THE UNIVERSITY OF TEXAS AT AUSTIN
CENTER FOR TRANSPORTATION RESEARCH

Economic and Safety Considerations: Motor Vehicle Safety Inspections for Passenger Vehicles in Texas

Mike Murphy
Nan Jiang
Zhe Han
Darren Hazlett
Carolina Baumanis
Ahmed Samiel Ahsan
Randy Machemehl
Zhanmin Zhang

Report Date:	October 2018
Project Title:	Cost, Revenue and Safety Considerations: Motor Vehicle Safety Inspections for Passenger Vehicles in Texas
Sponsoring Agency:	Texas Department of Public Safety
Performing Agency:	Center for Transportation Research at The University of Texas at Austin

Disclaimers

Author's Disclaimer: The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. This report does not constitute a standard, specification, or regulation.

Patent Disclaimer: There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine manufacture, design or composition of matter, or any new useful improvement thereof, or any variety of plant, which is or may be patentable under the patent laws of the United States of America or any foreign country.

Acknowledgments

The authors express appreciation to the following persons and groups that contributed to this report:

Texas Department of Public Safety

Texas Commission on Environmental Quality

Texas Comptroller of Public Accounts

Texas Department of Information Resources

Texas Department of Motor Vehicles

Alexander Ansley, National Highway Traffic Safety Administration

Mike Butler, Parsons

Charles Ray, DEKRA North America

Pete Villari, DEKRA North America

Abel Porras, TxDPS Vehicle Inspection Advisory Board

John Firm, Firm Automotive

Mike Sullivan, Group 1 Automotive

Shelly Richardson, HAF, Inc.

Ember Brillhart, Honda North America

Micah Harmon, Lavaca County

Shawn Dintino, North Central Texas Council of Governments

Joseph Battista, Parsons

Chris Murphy, Texas Chapter of Automotive Service Excellence

Dr. Michael St. Denis, Revecorp, Inc.

Brooke Remes, Stout Advisory

Joshua Swedlow, Stout Advisory

Stacy Dutton, Texas Auto Insurance Plan Association

Laura Kolstad, Texas Department of Transportation

Ed Martin, Texas State Inspection Association

Michael Nowels, Texas State Inspection Association

Laird Doran, The Friedkin Group / Gulf States Toyota

James Williams, Williamson County

James Loftin, Inspection Station Owner

Grady McGoldrick, Inspection Station Owner

Terry Meyer, Inspection Station Owner

James Bell, Inspection Station Owner

Stefanos Politis, UT's Center for Transportation Research

Robert Harrison, UT's Center for Transportation Research

Brandy Savarese, UT's Center for Transportation Research

Oscar Galvis, UT's Center for Transportation Research

Lisa Loftus-Otway, UT's Center for Transportation Research

Natalia Ruiz, UT's Center for Transportation Research

Srijith Balakrishnan, UT's Center for Transportation Research

North Central Texas Council of Governments

Heart of Texas Council of Governments

Deep East Texas Council of Governments

Alamo Area Council of Governments

Texoma Council of Governments

Brownsville Metropolitan Planning Organization

Corpus Christi Metropolitan Planning Organization

Harlingen–San Benito Metropolitan Planning Organization

San Angelo Metropolitan Planning Organization

List of Acronyms and Abbreviations

CMV	commercial motor vehicle
COG	council of government
CRIS	Crash Records Information System – a crash database maintained by TxDOT
CR-3	Crash Record – law enforcement officer crash record report filled out at the crash site. The data from CR-3 reports are used to create the CRIS database.
CTR	The University of Texas at Austin's Center for Transportation Research
FARS	Fatality Analysis Reporting System
MPO	metropolitan planning organization
NHTSA	National Highway Traffic Safety Administration
NSC	National Safety Council
PV	passenger vehicle (vehicle not classified as a commercial vehicle)
TxDPS	Texas Department of Public Safety
TxDMV	Texas Department of Motor Vehicles
TxDOT	Texas Department of Transportation
TxDIR	Texas Department of Information Resources
TCEQ	Texas Commission on Environmental Quality
TxCPA	Texas Comptroller of Public Accounts
VIC	Vehicle Inspection Connection – equipment used to collect data during a safety inspection and upload the data to the TxDPS Inspection database

Table of Contents

Executive Summary 1
Study Objectives 1
Study Methodology 1
Recommendations 2
Conclusions 2
Safety 2
Changes in Costs and Revenue 3
Public Perception 4
Chapter 1. Background and Introduction 6
1.1. Background 6
1.2. Study Framework 7
1.3. Organization of the Report 8
Chapter 2. Economic Impact Analysis 10
2.1. Summary of Economic Analysis 10
2.2. Additional Considerations 11
Chapter 3. Safety Impact Analysis 12
Chapter 4. Literature Review 25
4.1. Inspection Program Practices 25
4.2. Past Research on the Effectiveness of Inspection Programs 26
4.2.1. The Role of Vehicle Defects in Crashes 26
4.2.2. Safety Effectiveness of Inspection Programs 29
4.3. Chapter Summary 33
Chapter 5. Public Outreach 34
5.1. Stakeholder Interviews 34
5.1.1. Stakeholder Interview Findings 34
5.2. Workshop 35
5.2.1. Workshop Findings 36
5.3. Analysis of Vehicle Owner Survey 37
5.4. Analysis of Inspection Station Survey 40
5.5. Analysis of First-Time Failure Rate 42
5.5.1. First-Time Failure Rate Method 1 42
5.5.2. First-Time Failure Rate Method 2 44
5.5.3. First-Time Failure Rate Summary 46

Chapter 6. Inspection Databases Examination 47
6.1. TxDPS Inspection Database 47
6.2. Evaluation of Houston Taxi and Limousine Inspection Data 47
6.3. Evaluation of the Texas Highway Patrol High Value Dataset Database ... 48
Chapter 7. Conclusions and Recommendations.. 50
7.1. Conclusions... 50
7.1.1. Safety 50
7.1.2. Inspection Program Costs and Revenue 51
7.1.3. Public Perception of the Inspection Program..................................... 51
7.2. Recommendations... 53
References... 54

The appendices are provided in a separate file; their titles are listed here for quick reference.

Appendix A. Economic Impact Analysis
Appendix B. Data Preparation
Appendix C. Crash Costs
Appendix D. Defect and Non-Defect Crashes
Appendix E. Crashes Involving Out-of-State Vehicles
Appendix F. Statistical Analysis for Crashes Involving Out-of-State Vehicles
Appendix G. Supplementary Materials for Literature Review
Appendix H. Stakeholder Interviews
Appendix I. Workshop
Appendix J. Vehicle Owner Online Survey
Appendix K. Inspection Station Online Survey
Appendix L. Supplementary Materials for Houston Taxi and Limousines Inspection Data Evaluation
References for Appendices

List of Tables

Table 3.1 Number of crashes involving vehicles with defects 12
Table 3.2 Costs of crashes involving vehicles with defects using TxDOT crash costs 13
Table 3.3 Numbers of fatalities and crashes for PVs with and without defects 14
Table 3.4 Average vehicle age (years).. 21
Table 4.1. Summary of studies examining the contribution of defects to crashes.. 27
Table 4.2. Summary of studies examining the effectiveness of inspection programs 30
Table 5.1. Annual first-time failure rate and corresponding analysis period........ 44
Table 6.1 Comparative analyses of Houston taxi and limousine inspection data.. 48

List of Figures

Figure 1.1. A conceptual methodological framework for evaluating the safety and economic impacts of the Inspection Program................................. 7
Figure 3.1. Percentage of PVs with or without defects involved in fatal crashes.. 14
Figure 3.2. Types of defects for PVs 16
Figure 3.3. Types of defects for CMVs 16
Figure 3.4. Defect types of PVs stopped on the roadside and PVs in fatal crashes.. 17
Figure 3.5. Relationship between PV crash rate and percentage of crashes involving defective PVs with speed limit 19
Figure 3.6. Relationship between PV KAB crashes with speed limit 20
Figure 3.7. Vehicle age of defective vehicles involved in crashes in 2017 21
Figure 3.9. Average driver age of PVs involved in crashes with different severity levels in Texas in 2016.. 22
Figure 3.10. Percentage of defective PV drivers out of all drivers of PV involved in crashes in Texas in 2016... 23
Figure 3.11. Average age of PVs involved in crashes in Texas in 2016 24
Figure 4.1. Vehicle inspection program types by state 26

Figure 5.1. Vehicle owner responses: Do you think safety inspections benefit highway safety in Texas? 38

Figure 5.2. Vehicle owner responses: Do you think the safety inspection program provides you with a service or not? 39

Figure 5.3. Inspector responses: Do you think safety inspections benefit highway safety in Texas? 40

Figure 5.4. Inspector responses: Do vehicle inspections benefit highway safety in Texas? 41

Figure 5.5. Annual first-time failure curve 43

Figure 5.6. Histogram and cumulative probability of unadjusted first-time failure rate 46

Executive Summary

In 2017, the 85th Texas State Legislature passed Senate Bill (S.B.) 2076 with this requirement:

> "Not later than December 31, 2018, the Department of Public Safety and the Texas Department of Motor Vehicles shall:
>
> (1) conduct a study on the efficiency and necessity of the titling, including actions related to titling such as registration, and inspection of vehicles in this state; and
>
> (2) submit to the legislature a report on the results of the study that includes:
>
> a. identification of any elements of the vehicle titling, including actions related to titling such as registration, and inspection programs that can be eliminated; and
>
> b. recommendations for legislation to eliminate those elements."

S.B. 2076 was signed by Greg Abbott, the Governor of Texas, on June 15, 2017, and became effective September 1, 2017.

The Texas Department of Public Safety (TxDPS), using a competitive selection process, awarded a contract to The University of Texas at Austin's Center for Transportation Research (CTR) to conduct this study.

Study Objectives

The objectives of this study were to meet legislative requirements through these three tasks:

- Quantify the efficiency of the vehicle inspection program by analyzing the economic impacts of eliminating the passenger Motor Vehicle Safety Inspection Program (referred to in this document as the *Inspection Program*) in terms of potential cost and revenue changes for different entities impacted by the program;
- Address the necessity of the Inspection Program by assessing the safety impact of eliminating the Inspection Program on all road users and vehicle owners in Texas; and
- Make recommendations on whether the Inspection Program, as an element of vehicle titling, should be eliminated based on the economic and safety evaluations.

Study Methodology

This study undertook a review of current vehicle safety inspection programs worldwide and investigated methodologies to quantify the safety and economic impacts of the Inspection Program. The public's opinions about the Inspection Program were also solicited through surveys of rural and urban areas, a workshop, and stakeholder interviews. Vehicle inspection, registration, and crash databases maintained by TxDPS, the Texas Department of Motor Vehicles (DMV), the Texas Department of Transportation (TxDOT), and individual inspection stations were collected and evaluated. CTR used the information obtained from a literature review, public outreach, and an examination of inspection databases to perform the economic analysis and safety impact assessment, determining the potential change to the cost and revenue to vehicle owners, inspection

stations, and state agencies, as well as the potential impact on the public in terms of highway safety. The recommendations are based on the economic and safety impact evaluations.

Recommendations

The findings from this study's analysis indicate that the Inspection Program saves lives and enhances safety. The CTR team strongly recommends the following:

- Retain the Inspection Program.
- Conduct a further study to consider whether potential additional inspection items, such as tire age and recall information, should be included in the Inspection Program to further enhance highway safety in Texas.

Conclusions

After conducting a thorough investigation of the costs and safety impacts of eliminating motor vehicle safety inspections for passenger vehicles, the CTR study team identified the salient findings, summarized here, to reach our recommendations.

Safety

- The average crash costs related to vehicles with defects are more than $2 billion per year. Most defects are vehicle elements that would have failed a program inspection.
- The frequency of fatalities, incapacitating injuries, and non-incapacitating injuries is higher for crashes involving vehicles with defects. The number of fatalities per number of defective vehicles in crashes is about three times higher than that of vehicles without defects, as shown in this table:

Passenger Vehicles	2015		2016		2017	
	Defective	Non-defective	Defective	Non-defective	Defective	Non-defective
Fatalities per number of vehicles in crashes	1 fatality / 98 vehicles	1 fatality / 346 vehicles	1 fatality / 102 vehicles	1 fatality / 341 vehicles	1 fatality / 114 vehicles	1 fatality / 343 vehicles

- Crashes involving vehicles with defects are twice as likely to result in a fatality than crashes with vehicles that do not have defects.
- The most prevalent type of defect related to fatal crashes is slick or defective tires. Interestingly, 23.5% of survey respondents identified slick or defective tires as a vehicle element they had been asked to remedy during the course of their vehicle inspection history—meaning that the fatality crash rate would be higher without such inspections.
- Regarding vehicles from other states that are involved in crashes in Texas, the percentage of vehicles with defects is lower for those states that have vehicle safety inspection

requirements than states that do not. This indicates that a safety inspection program helps reduce the number of defective vehicles on the road.

- The percentage of crashes involving defective vehicles increases with higher speed limits—as does the severity of those crashes. Given that Texas has the highest speed limit in the nation and many high-speed roadways, it is important to consider the potential safety impact of eliminating the safety inspection program in Texas on highway safety, especially on roadways with high speed limits.
- Vehicles with defects that were involved in crashes are three years older than the average registered vehicle, which is nine years old. In other words, the percentage of vehicles with defect(s) and had crashes is higher for older vehicles. This highlights the importance of the Inspection Program to help ensure the key components (e.g., tires, brakes etc.) of old vehicles are in good condition.

Changes in Costs and Revenue

The following summary breaks down the allocation of the fees paid for inspections and registration and accounts for other benefits and costs of the program. Note that the costs to vehicle owners cover only the expenses specific to safety-only inspections, as drivers in certain urban counties must continue to obtain yearly emissions testing under federal law. The safety-only inspection fees comprise two components: $7 paid directly to the station operator at the time of inspection and a separate cost paid to the state at the time of vehicle registration.

- The present Inspection Program represents the following revenue and costs (where appropriate, these figures are rounded for the convenience of the reader):
  - The 12,000 station owners, employing 45,000 inspectors, share net revenue of $131 million per year ($7 per inspection).
  - The State of Texas receives revenue of $150 million per year, offset by $31 million of expenses.
  - The 19 million vehicle owners' expenses are $307 million in fees to stations and to the State of Texas, as well as time spent getting inspections (approximately $16 per vehicle per year).
- To discontinue the Inspection Program, the primary parties would incur these costs and savings:
  - Station owners would lose net revenue of over $131 million per year.
  - The State of Texas would lose revenue of approximately $150 million per year and incur a one-time expense of $1 million to discontinue the program.
  - Vehicle owners would save $307 million (approximately $16 per vehicle per year).

- Fees paid to the state at registration support the Clean Air Fund, the Texas Mobility Fund, and www.Texas.gov; the State of Texas will lose funding for these programs on the order of $39 million, $83 million, and $26 million respectively.
- If the Inspection Program were discontinued, stations in safety-only counties (with no emissions testing, which brings in emissions testing fees) may face closure. This would mean loss of businesses and loss of jobs, and may also severely affect the availability of commercial safety inspections in the state. Given the vital role of freight movement to Texas economy, determining the economic impacts of reducing the number of venues to service the commercial vehicle fleet would present a challenging situation.

Public Perception

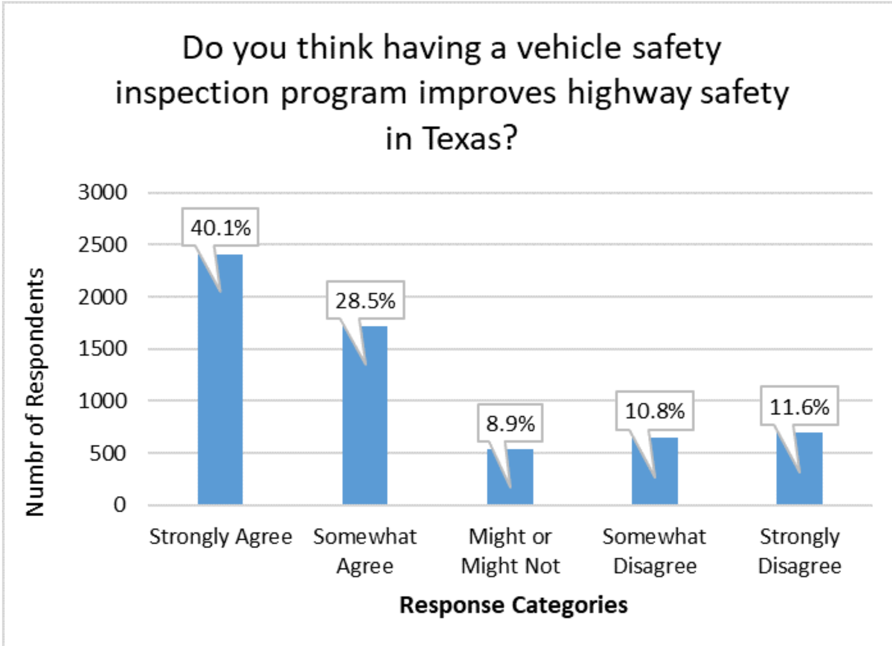
Survey analysis resulted in the following programmatic percentages (*occurring over the respondents' experience with the Inspection Program*) for the four categories of inspection results that were evaluated. Individuals in this group may have had their vehicle inspected over a span of 1 year to approximately 40 years and may have failed an inspection only one time, or up to every time they had their car inspected. Following are the four categories and their percentages:

- 37% of vehicle owners reported that their vehicles never required a replacement part or repair and thus always passed inspection the first time.
- 15.7% of vehicle owners reported that their vehicles never needed a repair or replacement part—however, the station operator observed a defect prior to beginning the inspection and told the owner to have it repaired, then return for an inspection. Thus, this group is counted among those who have had first-time inspection failures.
- 26.5% of vehicle owners reported that the inspection station failed their vehicle, but was able to perform the repairs so that the vehicle could pass inspection.
- 20.8% of vehicle owners reported that the inspection station failed their vehicle, but they went elsewhere for repairs (out of either choice or necessity), then returned to the station for a second inspection before passing.

