

The observed motorist disobedience caused both law enforcement agencies and public officials to advocate for raising the speed limit (32). Their insistence led to the passage of the Surface Transportation and Uniform Relocation Assistance Act (STURAA) in 1987, where all but five states relaxed their speed limits to 65 mph in rural areas (10, 16-18, 21) per Figure 1.2. Iowa was an early adopter of the law and raised its speed limit on May 12th, 1987 (18).

Researchers noticed a variety of trends that depended on the amount of time the study occurred after the relaxation, statistical modeling approach, and the inclusion of certain factors such as vehicle miles traveled (VMT) or traffic volumes. Baum et al. studied the amount of fatalities in the 38 states that raised their speed limits in 1987 after the first two years of implementation and found a fatality increase of 15% in year one, followed by an increase of 26% in year two (2, 10, 18). In 1991, Baum estimated that fatalities increased by 29% and the crash rate by 19% in states with the 65-mph limit, as opposed to 12% fewer deaths in those that kept the 55-mph limit (10).

Several studies observed fatality occurrences in a single state that had raised its speed limit to 65-mph (2, 3, 8, 55-59). The increases in fatalities were observed at anywhere from 18% in Alabama to 93% in New Mexico (2, 3, 8, 23, 55-56). The New Mexico study used rural interstate crash data from 1982-1988 to form a linear trend

regression and to compare fatal crash rates before and after the speed limit increase (10, 55). They concluded that the rate comparison meant that the 65-mph speed limit led to increased fatality rates (10, 55). Rock studied Illinois rural highways and found increases of 33%, 40%, and 19% for crashes, fatalities, and injuries respectively after the speed limit was raised (8, 10). Another study found that the fatal crash rate on rural interstates in Washington rose 110% more than would have been expected had the 55-mph limit had been maintained (2). Although the fatal crash rate did increase, it was noted that the total crash rate showed minute changes, indicating that only fatal crashes were on the rise (2).

Iowa road safety was also specifically analyzed during this period. Ledolter and Chan observed crash data covering before and after the legal changes from 1981 to 1991 (3, 10). Their analysis found statewide changes of a 20% increase in fatal accidents but a 37% reduction in major-injury accidents. They also found a 57% increase in fatal accidents on rural interstates specifically, the only segments where the limit was raised (3, 10). They concluded that the raised (to 65 mph) speed limit led to these fatal crash increases but other factors such as driver age and gender, road and weather conditions, and vehicle type could potentially impact their findings (3). A similar study was conducted by Muniandy. This study also indicated that fatal crash increases were due to the raised speed limit (21).

Conversely, some have argued that the increased speed limit saved lives (10, 17, 25). These researchers suggest that while fatalities or crashes increase on interstates, the overall fatality or crash rates decrease (25). Lave and Elias argue that the speed relaxation has saved lives by shifting traffic to the better engineered interstates more desirable with faster legal speeds and improved safety (10, 17). They investigated the statewide effects

of raising the speed limits by focusing on fatality rates instead of amounts by examining all road systems to explore the net effect of the 65-mph limit (17). They determined that the raised speed limits on interstates reduced overall statewide fatality rates by 3.4% to 5.1%, although those rates might have increased slightly on rural interstates themselves. They attributed this result to traffic shifts to interstates (10, 17, 23). Similar results were observed in Arizona, and other nationwide studies (10, 23, 60-62).

National Highway System Designation Act (NHSDA)

After over 20 years of federal influence, states regained that authority to set speed limits in 1995 when President Clinton signed the National Highway System Designation Act (NHSDA) into law (9-11, 13, 28). Many states increased rural interstate speed limits in response per Figure 1.3. However, similar to several adjoining mid-western states, Iowa initially maintained the 65 mph limit (19). However, in 1996 the Iowa legislature permitted the Iowa DOT to increase speed limits to 65 mph on certain divided, multi-lane highways (10). This action led to the implementation of the 65 mph speed limit on 248 miles of highway in 1996 and an additional 680 miles of rural freeways and expressways by 2001 (10). Studies from mid-1996 through 1997 determined that all crash rates increased by at least 20% (10). Fatal crashes and fatalities significantly increased by 497% and 587% respectively (10). Those are not specifically interstate crashes and non-interstate freeway crash rates were 2 to 3 times greater than interstate crash rates (10).

Analogous to post-STURAA, many research efforts were conducted following the repeal of the NMSL (10, 28, 63-66). As with the earlier studies on the 65-mph limit, several estimated increases in fatality rates, while some noted improved safety conditions (10, 28, 63-66). Farmer et al. compared rates on all highways using data from 24 states

that raised their speed limit and 7 states that did not (10, 63). They found a comparative 17% fatality rate increase in states with higher limits (10, 63). Patterson et al. observed 12 states that maintained their pre-repeal speed limits, 12 states that raised the limit to 70-mph, and 10 states that raised to 75-mph (10, 64). Their analysis yielded a 35% to 38% increase in the fatality rate in states that had a 70 or 75-mph speed limit (10, 64). Najjar et al., on the other hand, observed crash data on Kansas highways from 1993 to 1998 (excluding 1996) and found no statistically significant changes in crash, fatal crash, or fatality rates for urban or rural interstates (66).

State DOTs were also interested in the impacts of these increases and many performed (10). States including Arkansas, Iowa, Louisiana, Michigan, New Jersey, New Mexico, and Texas all experienced increases in fatality and injury crashes but not necessarily in total crashes (10). On the other hand, a New York study found that that total, fatal, and injury crash rates had declined by 4%, 29%, and 5% respectively (10).

Iowa Post-Repeal

Following 18 years of no increases beyond 65 mph, Iowa raised the rural interstate speed limit to 70 mph on July 1st, 2005 (19, 67). Four years later, Souleyrette studied the effects of the increase to 70 mph for 2.5 years after the change (67). This evaluation was more extensive than previous efforts in Iowa, which largely focused on crash and fatality rates. Two studies were conducted, a shorter study consisting of 2 years of before and 18 months of after data and a longer study with 14.5 years of before data and 2 ½ years of after data. The observed interstate highways are outlined in Figure 3.1.

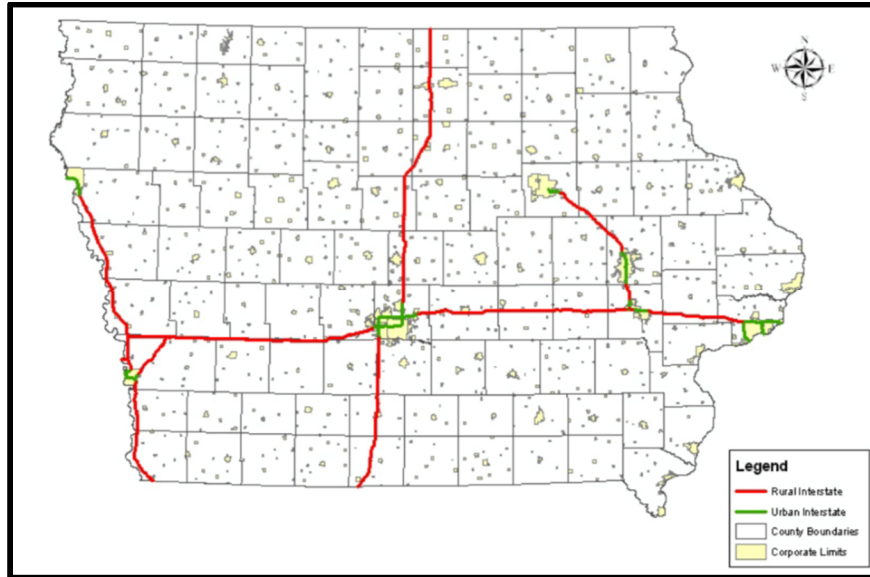


Figure 2.1: Interstate study sections used in Souleyrette 2009 study (67).

For the shorter study, changes in speeds, traffic volume on and off the rural interstate system, and safety for on and off system roads were studied (67). Subsequent to the 70-mph limit, Souleyrette determined that speed non-compliance decreased by about 12%, volumes increased about 5%, and there was no evidence of traffic diversion from off-system roads to rural interstates (67). For safety impacts, the following observations were made about specific interstate segments:

- Rural I-35 sections had increased frequencies.
- I-80 frequencies remained stagnant.
- I-35 south of Des Moines saw the fatal to total crash ratio more than double compared to the other Iowa major rural interstates.

The longer study consisted of a rural interstate crash analysis focusing on severity and frequencies. Additionally, daytime, nighttime, and cross-medians crashes were observed (67). Fatal crashes on rural interstates rose 31.3% and fatalities increased 13.6% (67). Table 3.1 contains the findings for each category for the longer study. Souleyrette

notes that the report is limited by a short 2 ½ after period, as well as high fuel prices and the Great Recession (67).

Table 2.1: Safety Impacts on Iowa Rural Interstates after 70 mph speed limit implementation (67).

| Crash Type | Annual Average Frequency Increase (2.5 years before and after) | Percentage Increase | Annual Average Frequency Increase (14.5 years before and 2.5 years after) | Percentage Increase |
|----------------------------------|--|---------------------|---|---------------------|
| Fatal | +6.0 | 31.3% | +4.5 | 21.8% |
| Serious (Fatal and Major Injury) | +12.0 | 15.2% | -12.2 | -12.1% |
| Nighttime | +2.0 | 26.3% | 1.32 | 16.0% |
| Serious Nighttime | +0.4 | 1.2% | -8.80 | 20.5% |
| Fatal Cross-Median | +4.0 | 76.9% | +3.87 | 72.5% |
| Serious Cross-Median | +5.6 | 58.3% | +6.8 | 80.0% |
| All Cross-Median | +14.8 | 31.6% | +15.4 | 33.3% |
| All Nighttime-Cross Median | +4.8 | 31.6% | +5.1 | 34.3% |

Another study published at that same time investigated the long-term impact of repealing the NMSL on fatalities and injuries through 2005 (13). Rural interstates between 1990 and 2005 were found to have a 9.1% increase in fatalities and an 11.88% increase in injuries in fatal crashes (13). Friedman also categorized results by the following categories in relation to fatalities and injuries in fatal crashes: expansion with no change (65-mph), increased 10 mph only after 1995-1996 (65-mph), expansion and 5 mph increase (70-mph), and expansion and 10 mph increase (75-mph) (13).

The results related to Iowa's situation (i.e. expansion with no change and expansion and 5-mph increase) are shown in Table 3.2 (13). His results show that for states such as Iowa that maintained a 65-mph speed limit after the 1995 repeal, fatalities and injuries decreased by about 8% and 4% (13). States that expanded the 65-mph limit and then increased it to 70-mph experienced an increase of 8% and 17% in fatalities and injuries, respectively (13). It should be noted that the data used for calculations in the

latter category does not directly apply to Iowa because the rural interstate speed limit was 65-mph throughout the observed time period. The expansion and 5 mph increase data was included because it is related to Iowa's current speed limit situation and indicates potential long-term impacts.

Table 2.2: Fatality and Injury in Fatal Crashes on Rural Interstates: 1990-2005 (13).

| Crash Type | No. of States | Percentage Change (%) |
|---------------------------------------|---------------|-----------------------|
| Fatalities | | |
| Expansion with no change (65 mph) | 10 | -8.43 |
| Expansion and 5 mph increase (70 mph) | 18 | +8.25 |
| Injuries | | |
| Expansion with no change (65 mph) | 10 | -3.84 |
| Expansion and 5 mph increase (70 mph) | 18 | +17.17 |

Thesis Motivation/Objective

Since the Kockelman synthesis in 2006 (10), few in-depth efforts regarding speed limits have been undertaken. During this time, several western states (e.g. South Dakota and Wyoming) have since raised their rural interstate speed limit to record high levels while other states have not altered their limit for over a decade (67). Based on these conditions, research should be conducted to determine the effects of the newer higher rural interstate speed limits and the long-term impacts of rural interstate speed limit increases.

Due to the readily available data and a significant time lapse since the last increase, this research effort observed the long-term impacts of rural speed limit increases in the state of Iowa. With 13 years of data available since the increase, the long-term impacts were able to be studied in great detail. Iowa last increased its rural interstate speed limit on July 1, 2005 to 70-mph (19, 67). This change marks a near return to its pre-NMSL rural interstate limit of 75-mph in the early 1970s (9).

Beyond the Souleyrette report 2 ½ years after the increase, no major effort has been conducted to analyze long-term 70 mph speed limit impacts. This study examined crash and road data from 2001 to 2018 using a long-term, multi-factor perspective analysis. The crash data analysis expanded previous studies by observing factors such as time, weather, manner of collision impact, vehicle configuration, and driver behavior in addition to crash severity and fatalities.

Overall, this endeavor synthesizes the traffic safety history of interstate speed limits and specifies issues resulting from those changes in Iowa. Ultimately, the goal of this thesis is to present useful information that can assist transportation engineers, traffic safety experts, legislators, and Departments of Transportation in making informed traffic safety decisions and provide a template for similar research in states across the nation.

CHAPTER 3. DATA METHODOLOGY

For both analyses, Iowa road data (geometric and traffic) from 2001 to 2015 and crash data from 2001 to 2018 were obtained. As the last Iowa legislative speed limit change occurred on July 1, 2005, 4 ½ years of data prior to the speed limit increase and 13 ½ years after the change are available. Both datasets contain geospatial references which facilitated relation of specific crashes to road location. The road data enabled reduction of the data to statewide interstate, rural interstate, and urban interstate, allowed for interstate segmentation, and contained the traffic volume attributes. The crash data contained attributes including crash severity, time, vehicle and driver characteristics, injury status, and environmental conditions and was used for the examination of specific issues related to those attributes. The functions of each dataset and the value of information contained therein will be explained more thoroughly for each analysis in the following sections.

During the 2001-2008 timeframe, two crash data confounding issues should be noted. The first issue is that Iowa significantly updated the statewide crash data report form effective January 1st, 2001 to compliant with Model Minimum Uniform Crash Criteria (MMUCC) (68) guidelines. This update caused reporting and collection/storage issues. Therefore, 2001 data may be less reliable than subsequent years. The second issue is related as the statewide crash data report form was again updated to be compliant with MMUCC 4th Edition (69) effective January 1st, 2015. This latter update modified many crash attribute fields significantly which caused observable aberrations. However, as Iowa is a Traffic and Criminal System (TraCS) (70) state with widespread use of

electronic reporting, the crash data quality is well regarded. Finally, road data quality has been standardized over the timeframe.

Software

Statistical Analysis System (SAS) 9.4 and ArcGIS were used reduce the road data to the interstate designations (i.e., statewide, rural, urban) and interstate commuter segments, and process the crash data related to these designations from a descriptive statistics standpoint. SAS was utilized to relate the data, generate frequency tables, and facilitate descriptive data analysis. Distinct steps within SAS included data importation, data subset development, crash data frequency generation, and multi-year consolidation over the 18-year timeframe from 2001-2018.

ArcGIS was subsequently used to produce statewide maps of the designated subsets. These maps are shown in Figures 3.1 through 3.3 for all observed networks.

Interstate Selection

The entire Iowa interstate system, consisting of a total of 783 miles, is shown in Figure 3.1. This network experienced an annual average of 4,109 crashes and an overall crash increase of 152% during the observed period. Speed limits across all Iowa interstates vary between 55 and 70 mph.

Rural Iowa interstates are shown in Figure 3.2. The mileage for the rural Iowa interstate network was 622 miles, nearly 80% of all Iowa interstates. This network experienced an annual average of 2,361 crashes and an overall 148% increase during the observed period. Speed limits for Iowa rural interstates have been set at 70 mph since July 1, 2005.

Urban Iowa interstates are shown in Figure 3.3. The mileage for the rural Iowa interstate network totals 161 miles, only 20% of all Iowa interstates. This network experienced an annual average of 1,766 crashes and an overall crash increase of 157% during the observed period. Speed limits for Iowa urban interstates range between 55 and 65 mph, depending on the geometric characteristics of the area (e.g., urban traffic levels and more dense interchange spacing).

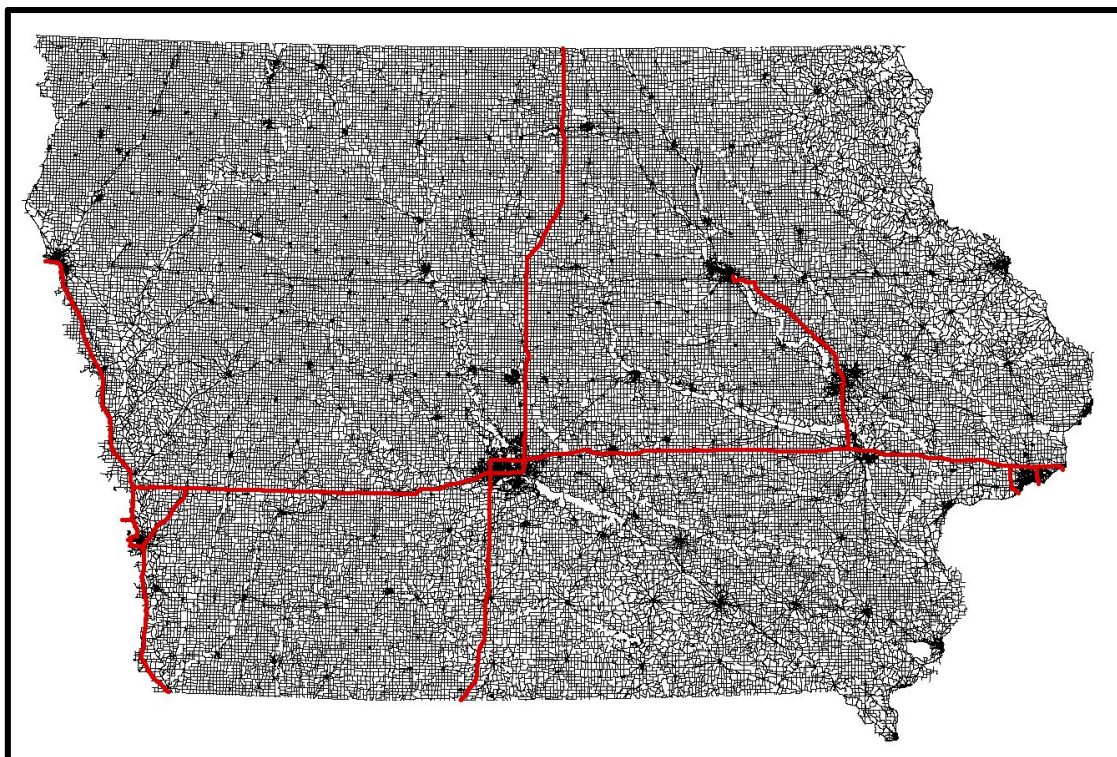


Figure 3.1: Statewide Iowa interstate network.

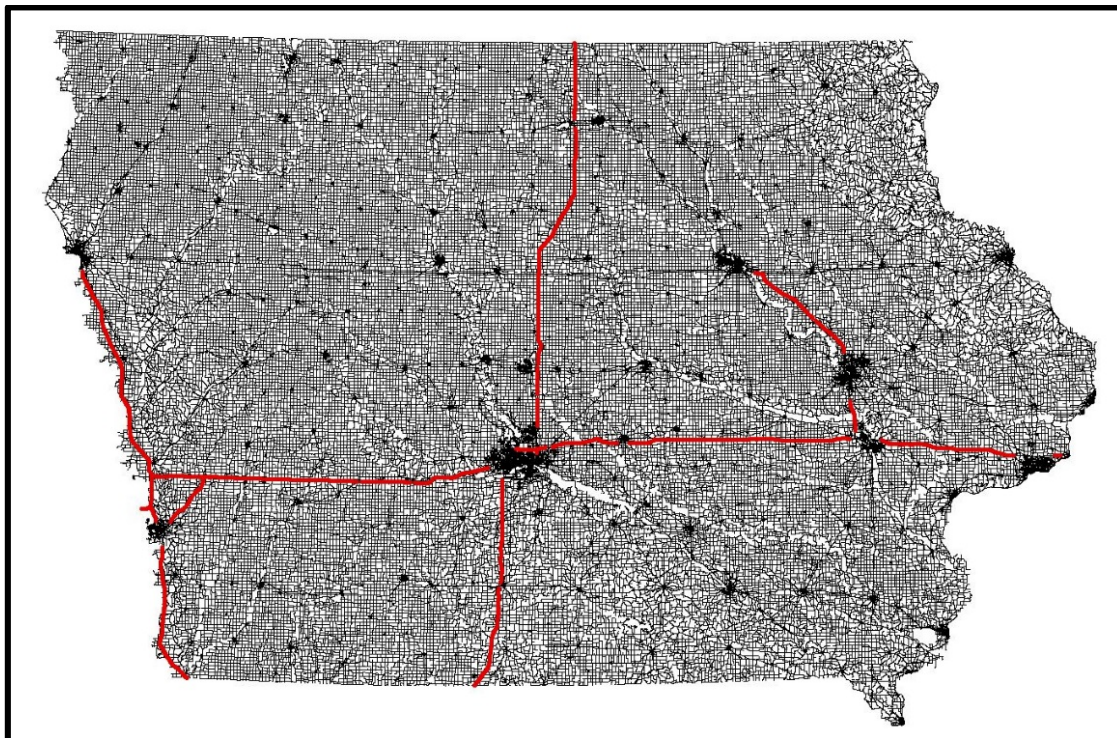


Figure 3.2: Rural Iowa interstate network.

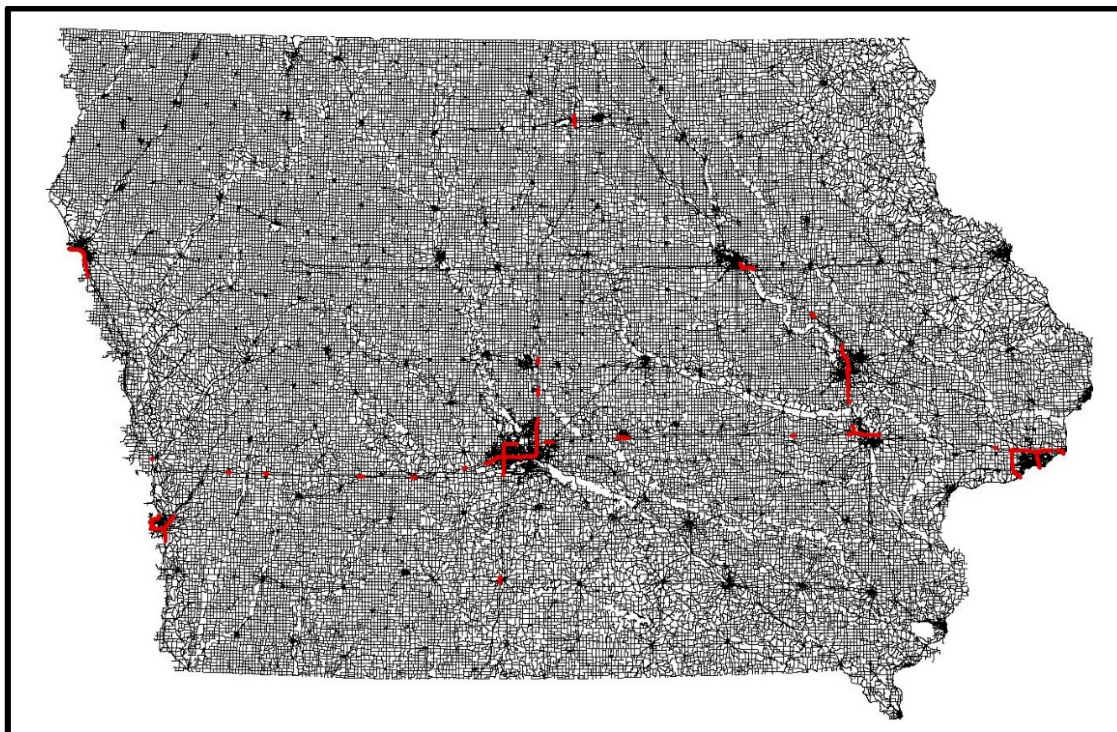


Figure 3.3: Urban Iowa interstate network.

Data Processing

In order to analyze the data, a series of functions were run in SAS. Data were imported and subset into categories then frequency tables were generated based on those subsets. The frequency tables were exported and permitted the development of descriptive statistics and trend graphs. The following sections outline those functions in greater detail.

Importation

Data importation involved both the importation of road data as well as crash data. For the road data, several tables exist but only the road, info, and traffic attribute tables were necessary. The road table specifies segment location and length, road system (e.g., interstate), and some general traffic data. The info table specifies whether the roadway section is within a city, on the edge of a city, or outside a city; the section access control level (e.g., fully controlled access); and whether the segment is a mainline or ramp section. The traffic data contains more detailed vehicle configuration-specific traffic data. Several fields imported and utilized in this analysis for road, info, and traffic dataset are shown in Table 3.1.

Table 3.1: Fields utilized from road, info, and traffic datasets in analysis.

| Road | Info | Traffic |
|---------------------|--------------------------|------------------------------|
| MSLINK | MSLINK | MSLINK |
| COUNTY NUMBER | IOWA CITY NUMBER | YEAR TRAFFIC COUNTED |
| JURISDICTIONAL CODE | CORP LINE CITY NUMBER | AVERAGE ANNUAL DAILY TRAFFIC |
| SYSTEM CODE | URBAN AREA CODE | MOTORCYCLES |
| ROAD NUMBER | FUNCTION CODE | AUTOMOBILES |
| ROAD NUMBER | ACCESS CONTROL | PICKUPS AND VANS |
| X COORDINATES | FEDERAL FUNCTIONAL CLASS | BUSES |
| Y COORDINATES | | 2 AXLE SINGE UNIT |

For the crash data, several more tables exist but, based on an extensive review of the available fields within these tables, only the crash type, driver characteristic, environmental condition, injuries, location/time, severity, and vehicle characteristic tables were included. These tables were selected because the contained fields held potentially interesting information and some were not typically covered in other speed limit studies. The initially selected crash tables and crash fields are shown in Table 3.2. Within these crash fields, specific attribute values related to crash exist. For example, inside of the driver condition field, researchers can investigate drivers that were reported as “emotional” or “alcohol influenced”. As many crash field attribute values were explored throughout each analysis, only the selected values will be mentioned in subsequent sections within this chapter.

Table 3.2: Crash fields initially reviewed for analysis from the crash dataset.

| Crash Type | Driver | Environmental | Injuries | Location & Time | Severity | Vehicle |
|---------------------|----------------------------|----------------------------|---------------|-----------------|----------------|-----------------------|
| First Harmful Event | Age | Contributing Circumstances | Injury Status | Day | Crash Severity | Occupants |
| Major Cause | Age Bins | Light Conditions | | Lighting | Fatalities | Vehicle Action |
| Manner of Crash | Condition | Surface Conditions | | Month | | Vehicle Configuration |
| | Contributing Circumstances | Weather Conditions | | Time Bins | | |
| | Gender | | | Time of Day | | |
| | Licensure State | | | | | |

Subsets

Data subset development used the imported road and crash tables. Initially, the road tables were used to create a statewide interstate subset, a rural interstate subset, and an urban interstate subset. The subset code used the road table to identify interstate segments that were later limited to mainline, limited access sections, this latter

designation likely redundant. Beyond this initial, statewide interstate set was further refined to either urban or rural, with urban sections defined by those designated as within or on the boundary of a corporate boundary and rural sections as the opposite. Following identification of interstate roadway segments, these subsets were related to the crash data and the crash tables of interest were limited similarly by statewide, urban, and rural interstate-related.

Frequencies

Crash data frequency generation followed the data subset development using the data subsets created in the prior step. Using SAS, frequencies were run on selected attributes within the imported crash tables for the attribute fields shown in Table 3.2. By exploring the frequencies files, attribute fields that seemed interesting were filtered to only fields where trends were discovered that may be tied to the rural interstate speed limit increase.

Multi-year consolidation of the annual frequency result tables was the final SAS step. The individual datasets created by SAS for each year were merged and also merged to cross-match files that attached a brief data descriptor to each attribute field value, from which final output files were created.

The merged frequency files were used for the descriptive analysis. This analysis used these frequency files to create graphs that observed the trends between each interstate subset during the observed period for a crash field. Initial speculation regarding the relationship between the speed limit increase and various crash attributed fields was made based on observations from the trend graphs. Upon further review, specific issues were culled from that and investigated in more detail.

Speed Limit Increase Impacts on Crashes by Interstate Type

After an initial investigation of the aforementioned crash fields shown in Table 3.2, these entities were refined to only include fields deemed significant based on yearly trend graphs and to fields without complications in the data. Some of these attribute values were derived from Iowa's adoption of the new crash report forms mentioned in the introduction of this chapter. Other crash field issues were removed from further analyses because of insignificant frequencies or the lack of additional data to statistically correlate an issue to the speed limit increase. The final selection of crash fields is listed in Table 3.3 and the specific crash field values are presented categorically by crash table below.

Table 3.3: Selected crash fields from the crash dataset.

| Crash Type | Driver | Injuries | Location & Time | Severity | Vehicle |
|---------------------|----------------------------|---------------|-----------------|----------------|-----------------------|
| First Harmful Event | Age Bins | Injury Status | Month | Crash Severity | Vehicle Configuration |
| Major Cause | Contributing Circumstances | | Time of Day | | |

Crash Type: The crash type dataset contains fields that define crashes by movements, collisions with specified objects, and actions deemed responsible for the event by the reporting agency. Selected crash type field issues were first harmful event and major cause.

- First Harmful Event:** First harmful event is “the first injury- or damage-producing event of a crash” (68). Attribute values for this field are broken into “non-collision harmful events”, “collision with person, motor vehicle, or non-fixed object”, and “collision with fixed object” categories and detail crash events that ultimately aid in countermeasure selection (68). Specific first harmful events of interest include collision with vehicle in traffic, overturn/rollover, collision with guardrail face, collision with traffic barrier (median or right side), and collision with ditch.

- Collision with vehicle in traffic crashes were the most frequent for both rural and urban interstates. As shown in Figure 3.4, rural and urban interstate frequency trendlines were largely parallel with greater frequencies on urban interstates, which is not surprising giving generally higher traffic in urban areas. The linear arrow trendlines (shown in black) indicate that this event type has continued to rise for the entire 18-year period, with perhaps some potential different slopes before and after the 70-mph limit was implemented in 2005, perhaps some general decline from 2007 through 2011, and then perhaps some more pronounced increase from 2011 through 2018. However, visual inspection is inconclusive.

Both rural and urban interstate frequencies declined in 2006 following the rural interstate speed limit increase then sharply increased immediately after but then seem to have returned to normal trends. Statewide interstate frequencies declined nearly 19% in 2006 but increased by 44% the following year. Between 2007 and 2011, rural and urban frequencies slowly declined to recent lows only to gradually rise above the previous crash frequency record.

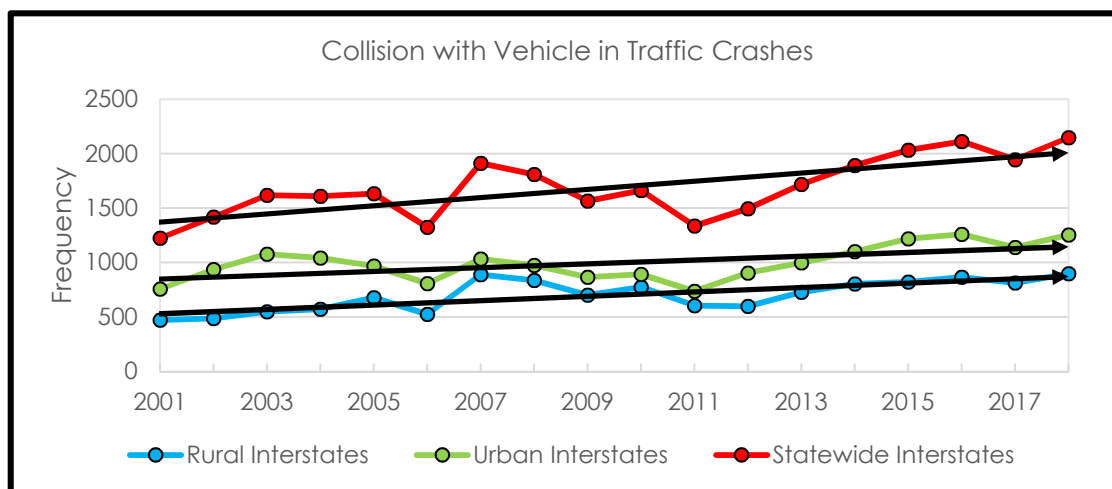


Figure 3.4: Collision with Vehicle in Traffic Crashes Yearly Trend Graph.

