Do Vehicle Safety Inspection Programs Result In Younger, Safer Fleets Or Do Younger, Safer Fleets Lead To Significantly Safer Vehicles: The national effects and underlying benefits of safety inspection programs

FINAL RESEARCH REPORT

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DISCLAIMER

Project Summary

States require inspections on vehicle safety components to be performed with varying frequencies and on various subsets of the fleet. In Pennsylvania, every passenger vehicle is inspected annually. Stakeholders have called for modifications or elimination of safety inspection programs. However, inspection data have not been available, so efforts to improve programs have been challenging. To date we have analyzed millions of Pennsylvania comprehensive vehicle safety and registration data records. While the commonly reported failure rate is about 2%, our findings suggest the actual rate is about 10 times higher [1].

We expanded our research from Pennsylvania to a nationwide analysis by using data from DOT's Fatality Analysis Reporting System (FARS), to evaluate and compare states with stringent, annual vehicle safety inspections versus those with less stringent programs by comparing fatal crash rates (fatal crashes per billion VMT). While this analysis was limited to fatal crashes and limited knowledge was available on the intensity of each state's inspection program, regression models were found to strongly support the vehicle safety inspection program. The results showed that safety inspections were statistically significant in reducing the fatality rate in states on average by 1.8 fatalities per billion VMT and also resulted in a highly significant urbanity coefficient of about 11 fatalities per billion VMT difference in urban versus rural locations (higher rural fatality rate, refer to Supplemental Figure 2). This led to the conclusion that urbanity must be accounted for in these analyses, as well as additional questions of whether there are other parameters that affect the fatality rates in different states, such as vehicle makes or vehicle ages. This work has been submitted to be considered for poster and/or publication for the Transportation Research Board's Annual Meeting [2].

There is no national standard for safety inspections; therefore, even states that do have programs may not execute them the same way. This led to limitations in accurately analyzing the program and resulted in numerous regression models to check any possible scenario. Lack of consistency of the crash attributions across crash data reported by each state and the difficulty in identifying the best way to assign a vehicle to a state (either registration or crash state) was a downfall to this section of the analysis. Improvements in data reporting, collection, and program oversight for both data collection and safety inspection programs are integral in further reducing vehicle crashes and therefore assessments of differences in fatality rates.

In addition to FARS data and as a result of the previous conclusions we were able to make in our most recent fatality rate analysis, we recently purchased 2015 national vehicle registration data from Hedges and Company. This data allows for additional comparisons between state vehicle fleets,

supplementing the current findings in strong urbanity fatality rate differences. From initial work with the 2015 registration data, questions arise as to whether vehicle age differs between states with more stringent safety inspection programs versus those with less stringent programs. Initial results resulted in states with more stringent programs having younger fleets on average. Detailed statistical analyses are necessary in order to determine whether the younger fleet is a result of these states having a more stringent safety inspection program or whether the younger fleet causes the significant results in lower fatality rates in those states with the more stringent safety inspection programs.

If vehicle age and vehicle make can be separated from the fatality rate results, then the true underlying effects of the safety inspection program can be found. Additionally, if the safety inspection program does lead to a younger vehicle fleet, there are numerous advantages (economic growth, reduced emissions, change in travel patterns) of newer vehicles that can also be examine as a result of the safety inspection program in addition to the safety benefits. The overall goal of this research is to provide an unbiased study on the effects of the safety inspection program that could help inform policy makers in each state and possibly even the U.S. government, depending on the findings.

[Administrative Note: Due to the departure of the lead post-doctoral researcher in this project, only about half of the proposed work was completed and funded. This project report includes only the work done.]

Project Description of Work Done

There are many states questioning the effectiveness of the vehicle safety inspection program. Presently, there are no studies either supportive or unsupportive of the program, leaving many states modifying and even discontinuing their program due to the lack of evidence. There are two major weaknesses in the transportation sector today; there is still a non-zero fatal crash rate and robust data are difficult to obtain. Consistency, availability, and oversight of data collection are necessary for using data to identify benefits and dangers on any topic; however since this is not always possible and cost-effective, analyses must take this into account and note limitations when discussing results.

Personal vehicle safety inspection programs today vary widely across their execution and oversight, making the program challenging to analyze and identify any benefits or disadvantages. One task in this research aims to classify current safety inspection programs in each state by their frequencies and rigorousness to find if there is any advantage in supporting these programs. In parallel, the quality of data used in this study is evaluated. Data used includes:

PA Department of Transportation (PennDOT) – We have negotiated a contract with PennDOT that allows us to receive ongoing data on the following state records in digital form:

- Complete list of **all** registered vehicles currently in the state as of time of request, including vehicle identification number, zip code, county, type of vehicle, etc.;
- Complete report of **all** information from the E-SAFETY database, including vehicle identification number, zip code, cost of inspection and repairs, pass/fail status, etc.

CompuSpections, LLC – We have been working with the CEO and Director of CompuSpections LLC for almost 2.5 years. CompuSpections is a small PA business that provides inspection record management and reporting software for inspection stations (ranging from small garages to large dealerships). Records are extremely comprehensive, including information such as all four actual tire tread measurements (in units of 1/32 of an inch) at time of inspection, all maintenance work done to meet state inspection program requirements, labor and material costs, final pass/fail status, etc. In short, this data can fill the gap identified above in terms of clearly noting what happens in the workflow of a safety inspection from time of entry to point of exit from the station and not simply whether the vehicle passes when leaving. CompuSpections will continue to provide us with a large amount of in-kind data (see letter) and expertise.

Past efforts to justify or modify the inspection program by the various stakeholders involved have been limited since their motivations have been questioned (e.g., by stations to maintain the current system and associated revenues). A primary goal of this effort is to have a study with multiple data sources but authored by researchers from CMU, a neutral third party. Our partnership with CompuSpections has already provided us with 10 million inspection records over 10 years and helped us to build relationships with other interested parties such as PennDOT, various state legislators, AAA, Pennsylvania Automotive Association (PAA), etc.

This study applies a negative binomial regression to provide further insight on the effectiveness of the state-level vehicle safety inspection program. Fatal crashes are compared between safety-classified and non-safety-classified states, while taking into account vehicle miles traveled, the vehicle registration state, the urban-/rural-ness and region of the crash location, the year of the crash, and the type of seatbelt law (primary offense or not). Regression results showed that states with a more stringent safety inspection program were significantly associated with decreased fatal crashes; states without any vehicle safety inspection program compared to those states that inspect all vehicles every year resulted in 20% (±5%) more fatal crashes. This results in states with no safety inspection program in urban areas reducing between 560 – 940 fatal crashes by implementing the safety inspection program (based on the fatal crash count in 2009). In these same states in rural areas in 2009, if they were to implement the safety inspection program, fatal crashes could be decreased between 1,200 – 2,000 fatal crashes.

Crash causes are evaluated to determine if crashes attributed to safety causes are lower in safety states than non-safety states. Furthermore, crashes attributed to non-safety causes are also compared assuming there should be no noticeable difference between the classified states. Note that by filtering to look at crash cause, much of the data are lost as there are no crash attributes recorded, or they were unknown. Additionally, it is concluded that crash causes across the states may vary due to the varying laws in states and who records the data. This led to the conclusion that data collection and entry must be more consistently entered, both qualitatively and quantitatively, across the nation to do similar analyses to provide more robust results.

1 INTRODUCTION

Today, technology plays a large role in society and is becoming extremely prominent in the transportation sector. Unfortunately, even with great improvements in technology, fatal vehicle crashes still occur due to lack of maintenance of the vehicle components. To understand this point, consider two, new, autonomous vehicles – one has brand new components (brakes, tires, lights, etc.) and the other has worn brake pads, bare tires, and burned-out lights. Which vehicle is the preferred vehicle to drive and is there a difference? This study explores the relationship between vehicles safety inspection programs and fatal crashes, while taking into account limitations with the currently available data.

1.1 Motivation

In recent years, states have been questioning the effectiveness of vehicle safety inspections. Common perceptions include that such programs are a waste of time and money, and inspectors identify false problems in hope to make more money. In 2009, Washington D.C. eliminated their safety inspection program due to claiming there was no evidence that the program resulted in fewer accidents. [1], [2] Similarly, in 2010, New Jersey no longer required safety inspections due to "lack of conclusive data" and the inability to justify the expense. [3] For the same reasons, Oklahoma discontinued their program back in 2001. [4] The common sentiment of many states that there is lack of data providing evidence that vehicle safety inspections aren't worth the time and money; yet, it cannot be inferred safety inspections do not reduce fatalities. More analyses are necessary before this statement can be confirmed and conclusions drawn. These questions may help lead toward a helpful conclusion on this topic of vehicle safety inspection programs.

These analyses are necessary especially with the increasing prominence of "big data". In order for performance of programs, such as vehicle safety inspection programs, to be assessed, the data must be reliable. In the near future, as more automation is introduced in vehicles, collection of quality vehicle data will be a likely benefit. Personal vehicle safety inspection programs today vary widely across their execution and oversight, making the program challenging to analyze and identify any benefits or disadvantages. This paper aims to classify current safety inspection programs in various models by their frequencies and rigorousness to find if there is any advantage in supporting these programs. In parallel, the quality of data used in this study is evaluated.

2 LITERATURE REVIEW

According to the Center for Disease Control (CDC), motor vehicle crashes remain a major source of morbidity and mortality in the US for many years now. As of 2013, accidents were in the top five for the leading cause of death over all age groups and motor vehicle crashes were the leading cause of death for those between the ages 1 to 44. [5] This statistic is alongside deaths resulting from heart disease, cancer, and chronic lower respiratory disease. “The National Highway Traffic Safety Administration estimates that highway crashes alone have an annual price tag of around $871 billion in economic loss and social harm.” [6], [7] Motor vehicle crashes are rightfully a large concern for the US population, yet there are few immediate solutions that will help reduce these high fatality rates.

Prior to data analysis and policy recommendations, it is important to understand how fatalities vary by region. Puentes and Tomer (2008) showed that urban and rural VMT trends differ, with a bigger gap in recent years. [8] Since vehicle fatalities are higher in rural areas than in urban areas [9]-[14], NHTSA suggests that motor vehicle fatalities be reported in terms of fatalities per VMT and separated by urban and rural regions. This results in higher rural fatality rates than urban fatality rates. [15] There are multiple reasons attributed to higher rural fatality rates, some of which include higher speeds and VMT. [10], [16] NHTSA reported that 2010 fatality rates were 2.5 times higher in rural areas than in urban areas; as a result, “states are encouraged to present both rural and urban VMT rates along with their overall VMT rate.” [14] Clark (2003) also found that mortality was higher in rural crash locations. [17] Kmet and Macarthur (2006) concluded that rural regions, both hospitality and death rates, among youth, were significantly higher. [18] Furthermore, Abdel-Aty et al. (1998) found that “very young and very old drivers have slightly higher odds of incurring an injury”, and the older drivers are more likely to be involved in fatal crashes. [19]

A handful of studies, all with varying conclusions, have evaluated the relationship between vehicle crashes and vehicle safety inspections; however, many of these studies are outdated. Many of these analyses do not consider location of the crash, either as urban or rural [20], and as the previous literature has shown, this is an important variable in crash analyses. Time series analyses have resulted in both proving safety inspections as effective in preventing crashes and deaths [21], [22] and as having no effect on preventing crashes [23].

