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Measuring the Effectiveness of Vehicle Inspection Regulations in Different States of the U.S.

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Abstract

The National Highway Traffic Safety Administration's (NHTSA) guideline on state motor vehicle inspection programs recommends that states should maintain a vehicle safety inspection program to reduce the crash outcomes from the number of vehicles with existing or potential conditions. Some states have started to terminate the vehicle safety inspection program because of insufficient effectiveness measures, budget constraints, and modern safer automobiles. Despite the consensus that these periodic inspection programs improve vehicle condition and improve safety, research remains inconclusive about the effect of safety inspection programs on crash outcomes. There is little recent research on the relationship between vehicle safety inspection programs and whether these programs reduce crash rates or crash severities. According to the 2011–2016 Fatality Analysis Reporting System (FARS) data, nearly 2.6% of fatal crashes happened as a result of the vehicle's pre-existing manufacturing defects. NHTSA's vehicle complaint database incorporates more than 1.4 million complaint reports. These reports contain extended information on vehicle-related disruptions. Around 5% of these reports involve some level of injury or fatalities. This study used these two databases to determine the effectiveness of vehicle inspection regulation programs in different states of the U.S. A statistical significance test was performed to determine the effectiveness of the vehicle safety inspection programs based on the states with and without safety inspection in place. This study concludes that there is a need for vehicle safety inspections to be continued for the reduction of vehicle complaints.

The National Highway Traffic Safety Administration's (NHTSA) guideline on state motor vehicle inspection programs recommends that states should maintain a vehicle safety inspection program to reduce the crash outcomes from the number of vehicles with existing or potential conditions. Some states have started to terminate the vehicle safety inspection program because of insufficient effectiveness measures, budget constraints, and modern safer automobiles. According to the report of the U.S. Government Accountability Office (GAO), the number of states requiring such inspections dropped from a high of 31 in 1975 to 16 in 2015 (*1*). Despite the consensus that these periodic inspection programs improve vehicle condition and improve safety, research remains inconclusive about the effect of safety inspection programs on crash outcomes. There is little recent research on the relationship between vehicle safety inspection programs and whether these programs reduce crash rates or crash severities. Three U.S. studies that aimed at finding the relationship between safety inspections and crash rates over the past two decades (*1*) have failed to find "statistically significant differences in crash rates in states with inspection programs compared to those without." This is mainly because of the unavailability of crash data associated with vehicular defects for all states. Fatality Analysis Reporting System (FARS) data can provide vehicular defect-associated information related to only fatal crashes. This shows that research needs to be conducted with additional resources and in newer directions.

According to the 2010–2014 FARS data, nearly 6.35% of fatal crashes consisted of vehicles' pre-existing defects (*2*). Newer sources of data (for example, NHTSA vehicle owner's complaints data) can fill the current

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research gap. Nationwide studies on crashes related to vehicle component failure face constraints because of the lack of nationwide crash data. NHTSA's vehicle owner's complaint database (*3*) incorporates more than 1.4 million complaint reports (as of June 15, 2018). The complaints are filed through several methods (for example, consumer letters, hotline vehicle owner's questionnaire). Around 5% of these reports involve some level of injury or fatalities. The complaints file contains all safety-related defect complaints received by NHTSA since 1994. This database includes vehicle-related information (e.g., manufacturer, make, model, and year), incident (e.g., involvement of crash or fire), number of injuries/deaths, fuel type, complaint medium, and other related information. In addition, the database contains a narrative text field that provides the detailed text content on the vehicle problem and its consequences.

Earlier Work and Research Context

This literature review focuses on three specific research areas: (1) studies on the effectiveness of vehicle inspection, (2) studies on vehicle defect-associated crashes, and (3) studies on transportation engineering-related hidden trend analysis using text mining.

Studies on the Effectiveness of Vehicle Inspection

Opinion toward the effectiveness of vehicle inspection varies. Summers showed that random safety inspections were as effective as the periodic inspections in preventing crashes and deaths (*4*). Loeb et al. developed an econometric model for the efficacy of inspection in reducing fatalities and injuries using cross-sectional data. They applied the model with the data from the state of New Jersey in 1984 and used it as a reference to compare with other states across the country. This study determined that the inspection program has positive safety effectiveness (*5*, *6*).

Garbacz and Kelly implemented a national time-series analysis to analyze mandated vehicle safety inspections impact on fatalities (*7*). This study concluded that the safety inspection cannot reduce fatalities, nor can it help to reduce costs. Leigh (*8*) and Merrell (*9*) both found no evidence that inspections significantly reduce fatality or injury rates. The study of Poitras and Sutter found that inspections had no significant impact on the number of older cars on road (*10*). A study conducted by Cambridge Systematics showed that the vehicle safety inspection program prevents one to two safety-related fatalities per billion vehicle miles traveled in a state with versus without a safety inspection program (*11*). This study found that Pennsylvania, which has had an inspection program in place, is expected to experience 127 to 187 fewer fatalities each year. Peck et al. are firm supporters of the safety inspection program (*12*). They analyzed Pennsylvania vehicle safety inspections data ranging from 2008 to 2012 and found that the state safety inspection fail rate for passenger vehicles is 12–18%, far higher than the often-cited rate of 2% (*12*). A 2008 study sponsored by North Carolina legislators compared crash data from Nebraska before and after the discontinuation of the state safety inspection. This study did not confirm the effectiveness of inspection in reducing the fatalities (*13*). Keall and Newstead showed that the periodic safety inspection can bring some level of safety benefits but more frequent inspection than once a year is not justified (*14*). Hoagland and Woolley. opposed the continuation of the inspection program as well (*15*). Utilizing a synthetic controls approach examining traffic fatality data from 2000 to 2015 on New Jersey (ended safety inspection requirements in 2010), the study concluded that ending the mandatory inspection program did not result in a significant increase in the frequency or intensity of crashes resulting from car failure (*15*).

Studies on Vehicle Defect-Associated Crashes

Very few studies have examined the relationship between vehicle defects and associated safety implications. Moodley and Allopi conducted an observational survey study of parked vehicles to investigate if the vehicles were adequately safe for driving (*16*). They found that 24% of these vehicles had tire defects, and 11% of them had defective lights. To devise methods to evaluate vehicles for safety it is important to find if vehicle defects are contributing factors to crashes, and if so, which defects are the most prominent. A United States Department of Transportation study found that defects in brake system or tires have been cited as the most frequent cause of crashes (*17*). Wolf found that 6% of crashes in trucks were caused by mechanical failure, whereas the Road Research Laboratory in the United Kingdom found that vehicle defects contributed 18% of all crashes (*18*). Researchers have found through crash reconstruction that vehicle defects contributed to 9% of the crashes (*19*).