Thus, 37% of vehicle owners have never failed an inspection and 63% of vehicle owners have failed an inspection at least once over the programmatic time span.

The CTR team used two methods of statistically analyzing the survey data to develop the first-time failure rate: one method provides an estimated range of 7.5% to 12.5% and the other method produces an average of 10.3%.

The results of the study survey indicate that the majority of Texas drivers polled perceive the Inspection Program as a beneficial program, one that enhances highway safety (as the following figure indicates).



Survey responses on the inspection program's role in highway safety

Please reference the full report below for all study details.

Chapter 1. Background and Introduction

This chapter describes the background for this report, the general framework for the study, and the organization of the report chapters and topics.

1.1. Background

In 2017, the 85th Texas State Legislature passed Senate Bill (S.B.) 2076 with this requirement:

> "Not later than December 31, 2018, the Department of Public Safety and the Texas Department of Motor Vehicles shall:
> (1) conduct a study on the efficiency and necessity of the titling, including actions related to titling such as registration, and inspection of vehicles in this state; and
> (2) submit to the legislature a report on the results of the study that includes:
> a. identification of any elements of the vehicle titling, including actions related to titling such as registration, and inspection programs that can be eliminated; and
> b. recommendations for legislation to eliminate those elements."

S.B. 2076 was signed by Greg Abbott, the Governor of Texas, on June 15, 2017, and became effective September 1, 2017.

The Texas Department of Public Safety (TxDPS), using a competitive selection process, awarded a contract to The University of Texas at Austin's Center for Transportation Research (CTR) to conduct this study.

The objectives of this study, designed to meet legislative requirements, were to:

- Quantify the efficiency of the vehicle inspection program by analyzing the economic impacts of eliminating the passenger (non-commercial) Motor Vehicle Safety Inspection Program (referred to in this document as the *Inspection Program*) in terms of potential cost and revenue changes for different entities impacted by the program;
- Address the necessity of the Inspection Program by assessing the safety impact of eliminating the Inspection Program on all road users and vehicle owners in Texas; and
- Make recommendations on whether the Inspection Program, as an element of vehicle titling, should be eliminated based on the economic and safety evaluations.

In Texas, vehicle inspection consists of one or two components depending on the location where the vehicle is registered. All vehicles are subject to the Inspection Program and are inspected annually for mandated safety items. The second component is the emission inspection, which is required only for those vehicles in an "emissions county" (currently 17 counties in Texas require enhanced vehicle emissions inspections to improve air quality). Annual inspections are federally mandated under the Clean Air Act (42 U.S.C. 85, subchapter I § 7401 et seq.), and are implemented through the State Implementation Plan. Both programs are administered by TxDPS, in conjunction with the Texas Commission on Environmental Quality (TCEQ). TCEQ's role is to design the

emissions component of the program and is the liaison between the state and the U.S. Environmental Protection Agency

This study considers only the Inspection Program and does not include an evaluation of safety inspections for commercial motor vehicles (CMVs) or emissions inspections for any vehicle.

1.2. Study Framework

The study team developed a conceptual framework for the analyses, shown in Figure 1.1, to guide the team's work according to the study scope.

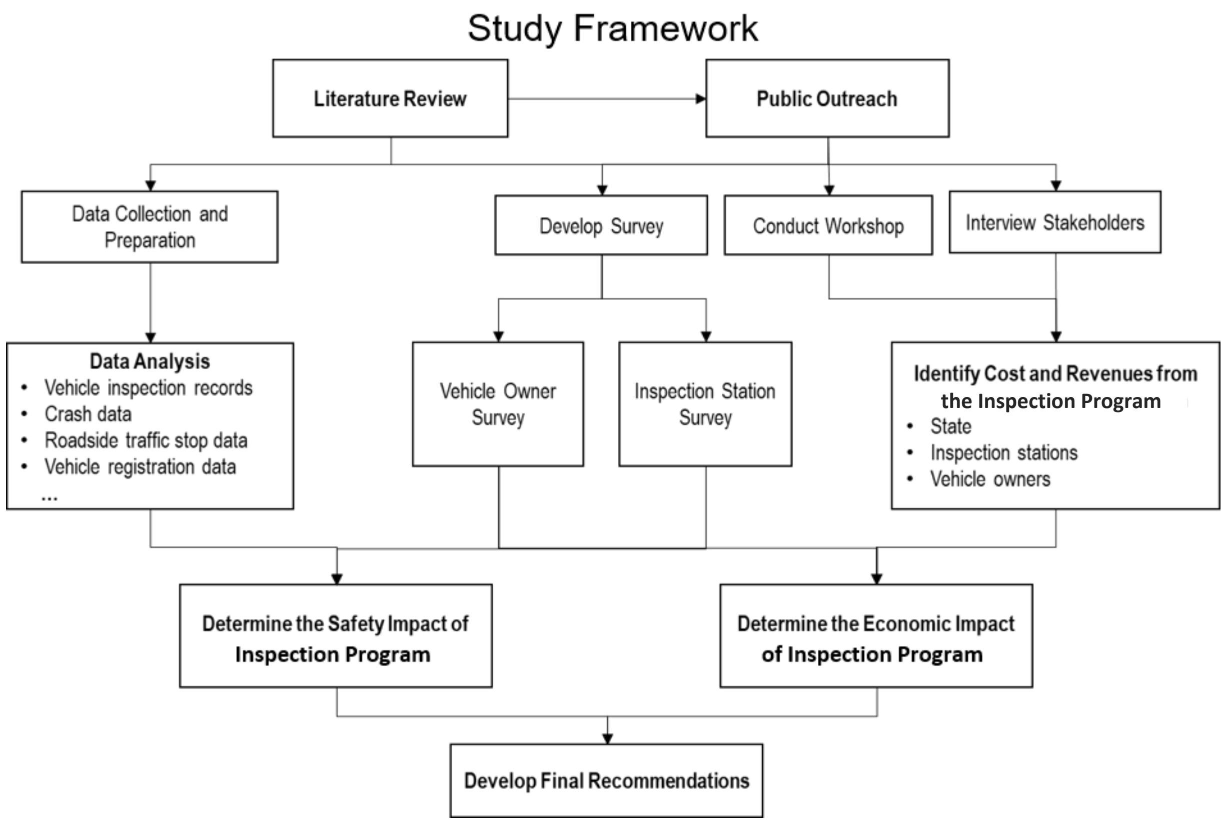


Figure 1.1. A conceptual methodological framework for evaluating the safety and economic impacts of the Inspection Program

As this framework indicates, the study started with a comprehensive literature review and public outreach. The literature review served as the basis of the study and provided useful information throughout the research duration. Based on the information gathered from the literature review and other sources, the study team developed a plan for public outreach. This included conducting a survey of vehicle owners and inspection station owner/operators, holding a stakeholder workshop, and interviewing stakeholders to gather information from the public regarding their opinions about the Inspection Program in Texas.

With information obtained from the literature review and public outreach, the study team identified important data sources for the safety and economic analysis. The data analysis started with

collecting, examining, and preparing the data. The major data sources used in this study include the statewide vehicle inspection database, crash database, roadside traffic citation database, vehicle registration database, and vehicle inspection records from individual vehicle inspection stations. These datasets were carefully analyzed using various data analysis techniques, such as comparative analysis, statistical analysis, etc. These data analysis results and meaningful insights gained from analyzing vehicle owner and inspection station survey responses formed the basis for determining the safety impact of the Inspection Program in Texas.

Information obtained from the literature review and public outreach also fed into the economic analysis component of this study, allowing the cost and revenues related to the Inspection Program to be evaluated from the perspectives of the inspection stations, the state, and vehicle owners. This analysis led to the economic impact evaluation produced by this study.

Finally, based on the major findings obtained from the safety impact and economic impact assessments, the study team developed the final recommendations regarding whether the Inspection Program should be either continued or eliminated.

1.3. Organization of the Report

To present the information most pertinent to the study objectives of the study, this report is organized into the following six chapters (with extensive supporting materials provided in the appendices):

- **Chapter 2. Cost and Revenue Analysis**

  The team researched and developed a detailed accounting for the inspection fees and licensing structure to address the primary affected parties: the station owners/inspectors, the State of Texas, and the vehicle owner. Section 2.1 summarizes the economic analysis for the present Inspection Program and outlines the effects should the Inspection Program be discontinued. Section 2.2 describes additional considerations discovered during the course of the economic investigation. The full economic evaluation is detailed in Appendix A.

- **Chapter 3. Safety Impact Assessment**

  This chapter presents the major findings from assessing the program's safety impact using various data sources, which include, for example, the economic and comprehensive costs arising from crashes involving vehicles with defects, a comparison between crashes involving vehicles with and without defects, an assessment of crashes in Texas involving out-of-state vehicles from states with and without inspection programs, and identification of major defect types found on vehicles that had crashes. Supporting details of each major finding are presented in this chapter and relevant appendices.

- **Chapter 4. Literature Review**

  In this chapter, the CTR team synthesizes a comprehensive literature review. Section 4.1 presents the current practices of inspection programs in Texas, other U.S. states, and other countries. Section 4.2 examines literature on the involvement of vehicle defects in crashes and the safety effectiveness of inspection programs, including the data and methodologies used for evaluating the safety and economic impacts of inspection programs. Major findings from the literature review are summarized in Section 4.3. More details, including a review of each citation, are provided in Appendix G.

- **Chapter 5. Public Outreach**

  Public outreach was needed to understand the industry stakeholders' and the public's perception of the existing Inspection Program and the direction these groups thought it should take. This chapter discusses the project's public outreach activities:

  - Stakeholder interviews (Section 5.1)
  - Stakeholder workshop (Section 5.2)
  - Vehicle owner survey (Section 5.3)
  - Inspection station survey (Section 5.4)
  - First-time failure rates (Section 5.5)

  This chapter analyzes the interview and survey results, summarizing important findings from these public outreach activities.

- **Chapter 6. Inspection Database Examination**

  Section 6.1 summarizes major findings from examining the statewide inspection database. Section 6.2 spotlights a specific inspection dataset to closely examine and contrast 714 inspection records for Houston taxis and limousines. Information such as first-time failure rate, average mileage, average number of failure reasons, and detailed summary on defective items are presented and analyzed using both Houston inspection program standards and the Inspection Program standards. Detailed analyses of both standards are provided in Appendix L. Section 6.3 examines the Texas Highway Patrol High Value Dataset Database for citations and warnings for vehicles stopped and found to have safety defects.

- **Chapter 7. Conclusions and Recommendations**

  The last chapter summarizes the study activities and major conclusions and provides the study team's final recommendations.

Chapter 2. Economic Impact Analysis

To conduct the economic analysis one needs a clear understanding of the revenue and expense structure of the Inspection Program relevant to 1) the vehicle inspection stations, 2) the Texas state budget, and 3) the vehicle owners. Delineating the revenues and expenses for various parties is complicated, for either continuing or discontinuing the Inspection Program. There are one-time expenses as well as aggregate program revenues and expenses, and there would be a loss of existing revenue to support various programs if the program were discontinued. The CTR team has attempted to identify and account for them as best as possible using 2017 or the most current data. Below is a summary of that analysis and the additional considerations discovered during the analysis. The full details of the economic evaluation appear in Appendix A.

2.1. Summary of Economic Analysis

The present Inspection Program represents the following revenue and costs:

- Station Owners and Inspectors
  - Revenue: $137,276,594 per year ($7 per inspection)
  - Expenses: $6,461,566 per year
  - Net revenue of approximately $131 million per year
- State of Texas
  - Revenue: $149,577,760 per year
  - Expenses: $31,204,253 per year
  - Net revenue of approximately $118 million per year
- Vehicle Owners
  - Expenses: $307,314,925 per year (approximately $307 million per year for the 19 million vehicle owners, or $16 per vehicle per year.)

To discontinue the Inspection Program, the primary parties would incur these costs and savings:

- Station Owners and Inspectors
  - Revenue: $0 - This represents a loss of $137,276,594 per year.
  - Expenses: $0
- State of Texas
  - Revenue: $0 - This represents a loss of $149,577,760 per year.
  - Expenses: $1,033,480 (one-time expense)
- Vehicle Owners
  - Expenses: $0

2.2. Additional Considerations

These additional considerations may factor into a legislative decision:

- None of the current fees paid to the state at registration are directed to TxDPS to administer the program.
- Inspection Program fees paid to the state, collected at registration, go to support the Clean Air Fund and the Texas Mobility Fund; these programs will receive less funding on the order of $39 million and $83 million respectively. Discussions with TCEQ indicated that the current fees account for approximately 33% of funding for the Clean Air Fund.
- The Texas Department of Information Resources (TxDIR) pointed out that Texas.gov fees collected with most of the transactions help support all the functions of www.Texas.gov as well as the safety inspection equipment deployment and troubleshooting. Loss of these fees would require replacement funding in some form. Currently this is approximately $26 million.
- If the Inspection Program were discontinued, there may not be enough commercial business to keep 12,000 inspection stations open to conduct only commercial safety inspections. Those stations in safety-only counties (with no emissions testing that brings in emissions testing fees) may face closure. This would mean loss of businesses and loss of jobs, and may also severely affect the availability of commercial safety inspections in the state.

Chapter 3. Safety Impact Analysis

This chapter presents the major findings from analyzing the safety impact of the Inspection Program. The ultimate goal of the analysis was to evaluate whether eliminating the Inspection Program could affect highway safety in Texas.

Data from various sources were collected, examined, and pre-processed in preparation for the analysis. These datasets—combined with useful information obtained from the literature review, workshop, stakeholder interviews, and surveys—formed the basis of the analysis. These three major data sources were used in this analysis:

- TxDOT Crash Records Information System (CRIS) Data (2010–2017)
- TxDPS "Texas Highway Patrol High Value Data Sets" (Roadside Traffic Stop – Citation Data, 2010–2016)
- TxDMV – Vehicle Registration Data (2015–2017)

Appendix B details the preparation and preprocessing of these data sets for the safety impact study (e.g., the method used to identify vehicles with defects within the crash data sets).

Safety Impact Analysis Major Finding 1

The average crash costs arising from vehicles with defects being involved in fatal, incapacitating-injury, and non-incapacitating-injury crashes are more than $2 billion per year, based on crashes occurring 2015–2017 and using TxDOT's Highway Safety Improvement Program crash costs.

Using the method described in Appendix B, the study team was able to identify vehicles with defects that were involved in crashes in Texas. Table 3.1 provides the statistics for crashes involving vehicles with defects by crash severity type from 2015 to 2017.

Table 3.1 Number of crashes involving vehicles with defects

Crash Severity Type	2015		2016		2017	
	PV	CMV	PV	CMV	PV	CMV
Fatal	85	31	92	23	87	21
Incapacitating Injury	308	38	364	46	343	44
Non-Incapacitating Injury	1,167	111	1,294	127	1,402	146
Possible Injury	1,573	159	1,801	123	1,767	144
Not Injured	6,220	734	6,934	734	6,808	885
Unknown	177	4	199	3	213	7
Total	**9,530**	**1,077**	**10,684**	**1,056**	**10,620**	**1,247**

PV: passenger vehicles and other non-commercial vehicles. CMV: commercial motor vehicles

On average, about 88 fatal crashes, 338 incapacitating-injury crashes, and 1288 non-incapacitating-injury crashes happened in Texas each year that were caused or potentially caused by PV defects.

The following crash costs were used by TxDOT when developing highway safety improvement programs (TxDOT, 2018). According to the TxDOT Highway Safety Improvement Program Manual, the average cost of each type of crash is based on modifications to the comprehensive cost figures provided by the National Safety Council (NSC) (TxDOT, 2015). NSC's comprehensive crash costs include wage and productivity losses, medical expenses, administrative expenses, motor-vehicle damage, uninsured employer costs, and the value of lost quality of life associated with deaths and injuries.