One goal of this paper is to compare safety caused crashes in states with versus states without a safety inspection program; however, this may be limited by the quality of data in FARS. Castle et al. (2014) compared death certificates from motor vehicle crashes to FARS data and found FARS data to show “considerable variation in the magnitude of underreporting”. Furthermore, they suspect similar underreporting in other types of injury deaths. This phenomenon is suggestively similar for underreporting vehicle component caused crashes and may hurt the understanding of the safety inspection policy issue. [24] A similar study showed that reported crashes from where police were absent had much higher percentages of missing data for the contributing factors of the crash. As a result, without knowing the source of data from which crashes were obtained, conclusions on crash causes may not be as strong. [25]

Previous studies on vehicle safety inspections were not always supportive of the programs, yet the methods used in those studies were vague, high-level analyses, which do not represent the actual effectiveness of the state-specific programs. A commonly referred to study by Cambridge Systematics, evaluated the effectiveness of Pennsylvania's vehicle safety inspection program. While conclusions aligned with findings in this paper, neither urbanity differences nor geographic regions were not accounted for in the model, the review of the state safety inspection programs was vague, and only one average time period was used as apposed to including multiple years worth of data. [26] Since safety inspection states have a more urban composure than non-safety inspection states, as shown in this analysis, it is possible results confounded and conclusions inaccurate. Another paper evaluated the Pennsylvania safety inspection program vehicle failure rates. The authors show that without the current vehicles safety inspection program in Pennsylvania, about 1-2 million vehicles would be in unsafe conditions to drive. Furthermore, older vehicles have a consistently higher failure rate along with high mileage vehicles. [27]

3 DATA

This analysis combines multiple, publically available, data sources, including vehicle travel data from the U.S. Department of Transportation (USDOT), population data from the Census Bureau, and vehicle crash data from the National Highway Traffic Safety Administration (NHTSA). Table 1 provides a summary of the data sources and relative content used for this analysis.

Table 1 Summary of Publically Available Data Sources

Data	Content	Source
VMT	Urban/rural by state, available after 1997	Highway Statistic Series - FHWA Office of Highway Policy Information [28]
Population	Urban/rural by state	U.S. Census [29]
Fatal Crashes	All records of motor vehicle fatal crashes and fatalities	NHTSA Fatality Analysis Reporting System (FARS) [30]
Non-fatal Crashes	Sampled from various police jurisdictions around the U.S.	NHTSA National Automotive Sampling System - General Estimates System (GES) [31]

More detailed information on these databases can be found in the Supplemental Information. Certain limitations of these vehicle crash data sources must be noted. The FARS database contains fatal crash statistics, beginning in 1975, of all crashes involving at least a motorized vehicle traveling on a public road and a resulting death within 30 days of the crash. Entries are recorded by police officers on duty and at the crash site location. Depending on state officer training and the available crash evidence, the cause of crash may not be determined correctly and may lead to inaccurate or unrepresentative results. While the database contains certain limitations that should be kept in mind, it is the best available national data and widely used to analyze fatal crashes.

The GES sampled data are from various police jurisdictions around the U.S. According to NHTSA, "in order for a crash to be eligible for the GES sample a police accident report (PAR) must be completed, it must involve at least one motor vehicle traveling on a traffic way, and the result must be property damage, injury, or death". [31] While these data are the best available for analyzing overall U.S. non-fatal vehicle crashes, there remain numerous challenges and concerns by using this dataset on a more detailed level, such as in this analysis. The data do not contain a "state" definition field; therefore, the driver zip code attribute was decoded and matched to a state. For consistency, the same method was used on the FARS data. Next, a representative test was performed to compare fatal crashes in GES with those in FARS. The two-sided t-test resulted in a p-value of 0.028; therefore the null hypothesis that the GES fatalities are equivalent to the FARS fatalities must be rejected. Since GES data are a sample, the sample may not be representative from all 50 states and this was evident when comparing the fatal crashes between the two databases. While GES data may be used in a countrywide analysis, it is not representative on the state level. As a result of the variations between GES and FARS fatal crash data, GES crash data were not used in this analysis.

3.1 Vehicle Safety Inspection Programs

The National Traffic and Motor Vehicle Safety Act of 1966 was initiated due to the increasing concern over the rising number of motor vehicle traffic fatalities. Safety inspection programs were federally mandated until 1973 for states to qualify for federal highway funds. [32] In addition to this Act, the automobile industry was pressed to focus on safety rather than aesthetics when designing new vehicles, which has had an impact on decreasing death rates. [33] After 1973, the vehicle safety inspection program became state mandated. Today, states may either require a strict safety inspection program, no program, or something in between. Since the federal government does not regulate vehicle safety inspections, each state manages the rigorousness of its own program (e.g., removing brake pads and measuring the thickness, measuring tire tread depth, testing aim of headlights and functionality of blinkers), and may decide to modify and/or discontinue its own state program at any time.

In addition to states modifying their programs at any time, states also vary in the depth and breadth of the inspection. Furthermore, each station within each state may vary in the intensity of the inspection and this is assessed based on rough estimates of how long an inspection takes in a given state. In any case, for this analysis, the states are assigned to a safety variable on a continuous scale. The safety scale is based on the percentage of the fleet that is inspected each year (based on the age distribution of the vehicle registration data) and the intensity of the inspection (estimated based on approximate time required for inspection). The percentage of vehicles inspected is used as a proxy for estimating the fraction of the safety program implemented from 0 to 1. States with biennial inspection programs are assigned a safety value of 0.5 in this case, since vehicles are inspected every 2 years (about half of the fleet every year). This information can be found on the AAA website which contains a digest of motor laws, specifying safety inspections in each state, if they exist at all. [34] Additionally, each state’s website information is then compared to the AAA website information. Finally, since each state's program may vary in intensity, the safety variable is adjusted based on approximated times of an inspection in that state versus another similarly defined state. This information is summarized in Table 2.

Table 2 Vehicle Safety Inspection Classifications by State, as of June 2015 (ratio based on vehicles inspected versus those registered and time of inspection)

(23) States with *some* safety program		**(27) States with *no* safety program**	
Hawaii (1)	Missouri (0.50)	Alabama	Minnesota
Maine (1)	Rhode Island (0.50)	Alaska	Montana
New Hampshire (1)	Utah (0.50)	Arizona	Nebraska
New York (1)	New Jersey* (0.47)	Arkansas	New Mexico
Pennsylvania (1)	Delaware (0.40)	Colorado	North Dakota
Vermont (1)	Oklahoma* (0.10)	Florida	Ohio
West Virginia (1)	Nevada (0.05)	Georgia	Oregon
Virginia (0.95)	California+ (0.04)	Idaho	South Carolina
North Carolina (0.90)	Connecticut+ (0.04)	Illinois	South Dakota
Texas (0.90)	Maryland+ (0.04)	Indiana	Tennessee
Massachusetts (0.80)		Iowa	Washington
Louisiana* (0.70)		Kansas	Wisconsin
Mississippi (0.70)		Kentucky	Wyoming
		Michigan	

* Program has recently been modified

+ Safety inspection required only at first registration of vehicle into the state

A limitation to any such classification in a historical analysis is that states can modify their program over time, as noted previously. Washington, D.C. (not included in this analysis due to its unique composure) and New Jersey have discontinued their safety programs within the past few years and Louisiana recently made annual inspections an alternative to the now required biennial inspections (as of September 2012). To help simplify this complexity, fatal crashes are analyzed until 2009, prior to many major program modifications, except Oklahoma is defined as periodic since its regulations changed in 2001, over the analysis period. Finally, while Hawaii and Alaska are not part of the contiguous U.S. and may not have similar interactions with vehicles from other states, they are still included in this analysis. A future variation of this analysis may not include these states.

3.2 Metrics Used

In order to compare crashes between states (and years), the crash statistics must account for varying VMT between observations of fatal crashes because locations and years vary in driving patterns. NHTSA has developed performance measures to be used in performing research analyses. They define the fatality rate per mile of travel (fatalities/VMT) to be used to track safety trends. According to their report on performance measures, reporting fatalities alone will not accurately represent smaller states with fewer possible fatalities and that traffic fatalities are "most obviously affected by the amount of travel" [14]; therefore, the metric of fatalities (or fatal crashes) is only analyzed while accounting for VMT in this analysis. Additionally, the metric of fatalities per fatal crash varies by location and time thus from here forward, only fatal crashes are reported in the results.

Due to Simpson's Paradox, and as specified by NHTSA, state fatal crash rates must be analyzed separately for urban and rural areas. This aligns closely with the previously referenced literature stating rural locations have higher fatal crash rates. As a result, fatal crashes taken from FARS are organized by state and separated into categories of urban and rural within each state (based on crash location) for each year of analysis, from 2000 through 2009. This accounts for differences in fatal crash counts and the urban-rural composition between states.

4 METHODS

It is hypothesized that safety inspection states have fewer fatal crashes than those without safety inspections. To test this hypothesis, states are first defined either as a safety state or not (refer to Table 2) then separated into urban and rural categories, where fatal crash counts are used.

4.1 Definition of Safety States

Refer to section 3.1 Vehicle Safety Inspection Programs for the state safety inspection classifications. In order to make a comparison of whether states with more stringent vehicle safety inspections are associated with lower fatal crashes, the analysis compares state fatal crashes while accounting for VMT, urbanity, inspection year, and geographic region. The hypothesis for this analysis is that both urban and rural fatal crashes are lower in states with an annual safety inspection program than in those with no safety inspection program. It is even more important to separate urban and rural rates since safety states seem to have much more urban composition than non-safety states, with much more rural composition, as shown in Figure 1.