A UK study estimated that vehicle defects are likely to be a contributing factor in around 3% of crashes (*20*). The findings indicated that reducing the frequency of testing of newer vehicles is likely to have adverse road safety consequences. Schoor and Niekerk attempted to establish the contribution of mechanical failures in traffic crashes (*21*). Data obtained from accident response units indicates that tires and brakes were the main contributors to mechanical failures resulting in crashes. Barry et al. found that an airbag is effective for the survival of vehicle occupants if a crash should occur. This implies that in the event of a crash, occupants in vehicles with a

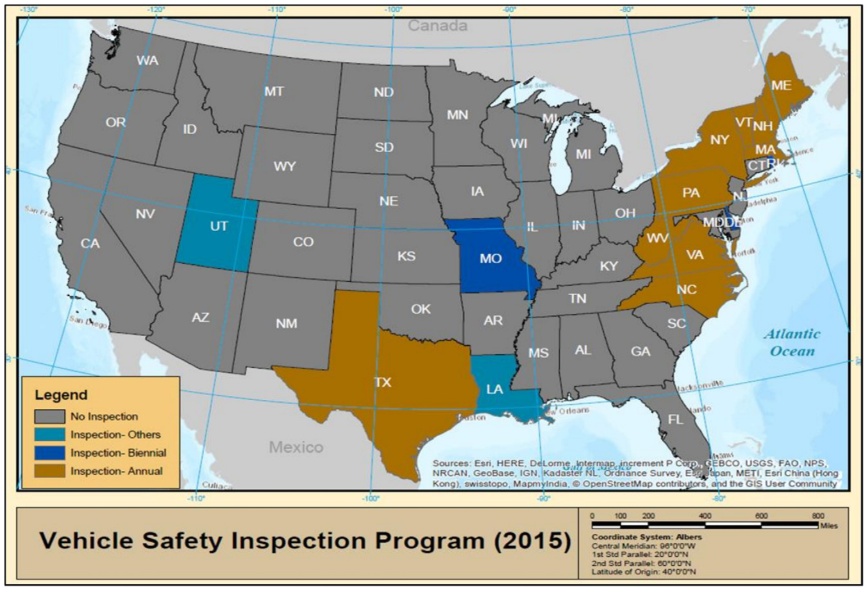


Figure 1. Vehicle inspection safety programs in the U.S. (*1*).

defective air bag system would have lesser protection and a higher chance of trauma. Barry et al. also found that the effectiveness of airbag becomes less clear when seat belts are employed (*22*). Kane et al. examined the complaints related to Toyota models, and this evaluation resulted in inconclusive findings (*23*).

Studies on Transportation Engineering-Related Hidden Trend Analysis using Text Mining

In recent years, several studies have incorporated text mining in transportation engineering research: consumer complaint analysis (*24*, *25*), understanding public sentiments on safety enhancement and bike sharing (*26*, *27*), identifying research trends from transportation engineering conference papers and journals (*28–32*), crash narrative investigation (*33–38*), text analytics using social media mining (*25*, *33*, *39–41*), and transportation-related surveys (*42*, *43*). Ghazizadeh et al. used text mining and latent Dirichlet analysis (LDA) to identify key patterns and non-trivial knowledge from the NHTSA complaint database. The analysis was conducted on a small subset of the complete data (*24*). Das et al. used all crash-associated contexts from the NHTSA complaint database and applied the empirical Bayes geometric mean method to determine the key contributors and non-trivial knowledge (*44*).

This paper is unique in two aspects: (1) for this study the authors performed text mining and topic modeling on the large textual content of NHTSA complaint data to determine the difference between the states regarding the vehicle inspection policy; and (2) this study incorporated statistical significance testing to determine the effectiveness of the vehicle inspection policy. This study goes beyond the current state-of-the-art studies by using two different datasets and innovative methods.

Data Preparation

Vehicle Inspection Program

Figure 1 and Table 1 show the states with different vehicle safety inspection policies. The states requiring safety inspections are Delaware, Hawaii, Louisiana, Maine, Massachusetts, Missouri, New Hampshire, New York, North Carolina, Pennsylvania, Rhode Island, Texas, Utah, Vermont, Virginia, and West Virginia. Eleven of these states require annual inspections, three (Delaware, Missouri, and Rhode Island) require biennial inspections, and two (Louisiana and Utah) specify other schedules. NHTSA standard 1349 C.F.R. Part 570 (Vehicle in Use Inspection Standards) specifies the minimum requirement for brakes, steering, suspension, tires, and wheel assemblies. The standard is applicable to all states with the inspection program. The states may include more inspection programs such as lighting, seatbelt, horns, wiper blades, and so forth, and specify the corresponding inspection criteria. GAO found that research on the value of safety inspections remains inconclusive because of the difficulty of quantifying its cost and benefits (*1*).

Table 1. Details of the Inspection Programs

Inspection program	States	Details
Annual	HI, ME, MA, NH, NY, NC, PA, TX, VT, VA, WV	States with inspection programs require an annual vehicle safety inspection
Biennial	DE, MO, RI	States with inspection programs require a biennial inspection
Other	LA, UT	Annual in areas where emissions inspections are required and biennial in all other areas in LA; Random roadside inspections in UT

Table 2. Comparison between Used Databases

Database	Years of data used	Advantages	Limitations
NHTSA Complaint data	2011–2016	• Provide crash and vehicle defect incident data • Provide vehicle complaint related information throughout the U.S.	• Limited to complaint data that were submitted to the NHTSA • Limited number of variables
FARS	2011–2016	• Contain all fatal crash-associated data for all states • Contain comprehensive list of variables	• Provide only fatal crash data • Contribution of vehicle defects is limited fatal crash data

To accomplish the research goal, this study used two databases: (1) FARS (2011–2016), and (2) NHTSA Vehicle Complaint Data (1995–2017). Table 2 shows a comparison between the used databases.

FARS Database

For 50 states, the District of Columbia, and Puerto Rico, NHTSA has maintained the FARS database since 1975. The FARS database contains over 989,451 crashes and is a census of all traffic crashes resulting in fatalities in the U.S. Specifically, to be recorded, the crash must "involve a motor vehicle traveling a traffic-way customarily open to the public and resulting in the death of a person (occupant of a vehicle or a non-motorist) within 30 days of the crash." The data come solely from existing documents, and major sources include coroner reports, police accident reports, hospital medical reports, states registration files, and state highway department records. There are more than 100 FARS data elements in each accident, characterizing the crash, the vehicle, and the people involved. FARS data are vital to understanding the features leading to crashes, such as characteristics of the road, driver, and vehicles (*45*). Though there is no comprehensive crash database for all police-reported crashes in the U.S., data from FARS can serve as a good substitute for a more comprehensive crash database for the U.S. The research team used 2011–2016 FARS data for this study.