- Fatal crash: $3,500,000 per crash (regardless of the number of fatalities)
- Incapacitating-injury crash: $3,500,000 per crash (regardless of the number of incapacitating injuries)
- Non-incapacitating-injury crash: $500,000 per crash (regardless of the number of non-incapacitating injuries)

Using these crash costs, the total costs of these crashes involving vehicles with defects were calculated and are shown in Table 3.2.

Table 3.2 Costs of crashes involving vehicles with defects using TxDOT crash costs

	2015	2016	2017
PV	$1.96 billion	$2.24 billion	$2.21 billion
CMV	$0.30 billion	$0.31 billion	$0.30 billion
Total	**$2.26 billion**	**$2.55 billion**	**$2.51 billion**

The NSC's crash economic calculations, which use different crash categories and costs, produce similar but higher overall total costs. These calculations can be found in Appendix C.

Regardless of the crash cost calculations used, the analysis shows that the crashes involving vehicles with defects can cause significant safety, economic, and societal impacts to the state.

Safety Impact Analysis Major Finding 2

The frequency of fatalities, incapacitating injuries, and non-incapacitating injuries is higher for crashes involving vehicles with defects. Defect-vehicle-related crashes are twice as likely to result in a fatality than crashes with vehicles that have no defects.

The study team compared vehicles with and without defects, and crashes involving vehicles with and without defects, with the goal of identifying whether significant differences exist.

Table 3.3 lists the number of fatalities per number of PVs in crashes. As the data shows, the number of fatalities per number of defective vehicles in crashes is about three times higher than that of vehicles without defects. In other words, if the same number of vehicles with and without defects are involved in crashes, the possibility of a fatality occurring is higher when vehicles have defects.

Table 3.3 Numbers of fatalities and crashes for PVs with and without defects

PV	2015		2016		2017	
	Defective	Non-defective	Defective	Non-defective	Defective	Non-defective
Number of fatalities	100	2,925	108	3,171	96	3,070
Number of vehicles in crashes	9,847	1,013,141	11,131	1,080,797	10,972	1,055,040
Fatalities per number of vehicles in crashes	**1 fatality / 98 vehicles**	**1 fatality / 346 vehicles**	**1 fatality / 102 vehicles**	**1 fatality / 341 vehicles**	**1 fatality / 114 vehicles**	**1 fatality / 343 vehicles**

The study team also compared the percentage of vehicles involved in fatal crashes among all vehicles, examining the categories of vehicles with or without defects. As shown in Figure 3.1, the 2015, 2016, and 2017 data all show that the percentage of fatal crashes among all crashes is higher for PVs with defects than PVs without defects. In other words, if we separate all vehicles involved in crashes each year in the CRIS database into two groups—one group with defects and another group without—the percentage of vehicles involved in fatal crashes is higher for the group of vehicles with defects.

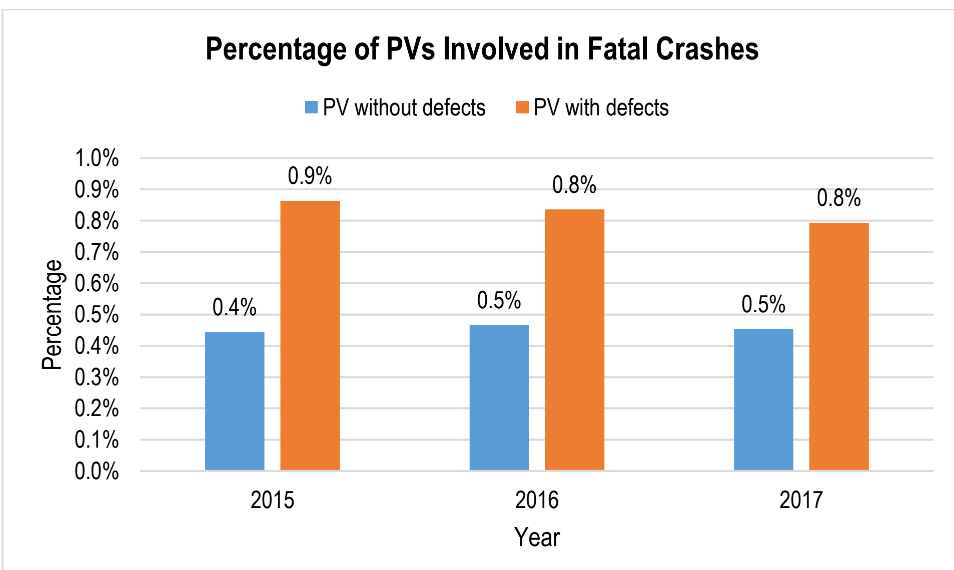


Figure 3.1. Percentage of PVs with or without defects involved in fatal crashes

Similar trends to those described in Table 3.4 and Figure 3.1 are observed with CMVs and both incapacitating and non-incapacitating injuries (see Appendix D for more details).

Safety Impact Analysis Major Finding 3
Defective or slick tires are the most prevalent type of defect related to fatal crashes. However, slick tires are not often detected by law enforcement officers during roadside stops, indicating the necessity of periodic professional inspections.

The study team analyzed the types of defects that law enforcement officers believe have or may have contributed to a crash, with the goal of identifying the major defect types and whether they are preventable by vehicle safety inspection.

Figures 3.2 and 3.3 show the analysis results for PVs and CMVs respectively[1]. The most frequently occurring type of defect for vehicles involved in all types of crashes (blue bars in Figure 3.2) are "Defective or Slick Tires" (33%) and "Defective or No Vehicle Brakes" (25%). In comparison, more than 70% of defective vehicles involved in fatal crashes (orange bars) have "Defective or Slick Tires." This finding indicates that problematic tires are a primary contributor to severe PV crashes related to vehicle defects.

"Defective or Slick Tires" (37%) and "Defective or No Vehicle Brakes" (18%) are also top defects for CMVs (blue bars in Figure 3.3). However, compared with the 70% of PVs, about only 30% of defective CMVs involved in fatal crashes have defective or slick tires (orange bars in Figure 3.3). More than 50% of them have other types of problems.

These defect type analyses indicate the importance of having well-functioning tires and brakes, especially for PVs. Checking these parts regularly is expected to help prevent some of these crashes, especially severe crashes.

[1] The defect type "Other (Explain In Narrative)" shown in these figures means the vehicle exhibited a type of defect that is rarer than the other types listed, such as these examples: lost tire, wheel/tire came off, mechanical failure (no specific reasons provided), vehicle malfunction (no specifics), possible brakes malfunction (cannot verify due to vehicle damage condition).

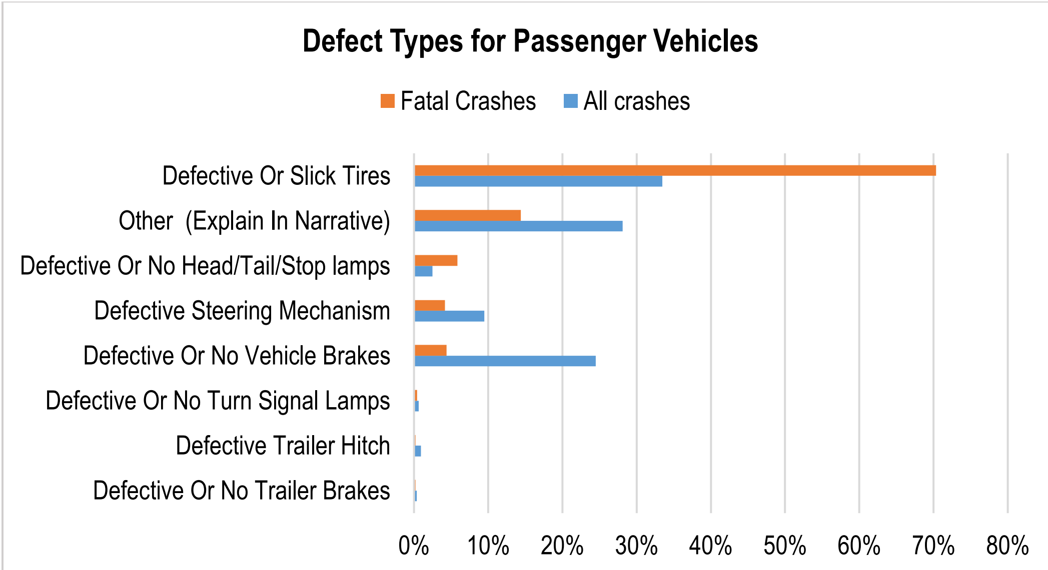


Figure 3.2. Types of defects for PVs

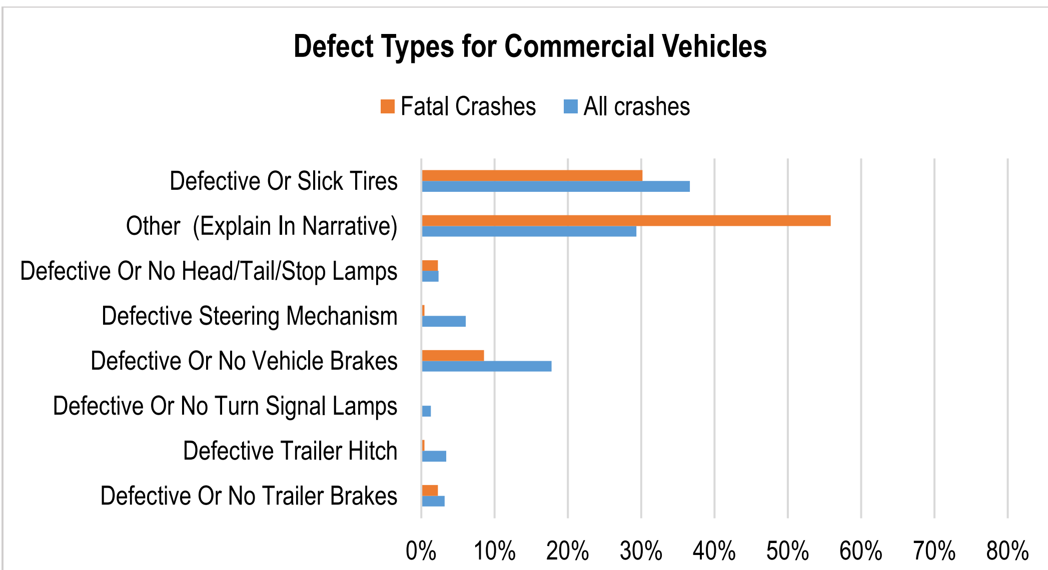
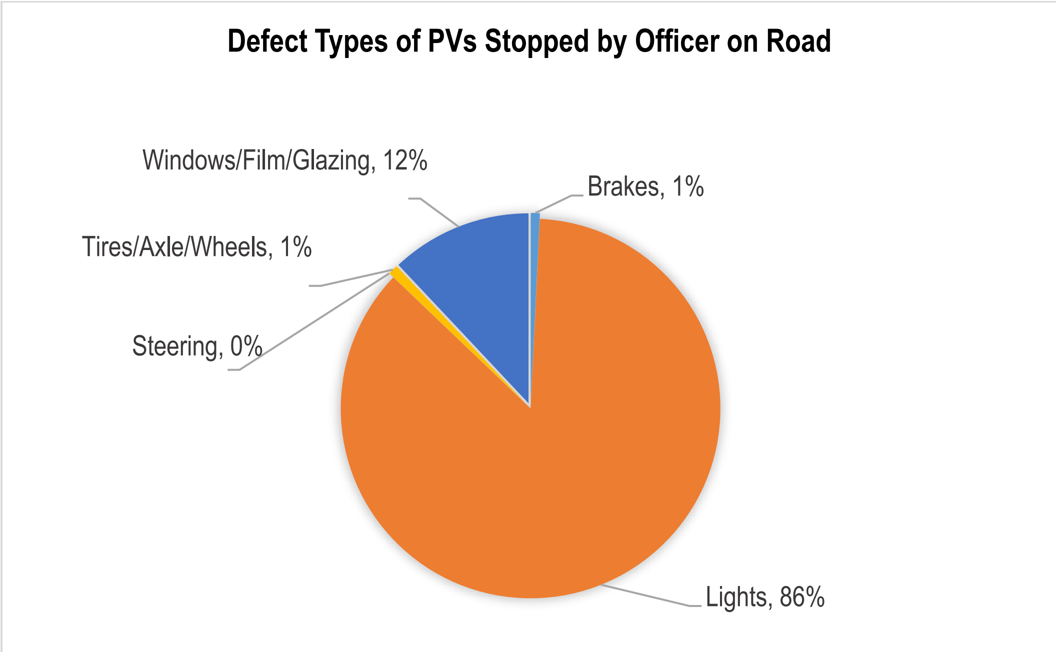


Figure 3.3. Types of defects for CMVs

The TxDPS citation data also stores information about the defect types of those defective vehicles stopped by law enforcement officers. The study team found that 53% of stopped CMVs and 10% of stopped PVs have one or more types of following defects:

- Brakes
- Lights
- Steering
- Tires/Axle/Wheels
- Windows/Film/Glazing

When comparing the defect types of PVs stopped by officers on the roadside to those of PVs involved in fatal crashes (see Figure 3.4), the study team found that even though less than 1% of vehicles stopped on the roadside have tire problems, almost 70% of those defective vehicles involved in fatal crashes have defective or slick tires. This difference shows that some types of vehicle defects are difficult to capture by law enforcement officers at roadside stops—yet these defects could cause severe crashes.



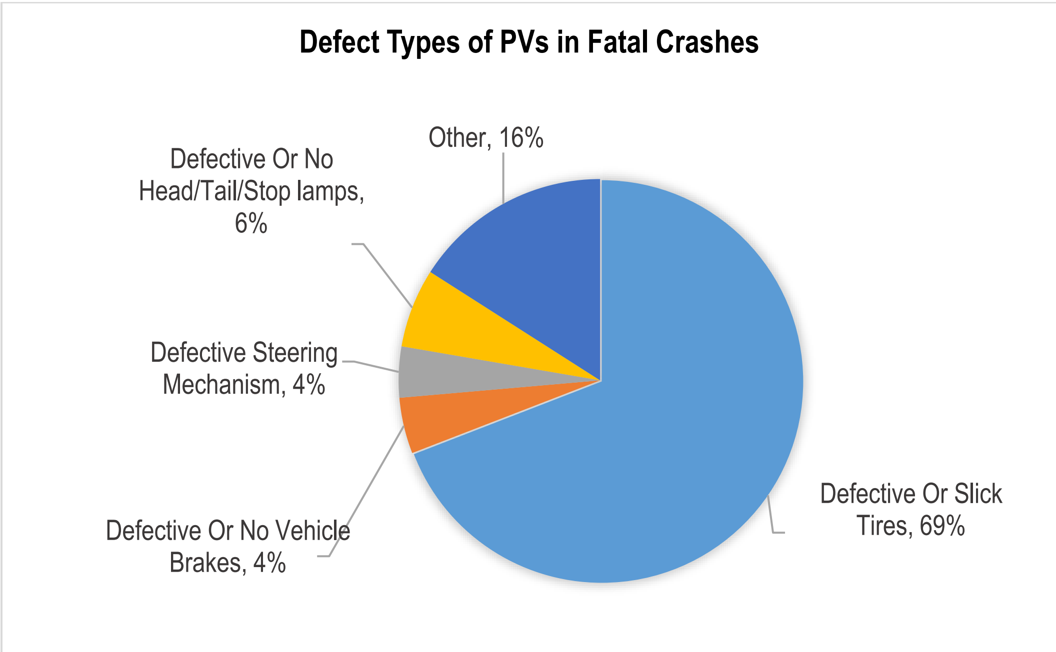


Figure 3.4. Defect types of PVs stopped on the roadside and PVs in fatal crashes

Safety Impact Analysis Major Finding 4

Regarding vehicles from other states that are involved in crashes in Texas, the percentage of vehicles with defects is lower for those states that have vehicle safety inspection requirements than states that do not. This indicates that a safety inspection program helps reduce the number of defective vehicles on the road.

For all crashes in Texas, the TxDOT crash database stores information about the U.S. state or other country in which the vehicles are registered (based on the license plates). The study team calculated the percentage of defective vehicles among all vehicles for all the U.S. states observed in the dataset. The average percentage from 2010 to 2017 for each state is used to compare states on the basis of whether they require PV safety inspections. Tables E.1 and E.2 in Appendix E list the number of all PVs and the subset of defective PVs that had crashes in Texas each year from 2010 to 2017, respectively for the home states that require and do not require vehicle safety inspections.

The average percentage of defective vehicles from states that do not require PV safety inspection is 0.83%; the percentage from states requiring PV safety inspection is 0.61%. On average, the states that do not require PV safety inspection have a higher percentage of defective vehicles. To test if this difference between these two groups of states is significant, the study team performed a t-test, which is a statistic test often used to test if the means of two samples are equal. The full statistical test results are shown in Appendix F.

The test results show that the P-value (0.01) is smaller than 0.05. This means we can conclude that, with 95% confidence, the percentage of defective vehicles from states with and without passenger safety inspection requirement is significantly different. The conclusion is that vehicle safety inspection programs reduce the number of defective vehicles.