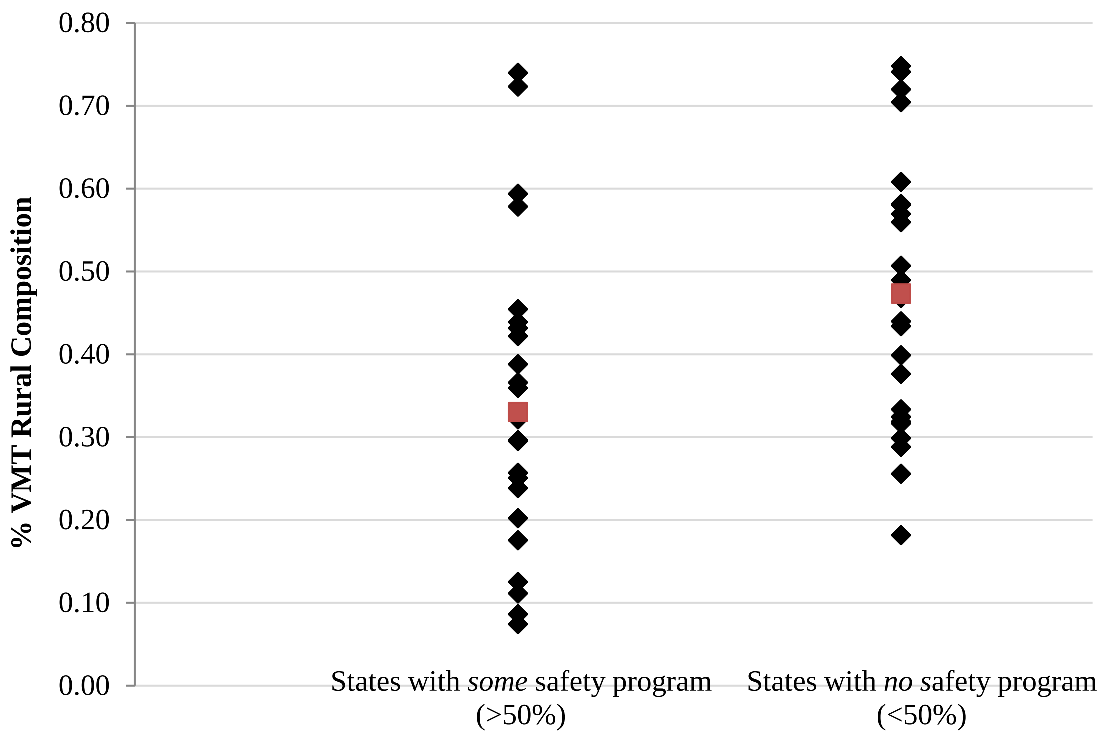

Figure 1 Percentage of rural VMT comparison between defined safety states and non-safety states with each state plotted and averages shown in red

Figure 1 shows the comparison of rural VMT composition between types of states. A t-test was performed to test the null hypothesis of whether the percentage of rural VMT is equal between the two categories of states. This test results in a p-value of 0.01. Therefore, we can reject the null hypothesis that the rural composition is equal between the types of states; hence we cannot accept that these percentages are the same and must account for rural composition in this safety program analysis.

4.2 Defining the Crash Data

Fatal crashes from FARS are used to analyze whether safety inspections are statistically significantly associated with fewer fatal crashes. Limitations to the data recorded in FARS include but are not limited to: (1) the reason attributed to the crash (safety cause or otherwise), (2) the vehicle that caused the crash in multivehicle crashes, and (3) crashes occurring in different states from where the vehicle is registered. Inconsistency in the reason attributed with the crash cause may be due to either lack of knowledge when recording the crash, misclassification of the crash cause, or another contributing reason being more apparent or obvious than the true reason. For example, a vehicle may have been speeding in rainy weather, yet driving on bare tires or with worn brake pads. The reason for this crash may therefore vary based on who fills out the crash report and/or where the crash occurred. Additionally, in states where safety inspections are not a requirement, unsafe vehicle components may not be an obvious reason for the crash cause, whereas in a state that requires safety inspections, there may be more cognizance of safety issues.

To complete this analysis, each vehicle in the crash was assigned to a state based on its registration location and assigned to either an urban or a rural location based on where the crash occurred. This categorization is necessary so to be able to determine vehicles involved in fatal crashes as being inspected or not; additionally, crash location is important to distinguish since fatal crashes are more prevalent in rural areas, as noted in the previous literature.

The following sections go into detail on the analyses performed to find whether states with safety inspections are associated with statistically significant fewer fatal crashes. Additionally, it is examined whether safety-component caused fatal crashes are lower than other crash causes in states with safety inspection programs. However, the crash cause variable is a known weakness in the data and must be cautiously analyzed due to the inconsistent reporting between states mentioned previously.

4.3 Regression Analysis

In order to identify the vehicle safety program effectiveness, a negative binomial (NB) regression was utilized. Fatal crashes in the U.S. are compared between states and used as the dependent, discrete, count variable in the regression and are overdispersed (i.e., skewed, the variance of the crash data exceeds the mean). Refer to the supplemental information for additional model specifications. The independent variables in the regression analysis included a safety variable (continuous based on the percentage of registered vehicles that are inspected for safety components and stringency of the state's program), vehicle miles traveled (continuous), urbanity (urban or rural), crash year (continuous, 2000-2009), seatbelt law (primary, secondary, other), state (categorical). The data consisted of 1,000 observations, one observation per state per year per urban-rural location. Model selection of included independent variables, based on the regression's AIC value, is performed in order to determine which variables to retain in the model in addition to checking for multicollinearity. The final regression equation used is displayed in Equation 1.

$$\text{Function (Fatal Crashes)} = \beta_0 + \beta_1 * Safety + \beta_2 * VMT + \beta_3 * Year + \beta_4 * Urbanity + \beta_4 * Region + \beta_5 * Seatbelt$$

$$where\ \beta_i \ldots \beta_5\ are\ the\ regression\ coefficients\ with\ the\ assumption\ that\ the\ number\ of\ fatal\ crashes\ follows\ a\ negative\ binomial\ distribution\ function$$

Eq. 1

Significance of the regression formula in determining whether states with the safety inspection program were associated with statistically significant fewer fatal crashes was determined by whether the coefficient was negative, indicating fewer fatal crashes for states with a vehicle safety inspection program, and whether the safety variable in the regression resulted in a p-value less than the critical p-value of 0.05. The District of Columbia was excluded from the regression due to its unique composition and size in comparison to other states.

4.4 Hypothesis Test

A two-proportion z-test is used to test whether the proportions of fatalities associated with a safety cause differs between safety states and non-safety states. First, the null hypothesis (H_0) is defined: the fatal crash rate of safety-attributed fatalities in safety states is equal to the fatal crash rate of safety-attributed fatalities in non-safety states (Equation 2). This is applied separately for urban and rural locations due to the reasons addressed in previous sections. Additionally, this same hypothesis is checked for non-safety-attributed fatalities. Significance of this hypothesis is compared with an alpha value of 0.05.

$$H_0: p_{safety\ states,i} = p_{non-safety\ states,i}\ and\ H_a: p_{safety\ states,i} \neq p_{non-safety\ states,i};\ where,$$

$$p = proportion\ of\ fatalities,$$

$$i = safety - attributed\ or\ non - safety\ attributed$$

Eq. 2

It is hypothesized that the safety-attributed fatal crash rate will be significantly lower in safety states than non-safety states and that there will be no significant difference in non-safety attributed fatal crash rates in either defined state. And these results will be similar in both urban and rural regions.

5 RESULTS

This section provides a summary of the overall results found from the statistical tests described in the previous section.

5.1 Regression Analysis

The negative binomial regression model is used and results are reported in Table 3. All coefficients have also been reported on an exponential scale in order to more easily interpret the results; these exponentiated coefficients are referred to as incident rate ratios (IRR). The IRR can be interpreted as the percentage change in incidence or risk of fatal crashes for each unit increase in the independent variable and is displayed with Table 3 along with additional regression results.

Table 3 Negative Binomial Regression Results

Coefficients	Estimate	IRR	Std. Error	Pr(>|z|)	
(Intercept)	5.73	309	0.081	< 2e-16	***
VMT	0.026	1.03	0.001	< 2e-16	***
Safety	-0.222	0.801	0.061	3.01E-04	***
Year	-0.024	0.976	0.006	1.42E-04	***
Urban/Rural					
Rural	-	-	-	-	
Urban	-0.835	0.434	0.037	< 2e-16	***
Division					
East North Central Division	-	-	-	-	
East South Central Division	0.184	1.20	0.089	3.93E-02	*
Middle Atlantic Division	0.013	1.01	0.106	9.04E-01	
Mountain Division	-0.166	0.847	0.080	3.88E-02	*
New England Division	-0.690	0.502	0.093	9.00E-14	***
Pacific Division	-0.513	0.599	0.084	1.22E-09	***
South Atlantic Division	-0.010	0.990	0.077	0.893	
West North Central Division	-0.442	0.643	0.079	2.38E-08	***
West South Central Division	0.138	1.15	0.090	0.126	
Seatbelt					
Other	-	-	-	-	

Primary	0.183	1.20	0.059	0.002	**
Secondary	0.354	1.43	0.056	2.48E-10	***
No. Observations	1000				
AIC	13300				
Theta	3.117				
Std. Err.	0.136				
2 x log-likelihood	-13267.57				

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

These results show all continuous variables (VMT, Year, Safety) being significant at the 5% level, as well as the binary Urban/Rural variable. Dummy variables are used for both Division and Seatbelt categories, some of which are significant at the 5% level and some not. Including all of these variables is important for predicting fatal crashes as they affect the estimate values. For the purpose of this paper, we find that states with more stringent vehicle safety inspection programs are significantly associated with a lower risk (20% ± 5% decrease) of fatal crashes. The VMT and Year variables are significant but small, thus they have less of an impact on the number of fatal crashes. The binary urban/rural variable is significant and large, with results showing a lower fatal crash risk in urban areas (57% ± 1.6% decrease) versus rural. This aligns with previous studies, as mentioned in the literature review section, that the fatal crash rate is lower in urban areas than rural areas and that urbanity must be accounted for in any crash analysis and while including VMT patterns.

Given the fatal crash data and the previous regression results, estimated scenarios of implementing a safety inspection program in non-safety inspection states is evaluated. The data from FARS can be separated into urban fatal crashes and rural fatal crashes from 2009. Looking at states with *no* safety inspection program, fatal crashes in urban areas (totaling about 3,740 in 2009) could be decreased by approximately 560 – 940 fatal crashes by implementing the safety inspection program. In rural areas, in 2009, there were about 8,000 fatal crashes in states with *no* safety inspection program. If those states were to implement the safety inspection program, fatal crashes could be decreased by about 1,200 – 2,000 fatal crashes.

5.2 Hypothesis Test

This test proved to be more challenging, as FARS does not define the vehicle that caused the crash. In this case, since the vehicle causing the crash is unknown, it is impossible to define whether the crash was caused by a safety component or not. It is possible to evaluate only one-vehicle crashes, yet this will not represent the fatal crash results entirely. Some literature, discussed earlier in this paper, had discussed the large underreporting of various attributes in crashes, which can lead to a very thin data sample. Furthermore, there is some evidence supporting that safety states are more aware of safety features in a crash, whereas in non-safety states, they are less aware. This leads to discrepancies in how crashes are recorded in each state and how detail-oriented those crashes are recorded.