NHTSA Vehicle Complaint Database

As another effort to improve road safety, NHTSA keeps records of public complaints about vehicles and transportation-related equipment. The data are typically reported by the vehicle owner and attorneys by phone, fax, mail, or online. The respondents provide component failure information and describe its consequences. Analysts at the NHTSA-ODI (Office of Defects Investigation) identify the failed component and complete the "specific component's description" field after receiving the report. The database also contains vehicle characteristics and crash information. Several records may exist for each incident as a result of the possibility of multi failure in one event. Moreover, NHTSA-ODI uses the database as a major source to identify and analyze safety issues, spot safety trends for proper impact, track existing recalls, and order investigations for defects that may result in safety failure. For ease of searching, NHTSA integrated all recall information and all complaints data in early 2000. As of June 15, 2018, this database incorporates 1,416,390 complaint reports in structured form with 49 variables. Around 7.26% of these reports involve some level of injury or fatalities. The complaints file contains all safety-related defect complaints received by NHTSA since January 1, 1995, and some incomplete rerecords for earlier years. The number of reports associated with some level of injury or deaths is 67,201 (around 4.9% of total complaint entries). However, approximately 26% of those complaint reports of injury or death are not associated with traffic crashes. The research team collected 1995–2017 NHTSA complaint data for this study. To keep the comparison limited to similar years, only 2011–2016 NHTSA complaint data were used for analysis.

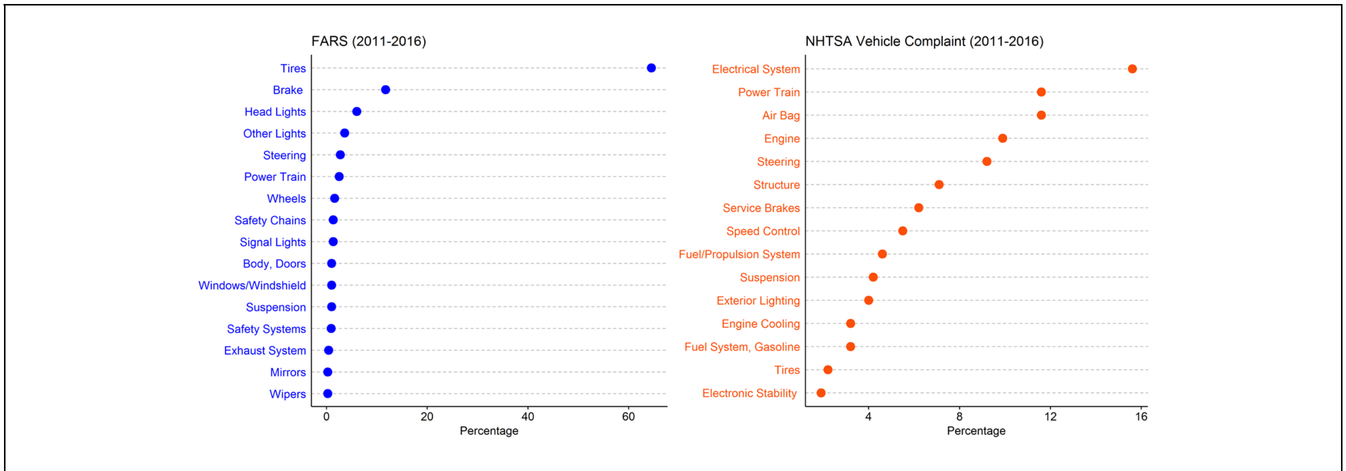


Figure 2. Comparison between major vehicular defects among NHTSA complaint database and FARS.

Data Analysis

Exploratory Data Analysis

Figure 2 shows key risk factors from two data sources: (1) FARS 2011–2016 crash data, and (2) NHTSA vehicle complaint. NHTSA provides two columns on complaints. "COMPDESC" provides short and specific problem-related complaints, and "CDESCR" provides a detailed description of the complaints. Risk factors from NHTSA were determined by a sentence stemming (identifying the key theme) method. In 2011–2016 FARS data, 5,685 crashes (around 2.6% of all fatal crashes) occurred because of vehicular defects. FARS uses a variable named "MFACTOR" to classify vehicle defects.

The top five vehicular defects in the FARS database are tires, brake, headlight, other lights, and steering. The NHTSA vehicle complaint dataset has electric system, power train, airbag, engine, and steering as the top five factors. The top five defects comprise nearly 85% of all defect-related fatal crashes in the FARS dataset. For the NHTSA complaint dataset, the top five defects contribute to approximately 60% of all complaints. Steering is listed as one of the top five defects in both datasets. It is interesting to find that tire is not the significant defect in the NHTSA complaint dataset. One possible reason is tire-related issues (for example, worn tires) are likely caused by roadway hazards rather than the company branding. The complaints are thus less populated for the tire-related issues. The top vehicular defects identified from FARS are in line with the findings of Schoor and Niekerk (*21*).

Text Mining and Topic Modeling

Text mining is usually defined as the method that uncovers and extracts interesting and non-trivial knowledge from a complex and unstructured or structured textual content. It incorporates multiple subject areas including information retrieval, classification, and other tools of natural language processing. As previously noted, the NHTSA vehicle complaint database contains two variables (COMPDESC and CDESCR) with textual content on the vehicle complaints and their natures. Text mining is the most appropriate tool for extracting knowledge from these two variables. For text mining approach, a set of standardized steps are taken. The dataset is divided into three datasets based on state inspection approaches: (1) Dataset A: states without inspection, (2) Dataset B: states with annual inspection, and (3) Dataset C: states with biennial and other inspection methods. The authors developed three separate corpora based on each dataset. Each corpus contains a large amount of textual context. For example, dataset A contains 22 years of complaint text descriptions from 34 states. The final corpora removes all reduction words, punctuation, and numbers to produce comparisons with more robust contexts. The detailed text mining steps are not discussed here. Interested readers can consult Silge and Robinson's book for text mining steps and associated codes (*46*).

An examination of the word frequencies of each corpus can show interest patterns of each dataset (as shown in Figure 3). Words that are close to the line in these plots have similar frequencies in both corpora. Similarly, words that are far from the line showed higher frequencies in one dataset compared with the other dataset. Words with high frequencies are colored in gray and words with low frequencies are colored in green. The differences between "no inspection vs. annual inspection" and "no inspection vs. biennial and other inspection" are not very distinctive. However, closer observation can reveal some differences. The term "engine" is present for approximately 10% in all three datasets. Seatbelt issues