- Overturn/Rollover crashes are shown in Figure 3.5. Urban interstate frequencies remained constant throughout most of the observed period, with a slight decline from 2011 onwards. Rural interstates overturn/rollover crashes greatly fluctuated. Prior to the speed limit increase in mid-2005, frequencies increased annually by 10 to 25%. These crashes declined by 46% in 2006, one year after the implementation of the speed limit increase. Despite that decrease, 2007 saw overturn/rollover rural crashes increase by over 110% from 2006 levels but generally match the trend prior to 2006. For the following two years, frequencies remained relatively constant only to increase 43% to over 500 crashes in 2010.

Curiously, in 2011, overturn/rollover crashes decreased to less than half those of the prior year. Rural interstate frequencies of about 200 crashes per year were reported after the significant 2011 decline. These apparently significant declines in 2011 likely have nothing to do with the 2005 speed limit change but, rather, spark interest as a casual factor. It should be noted that the rural interstate frequency drop in 2001 was avoided in trendline analysis as the recorded amounts were possibly due to the of the 2001 Iowa crash report form change and associated reporting issues.

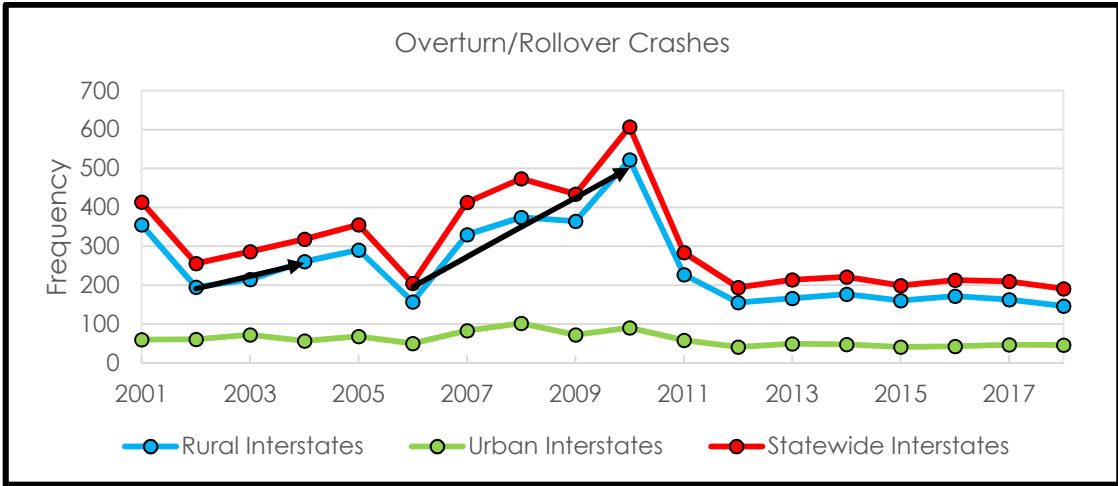


Figure 3.5: Overturn/Rollover Crashes Yearly Trend Graph.

- Collision with guardrail face crashes, shown in Figure 3.6, were fairly steady until 2006. After 2006, rural interstate frequencies experienced a steady increase to 334 crashes in 2014. Additionally, urban interstate frequencies increased 231% to 192 crashes in 2014. For this event all frequencies drop sharply to less than 100 crashes per year on both rural and urban interstates from 2015 onwards. This drastic adjustment was likely due to crash report form changes in 2015 that adjusted how these crashes were recorded.

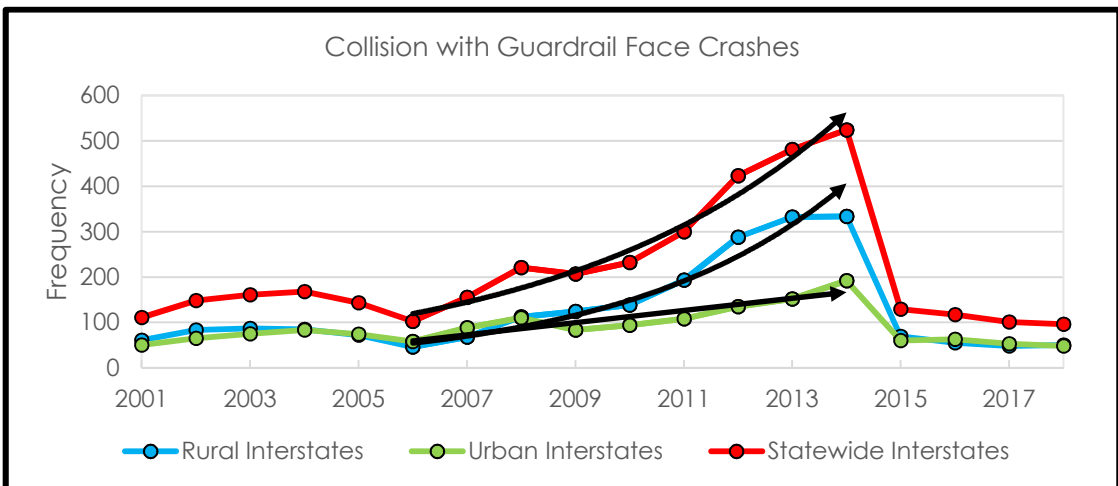


Figure 3.6: Collision with Guardrail Face Crashes Yearly Trend Graph.

- Collision with traffic barrier crashes frequencies are shown in Figure 3.7. Similar to other first harmful event attribute values, rural and urban interstate crashes declined to low records in 2006, only to rise 188% and 90% in 2007. While rural interstate frequencies have risen slightly throughout the 18-year observation period, crashes have largely remained at around 50 per year. Statewide and urban frequencies, however, have two distinct periods, highlighted by the average trendlines. Prior to the speed limit increase (2001 to 2004), urban interstate concrete traffic barrier crashes were averaging about 70 per year. Statewide interstate frequencies were slightly higher at nearly 100 crashes per year. Following the 70-mph speed limit increase (2006 to 2018), both average frequencies rose to about 125 and 170 crashes per year, respectively. While those are interesting developments, it should be emphasized that the rural interstate frequencies did not change significantly when the rural interstate speed limit was increased.

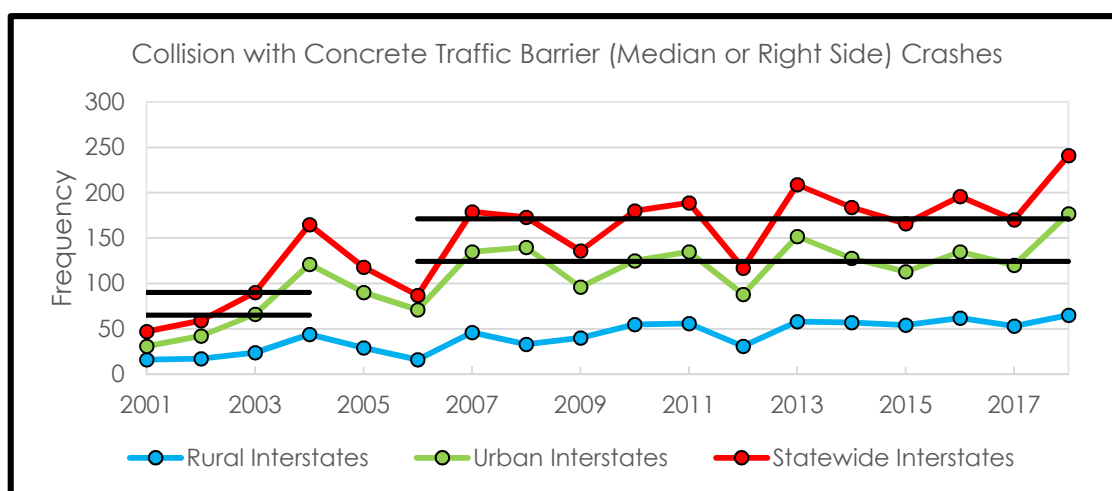


Figure 3.7: Collision with Concrete Traffic Barrier (Median or Right Side) Crashes Yearly Trend Graph.

- Collision with ditch crashes frequencies, presented in Figure 3.8, fluctuated most on rural interstates. Before the 70-mph speed limit (2001 to 2004), rural interstate ditch crashes averaged around 100 crashes per year. After the increase (2006 to 2018), these frequencies rose to about 125 per year and, based on 2018 records, appear to be rising again. This apparent jump occurred after the higher rural interstate speed limit implementation; thus, further statistical analysis of this issue is warranted.

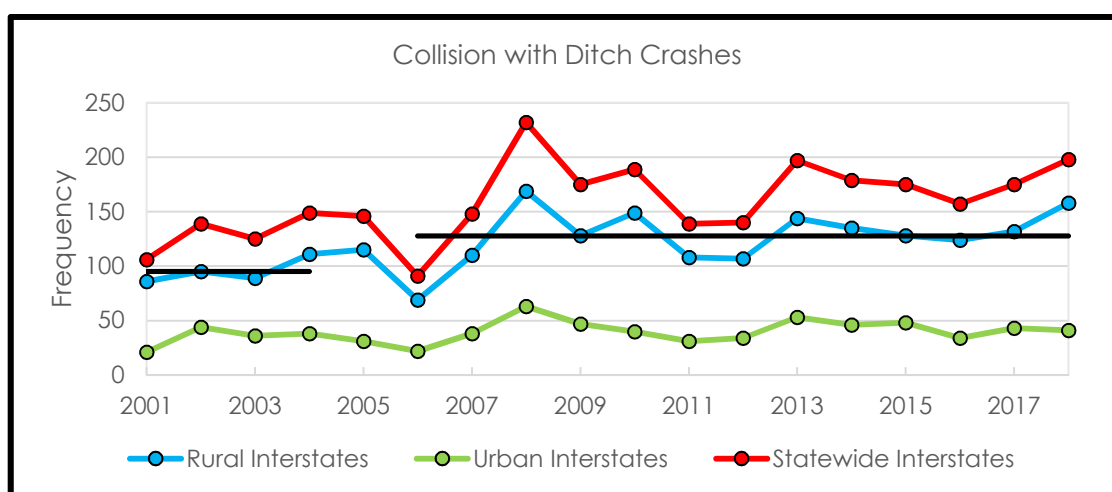


Figure 3.8: Collision with Ditch Crashes Yearly Trend Graph.

- **Major Cause:** Major cause is the action deemed most responsible for a crash and is a derived element based primarily on driver contributing circumstances. Major cause combines the driver contributing circumstances from all drivers involved in a crash into a single, most likely, cause of a crash. Major cause elements can range from running a stop sign to the presence of an animal. Major cause was retained for analysis because it is the most significant reason for the occurrence of a crash and indicated the common problems experienced by drivers. Selected attribute values were driving too fast for conditions crashes, improper/erratic lane changing crashes, following too close crashes, lost control crashes, and ran off road crashes.

- Driving too fast for conditions crash frequencies are shown in Figure 3.9. Average trend lines were added to all interstate types and separated into two periods, prior to the 70-mph speed limit (2001 to 2004) and after the increase (2006 to 2018). Average frequencies in the early period were much lower, about 175 crashes per year for rural and urban interstates. The latter period average crashes increased by 86% on rural interstates and 50% on urban interstates. Statewide, crash averages went from about 300 crashes per year to 550 crashes per year after the speed limit increase.

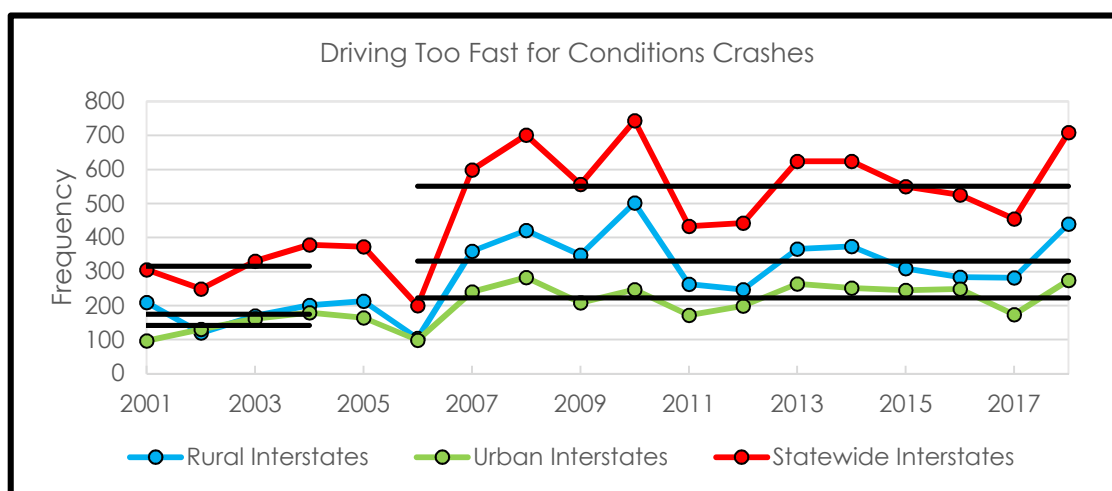


Figure 3.9: Driving Too Fast for Conditions Crashes Yearly Trend Graph.

- Ran off road crash frequencies are shown in Figure 3.10. Notable changes occurred in both roadway systems around the time of the speed limit increase. Frequencies decreased slightly in 2006 and increased again in 2007 and 2008. Rural and urban interstate ran off road crashes were nearly identical until 2015, when rural crashes overtook urban frequencies by about 200 crashes per year through 2018. Average trend lines on the graph showcase this trend as rural interstate frequencies increased at a greater rate from 2012 to 2018 than urban interstates.

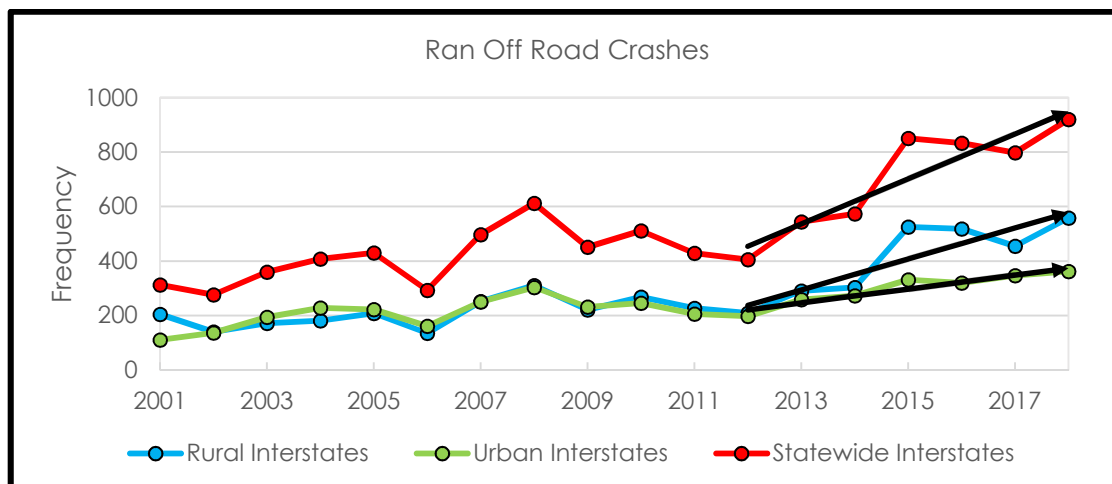


Figure 3.10: Ran Off Road Crashes Yearly Trend Graph.

- Following too close crashes, shown in Figure 3.11, displayed similar trends with the exception that urban interstate frequencies were typically about 100 crashes per year greater than rural interstate frequencies through 2011, which is not unexpected given the generally higher volumes and smaller headways. From 2011 onwards, frequencies among each interstate grouping steadily increased with urban interstate following too close crashes increasing slightly more than those on rural interstates. While this trend is interesting, more crashes of this nature occurred on urban interstates and the uptick in frequencies began 6 years after the rural interstate speed limit increase so it may not be that applicable to the 70-mph speed limit.

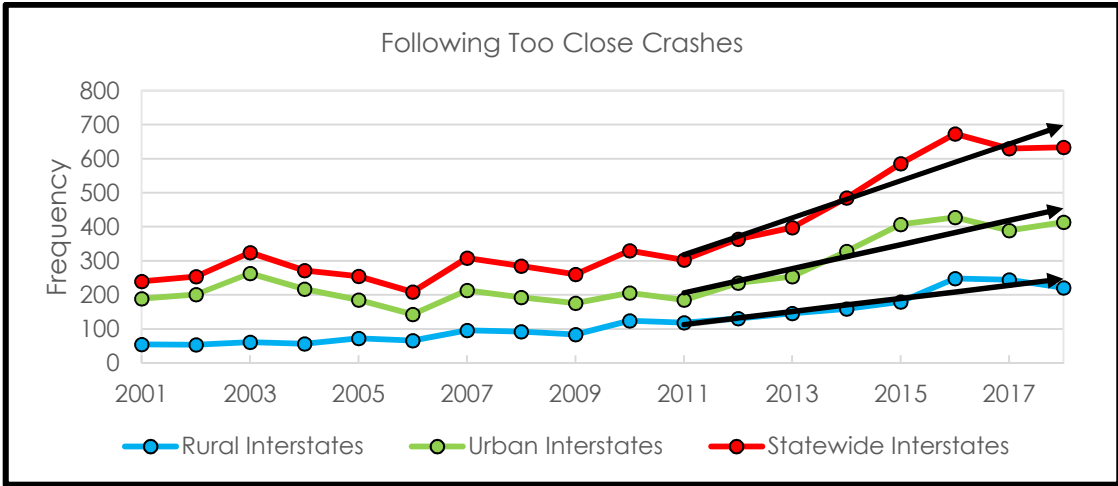


Figure 3.11: Following Too Close Crashes Yearly Trend Graph.

- o Lost control crash frequencies are shown in Figure 3.12. This major cause attribute value was more prominently observed on rural interstates and thus experienced a more significant frequency decrease in 2006 and increase in 2007 than urban interstates. On average, both rural and statewide interstate lost control crashes gradually increased about 40% to 50% in the period after the 70-mph speed limit was implemented (2006 to 2018).

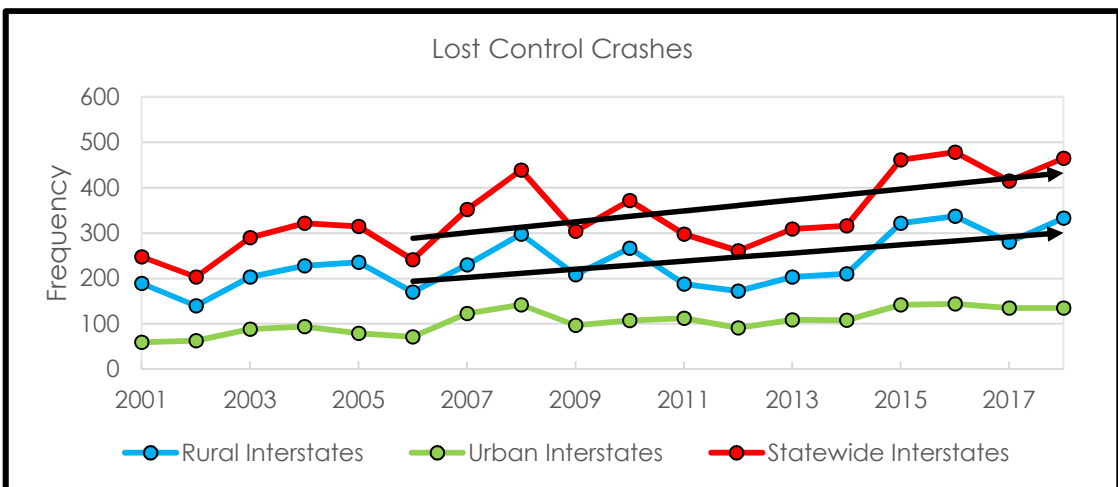


Figure 3.12: Lost Control Crashes Yearly Trend Graph.

- Improper/erratic lane changing crash frequencies are shown in Figure 3.13. Until 2013, these crashes were insignificant, with only about 50 statewide frequencies per year. This changed by 2018, when both rural and urban interstate frequencies soared by 345% and 200% respectively from 2013. While this increase could be due to the introduction of the 2015 Iowa crash report form, this uptrend had started prior to that. However, this does not seem related to the 2005 speed limit increase.

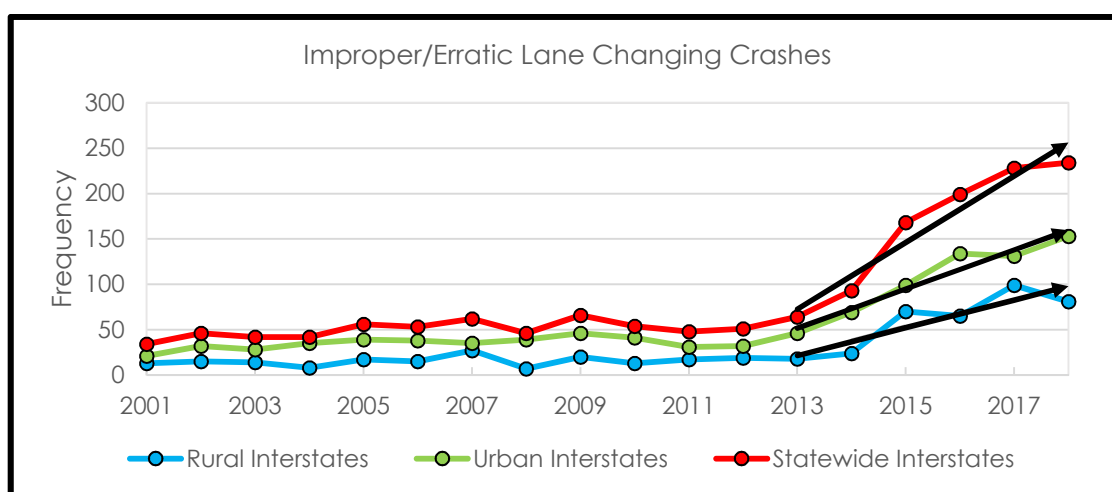


Figure 3.13: Improper/Erratic Lane Changing Crashes Yearly Trend Graph.

Driver: The driver dataset provides information about drivers involved in crashes (e.g. age, gender, or condition). Selected driver crash fields included driver age bins and driver contributing circumstances.

- **Driver Age Bins:** Driver age bins condense driver age frequencies into 5-year age bins. These frequencies indicate drivers involved with crashes for a specified age group. The bins were utilized for analysis instead of individual ages to simplify the process. In addition to 5-year driver age summarizations, the bins were combined into young, middle-age, and old drivers to showcase trends among more general age groups.

Based on the yearly trend graphs shown below, the changes of 5 distinct periods were noted for each generalized group. These include 2001-2004 (pre 70-mph rural speed limit increase), 2005-2006 (during/directly after implementation decrease), 2006-2007 (one year following implementation increase), 2010-2011 (notable decrease), and 2011-2018 (recent long-term increase). Yearly trend graphs for young, middle age, and older drivers are shown in Figures 3.14 through 3.16 and frequency changes in these age groups for the previously mentioned time periods are presented in Tables 3.4 through 3.7.

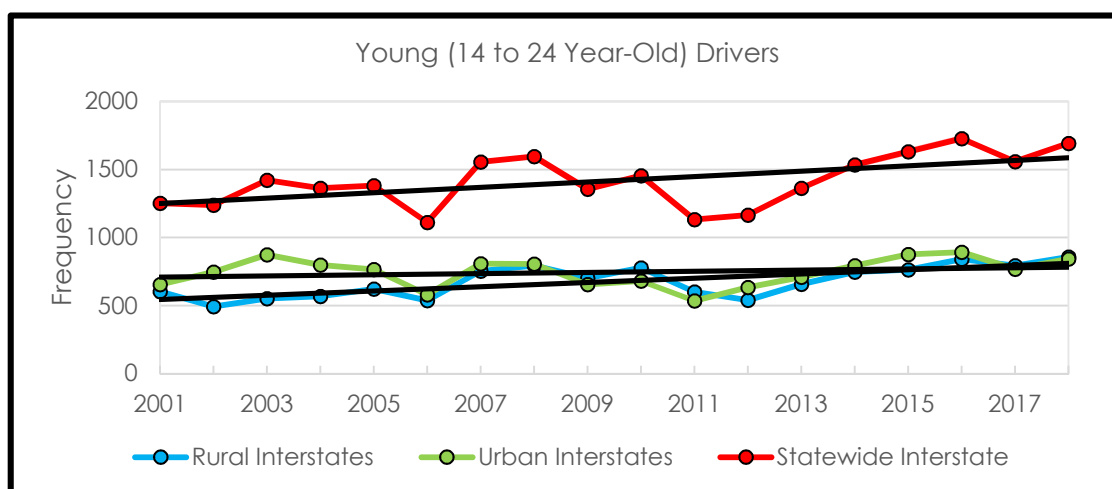


Figure 3.14: Young (14 to 24 Year-Old) Drivers Involved with Crashes Yearly Trend Graph.

Table 3.4: Young Driver changes in frequencies among distinct periods.

| Time Period | Rural | | Urban | | Statewide | |
|-------------|---------------------|--------------------------------|---------------------|--------------------------------|---------------------|--------------------------------|
| | Change in Frequency | Percentage Change in Frequency | Change in Frequency | Percentage Change in Frequency | Change in Frequency | Percentage Change in Frequency |
| 2001-2004 | -34 | -5.6% | +145 | +22.2% | +57 | +8.8% |
| 2005-2006 | -84 | -13.5% | -187 | -24.4% | -72 | -19.5% |
| 2006-2007 | +216 | +40.1% | +229 | +39.6% | +99 | +39.9% |
| 2010-2011 | -176 | -22.6% | -146 | -21.4% | -55 | -22.1% |
| 2011-2018 | +255 | +42.4% | +309 | +57.8% | +289 | +49.4% |

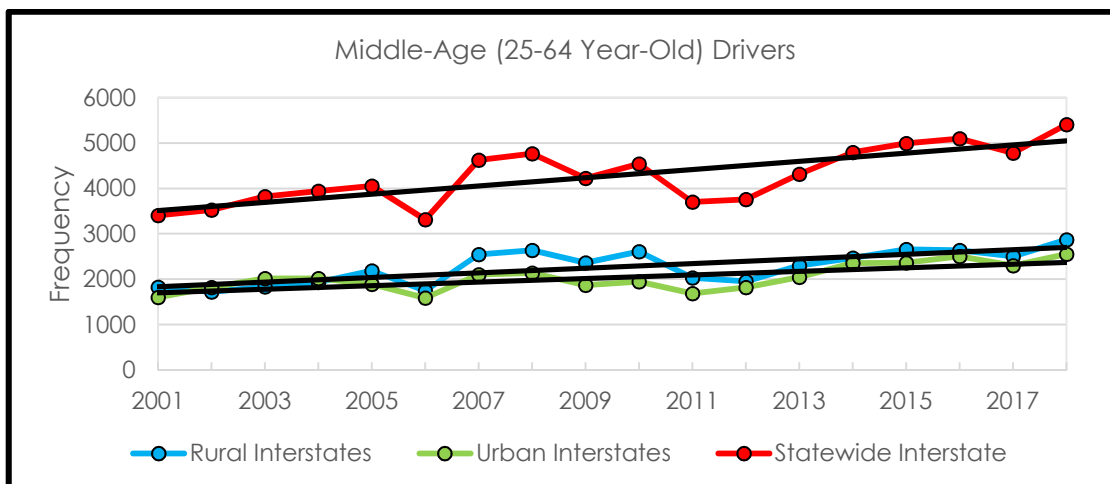


Figure 3.15: Middle-Age (25 to 64 Year-Old) Drivers Involved with Crashes Yearly Trend Graph.

Table 3.5: Middle Age Driver changes in frequencies among distinct periods.

| Time Period | Rural | | Urban | | Statewide | |
|-------------|---------------------------|--------------------------------------|---------------------------|--------------------------------------|---------------------------|--------------------------------------|
| | Change in Crash Frequency | Percentage Change in Crash Frequency | Change in Crash Frequency | Percentage Change in Crash Frequency | Change in Crash Frequency | Percentage Change in Crash Frequency |
| 2001-2004 | +106 | +5.8% | +416 | +26.0% | +531 | +15.6% |
| 2005-2006 | -444 | -20.3% | -302 | -16.0% | -736 | -18.2% |
| 2006-2007 | +803 | +46.1% | +515 | +32.4% | +1308 | +39.5% |
| 2010-2011 | -574 | -22.0% | -261 | -13.4% | -838 | -18.5% |
| 2011-2018 | +834 | +41.0% | +867 | +51.4% | +1708 | +46.2% |

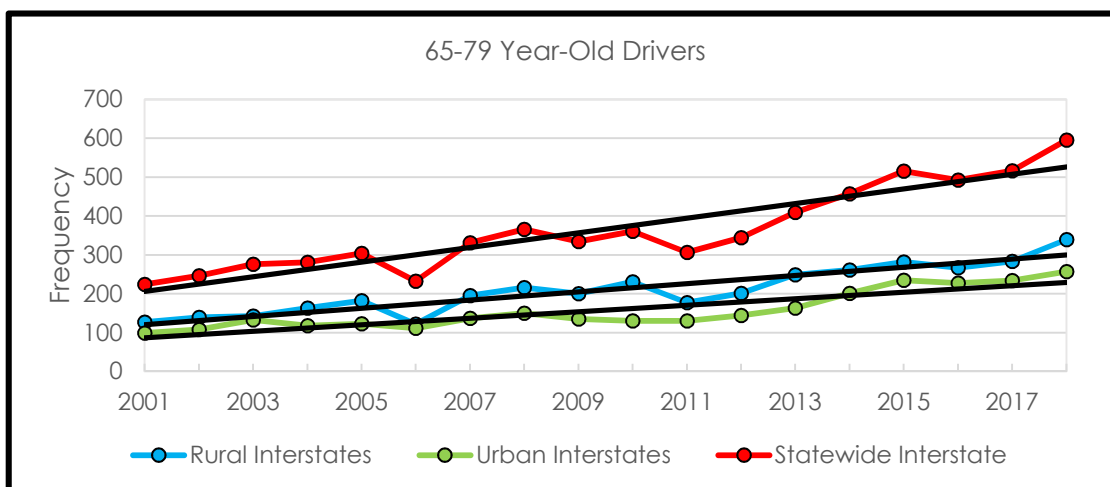


Figure 3.16: Old (65 to 79 Year-Old) Drivers Involved with Crashes Yearly Trend Graph.

Table 3.6: Old Driver changes in frequencies among distinct periods.

| Time Period | Rural | | Urban | | Statewide | |
|-------------|---------------------------|--------------------------------------|---------------------------|--------------------------------------|---------------------------|--------------------------------------|
| | Change in Crash Frequency | Percentage Change in Crash Frequency | Change in Crash Frequency | Percentage Change in Crash Frequency | Change in Crash Frequency | Percentage Change in Crash Frequency |
| 2001-2004 | +36 | +28.3% | +19 | +19.2% | +22 | +9.8% |
| 2005-2006 | -60 | -33.0% | -12 | -9.8% | -72 | -23.7% |
| 2006-2007 | +73 | +59.8% | +26 | +23.4% | +99 | +42.7% |
| 2010-2011 | -54 | -23.4% | 0 | 0% | -55 | -15.2% |
| 2011-2018 | +162 | +91.5% | +127 | +97.7% | +289 | +94.4% |

Younger driver linear trend lines showed that rural and statewide interstates have increased over the 18-year observation period, while the urban interstate linear trend indicated a gradual decrease. Middle age and old driver linear trend lines both exhibit frequency increases on all interstate types, including near parallel increases of rural and urban interstates. On rural interstates, older drivers fluctuated during the observed periods more than any other age group. However, nothing particularly notable regarding an impact due to the 2005 speed limit change is evident.

A comparison between Tables 3.5 and 3.6 (middle age and older drivers on rural interstates) showed that older drivers had:

- **2001-2004:** +22.5% higher frequency increase
- **2005-2006:** -12.7% higher frequency decrease
- **2006-2007:** +13.7% higher frequency increase
- **2011-2018:** +50.5% higher frequency increase

Between each age group on urban interstates, middle age drivers had greater observed changes than either old or young drivers, except for the 2011-2018 period when older drivers involved with crashes rose by 46.3%. A comparison between middle age and older drivers revealed that:

- **2001-2004:** +6.8% higher frequency increase
- **2005-2006:** -6.2% higher frequency decrease
- **2006-2007:** +9.0% higher frequency increase
- **2010-2011:** -13.4% higher frequency decrease

Statewide interstates changes among the specified time periods were more varied between each driver age group. For 2001-2004, young driver frequencies increased 6.8% more than middle age drivers (the next most significant group). Older drivers otherwise fluctuated more than both young and middle age driver frequencies, decreasing 5.5% more than middle age drivers for 2005-2006 and increasing 48.2% more than middle age drivers for 2011-2018.