It is therefore concluded that no insightful conclusions can be drawn on specific coded fatalities. The lack of consistency here is evident and more strongly suggests the need for data consistency, management, and oversight. Robust data are necessary for the advancement and improvements in vehicle safety. With more detailed data, including which vehicle is the primary cause of the crash, a more in-depth analysis, evaluating the crash cause, can be implemented.

6 FUTURE WORK

Limited access to quality data in transportation is a problem currently and will continue to be in most situations because of issues pertaining to privacy. The transportation sector is changing fast with the introduction of more automated features in vehicles and this will require a stronger need for high quality, anonymized, transportation data to monitor resulting changes. This implies that stronger policies are needed for data gathering and improved data collection.

Higher quality vehicle inspection data, will allow for stronger predictions to be made on the exact time of when certain vehicle maintenance work is necessary. Crashes due to driver error will likely decrease with increased automation in vehicles. As a result, it is likely other crash causes will become even more visible, such as maintenance issues, which are largely under- and un-reported according to literature presented previously. Autonomous vehicles are predicted to be safer, but would preference be to ride in an autonomous vehicle with new brakes and tires, or an autonomous vehicle with worn brake pads and tires with no tread? Additionally, this is technologically important because a stopping algorithm in an automated vehicle is based on the tested stopping distance of the brakes. However, worn brake pads will result in greater variation of this stopping distance, which will likely be larger. Vehicle maintenance is an ongoing issue and will continue to be important for safe driving and reduction of fatal crashes, even with the introduction of autonomous vehicles.

Any crash that costs money is likely recorded in an insurance claim. If there is proper oversight, this insurance data could provide valuable information on crashes of all costs, from property damage to vehicles that are totaled. This allows for the inclusion of non-fatal crashes into the analysis, in addition to the ability to identify which vehicle, if more than one is involved, is at fault, allowing for reliable multivehicle crash analyses. Of course, all of these insurance records would need to be anonymized to protect personal identifiable information. Furthermore, as seen in some previous literature, driver age may have an influence on the severity of crash. As a result, future work should include a comparison between the distributions of registered driver ages in states and even between the urban/rural areas in states.

An added benefit with full implementation and higher quality vehicle safety inspection data leads to the ability to track a vehicle in a crash back to the last inspection to identify any possible reason, outside driver error, for the crash, including the possibility that the inspector should not have passed the vehicle. This leads to the further need for high quality inspection data, which allows for monitoring of the performance of both inspectors and inspection stations to be sure honest and accurate evaluations of vehicles are made.

Vehicle safety inspections provide numerous advantages outside of safety. More analyses are necessary to identify the effect on local economies and job opportunities as a result of these required inspections in states. Additionally, recording vehicle conditions allows for the ability to calculate annual mileage driven, providing opportunities for calculating more accurate travel patterns or implementing mileage-based fees to support the on-going issue of highway funding.

7 CONCLUSION

While this analysis was limited to fatal crashes and limited knowledge on the intensity of each state's inspection program, the results from the negative binomial regression model was found to strongly support the vehicle safety inspection program, producing results showing about 20% (±5%) fewer fatal crashes in states with more stringent safety program. There is no national standard for safety inspections; therefore, even states that do have programs may not execute them the same way. Additionally, because of how fatal crash data is recorded, there is no way to determine which vehicle is at fault in a multivehicle crash. This led to limitations in accurately analyzing the cause of crashes, not allowing for an in depth analysis of safety-specific crashes (i.e., those reported with a cause of crash due to brake, tires, etc.). Improvements in data reporting, collection, and program oversight for both data collection and safety inspection programs are integral in further reducing vehicle crashes, both fatal and non-fatal.

Accomplishments

The work in this study was submitted as:

D. Peck, H. S. Matthews, P. Fischbeck, and C. T. Hendrickson, "Failure rates and data driven policies for vehicle safety inspections in Pennsylvania ," *Transportation Research Part A*, vol. 78, no. C, pp. 252–265, Aug. 2015.

D. Peck, H. S. Matthews, P. Fischbeck, and C. T. Hendrickson, "The Effect Of Vehicle Safety Inspections On Urban/Rural Fatality Rates," *Transportation Research Record*.

In addition, we held various briefings for policymakers of PennDOT in Harrisburg and at the Safety Summit 2016.

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9 REFERENCES

[1] T. Craig, "D.C. Ending Required Safety Inspections on Private Cars," *washingtonpost.com*, 15-Sep-2009. [Online]. Available: http://www.washingtonpost.com/wp-dyn/content/article/2009/09/14/AR2009091402794.html. [Accessed: 30-Jul-2015].

[2] S. S. Carty, "D.C. junks car safety inspections: Will others, too?," *usatoday30.usatoday.com*, 09-Dec-2009. [Online]. Available: http://usatoday30.usatoday.com/money/autos/2009-12-10-inspections10_CV_N.htm. [Accessed: 30-Jul-2015].

[3] M. Frassinelli, Ed., *N.J. will drop requirements for mechanical inspections of cars to save $11M yearly*, 2010. [Online]. Available: http://www.nj.com/news/index.ssf/2010/07/nj_to_drop_requirements_mechan.html. [Accessed: Jul-2014].

[4] *Mandatory Vehicle Inspections Abolished; Repeal will Save Oklahomans $12 Million*. [Online]. Available: http://www.oksenate.gov/news/press_releases/press_releases_2001/pr050101.html. [Accessed: Jun-2014].

[5] National Center for Injury Prevention & Control, "10 Leading Causes of Death by Age Group, United States - 2013."

[6] Centers for Disease Control and Prevention, "Ten Significant Public Health Achievements -- United States, 2001-2010: Motor Vehicle Safety," *cdc.gov*. [Online]. Available: http://www.cdc.gov/Motorvehiclesafety/mmwr_achievements.html. [Accessed: 27-Jul-2015].

[7] L. Blincoe, T. R. Miller, E. Zaloshnja, and B. A. Lawrence, "The Economic and Societal Impact Of Motor Vehicle Crashes, 2010," U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, DC, DOT HS 812 013, May 2014.

[8] R. Puentes and A. Tomer, "The Road…Less Traveled: An Analysis of Vehicle Miles Traveled Trends in the U.S," 2008.

[9] U S Department of Transportation National Highway Traffic Safety Administration, "Traffic

Safety Facts 2008 Data: Rural/Urban Comparison," pp. 1–6, Aug. 2010.

[10] M. Burgess, "Contrasting Rural and Urban Fatal Crashes 1994 - 2003," U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, D.C., DOT HS 809 896, Dec. 2005.

[11] D. E. Clark and B. M. Cushing, "Rural and urban traffic fatalities, vehicle miles, and population density," *Accident Analysis & Prevention*, vol. 36, no. 6, pp. 967–972, Nov. 2004.

[12] C. Zwerling, C. Peek-Asa, P. S. Whitten, S.-W. Choi, N. L. Sprince, and M. P. Jones, "Fatal motor vehicle crashes in rural and urban areas: decomposing rates into contributing factors," *Injury Prevention*, vol. 11, no. 1, pp. 24–28, Feb. 2005.

[13] J. H. Hedlund and P. R. Group, "Traffic safety performance measures for states and federal agencies," 2008.

[14] J. Hedlund, "Traffic Safety Performance Measures for States and Federal Agencies," U.S. Department of Transportation, National Highway Traffic Safety Administration, Washington, D.C., DOT HS 811 025, Aug. 2008.

[15] National Center for Statistics & Analysis, Ed., "Traffic Safety Facts 2010 Data," National Highway Traffic Safety Administration, DOT HS 811 637, Jul. 2012.

[16] M. E. Rakauskas, N. J. Ward, and S. G. Gerberich, "Identification of differences between rural and urban safety cultures," *Accident Analysis & Prevention*, vol. 41, no. 5, pp. 931–937, Sep. 2009.

[17] D. E. Clark, "Effect of population density on mortality after motor vehicle collisions," *Accident Analysis & Prevention*, vol. 35, no. 6, pp. 965–971, Nov. 2003.

[18] L. Kmet and C. Macarthur, "Urban–rural differences in motor vehicle crash fatality and hospitalization rates among children and youth," *Accident Analysis & Prevention*, vol. 38, no. 1, pp. 122–127, Jan. 2006.

[19] M. A. Abdel-Aty, C. L. Chen, and J. R. Schott, "An assessment of the effect of driver age on traffic accident involvement using log-linear models," *Accident Analysis &*

Prevention, vol. 30, no. 6, pp. 851–861, Nov. 1998.

[20] D. Merrell, M. Poitras, and D. Sutter, “The Effectiveness of Vehicle Safety Inspections: An Analysis Using Panel Data,” *Southern Economic Journal*, vol. 65, no. 3, pp. 571–583, Jan. 1999.

[21] W. M. Crain, “Vehicle safety inspection systems: How effective?,” American Enterprise Institute, Washington, D.C., P-25 Series, 1980.

[22] P. D. Loeb and B. Gilad, “The Efficacy and Cost-Effectiveness of Vehicle Inspection,” *Journal of Transport Economics and Policy*, vol. 18, no. 2, pp. 145–164, May 1984.

[23] C. Garbacz and G. Kelly, “Automobile Safety Inspection: New Econometric and benefit/cost estimates,” *Applied Economics*, vol. 19, no. 6, pp. 763–771, 1987.

[24] I.-J. P. Castle, H.-Y. Yi, R. W. Hingson, and A. M. White, “State Variation in Underreporting of Alcohol Involvement on Death Certificates: Motor Vehicle Traffic Crash Fatalities as an Example,” *Journal of Studies on Alcohol and Drugs*, vol. 75, no. 2, pp. 299–312, Mar. 2014.

[25] R. Tay, L. Kattan, and Y. Bai, “Factors Contributing to Police Attendance at Motor Vehicle Crash Scenes,” *Journal of the Transportation Research Forum*, vol. 53, no. 3, pp. 101–115, 2014.

[26] Cambridge Systematics Inc., “Pennsylvania's Vehicle Safety Inspection Program Effectiveness Study,” pp. 1–79, Mar. 2009.

[27] D. Peck, H. S. Matthews, P. Fischbeck, and C. T. Hendrickson, “Failure rates and data driven policies for vehicle safety inspections in Pennsylvania ,” *Transportation Research Part A*, vol. 78, no. C, pp. 252–265, Aug. 2015.

[28] *Highway Statistics Series*. [Online]. Available: https://www.fhwa.dot.gov/policyinformation/quickfinddata/qftravel.cfm. [Accessed: Jul-2014].