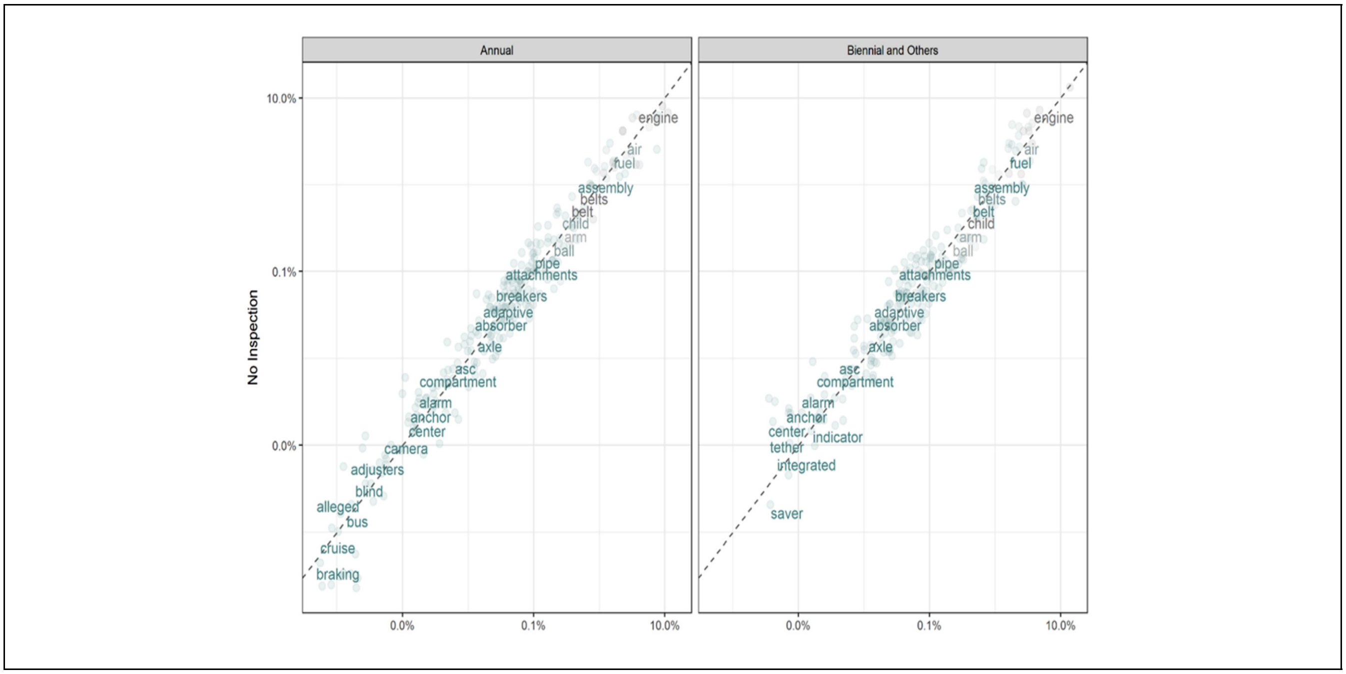


Figure 3. Comparing word frequencies of three corpora.

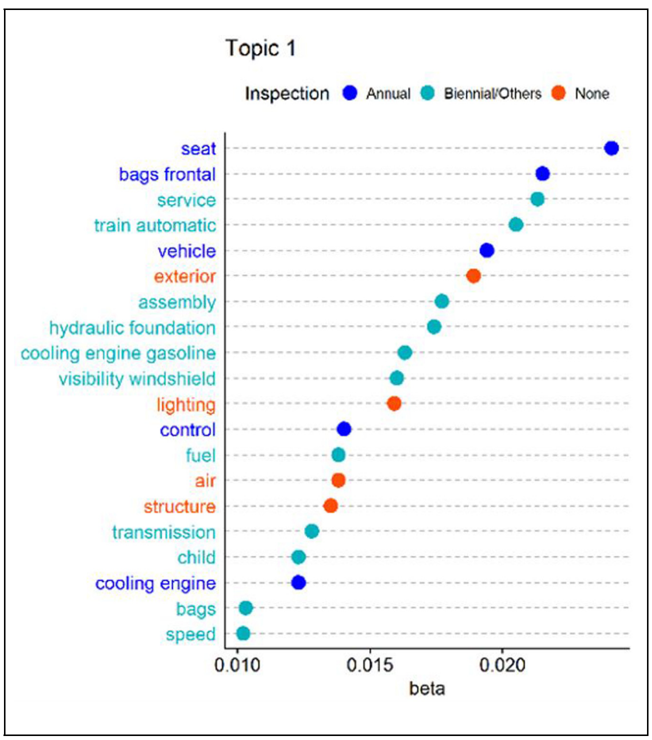


Figure 4. Topic 1 terms.

are higher in frequencies in the text content of the states with an annual inspection. Similarly, child-restraint issues are higher in states with biennial or other inspections. Most of the key terms are similar in both comparison plots with a few exceptions. Some terms are present in the annual comparison plot which are not present in the other plot. These defect-associated terms are camera, adjusters, blind, alleged, bus, cruise, and braking. Terms that are not present in the annual plot (but present in the biennial and other plot) are tether, indicator, integrated, and saver.

Topic modeling identifies the non-trivial patterns or topics from an unstructured and complex textual dataset. LDA is the most popular method for fitting a topic model. In this method, each document is considered as a mixture of topics, and each topic is considered as a mixture of words. This method allows documents overlapping in relation to content, rather than being separated into discrete groups. This process follows the typical usage pattern of natural language (*46*). A parameter, known as the per-topic-per-word probability (β), was used to examine the probability of a text being generated in a topic (see Figures 4 and 5). The authors developed three topics with a list of two words in each topic to use with the LDA algorithm. The terms are color-coded based on the dataset type. The top five words in Topic 1 are seat, bags frontal, service, train automatic, and vehicle. The term "seat" has a β value of 0.025. It indicates that the probability of the term "seat" being generated in topic 1 is 0.025. The analysis of the terms indicates three definite patterns of the topics: (1) Topic 1 (restraint, airbag, lighting, and exterior), (2) Topic 2 (electric, power, brake, and transmission), and (3) Topic 3 (airbag, transmission, electric, and fuel).

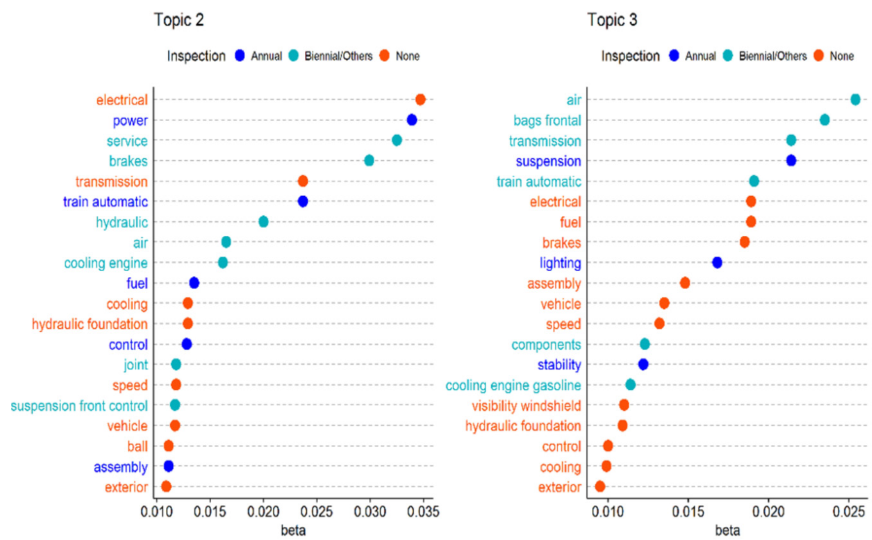


Figure 5. Topic 2 and Topic 3 terms.