For the individual 5-year age bins, each bin was analyzed for notable trends and two main different trend lines emerged. The first was a linear trend line change between 2001-2004 and 2006-2018, shown in Figures 3.17 to 3.20 for the 5-year age bins between ages 50 and 69. These comparisons typically showed a flattening of trends or a continuation of trends between 2001-2004 and 2006-2018, with some exceptions. Rural interstates for 60 to 64 year-old drivers involved with crashes were decreasing during 2001-2004, then increased from 2006 to 2018. Despite this, there is little evidence that the speed limit increase impacted these frequencies. The only noteworthy potential correlation to the 70-mph speed limit is the increase of older drivers involved with crashes, which may suggest that older drivers are less comfortable with these speeds.

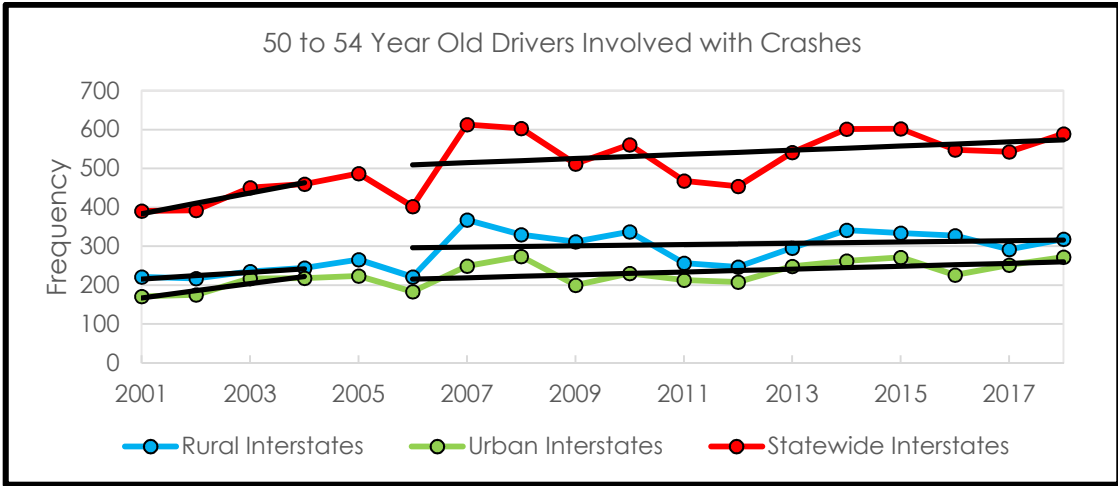


Figure 3.17: 50 to 54 Year-Old Drivers Involved with Crashes Yearly Trend Graph.

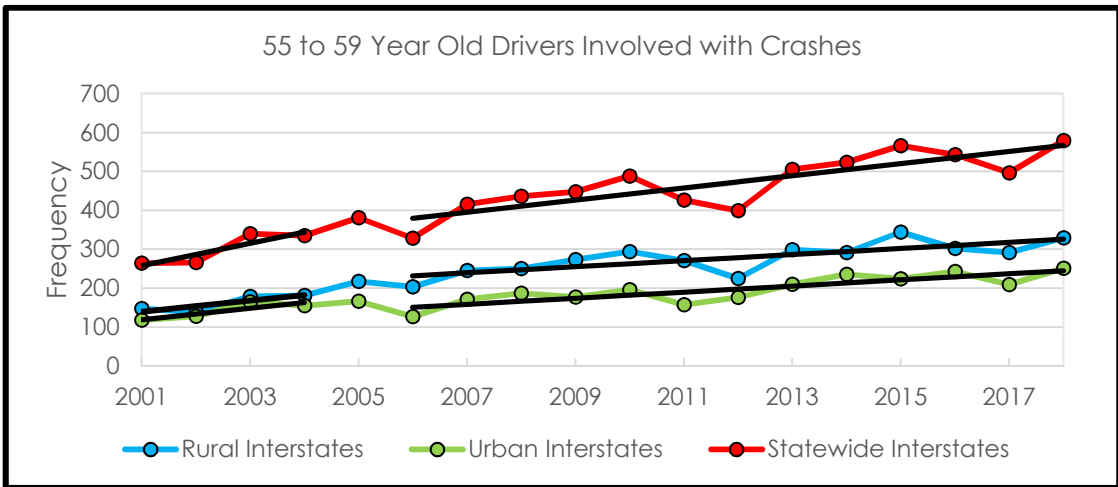


Figure 3.18: 55 to 59 Year-Old Drivers Involved with Crashes Yearly Trend Graph.

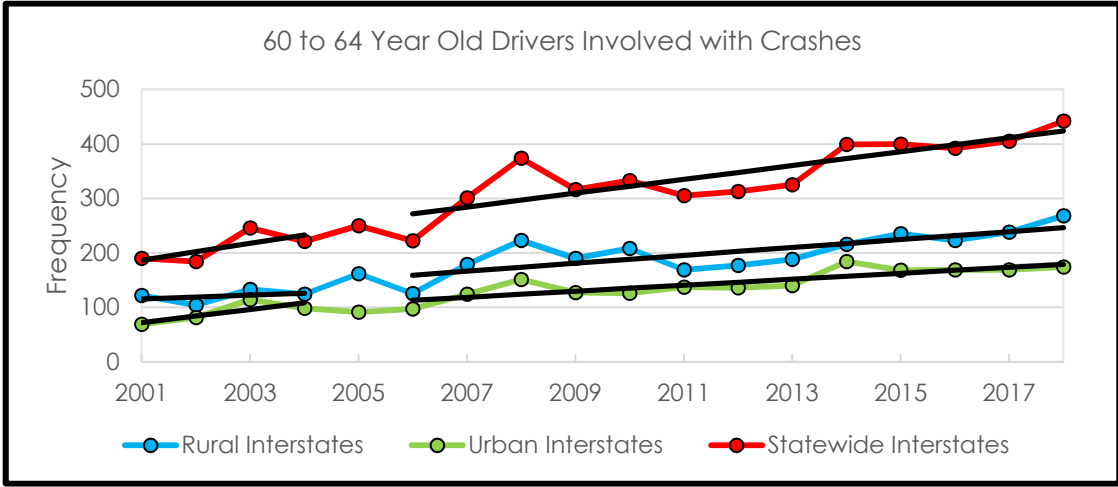


Figure 3.19: 60 to 64 Year-Old Drivers Involved with Crashes Yearly Trend Graph.

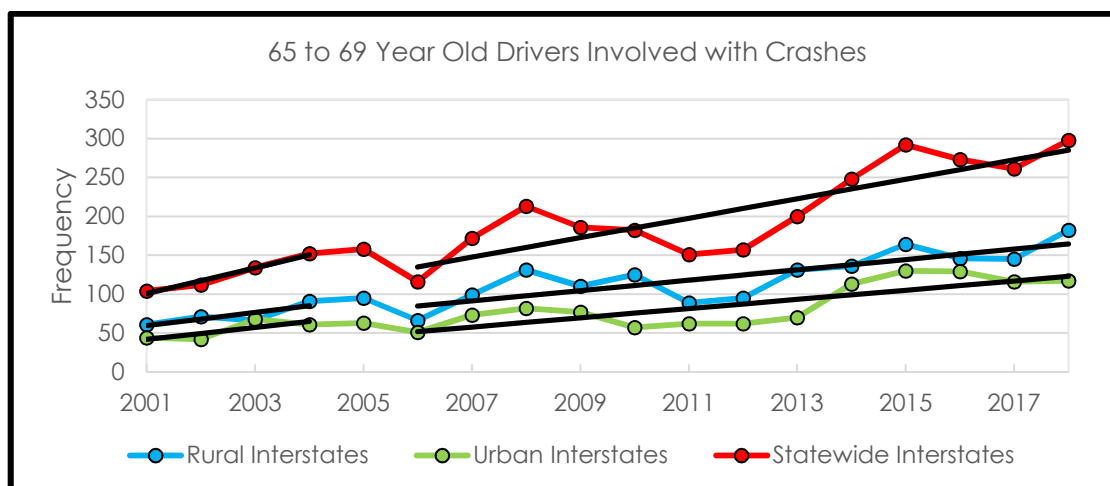


Figure 3.20: 65 to 69 Year-Old Drivers Involved with Crashes Yearly Trend Graph.

The second trend was exponential frequency growth, shown in Figures 3.21 and 3.22 for 70 to 74 year-old drivers and 75 to 79 year-old drivers. Although upon initial analysis these age groups appeared to have a notable exponential trend, the trend lines still follow a very linear relationship. Additionally, these exponential trend lines indicate little change around the implementation period of the 70-mph rural interstate speed limit and constant growth throughout entire observation period.

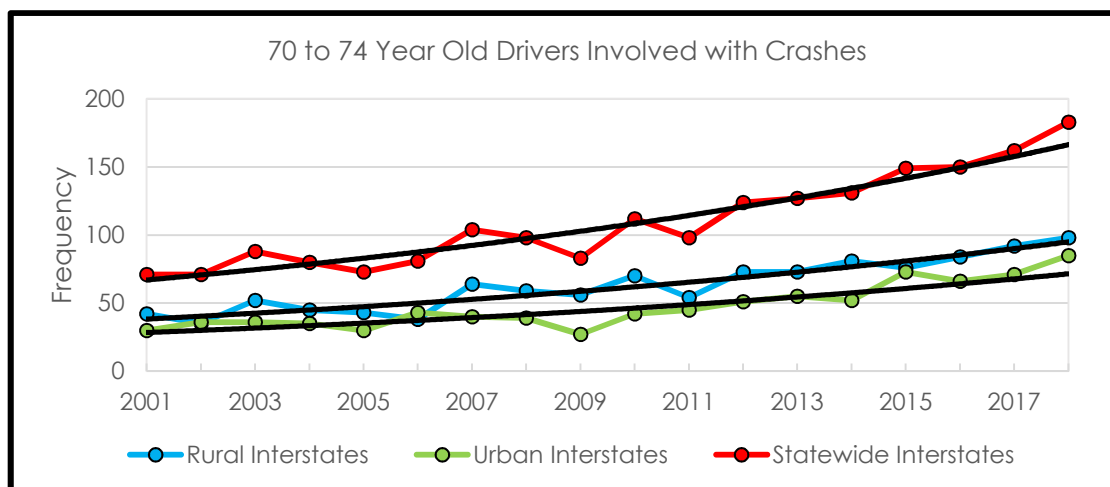


Figure 3.21: 70 to 74 Year-Old Drivers Involved with Crashes Yearly Trend Graph.

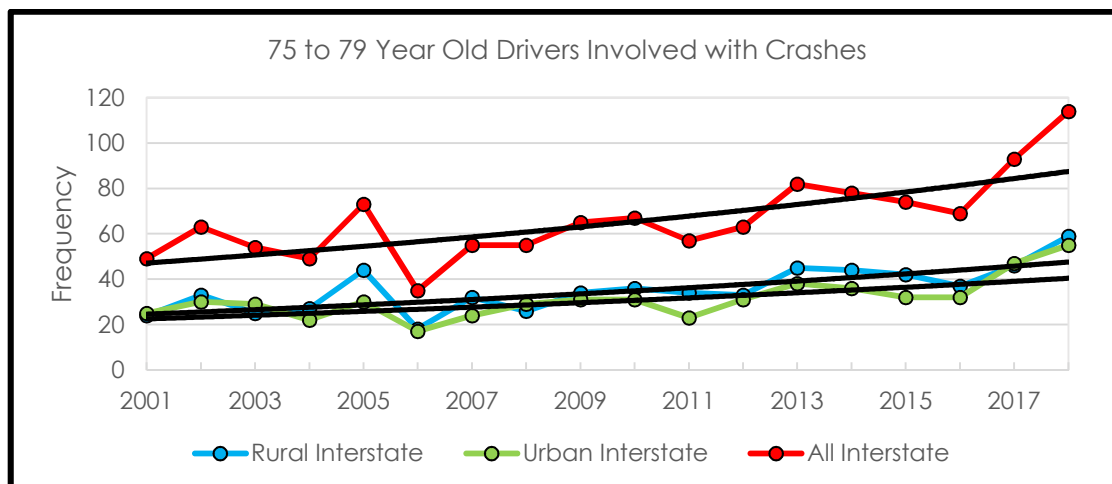


Figure 3.22: 75 to 79 Year-Old Drivers Involved with Crashes Yearly Trend Graph.

- **Driver Contributing Circumstances:** Driver contributing circumstances are actions performed by the driver that led to a crash. These actions include aggressive activities, such as road rage or operating a vehicle in a reckless manner, to more passive acts like failure to dim lights or signal intentions. From the many attribute value options, lost control, driving too fast for conditions, followed too close, and exceeded authorized speed were selected due to their close relation to subject of speed and speed limits. Some of these attributes are similar to those found in the major cause crash field, but in this case, they are not limited to just being the sole cause of a crash.
 - Lost control frequencies, shown in Figure 3.23, had the greatest amount of frequencies of all three selected attribute values. Overall, all interstate types experienced a notable decrease from 2005 to 2006, an increase from 2006 to 2007, a gradual decline from 2008 to 2012, and a gradual increase from 2012 to 2018. Rural interstates had more recorded occurrences of lost control drivers involved with crashes and the frequency fluctuations had more

variation than on urban interstates. These changes could be due to the speed limit increase or possibly just an increase in traffic volume.

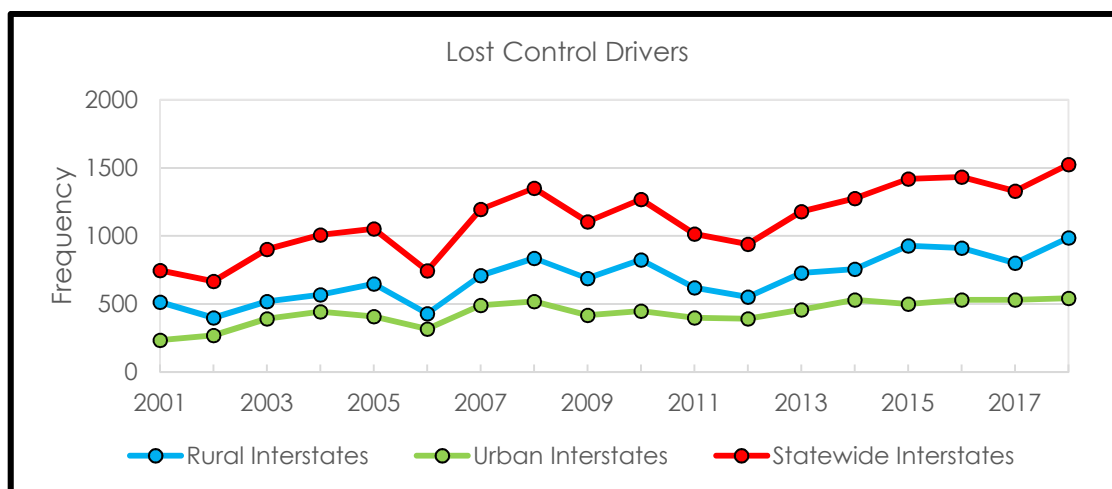


Figure 3.23: Lost Control Driver Yearly Trend Graph.

- Driving too fast for conditions frequencies are shown in Figure 3.24. Similar to lost control frequencies, all interstate types experienced a notable decrease from 2005-2006 and a large increase, particularly for statewide and rural interstates, from 2006-2007. The 2005-2006 decrease was about 50% for both systems and the 2006-2007 increase was about 200% on statewide interstates and 231% on rural interstates. Overall, statewide interstate frequencies increased on average by an additional 200 per year from 2001-2004 to 2006-2018. Further statistical analysis will determine if the frequency increases involved the speed limit increase or were simply due to increases in traffic volume.

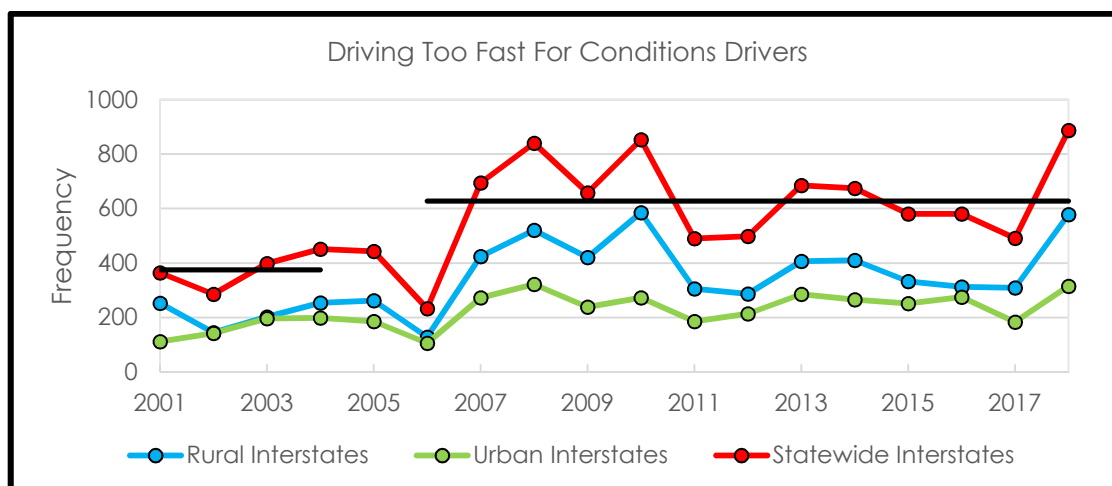


Figure 3.24: Driving Too Fast for Conditions Driver Yearly Trend Graph.

- Followed too close frequencies are shown in Figure 3.25. This attribute value was more commonly observed on urban interstates, but each interstate category saw slight changes surrounding the time of the rural interstate speed limit increase. The most significant trend was the shift from an average flat/slightly decreasing linear trend line to a large increasing linear trend line from 2013 onward for all interstate types. Although the driver frequency uptick after 2013 is notable, there is little evidence to suggest this trend was caused by the 2005 speed limit change.

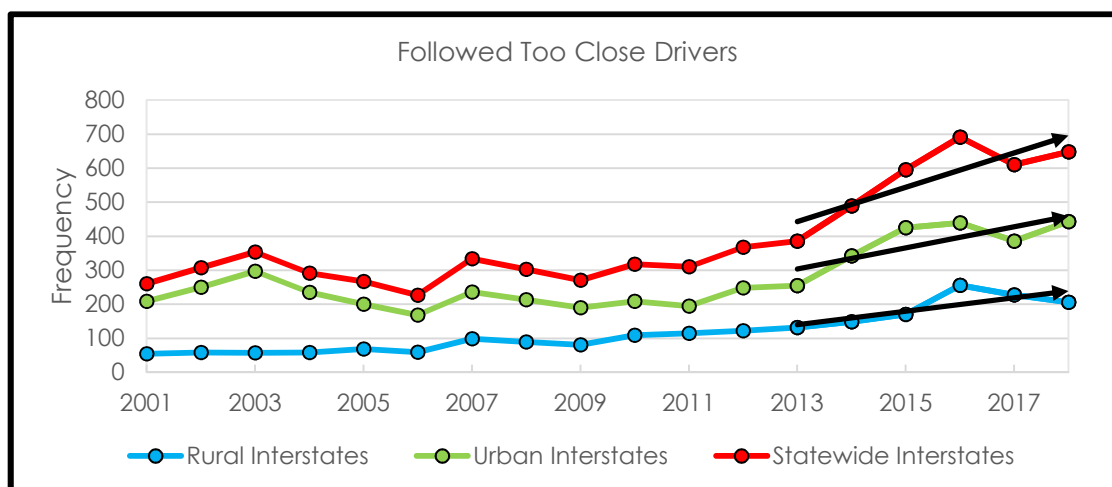


Figure 3.25: Followed Too Close Driver Yearly Trend Graph.

- Exceeded Authorized Speed frequencies are shown in Figure 3.26. This attribute value was primarily included in the analysis because it relates directly to speed limits and how driver non-compliance with speed limits influences crashes. These frequencies were much lower than the previously mentioned attribute values, ranging from between 15 to 45 drivers per year on statewide interstates. Rural and urban interstate frequencies both gradually declined from 20 drivers per year in 2001 to below 10 per year in 2010, only to slowly rise back to previous levels. Statewide, this resulted in a “v-shaped” linear trend line, where frequencies declined until 2011 and rose through 2018. This trend may be due to speeding drivers being satisfied directly after the 70-mph speed limit implementation and later becoming less compliant similar to the early 1980s after about a decade of the 55-mph speed limit.

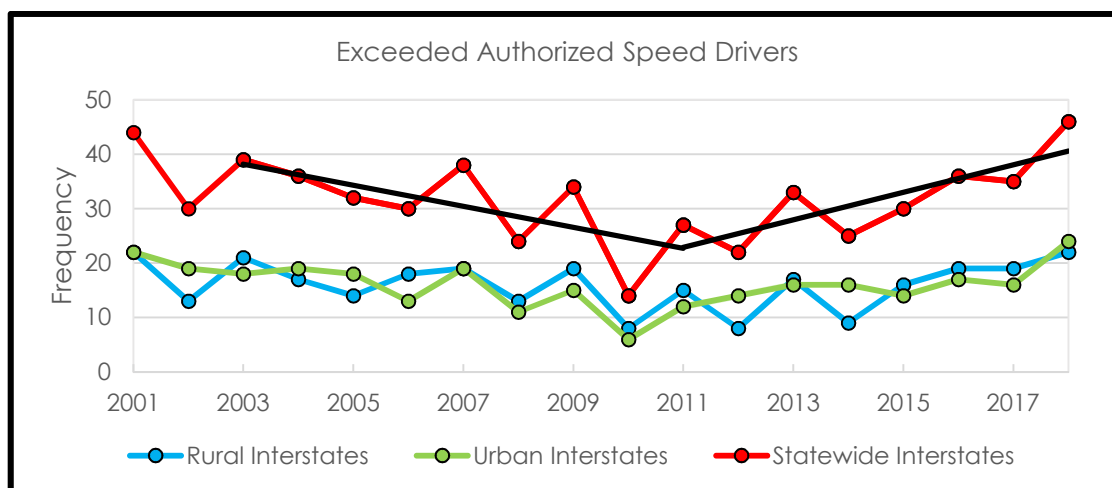


Figure 3.26: Exceeded Authorized Speed Driver Yearly Trend Graph.

Injury: The injury dataset contains fields that describe injured person by status, gender, and age as well as additional information about how the injuries were received (e.g. airbag deployment, ejection from the vehicle). Injury status was the only selected variable from this dataset because injury frequencies categorized by severity tells us important safety information that could relate directly to a speed limit increase.

- **Injury Status:** Injury status contains injury frequencies sorted by severity. The attribute values range from very severe (i.e. fatal, suspected serious/incapacitating, and suspected minor/non-incapacitating injuries) to less significant (possible, uninjured, and unknown injuries.) The two most severe categories, fatal and suspected serious/incapacitating injuries were selected for analysis. These severe injury issues are ones that most DOTs seek to reduce and that some people assume rise significantly with increasing speed limits.
 - Fatal injury frequencies are shown in Figure 3.27. Rural interstate fatal injury frequencies ranged in between 20 and 40 per year, while urban interstate frequencies were only within 10 to 20 per year. The effect of the speed limit increase in 2005 on rural interstates is difficult to discern because fatal injuries fluctuated prior to implementation and were on an average decline through 2018. However, there were two years of about 5 additional fatal injuries per year directly after implementation, then a nearly 20 frequency drop followed by a 20 frequency increase. This interesting pattern was possibly somewhat impacted by the speed limit increase, but other factors must be involved to cause such large changes years after the increase occurred.

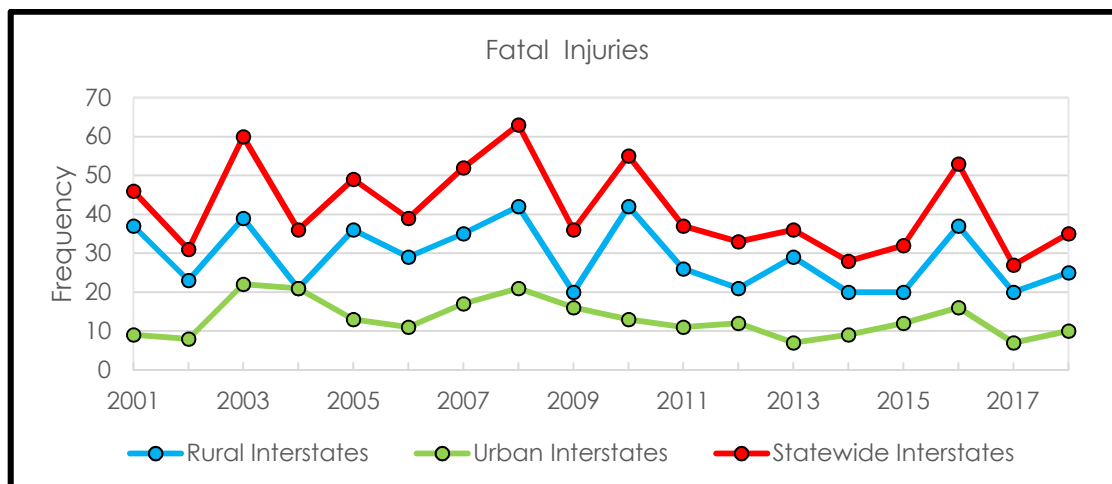


Figure 3.27: Fatal Injury Yearly Trend Graph.

- Suspected serious/incapacitating injury frequencies are shown in Figure 3.28. Prior to the 70-mph rural interstate, rural interstate suspected serious injuries slowly declined from about 100 frequencies per year to 72. Conversely, urban interstate suspected serious injuries were slowly rising from 52 to 72 per year in that period. In the year of the speed limit increase, rural interstate frequencies rose by almost 50 and then declined in 2006 and remained around 100 per year until significantly declining again in 2009. Suspected serious injuries have on average stayed around 70 per year through 2018. Urban interstates frequencies declined in 2005, steadily rose again to 69 per year, and once again fell below 50 in 2009 where this type of injury has stayed. The rural interstate frequency increase in 2005, and overall high frequencies in comparison to the observation period, imply that the 70-mph speed limit increase may have been a contributing factor. While this is possible, many other confounding factors including vehicle technology improvements and roadway improvements (e.g., median cable barriers) happened during the observation period.

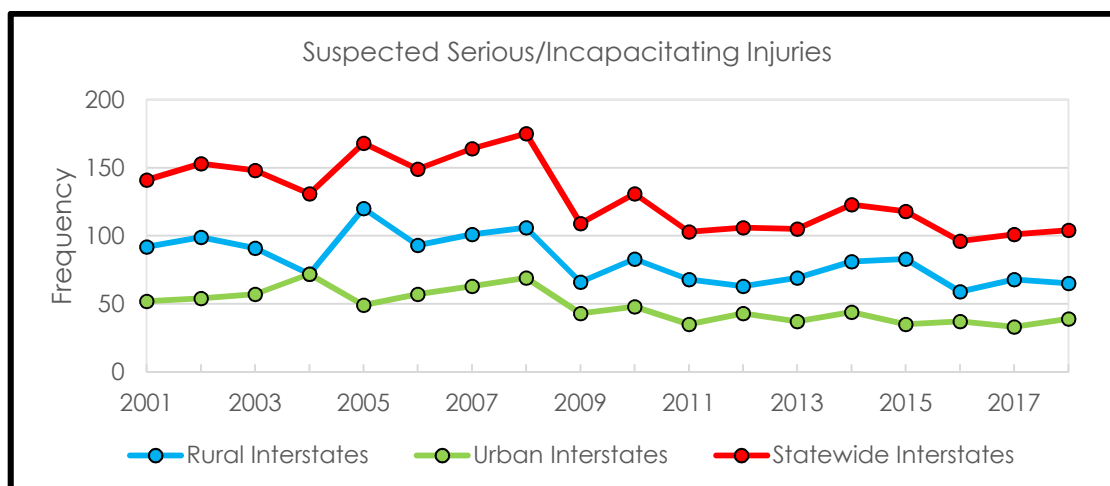


Figure 3.28: Suspected Serious/Incapacitating Injury Yearly Trend Graph.

Location & Time: The location and time dataset contains fields that describe crashes by the location and the time of occurrence of a crash. Location is defined by such fields as rural/urban, city, and county, while time is defined by month, time of day, day of week, and lighting. Of the plethora of field options, only month and time of day were analyzed.

- Month:** The month crash field simply labels each crash by the month in which it occurred. Figure 3.29 shows rural interstate crashes organized by month. Urban interstates were not shown because the speed limit increase did not directly apply to those roads and noticeable frequency trends and changes would be difficult to discern. While various monthly rural interstate crash frequencies fluctuate from year to year, some months had distinct trends. December crashes increased by 138% in 2007 and peaked at almost 500 crashes per year in 2008 and 2009, until significantly declining in 2010. This trend of increased frequencies in the first few years after the speed limit increase also occurred with other winter months such as January, February, and November. These trends may suggest that speed limit increase impacted drivers in winter months directly following implementation.

Winter month frequencies also increased in the early 2010s, but most began to decline by 2018.

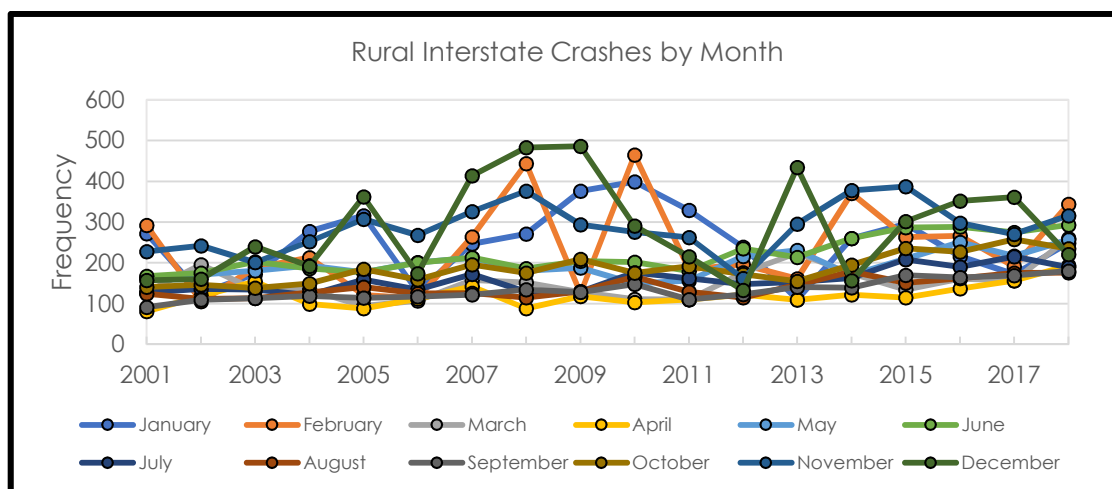


Figure 3.29: Rural Interstate crashes by Month.

- Time Bin:** The time bin crash field simply categorizes crashes by time of occurrence in two-hour bins. For this field, observations were averaged between four 4-year periods, 2001-2004 (before), 2006-2009 (immediately after), and 2011-2014 (longer-term after), and 2015-2018 (recent after). Urban interstate trends are not shown here because no major trend was found amongst those frequencies and because the speed limit increase only indirectly impacts those roadways.

Figure 3.30 shows the rural interstate crash frequency trends for trend period. In the comparison of 2001-2004 and 2006-2009 crashes, time bins including Midnight to 1:59 AM and 6:00 AM through 5:59 PM all had average frequency increases of 25% or greater. Crashes that occurred between 8:00 AM to 9:59 AM and 10:00 AM to 11:59 AM experienced especially significant changes, with increases of 41% and 45% respectively. Due to the timing, that the speed limit increase may be potentially be a cause of the crash increases, specifically in the aforementioned time

bins. The traffic volume difference between the time bins, as well as overall traffic volume growth might also explain some of these increases.