[29] United States Census Bureau, Ed., *Population Estimates*. [Online]. Available:

http://www.census.gov/popest/data/index.html. [Accessed: 06-Mar-2014].

[30] *Fatality Analysis Reporting System Encyclopedia*. [Online]. Available: http://www-fars.nhtsa.dot.gov/Main/index.aspx. [Accessed: 21-Apr-2014].

[31] U S Department of Transportation, National Highway Traffic Safety Administration, National Center for Statistics & Analysis, "National Automotive Sampling System (NASS) General Estimates System (GES) Analytical User's Manual 1988-2012," pp. 1–418, Jan. 2014.

[32] U S Department of Transportation, Ed., *Highway Safety Improvement Program History*. [Online]. Available: http://safety.fhwa.dot.gov/hsip/gen_info/hsip_history.cfm. [Accessed: 03-Jan-2014].

[33] Insurance Institute for Highway Safety, Ed., "Saving lives: Improved vehicle designs bring down death rates," *iihs.org*, 29-Jan-2015. [Online]. Available: http://www.iihs.org/iihs/sr/statusreport/article/50/1/1. [Accessed: 21-Jul-2015].

[34] *Digest of Motor Laws*. [Online]. Available: http://drivinglaws.aaa.com/laws/safety-inspection/#. [Accessed: Mar-2014].

[35] "Enforcement of the Safety Belt Use Laws." [Online]. Available: http://www.iihs.org/iihs/topics/laws/safetybeltuse?topicName=Safety%20belts#tableData. [Accessed: 19-Feb-2016].

10 SUPPLEMENTAL INFORMATION

10.1 Data

Office of Highway Policy Information: Highway Statistics Series

The USDOT Federal Highway Administration's Office of Highway Policy Information (OHPI) Highway Statistics Series reports urban and rural vehicle miles traveled (VMT) for each U.S. state and the District of Columbia. This specific VMT breakdown is available from 1997 through 2011. Prior to 1997 overall U.S. urban and rural statistics are reported as country averages and are not state-by-state specific averages. As a result, this limits the analysis to beginning in 1997. [28]

United States Census Bureau: Population

The Census Bureau's Population Estimates Program releases data annually that estimates population based on current data containing births, deaths and migration. Both national estimates as well as more aggregate levels of population estimates, such as by state and county, are estimated. As a result, population estimates are used by state and by urbanity level. [29]

Vehicle Safety Inspection Laws by State

Not all states implement vehicle safety inspection programs and even if they do, they are not implemented equivalently across those states. Table 4 presents the values used as the continuous variable.

Table 4 Vehicle Safety Inspection Variable Definition by State

State Name	% of Vehicles Registered + Stringency	Notes
Alabama	0	
Alaska	0	
Arizona	0	
Arkansas	0	
California	0.04	at first car registration only
Colorado	0	
Connecticut	0.04	at first car registration only
Delaware	0.4	every two years, first 5 model years exempt, 15-20 min (<30 min)
Florida	0	
Georgia	0	
Hawaii	1	
Idaho	0	
Illinois	0	
Indiana	0	
Iowa	0	
Kansas	0	
Kentucky	0	
Louisiana	0.7	every 2 years as of Sept 2012, annual prior, 5-10 min inspection
Maine	1	
Maryland	0.04	move in from out of state or purchase a used vehicle
Massachusetts	0.8	15 min for both safety and OBD
Michigan	0	

State Name	% of Vehicles Registered + Stringency	Notes
Alabama	0	
Alaska	0	
Arizona	0	
Arkansas	0	
California	0.04	at first car registration only
Colorado	0	
Connecticut	0.04	at first car registration only
Delaware	0.4	every two years, first 5 model years exempt, 15-20 min (<30 min)
Florida	0	
Georgia	0	
Hawaii	1	
Idaho	0	
Illinois	0	
Indiana	0	
Iowa	0	
Kansas	0	
Kentucky	0	
Louisiana	0.7	every 2 years as of Sept 2012, annual prior, 5-10 min inspection
Maine	1	
Minnesota	0	state does not require vehicle safety inspections but every municipality has the authority to set up maintain and determine the rules for operating vehicle inspection stations
Mississippi	0.7	

State Name	% of Vehicles Registered + Stringency	Notes
Alabama	0	
Alaska	0	
Arizona	0	
Arkansas	0	
California	0.04	at first car registration only
Colorado	0	
Connecticut	0.04	at first car registration only
Delaware	0.4	every two years, first 5 model years exempt, 15-20 min (<30 min)
Florida	0	
Georgia	0	
Hawaii	1	
Idaho	0	
Illinois	0	
Indiana	0	
Iowa	0	
Kansas	0	
Kentucky	0	
Louisiana	0.7	every 2 years as of Sept 2012, annual prior, 5-10 min inspection
Maine	1	
Missouri	0.5	every 2 years
Montana	0	
Nebraska	0	

State Name	% of Vehicles Registered + Stringency	Notes
Alabama	0	
Alaska	0	
Arizona	0	
Arkansas	0	
California	0.04	at first car registration only
Colorado	0	
Connecticut	0.04	at first car registration only
Delaware	0.4	every two years, first 5 model years exempt, 15-20 min (<30 min)
Florida	0	
Georgia	0	
Hawaii	1	
Idaho	0	
Illinois	0	
Indiana	0	
Iowa	0	
Kansas	0	
Kentucky	0	
Louisiana	0.7	every 2 years as of Sept 2012, annual prior, 5-10 min inspection
Maine	1	
Nevada	0.05	Inspections will be limited to an examination of tires and brakes on vehicles with a weight of less than 10,000 lbs. and vehicles that are more than 2 years old

State Name	% of Vehicles Registered + Stringency	Notes
Alabama	0	
Alaska	0	
Arizona	0	
Arkansas	0	
California	0.04	at first car registration only
Colorado	0	
Connecticut	0.04	at first car registration only
Delaware	0.4	every two years, first 5 model years exempt, 15-20 min (<30 min)
Florida	0	
Georgia	0	
Hawaii	1	
Idaho	0	
Illinois	0	
Indiana	0	
Iowa	0	
Kansas	0	
Kentucky	0	
Louisiana	0.7	every 2 years as of Sept 2012, annual prior, 5-10 min inspection
Maine	1	
New Hampshire	1	
New Jersey	0.47	according to AAMVA, biennially in 2003, then discontinued in 2010

State Name	% of Vehicles Registered + Stringency	Notes
Alabama	0	
Alaska	0	
Arizona	0	
Arkansas	0	
California	0.04	at first car registration only
Colorado	0	
Connecticut	0.04	at first car registration only
Delaware	0.4	every two years, first 5 model years exempt, 15-20 min (<30 min)
Florida	0	
Georgia	0	
Hawaii	1	
Idaho	0	
Illinois	0	
Indiana	0	
Iowa	0	
Kansas	0	
Kentucky	0	
Louisiana	0.7	every 2 years as of Sept 2012, annual prior, 5-10 min inspection
Maine	1	
New Mexico	0	
New York	1	
North Carolina	0.9	

State Name	% of Vehicles Registered + Stringency	Notes
Alabama	0	
Alaska	0	
Arizona	0	
Arkansas	0	
California	0.04	at first car registration only
Colorado	0	
Connecticut	0.04	at first car registration only
Delaware	0.4	every two years, first 5 model years exempt, 15-20 min (<30 min)
Florida	0	
Georgia	0	
Hawaii	1	
Idaho	0	
Illinois	0	
Indiana	0	
Iowa	0	
Kansas	0	
Kentucky	0	
Louisiana	0.7	every 2 years as of Sept 2012, annual prior, 5-10 min inspection
Maine	1	
North Dakota	0	
Ohio	0	
Oklahoma	0.1	eliminated May 2001
Oregon	0	

State Name	% of Vehicles Registered + Stringency	Notes
Alabama	0	
Alaska	0	
Arizona	0	
Arkansas	0	
California	0.04	at first car registration only
Colorado	0	
Connecticut	0.04	at first car registration only
Delaware	0.4	every two years, first 5 model years exempt, 15-20 min (<30 min)
Florida	0	
Georgia	0	
Hawaii	1	
Idaho	0	
Illinois	0	
Indiana	0	
Iowa	0	
Kansas	0	
Kentucky	0	
Louisiana	0.7	every 2 years as of Sept 2012, annual prior, 5-10 min inspection
Maine	1	
Pennsylvania	1	
Rhode Island	0.5	biennially
South Carolina	0	

State Name	% of Vehicles Registered + Stringency	Notes
Alabama	0	
Alaska	0	
Arizona	0	
Arkansas	0	
California	0.04	at first car registration only
Colorado	0	
Connecticut	0.04	at first car registration only
Delaware	0.4	every two years, first 5 model years exempt, 15-20 min (<30 min)
Florida	0	
Georgia	0	
Hawaii	1	
Idaho	0	
Illinois	0	
Indiana	0	
Iowa	0	
Kansas	0	
Kentucky	0	
Louisiana	0.7	every 2 years as of Sept 2012, annual prior, 5-10 min inspection
Maine	1	
South Dakota	0	
Tennessee	0	
Texas	0.5	https://www.txdps.state.tx.us/rsd/vi/inspection/inspectionCriteria.aspx

State Name	% of Vehicles Registered + Stringency	Notes
Alabama	0	
Alaska	0	
Arizona	0	
Arkansas	0	
California	0.04	at first car registration only
Colorado	0	
Connecticut	0.04	at first car registration only
Delaware	0.4	every two years, first 5 model years exempt, 15-20 min (<30 min)
Florida	0	
Georgia	0	
Hawaii	1	
Idaho	0	
Illinois	0	
Indiana	0	
Iowa	0	
Kansas	0	
Kentucky	0	
Louisiana	0.7	every 2 years as of Sept 2012, annual prior, 5-10 min inspection
Maine	1	
Utah	0.5	every 5 years, vehicles over 10 years old; http://dmv.utah.gov/register/inspections
Vermont	1	
Virginia	0.95	

State Name	% of Vehicles Registered + Stringency	Notes
Alabama	0	
Alaska	0	
Arizona	0	
Arkansas	0	
California	0.04	at first car registration only
Colorado	0	
Connecticut	0.04	at first car registration only
Delaware	0.4	every two years, first 5 model years exempt, 15-20 min (<30 min)
Florida	0	
Georgia	0	
Hawaii	1	
Idaho	0	
Illinois	0	
Indiana	0	
Iowa	0	
Kansas	0	
Kentucky	0	
Louisiana	0.7	every 2 years as of Sept 2012, annual prior, 5-10 min inspection
Maine	1	
Washington	0	
West Virginia	1	
Wisconsin	0	
Wyoming	0	