The top five key topics in dataset A (states without inspection) are seat, airbag, power, suspension, and train automatic. The top five topics in dataset B (with annual inspection) are airbag, transmission, service, brakes, and train automatic. These terms for dataset C are electric, transmission, fuel, exterior, and brakes. Terms in dataset B and dataset C have higher β values than those in dataset A.

The text mining and topic modeling on the complex textual content of large NHTSA complaint data reveals several key differences among the states with different inspection regulations. However, the observed differences require further investigation because of the complexity of the dataset and its incorporation of states altogether for analysis.

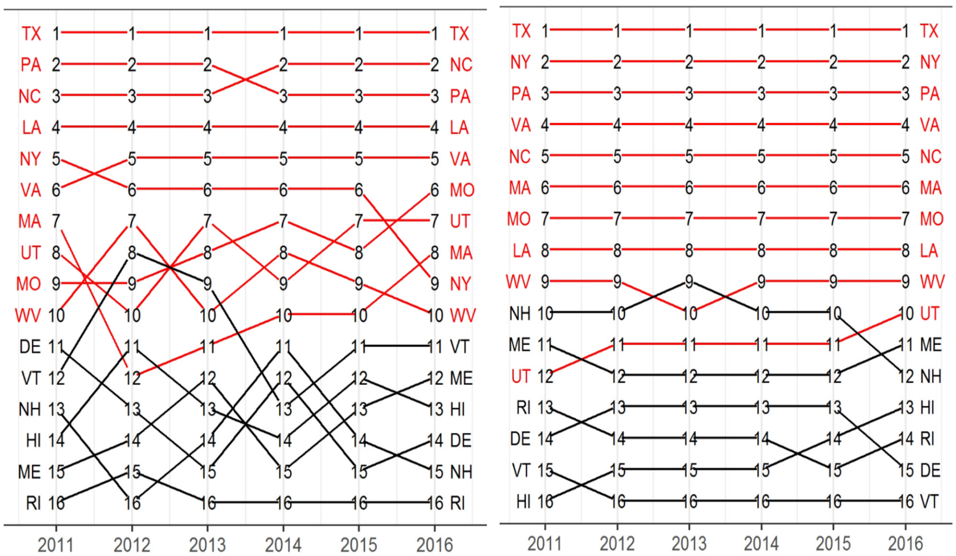
Ranking by States

Given the complexity in data, visualization of data using all states is difficult. This study used slope graphs to make this less complex. Figure 6 shows the ranking of states with vehicle inspection program in the FARS database when filtered to include records with vehicle defects only and NHTSA database. Texas and Louisiana are the two states that remained in their respective ranks throughout the years (shown in Figure 6). Texas ranked first in both databases, which is not unexpected because Texas experienced the highest number of fatal crashes for the last several years. The top four ranks in the FARS data remained almost constant over the years (except ranking change of Pennsylvania and North Carolina in 2013 and 2014). New York observed a decrease in ranking from 2011 to 2016 (from fifth to ninth). One possible reason is the decrease in all fatal crashes in New York (a 5% decrease from 2011 to 2016). Massachusetts data show a drop from seventh to twelfth during 2011–2012 and then gradually reaches the eighth position in 2016.

For the NHTSA complaint data from 2011 to 2016, the slope graph clearly shows that there is almost no change in the top 8 ranked states. For example, New York ranked second based on yearly NHTSA complaints, whereas it ranked ninth based on FARS dataset in 2016. New Hampshire observed a gradual decrease of complaints over the years. State motor vehicle registration data show that vehicle ownership per 1,000 people increased by 15% from 2015 to 2016 (*47*).

For the states without inspection, the ranking changes are not straightforward. The slope graph (shown in Figure 7) shows that there is almost no change regarding the top five rankings in both FARS data that include records with vehicle defects only and NHTSA complaint data from 2011 to 2016. Some of the states in FARS data show wide variations in ranking over the years. For example, based on FARS data, Kentucky reached the 15th position in 2014 (a sharp change from 2011) and then moved to the ninth position in 2015. New Mexico positions at eighth place in 2013, a change from the 15th position in 2012, observed a sharp decrease until 2015 (ranked at 25th) and then attained a 16th ranking in 2016.

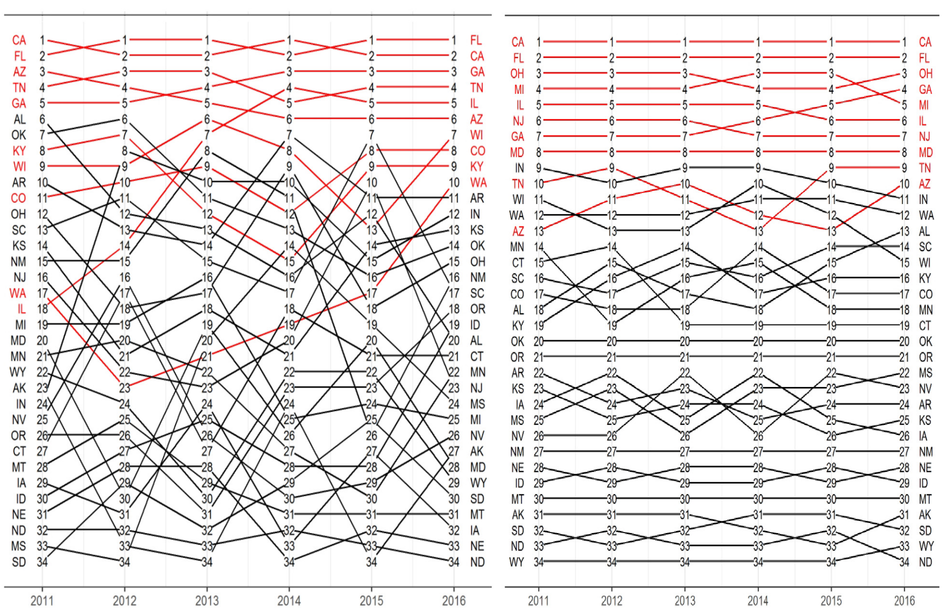
Based on the yearly NHTSA complaints, the top eight states almost remained the same in the rankings. For example, Tennessee and Arizona states oscillated



(a) Ranking of states with inspection (based on FARS fatal crashes associated with vehicle defects)

(b) Ranking of states with inspection (based on yearly NHTSA complaints)

Figure 6. Slope graph of states with vehicle inspections (the top 10 rankings in 2016 are colored in red).



(a) Ranking of states without inspection (based on FARS fatal crashes associated with vehicle defects)

(b) Ranking of states without inspection (based on yearly NHTSA complaints)

Figure 7. Slope graph of states without vehicle inspections (the top 10 rankings in 2016 are colored in red).

between ninth and 13th ranks from 2011 to 2016. Additional research and analysis can reveal the reasons behind the ranking changes, but it is not the scope of the current study.