Safety Impact Analysis Major Finding 5

The analysis of the relationship between crashes and speed limit shows that the percentage of crashes involving defective vehicles increases with higher speed limits—as does the severity of those crashes. Given that Texas has the highest speed limit in the nation and many high-speed roadways, it is important to consider the potential safety impact of eliminating the Inspection Program in Texas on highway safety, especially on roadways with high speed limits.

The study team examined the relationship between speed limit and number and severity of crashes, considering the high speed limits found in Texas.

As shown in Figure 3.5, the overall number of crashes per million vehicle miles traveled (VMT) does not increase much as the speed limit rises, once the speed limit is greater than 45 mph. However, the percentage of crashes with defective PVs increases dramatically with the increase in speed limit, especially when the speed limit is greater than 60 mph. This indicates that defective vehicles are more likely to have crashes on roadways with higher speed limits. This is

understandable. If a driver is operating a vehicle with defective brakes or tires, should an unexpected event requiring evasive maneuvers or braking occur while the vehicle is at a lower speed, the driver may still be able to react and take actions to avoid a crash. However, this would be much more difficult at a high speed.

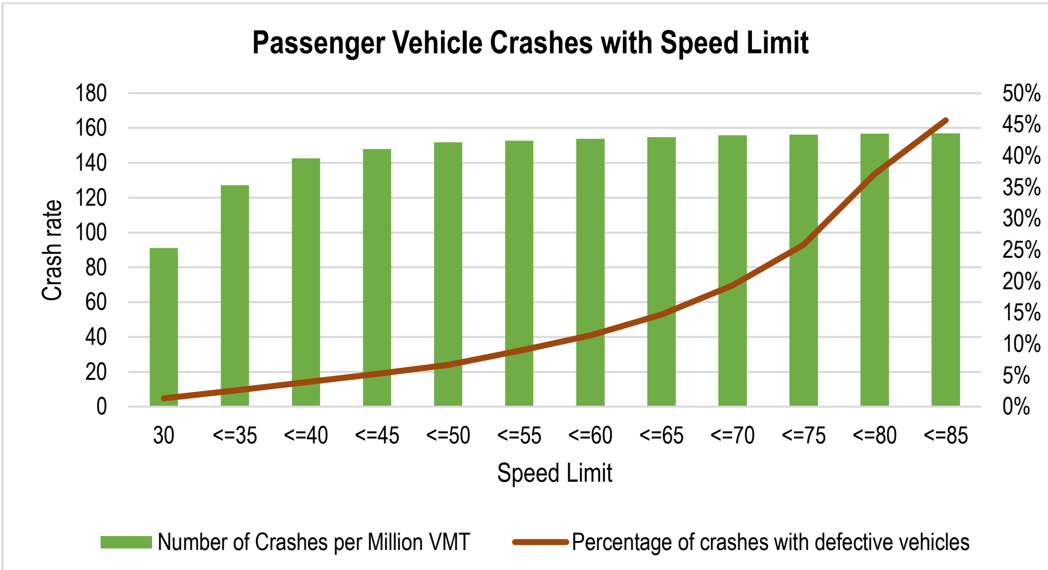
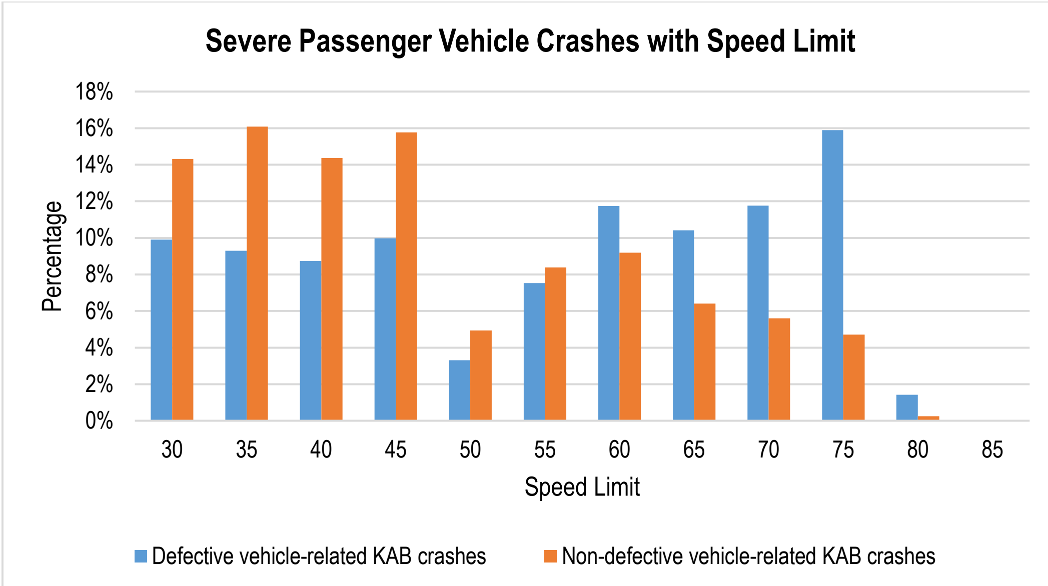


Figure 3.5. Relationship between PV crash rate and percentage of crashes involving defective PVs with speed limit

Not only do a higher percentage of defective-vehicle-related crashes happen on roadways with higher speed limits, the severity of crashes increases with speed limit as well. As shown in Figure 3.6, when the speed limit is lower than 60 mph, the percentage of severe crashes (i.e., fatal, incapacitating-injury, and non-incapacitating-injury crashes—often referred to with the term "KAB," in which K refers to fatalities, A to incapacitating crashes, and B to non-incapacitating crashes) among all crashes for non-defective vehicles is higher than that for defective vehicles. However, when the speed limit is equal to or higher than 60 mph, the percentage of severe crashes among all crashes for vehicles with defects is much higher than vehicles without defects.



(Note: KAB is a severity measure that represents fatalities [K], incapacitating-injury crashes [A], and non-incapacitating-injury crashes [B])

Figure 3.6. Relationship between PV KAB crashes with speed limit

Based on TxDOT Pavement Management Information System 2015 data provided by TxDOT, Texas has over 118,000 lane miles of roadways with speed limits equal to or higher than 60 mph and carrying over 340 million VMT per day. Texas is also the only state that has speed limits as high as 85 mph. Because Texas has such high speed limits and such an extensive network of those high-speed roadways, given the relationship between speed limit and defective PV crashes it is important to have a program help to reduce the number of defective vehicles on Texas roadways.

Safety Impact Analysis Major Finding 6

Vehicles with defects that were involved in crashes are three years older than the average registered vehicle, which is nine years old. The percentage of vehicles with defects that had crashes is higher for older vehicles. This highlights the importance of the Inspection Program's role in ensuring that the vital components (e.g., tires, brakes, etc.) of old vehicles are in good condition.

Based on information about vehicle model year obtained from vehicle registration data and from TxDOT's CRIS database, the study team calculated for 2015–2017 the average model year of all vehicles registered in Texas, all vehicles involved in crashes in Texas, and all defective vehicles involved in crashes in Texas. The results are shown in Table 3.4. The average age of PV with defects that had crashes are three years older than the average vehicle. This is as expected, since older cars tend to have more defects due to wear and tear.

Table 3.4 Average vehicle age (years)

	All vehicles	Vehicles in crashes	Defective vehicles in crashes
PV	9	8	12
CMV	9	8	11

The blue columns in Figure 3.7 represent the number of defective PVs involved in crashes in 2017 with different vehicle ages. The orange line shows the percentage of these vehicles among all vehicles registered in 2017 with the same vehicle age.

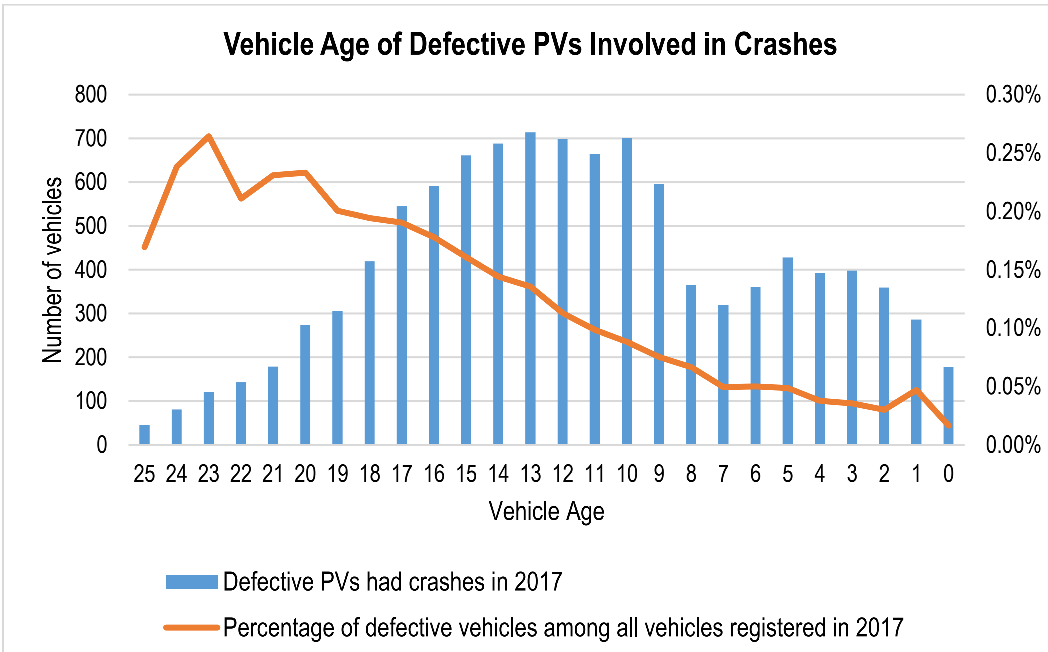


Figure 3.7. Vehicle age of defective vehicles involved in crashes in 2017

As shown in Figure 3.7, more vehicles between 10 to 15 years old had defects and were involved in crashes. This matches with the average age of vehicles with defects that were involved in crashes (12 years old) shown in Table 3.4.

The percentage of vehicles with defects that had crashes among all registered vehicles with the same age decreases as vehicles get younger, as demonstrated by the orange line in Figure 3.7. This shows that older vehicles are more likely to have both defects and crashes.

Safety Impact Assessment Major Finding 7

Younger drivers are disproportionately involved in defect vehicle crashes. The average age of drivers of defective vehicles that had crashes was 34, while the average driver involved in all crashes was 38, and the average licensed driver in Texas is 46.

Based on FHWA data, the average age of Texas-licensed drivers in 2016 was 46 years. (Please see Appendix D for data source and calculations.)

Considering the 2016 crash data, the study team found that the average driver age of all PVs involved in crashes was 38 and that the average driver of PVs with defects and crashes was 34. Drivers of defective PVs that have had crashes were 12 years younger than the average driver in Texas.

The 4–to-5-years age difference between drivers of PVs without defects and PVs with defects is also apparent when assessing separately the crashes with different severity types, as shown in Figure 3.9.

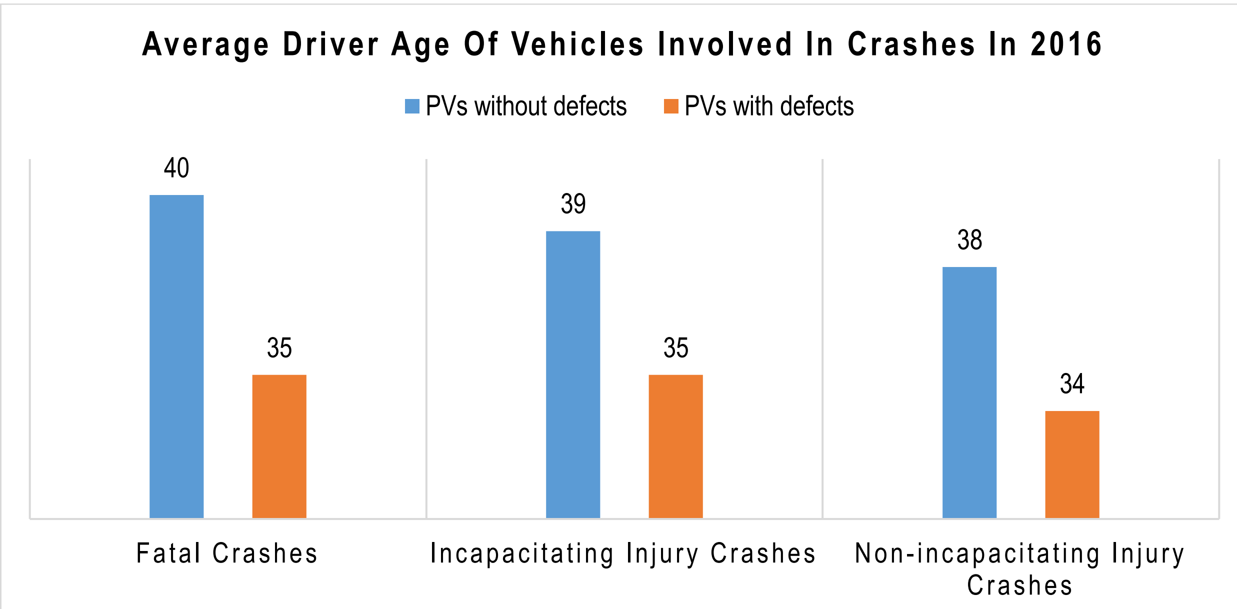


Figure 3.9. Average driver age of PVs involved in crashes with different severity levels in Texas in 2016

Figure 3.10 shows the percentage of PV drivers by age group who were involved in defect or non-defect vehicle crashes, using 2016 crash data. It is obvious that drivers of defect vehicles are more concentrated in those younger age groups. This is consistent with the previous statement that the average age of defective vehicle drivers is younger than that of non-defective vehicle drivers. We observe the same trend exhibited in Figure 3.10 if only fatal, incapacitating, and non-incapacitating crashes are considered.

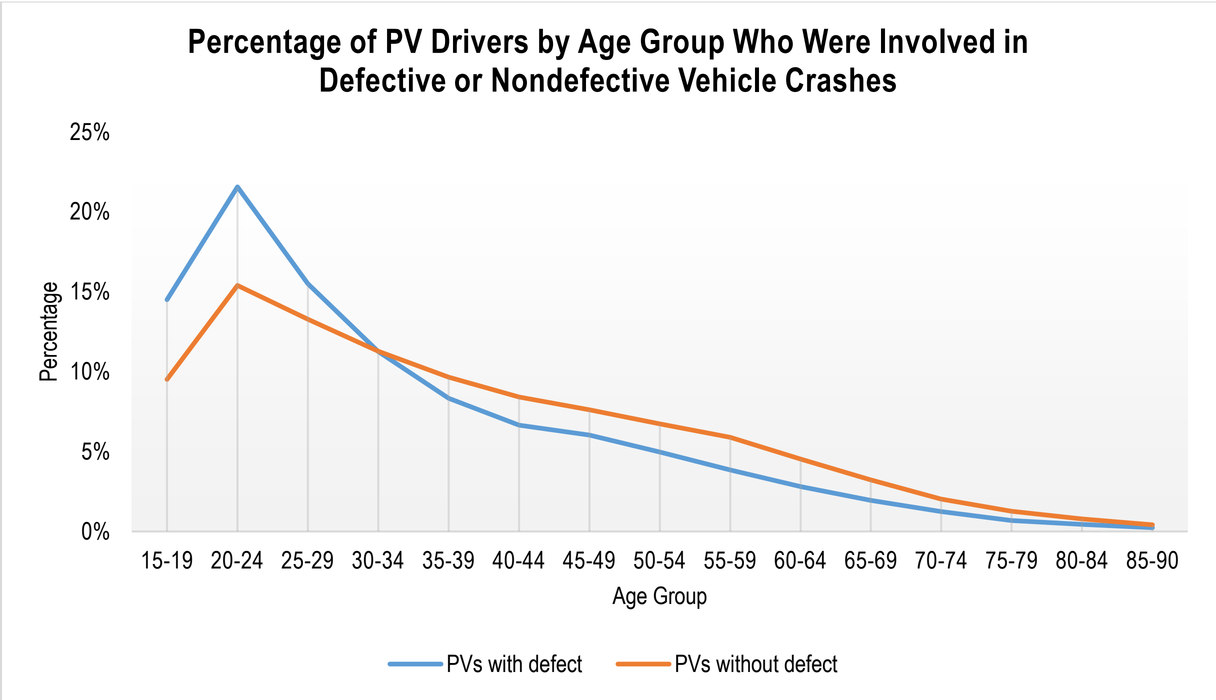


Figure 3.10. Percentage of defective PV drivers out of all drivers of PV involved in crashes in Texas in 2016

This analysis indicates that drivers younger than 30 are disproportionately involved in all vehicle crashes and especially defect vehicle crashes. While younger driver have less experience, defect vehicles add another element of risk, resulting in even more involvement in crashes.

As shown in Table 3.4, defective vehicles in crashes are three years older than the average Texas-registered vehicle. Looking at the 2016 crash data specifically, the PVs with defects involved in fatal, incapacitating, and non-incapacitating injury crashes are also three to four years older than those vehicles without defects, as shown in Figure 3.11.