Seatbelt Laws by State

The seatbelt laws are defined as a primary enforcement, secondary enforcement, or other and used as a dummy variable in the regression analysis (Table 5). These state definitions are taken from the Insurance Institute for Highway Safety. [35]

Table 5 Seatbelt Laws by State with Assigned Categorical Variable

State Name	Assigned Dummy Variable	Initial Effective Date	Safety Belt Law: Primary enforcement?
Alabama	1	7/18/91	yes; effective 12/09/99
Alaska	1	9/12/90	yes; effective 05/01/06
Arizona	0	1/1/91	no
Arkansas	2	7/15/91	yes; effective 06/30/09
California	1	1/1/86	yes; effective 01/01/93
Colorado	0	7/1/87	no
Connecticut	1	1/1/86	yes; effective 01/01/86
Delaware	1	1/1/92	yes; effective 06/30/03
Florida	2	7/1/86	yes; effective 6/30/09
Georgia	1	9/1/88	yes; effective 07/01/96
Hawaii	1	12/16/85	yes; effective 12/16/85
Idaho	0	7/1/86	no
Illinois	1	1/1/88	yes; effective 07/03/03
Indiana	1	7/1/87	yes; effective 07/01/98

State Name	Assigned Dummy Variable	Initial Effective Date	Safety Belt Law: Primary enforcement?
Iowa	1	7/1/86	yes; effective 07/01/86
Kansas	2	7/1/86	yes; effective 6/10/10 (secondary for rear seat occupants >18)
Kentucky	2	7/15/94	yes; effective 07/20/06
Louisiana	1	7/1/86	yes; effective 09/01/95
Maine	2	12/26/95	yes; effective 09/20/07
Maryland	1	7/1/86	yes; effective 10/01/97 (secondary for rear seat occupants; effective 10/01/13)
Massachusetts	0	2/1/94	no
Michigan	1	7/1/85	yes; effective 04/01/00
Minnesota	2	8/1/86	yes; effective 06/09/09
Mississippi	2	7/1/94	yes; effective 05/27/06
Missouri	2	9/28/85	no (yes for children <16)
Montana	0	10/1/87	no
Nebraska	0	1/1/93	no
Nevada	0	7/1/87	no
New Hampshire	0	n/a	no law
New Jersey	1	3/1/85	yes; effective 05/01/00 (secondary for rear seat occupants; effective 1/20/11)
New Mexico	1	1/1/86	yes; effective 01/01/86
New York	1	12/1/84	yes; effective 12/01/84
North Carolina	2	10/1/85	yes; effective 12/01/06 (secondary for rear seat occupants)
North Dakota	0	7/14/94	no
Ohio	0	5/6/86	no
Oklahoma	1	2/1/87	yes; effective 11/01/97

State Name	Assigned Dummy Variable	Initial Effective Date	Safety Belt Law: Primary enforcement?
Oregon	1	12/7/90	yes; effective 12/07/90
Pennsylvania	2	11/23/87	no (yes for children <18 years)
Rhode Island	0	6/18/91	yes; effective 6/30/11
South Carolina	2	7/1/89	yes; effective 12/09/0517
South Dakota	0	1/1/95	no
Tennessee	2	4/21/86	yes; effective 07/01/04
Texas	1	9/1/85	yes; effective 09/01/85
Utah	2	4/28/86	yes;18 effective 05/12/15 through 07/01/18
Vermont	0	1/1/94	no
Virginia	0	1/1/88	no
Washington	1	6/11/86	yes; effective 07/01/02
West Virginia	2	9/1/93	yes; effective 07/1/2013
Wisconsin	2	12/1/87	yes; effective 06/30/09
Wyoming	0	6/8/89	no

10.2 Simpson's Paradox

Using the VMT data provided by OHPI, fatal crash rates are then calculated, along with each state's urban-rural VMT values, as this varies within each state. All of these estimates are necessary because each state's overall fatal crash rate will vary depending on the type of area analyzed; this is where accounting for Simpson's Paradox is critical. Table 6 an example of this (values are taken from NHTSA's report as an example).

Table 6 Simpson's Paradox of State Fatal crash Rates [14]

	Urban fatal crash rate	%Urban VMT	Rural fatal crash rate	%Rural VMT	State Average	Urban/Rural Weighted State Average
State A	0.92	80%	2.68	20%	1.8	**1.27**
State B	0.87	23%	2.49	77%	**1.68**	2.12

State B has lower fatal crash rates for each of the urban and rural locations when compared to State A's equivalent. However, State B's rural composition is greater than State A, so as a result State B's weighted average rate will appear much higher overall than that of State A's. Using this information, overall state average fatal crash rates can be equivalently calculated both by weighted VMT (Equation 3a) and as an overall average (Equation 3b).

$$weighted\ average\ fatality\ rate_i =$$

$$\left[\%\ urban * \left(\frac{Fatal\ Crashes_i}{1\ Billion\ VMT_{i,}}\right)_{urban}\right] + \left[\%\ rural * \left(\frac{Fatal\ Crashes_i}{1\ Billion\ VMT_{i,}}\right)_{rural}\right];\ \ where\ i = state$$

Eq. 3a

$$overall\ average\ fatal\ crash\ rate_i =$$

$$\frac{\sum Fatal\ Crashes_i}{\sum 1\ Billion\ VMT_{i,}};\ \ where\ i = state$$

Eq. 3b

Equation 3a and Equation 3b are equivalent when percent urbanity is calculated using VMT proportions. This shows that fatal crash rates must be analyzed by urbanity since these percentages have an impact in calculating overall fatal crash rates. To observe the true effectiveness of a program based on VMT, urban and rural rates must be analyzed separately due to Simpson's Paradox, or the urbanity of a crash location must be accounted for in any statistical tests on fatal crash rates.

Equation 4 denotes the formula, as specified in NHTSA’s performance measures, for calculating fatal crash rates in a given state for a given area (urban or rural), which is calculated for each year and averages across years, between 2000 through 2009.

$$fatal\ crash\ rate_{i,j} = \frac{Fatal\ Crashes_{i,j}}{Billion\ Vehicle\ Miles\ Traveled_{i,j}};\ where,$$

$$i = state$$

$$j = urban\ or\ rural$$

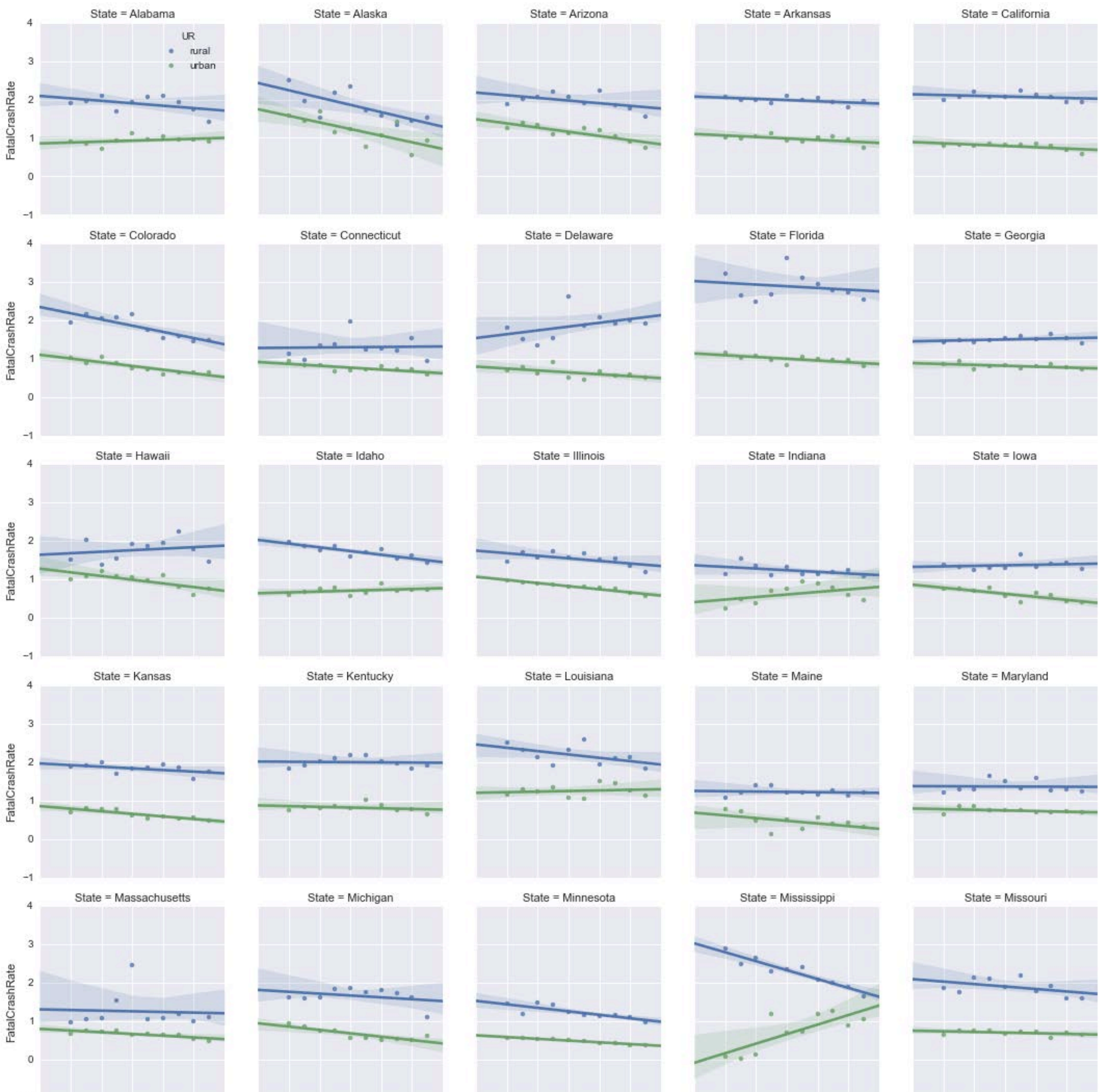
Eq. 4

Due to Simpson’s Paradox, fatal crash and VMT values will be analyzed separately in the analysis.

10.3 Regression Analysis – Model Checking

In order to accurately model fatal crashes or the fatal crash rate, initially a linear regression was modeled using the continuous fatal crash rate. After careful statistical evaluation, it was found that a linear regression could not be used to model the fatal crash rate due to heteroskedasticity. In addition, the QQ plot of the jackknife regression residuals fall outside of the red, dashed 95% confidence interval bands. The R Code and resulting output is presented below. These results led to the use of a count-based regression model on fatal crash counts. A poisson model was applied; however, overdispersion was observed (the variance to mean ratio was greater than 1). Thus, the final model chosen was the negative binomial distribution.