Statistical Significance Test

The authors applied statistical significance test to investigate the safety effectiveness of state-maintained vehicle inspections. It is important to consider monthly data, to achieve enough variation to capture the significance, to perform the statistical significance test of vehicle inspection status on traffic safety between the states with inspection and states without inspection. As FARS data are limited to fatal crashes only, NHTSA complaint data would be effective in determining the significance of vehicle inspection regulations for different states. To accomplish the research goals, three datasets were prepared:

- Dataset 1: Monthly average vehicle complaints from NHTSA vehicle complaint data (2011–2016)
- Dataset 2: Monthly average vehicle complaint-involved crashes from NHTSA vehicle complaint data (2011–2016)
- Dataset 3: Monthly average fatal crashes from FARS (2011–2016)

The research question is to investigate whether the mean measures (complaints, complaint-involved crashes, and fatal crashes) across the states with inspection and states without inspection change during the two time periods (for convenience, the first time is named as "before" and the second as "after"). The before and after periods hypothetically considered are 2011–2013, and 2014–2016, respectively. The null hypothesis is that the mean measures are equal in both before and after years. "Cohen's *d*" statistic is used to evaluate the differences in mean measures. This statistic is used to evaluate the effectiveness of an intervention (for example, annual safety inspection) in which the group means are compared. The statistic can be written as:

$$Cohen'sd = \frac{mean\,difference}{standard\ deviation} \quad (1)$$

This statistic can measure the size of the effect in relation to standard deviation. For example, $d = 2.0$ indicates that the intervention changed the mean by two times of the standard deviation.

From Figure 8, the average monthly vehicle complaints of the states without inspection has the effect size of 2.508 (Figure 8(i)*a*). This indicates that the mean monthly vehicle complaint is changed by 2.508 times the standard deviation. For the states with inspection, this value is 2.088 (Figure 8(i)*b*). Both differences are individually statistically significant (see Figure 8). The effect size of the states with inspection program is lower than the states without inspection. This indicates that states with inspection anticipate fewer monthly complaints than the states without inspection. This conclusion is in the favor of mandatory yearly or biennial inspection strategies.

Similarly, a significance test on the dataset 2 also shows that there is an increase in the after year mean measures when compared with the before years. Both comparisons are also statistically significant. The effect size of states without inspection is 0.225 higher than the states with an inspection. The observation infers that states without inspection experience a higher number of vehicle complaint-induced crashes than the states with inspection. This finding is also supportive of the mandatory state inspections.

Analysis on dataset 3 shows that the effect size is statistically insignificant for the states without inspection. This implies that there is no clear evidence of an increase in fatal crashes for the states without vehicle inspection. The significance test for the states with vehicle inspection shows significance at the level of 0.05. This means there is not enough information available to show if there is any difference between the states with and without an inspection program. Thus, a conclusive finding from the significance test cannot be achieved from the FARS data. Unlike NHTSA data that has the vehicle-related factors only, FARS includes all factors, and the law enforcement officer may not be able to record the exact vehicle problem. This could be the possible reason for the insignificance. Alternatively, it is possible that the inspection may have an effect on non-fatal crashes only. This issue would be an excellent topic for future research.

Conclusions

It is widely believed that the periodic inspection of all registered vehicles has a potential to reduce the number of vehicles with existing or potential conditions that may contribute to crashes or increase the severity of crashes that do occur. However, the number of states requiring such inspections dropped from a high of 31 in 1975 to 16 in 2015. Research remains inconclusive about the effect of safety inspection programs on crash outcomes because of the limitation of comprehensive databases. This paper addressed these differences between the states with and without vehicle inspections by using newer data sources like NHTSA complaint data.

The study has two major contributions. Researchers performed text mining and topic modeling on the textual contents of NHTSA complaint data in effort to understand the patterns of vehicular defects. The authors applied statistical significance testing to investigate the safety effectiveness of state-maintained vehicle inspections.

The findings from the text mining and topic modeling are below:

- Issues related to the engine are present a majority of the time in the complaints received from all states, irrespective of the type of inspection program the states have.
- Seatbelt issues are higher in frequencies in the text content of the states with an annual inspection.