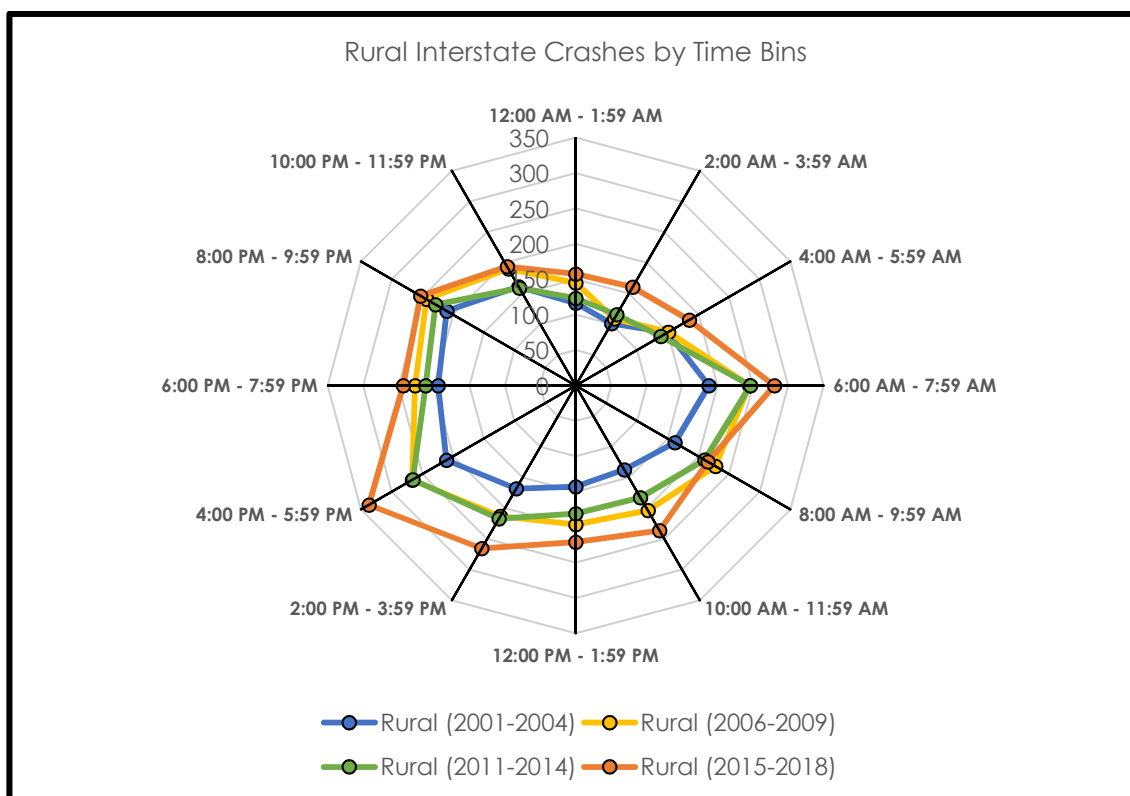


Figure 3.30: Rural Interstate crashes by Time of Day.

The second period comparison, 2006-2009 and 2011-2014, showed much different results. Most of time bin crash frequencies decreased slightly, with crashes between 10:00 PM and 11:59 PM and Midnight to 1:59 AM declining by 17% and 15%.

Since the latter compared time period is between 6 to 9 years after the speed limit increase, these results could imply that drivers became accustomed to the higher speed limit and safety increased. As with the first comparison, traffic volumes could alter this thinking, if they declined during 2011-2014.

The final period comparison was average crashes in 2011-2014 and 2015-2018.

Frequencies once again increased, most notably in the bins from Midnight through

5:59 AM, 10:00 AM to 11:59 AM, and 4:00 PM to 5:59 PM, by 27% to 39%. These increases could be due to potential driver disobedience after over a decade of the 70-mph speed limit (similar to the 1980s) or simply traffic volume growth. The interesting element to note is that the late night time bins were some of the times to experience the most growth. This could suggest more speeding was occurring at those times after a long period of no speed limit changes. Conversely, the late night percentage increases could simply be higher due to the scarcity of crashes at this time, making any increase seem intensified.

Severity: The severity dataset has fields that describe the severity of crashes by a variety of terms. These include crash severity, number of fatalities, number of injuries, amount of property damage, number of vehicles involved in a crash, and total number of occupants. Of these fields, only crash severity was selected for a descriptive statistics analysis. This decision was due to the injury information already being gathered in the injury dataset and the crash severity field contains crash frequencies categorized by different severity levels.

- **Crash Severity:** As stated above, the crash severity field sorts crashes by categories including fatal, major injury, minor injury, possible/unknown injury, and property damage only crashes. Fatal, major injury, and all crashes (a summation of all crash severity categories) were selected from those attribute values because of notable trends that occurred throughout the 18-year observation period.
 - Figure 3.31 shows annual frequencies for fatal crashes. Rural interstate fatal crash frequencies were in decline from 2001 to 2004 but ticked up by 13 crashes in 2005. Although a slight decline occurred in 2006, frequencies again

began to increase and hit a peak of 38 crashes in 2008. From 2009 onwards, rural interstate fatal crashes fluctuated between 15 and 32 per year. Urban interstate fatal crashes began slowly rising from 10 in 2005 to 17 in 2008, only to decline slightly to 6 in 2013. Frequencies then again rose to 14 by 2016 and were followed by two years of fewer than 10 fatal crashes.

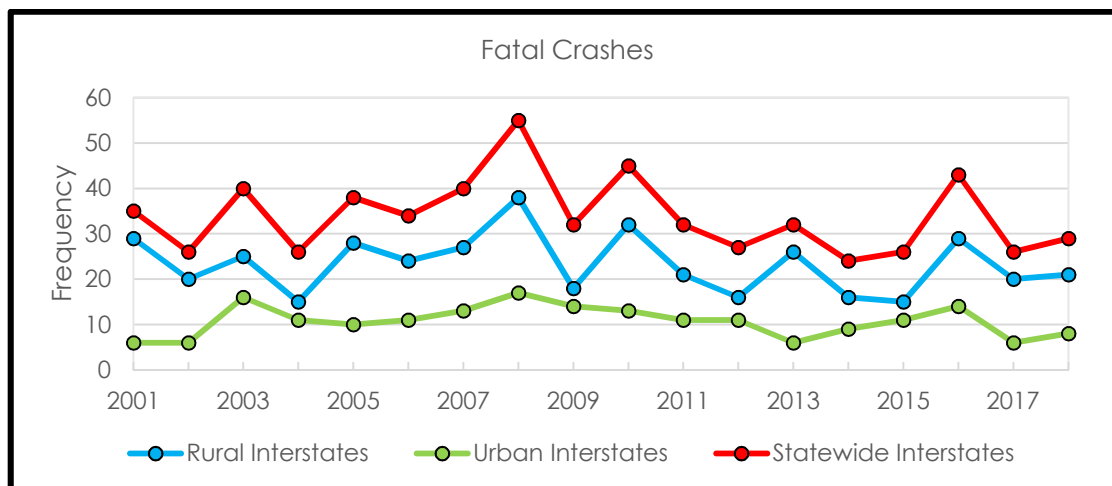


Figure 3.31: Fatal Crashes Yearly Trend Graph.

- Major injury crash frequencies are shown in Figure 3.32. Rural and urban interstate frequencies had similar parallel trends, with urban major injury crash frequencies around 15 fewer compared to those on rural interstates. Both categories began to climb after 2005, reaching peaks of 82 and 58 crashes per year in 2008 for rural and urban interstates respectively. In 2009, rural and urban interstate major injury crashes declined by 41% and ranged between 40 to 60 per year on rural interstates and 20 to 40 per year on urban interstates.

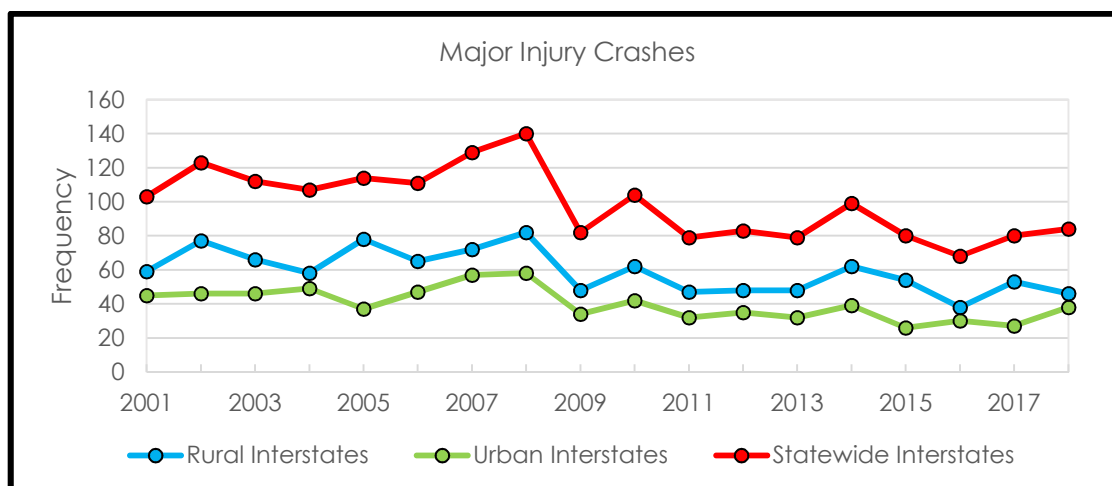


Figure 3.32: Major Injury Crashes Yearly Trend Graph.

- Figure 3.33 documents the yearly frequencies for all crashes that occurred on the interstate system. From 2001 to 2004, rural and urban interstate crashes were slowly rising, with rural crashes outpacing urban frequencies. Both systems reported decreases of around 16% in 2006, but then increased by 41% (rural interstates) and 35% (urban interstates). After each hitting peaks in 2008, crashes remained at a constant level until declining by 784 crashes on interstates statewide in 2011. Since that time, rural and urban interstate crashes have steadily risen, increasing by 875 and 692 respectively from 2011 to 2018. This pattern suggests that crashes increased (particularly on rural interstates) following the rural interstate speed limit increase in 2005.

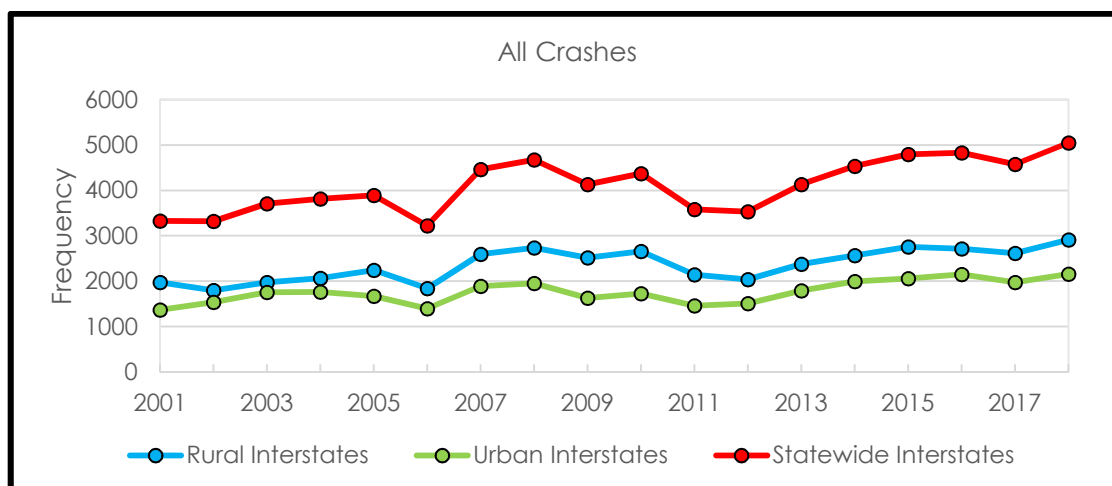


Figure 3.33: All Crashes Yearly Trend Graph.

While the speculations about the potential relationship between the crash severity trends and 2005 speed limit increase could exist, many confounding factors occurred at the same time. These factors were mentioned earlier in the injury status section.

Vehicle: The vehicle dataset contains crash fields that describe crashes by aspects of the vehicle(s) involved with a crash. Some of these fields include vehicle configuration, year, color, make, model, style, cargo body type, and occupants. Vehicle configuration was the only field selected for analysis because significant trends were not anticipated for vehicle color, make, and year. Additionally, vehicle configuration encompasses many of the aspects of vehicle style and cargo body type, so using just that field reduced time spend on initial analysis.

- Vehicle Configuration:** Vehicle configuration defines crashes by about 40 different types. These types include passenger cars, sport utility vehicles (SUVs), pick-up trucks, trucks/trailers, motorcycles, ATVs, and school buses. Due to the many options available, some configurations were combined into frequencies that represented passenger and commercial vehicles involved with crashes. Passenger

vehicles included passenger cars, four-tire trucks (pick-ups), and SUVs, and commercial vehicles encompassed single-unit trucks (2-axle, 6-tire), single-unit trucks (≥ 3 axles), trucks/trailers, and tractors/semi-trailers. This synthesis painted a picture which showed the general trends among similar vehicle types.

- Passenger vehicles involved in crashes are shown in Figure 3.34. Prior to the 70-mph rural interstate speed limit increase in 2005, passenger vehicle frequencies were greater on urban interstates and formed an arc-like trend, peaking at 2512 vehicles in 2003. Frequencies decreased by around 20% on both systems in 2006, then increased by 33% on urban interstates and 54% on rural interstates respectively in 2007. Between 2007 and 2010, passenger vehicles involved in crashes fluctuated somewhat but stayed near 2007 levels. Notably, rural interstate frequencies did surpass urban interstate frequencies in 2010. After a slight decline in 2011, both systems have each steadily risen to about 3000 vehicles per year by 2018.

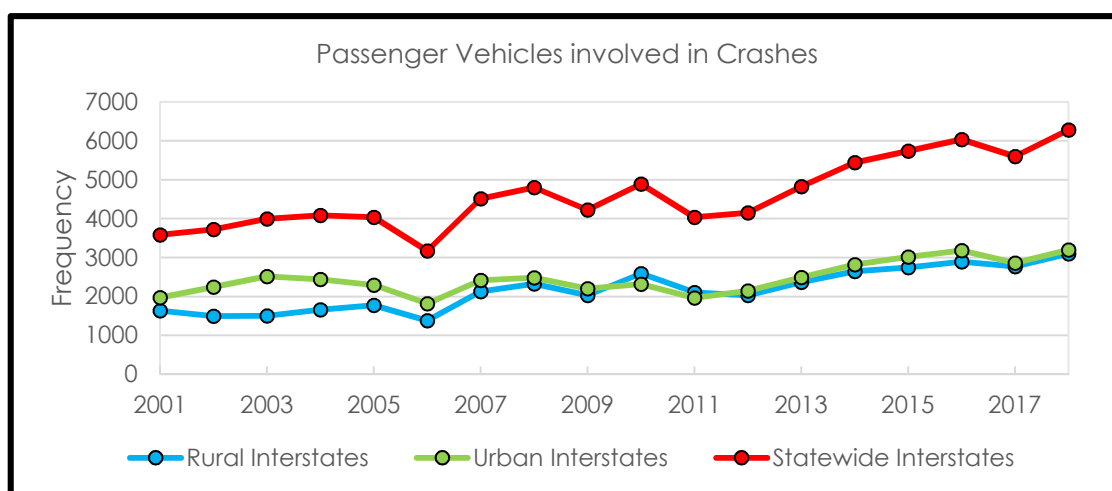


Figure 3.34: Passenger Vehicles Involved in Crashes Yearly Trend Graph.

- Figure 3.35 shows annual frequencies for commercial vehicles involved in crashes. These vehicles were more so involved with crashes on rural interstates than urban interstates. From 2001 to 2004, rural interstate frequencies ranged between about 425 and 500 per year, then rose 41% in 2005 to 661 vehicles. A decline similar in magnitude followed in 2006, but frequencies rebounded again by over 74% in 2007. Following another large decline and increase in 2009 and 2010, rural interstate frequencies fell to the recent low of 532 vehicles in 2012. Since that time, passenger vehicles involved in crashes have risen, peaking at nearly 800 vehicles in 2015 and 2018. Urban interstate frequencies did not show as much variance throughout the 18-year observation period. After a slight increase in the early 2000s, frequencies dipped slightly in 2006 and then rose by almost 40% in 2007. After a 26% decline in 2009, urban interstate commercial vehicle frequencies slowly climbed to record highs at around 400 vehicles per year in 2014 and 2018.

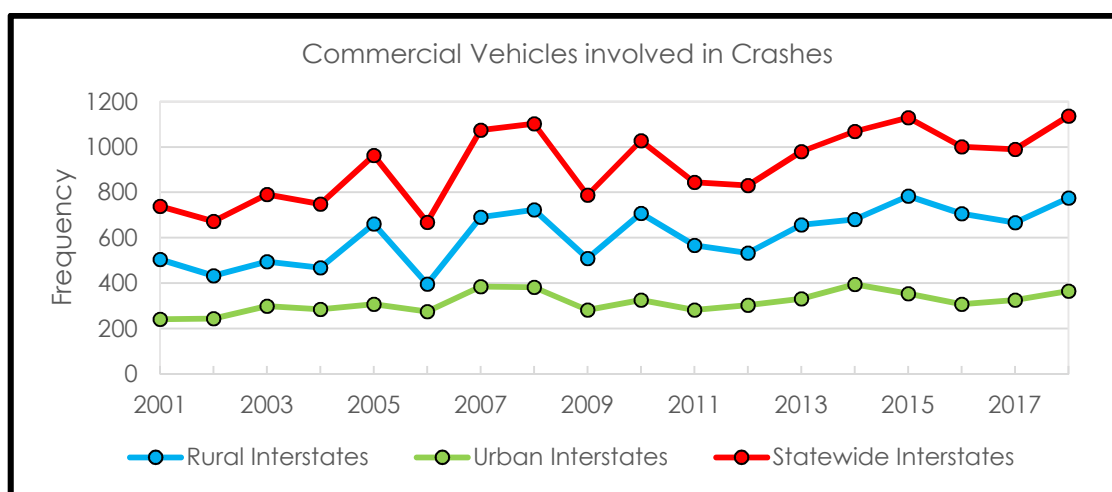


Figure 3.35: Commercial Vehicles Involved in Crashes Yearly Trend Graph.

- Figure 3.36 presents the vehicle configuration frequencies for both passenger and commercial vehicles on rural interstates. This graph especially highlights the differences between the two categories, showing that soon after the 2005 speed limit increase, passenger vehicles began to increase in frequency. Prior to that increase, the average trend line showed little to no increase for those vehicles. Commercial vehicles, however, have largely remained constant with only a small decline then increase in 2006 and 2007 and a slight long-term increase from 2012 onwards.

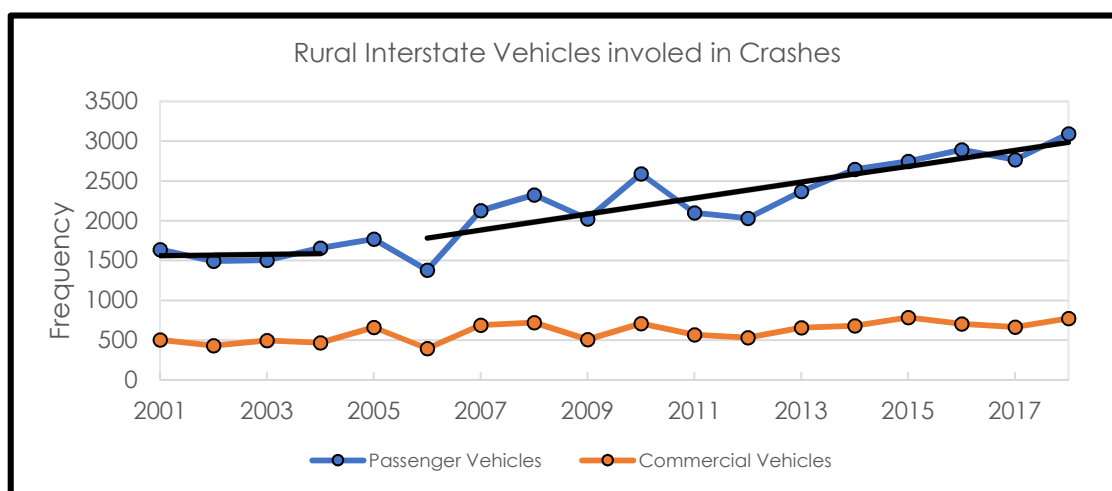


Figure 3.36: Rural Interstate vehicles involved in Crashes.

Using the results of this initial analysis, the attribute values with interesting trend lines were prepared for a statistical analysis that could determine if certain trends were actually significant. This process will help eliminate trends that appear relevant and specify which values could be attributed to the speed limit increase.

CHAPTER 4. STATISTICAL ANALYSIS

After the initial descriptive analysis, selected attribute values were further analyzed by a statistical technique known as linear regression. Linear regression is an application that “models a linear relationship between a continuous dependent variable and one or more independent variables” (71). The linear regression technique was chosen because it was appropriate for “modeling a wide variety of relationships between variables, assumptions are frequently satisfied in many practical applications, and model outputs are simple to convey to others” (71). This chapter will describe the statistics behind linear regression modelling and layout the procedure used in SAS to model the data.

Linear Regression

As stated before, linear regression is a statistical method used to model the relationship between a dependent variable (Y) and an independent variable (X) in order to explain the way in which the independent variable affects the dependent variable (71). The model for simple linear regression is shown in Equation 4.1.

Equation 4.1: Simple Linear Regression Model (71).

$$Y_i = \beta_0 + \beta_1 X_{1i} + \varepsilon_i$$

The variables in the model include the dependent variable (Y), independent variable (X), a constant term (β_0), a constant multiplier (β_1) for the independent variable, and the disturbance term (ε_1) (71). β_0 is the intercept point where the line crosses the Y axis and β_1 is the slope of the regression line and are known as “the betas” (71). The beta terms embody the actual relationship between X and Y (71). ε_1 represents the difference

between the true variable relationship and a statistical model (71). For the purposes of this research, Y is the crash rate for each section for each year and X is the year.

Linear regression is based on several assumptions, shown in Table 4.1.

Table 4.1: Assumptions of a Linear Regression model (71).

| Statistical Assumption | Meaning | Mathematical Expression |
|--|--|---|
| Function form | Regression model form requires the relationship between variables to be linear or “straight-line”. | $Y_i = \beta_0 + \beta_1 X_{1i} + \varepsilon_i$ |
| Zero mean of disturbances | Disturbances, on average, are equal to zero. | $E[\varepsilon_i] = 0$ |
| Homoscedasticity of disturbances | The impacts of unobserved effects, measurement errors, and true random variations, are not systematic across all observations. | $VAR[\varepsilon_i] = \sigma^2$ |
| Non-autocorrelation of disturbances | Disturbances are independent across observations. | $COV[\varepsilon_i, \varepsilon_j] = 0 \text{ if } i \neq j$ |
| Uncorrelatedness of regressor and disturbances | Regressors are not related to the disturbance term but rather elements outside of a model. | $COV[X_i, \varepsilon_j] = 0 \text{ for all } i \text{ and } j$ |
| Normality of disturbances | Disturbance terms must be approximately normally distributed in order to make inferences about model parameters. | $\varepsilon_i \approx N(0, \sigma^2)$ |

If these assumptions are met, or remedial actions are taken in the case of an assumption being broken, a linear regression model is created and conclusions can be surmised.

For this thesis, the simple linear regression model was expanded for statistical analysis using qualitative variables. Qualitative variables are variables that “describe data that fit into categories”. This is useful as regression can use these variables to differentiate between populations and fit multiple populations in a single model (72). Fittings of multiple populations in a model allow “the ability to test for different slopes or intercepts in the populations and more degrees of freedom for the analysis” (72). The linear regression model with qualitative variables is shown in Equation 4.2.

Equation 4.2: Simple Linear Regression Model with an Indicator Variable and Interaction Term (72).

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{1i} X_{2i} + \varepsilon_i$$

Similar to the simple linear regression model, Y_i represents the dependent variable and $\beta_0, \beta_1, \beta_2,$ and β_3 are “the betas” or the estimated parameters. X_i is still the independent variable but each one has a unique function. X_{1i} is a quantitative variable or a variable that is “measured on a numeric scale” (73). X_{2i} is qualitative variable or indicator variable. These variables “take on the values of 0 or 1” to “sort data in mutually exclusive categories” (71, 72). The combination term $X_{1i}X_{2i}$ is called the interaction, which describes “the effect of one independent variable may depend on the level of the other independent variable” (71). Again, for the purposes of this research, Y is the crash rate for each section for each year and X_1 is the year.

For the models used in this analysis, the independent variables in Equation 4.2 represent the following:

- **X_{2i} :** For the indicator variable, 0 represents when the year of the crash rate data are of one date range (e.g. 2001-2004) and 1 is when the years of the other date range (e.g. 2006-2009). This variable changes the intercept term of the regression model when the latter date range is in effect.
- **$X_{1i}X_{2i}$:** The interaction variable adjusts the slope of the model for the latter date range.

Based on the effects of the indicator variable, two models are formed for each date range (e.g., 2001-2004 and 2006-2009) which are shown in Equations 4.3 and 4.4.

Equation 4.3: Model from Equation 4.2 if $X_{2i} = 0$

$$Y_i = \beta_0 + \beta_1 X_{1i} + \varepsilon_i$$

Equation 4.4: Model from Equation 4.2 if $X_{2i} = 1$

$$Y_i = (\beta_0 + \beta_2) + (\beta_1 + \beta_3)X_{1i} + \varepsilon_i$$

These models estimate crash rates (Y_i) of particular types of crashes using year (X_i) and investigate the differences between the slopes of one time period and another time period. The difference in slopes between two models is depicted by the interaction term and a significant β_3 . If the β_3 term is significant, it means that there is a statistically significant change in slopes between the two timeframes in the model, which is what we are interested in. The interaction is the highest order term and therefore we are mainly focused on that term and less so with the other terms for this analysis. Although the other terms are not as important, their meaning is described as follows:

- β_0 : The significance of β_0 indicates if the intercept is equal to 0. The magnitude and sign (+/-) of the parameter estimate indicates the offset from the 0 intercept.
- β_1 : The significance of β_1 is the slope for the first model division and indicates whether a change over the years in the first time period is detectable. If the term is not significant, then no noticeable change is found.
- β_2 : The β_2 indicates the impact on the second time period model intercept but is only interpreted when β_3 is not significant, due to the way the model was established.

In order to develop these models for each dataset, Statistical Analysis Software (SAS) 9.4 was utilized. The procedure used by the program is explained in the following section.

SAS: The REG Procedure

One linear regression modelling procedure in SAS is called the “REG Procedure” or “REG PROC”. This function uses “qualitative variables to distinguish between populations” and fits two populations in one model (72). The ability to model two

populations together allows “for testing for different slopes or intercepts in the populations and more degrees of freedom are available for the analysis” (72).

Using the REG PROC function, the variables of interest from Chapter 3 were comparatively modeled to determine if the frequency changes across different periods of time (i.e. before and after the speed limit increase) were statistically significant. The time periods modelled together include:

- **2001-2004 vs. 2006-2009:** To examine whether the model for the 2001-2004 before period is different than the 2006-2009 after period. However, 2001 crash data has known issues due to a crash report form change and reporting inconsistencies related to this.
- **2002-2004 vs. 2006-2008:** To examine whether the model for the 2002-2004 before period is different than the 2006-2008 after period. Here, 2001 crash data was discarded due to the known issues resulting from a crash form change and reporting inconsistencies.
- **2006-2009 vs. 2011-2014:** To examine whether the after period impacts remained consistent in the short-term.
- **2006-2009 vs. 2015-2018:** To examine whether the after period impacts remained consistent in the long-term.
- **2011-2014 vs. 2015-2018:** To examine whether the after period impacts remained consistent between the short-term and long-term.

Similar to the SAS data selection process described in Chapter 3, code was developed to import the data of interest, to subset each safety issue into the compared time periods, and to create detailed output files that include analysis of variance,

parameter estimates, fit plots, and fit diagnostic graphs. Examples of direct SAS output files for 2006-2009 vs. 2011-2014 lost control crashes are described in the following tables and figures. However, due to a lack of statistically significant results for time periods beyond the immediate before and after period and to focus this thesis, only the first two timeframe options (i.e., 2001-2004 vs. 2006-2009 and 2002-2004 vs. 2006-2008) were retained for results and conclusion purposes.

Table 4.2 outlines the measures used for variance analysis of linear regression models. These data are called goodness-of-fit statistics and used to “compare the results across multiple studies, compare competing models within a single study, and provide feedback on the understanding of the uncertainty involved with the observed variable” (71).

Table 4.2: Measures used in variance analysis (71).

| Statistical Measure | Definition | Statistical Measure | Definition |
|--------------------------------|--|-------------------------------------|---|
| Degrees of Freedom (DF) | The number of values in a statistic that vary freely. | Dependent Mean | Mean of the dependent variable. |
| Sum of Squares | A measure of deviation from the mean. | Coefficient of Variance | The ratio of the standard deviation (σ) to the mean. |
| Mean Square | An estimate of the population variance based on the variability among a set of measures. | F Value | A ratio of mean squares that tests the statistical difference between competing models. |
| R-Square | A measure that represents the proportion of variance. | Root Mean Square Error (MSE) | A measure of the differences between values predicted by a model or an estimator and the observed values. |
| Adjusted R-Square | Modified version of R-square that is adjusted for the number of predictors in a model. | | |

Figure 4.1 details the results of the variance analysis measures and Figure 4.2 shows the parameter estimates for the aforementioned lost control crashes model comparison. The parameter estimates table include DF, the parameter estimate, standard

error, the t-value, and probability. The t-value measures the “size of the difference relative to the variation in a sample” and the probability (P) observes the “t-value that is as extreme or more extreme than currently observed t-value under a model that assumes that the hypothesis being tested is true” (71).

| Analysis of Variance | | | | | |
|----------------------|-----|----------------|-------------|---------|--------|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 1 | 79.73825 | 79.73825 | 4.84 | 0.0285 |
| Error | 310 | 5102.31104 | 16.45907 | | |
| Corrected Total | 311 | 5182.04928 | | | |

| | | | |
|----------------|----------|----------|--------|
| Root MSE | 4.05698 | R-Square | 0.0154 |
| Dependent Mean | 5.08462 | Adj R-Sq | 0.0122 |
| Coeff Var | 79.78922 | | |

Figure 4.1: Analysis of Variance for 2006-2009 vs. 2011-2014 lost control crashes.

| Parameter Estimates | | | | | | |
|---------------------|-----------|----|--------------------|----------------|---------|---------|
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 6.93059 | 0.86956 | 7.97 | <.0001 |
| YEAR | YEAR | 1 | -0.18460 | 0.08387 | -2.20 | 0.0285 |

Figure 4.2: Parameter Estimates for 2006-2009 vs. 2011-2014 lost control crashes.

Figures 4.3 and 4.4 showcase the visual outputs from SAS for the lost control crashes model comparison. Figure 4.3 shows the fit diagnostics graphs, which contain residual graphs in order to prove that all linear regression assumptions are met. The linearity assumption is ensured by the disturbance plots the absence of any curvilinear trends in the plot. If these non-linear trends appear, remedial actions will have to be taken to proceed with modelling in linear regression. Scatter plots assess the homoscedasticity or constancy of disturbances in a model and the histogram is to prove that the peak of the distribution occurs evenly around zero for normality.

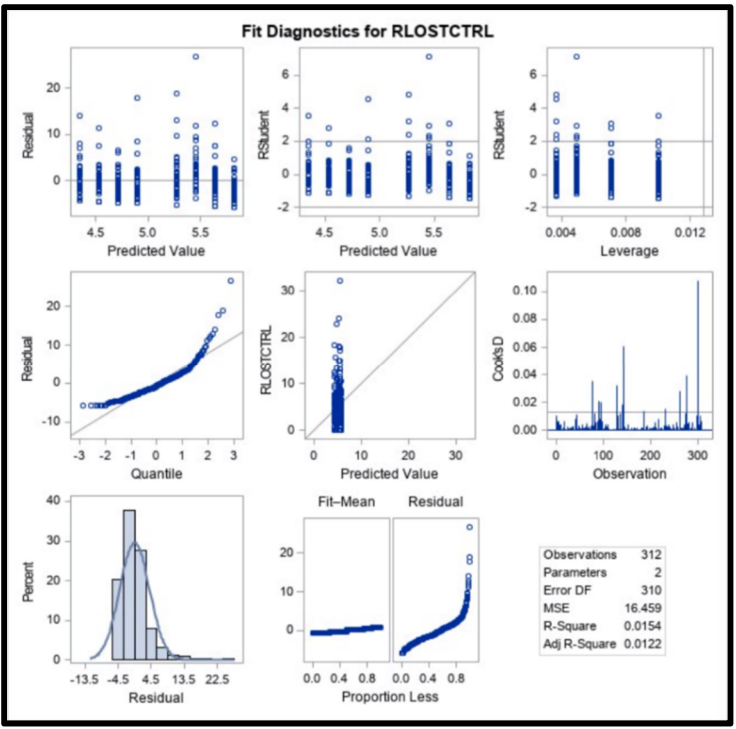


Figure 4.3: SAS fit diagnostics graph for 2006-2009 vs. 2011-2014 lost control crashes.