In addition to checking the linear regression model, once the negative binomial regression model was implemented, initially a state variable was included in order to model a fixed-effects regression based on the state. This was done initially due to the difference between urban and rural fatality rates between all of the states (Figure 2). Unfortunately, including this state variable led to perfect multicollinearity between the state variable and the safety variable. As a result, rather than accounting for each state, a region variable was used (Division). This allowed for separation by geographic region on a slightly more general scale than by state.



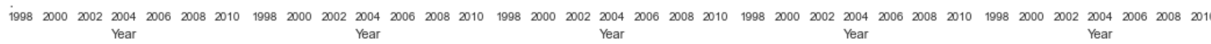


Figure 2 Fatal Crash Rate by State over Time while accounting for Urbanity, (a) First 25 states

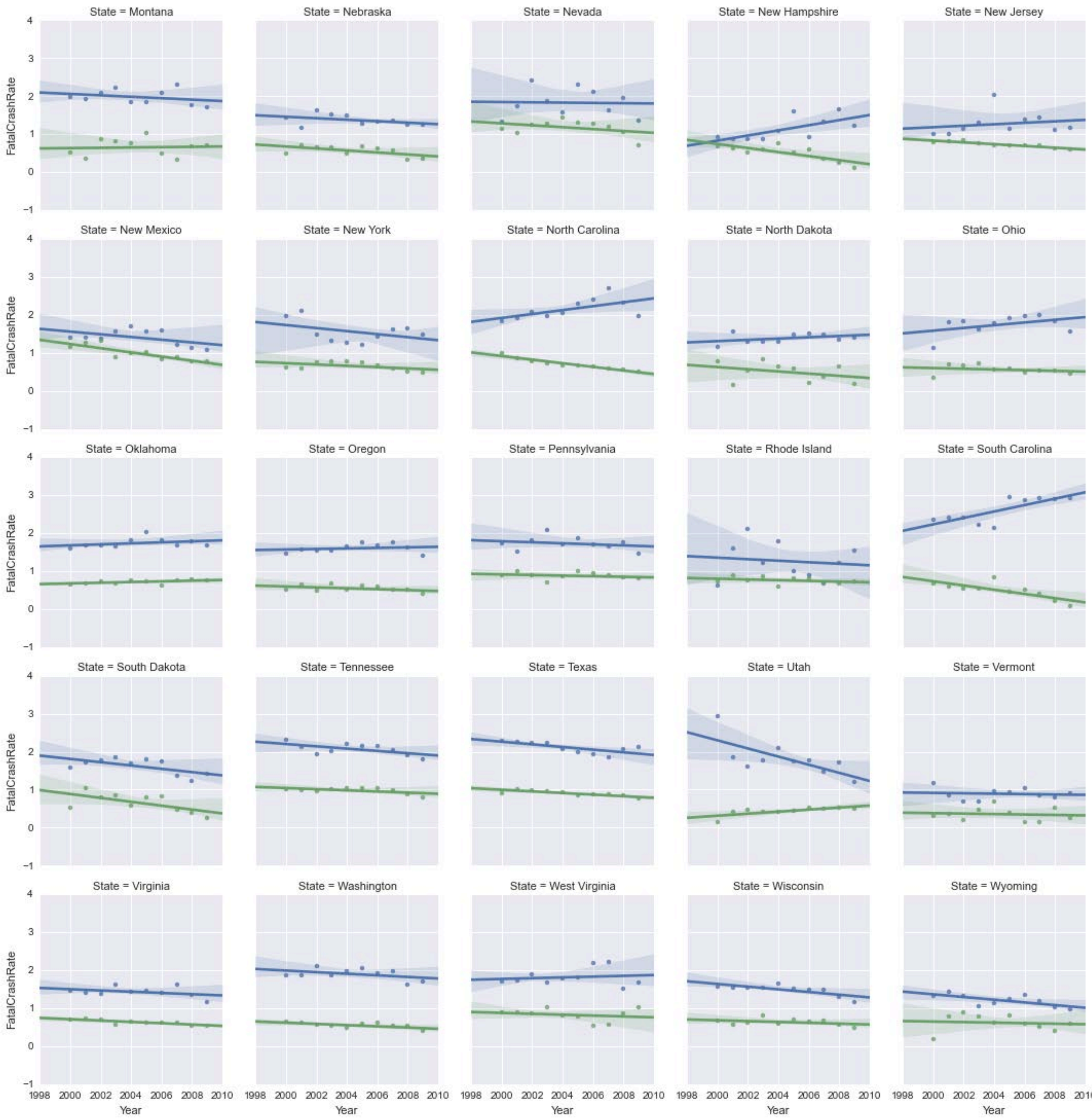


Figure 2 (b) Remaining 25 States

Prior to the statistical analyses, a simple histogram of the fatal crash rate is observed and found to be skewed (Figure 3).

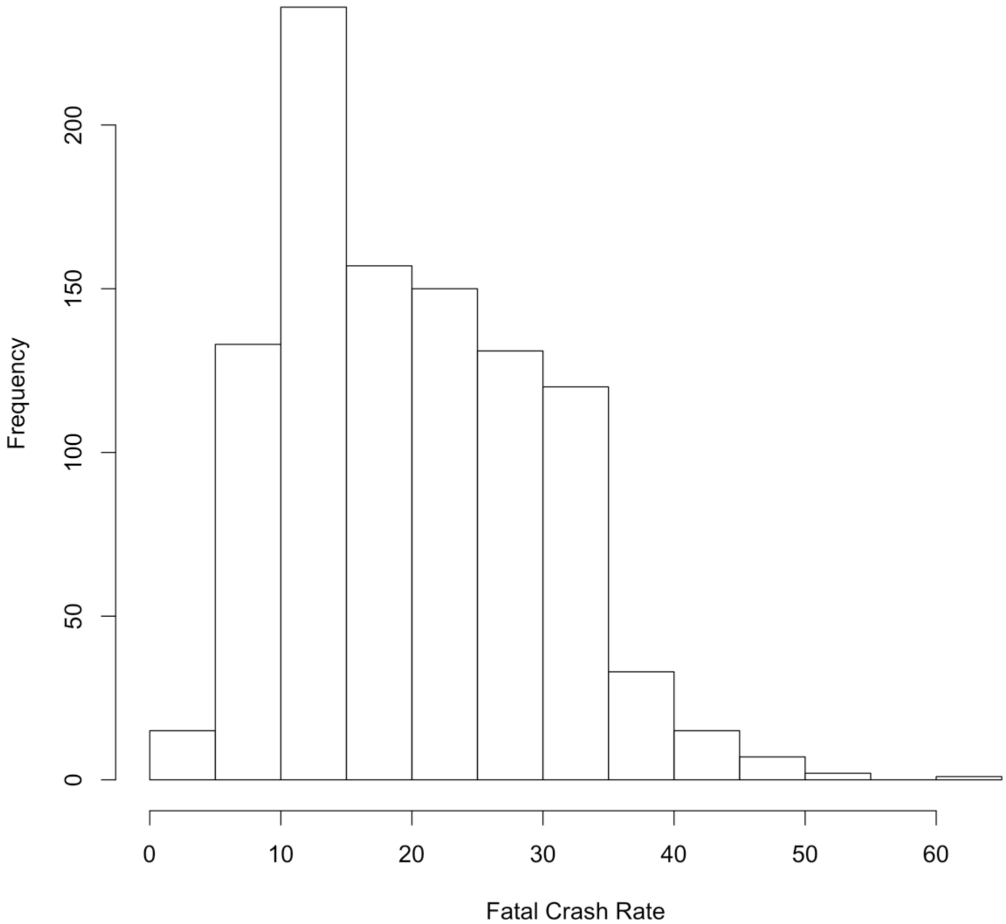


Figure 3 Histogram of Vehicle Fatal Crash Rate

R code:

df <- read.csv(file = "filename") # load data from file into dataframe in R

 # Regression Formula, "factor" creates dummy variables for possible categories

formula <- "FatalCrashes ~ VMT + Safety + Year + factor(UR) + factor(Division) + factor(SafetyBelt)"

```
# Negative binomial regression using previously defined formula and loaded data
m1 <- glm.nb(formula, data = df)
summary(m1)

# Checking model assumption: compare Negative Binomial to poisson
m3 <- glm(formula, family = "poisson", data = df)
pchisq(2 * (logLik(m1) - logLik(m3)), df = 1, lower.tail = FALSE)

# Negative Binomial Regression showing IRR [Incidence Rate Ratio] (2.5%, 97.5%)
(est <- cbind(Estimate = coef(m1), confint(m1, level = 0.9)))
est_exp <- exp(est)
est_exp

# Check independent variables for perfect multicollinearity
summary(lm(df$Safety ~ factor(df$Division) +  factor(df$UR) + df$Year + df$VMT +
df$SafetyBelt))
```

```
#q-q plot

norm <- rnorm(10000, mean(df$FatalCrashRate), sd(df$FatalCrashRate))

png(filename = "qqplot.png", width = 3000, height = 3000, res = 300)

par(cex = 1.3)

major.q <- quantile(df$FatalCrashRate, probs = seq(.05, .95, .05))

normal.q <- quantile(norm, probs = seq(.05, .95, .05))

min <- min(floor(min(major.q, normal.q)))

max <- max(ceiling(max(major.q, normal.q)))

plot(normal.q, major.q,

    xlim = c(min, max),

    ylim = c(min, max),

    ylab = "Quantiles of Fatal Crash Rates",

    xlab = "Quantiles of Normal Distribution",

    pch = 19,

    col = rgb(0, 0, 0, .5))

abline(0,1)

dev.off()
```