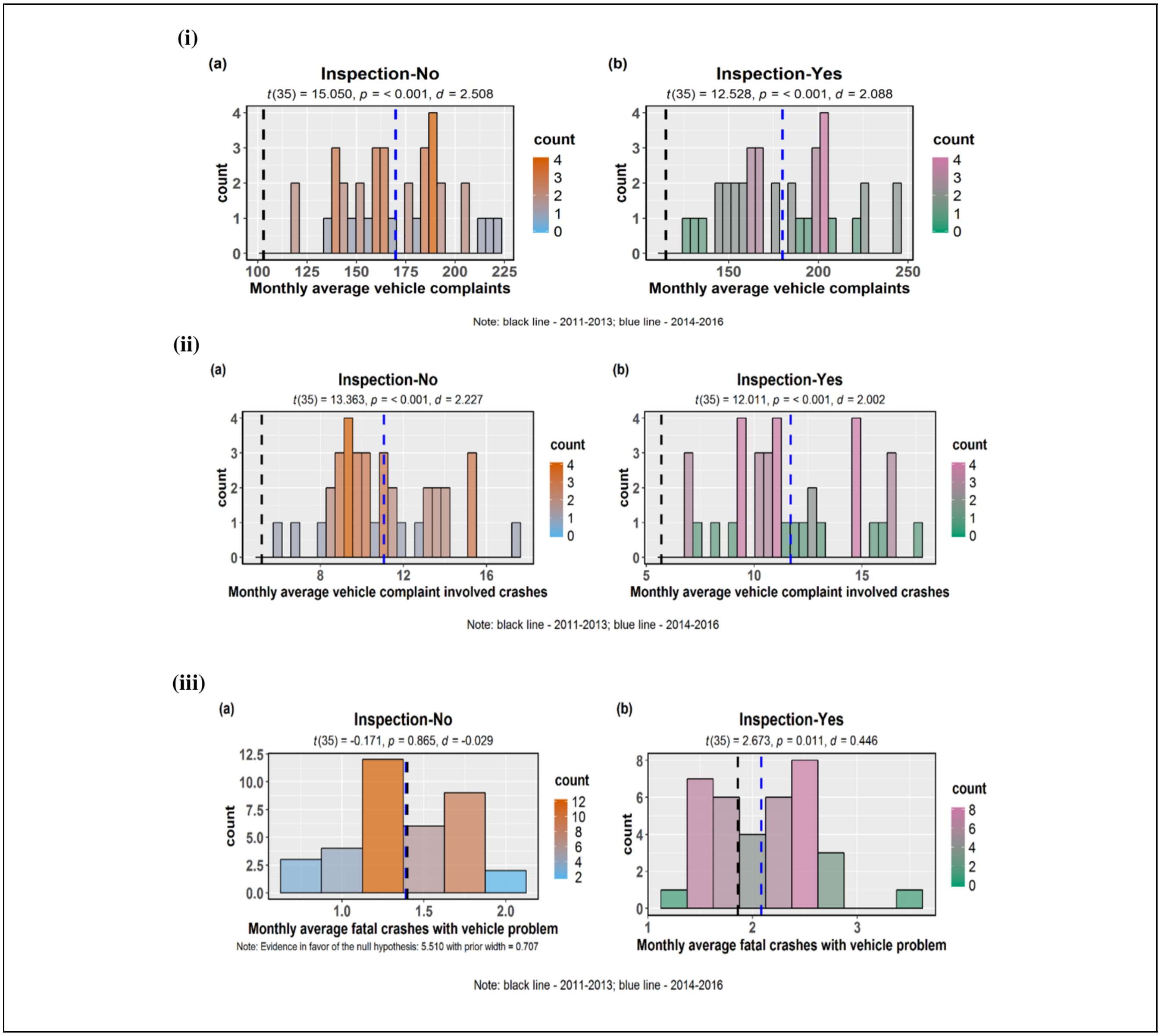


Figure 8. Statistical significance tests. (i) Dataset 1: NHTSA complaint data (all complaints); (ii) Dataset 2: NHTSA complaint data (complaints associated with crashes); (iii) Dataset 3: FARS crash data.

- Child-restraint issues are higher in states with biennial or other inspections.
- Most of the key terms are similar in both comparison plots with a few exceptions.
- The top five key topics identified in states without inspection are seat, airbag, power, suspension, and train automatic. The top five topics in states with annual inspection are airbag, transmission, service, brakes, and train automatic. For states with biennial and other inspections, the top topics are electric, transmission, fuel, exterior, and brakes.

The authors applied statistical significance testing to investigate the safety effectiveness of state-maintained vehicle inspections. The analysis used the "Cohen's *d*" statistic to evaluate the differences in mean measures (complaints, complaint-involved crashes, and fatal crashes) across the states with and without inspection during the two time periods. For the NHTSA data, the results indicate that states with inspection anticipate a smaller number of monthly vehicle complaints and complaint-induced crashes than the states without inspection. This shows that the mandatory vehicle inspection programs may have a positive effect on safety. Analysis of the FARS data did not reveal any evidence that relates to the safety effectiveness of the inspection program.

Given the number of factors that affect the traffic safety and the variation among states, it is difficult to isolate the role of a vehicle inspection program. Unlike most other studies, this study used newer techniques to identify the safety effectiveness of the inspection program. Further research needs to be conducted with traditional methods such as regression modeling to validate the results of this study. NHTSA may not receive all the vehicle complaints and so the results presented in this study may not be completely unbiased. Future research can be conducted by accounting for underreporting of the complaints. Also, as the analysis using FARS data did not yield any results, it is recommended to conduct the analysis using other data sources such as national representative database General Estimates System. It is also recommended to evaluate the effectiveness of inspection programs on different crash severity levels.

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Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: SD and SRG; data collection: SD; analysis and interpretation of results: SD and SRG; draft manuscript preparation: SD, SRG, KD, XS, and CM. All authors reviewed the results and approved the final version of the manuscript.

References

1. *Vehicle Safety Inspections: Improved DOT Communication Could Better Inform State Programs*. GAO-15-705. U.S. Government Accountability Office, 2015.
2. *Fatality Analysis and Reporting System*. National Highway Traffic Safety Administration, Washington, D.C.ftp://ftp.nhtsa.dot.gov/fars/. Accessed July 27, 2018.
3. *NHTSA/ODI Databases*. National Highway Traffic Safety Administration, Office of Defects Investigation, Washington, D.C.http://www-odi.nhtsa.dot.gov/downloads/. Accessed July 27, 2018.
4. Summers, B. Vehicle Safety Inspection Systems: How Effective? *Managerial and Decision Economics*, Vol. 4, No. 3, 1982, p. 251.
5. Loeb, P. D., and B. Gilad. The Efficacy and Cost-Effectiveness of Vehicle Inspection: A State Specific Analysis Using Time Series Data. *Journal of Transport Economics and Policy*, Vol. 18, No. 2, 1984, pp. 145–164.
6. Loeb, P. D. The Efficacy and Cost Effectiveness of Motor Vehicle Inspection Using Cross-Sectional Data: An Econometric Analysis. *Southern Economic Journal*, Vol. 52, No. 2, 1985, pp. 500-509.
7. Garbacz, C., and J. G. Kelly. Automobile Safety Inspection: New Econometric and Benefit/Cost Estimates. *Applied Economics*, Vol. 19, No. 6, 1987, pp. 763–771.
8. Leigh, J. P. Non-Random Assignment, Vehicle Safety Inspection Laws and Highway Fatalities. *Public Choice*, Vol. 78, No. 3, 1994, pp. 373–387.
9. Merrell, D., M. Poitras, and D. Sutter. The Effectiveness of Vehicle Safety Inspections: An Analysis Using Panel Data. *Southern Economic Journal*, Vol. 65, No. 3, 1999, p. 571.
10. Poitras, M., and D. Sutter. Policy Ineffectiveness or Offsetting Behavior? An Analysis of Vehicle Safety Inspections. *Southern Economic Journal*, Vol. 68, No. 4, 2002, p. 922.
11. Cambridge Systematics, Inc. *Pennsylvania's Vehicle Safety Inspection Program Effectiveness Study*. PA-2009-004-070609. www.dot.state.pa.us/public/dvspubsforms/BMV%20Safety%20Inspection%20Bulletins/Inspection%20Program%20Effectiveness%20Study.pdf. Accessed July 27, 2018.
12. Peck, D., 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: Policy and Practice*, Vol. 78, 2015, pp. 252–265.
13. *Close Doubtful Return on the Public's $141 Million Investment in Poorly Managed Vehicle Inspection Programs*. www.ncleg.net/PED/Reports/documents/VSI/VSI Report.pdf. Accessed July 27, 2018.
14. Keall, M. D., and S. Newstead. An Evaluation of Costs and Benefits of a Vehicle Periodic Inspection Scheme with Six-Monthly Inspections Compared to Annual Inspections. *Accident Analysis & Prevention*, Vol. 58, 2013, pp. 81–87.
15. Hoagland, A., and T. Woolley. It's No Accident: Evaluating the Effectiveness of Vehicle Safety Inspections. *Contemporary Economic Policy*, Vol. 36, No. 4, 2018, pp. 607–628.
16. Moodley, S., and D. Allopi. An Analytical Study of Vehicle Defects and their Contribution to Road Accidents. *Proceedings of the 27th Southern Africa Transport Conference*, Pretoria, South Africa, 2008.
17. *National Traffic Safety Newsletter*. U.S. Department of Transportation, NHTSA Washington D.C., 1975.
18. Wolf, R. *Truck Accidents and Traffic Safety – An Overview*. SAE meeting, Detroit, 1968.
19. Kinsey, G. Contribution of Unroadworthy Vehicles to Accidents. *Proc., 2nd Conference National Institute of Transport and Road Research*, Pieterburg, South Africa, 1976.
20. Transport Research Laboratory. *Effect of Vehicle Defects in Road Accidents*. PPRO 04/045/004.www2.ewu.edu/Documents/CBPA/NWTTAP/Newsletter/Publications/PPR565.pdf. Accessed July 27, 2018.
21. Schoor, O. V., and J. L. Niekerk. Mechanical Failures as a Contributing Cause to Motor Vehicle Accidents-South Africa. *Accident Analysis & Prevention*, Vol. 33, No. 6, 2001, pp. 713–721.
22. Barry, S., S. Ginpil, and T. J. O'Neill. The Effectiveness of Air Bags. *Accident Analysis & Prevention*, Vol. 31, No. 6, 1999, pp. 781–787.
23. Kane, S., E. Liberman, T. DiViesti, and F. Click. Toyota Sudden Unintended Acceleration. http://www.rightinginjustice.com/media/2010/02/SRS-Report-on-Toyota-Sudden-Unintended-Acceleration.pdf. Accessed July 27, 2018.