Figure 4.4 shows the fit plot for 2006-2009 vs. 2011-2014 lost control crashes. These linear regression models provide all of the necessary information to determine whether the rural interstate speed limit increase in 2005 had a statistically significant effect on lost control crashes or any of the other selected safety issues.

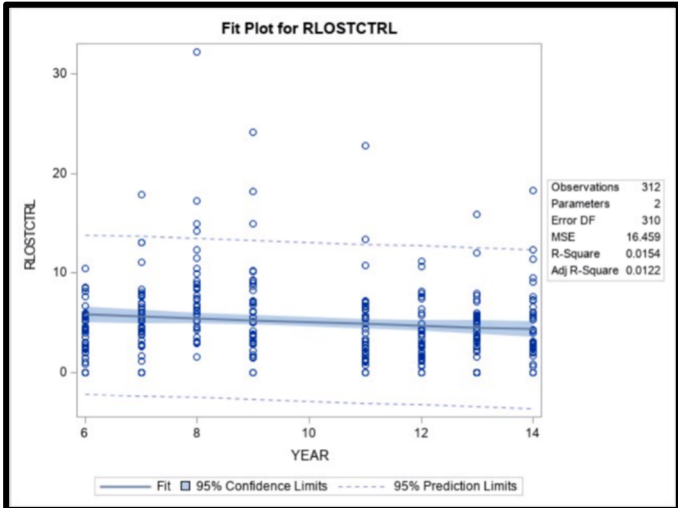


Figure 4.4: SAS fit plot for 2006-2009 vs. 2011-2014 lost control crashes.

While the SAS output is helpful, the linear regression data was exported into Microsoft Excel to develop more visual fit plot graphs. Figure 4.5 shows the fit plot for the lost control crashes example discussed in this chapter. In this figure, the dotted fit line is for the base model with simply intercept and year, as shown in Figure 4.6. The solid fit lines covering years 6 through 9 and 11 through 14 are the individual models per Equations 4.3 and 4.4. Graphs such as these will recur throughout Chapter 5. Results. In Chapter 5, each of the individual topics will be discussed primarily from the standpoint of the comparative Equation 4.3. vs. 4.4 standpoint as this enables assessment of the before vs. after nature of the analysis.

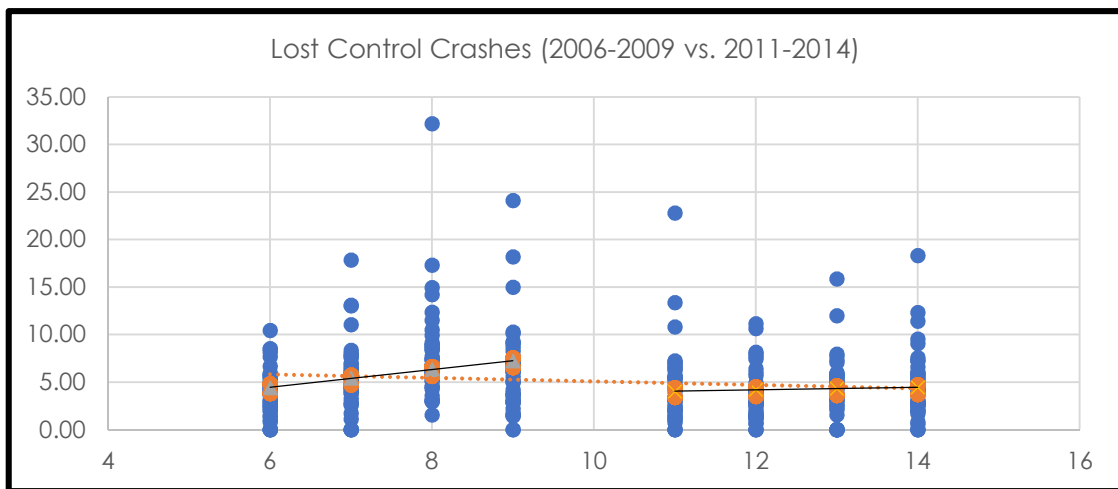


Figure 4.5: Excel fit plot for 2006-2009 vs. 2011-2014 lost control crashes.

CHAPTER 5. RESULTS

This chapter highlights the statistical analysis of the data with the linear regression models discussed in Chapter 4. Results were organized by the time periods being compared (e.g., 2001-2004 vs. 2006-2009). Attribute values outlined in Chapter 3 that did not display a notable trend were not included.

2001-2004 vs. 2006-2009

Total Crashes

The base total crash models, with simply intercept and year, for 2001-2004 vs. 2006-2009 was found to be statistically significant at the 90th percentile. This base model is graphed in Figure 5.1 based on Model Equation 5.1 resulting from the results output from SAS shown in Figure 5.2. The model has a clear intercept offset from 0 and shows an increase in the crash rate of about 2.54 per year.

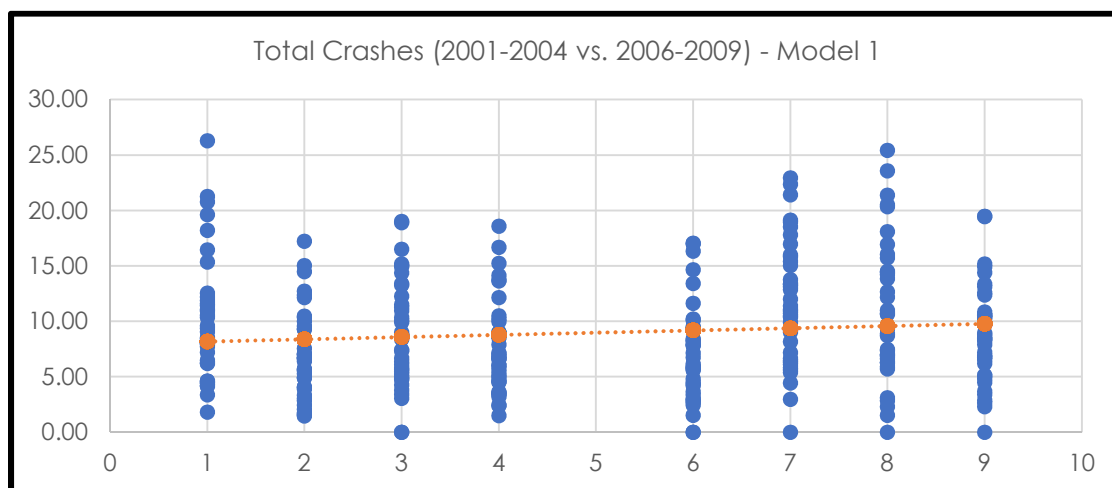


Figure 5.1: Total Crashes (2001-2004 vs. 2006-2009) – Model 1.

Model Equation 5.1: Total Crashes (2001-2004 vs. 2006-2009) – Model 1.

$$Y_i = 49.03729 + 2.54024(YEAR) + \varepsilon_i$$

The SAS output, shown in Figure 5.2, confirms through the $P_r > |t|$ parameter estimates, both variables (intercept and YEAR) were statistically significant. In addition,

the R-square value is 13.0% and adjusted R-square value is 12.7%. These measures indicate how close the data are to the fitted regression line and, in this particular case, are low. Lower R-square and adjusted R-square values typically suggest that a model explain little to no variability of the response data around the mean. However, for transportation models and other models that predict human behavior, a low R-square value is commonly observed. Even so, this research effort is more concerned with finding trends within the data and not as much with the fit of the models.

| Analysis of Variance | | | | | |
|----------------------|-----|----------------|-------------|---------|--------|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 1 | 15100 | 15100 | 46.26 | <.0001 |
| Error | 310 | 101195 | 326.43548 | | |
| Corrected Total | 311 | 116295 | | | |

| | | | |
|----------------|----------|----------|--------|
| Root MSE | 18.06753 | R-Square | 0.1298 |
| Dependent Mean | 61.73851 | Adj R-Sq | 0.1270 |
| Coeff Var | 29.26460 | | |

| Parameter Estimates | | | | | | |
|---------------------|-----------|----|--------------------|----------------|---------|---------|
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 49.03729 | 2.12928 | 23.03 | <.0001 |
| YEAR | YEAR | 1 | 2.54024 | 0.37350 | 6.80 | <.0001 |

Figure 5.2: Total Crashes (2001-2004 vs. 2006-2009) – Model 1 SAS Output.

Model 2 is also statistically significant at the 90th percentile. This model is visualized in Figure 5.3 and detailed in Model Equations 5.2 and 5.3, resulting from the results output from SAS shown in Figure 5.4. The intercepts were offset from 0 in both equations. For the first period, a decrease in crash rate of about 1.57 per year is evident. For the second period, an increase in crash rate of roughly 6.90 per year is evident. Overall, the model is statistically significant. Although the YEAR variable is not shown to be significant, for the purposes of this analysis, we are primarily interested in the INTERACTION to discern differences between the before and after periods. There is an

obvious difference between the two periods, indicating that perhaps the speed limit change resulting in additional total crashes even when taking into account volumes increases. This appears to be true at least in the short-term (4 years) and barring any other, unknown casual factor having had an impact.

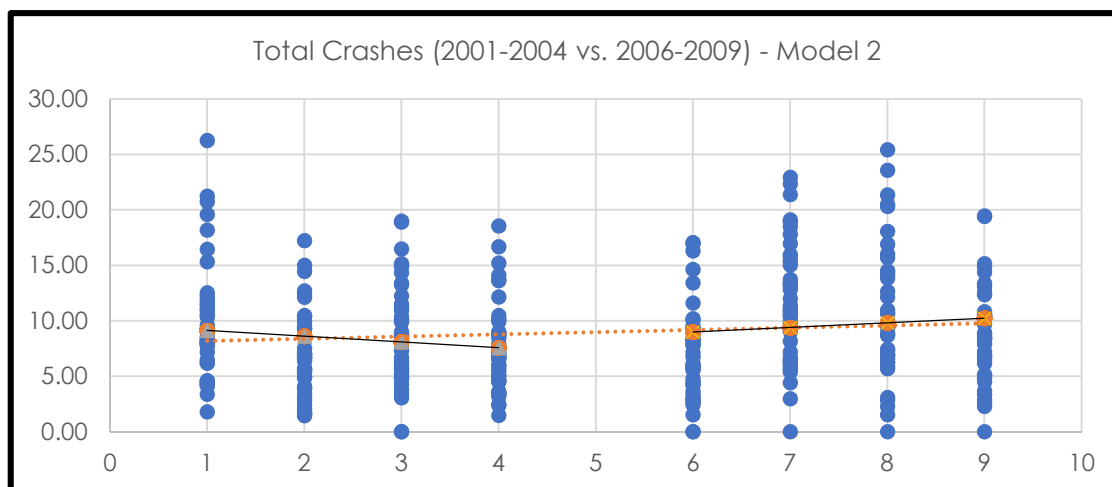


Figure 5.3: Total Crashes (2001-2004 vs. 2006-2009) – Model 2.

Model Equation 5.2: Total Crashes (2001-2004) – Model 2.

$$Y_i = 59.38116 - 1.57303(YEAR) + \varepsilon_i$$

Model Equation 5.3: Total Crashes (2006-2009) – Model 2.

$$Y_i = (59.38116 - 43.07446) + (-1.57303 + 8.46927)YEAR + \varepsilon_i$$

Based on the parameter estimates shown in Figure 5.4, there is a statistically significant difference between the slopes for the before and after period models. This means that there is an indication of a difference in the total crashes for the before speed limit change period and the after speed limit change period. The R-square and adjusted R-square values are slightly higher at 19.0% and 18.2%.

| Analysis of Variance | | | | | |
|----------------------|-----|----------------|-------------|---------|--------|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 3 | 22100 | 7366.68672 | 24.09 | <.0001 |
| Error | 308 | 94195 | 305.82656 | | |
| Corrected Total | 311 | 116295 | | | |

| | | | |
|----------------|----------|----------|--------|
| Root MSE | 17.48790 | R-Square | 0.1900 |
| Dependent Mean | 61.73851 | Adj R-Sq | 0.1821 |
| Coeff Var | 28.32575 | | |

| Parameter Estimates | | | | | | |
|---------------------|-----------|----|--------------------|----------------|---------|---------|
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 59.38116 | 3.42966 | 17.31 | <.0001 |
| YEAR | YEAR | 1 | -1.57303 | 1.25233 | -1.26 | 0.2100 |
| YR20062009 | | 1 | -43.07446 | 10.09664 | -4.27 | <.0001 |
| INTERACT | | 1 | 8.46927 | 1.77107 | 4.78 | <.0001 |

Figure 5.4: Total Crashes (2001-2004 vs. 2006-2009) – Model 2 SAS Output.

Too Fast Crashes

Model 2 elements for too fast crashes comparing these two time periods were found to be statistically significant. The model is shown in Figure 5.5 and in Model Equations 5.4 and 5.5, resulting from the results output from SAS shown in Figure 5.6. In this case, there is a non-zero intercept, and a crash rate decrease of roughly 0.82 per year during the first period and a crash rate increase of 1.91 per year during the second period. Overall, there is an obvious difference between the two periods, indicating that perhaps the speed limit change resulting in additional too fast crashes even when taking into account volume increases. This appears to be true at least in the short-term (4 years) and barring any other, unknown casual factor having had an impact.

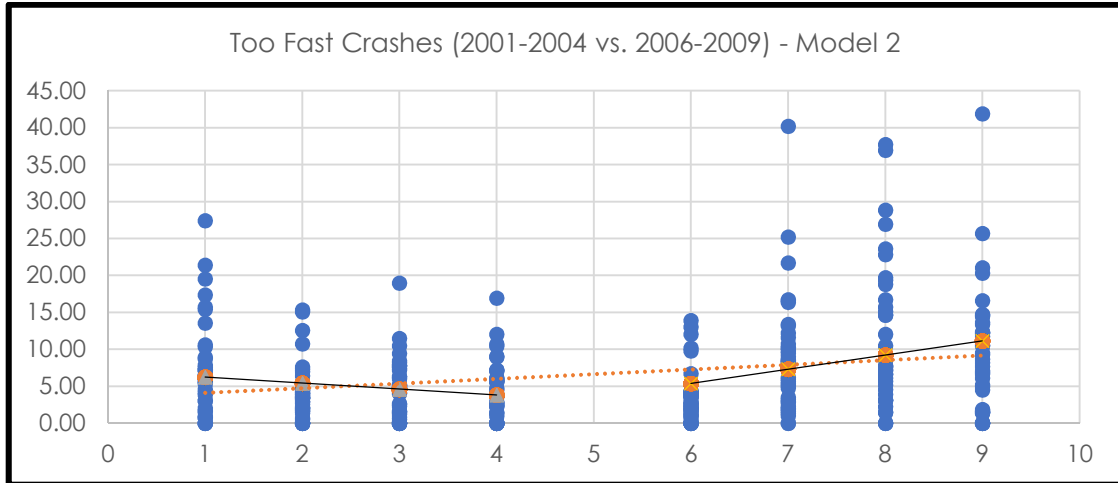


Figure 5.5: Too Fast Crashes (2001-2004 vs. 2006-2009) – Model 2.

Model Equation 5.4: Too Fast Crashes (2001-2004) – Model 2.

$$Y_i = 7.06686 - 0.81528(YEAR) + \varepsilon_i$$

Model Equation 5.5: Too Fast Crashes (2006-2009) – Model 2.

$$Y_i = (7.06686 - 13.15192) + (-0.81528 + 2.72981)YEAR + \varepsilon_i$$

Based on the parameter estimates shown in Figure 5.6, there is a statistically significant difference between the slopes for the before and after periods and suggest that there is a trend change from before the speed limit increase was implemented and after it was enacted. The R-square and adjusted R-square values were 11.2% and 10.4%, slightly below the corresponding model 2 values for total crashes.

| Analysis of Variance | | | | | |
|----------------------|-----|----------------|-------------|---------|--------|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 3 | 1665.80545 | 555.26848 | 12.98 | <.0001 |
| Error | 308 | 13180 | 42.79268 | | |
| Corrected Total | 311 | 14846 | | | |

| | | | |
|----------------|----------|----------|--------|
| Root MSE | 6.54161 | R-Square | 0.1122 |
| Dependent Mean | 6.65124 | Adj R-Sq | 0.1036 |
| Coeff Var | 98.35171 | | |

| Parameter Estimates | | | | | | |
|---------------------|-----------|----|--------------------|----------------|---------|---------|
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 7.06686 | 1.28292 | 5.51 | <.0001 |
| YEAR | YEAR | 1 | -0.81528 | 0.46845 | -1.74 | 0.0828 |
| YR20062009 | | 1 | -13.15192 | 3.77680 | -3.48 | 0.0006 |
| INTERACT | | 1 | 2.72981 | 0.66249 | 4.12 | <.0001 |

Figure 5.6: Too Fast Crashes (2001-2004 vs. 2006-2009) – Model 2 SAS Output.

Run Off Road Crashes

Model 2 for run off road crashes is graphed in Figure 5.7 and presented in Model Equations 5.6 and 5.7, resulting from the results output from SAS shown in Figure 5.8. The first time period (2001-2004) has an intercept that is not 0 and a minimal decreasing crash rate of 0.46 per year. The second time period (2006-2009) also has a non-zero intercept and an increasing crash rate of about 0.77 per year. Overall, there is an obvious difference between the two periods, indicating that perhaps the speed limit change resulted in additional run off road crashes even when taking into account volume increases. This appears to be true at least in the short-term (4 years) and barring any other, unknown causal factor having had an impact.

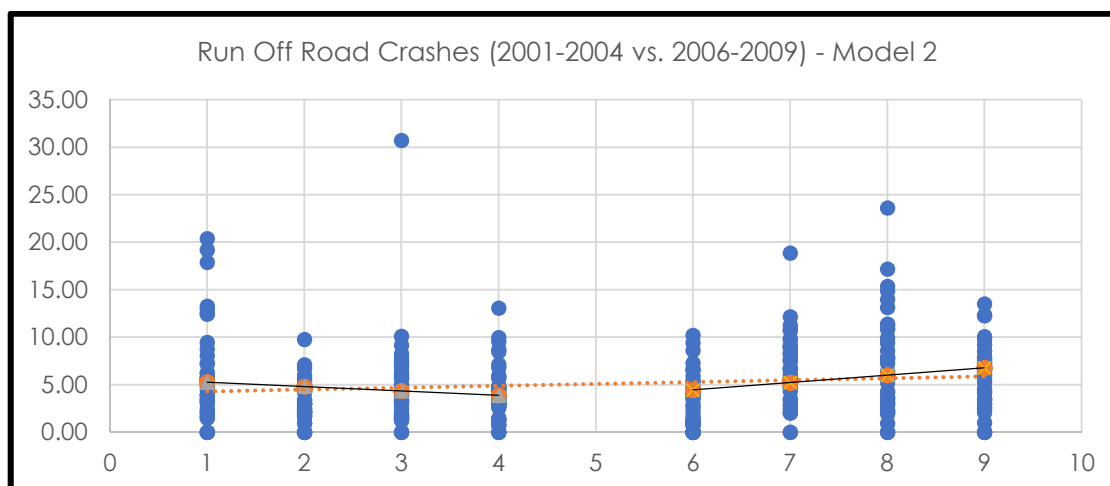


Figure 5.7: Run Off Road Crashes (2001-2004 vs. 2006-2009) – Model 2.

Model Equation 5.6: Run Off Road Crashes (2001-2004) – Model 2.

$$Y_i = 5.72614 - 0.45846(YEAR) + \varepsilon_i$$

Model Equation 5.7: Run Off Crashes (2006-2009) – Model 2.

$$Y_i = (5.72614 - 5.91235) + (-0.45846 + 1.23152)YEAR + \varepsilon_i$$

Based on the parameter estimates shown in Figure 5.8, there are some indications that there is a statistically significant trend. All parameters are statistically significant at the 90th percentile, except for the slope of the first time period. Overall, the model is statistically significant. Although the YEAR variable is not shown to be significant, for the purposes of this analysis, we are primarily interested in the INTERACTION to discern differences between the before and after periods. The R-square and adjusted R-square values were 4.4% and 3.5%, much lower than other regression models observed in this comparison.

| Analysis of Variance | | | | | |
|----------------------|-----|----------------|-------------|---------|--------|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 3 | 240.55887 | 80.18629 | 4.72 | 0.0031 |
| Error | 308 | 5236.60603 | 17.00197 | | |
| Corrected Total | 311 | 5477.16490 | | | |

| | | | |
|----------------|----------|----------|--------|
| Root MSE | 4.12334 | R-Square | 0.0439 |
| Dependent Mean | 5.09587 | Adj R-Sq | 0.0346 |
| Coeff Var | 80.91536 | | |

| Parameter Estimates | | | | | | |
|---------------------|-----------|----|--------------------|----------------|---------|---------|
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 5.72614 | 0.80865 | 7.08 | <.0001 |
| YEAR | YEAR | 1 | -0.45846 | 0.29528 | -1.55 | 0.1215 |
| YR20062009 | | 1 | -5.91235 | 2.38061 | -2.48 | 0.0135 |
| INTERACT | | 1 | 1.23152 | 0.41759 | 2.95 | 0.0034 |

Figure 5.8: Run Off Road Crashes (2001-2004 vs. 2006-2009) – Model 2 SAS Output.

Rollover Crashes

Model 2 for rollover crashes is presented in Figure 5.9 and detailed in Model Equations 5.8 and 5.9, resulting from the results output from SAS shown in Figure 5.10. The first time period has a non-zero intercept and had a crash rate decrease of about 1.30 per year. The latter time period also had a non-zero intercept and a crash rate increase of around 1.65 per year. Overall, there is an obvious difference between the two periods, indicating that perhaps the speed limit change was possibly the cause of additional rollover crashes. This observation seems to be true in the short-term (4 years) unless an unknown confounding factor is having an additional impact.

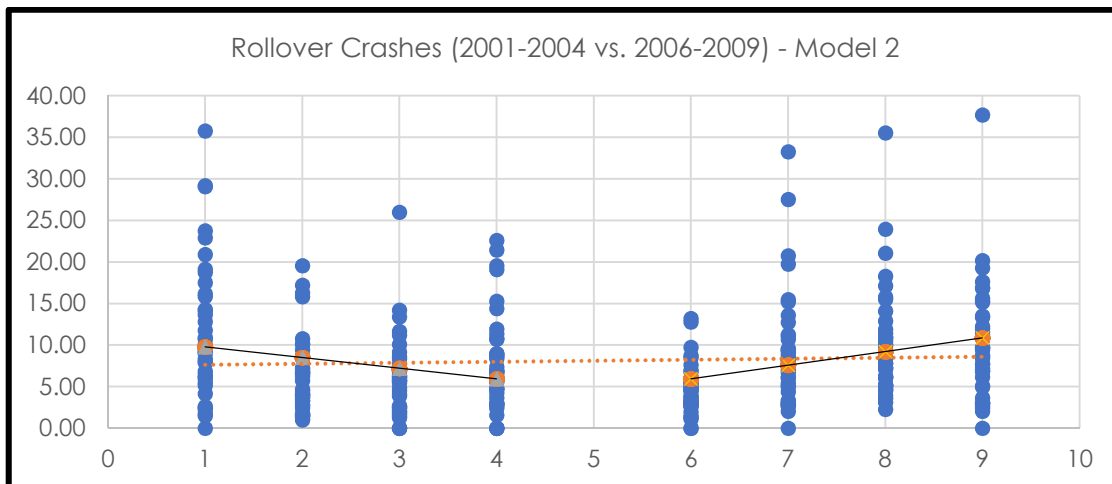


Figure 5.9: Rollover Crashes (2001-2004 vs. 2006-2009) – Model 2.

Model Equation 5.8: Rollover Crashes (2001-2004) – Model 2.

$$Y_i = 11.07794 - 1.28938(YEAR) + \varepsilon_i$$

Model Equation 5.9: Rollover Crashes (2006-2009) – Model 2.

$$Y_i = (11.07794 - 15.02787) + (-1.28938 + 2.93647)YEAR + \varepsilon_i$$

The rollover crash parameter estimates produced by SAS show that the intercept is not equal to 0, slopes for each time period are consistent, and that there is a statistically significant difference between the trend of rollover crashes prior to the implementation of the 70-mph speed limit increase and after that change. Also, all parameter estimates are significant at the 90th percentile. The R-square and adjusted R-square values were 6.8% and 5.8%.

| Analysis of Variance | | | | | | |
|----------------------|-----|----------------|-------------|---------|--------|--|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F | |
| Model | 3 | 876.69468 | 292.23156 | 7.43 | <.0001 | |
| Error | 308 | 12109 | 39.31593 | | | |
| Corrected Total | 311 | 12986 | | | | |

| | | | |
|----------------|----------|----------|--------|
| Root MSE | 6.27024 | R-Square | 0.0675 |
| Dependent Mean | 8.12888 | Adj R-Sq | 0.0584 |
| Coeff Var | 77.13539 | | |

| Parameter Estimates | | | | | | |
|---------------------|-----------|----|--------------------|----------------|---------|---------|
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 11.07794 | 1.22970 | 9.01 | <.0001 |
| YEAR | YEAR | 1 | -1.28938 | 0.44902 | -2.87 | 0.0044 |
| YR20062009 | | 1 | -15.02787 | 3.62013 | -4.15 | <.0001 |
| INTERACT | | 1 | 2.93647 | 0.63501 | 4.62 | <.0001 |

Figure 5.10: Rollover Crashes (2001-2004 vs. 2006-2009) – Model 2 SAS Output.

Single Crashes

Model 2 for single crashes are shown in Figure 5.11 and denoted by Model Equations 5.10 and 5.11, resulting from the results output from SAS shown in Figure 5.12. For the 2001-2004 period, there is a non-zero intercept and a crash rate decrease of 1.54 per year. The 2006-2009 period also had a non-zero intercept and an increase of the crash rate of roughly 1.55 per year. Overall, there is a notable difference between the first and second time periods and might indicate that the 2005 speed limit change was a factor in at least the short term.

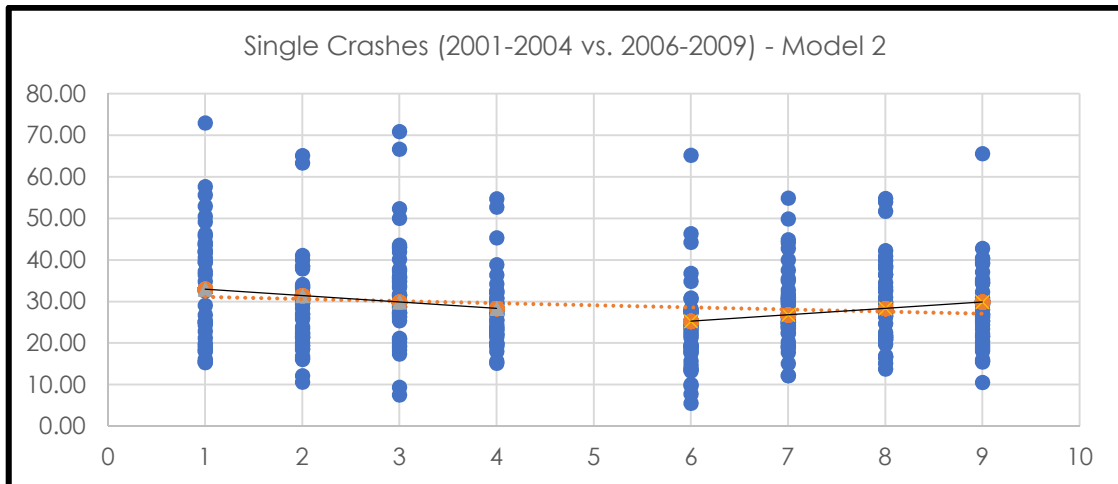


Figure 5.11: Single Crashes (2001-2004 vs. 2006-2009) – Model 2.

Model Equation 5.10: Single Crashes (2001-2004) – Model 2.

$$Y_i = 34.50349 - 1.54487(YEAR) + \varepsilon_i$$

Model Equation 5.11: Single Crashes (2006-2009) – Model 2.

$$Y_i = (34.50349 - 18.52495) + (-1.54487 + 3.09493)YEAR + \varepsilon_i$$

While the estimators show that the intercept is not equal to 0, the slope for the 2006-2009 time period is consistent, and the interaction is significant, the first time period was not statistically proven to be consistent (or at least not to the same degree as the other estimates). Despite this, the INTERACTION variable is statistically significant to the 90th percentile, so the implementation of the 70-mph speed limit could be responsible for the latter period increases. The R-square and adjusted R-square were 4.0% and 3.1%, similar to run off road crashes.

| Analysis of Variance | | | | | |
|----------------------|-----|----------------|-------------|---------|--------|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 3 | 1653.50672 | 551.16891 | 4.29 | 0.0055 |
| Error | 308 | 39551 | 128.41180 | | |
| Corrected Total | 311 | 41204 | | | |

| | | | |
|----------------|----------|----------|--------|
| Root MSE | 11.33189 | R-Square | 0.0401 |
| Dependent Mean | 29.12263 | Adj R-Sq | 0.0308 |
| Coeff Var | 38.91096 | | |

| Parameter Estimates | | | | | | |
|---------------------|-----------|----|--------------------|----------------|---------|---------|
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 34.50349 | 2.22237 | 15.53 | <.0001 |
| YEAR | YEAR | 1 | -1.54487 | 0.81149 | -1.90 | 0.0579 |
| YR20062009 | | 1 | -18.52495 | 6.54247 | -2.83 | 0.0049 |
| INTERACT | | 1 | 3.09493 | 1.14763 | 2.70 | 0.0074 |

Figure 5.12: Single Crashes (2001-2004 vs. 2006-2009) – Model 2 SAS Output.

Passenger Cars involved in Crashes

The model for passenger cars involved in crashes is shown in Figure 5.13 and detailed in Model Equations 5.12 and 5.13, resulting from the results output from SAS shown in Figure 5.14. For 2001-2004, the individual equation had a non-zero intercept with a decreasing crash rate of about 1.67 per year. The 2006-2009 period also had an intercept that was not zero and a notable crash rate increase of 4.89 per year. Overall, there is a distinct change between these two periods, which indicates that speed limit increase increased the number crashes that involved passenger cars, at least in the immediate four years following 2005.

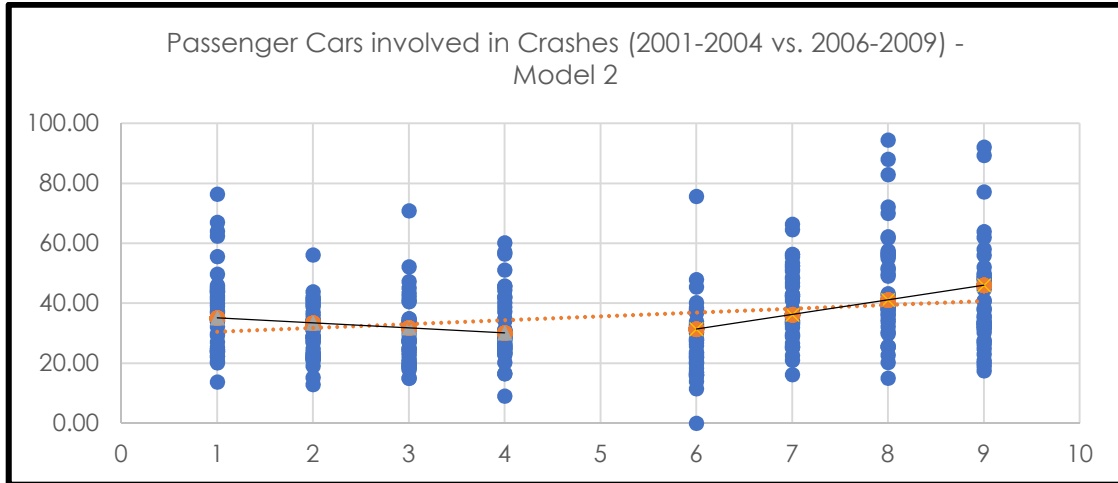


Figure 5.13: Passenger Cars involved in Crashes (2001-2004 vs. 2006-2009) – Model 2.