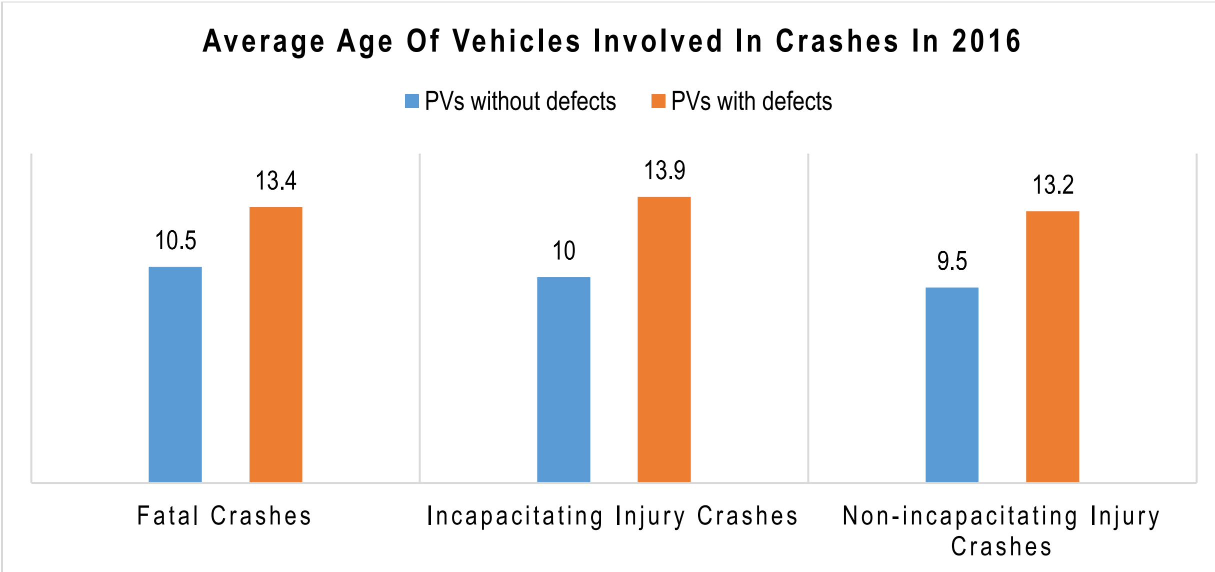


Figure 3.11. Average age of PVs involved in crashes in Texas in 2016

In addition, based on a study conducted by the National Highway Traffic Safety Administration (NHTSA, 2013), there is a higher risk of fatalities in older vehicles due to fewer safety features. Thus, eliminating the safety inspection program may increase the risk of injury or death for younger drivers and drivers of older vehicles with defects.

Chapter 4. Literature Review

This chapter synthesizes a comprehensive literature review, providing the current inspection program practices of Texas, other U.S. states, and some major countries around the world. The study team also reviewed extensive literature examining the involvement of vehicle defects in crashes and the effectiveness of inspection programs in terms of crash reduction.

4.1. Inspection Program Practices

In Texas, vehicle inspection consists of one or two components, depending on the location where the vehicle is registered. All vehicles are subject to the Inspection Program and are inspected annually for safety items. The potential second component is the emission inspection, which is required only for those vehicles in emissions counties (currently 17 counties) for gasoline-powered vehicles that are model age 2 to 24 years. Annual emissions inspections are mandated by the TCEQ, but both programs are managed by TxDPS.

For a regular PV, the following items will be inspected during the annual safety inspection: horn, windshield wipers, mirror, steering, seat belts, brake system (parking—beginning with 1960 models), tires, wheel assembly, exhaust system, exhaust emission system (beginning with 1968 models), beam indicator (beginning with 1948 models), tail lamps, stop lamps, license plate lamp, rear red reflectors, turn signal lamps (beginning with 1960 models), head lamps, gas caps on vehicles 2 to 24 model years old, window tint; and the motor, serial, or vehicle identification number. The costs of the Inspection Program are summarized in Chapter 2 and fully detailed in Appendix A.

The study team also investigated how other U.S. states and the District of Columbia perform vehicle inspection programs. Four states have only safety inspection programs. Eighteen states (including the District of Columbia) operate only emission inspection programs. Fourteen states maintain both safety inspection and emission inspection programs. The other 15 states do not have either a state inspection program or emission inspection program. In other words, a total of 18 states maintain a state safety inspection program and 32 states operate a state emission inspection program. Figure 4.1 presents vehicle inspection program types by state.

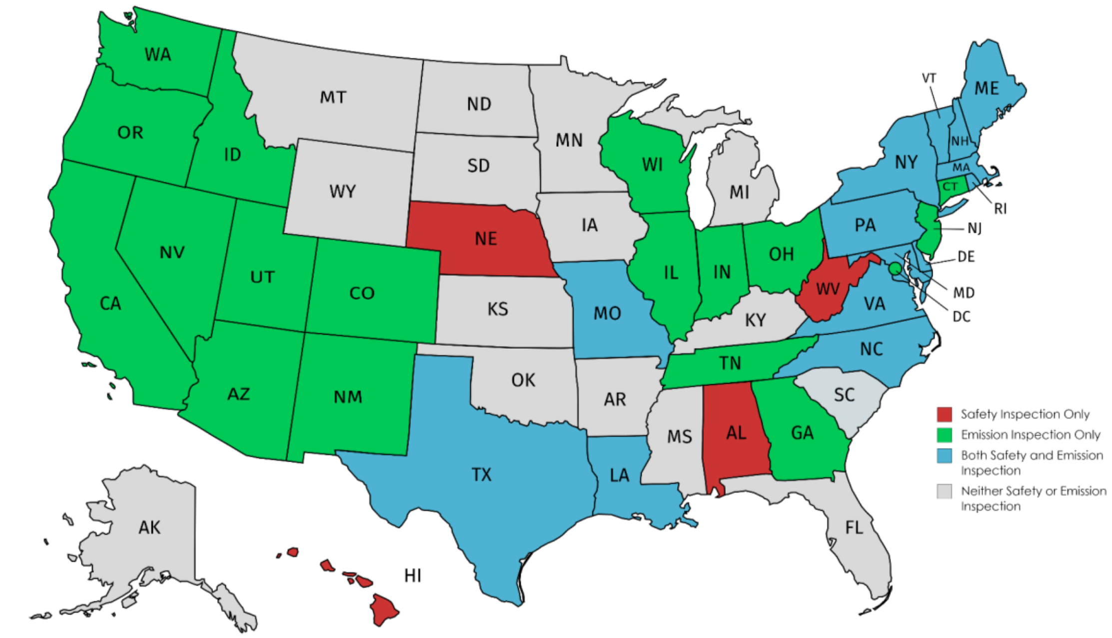


Figure 4.1. Vehicle inspection program types by state

More detailed information on vehicle inspection programs in other U.S. states is provided in Appendix G.1. In addition, the study team examined the vehicle inspection program practices in other major countries. Different vehicle components are checked and different tests are performed in order to evaluate a vehicle's risk for crash and contribution to emissions. More detailed information on vehicle inspection programs in other countries is provided in Appendix G.2.

4.2. Past Research on the Effectiveness of Inspection Programs

4.2.1. The Role of Vehicle Defects in Crashes

While design and manufacture of vehicle parts (such as brakes, tires, and steering) has improved over the years, the fact is that poor maintenance still causes crashes.

Researchers have conducted a series of studies investigating the contribution of vehicle defects to accidents and crashes. In general, researchers have found that vehicle defects directly contribute to under 10% of all accidents (Crain, 1980; White, 1988; Queensland Travelsafe Committee, 1990; Case at al., 1991; Asander, 1993; Youngman and Stolinski, 1994; Gardner, 1995). However, it is worthwhile to know that the statistics and findings may vary significantly in different countries and studies, depending on the data set and methodologies used. For example, braking, structural, and steering defects are identified as the most common defects in Sweden (Vaughan, 1993b), while tire defects are identified as the most common defects in Australia crash data, followed by braking defects (Case et al., 1991; Vaughan 1993a). This may be due to the fact that accidents may be caused by more than one factor, and it may be difficult to determine the true causes of crashes (Gardner, 1995). Table 4.1 summarizes the studies examining the contribution of defects to crashes (Rechnitzer et al., 2000).

Table 4.1. Summary of studies examining the contribution of defects to crashes

Authors	Findings	Implications
Treat (1977)	Of all crashes studied in-depth, 4.5% had defects that definitely played a significant role in causing the crash, and 12.6% had defects that probably played a contributory role in causing the crash.	Vehicle defects can contribute to causing crashes.
McLean et al. (1979)	Of the vehicles and crashes studied, 12 (17.6%) out of 68 crashed motorcycles were found to have defects. One (1.5%) was considered as definitely contributing to the crash. For PVs, 11 (2.8%) out of 386 cars were found to have defects. Three (0.8%) were considered as definitely contributing to the crash.	A small proportion of crashes are caused by vehicle defects.
Grandel (1985)	Vehicle defects may have contributed to 6.4% of PV crashes, and 5% of two-wheeled vehicle crashes.	Vehicle defects can contribute to causing crashes.
Rompe and Seul (1985)	In general, vehicle defects play a significant causal role in 3–24% of crashes—specifically, 1.3% in Japan. In general, vehicle defects play a contributory role in 4–19% (and possibly up to 33%) of crashes.	
RACQ (1990)	In general, vehicle defects have a significant causal role in 5% of crashes.	
Case et al. (1991)	Vehicle defects contribute to 5.8% of crashes. In addition, 0.6–1.8% of these defects may have been detected in an inspection.	
Asander (1993)	Finland: defects were direct causes or increased damage or injury in 23% of crashes Denmark: defect played a major causal role, were a contributing cause, or increased the consequences in 7–9% of crashes	
Vaughan (1993b)	Brake defects have been found to cause accidents.	Vehicle defects can cause crashes.
Gardner (1995)	In general, vehicle defects have a significant causal role in 2–10% crashes.	
Haworth et al. (1997a)	Mechanical faults contributed to 12% of crashes overall. Mechanical faults contributed to 28% of single-vehicle crashes, and 7% of multi-vehicle crashes.	Defects may cause crashes. Mechanical faults may result in more single-vehicle motorcycle crashes than multi-vehicle crashes.
Haworth et al. (1997b)	3% of crashes were caused by mechanical defects. 37% of crashed vehicles were un-roadworthy.	Defects may cause crashes in some cases.
James Fazzalaro (2007)	Vehicle defects are shown as contributing factors in only about 1% of reported accidents in Connecticut.	
Peck et al. (2015)	The Pennsylvania state safety inspection fail rate for light-duty vehicles is 12–18%, well above the often-cited rate of 2%.	
Manitoba Infrastructure (2018)	The Province of Manitoba, Canada, published the 2017 Commercial Vehicle Safety Alliance inspection report, in which the failure rate for the CMV inspection is given as 30.61% in 2017.	

Table 4.1 reveals that between 1.3% and 24% of crashed vehicles had a defect that played a significant causal role in the crash. According to studies that carried out in-depth inspection and crash investigations (McLean, 1979: Treat, 1977), defects play a significant causal role in 2.9% to 4.5% of car crashes. Table 4.1 also indicates that between 3% and 19% of crashed vehicles had a defect that played a contributory role in the crash. Comprehensive studies indicate that vehicle defects are a contributing factor in 6.5% to 12.6% of car crashes. For motorcycle crashes, it would appear that in 5% to 12% of crashes defects play a contributory role. The detailed review of each study is provided in Appendix G.3.1.

4.2.1.1. Under-Reporting of Defects in Crash Data

An important caveat in considering the research on this topic is that defects are often under-reported due to methodological and statistical shortcomings, as identifying and assessing defects in crashed vehicles is difficult. The expertise and level of investigation that officers on the scene can provide are also factors affecting the determination of defects and their contribution to crashes. When attempting to measure the effects of inspection programs on crash rates, researchers have encountered difficulties in isolating the effects of inspection programs from those effects resulting from other major safety-related programs, other changes in vehicle fleets, and differences between jurisdictions. These problems would suggest an under-reporting of the effects of defects on crashes.

During the investigation of an accident, police officers prepare initial crash reports. However, they do not have enough time, equipment, or qualifications to detect any but the most obvious defects. This then further reinforces the view that defects are not the leading contribution factors in accidents. According to the National Highway Traffic Safety Administration (NHTSA) (1989), Vaughan (1993b), and the Government Accountability Office (GAO) (2015), the contribution of vehicle defects in an accident is under-reported, which results in a lack of reliable crash data on the contribution of vehicle defects to crashes (Rechnitzer et al., 2000). Other reasons why defects may be under-reported is that defects that have caused an accident may be un-diagnosable (e.g., a vapor lock in the footbrake), unrecognized (e.g., drowsiness induced by carbon monoxide poisoning), not tested, or simply not reported (White, 1986b; Rechnitzer et al., 2000). Researchers have found that since crashes are very complicated and often caused by more than one factor, it is difficult for the police officers to identify all the causes (Asander, 1993; Vaughan, 1993a; Vaughan, 1993b; Gardner, 1995). Therefore, worn brakes or tires, for example, may not be recognized or reported if driver error or poor road conditions were involved. The study conducted by Vaughan (1993b) showed that although brakes out of adjustment are the most common serious problem found in the inspection of vehicles at inspection stations, they do not often appear in police reports.

The study team also reviewed literature on the effect of vehicle age in crashes. In general, they found that older vehicles are more likely to be involved in a crash. The corresponding discussion is provided in Appendix G.3.2.

4.2.2. Safety Effectiveness of Inspection Programs

Past studies on the safety impact of vehicle inspections have primarily comprised the following four aspects:

- Comparative studies between jurisdictions that do and do not have inspection programs.
- Before-and-after studies of jurisdictions that have introduced inspection programs.
- Studies comparing the crash rates of vehicles that undergo inspection programs with those vehicles that do not, within the same jurisdiction, and
- Analyses of accident rates of inspected vehicles between periodic inspections.

It is difficult to conduct analyses of the safety effects of periodic vehicle inspection programs as safety effects are likely to be small and compounding factors complicate the interpretation of any safety effects inferred. In conducting the literature review, the study team found significant variation in study findings regarding the role of vehicle defects in crash causation and the effectiveness of inspection programs in reducing defects and crashes. In addition, the effect of inspection programs on accident rates as assessed by the studies varied a great deal, ranging from no effect to an accident reduction rate of up to 16%. Table 4.2 summarizes the studies examining the effectiveness of inspection programs.

Table 4.2. Summary of studies examining the effectiveness of inspection programs

Authors	Findings	Implications on Effectiveness of Inspection Programs
Fuchs and Leveson (1967)	Inspection program is negatively related to mortality, but the net effect of inspection is very small and does not generally differ from zero at high levels of statistical significance.	Inspection program was found to have significant negative effect on accident death rates when the inspection variable was the only independent variable. When more regressors were added to the model, the efficacy of inspection program in reducing mortality rates was not statistically significant.
Little (1971)	Some test states experienced an increase (5%) in death rates following the introduction of inspection program, and some experienced a decrease in death rates over the same period of time. There was no statistical difference in crash rates between inspecting and non-inspecting control groups over time. There was no statistically significant difference in the increase in death rates between test states and the nation as a whole.	Unable to prove inspection program is effective. There was no statistical difference in crash rates between inspecting and non-inspecting control groups over time.
Schroer and Peyton (1979)	Inspected cars had 9.1% fewer accidents than uninspected cars for the first year after inspection. Those who returned for inspections at periodic intervals experienced 21% fewer accidents than those who had never had an inspection. There is a 5.3% reduction in accident rate for inspected vehicles compared to their accident rates before inspection. Those that did not return approached the same accident rate as those who had never been inspected.	Inspection program is effective in reducing accidents. The probability of having an accident decreases immediately after an inspection, then increases until the next inspection.
Crain (1980)	No statistically significant differences in fatality rates between states with periodic motor vehicle inspection and states without it. There was a non-significant tendency toward higher fatality rates in states with periodic motor vehicle inspection. States with random inspections experienced the lowest accident rates.	Unable to prove inspection program is effective in reducing fatality rates. There are no statistically significant differences in fatality rates between states with periodic motor vehicle inspection and states without it.
Loeb and Gilad (1984)	Inspection program reduces fatality rates and accident rates, but not injury rates.	Inspection program is found to be effective in reducing fatality rates and accident rates, but not effective in reducing injury rates.
Berg et al. (1984)	The number of cars in police-reported accidents and the number of injury accidents decreases after the introduction of inspection program.	The inspection program is found to be associated with a decrease in accident and injury rates.