24. Ghazizadeh, M., A. D. McDonald, and J. D. Lee. Text Mining to Decipher Free-Response Consumer Complaints. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, Vol. 56, No. 6, 2014, pp. 1189–1203.
25. Das, S., A. Dutta, G. Medina, L. Minjares-Kyle, and Z. Elgart. *Extracting Patterns from Twitter to Promote Biking*. IATSS Research, 2018.
26. Das, S., X. Sun, and A. Dutta. Investigating User Ridership Sentiments for Bike Sharing Programs. *Journal of Transportation Technologies*, Vol. 5, No. 2, 2015, pp. 69–75.
27. Chen, F., and R. Krishnan. *Transportation Sentiment Analysis for Safety Enhancement*. Technologies for Safe and Efficient Transportation, Carnegie Mellon University, Pittsburgh. utc.ices.cmu.edu/utc/CMU%20Reports%202013%202/Final%20Report%20Chen.pdf. Accessed July 27, 2018.
28. Das, S., X. Sun, and A. Dutta. Text Mining and Topic Modeling of Compendiums of Papers from Transportation Research Board Annual Meetings. *Transportation Research Record: Journal of the Transportation Research Board*, 2016. https://doi.org/10.3141/2552-07.
29. Das, S., K. Dixon, X. Sun, A. Dutta, and M. Zupancich. Trends in Transportation Research. *Transportation Research Record: Journal of the Transportation Research Board*, 2017. https://doi.org/10.3141/2614-04.
30. Boyer, R. C., W. T. Scherer, and M. C. Smith. Trends Over Two Decades of Transportation Research. *Transportation Research Record: Journal of the Transportation Research Board*, 2017. https://doi.org/10.3141/2614-01.
31. Sun, L., and Y. Yin. Discovering Themes and Trends in Transportation Research using Topic Modeling. *Transportation Research Part C: Emerging Technologies*, 77, 2017, pp. 49–66.
32. Das, S., and A. Dutta. Knowledge Extraction from Transportation Research Thesaurus. Presented at 97th Annual Meeting of the Transportation Research Board, Washington, D.C., 2018.
33. Das, S., A. Dutta, and S. Datta. Injury Severity Analysis from Crash Narratives: A Case Study of Interpretable Machine Learning Using Tree and Utility Pole Related Traffic Crashes. Presented at 98th Annual Meeting of the Transportation Research Board, Washington, D.C., 2019.
34. Das, S., X. Sun, M. Zupancich, and A. Dutta. Twitter in Circulating Transportation Information: A Case Study on Two Cities. Presented at 96th Annual Meeting of the Transportation Research Board, Washington, D.C., 2017.
35. Das, S., B. Brimley, T. Lindheimer, and A. Pant. *Safety Impacts of Reduced Visibility in Inclement Weather*. Center for Advancing Transportation Leadership and Safety, University of Michigan, Ann Arbor. www.atlas-center.org/wp- content/uploads/2017/ 04/SafetyImpacts_VisibilityWeather_FinalReport.pdf. Accessed July 27, 2018.
36. Brown, D. E. Text Mining the Contributors to Rail Accidents. *IEEE Transactions on Intelligent Transportation Systems*, Vol. 17, No. 2, 2016, pp. 346–355.
37. Bazargan, M., M. Johnson, and A. Vijayanarayanan. *An Evaluation of AIRES and STATISTICA Text Mining Tools as Applied to General Aviation Accidents*. DOT/FAA/TC-TN13/7, FAA, U.S. Department of Transportation, 2013.
38. Raghavan, V., R. Benton, X. Sun, and S. Das. *Mining Potentially Interesting Positive and Negative Association Patterns from Traffic Safety Data*. LTRC Research Report, 2013.
39. Gu, Y., Z. Qian, and F. Chen. From Twitter to detector: Real-Time Traffic Incident Detection Using Social Media Data. *Transportation Research Part C: Emerging Technologies*, Vol. 67, 2016, pp. 321–342.
40. Das, S., L. Minjares-Kyle, K. Dixon, A. Palanisamy, and A. Dutta. #TRBAM: Understanding Communication Patterns and Research Trends by Twitter Mining. Presented at 97th Annual Meeting of the Transportation Research Board, Washington, D.C., 2018.
41. Das, S., A. Dutta, T. Lindheimer, M. Jalayer, and Z. Elgart. Youtube as a Source of Information in Understanding Autonomous Vehicle Consumers: A Natural Language Processing (NLP) Study. Presented at 98th Annual Meeting of the Transportation Research Board, Washington, D.C., 2019.
42. Minjares-Kyle, L., S. Das, G. Medina, and R. Henk. Knowledge about Crash Risk Factors and Self-Reported Driving Behavior: Exploratory Analysis on Multi-State Teen Driver Survey. Presented at 97th Annual Meeting of the Transportation Research Board, Washington, D.C., 2018.
43. Fitzpatrick, K., R. McCourt, and S. Das. Attitudes among Transportation Professionals Changing with Respect to the Setting of Posted Speed Limits. *Transportation Research Record: Journal of the Transportation Research Board*, 2019.
44. Das, S., A. Mudgal, A. Dutta, and S. Geedipally. Vehicle Consumer Complaint Reports Involving Severe Incidents: Mining Large Contingency Tables. *Transportation Research Record: Journal of the Transportation Research Board*, 2018. 2672: 72–82.
45. Koehler, S., and P. Brown. *Forensic Epidemiology*. International Forensic Science and Investigation. 19. CRC Press, Boca Raton, Fla., 2011.
46. Silge, J., and D. Robinson. *Text Mining with R. O'Reilly*, 2018. https://www.tidytextmining.com/. Accessed July 27, 2018.
47. Federal Highway Administration. *Vehicle Registration Data*. https://www.fhwa.dot.gov/policyinformation/quickfinddata/qfvehicles.cfm. Accessed July 27, 2018.
48. Mehrotra, S., and S. Roberts. Identification and Validation of Themes from Vehicle Owner Complaints and Fatality Reports using Text Analysis. Presented at 97th Annual Meeting of the Transportation Research Board, Washington, D.C., 2018.

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