Model Equation 5.12: Passenger Cars involved in Crashes (2001-2004) – Model 2.

$$Y_i = 36.79526 - 1.67058(YEAR) + \varepsilon_i$$

Model Equation 5.13: Passenger Cars involved in Crashes (2006-2009) – Model 2.

$$Y_i = (36.79526 - 34.80301) + (-1.67058 + 6.56404)YEAR + \varepsilon_i$$

From the parameter estimates, it was determined that the intercept is not 0, the slope for the first time period is inconsistent, the slope for the second period is consistent, and that there is a statistically significant difference between the slopes of the models for each time period. The INTERCEPT, INTERACTION, and YR20062009 were all significant to the 90th percentile. This means that there is some sort of change in the trend of passenger cars involved in crashes from the earlier timeframe to the latter one. The R-square and adjusted R-square were 11.7% and 10.8%.

| Analysis of Variance | | | | | |
|----------------------|-----|----------------|-------------|---------|--------|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 3 | 8091.73017 | 2697.24339 | 13.53 | <.0001 |
| Error | 308 | 61383 | 199.29527 | | |
| Corrected Total | 311 | 69475 | | | |

| | | | |
|----------------|----------|----------|--------|
| Root MSE | 14.11720 | R-Square | 0.1165 |
| Dependent Mean | 35.65600 | Adj R-Sq | 0.1079 |
| Coeff Var | 39.59277 | | |

| Parameter Estimates | | | | | | |
|---------------------|-----------|----|--------------------|----------------|---------|---------|
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 36.79526 | 2.76861 | 13.29 | <.0001 |
| YEAR | YEAR | 1 | -1.67058 | 1.01095 | -1.65 | 0.0995 |
| YR20062009 | | 1 | -34.80301 | 8.15057 | -4.27 | <.0001 |
| INTERACT | | 1 | 6.56404 | 1.42970 | 4.59 | <.0001 |

Figure 5.14: Passenger Cars involved in Crashes (2001-2004 vs. 2006-2009) – Model 2 SAS Output.

2002-2004 vs. 2006-2008

Total Crashes

The model comparing 2002-2004 and 2006-2008 total crashes is shown in Figure 5.15 and detailed in Model Equations 5.13 and 5.14, resulting from the results output from SAS shown in Figure 5.16. Both time periods have intercepts that were not equal to 0. The first time period had an increasing crash rate of about 3.02 per year, while the latter period had a significant increasing crash rate of a 12.7 per year crash rate increase.

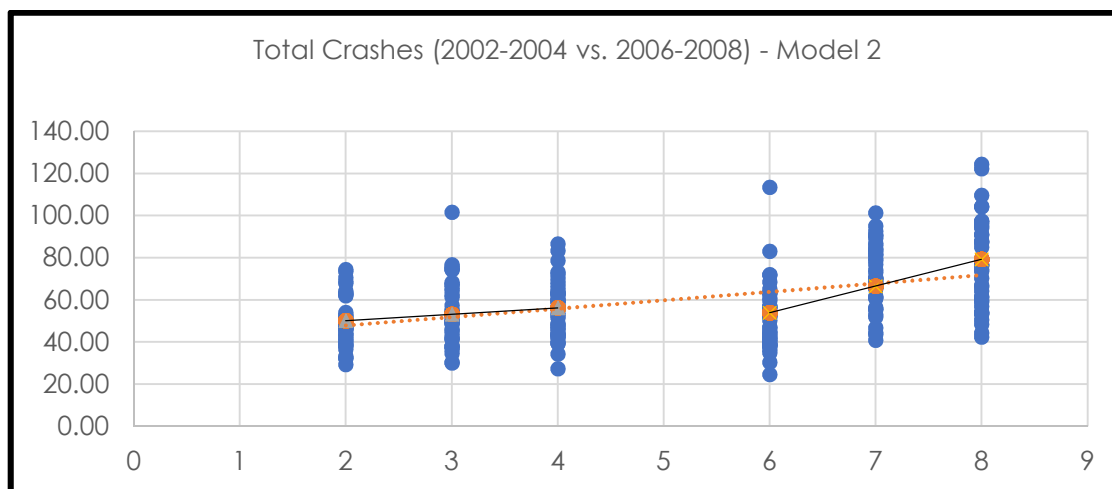


Figure 5.15: Total Crashes (2002-2004 vs. 2006-2008) – Model 2.

This model, which excludes 2001 and 2009, has more drastic crash rate changes in both time periods compared to the 2001-2004 vs. 2006-2009 model. The first period 3-year slope is increasing rather than decreasing and the latter period 3-year slope is nearly twice as much as the 4-year slope for total crashes. It appears that there is a definite difference between each time period in the short-term and that the speed limit increase likely was a strong cause of these changes.

Model Equation 5.13: Total Crashes (2002-2004) – Model 2.

$$Y_i = 44.06952 + 3.02046(YEAR) + \varepsilon_i$$

Model Equation 5.14: Total Crashes (2006-2008) – Model 2.

$$Y_i = (44.06952 - 66.23706) + (3.02046 + 9.64691)YEAR + \varepsilon_i$$

From the parameter estimators, it was shown that the intercept is not equal to 0, the slope for the second time period is consistent, and that a statistically significant difference in the total crashes trend between the two observed periods exists. The INTERCEPT, YR20062008, and INTERACT variables were all significant to the 90th percentile. The R-square and adjusted R-square values were 28.4% and 27.5%, which are about twice as high as the corresponding values for the 2001-2004 vs. 2006-2009 model comparison. These findings indicate that the speed limit increase to 70-mph could have likely been a factor that contributed to these increases.

| Analysis of Variance | | | | | |
|----------------------|-----|----------------|-------------|---------|--------|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 3 | 23690 | 7896.61764 | 30.43 | <.0001 |
| Error | 230 | 59681 | 259.48385 | | |
| Corrected Total | 233 | 83371 | | | |

| | | | |
|----------------|----------|----------|--------|
| Root MSE | 16.10850 | R-Square | 0.2841 |
| Dependent Mean | 59.81746 | Adj R-Sq | 0.2748 |
| Coeff Var | 26.92943 | | |

| Parameter Estimates | | | | | | |
|---------------------|-----------|----|--------------------|----------------|---------|---------|
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 44.06952 | 5.67082 | 7.77 | <.0001 |
| YEAR | YEAR | 1 | 3.02046 | 1.82393 | 1.66 | 0.0991 |
| YR20062008 | | 1 | -66.23706 | 14.04938 | -4.71 | <.0001 |
| INTERACT | | 1 | 9.64691 | 2.57942 | 3.74 | 0.0002 |

Figure 5.16: Total Crashes (2002-2004 vs. 2006-2008) – Model 2 SAS Output.

Lost Control Crashes

The model for lost control crashes is shown in Figure 5.17 and detailed in Model Equations 5.15 and 5.16, resulting from the results output from SAS shown in Figure 5.18. The earlier time period had a non-zero intercept and a slight crash rate increase of 0.82 per year. The latter period had an intercept not equal to 0 and an increase of 2.04 per year in the crash rate. In comparison of both periods, there is seemingly a difference that could indicate that the speed limit increase was responsible for this change.

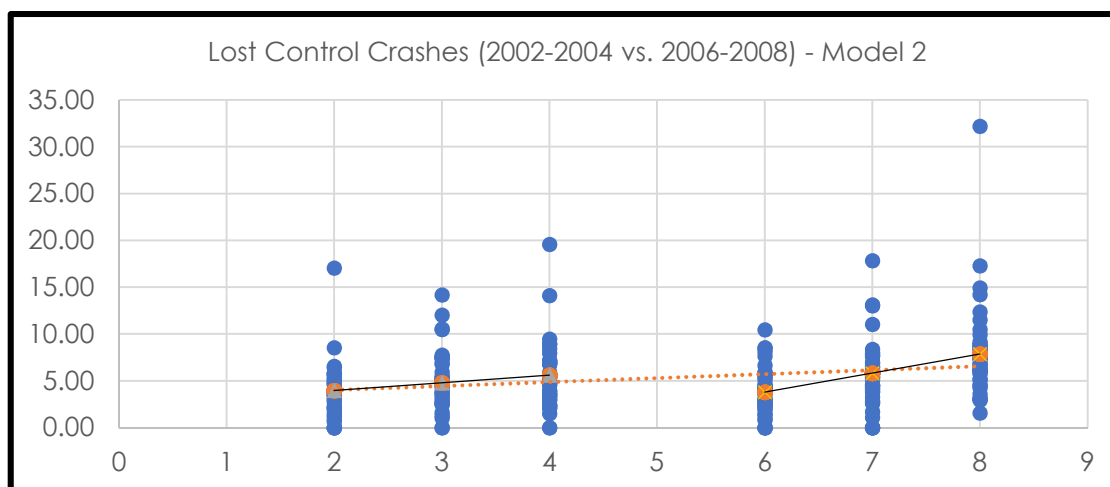


Figure 5.17: Lost Control Crashes (2002-2004 vs. 2006-2008) – Model 2.

Model Equation 5.15: Lost Control Crashes (2002-2004) – Model 2.

$$Y_i = 2.33068 + 0.81848(YEAR) + \varepsilon_i$$

Model Equation 5.16: Lost Control Crashes (2006-2008) – Model 2.

$$Y_i = (2.33068 - 10.76633) + (0.81848 + 1.21714)YEAR + \varepsilon_i$$

This model indicates that all variables are statistically significant to the 90th percentile. The R-square and adjusted R-square values were 12.5% and 11.3%. Overall, this indicates that there is a statistically significant change in the slopes of each model. Notably, the lost control crash rate more than doubles in the 3-year period following the speed limit increase.

| Analysis of Variance | | | | | |
|----------------------|-----|----------------|-------------|---------|--------|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 3 | 437.22995 | 145.74332 | 10.92 | <.0001 |
| Error | 230 | 3070.76214 | 13.35114 | | |
| Corrected Total | 233 | 3507.99209 | | | |

| | | | |
|----------------|----------|----------|--------|
| Root MSE | 3.65392 | R-Square | 0.1246 |
| Dependent Mean | 5.29988 | Adj R-Sq | 0.1132 |
| Coeff Var | 68.94351 | | |

| Parameter Estimates | | | | | | |
|---------------------|-----------|----|--------------------|----------------|---------|---------|
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 2.33068 | 1.28632 | 1.81 | 0.0713 |
| YEAR | YEAR | 1 | 0.81848 | 0.41373 | 1.98 | 0.0491 |
| YR20062008 | | 1 | -10.76633 | 3.18685 | -3.38 | 0.0009 |
| INTERACT | | 1 | 1.21714 | 0.58510 | 2.08 | 0.0386 |

Figure 5.18: Lost Control Crashes (2002-2004 vs. 2006-2008) – Model 2 SAS Output.

CHAPTER 6. CONCLUSIONS

For this research, traffic safety impacts of interstate speed limit increases were synthesized from previous studies. From this, observed crash and road volume data for the State of Iowa were examined more broadly than had done before. Prior studies focused primarily on severity, whereas this research examined many additional crash factors. In this chapter, concluding thoughts regarding the results shown in Chapter 5 are summarized for each timeframe (i.e., 2001-2004 vs. 2006-2009 and 2002-2004 vs. 2006-2008). Recommendations for further research are suggested.

Summary

2001-2004 vs. 2006-2009

As the 2001-2004 and 2006-2009 time periods represent a 4-year before-and-after timeframe for the 2005 Iowa speed limit increase to 70 mph. From the results for this timeframe, it was determined that several crash factors exhibited statistically significant differences in the crash rate trends between the two time periods. These factors include total, driving too fast for conditions, run-off-road, rollover, single, and passenger car crashes. The speed limit increase could have had a primary role in impacting crash rates for these issues; however, as the R-squared values for these models are not high, there could exist other confounding factors. Notably, total crashes went from a slowly declining trend to a crash rate increase of 8.47 per year. Driving too fast for conditions, run-off-road, rollover, and single crashes featured similar trends with declines in the before period and similar increases during the after period. Passenger car crash also declined during the before period but increased at rate nearly 4 times that of the earlier decrease.

Overall, the speed limit increase appears to have impacted the total crash rate, at least from the results resulting from the comparison of these two timeframes.

Additionally, the crash rates for other factors, particularly those involving directly related to speeding or higher speeds (i.e., driving too fast for conditions, run-off-road, rollover, single vehicle, and passenger car crashes). Related to each, some speculation as to possible reasons include:

- Total crashes: Despite a lack of indication that severe crash rates increased after the speed limit increase, total crash rates did. Among other reasons, this may be due to a reduced margin of error caused by the 5-mph increase. Another potential reason might be a shifting of traffic to the higher speed system which is better designed for the speeds; thus, less severity due to higher design standards but more crashes. This could be determined by investigating the changes in the crash rates among all roadways versus the interstate change rate trends in this period.
- Driving too fast for conditions: As driving too fast for conditions is assigned by law enforcement personnel, this could be a manifestation of greater awareness on their part. However, this could also be a result of people feeling emboldened to maintain higher speeds even when conditions are not appropriate. Additionally, drivers may have been willing to go much more over the speed limit than normal because the time period observed was directly after implementation.
- Run-off-road: Again, an increase in run-off-road crashes after the speed limit increase could result from a reduced margin of error due to the 5-mph increase. The changes in the crash rate were not vastly different, so perhaps the small increase in the latter period was due more so to other elements like traffic growth.

- Rollover: Similar to the previous issues, an increase in run-off-road crashes after the speed limit increase could result from a reduced margin of error and decreased ability to sufficiently slow a vehicle prior to the edge of roadway due to the 5-mph increase.
- Single vehicle: The increase in single vehicle crashes seems to follow the pattern of run-off-road and rollover crashes where only one vehicle, and thus one driver, is failing to maintain control which may have been exacerbated by the 5-mph increase.
- Passenger cars: Comparatively, drivers of passenger vehicles are likely less well trained and less experienced than commercial vehicle drivers. It is possible that the statistical significance of passenger cars and not commercial vehicles supports that assertion.

For all of these speculations, further study might be undertaken given the data. However, this may involve data investigation to the point of perusal of actual crash reports and narratives. Due to the frequencies of crashes as well as the accessibility of these reports and narratives, this is likely prohibitive.

2002-2004 vs. 2006-2008

The 2002-2004 vs. 2006-2008 comparison was observed to remove data that might be marred with issues related to the 2001 crash report form change. Only two issues, total crashes and lost control crashes, produced possibly statistically significant models. In comparison to the 2001-2004 vs. 2006-2009 model, total crashes (the only crossover crash type) increased by twice the amount that the first model decreased in the earlier time period and also increased nearly twice the first models' latter period. The

determination of the significance of lost control crashes is also interesting, as that was not the case in the 2001-2004 vs. 2006-2009 model.

- Total crashes: Similar to reasons mentioned in the 2001-2004 vs. 2006-2009 model, total crashes might have increased due to a reduced margin of error and/or a traffic shift to interstate roadways. The model for this issue might provide a significant case to avoid using 2001 data in the future, due to skewing of trends that it can cause.
- Lost control crashes: Like run-off road and rollover crashes, increases in lost control crashes could be due to a reduced margin of error due to the 5-mph increase. This reduced allotment for error did not allow drivers enough time to slow down a vehicle or make a driving decision that could have prevented the crash.

Recommendations for Future Research

While this effort produced several results that indicate the effects of the rural interstate speed limit increase in Iowa to 70-mph in the short term, there are additional avenues of research to pursue. The following outlines the future analytical directions such efforts could include.

Iowa Speed Limit Research

1. Return to the statistical analysis procedure for Iowa interstate crash, roadway, and traffic data to:
 - a. Fit more precise models and/or re-evaluate the statistical analyses performed in this thesis.
 - b. Explore a wider range of potential causal and resultant factors beyond those discussed in this thesis.

- c. Utilize and expand on the potential long-term impacts of the speed limit increase (e.g., 2011-2014 and 2015-2018)
- d. Examine different interstate commuter and non-commuter routes and sections to determine if differences exist. For this, the sections and commuter/non-commuter routes could be refined by an evaluated set of criteria to be applied more consistently.
- e. Similar to the sections and routes examination, investigate the impacts of the segmentation of the interstate system including non-segmentation (which would seem to negate the examination of sections and possibly commuter routes). The sections were originally developed as 3,500 short segments based on Iowa DOT's base records segmentation and could easily result in many segments with zero crashes, thereby potentially skewing results.
- f. Consider other spatial analyses, such as the effects of speed limit increases on sections of interstate near major urban centers or origin-destinations for different kinds of trip purposes.
- g. Further analyze severity based on some of these spatial considerations. For example, perhaps predominantly rural interstate sections realize higher severity than more urban sections (though still rural).
- h. Compare rural and urban interstate systems as the urban system speed limits were not increased, except on the fringes. As part of this, interchange frequency or density could become a factor to analyze.

- i. Extend the analyses beyond the interstate system and examine speed limit increases, or lack thereof, on different systems from a road classification (i.e., interstate, freeway, expressway, two-lane, etc.) standpoint.
- j. Examine potential impacts on non-interstate system routes both in close proximity of the interstate (i.e., “speed bleed”) or parallel to the interstate system.
- k. Extend the analysis back before the original Relaxation and Repeal periods. However, these data may no longer be available and, even if they are, the Iowa crash report form changed effective January 1, 2001 which could cause some further issues if data before and after this change were compared.
- l. Related to this, inclusion of historic interstate countermeasures such as flattened medians and cable median barrier installation could be used to adjust applicable sections. This could be extended to the non-interstate system as well but these changes are not necessarily readily available and the non-interstate system changes more frequently and markedly (e.g., two-lane conversion to four-lane expressway). As a further confounding factor, work zones could also be analyzed, were the data available. This could also relate to the impact of the implementation of the seat belt use law, first as a secondary then a primary offense.
- m. Expand the analysis beyond crash rate and examine frequency and density impacts, perhaps by including volume in ranges.

- n. Using volume factors to estimate travel for periods of the day, days of the week, or both simultaneously to consider speed limit increase impacts on daily commutes vs. late night.
- o. Examining vehicle fleet age or model year to assess changes in vehicle safety devices.

Other States/National Speed Limit Research

- 2. Extend to additional states which could include all the suggested analyses for Iowa crash roadway, and traffic data.
- 3. Quantify the costs of speed limit increases similar to efforts published by Gates and Savolainen. Their papers estimated the cost of a then-recent speed limit in Michigan by determining the costs of infrastructure changes, time-savings, crashes, and fuel consumption. This effort could be applied to already available Iowa crash, road, and traffic data, other states, or eventually be compiled to create a national cost estimate.

The Iowa rural interstate speed limit to 70-mph in 2005 likely resulted in some increases in crash rates among several categories. These typically occurred soon after the new speed limit was implemented and declined thereafter. When considering future speed limit increases, safety engineers and professionals should consider ways to mitigate driving too fast, run off road, rollover, and lost control crashes directly after implementation. For long-term concerns, those who oversee interstate roadways should consider ways to lower the initial crash spikes sooner, as some issues like total crashes had overall increasing crash rates into the early and mid 2010s.

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APPENDIX A. U.S. INTERSTATE SPEED LIMIT HISTORY

Appendix A contains a set of tables that indicate the rural interstate speed limit of each state for prior to the National Maximum Speed Law (NMSL), following the Surface Transportation and Uniform Relocation Assistance Act (STURAA) and National Highway System Designation Act (NHSDA), and any other additional changes.

Table A.1: Pre-National Maximum Speed Law (NMSL) Rural Interstate Speed Limits (9).

| State | Pre-NMSL Maximum Speed Limit (mph) | State | Pre-NMSL Maximum Speed Limit (mph) |
|---------------|------------------------------------|----------------|------------------------------------|
| Alabama | 70 | Montana | Basic Law |
| Alaska | 70 | Nebraska | 75 |
| Arizona | 75 | Nevada | Basic Law |
| Arkansas | 75 | New Hampshire | 70 |
| California | 70 | New Jersey | 70 |
| Colorado | 70 | New Mexico | 70 |
| Connecticut | 60 | New York | 55 |
| Delaware | 60 | North Carolina | 70 |
| Florida | 70 | North Dakota | 75 |
| Georgia | 70 | Ohio | 70 |
| Hawaii | 70 | Oklahoma | 70 |
| Idaho | 70 | Oregon | 75 |
| Illinois | 70 | Pennsylvania | 65 |
| Indiana | 70 | Rhode Island | 60 |
| Iowa | 75 | South Carolina | 70 |
| Kansas | 75 | South Dakota | 75 |
| Kentucky | 70 | Tennessee | 75 |
| Louisiana | 70 | Texas | 70 |
| Maine | 70 | Utah | 70 |
| Maryland | 70 | Vermont | 65 |
| Massachusetts | 65 | Virginia | 70 |
| Michigan | 70 | Washington | 70 |
| Minnesota | 65 | West Virginia | 70 |
| Mississippi | 70 | Wisconsin | 70 |
| Missouri | 70 | Wyoming | 75 |

Table A.2: Post-Surface Transportation and Uniform Relocation Assistance Act (STURAA)
Rural Interstate Speed Limits (18).

| State | Post-STURAA Speed Limit (mph) | Date of Increase | State | Post-STURAA Speed Limit (mph) | Date of Increase |
|---------------|-------------------------------|------------------|----------------|-------------------------------|------------------|
| Alabama | 65 | 7/20/1987 | Montana | 65 | 4/16/1987 |
| Alaska | 65 | 1/15/1988 | Nebraska | 65 | 4/27/1987 |
| Arizona | 65 | 4/15/1987 | Nevada | 65 | 4/13/1987 |
| Arkansas | 65 | 4/20/1987 | New Hampshire | 65 | 4/16/1987 |
| California | 65 | 5/28/1987 | New Jersey | 55 | NA |
| Colorado | 65 | 4/10/1987 | New Mexico | 65 | 4/2/1987 |
| Connecticut | 55 | NA | New York | 65 | NA |
| Delaware | 55 | NA | North Carolina | 65 | 8/10/1987 |
| Florida | 65 | 4/27/1987 | North Dakota | 65 | 4/16/1987 |
| Georgia | 65 | 2/22/1988 | Ohio | 65 | 7/15/1987 |
| Hawaii | 55 | NA | Oklahoma | 65 | 4/6/1987 |
| Idaho | 65 | 5/2/1987 | Oregon | 65 | 9/27/1987 |
| Illinois | 65 | 4/27/1987 | Pennsylvania | 65 | 7/13/1995 |
| Indiana | 65 | 6/1/1987 | Rhode Island | 55 | NA |
| Iowa | 65 | 5/12/1987 | South Carolina | 65 | 7/15/1987 |
| Kansas | 65 | 5/14/1987 | South Dakota | 65 | 4/15/1987 |
| Kentucky | 65 | 6/8/1987 | Tennessee | 65 | 5/8/1987 |
| Louisiana | 65 | 4/8/1987 | Texas | 65 | 5/9/1987 |
| Maine | 65 | 6/17/1987 | Utah | 65 | 5/21/1987 |
| Maryland | 65 | NA | Vermont | 65 | 4/21/1987 |
| Massachusetts | 55 | NA | Virginia | 65 | 7/1/1988 |
| Michigan | 65 | 11/29/1987 | Washington | 65 | 4/20/1987 |
| Minnesota | 65 | 6/17/1987 | West Virginia | 65 | 4/20/1987 |
| Mississippi | 65 | 4/14/1987 | Wisconsin | 65 | 7/17/1987 |
| Missouri | 65 | 5/1/1987 | Wyoming | 65 | 5/19/1987 |

Table A.3: Post-National Highway System Designation Act (NHSDA) Rural Interstate Speed Limits (7, 9, 19).

| State | Post-NHSDA Speed Limit (mph) | Date of Increase | State | Post-STURAA Speed Limit (mph) | Date of Increase |
|---------------|------------------------------|------------------|----------------|-------------------------------|------------------|
| Alabama | 70 | 5/21/1996 | Montana | No Daytime Speed Limit | 12/8/1995 |
| Alaska | 65 | NA | Nebraska | 75 | 9/1/1996 |
| Arizona | 75 | 12/8/1995 | Nevada | 75 | 12/8/1995 |
| Arkansas | 70 | 8/19/1996 | New Hampshire | 65 | NA |
| California | 70 | 1/8/1996 | New Jersey | 65 | 1/19/1998 |
| Colorado | 75 | 6/24/1996 | New Mexico | 75 | 5/15/1996 |
| Connecticut | 65 | 10/1/1998 | New York | 65 | NA |
| Delaware | 65 | 1/17/1996 | North Carolina | 70 | 8/5/1996 |
| Florida | 70 | 4/8/1996 | North Dakota | 70 | 7/1/1996 |
| Georgia | 70 | 7/1/1996 | Ohio | 65 | NA |
| Hawaii | 60 | Unknown | Oklahoma | 70 | 12/15/1995 |
| Idaho | 75 | 5/1/1996 | Oregon | 65 | NA |
| Illinois | 65 | NA | Pennsylvania | 65 | NA |
| Indiana | 65 | NA | Rhode Island | 65 | 5/12/1996 |
| Iowa | 65 | NA | South Carolina | 70 | 4/30/1999 |
| Kansas | 70 | 3/7/1996 | South Dakota | 75 | 4/1/1996 |
| Kentucky | 70 | 7/10/1997 | Tennessee | 70 | 3/25/1998 |
| Louisiana | 70 | 8/15/1997 | Texas | 75 | 12/8/1995 |
| Maine | 65 | NA | Utah | 75 | 3/1996 |
| Maryland | 65 | NA | Vermont | 65 | NA |
| Massachusetts | 65 | NA | Virginia | 65 | NA |
| Michigan | 70 | 8/1/1996 | Washington | 70 | 3/15/1996 |
| Minnesota | 70 | 7/1/1997 | West Virginia | 70 | 8/25/1997 |
| Mississippi | 70 | 2/29/1996 | Wisconsin | 65 | NA |
| Missouri | 70 | 3/13/1996 | Wyoming | 75 | 12/8/1995 |

Table A.4: Further Rural Interstate Speed Limits Increases (4, 7, 10, 11, 19, 29-35).

| State | Speed Limit (mph) | Date of Increase | State | Speed Limit (mph) | Date of Increase |
|---------------|-------------------|------------------|----------------|-------------------|------------------------|
| Alabama | 70 | NA | Montana | 75 (80) | 5/28/1999 (10/1/2015) |
| Alaska | 65 | NA | Nebraska | 75 | NA |
| Arizona | 75 | NA | Nevada | 80 | 5/15/2017 |
| Arkansas | 75 | 4/7/2017 | New Hampshire | 70 | 1/1/2014 |
| California | 70 | NA | New Jersey | 65 | NA |
| Colorado | 75 | NA | New Mexico | 75 | NA |
| Connecticut | 65 | NA | New York | 65 | NA |
| Delaware | 65 | NA | North Carolina | 70 | NA |
| Florida | 70 | NA | North Dakota | 75 | 8/1/2003 |
| Georgia | 70 | NA | Ohio | 70 | 7/1/2013 |
| Hawaii | 60 | NA | Oklahoma | 75 | 7/1/2011 |
| Idaho | 80 | 7/1/2014 | Oregon | 70 | 3/1/2016 |
| Illinois | 70 | 1/17/2014 | Pennsylvania | 70 | 7/1/2014 |
| Indiana | 70 | 7/1/2005 | Rhode Island | 65 | NA |
| Iowa | 70 | 7/1/2005 | South Carolina | 70 | NA |
| Kansas | 75 | 7/1/2011 | South Dakota | 80 | 4/1/2015 |
| Kentucky | 70 | NA | Tennessee | 70 | NA |
| Louisiana | 75 | 4/2011 | Texas | 80 (85) | 2/13/2008 (10/24/2012) |
| Maine | 75 | 9/30/2011 | Utah | 80 | 2008 |
| Maryland | 70 | 10/1/2015 | Vermont | 65 | NA |
| Massachusetts | 65 | NA | Virginia | 70 | 7/1/2010 |
| Michigan | 75 | 5/15/2017 | Washington | 75 | 8/1/2015 |
| Minnesota | 70 | NA | West Virginia | 70 | NA |
| Mississippi | 70 | NA | Wisconsin | 70 | 7/16/2015 |
| Missouri | 70 | NA | Wyoming | 80 | 7/1/2014 |

APPENDIX B. SAS OUTPUT FOR CHAPTER 5 CRASH FIELDS

Appendix B includes the SAS REG procedure output. These output files contain parameters and graphs that describe each crash type linear regression model discussed in Chapter 5. These parameters and graphs include analysis of variance values, parameter estimates, fit diagnostics, residuals, and fit plots.

2001-2004 vs. 2006-2009

Total Crashes

| SAS Output | | Page 1 of 19 | | | | |
|---|-----------|----------------|--------------------|----------------|---------|---------|
| The SAS System | | | | | | |
| The REG Procedure Model: MODEL1 Dependent Variable: RTOTALC | | | | | | |
| Number of Observations Read | | 312 | | | | |
| Number of Observations Used | | 312 | | | | |
| Analysis of Variance | | | | | | |
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F | |
| Model | 1 | 15100 | 15100 | 46.26 | <.0001 | |
| Error | 310 | 101195 | 326.43548 | | | |
| Corrected Total | 311 | 116295 | | | | |
| Root MSE | | 18.06753 | R-Square | 0.1298 | | |
| Dependent Mean | | 61.73851 | Adj R-Sq | 0.1270 | | |
| Coeff Var | | 29.26460 | | | | |
| Parameter Estimates | | | | | | |
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 49.03729 | 2.12928 | 23.03 | <.0001 |
| YEAR | YEAR | 1 | 2.54024 | 0.37350 | 6.80 | <.0001 |

Figure B.1: Total Crashes (2001-2004 vs. 2006-2009) – Model 1 Analysis of Variance and Parameter Estimates Output.

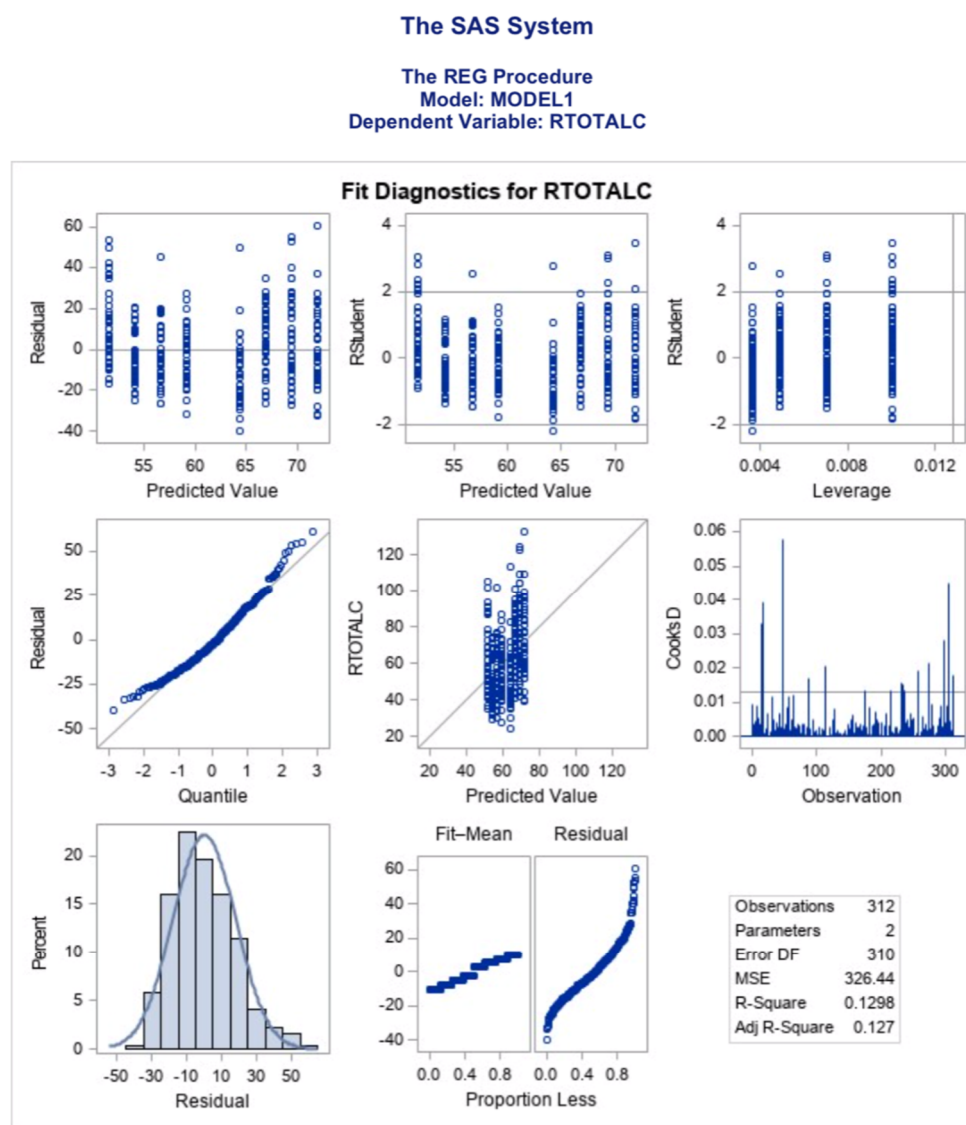


Figure B.2: Total Crashes (2001-2004 vs. 2006-2009) – Model 1 Fit Diagnostics Output.