Authors	Findings	Implications on Effectiveness of Inspection Programs
Rompe and Seul (1985)	Inspection program could reduce the number of accidents caused by vehicle defects by about 50%. Inspection program might also affect and reduce the crashes by improving the drivers' knowledge and understanding of the need for regular maintenance, safety issues, and the condition of their own cars.	Inspection program is effective in reducing accidents caused by vehicle defects.
White (1986a)	The probability of having an accident is lowest immediately following an inspection, and then increased by 10–15% over the next six months until a peak one week before the next inspection.	The probability of having an accident decreases immediately after an inspection, then increases until the next inspection.
NHTSA (1989)	Overall crash rate was higher in states without inspection program. Vehicles with defects reported as the contributing cause to the accident were 0.25-2.5% higher in states without inspection program. Vehicles are 2.5% more likely to have tire failure in states without inspection program. No difference in fatality rates between states with and without inspection program.	Inspection program is found to be effective in reducing accident rate, but researchers were unable to find that inspection program is effective in reducing fatality rate. Inspection programs are associated with a decrease in the incidence of defects in the vehicle fleet. Factors other than inspection program may affect the accident rates.
Asander (1993)	After the introduction of inspection program to Sweden, there were fewer defects in the vehicle fleet (7–8% cars with serious defects were replaced), and a 16% decrease in accidents with personal injury.	Inspection program is found to be effective in reducing accidents with personal injury. Inspection program is associated with a decrease in the number of defects in the vehicle fleet.
Fosser (1992)	A study in Norway indicates that there was no difference in the crash rate between cars that undergo inspection program and those that do not. It needs to be pointed out that Norway conducts a significant level of random roadside inspections in addition to the periodically required testing.	Unable to prove inspection program is effective in reducing crash rates.
Holdstock et al. (1994)	Regression analysis using 1990–1991 data for 50 states, District of Columbia, and 10 Canadian provinces. Unable to establish a statistically significant effect of vehicle inspection program on fatality rates or injury rates.	Unable to prove inspection program is effective in reducing fatality rates or injury rates.
Merrell et al. (1999)	Fixed-effect regression analysis using 1981–1993 panel data of 50 states. Unable to establish a statistically significant effect of vehicle inspection program on fatalities or injury rates.	Unable to prove inspection program is effective in reducing fatality rates or injury rates.
Poitras and Sutter (2002)	Inspection has no significant impact on old cars or repair industry revenue, which implies that inspection does not improve the mechanical condition of vehicles.	Unable to prove inspection program is effective in old cars or repair industry revenue. The study makes a distinction between policy ineffectiveness and Peltzman-type offsetting behavior as sources of inspection failure.

Authors	Findings	Implications on Effectiveness of Inspection Programs
Sutter and Poitras (2002)	Regression analysis using 1981–1993 panel data of 50 states. Unable to establish a statistically significant effect of vehicle inspection program on fatality rates or injury rates.	Unable to prove inspection program is effective in reducing fatality rates or injury rates.
Christensen and Elvik (2007)	Inspections strongly improved the technical condition of inspected vehicles, but did not have a statistically significant effect on crash rates.	Unable to prove inspection program is effective in reducing crash rates. However, inspection programs strongly improved the technical condition of inspected vehicles.
Vlahos et al. (2009)	States with vehicle safety inspection programs have significantly fewer fatal crashes than states without programs. Pennsylvania can be expected to have between 115 and 169 fewer fatal crashes each year, corresponding to between 127 and 187 fewer fatalities each year, than it would if it did not have a vehicle safety inspection program. The benefits of the program as derived from all three models exceed the user costs of the program.	Inspection program is found to be effective in improving highway safety and saving lives.
Keall and Newstead (2013)	Going from annual to biannual inspections may reduce likelihood of crashes (8%) and the prevalence of vehicle defects (13.5%). The wide confidence interval for the drop in crash rate (0.4–15%) indicated considerable statistical uncertainty.	Inspection program is found to be effective in reducing crash rate and vehicle defects.
GAO (2015)	Pennsylvania state data show that in 2014, about 20% of vehicles in the state failed inspection and then underwent repairs to pass, well above the often-cited 2%. New Jersey and Oklahoma: A before-and-after analysis indicates that crashes involving vehicle component failure were generally between 2 and 3% of all crashes and varied little after the elimination of safety inspection program. Crash rate did not significantly change for either state.	The analysis does not provide sufficient evidence to conclude that inspection programs did not have an effect on crash rates because additional factors—such as implementation or increased enforcement of traffic safety laws—could influence crash rates.
Peck et al. (2015)	The state safety inspection fail rate for light-duty vehicles is 12–18%, well above the often-cited rate of 2%. Vehicles more than three years old or with more than about 30,000 miles can have much higher rates. The importance of vehicle maintenance over a vehicle's lifetime is proven to be evident.	Inspection program is found to be effective in improving highway safety. Vehicle safety inspections should continue to be implemented in order to keep driving conditions safe.

As Table 4.2 indicates, past literature presents significant variation regarding the effectiveness of inspection programs, which is potentially due to the methodological and statistical shortcomings evident in many of the studies. This is noted by reviewers as well as authors of individual papers about their own studies. Another reason for the variation in the results may be due to other factors that affect the various jurisdictions studied, such as differing levels of other traffic safety measures or different driving environments. These may not have been accounted for in the analyses of the various studies.

The detailed review of each study is provided in Appendix G.3.3.

4.3. Chapter Summary

This chapter summarized the study team's comprehensive literature review of current inspection program practices in Texas, other U.S. states, and other major countries. The extensive review of past studies regarding vehicle defects and effectiveness of inspection programs serves as a solid foundation for this project. Following are some findings from the literature review:

- Crashes are often caused by many factors. The most common vehicle defects that contribute to crashes are braking, tire, and steering defects.
- Vehicle defects are under-reported as the contributing factors in many cases.
- An inspection program improves the condition of vehicles on the road.
- An inspection program increases drivers' understanding of the need for regular maintenance, safety issues, and the condition of their own cars.
- The safety benefits of inspection programs are difficult to establish because of the limited amount of information available concerning the role that component failures play in highway crashes.
- In the relevant body of literature, the various studies' conclusions differ significantly depending on the assumptions made, methodologies applied, and the available datasets used.

Chapter 5. Public Outreach

This study employed various public outreach methods to inform the research efforts:

- Stakeholder interviews
- Workshop with stakeholders
- Survey of Texas vehicle owners
- Survey of inspection station operators

5.1. Stakeholder Interviews

The purpose of the both the interviews and the workshop was to provide a forum to discuss the potential safety impacts and costs associated with eliminating the Inspection Program. The interviews and workshop aimed to identify issues critical to conducting this study and accomplish the following main objectives:

- Present a preliminary list of issues considered important in identifying the impacts of eliminating the Inspection Program.
- Identify additional factors and data sources for evaluating the Inspection Program's safety and cost impacts.

Other objectives that guided the framework for the subsequent data collection and analysis process include identification of other state agencies that will be affected if the Inspection Program is eliminated as well as potential changes to employees staffing levels, inspection fee allocation, and state revenue.

5.1.1. Stakeholder Interview Findings

To obtain more insight into the Inspection Program, the CTR team interviewed nine stakeholders who are experienced industry professionals, including inspectors, car dealers, and inspection station owners. Their experiences, which provided valuable context for this study, are summarized in Appendix H.

The general consensus from the stakeholder interviews is that Texas needs and should retain the Inspection Program. Various stakeholders made several informed suggestions with respect to potential program improvements. Following are key takeaways from the stakeholder interviews.

5.1.1.1. Stakeholder-Identified Issues

- *The inspection process has changed over time, meaning certain important inspection items have been removed*. For example, headlight alignment is no longer conducted, but some station operators believe this inspection step is still needed.

- *Station operators view the Two Steps, One Sticker process as much easier to manage compared to the previous program*. However, there are some disadvantages to having one sticker. In the past, a law enforcement officer could remove the inspection sticker from a crashed vehicle to ensure it was re-inspected after repairs. Now, officers cannot remove an inspection sticker to enforce post-crash safety inspections.
- *Vehicle recall data is a critical piece of information to provide to the motorist during an inspection*. Emission-county inspection equipment can provide vehicle recall data on the final inspection report, but safety-only equipment cannot provide vehicle recall data. The Takata "Alpha" airbag recall, the biggest in history, is attempting to remedy defective airbags that have a 50% chance of causing death or serious injury if activated. Yet, only 65% of vehicle owners perform recall repairs in general, even though repairs are free of charge. Studies in other states have shown up to a 400% increase in recall completion rates by printing recall data on inspection reports (see Appendix I for more detail).
- *The $7 safety inspection fee is likely inadequate for the time and resources an inspection station allocates to an inspection.*

5.1.1.2. Additional Factors Identified by Stakeholders

- *The systemically captured percentage at which vehicles fail a safety inspection the first time through does not represent reality*. Inspection station operators recognize that some vehicles are inspected and repaired without documenting the fact that the vehicle failed inspection the first time. This is partially due to high inspection volume rates near the end and the beginning of the month and the fact that documenting the failure–repair–pass process is time-consuming.
- *DPS conducts both routine audits of station operations and audits using 'decoy' drivers and vehicles that have a defect*. Inspectors and/or inspection stations can receive a citation for non-compliance if the inspector does not discover the defect during a routine inspection. This is an additional cost impact to consider in the efficiency evaluation.
- *Emission counties have different inspection equipment compared with safety-only counties*. Emission-county station operators purchase inspection equipment whereas DIR provides the safety-only equipment at no cost.
- *Some inspectors are concerned about battery leakage that could affect the driver or passenger's safety.* Some car manufacturers have moved the battery to the rear of the vehicle underneath the backseat or in the trunk, but within the passenger compartment space. This item is not currently inspected.

5.2. Workshop

The June 2018 workshop had two major components: the morning plenary session and the after-lunch breakout sessions. The morning plenary session featured presentations from the CTR team on the scope and preliminary findings of this study. The afternoon session was the more interactive

portion of the study in which breakout groups discussed various facets of the Inspection Program. Appendix I contains the workshop agenda, plenary session summary, a listing of the questions provided to the breakout groups, and a summary of participants' responses to those questions. Note that the workshop presentations are available upon request from CTR.

5.2.1. Workshop Findings

This section comprehensively reviews the feedback provided during the workshop, which helped identify factors to consider when assessing the impact of the Inspection Program practices in Texas. Following are some notable findings from the workshop.

5.2.1.1. Workshop-Identified Issues

- *Incorporating vehicle recall information into the inspection report has a potential economic and safety benefit for Texas.* Adding recall information to safety inspection reports could create an estimated $242 million of potential Texas revenue inflow at present. Furthermore, incorporating recall information into the vehicle inspection report can add additional value to the Inspection Program by further enhancing safety for all road users.
- *Ride-hailing and ride-sharing vehicles can receive even greater benefits from the Inspection Program.* Ride-hailing and ride-sharing vehicles accumulate many more miles per year and deteriorate at a faster rate than the average privately owned vehicles. At present, these vehicles are inspected under the Inspection Program and do not have a separate inspection. Since these vehicles are more prone to faster rates of wear and tear, they likely benefit to a greater extent from the Inspection Program.
- *Some people may perceive that safety inspectors do not take their job seriously; however, inspectors understand that their job results in saving lives.* Some supporters of the elimination of motor vehicle inspections for passenger vehicles believe that safety inspectors do not take their job seriously, rendering the program ineffective. However, according to the Co-Chair of the Texas State Inspection Association, many companies (such as large tire companies, for example) routinely hold well-attended seminars to emphasize the importance of proper inspection of wear-and-tear items. These seminars are very effective in encouraging inspectors to take pride in their work and re-emphasizing the life-and-death stakes involved. Inspectors know that the outcome of their efforts is saving lives on the road.
- *Increasing the scope of the vehicle safety inspection program such that an inspection becomes too complex could result in false failures from over-testing.* As the complexity of the inspection test increases, the probability that a false failure (an item flagged as defective when in fact it is not) also increases. Additionally, adding more items to the safety inspection process would most likely warrant an inspection fee increase. Survey responses to date have shown that the majority of vehicle owners believe the fee is currently "about right," cautioning against increasing the scope too much.

- *Stakeholders unanimously agreed that Texas needs an Inspection Program and will continue to need one for the foreseeable future*. Stakeholders agreed that neither recent vehicle advancements nor advancements in the next 20 years will eliminate the need to check the wear-and-tear items that are checked during a safety inspection.

5.2.1.2. Additional Factors Identified in the Workshop

- *Annual, first-time failure rate is a tough statistic to mine from existing records, but a first-time failure rate obtained from both vehicle owner and station operator survey responses could overcome this difficulty*. Upon requesting a car inspection, customers are sometimes advised to first fix a failing component as a courtesy and a display of customer service. A number of these interactions are never recorded as failed inspections, making the recorded first-time failure rate lower than the true first-time failure rate. Survey responses about experiential first-time failure rates over time obtained from both motor vehicle operators and inspection station owners could provide a statistically significant estimate of the true first-time failure rate.
- *Eliminating the Inspection Program also eliminates the opportunity to implement future enhancements*. Having vehicle safety inspections for PVs provides an opportunity to increase the scope of the safety inspections in the future, enhancing the benefits of the program.
- *Stakeholders unanimously agreed that the risk for fatality crashes will increase if the Inspection Program is eliminated.* Vehicles with defects have a higher risk of being involved in a crash, including fatality crashes. Additionally, the severity of a crash increases as speed limits increase. Ceasing the program increases the likelihood that more vehicles with defects will be present on Texas roads. Given that Texas has some of the highest posted speeds in the nation, this development would further augment the risk for fatality crashes.

5.3. Analysis of Vehicle Owner Survey

The CTR team conducted an anonymous online survey of vehicle owners using various methods described in Appendix J. A total of 5,937 completed surveys were received from 234 of 254 counties in Texas[2]. This section focuses on only 2 of the 15 questions; Appendix J provides extensive analysis of all survey questions and responses.

It should be noted that these responses do not represent the vehicle owners' experiences or opinions based on just one annual safety inspection. The survey was designed to obtain responses about the safety inspections over the period of time that a survey respondent had their vehicle inspected in

[2] The study team's analysis, submitted to TxDPS on August 31, 2018, was based on 5,937 100% completed vehicle owner surveys. However, to obtain additional data the team continued to invite the public to take the survey from September to November, obtaining an additional 3,366 100% completed surveys (bringing the total number collected to 9,303). These were used to further validate the analysis results and models. Note that the study conclusions, models, and analyses results did not change when the new survey responses were incorporated.

Texas. Thus, these responses do not represent a single year, but the combined experience of 5,937 men and women who have had vehicles inspected over a period from 1 to 40 years. Thus, the survey information provides a programmatic assessment of the Inspection Program.

Figure 5.1 shows the survey responses to this question: “Do you think that safety inspections benefit highway safety in Texas?” The survey responses are subdivided for each response category regarding whether the motorist indicated they had never needed parts or repairs (never failed an inspection) during the entire time they have had vehicle inspections in Texas and those who have needed parts or repairs (have failed a safety inspection at least one time).

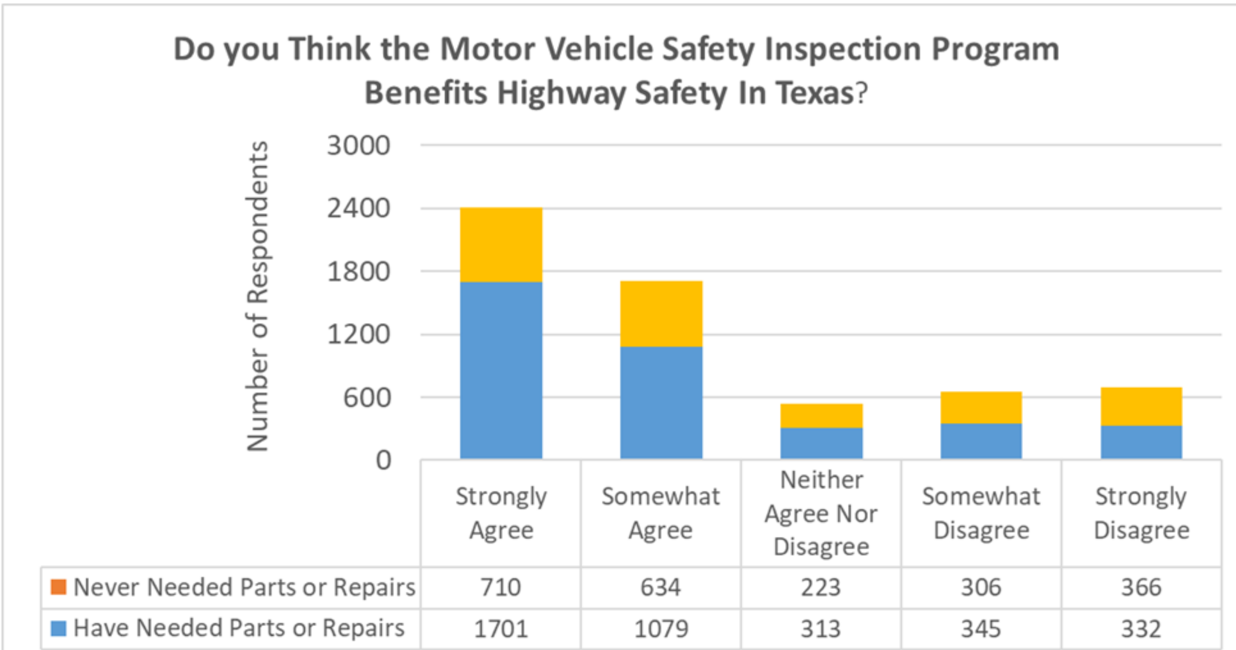


Figure 5.1. Vehicle owner responses: Do you think safety inspections benefit highway safety in Texas?