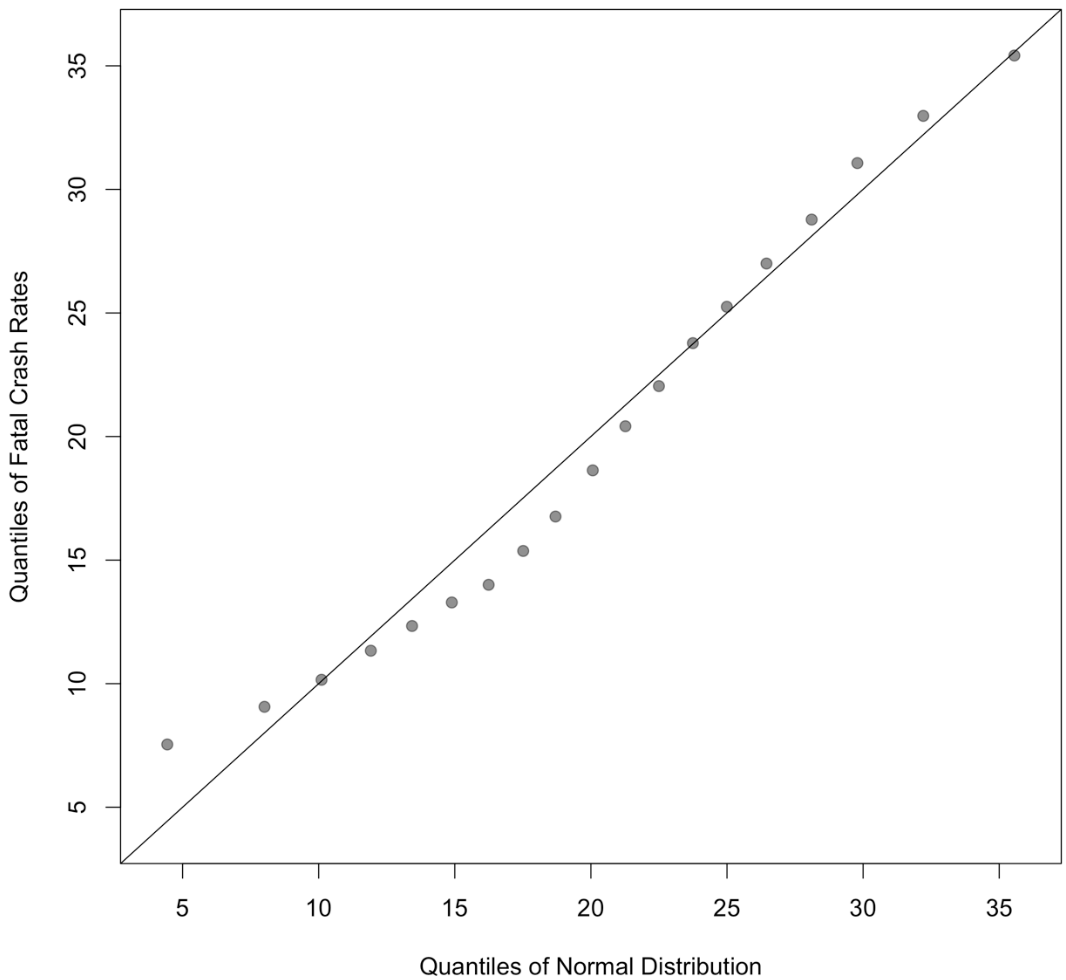


Figure 4 Q-Q Plot of Fatal Crash Rate to Estimated Normal Distribution

This slight ‘S’ curve shows potential problems with using a linear regression model with this data. In order to check for heteroskedasticity, jackknife residuals are plotted against the fitted values.

```
png(filename = "jackknife.png", width = 3000, height = 3000, res = 300)
par(cex = 1.3)
qqPlot(linReg,
    pch = 19,
    col = rgb(0, 0, 0, .3),
    ylab = "Jackknife Residuals")
dev.off()
```

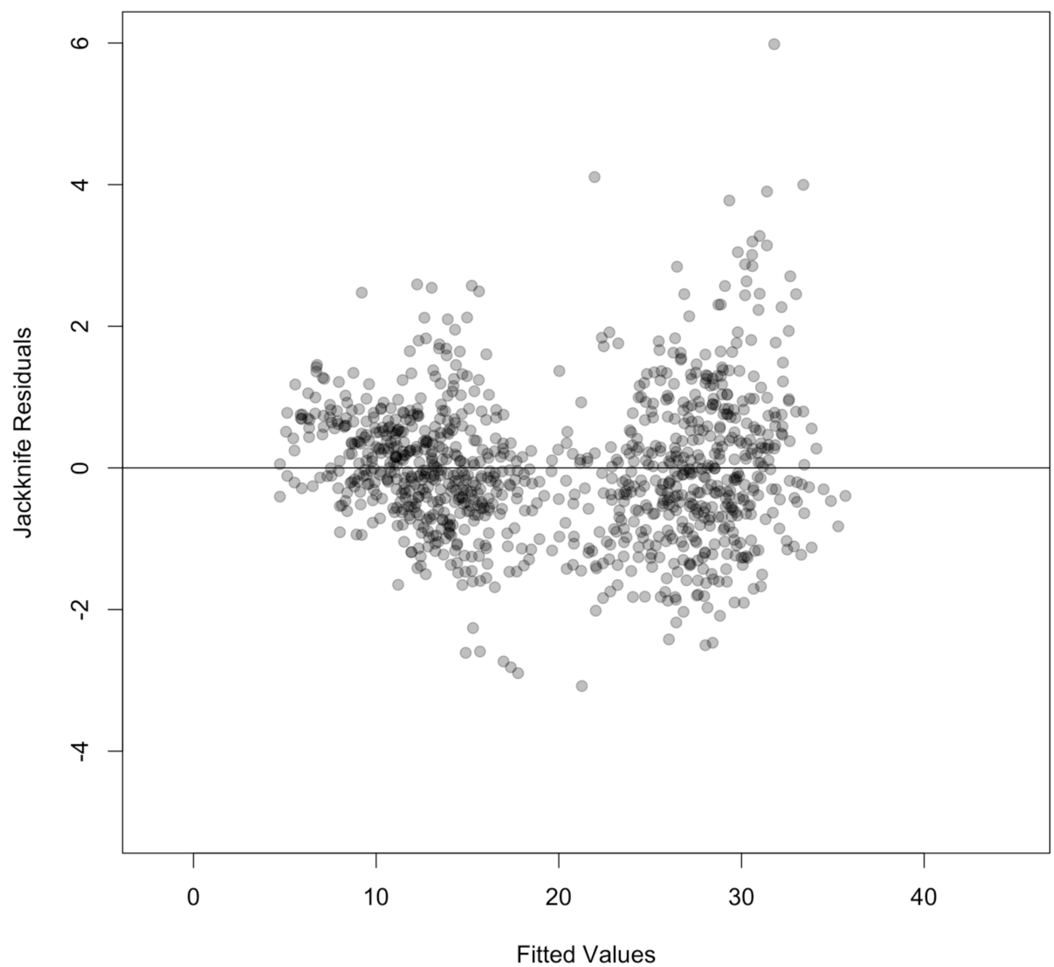


Figure 5 Q-Q Plot of Jackknife Residuals versus Fitted Values

Heteroskedasticity is present and obviously shown by the separation between the data.

```
png(filename = "resfitted.png", width = 3000, height = 3000, res = 300)
par(cex = 1.3)
plot(jitter(fitted(linReg)), # Plot the fitted/predicted values
    jitter(rstudent(linReg)), # Plot the jackknife residuals
    xlab = "Fitted Values",
    ylab = "Jackknife Residuals",
    pch = 19,
    col = rgb(0, 0, 0, .3),
    ylim = c(-5, 6),
    xlim = c(-2, 45))
abline(h = 0)
dev.off()
```

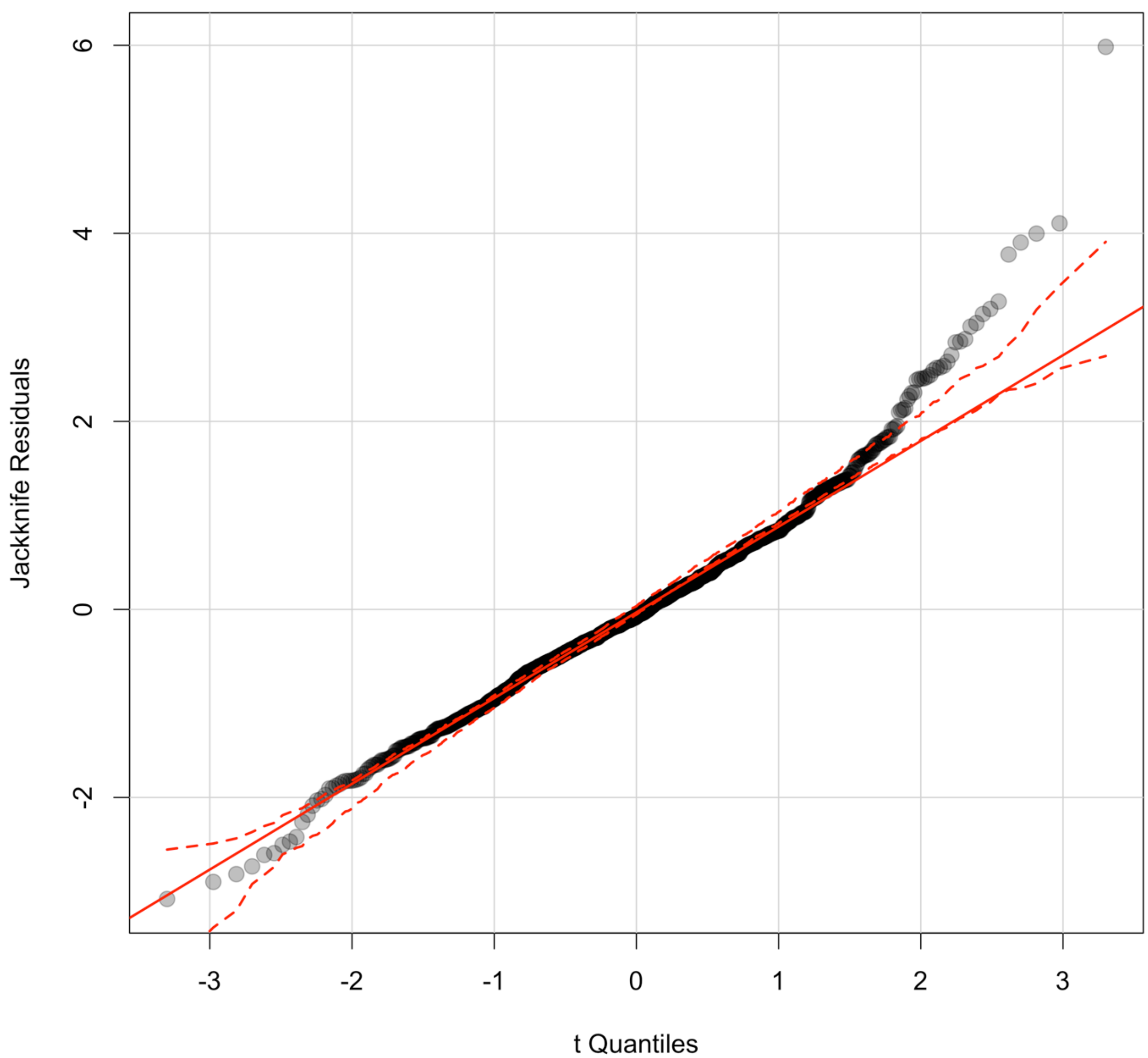


Figure 6 Jackknife Residuals with 95% Confidence Bounds versus the Fitted Normal Distribution

Linear regression jackknife residuals plotted here do not follow a normal distribution within a 95% confidence interval (red dashed lines); as a result, the use of a linear regression model is not an option for accurate predicting power and thus is not used.