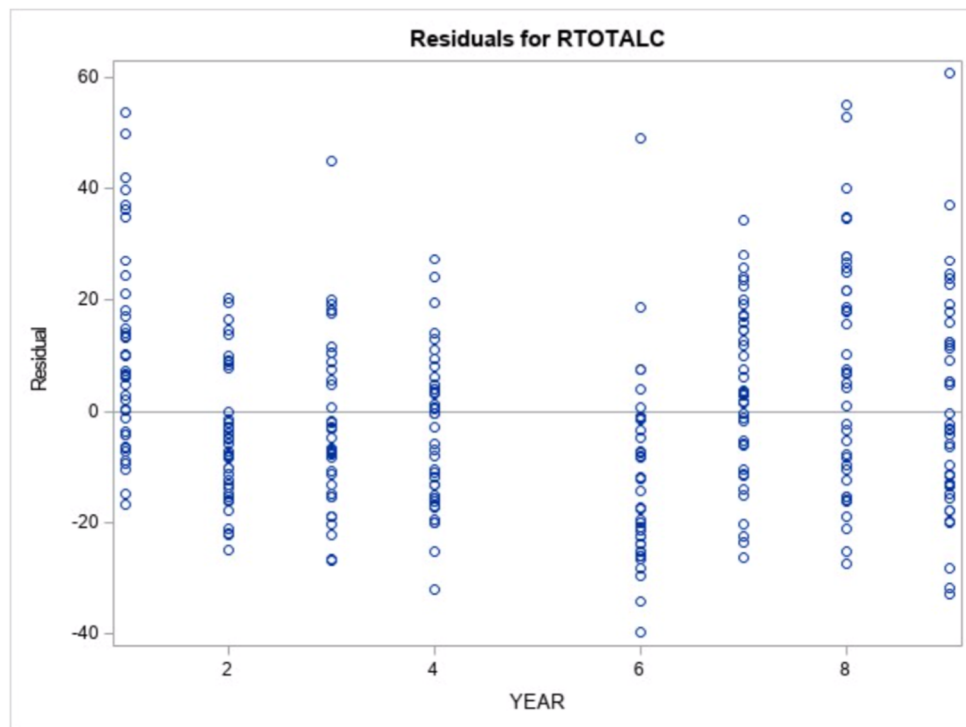


Figure B.3: Total Crashes (2001-2004 vs. 2006-2009) – Model 1 Residuals Output.

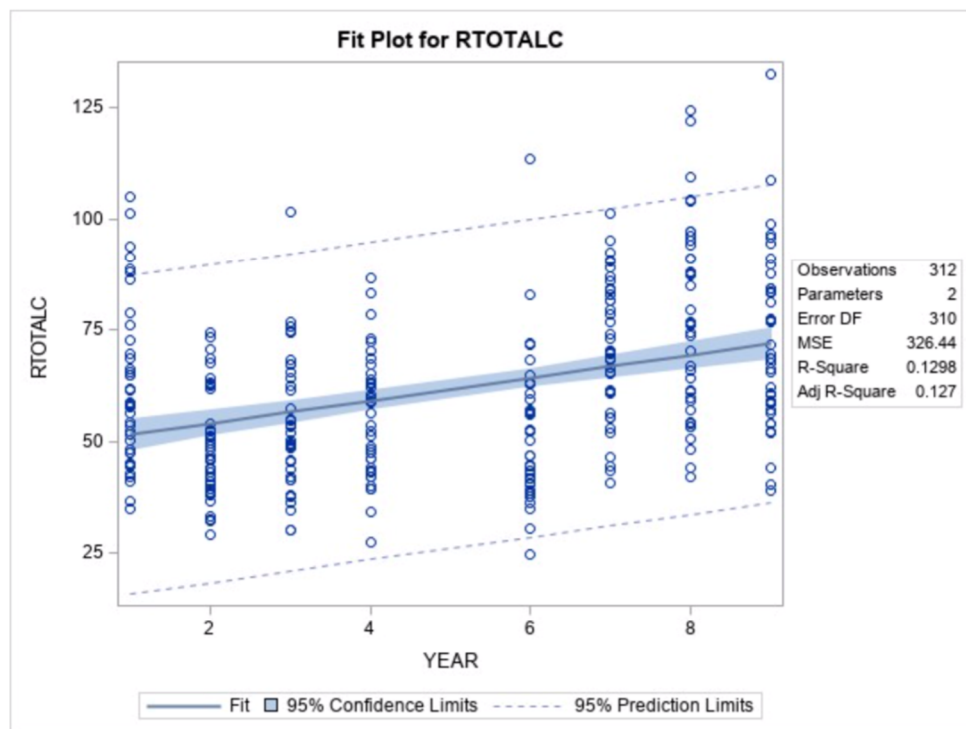


Figure B.4: Total Crashes (2001-2004 vs. 2006-2009) – Model 1 Fit Plot Output.

The SAS System

The REG Procedure
 Model: MODEL1
 Dependent Variable: RTOTALC

| | |
|-----------------------------|-----|
| Number of Observations Read | 312 |
| Number of Observations Used | 312 |

| Analysis of Variance | | | | | |
|----------------------|-----|----------------|-------------|---------|--------|
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
| Model | 3 | 22100 | 7366.68672 | 24.09 | <.0001 |
| Error | 308 | 94195 | 305.82656 | | |
| Corrected Total | 311 | 116295 | | | |

| | | | |
|----------------|----------|----------|--------|
| Root MSE | 17.48790 | R-Square | 0.1900 |
| Dependent Mean | 61.73851 | Adj R-Sq | 0.1821 |
| Coeff Var | 28.32575 | | |

| Parameter Estimates | | | | | | |
|---------------------|-----------|----|--------------------|----------------|---------|---------|
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 59.38116 | 3.42966 | 17.31 | <.0001 |
| YEAR | YEAR | 1 | -1.57303 | 1.25233 | -1.26 | 0.2100 |
| YR20062009 | | 1 | -43.07446 | 10.09664 | -4.27 | <.0001 |
| INTERACT | | 1 | 8.46927 | 1.77107 | 4.78 | <.0001 |

Figure B.5: Total Crashes (2001-2004 vs. 2006-2009) – Model 2 Analysis of Variance and Parameter Estimates Output.

The SAS System

The REG Procedure
 Model: MODEL1
 Dependent Variable: RTOTALC

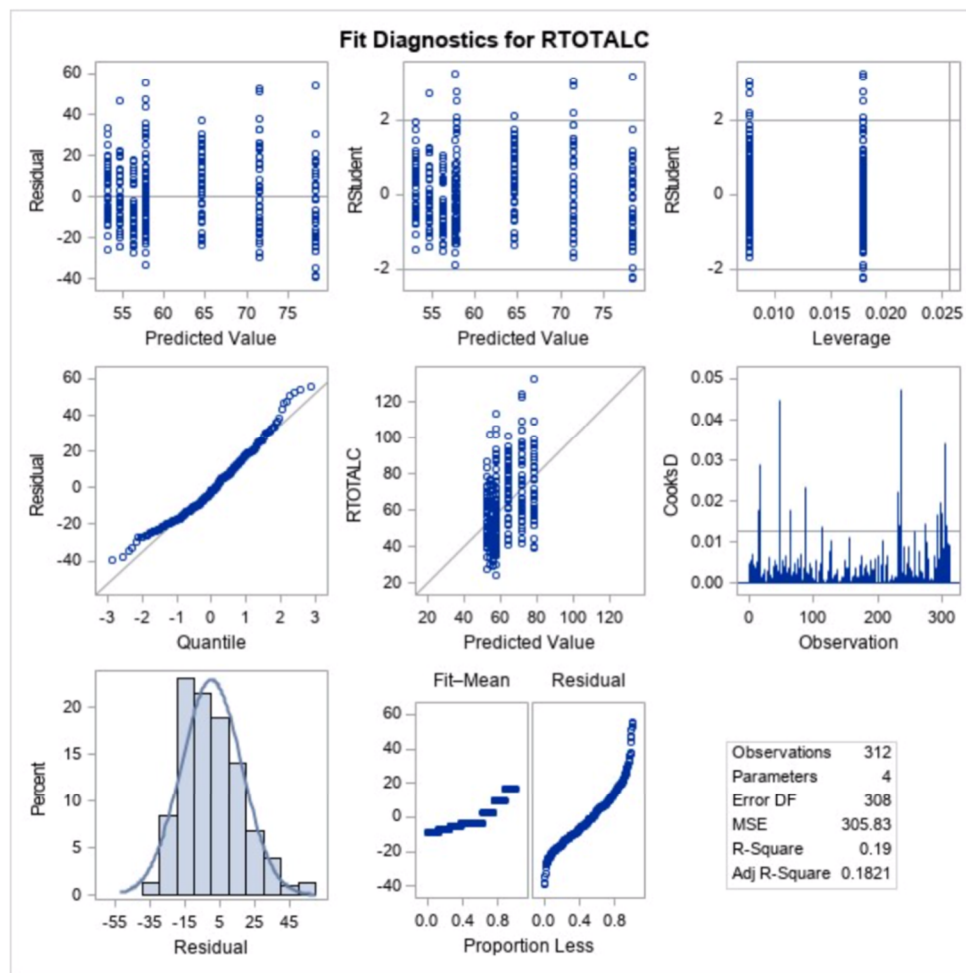


Figure B.6: Total Crashes (2001-2004 vs. 2006-2009) – Model 2 Fit Diagnostics Output.

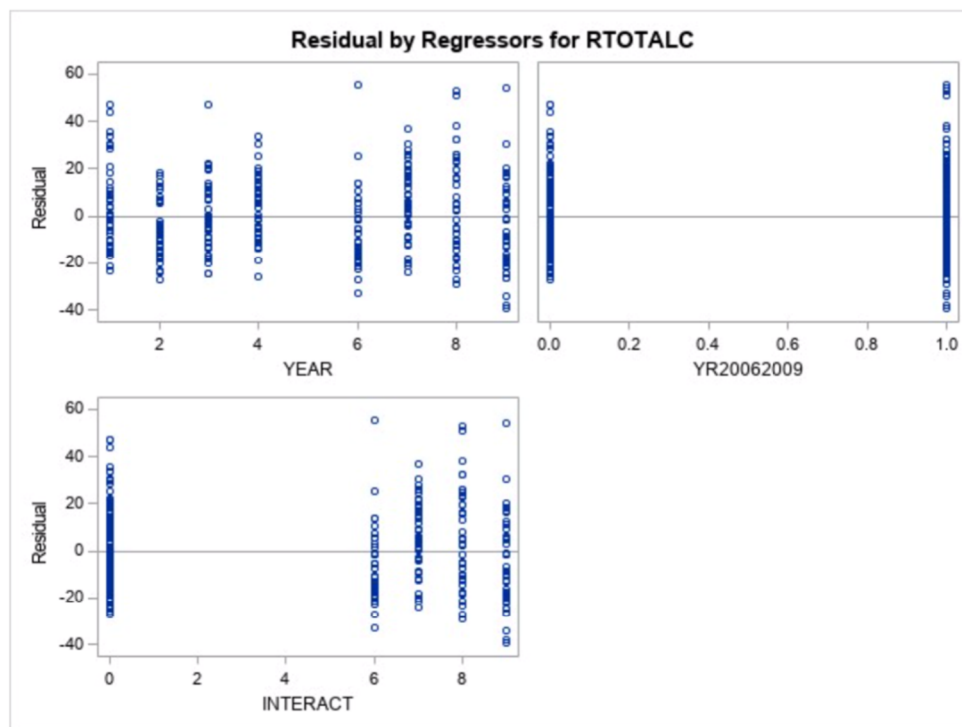


Figure B.7: Total Crashes (2001-2004 vs. 2006-2009) – Model 2 Residual Output.

Driving Too Fast Crashes

| SAS Output | | Page 5 of 19 | | | | |
|--|-----------|----------------|--------------------|----------------|---------|---------|
| The SAS System | | | | | | |
| The REG Procedure Model: MODEL1 Dependent Variable: RTOOFAST | | | | | | |
| Number of Observations Read | | 312 | | | | |
| Number of Observations Used | | 312 | | | | |
| Analysis of Variance | | | | | | |
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F | |
| Model | 3 | 1665.80545 | 555.26848 | 12.98 | <.0001 | |
| Error | 308 | 13180 | 42.79268 | | | |
| Corrected Total | 311 | 14846 | | | | |
| Root MSE | | 6.54161 | R-Square | 0.1122 | | |
| Dependent Mean | | 6.65124 | Adj R-Sq | 0.1036 | | |
| Coeff Var | | 98.35171 | | | | |
| Parameter Estimates | | | | | | |
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 7.06686 | 1.28292 | 5.51 | <.0001 |
| YEAR | YEAR | 1 | -0.81528 | 0.46845 | -1.74 | 0.0828 |
| YR20062009 | | 1 | -13.15192 | 3.77680 | -3.48 | 0.0006 |
| INTERACT | | 1 | 2.72981 | 0.66249 | 4.12 | <.0001 |

Figure B.8: Driving Too Fast Crashes (2001-2004 vs. 2006-2009) – Model 2 Analysis of Variance and Parameter Estimates Output.

The SAS System

The REG Procedure
 Model: MODEL1
 Dependent Variable: RTOOFAST

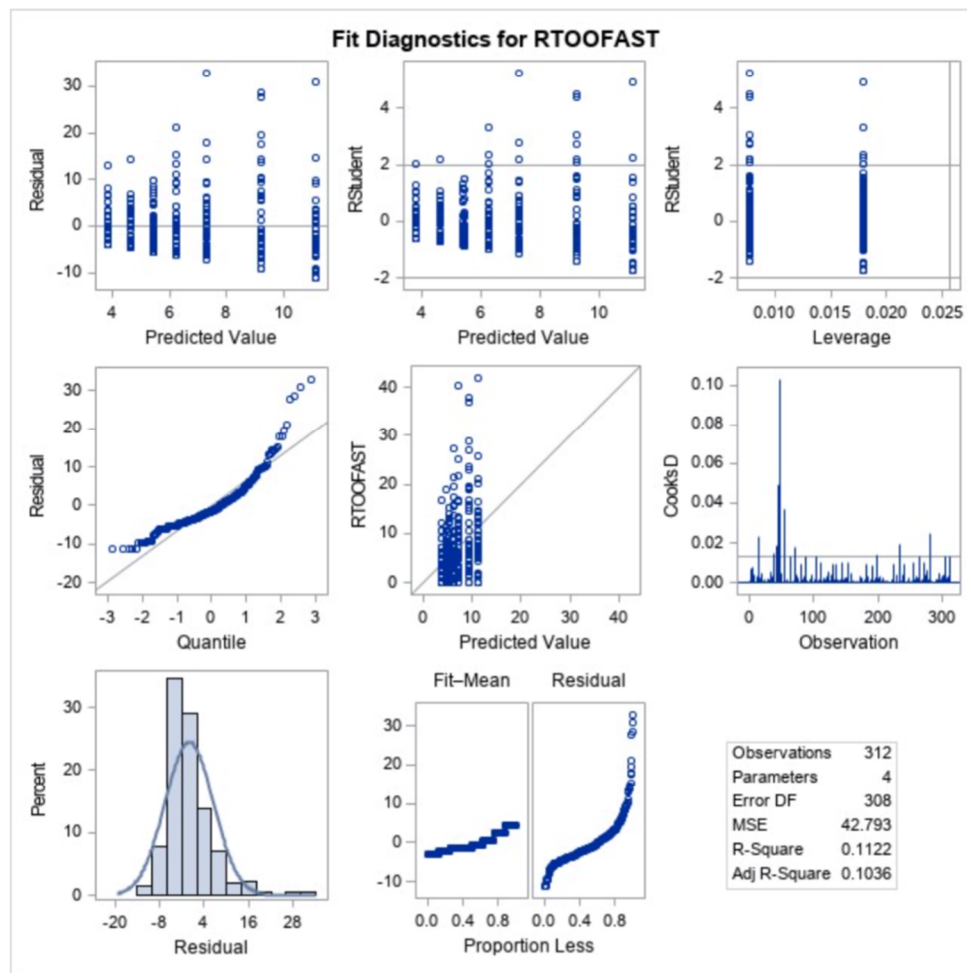


Figure B.9: Driving Too Fast Crashes (2001-2004 vs. 2006-2009) – Model 2 Fit Diagnostics Output.

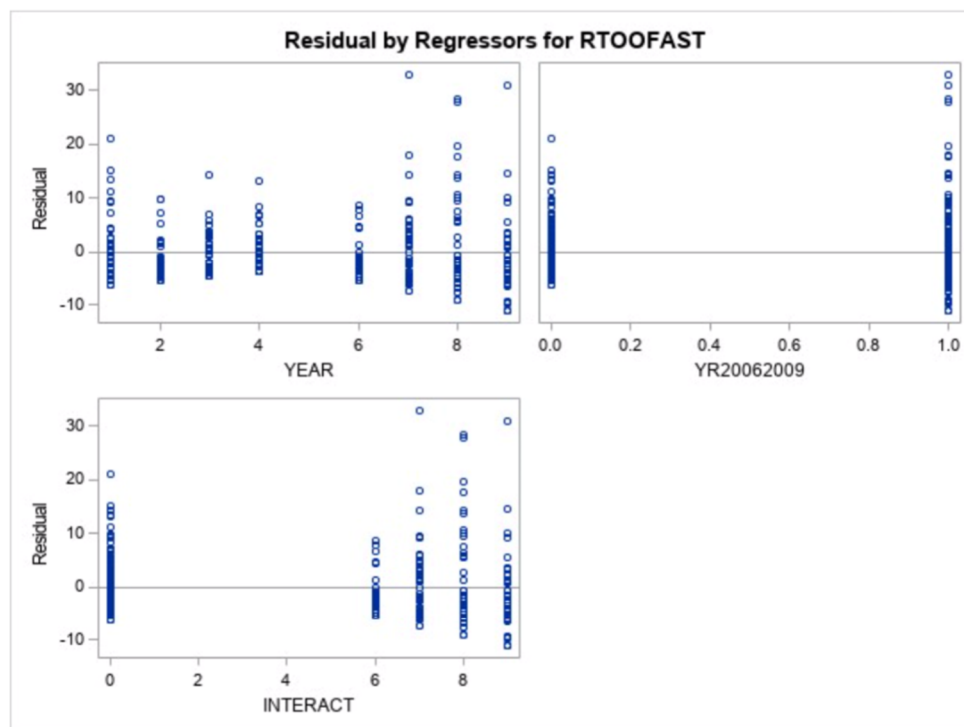


Figure B.10: Driving Too Fast Crashes (2001-2004 vs. 2006-2009) – Model 2 Residual Output.

Run Off Road Crashes

| SAS Output | | Page 5 of 19 | | | | |
|--|-----------|----------------|--------------------|----------------|---------|---------|
| The SAS System | | | | | | |
| The REG Procedure Model: MODEL1 Dependent Variable: RROR | | | | | | |
| Number of Observations Read | | 312 | | | | |
| Number of Observations Used | | 312 | | | | |
| Analysis of Variance | | | | | | |
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F | |
| Model | 3 | 240.55887 | 80.18629 | 4.72 | 0.0031 | |
| Error | 308 | 5236.60603 | 17.00197 | | | |
| Corrected Total | 311 | 5477.16490 | | | | |
| Root MSE | | 4.12334 | R-Square | 0.0439 | | |
| Dependent Mean | | 5.09587 | Adj R-Sq | 0.0346 | | |
| Coeff Var | | 80.91536 | | | | |
| Parameter Estimates | | | | | | |
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 5.72614 | 0.80865 | 7.08 | <.0001 |
| YEAR | YEAR | 1 | -0.45846 | 0.29528 | -1.55 | 0.1215 |
| YR20062009 | | 1 | -5.91235 | 2.38061 | -2.48 | 0.0135 |
| INTERACT | | 1 | 1.23152 | 0.41759 | 2.95 | 0.0034 |

Figure B.11: Run Off Road Crashes (2001-2004 vs. 2006-2009) – Model 2 Analysis of Variance and Parameter Estimates Output.

The SAS System

The REG Procedure
 Model: MODEL1
 Dependent Variable: RROR

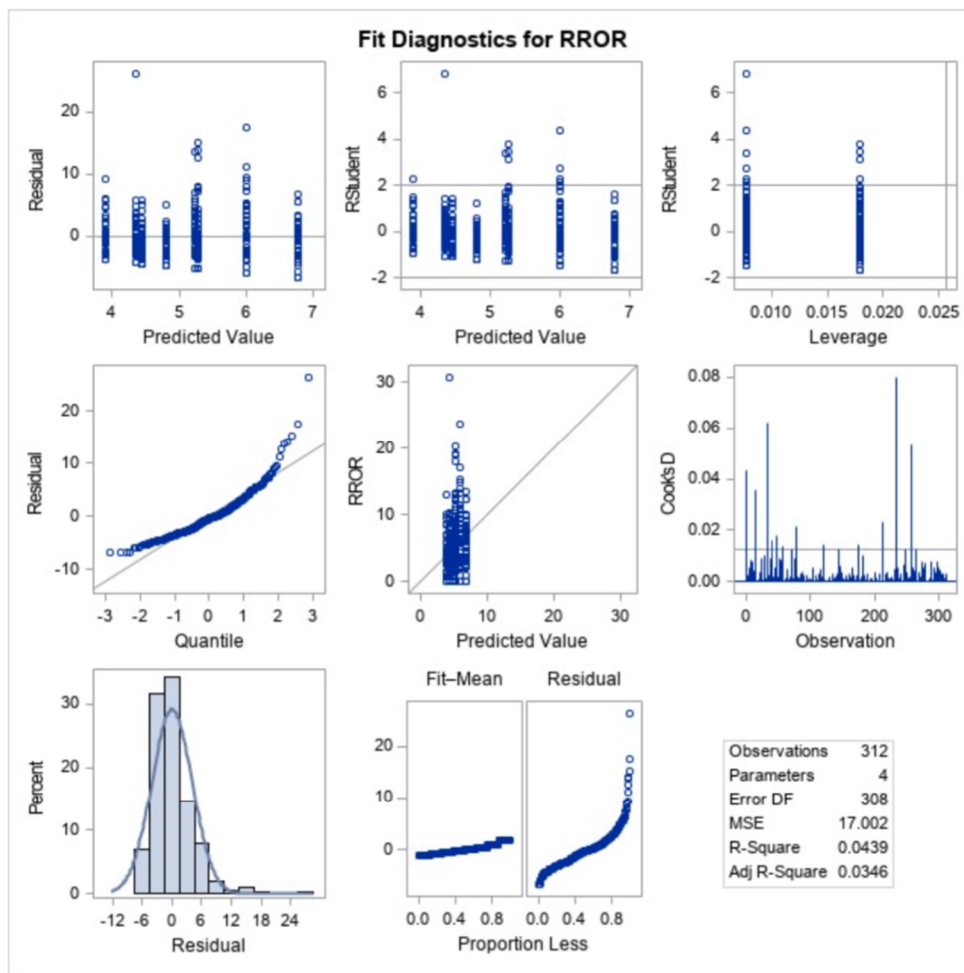


Figure B.12: Run Off Road Crashes (2001-2004 vs. 2006-2009) – Model 2 Fit Diagnostics Output.

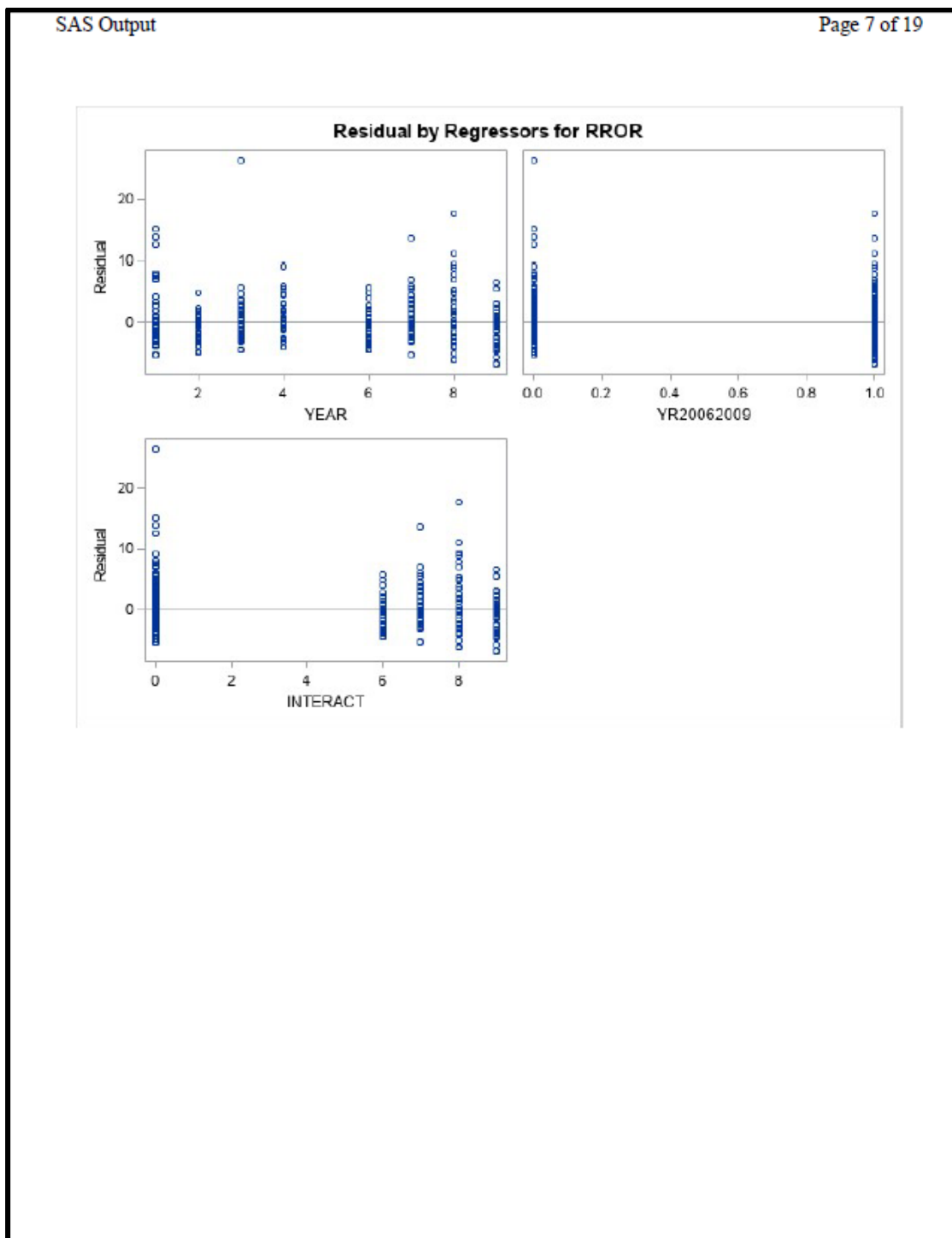


Figure B.13: Run Off Road Crashes (2001-2004 vs. 2006-2009) – Model 2 Residuals Output.

Rollover Crashes

| The SAS System | | | | | | |
|-------------------------------|-----------|----------------|--------------------|----------------|---------|---------|
| The REG Procedure | | | | | | |
| Model: MODEL1 | | | | | | |
| Dependent Variable: RROLLOVER | | | | | | |
| Number of Observations Read | | 312 | | | | |
| Number of Observations Used | | 312 | | | | |
| Analysis of Variance | | | | | | |
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F | |
| Model | 3 | 876.69468 | 292.23156 | 7.43 | <.0001 | |
| Error | 308 | 12109 | 39.31593 | | | |
| Corrected Total | 311 | 12986 | | | | |
| Root MSE | | 6.27024 | R-Square | 0.0675 | | |
| Dependent Mean | | 8.12888 | Adj R-Sq | 0.0584 | | |
| Coeff Var | | 77.13539 | | | | |
| Parameter Estimates | | | | | | |
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 11.07794 | 1.22970 | 9.01 | <.0001 |
| YEAR | YEAR | 1 | -1.28938 | 0.44902 | -2.87 | 0.0044 |
| YR20062009 | | 1 | -15.02787 | 3.62013 | -4.15 | <.0001 |
| INTERACT | | 1 | 2.93647 | 0.63501 | 4.62 | <.0001 |

Figure B.14: Rollover Crashes (2001-2004 vs. 2006-2009) – Model 2 Analysis of Variance and Parameter Estimates Output.

The SAS System

The REG Procedure
 Model: MODEL1
 Dependent Variable: RROLLOVER

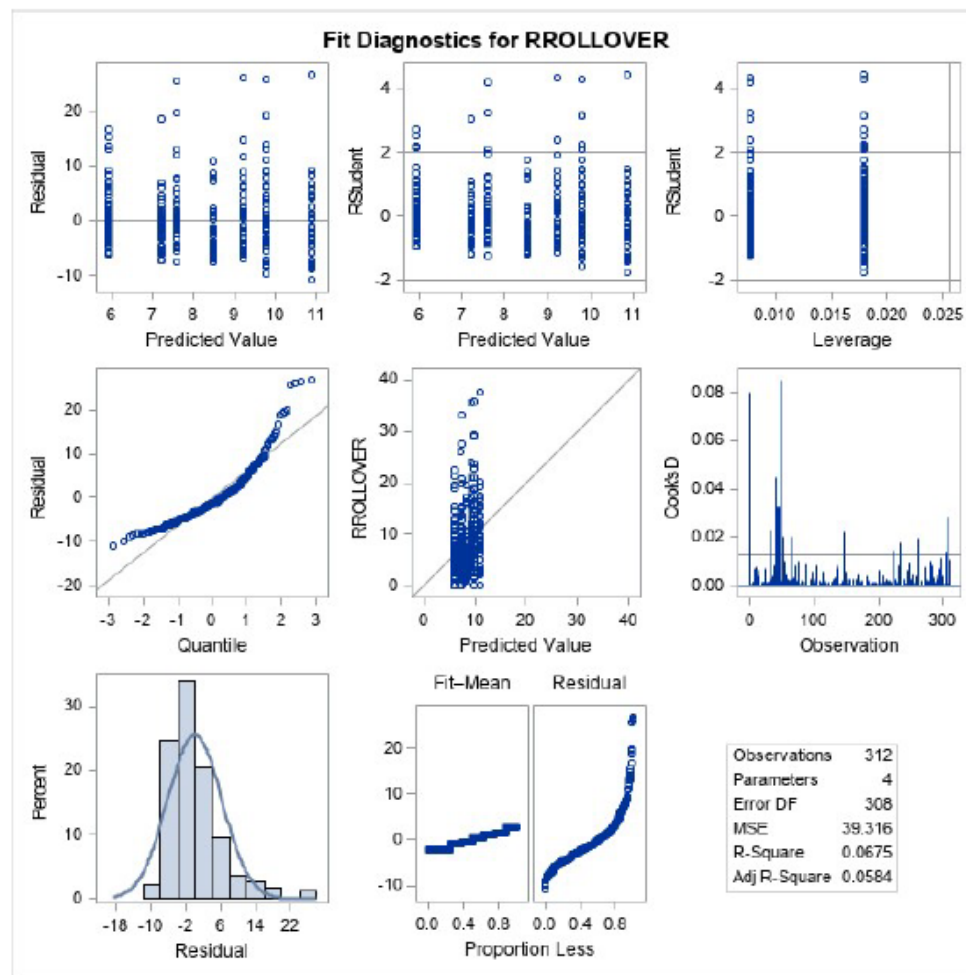


Figure B.15: Rollover Crashes (2001-2004 vs. 2006-2009) – Model 2 Fit Diagnostics Output.