Approximately 68.3% of survey respondents either ‘Strongly’ or ‘Somewhat Agree’ that safety inspections benefit highway safety, while 22.4% either ‘Strongly’ or ‘Somewhat Disagree’ that safety inspections benefit highway safety. It should be noted that 44% of respondents who ‘Strongly’ or ‘Somewhat Agree’ have never needed parts or repairs, whereas 67% of respondents who ‘Strongly’ or ‘Somewhat Disagree’ have never needed parts or repairs.

Figure 5.2 shows the number of responses to the question of whether vehicle owners think that a safety inspection is a service or not, to which 80% responded that they perceive a safety inspection as a service.

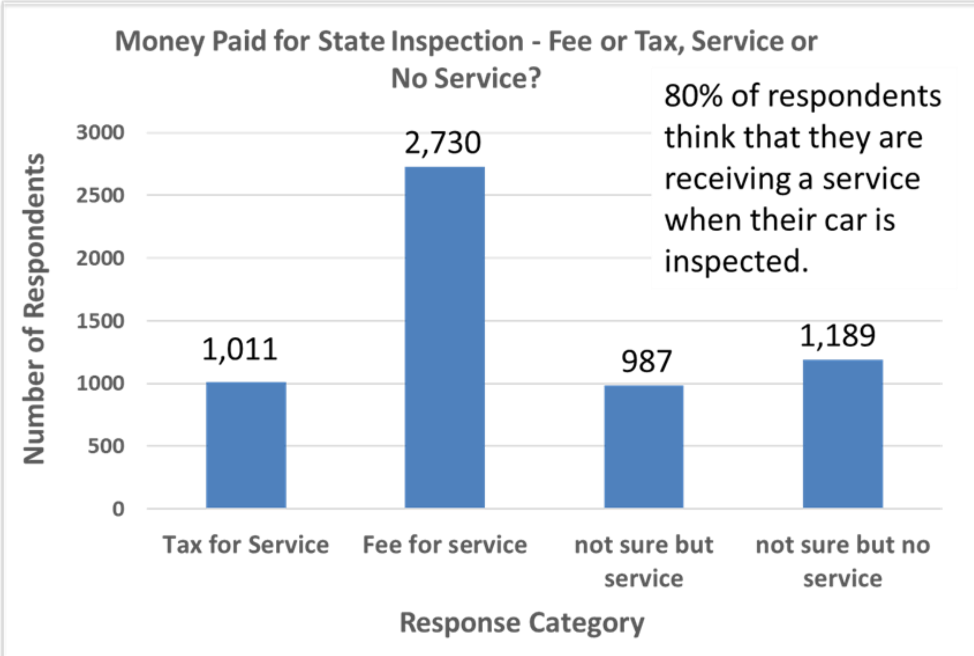


Figure 5.2. Vehicle owner responses: Do you think the safety inspection program provides you with a service or not?

Following are some key conclusions obtained by examining the full set of responses (which are provided in Appendix J).

- Approximately 25% of vehicle owners who reported they had never needed parts or repairs to pass a safety inspection also indicated that the inspection station operator had noticed one or more defects before the inspection started and told them to have the defects repaired, then come back for the inspection. Thus, based on these survey results, first-time failures are under-reported by approximately 25% during the time span represented by this group of survey respondents.
- A majority (68.7%) of survey respondents think that safety inspections benefit highway safety in Texas.
- Approximately 80% of survey respondents think that the Inspection Program provides a service.
- Approximately 88.7% of survey respondents think that vehicle defects such as defective or slick tires, bad brakes, or defective steering mechanisms can contribute to crashes.
- Though some vehicle owners repair maintenance problems as they occur, approximately 45.6% of survey respondents think that they better maintain their vehicle because they know it will eventually need to pass a safety inspection. Some motorists make repairs just prior to the safety inspection while others use the safety inspection as their maintenance program.

5.4. Analysis of Inspection Station Survey

The CTR team conducted an anonymous online survey of inspection station owners through email distribution to over 6,500 stations. A total of 1,582 completed surveys were received from 183 of the 254 Texas counties. Of the 1,582 completed surveys, 757 were from the 17 emissions counties and 805 were from safety-only counties. This section focuses on responses to only two of the survey questions; Appendix K provides extensive analysis of all survey responses.

It should be noted that these responses do not represent the station operator's experience or opinions based on just one year of conducting safety inspections. The survey was designed to obtain responses about safety inspections over the period of time that a survey respondent had performed safety inspections at their station in Texas. Thus, these responses do not represent a single year, but the combined experience of 1,582 station operators who have been performing safety inspections anywhere from 1 to 30 or more years. Thus, the survey information provides a programmatic assessment of the Inspection Program from the inspectors' perspective.

Figure 5.3 shows the survey responses to this question: "How will your business be impacted if safety inspections in Texas are eliminated?"

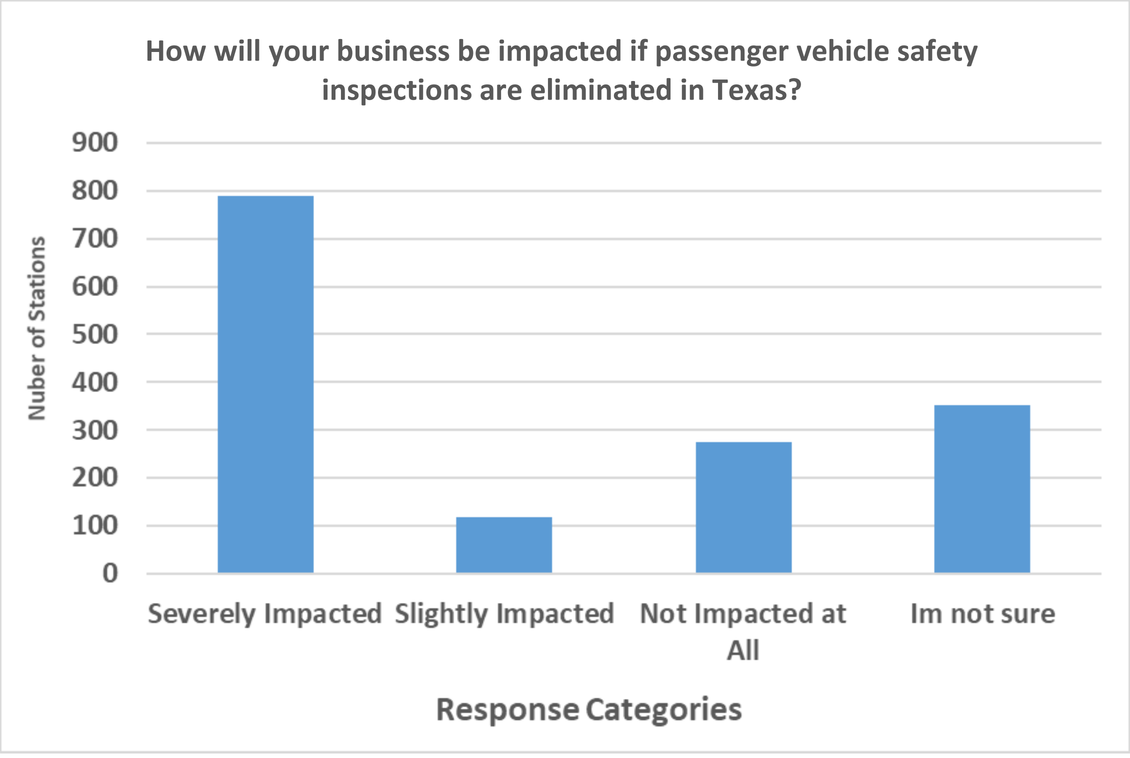


Figure 5.3. Inspector responses: Do you think safety inspections benefit highway safety in Texas?

Approximately 50.5% (790) of station operators surveyed indicated that their business would be severely impacted; 7.8% (119) would be slightly impacted; 17.9% (274) would not be impacted at all; and 22.9% (351) were unsure how their business would be impacted.

Figure 5.4 shows responses to this question: "Do you think the Vehicle Safety Inspection Program improves highway safety in Texas?" Approximately 82.5% of survey respondents indicated 'Definitely' or 'Probably Yes', 7.8% indicated that safety inspections 'Might or Might Not Improve Highway Safety', and 9.6% of stations indicated 'Probably' or 'Definitely Not'.

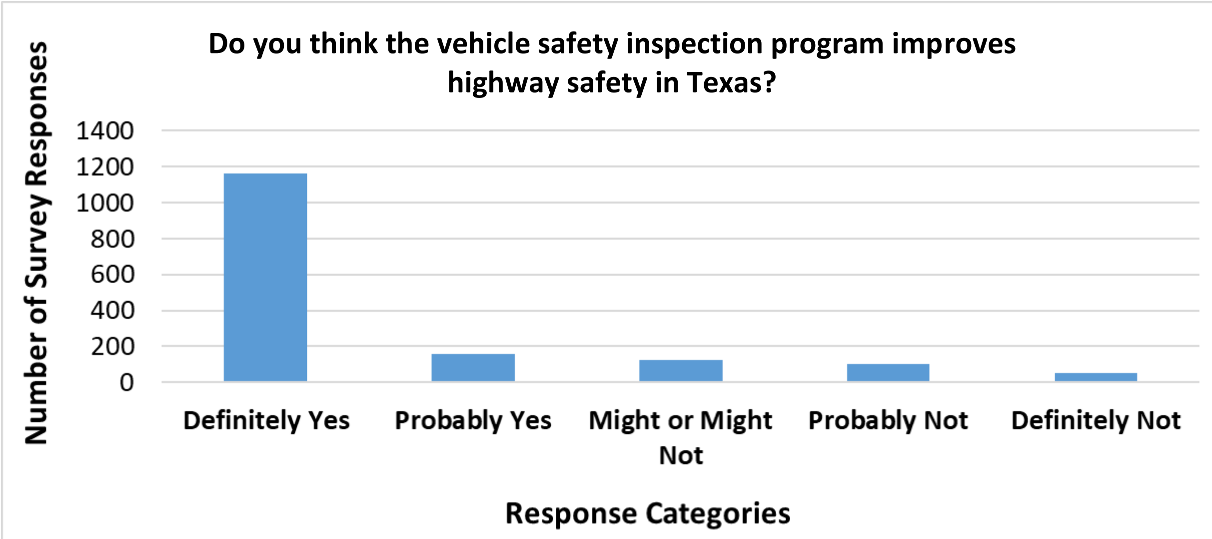


Figure 5.4. Inspector responses: Do vehicle inspections benefit highway safety in Texas?

The majority of inspection station operators think that safety inspections do benefit highway safety. Further, these station operators pointed out that low-income individuals or families may not be able to perform maintenance of their vehicles as needed. In other cases, elderly drivers may not be aware of maintenance issues and appreciate having a safety inspection to ensure that defects are addressed and their vehicles are in compliance.

An extremely important point that should be emphasized is that safety inspections not only benefit the vehicle owner, but also benefit all other drivers on the road. Crashes involving vehicles with defects often occur with another vehicle that does not have defects. In some cases, fatalities or serious injuries resulting from the crash occur in the vehicle without defects. Thus, everyone benefits when all vehicles on the road are in compliance with safety inspection requirements.

Of every 1,000 vehicles inspected, it is estimated that the station operator performs repairs on approximately 265 vehicles (26.5%). The remaining vehicles either pass inspection with no need for repairs or fail inspection and may choose to go elsewhere for parts and repairs, including fixing their vehicle themselves, before the final inspection is performed.

Some station owners who responded that they 'Probably' or 'Definitely [did] Not' think safety inspections support safety took the time to comment that this sentiment reflects their opinions about the state rules and the inspection fee that affects their business operations, rather than directly about how safety inspections affect highway safety.

Following are some key conclusions obtained by examining the full set of responses (which are provided in Appendix K).

- Approximately 25% of the time, inspection station operators noticed one or more defects before the inspection started and told the vehicle owner to have the those items repaired, then come back for the inspection. Thus, again, first-time failures are under-reported by approximately 25% during the time span represented by this group of survey respondents.
- A majority of inspection station operators believe that safety inspections improve highway safety in Texas.
- On average, inspection stations replace parts or perform repairs on about 26.5% of the vehicles they inspect; the rest of the vehicles pass inspection with no need for repairs or are sent elsewhere for repairs due to various reasons.

5.5. Analysis of First-Time Failure Rate

One goal of the CTR team was to develop the annual first-time failure rate, currently not captured in the program. The first-time failure rate includes these categories:

1. vehicles that fail and are repaired at a location other than the inspection station;
2. vehicles that initially fail but are repaired at the inspection station; and
3. vehicles for which, before the inspection, the inspection station personnel told the vehicle owner to fix a component that would fail and then return for an inspection.

Essentially, none of the vehicles in these three categories pass the first time they are presented for inspection. Vehicles that fail under Category 2 are not usually accounted for in the current reporting mechanism; there is no mechanism to capture vehicles that would fail under Category 3.

The CTR team developed two approaches to determine the first-time failure rate using the data from the vehicle owner surveys.

5.5.1. First-Time Failure Rate Method 1

Appendix A.1.5.3 presents a method for determining an annual failure rate, which captures Scenario 1, of 2.63%. Appendix J.2 presents results from the Vehicle Owner Inspection Survey that concluded that 63% of vehicles had failed one or more times over the span of time represented by the survey respondents’ inspection histories. Thus, 37% of respondents indicated that they had never been required to obtain a repair or replacement part and therefore their vehicle had never failed an inspection.

The study team developed a methodology to approximate the annual first-time failure rate from these survey responses of a respondent’s programmatic failure rate experience. Based on the responses from the vehicle owner survey, the study team approximated the annual first-time failure rate using this calculation:

$$Annual\ \ first\ time\ \ failure\ rate\ (y) = \frac{Total\ number\ of\ \ failures\ \ from\ \ survey}{Total\ number\ of\ \ inspections\ \ performed}$$

$$= \frac{a}{n * v * t}$$

where

a is the total number of failures from survey;
n is the number of total valid responses;
v is the average number of vehicles each respondent owns; and
t is the analysis period, which equals to the average of respondents' experience with the Inspection Program in years.

According to the survey results, there were in total 8,091 first-time failures from 5,998 valid respondents. Therefore, *a* = 8,091 and *n* = 5,998. In addition, there were 16,162,382 licensed drivers in Texas in 2016 (FHWA, 2018). Based on the registration data obtained from TxDMV, the total number of registered passenger vehicles (1980 and newer models) in 2016 was 19,640,255. This indicates that the average passenger vehicles per licensed driver in Texas is about 1.2 ($v = 1.2$). The annual first-time failure rate becomes:

$$Annual\ \ first\ time\ \ failure\ rate\ (y) = \frac{8,091}{5,998 * 1.2 * t}$$

Figure 5.5 shows the annual first-time failure rate with different analysis periods.

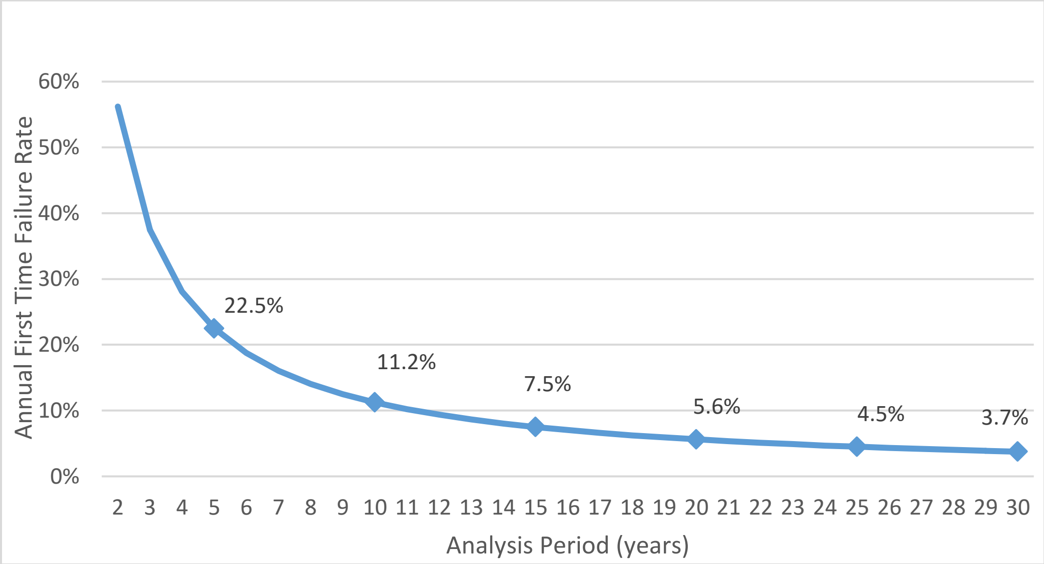


Figure 5.5. Annual first-time failure curve

The annual first-time failure rate and the corresponding analysis period until year 30 is listed in Table 5.1.