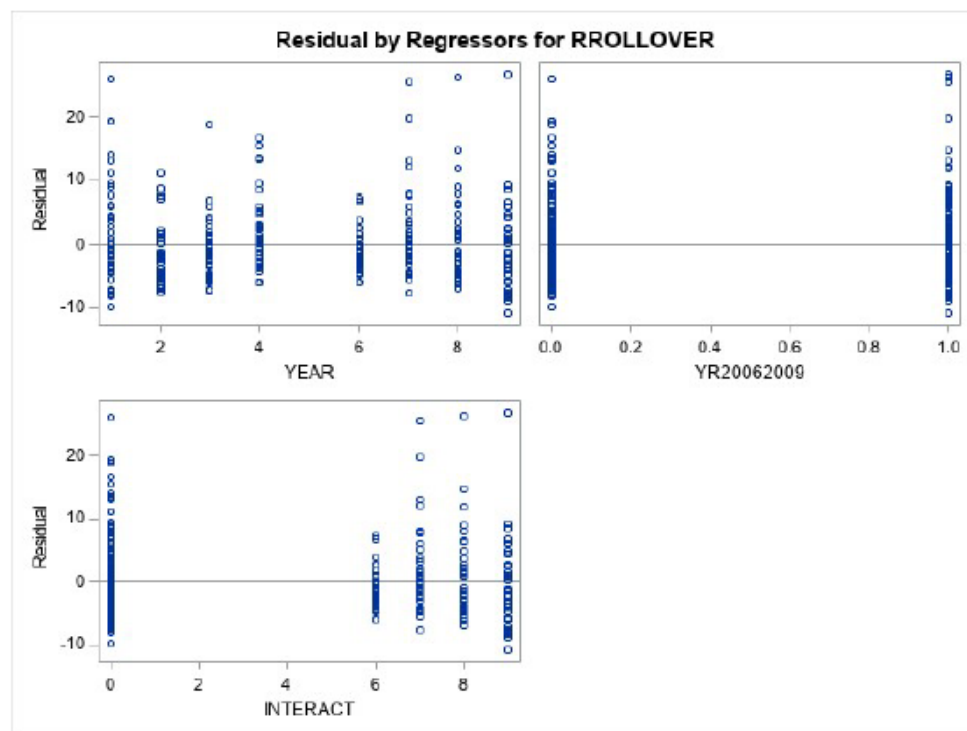


Figure B.16: Rollover Crashes (2001-2004 vs. 2006-2009) – Model 2 Residuals Output.

Single Vehicle Crashes

| SAS Output | | Page 5 of 19 | | | | |
|---|-----------|----------------|--------------------|----------------|---------|---------|
| The SAS System | | | | | | |
| The REG Procedure Model: MODEL1 Dependent Variable: RSINGLE | | | | | | |
| Number of Observations Read | | 312 | | | | |
| Number of Observations Used | | 312 | | | | |
| Analysis of Variance | | | | | | |
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F | |
| Model | 3 | 1653.50672 | 551.16891 | 4.29 | 0.0055 | |
| Error | 308 | 39551 | 128.41180 | | | |
| Corrected Total | 311 | 41204 | | | | |
| Root MSE | | 11.33189 | R-Square | 0.0401 | | |
| Dependent Mean | | 29.12263 | Adj R-Sq | 0.0308 | | |
| Coeff Var | | 38.91096 | | | | |
| Parameter Estimates | | | | | | |
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 34.50349 | 2.22237 | 15.53 | <.0001 |
| YEAR | YEAR | 1 | -1.54487 | 0.81149 | -1.90 | 0.0579 |
| YR20062009 | | 1 | -18.52495 | 6.54247 | -2.83 | 0.0049 |
| INTERACT | | 1 | 3.09493 | 1.14763 | 2.70 | 0.0074 |

Figure B.17: Single Vehicle Crashes (2001-2004 vs. 2006-2009) – Model 2 Analysis of Variance and Parameter Estimates Output.

The SAS System

The REG Procedure
 Model: MODEL1
 Dependent Variable: RSINGLE

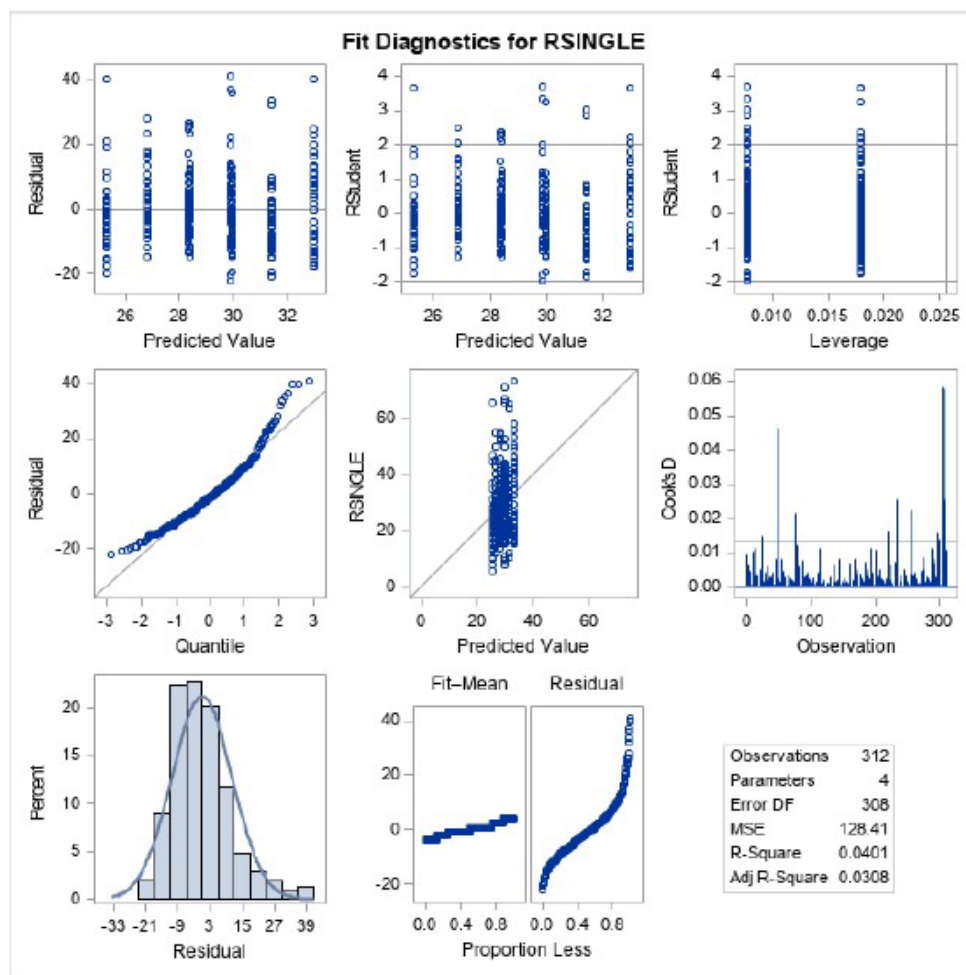


Figure B.18: Single Vehicle Crashes (2001-2004 vs. 2006-2009) – Model 2 Fit Diagnostics Output.

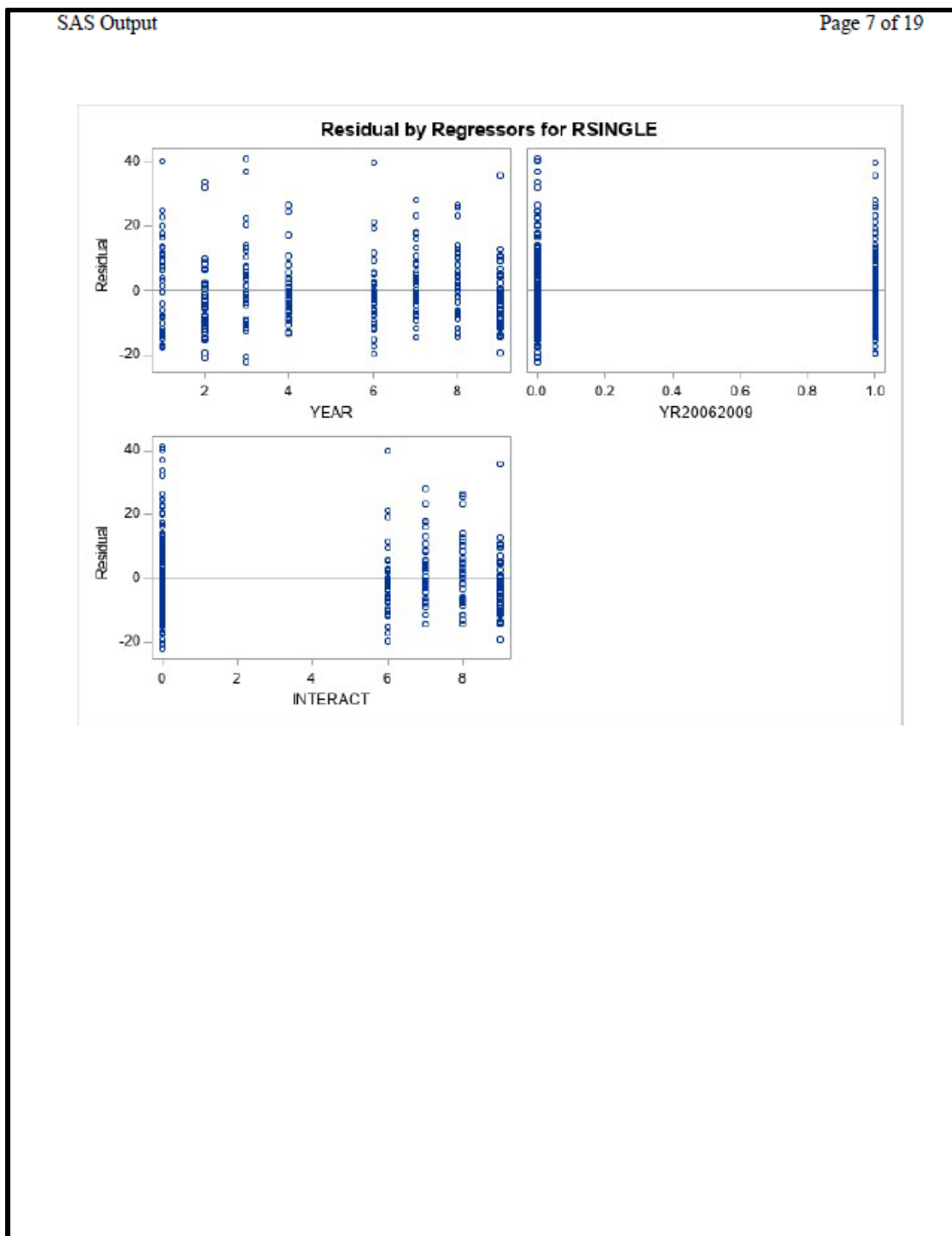


Figure B.19: Single Vehicle Crashes (2001-2004 vs. 2006-2009) – Model 2 Residuals Output.

Passenger Car Crashes

| SAS Output | | Page 5 of 19 | | | | |
|--|-----------|----------------|--------------------|----------------|---------|---------|
| The SAS System | | | | | | |
| The REG Procedure Model: MODEL1 Dependent Variable: RPASSCAR | | | | | | |
| Number of Observations Read | | 312 | | | | |
| Number of Observations Used | | 312 | | | | |
| Analysis of Variance | | | | | | |
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F | |
| Model | 3 | 8091.73017 | 2697.24339 | 13.53 | <.0001 | |
| Error | 308 | 61383 | 199.29527 | | | |
| Corrected Total | 311 | 69475 | | | | |
| Root MSE | | 14.11720 | R-Square | 0.1165 | | |
| Dependent Mean | | 35.65600 | Adj R-Sq | 0.1079 | | |
| Coeff Var | | 39.59277 | | | | |
| Parameter Estimates | | | | | | |
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 36.79526 | 2.76861 | 13.29 | <.0001 |
| YEAR | YEAR | 1 | -1.67058 | 1.01095 | -1.65 | 0.0995 |
| YR20062009 | | 1 | -34.80301 | 8.15057 | -4.27 | <.0001 |
| INTERACT | | 1 | 6.56404 | 1.42970 | 4.59 | <.0001 |

Figure B.20: Passenger Car Crashes (2001-2004 vs. 2006-2009) – Model 2 Analysis of Variance and Parameter Estimates Output.

The SAS System

The REG Procedure
 Model: MODEL1
 Dependent Variable: RPASSCAR

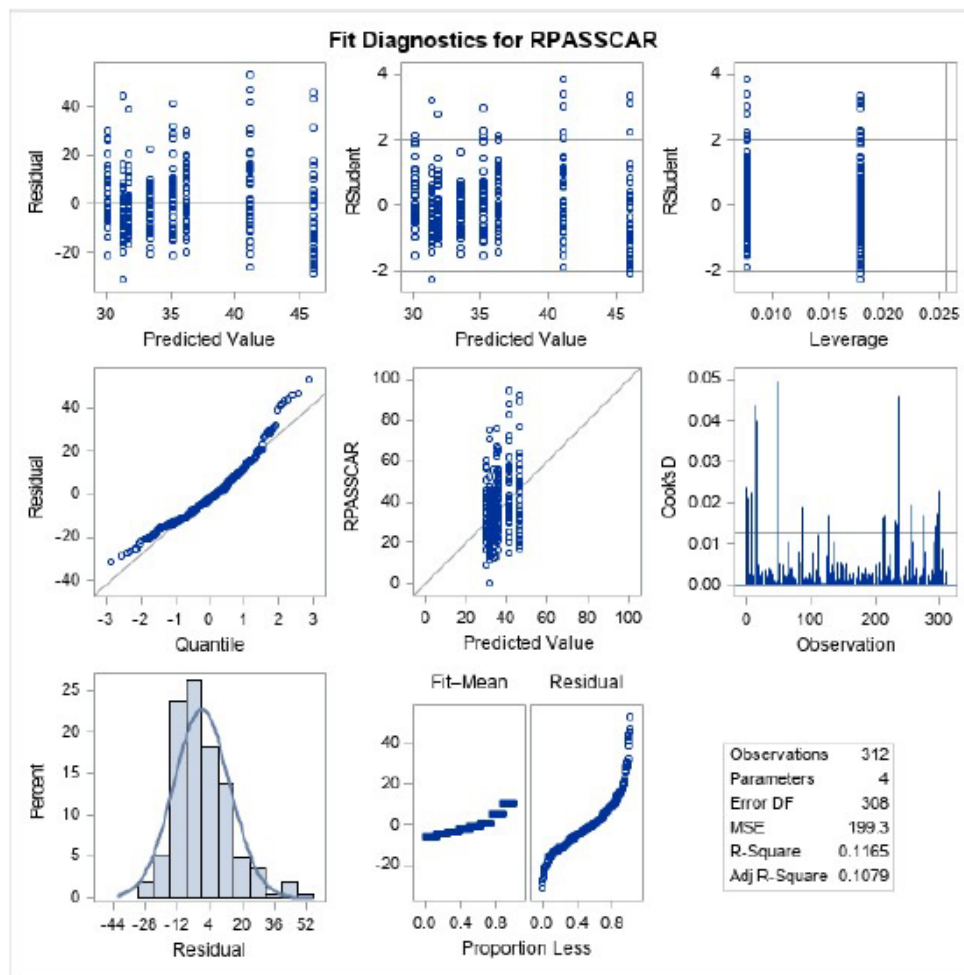


Figure B.21: Passenger Car Crashes (2001-2004 vs. 2006-2009) – Model 2 Fit Diagnostics Output.

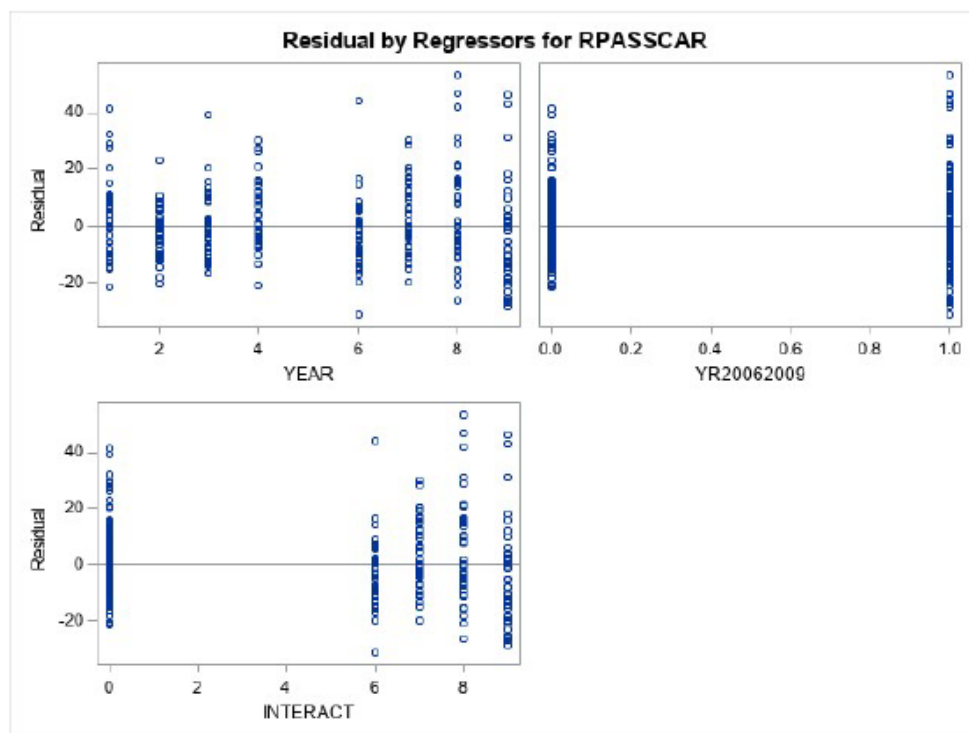


Figure B.22: Passenger Car Crashes (2001-2004 vs. 2006-2009) – Model 2 Residuals Output.

2002-2004 vs. 2006-2008

Total Crashes

| SAS Output | | Page 5 of 19 | | | | |
|---|-----------|----------------|--------------------|----------------|---------|---------|
| The SAS System | | | | | | |
| The REG Procedure Model: MODEL1 Dependent Variable: RTOTALC | | | | | | |
| Number of Observations Read | | 234 | | | | |
| Number of Observations Used | | 234 | | | | |
| Analysis of Variance | | | | | | |
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F | |
| Model | 3 | 23690 | 7896.61764 | 30.43 | <.0001 | |
| Error | 230 | 59681 | 259.48385 | | | |
| Corrected Total | 233 | 83371 | | | | |
| Root MSE | | 16.10850 | R-Square | 0.2841 | | |
| Dependent Mean | | 59.81746 | Adj R-Sq | 0.2748 | | |
| Coeff Var | | 26.92943 | | | | |
| Parameter Estimates | | | | | | |
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 44.06952 | 5.67082 | 7.77 | <.0001 |
| YEAR | YEAR | 1 | 3.02046 | 1.82393 | 1.66 | 0.0991 |
| YR20062008 | | 1 | -66.23706 | 14.04938 | -4.71 | <.0001 |
| INTERACT | | 1 | 9.64691 | 2.57942 | 3.74 | 0.0002 |

Figure B.23: Total Crashes (2002-2004 vs. 2006-2008) – Model 2 Analysis of Variance and Parameter Estimates Output.

The SAS System

The REG Procedure
 Model: MODEL1
 Dependent Variable: RTOTALC

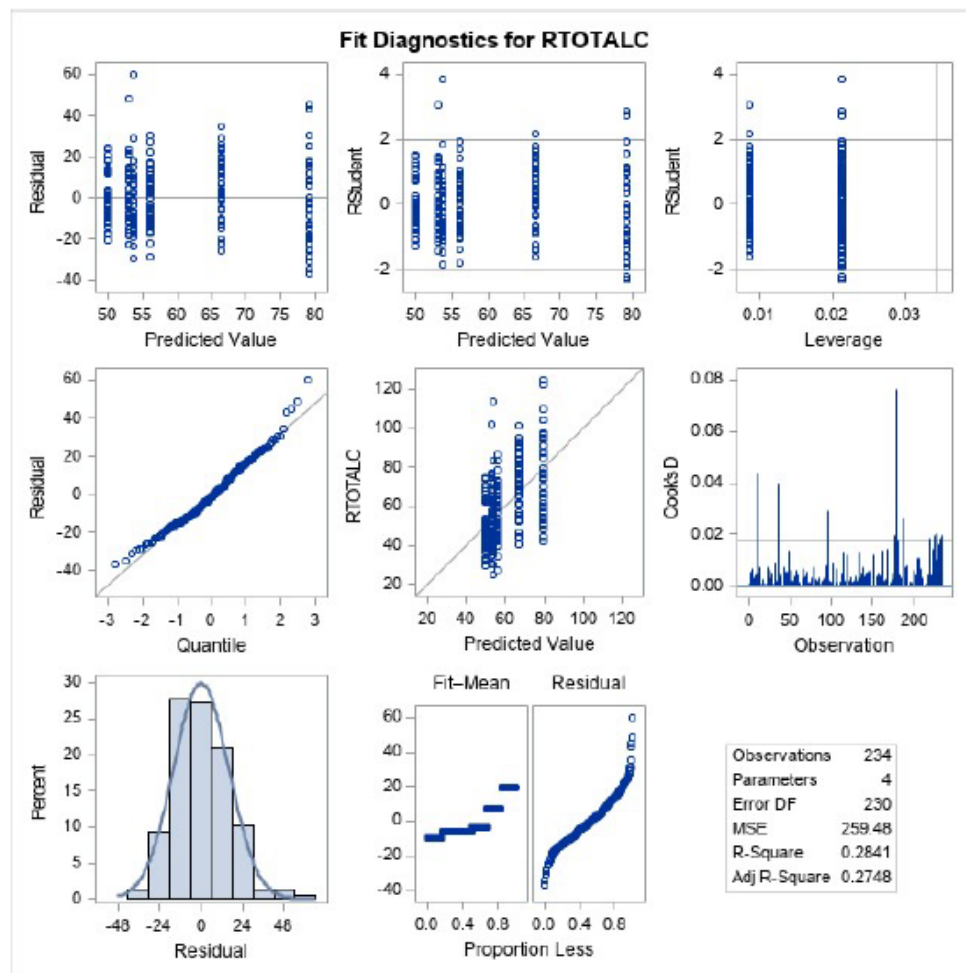


Figure B.24: Total Crashes (2002-2004 vs. 2006-2008) – Model 2 Fit Diagnostics Output.

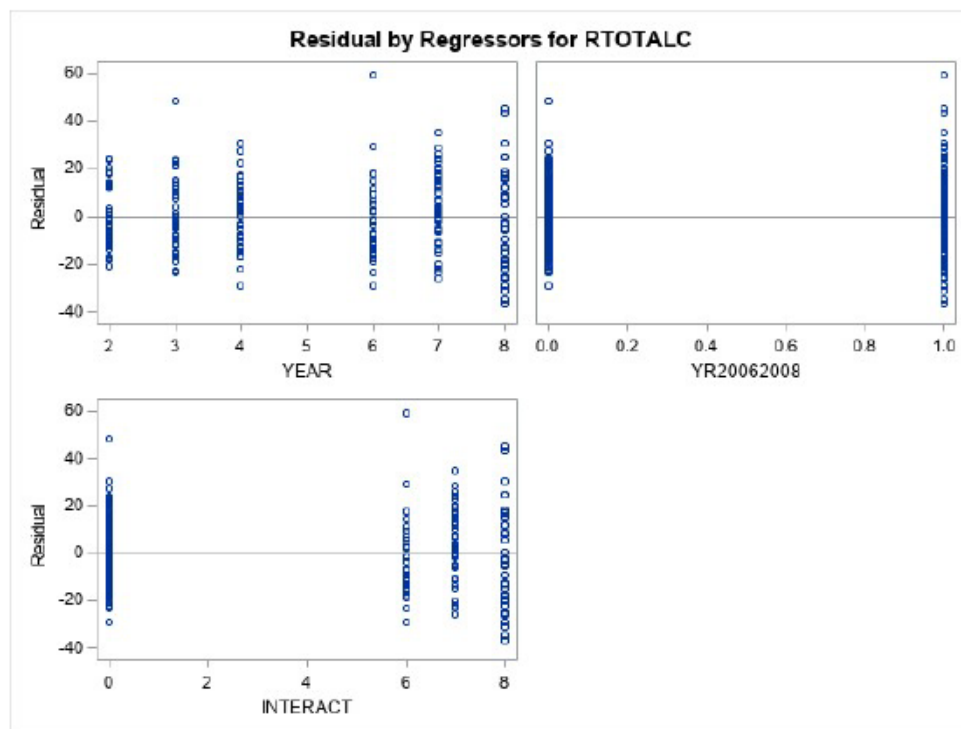


Figure B.25: Total Crashes (2002-2004 vs. 2006-2008) – Model 2 Residuals Output.

Lost Control Crashes

| SAS Output | | Page 5 of 19 | | | | |
|---|-----------|----------------|--------------------|----------------|---------|---------|
| The SAS System | | | | | | |
| The REG Procedure Model: MODEL1 Dependent Variable: RLOSTCTRL | | | | | | |
| Number of Observations Read | | 234 | | | | |
| Number of Observations Used | | 234 | | | | |
| Analysis of Variance | | | | | | |
| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F | |
| Model | 3 | 437.22995 | 145.74332 | 10.92 | <.0001 | |
| Error | 230 | 3070.76214 | 13.35114 | | | |
| Corrected Total | 233 | 3507.99209 | | | | |
| Root MSE | | 3.65392 | R-Square | 0.1246 | | |
| Dependent Mean | | 5.29988 | Adj R-Sq | 0.1132 | | |
| Coeff Var | | 68.94351 | | | | |
| Parameter Estimates | | | | | | |
| Variable | Label | DF | Parameter Estimate | Standard Error | t Value | Pr > t |
| Intercept | Intercept | 1 | 2.33068 | 1.28632 | 1.81 | 0.0713 |
| YEAR | YEAR | 1 | 0.81848 | 0.41373 | 1.98 | 0.0491 |
| YR20062008 | | 1 | -10.76633 | 3.18685 | -3.38 | 0.0009 |
| INTERACT | | 1 | 1.21714 | 0.58510 | 2.08 | 0.0386 |

Figure B.26: Lost Control Crashes (2002-2004 vs. 2006-2008) – Model 2 Analysis of Variance and Parameter Estimates Output.

The SAS System

The REG Procedure
 Model: MODEL1
 Dependent Variable: RLOSTCTRL

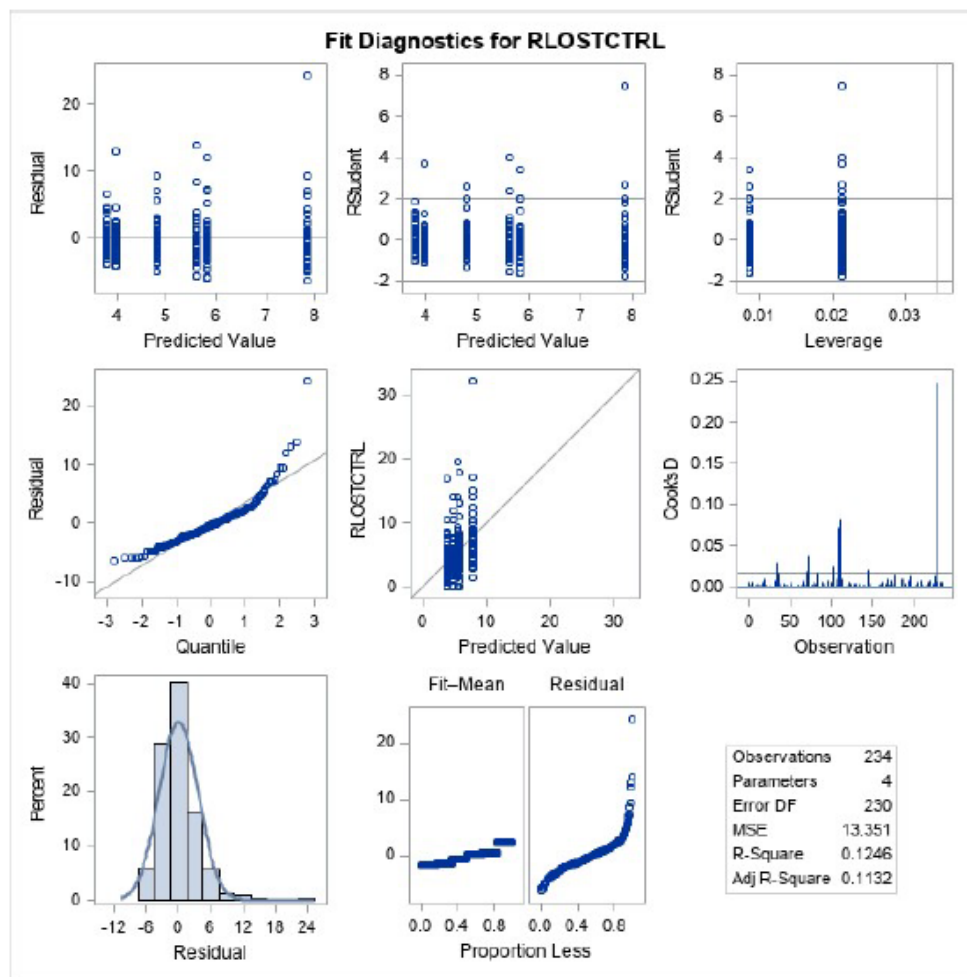


Figure B.27: Lost Control Crashes (2002-2004 vs. 2006-2008) – Model 2 Fit Diagnostics Output.

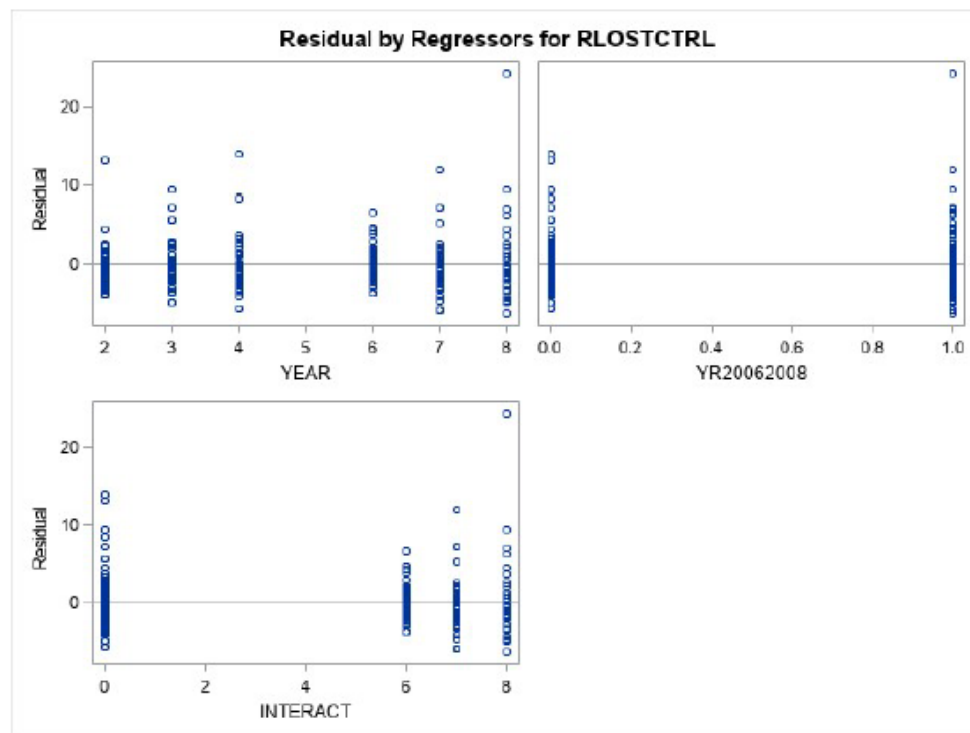


Figure B.28: Lost Control Crashes (2002-2004 vs. 2006-2008) – Model 2 Residuals Output.