Table 5.1. Annual first-time failure rate and corresponding analysis period

Analysis Period	Annual First-time Failure Rate	Analysis Period	Annual First-time Failure Rate
2	56.2%	17	6.6%
3	37.5%	18	6.2%
4	28.1%	19	5.9%
5	22.5%	20	5.6%
6	18.7%	21	5.4%
7	16.1%	22	5.1%
8	14.1%	23	4.9%
9	12.5%	24	4.7%
10	11.2%	25	4.5%
11	10.2%	26	4.3%
12	9.4%	27	4.2%
13	8.6%	28	4.0%
14	8.0%	29	3.9%
15	7.5%	30	3.7%
16	7.0%		

As shown in Figure 5.5 and Table 5.1, as the analysis period increases, the first-time failure rate decreases. This approach results in an approximate first-time failure rate if one picks an analysis period. The unknown remaining factor is determining an analysis period that is reasonable.

According to the registration data obtained from TxDMV, the average model year of a PV in 2017 is 2009. This probably represents a reasonable lower bound on a person's programmatic experience with the system and consequently an upper limit for the first-time failure rate of 12.5%.

Many people will have had multiple vehicles and more years of experience with the Inspection Program, so it is more difficult to develop an upper bound for the analysis period. Most of the data used in developing this analysis approach was contained in an analysis period of less than 15 years, so using 15 years results in a first-time failure rate of 7.5%.

The CTR team determined that more study is needed to establish an upper and lower bound that represents the failure rate based on this data, but 7.5% to 12.5% is a reasonable range. However, one should note that all analysis periods up to 30 years result in an approximate annual failure rate higher than the currently captured 2.63%.

5.5.2. First-Time Failure Rate Method 2

The study team also developed another methodology to determine the annual first-time failure rate based on the survey responses, which focuses more on the individual level. In the survey, vehicle owners were asked to indicate the number of times that they had repairs or purchased replacement parts as a result of a safety inspection (Question 11 in Appendix J). The answers ranged from zero (vehicle never needed any repairs or replacement parts) to as many as 30 times. The study team

interpreted the number of times parts were purchased as the number of failures, because those safety issues would cause a vehicle to fail a safety inspection unless remedied.

To obtain the adjusted first-time failure rate, the study team conducted these tasks:

- established the maximum and minimum analysis periods for each individual who had repairs or purchased replacement parts as a result of a safety inspection;
- calculated all probable unadjusted (without considering the average vehicle ownership rate) first-time failure rates for each individual within the minimum and maximum analysis periods;
- summarized and analyzed the statistics of all probable unadjusted first-time failure rates;
- adjusted the first-time failure rates by considering the average vehicle ownership rate.

The maximum analysis period is set as 30 years since the maximum reported number was 30 times. The minimum analysis period is determined when the unadjusted failure rate reaches 100%. Therefore, it varies from individual to individual and equals to the number of times each respondent reported. For example, if the vehicle owner failed three times, the minimum analysis period is three years and the maximum is 30 years. The respondent might fail three times in three years, or they might fail three times in four years, or five years, or 30 years. Following are all probable unadjusted first-time failure rates: $3/3 = 100\%$, $3/4 = 75\%$, $3/5 = 60\%$, … $3/28 = 10.7\%$, $3/29 = 10.3\%$, $3/30 = 10\%$. Similarly, if the vehicle owner failed seven times, then all probable unadjusted first-time failure rates are $7/7 = 100\%$, $7/8 = 87.5\%$, … $7/29 = 24.1\%$, $7/30 = 23.3\%$. In addition, for those who never failed an inspection, all probable unadjusted first time failure rates are: $0/1 = 0\%$, $0/2 = 0\%$, … $0/29 = 0\%$, $0/30 = 0\%$.

The study team calculated all probable unadjusted first-time failure rates for each individual. Consequently, a total of 171,932 probable unadjusted first-time failure rates were obtained. The histogram and cumulative probability of all unadjusted first-time failure rates are presented in Figure 5.6.

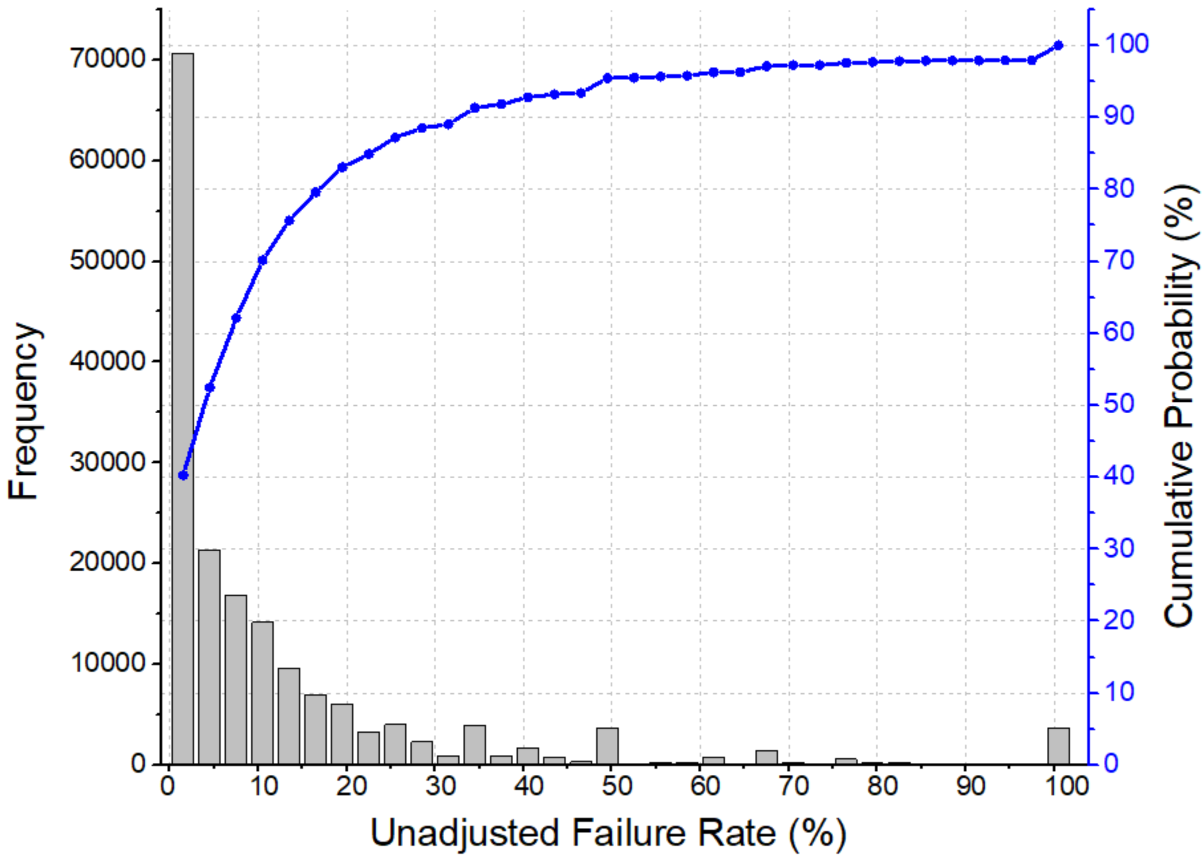


Figure 5.6. Histogram and cumulative probability of unadjusted first-time failure rate

As Figure 5.6 illustrates, the histogram shows an exponential distribution, which is expected because exponential distribution is one of the most common failure distributions in reliability engineering (Ebeling, 2004). Theoretically speaking, failures due to completely random or chance events will follow exponential distribution (Ebeling, 2004). The mean value of all the unadjusted first time failure rates is 12.4%. By considering the average vehicle ownership is 1.2 vehicle per licensed driver, the adjusted mean value of the first time failure rate is $\frac{12.4\%}{1.2} = 10.3\%$, which is in the range of 7.5% to 12.5% from Method 1 and is obviously higher than the currently captured 2.63%. More detailed analyses regarding this methodology can be found in Appendix J.4.

5.5.3. First-Time Failure Rate Summary

If using only the data from the vehicle owner surveys, the true first-time failure rate is unknown. However, by using two methods of statistically analyzing the data available, the CTR team developed estimates of the first-time failure rate that agree closely. Method 1 produced an estimated range of 7.5% to 12.5% and Method 2 produced an estimated average of 10.3%. These values are all in the same range and are higher than the 2.63% captured in the TxDPS database system currently.

Chapter 6. Inspection Databases Examination

This study analyzed three inspection databases to inform the assessment of the Inspection Program:

- The TxDPS inspection database
- An inspection station's records of the City of Houston's inspection program for taxis and limousines
- The Texas Highway Patrol's High Value Dataset

6.1. TxDPS Inspection Database

The CTR team reviewed the TxDPS Inspection Database but was not able to develop additional information for this report.

6.2. Evaluation of Houston Taxi and Limousine Inspection Data

The study team had an unexpected opportunity to analyze a highly specific inspection database, which provided a valuable comparison to the standard Inspection Program data sets. The City of Houston developed its own inspection standards for taxis and limousines that examined about 77 items, including most of the items that are inspected during mandatory state inspection. This inspection was separate from and in addition to the mandatory state Inspection Program. Houston ran this program from 2011 through 2016. As mentioned in Appendix H.2, CTR borrowed the paper copies of Houston taxi and limousine inspection records from an inspection station with whom the City of Houston had contracted to provide taxi and limousine inspections. Since all the taxis and limousines are registered as PVs and they directly serve the traveling passengers, these records are relevant to this study.

The study team analyzed 714 Houston taxi and limousine inspection records. Since the taxis and limousines followed the same Houston inspection standard, the study team combined taxi and limousine inspection results for analysis purposes. Table 6.1 compares the Houston inspection standards (more items are inspected) and statistics with those of the Inspection Program.

Table 6.1 Comparative analyses of Houston taxi and limousine inspection data

	Houston Taxi/Limo Inspection Standards	Inspection Program Standards
First-time failure rate	82.6%	71.6%
Average mileage (miles)	257,640	
Average vehicle age when inspected (years)	6	
For vehicles failed the first inspection, average duration until re-inspection (days)	7	Not Applicable
Average number of defective items per vehicle	4	2
Top six most common defective items (percentages of vehicles)	Brakes (38.5%) Suspension (35.4%) Steering (25.4%) Engine (23.2%) Head lamps (20.2%) Wheel and wheel covers (18.5%)	Brakes (38.5%) Steering (25.4%) Head lamps (20.2%) License plate lamp (16.9%) Stop lamps (14.0%) Tires (13.3%)

As Table 6.1 shows, the first-time failure rate was very high for Houston taxis and limousines under the Houston standards (82.6%), and even under Inspection Program standard (71.6%) where fewer items are inspected. The taxis and limousines have high mileage despite the average vehicle age of only six years. The average number of defective items per vehicle is four under the Houston inspection standard, while the average number of defective items per vehicle is two under Inspection Program standard. Brakes, steering, and head lamps are found to be the top-three most common defective items under the Inspection Program standard.

The high rate of first-time failure for these high-mileage vehicles signifies the importance of ensuring that PVs used for commercial purposes (including PVs used by the increasingly prevalent transportation network companies such as Uber and Lyft) are subject to inspection. More detailed analyses of this data can be found in Appendix L.

6.3. Evaluation of the Texas Highway Patrol High Value Dataset Database

An evaluation of the Texas Highway Patrol High Value Dataset Database for 2013 to 2016 described in Appendix B showed the following:

- 84% of roadside traffic stops by law enforcement for vehicle defects result in warnings, with the remaining 16% as citations.
- About 45% of citations issued by law enforcement for vehicle defects are adjudicated as citations by the courts; the remaining 55% are adjudicated as warnings.
- 56% of vehicle defect warnings and citations are issued during hours of darkness; thus, the majority of warnings are associated with defective lighting.

It would be difficult or impossible to effectively examine tire conditions during hours of darkness. In addition, defective lighting can be observed while a vehicle is in motion, whereas

defective or slick tires cannot. Thus, few warnings or citations are issued for defective or slick tires either during hours of daylight or darkness.

The study team was not able to determine if a process is in place to ensure that vehicle defects identified by law enforcement officers during roadside stops are repaired by the vehicle owner.

Chapter 7. Conclusions and Recommendations

7.1. Conclusions

The CTR study team conducted a thorough investigation of the costs and safety impacts of eliminating the Inspection Program. The team reached the following conclusions based on a thorough analysis of safety impacts, analysis of relevant data sets, examination of the Inspection Program's costs and revenues, and a multi-faceted public outreach component.

7.1.1. Safety

- The average crash costs related to vehicles with defects are more than $2 billion per year Most defects are vehicle elements that would have failed a program inspection.
- The frequency of fatalities, incapacitating injuries, and non-incapacitating injuries is higher for crashes involving vehicles with defects. The ratio of fatalities per number of vehicles in crashes is about three times higher for vehicles with defects than that of vehicles without defects, as shown in the following table:

PV	2015		2016		2017	
	Defective	Non-defective	Defective	Non-defective	Defective	Non-defective
Fatalities per number of vehicles in crashes	1 fatality / 98 vehicles	1 fatality / 346 vehicles	1 fatality / 102 vehicles	1 fatality / 341 vehicles	1 fatality / 114 vehicles	1 fatality / 343 vehicles

- Crashes involving vehicles with defects are twice as likely to result in a fatality than crashes with vehicles that do not have defects.
- The most prevalent type of defect related to fatal crashes is slick or defective tires. Interestingly, 23.5% of survey respondents identified slick or defective tires as a vehicle element they had been asked to remedy during the course of their vehicle inspection history—meaning that the fatality crash rate would likely be higher without such inspections.
- When vehicles from other states are involved in crashes in Texas, the percentage of vehicles with defects is found to be lower for those states that have vehicle safety inspection requirements than states that do not. This indicates that the inspection programs in general may help reduce the number of defective vehicles on the nation's roads.
- The percentage of crashes involving defective vehicles increases with higher speed limits—as does the severity of those crashes. Given that Texas has the highest speed limit in the nation and many high-speed roadways, it is important to consider the potential safety impact of eliminating the safety inspection program in Texas on highway safety, especially on roadways with high speed limit.

- Ensuring that the vehicle owner remedies the defects found by law enforcement officers during roadside traffic stops can enhance highway safety.
- Vehicles with defects that were involved in crashes are three years older than the average registered vehicle, which is nine years old. In other words, the percentage of vehicles with one or more defects that had crashes is higher for older vehicles. This highlights the importance of the Inspection Program to make sure the key components (e.g., tires, brakes, etc.) of old vehicles are in good condition.

7.1.2. Inspection Program Costs and Revenue

- The cost to the State of Texas for operating the Inspection Program is approximately $32 million per year.
- The State of Texas receives revenues of approximately $150 million per year in safety inspection fees paid at annual vehicle registration, inspection station and inspection technician licensing and certifications, and other fees.
- The 12,000 station owners, employing 45,000 inspectors, share net revenue of $131 million per year from the $7 per vehicle inspection fee.
- Eliminating the Inspection Program would result in a loss of revenue to the Clean Air Fund of approximately $39 million per year and a loss of revenue to the Texas Mobility Fund of approximately $83 million per year.
- The cost to motorists for inspection fees and time is estimated to be approximately $307 million per year. This is approximately $16 per vehicle per year for each of the 19 million vehicles owners, in terms of fees and time spent.

7.1.3. Public Perception of the Inspection Program

- In a survey of 5,937 drivers, approximately 80% think that they receive a service when having their vehicle inspected.
- Approximately 89% of survey respondents think that vehicle defects that are corrected through the Inspection Program either ‘definitely’ or ‘probably’ could contribute to an accident.
- Approximately 68.6% of survey respondents ‘strongly agree’ or ‘somewhat agree’ that the Inspection Program benefits highway safety in Texas.
- Approximately 60.6% of survey respondents think that having their vehicle inspected ‘definitely’ or ‘probably’ benefits highway safety in Texas.
- The survey analysis resulted in the following percentages for the four categories of inspection results that were evaluated. It bears noting that these are programmatic percentages, representing decades of respondent experiences. Individuals in this group may had their vehicle inspected over a span of 1 year to approximately 40 years. Further,

respondents might have failed only 1 time, or might have failed 8, 10, or 15 times, or up to every time they had their car inspected, according to respondent comments. Following are the four inspection result categories and their percentages

  - 37% of vehicle owners reported that their vehicles have never required a replacement part or repair and thus have always passed inspection the first time.
  - 15.7% of vehicle owners reported that their vehicle has never needed a repair or replacement part—however, the station operator observed a defect prior to beginning the inspection and told the owner to have it repaired and then return for an inspection. Thus, this group is counted among those who have had first-time inspection failures.
  - 26.5% of vehicle owners reported that the inspection station failed their vehicle, but was able to perform the repairs so that the vehicle could pass inspection.
  - 20.8% of vehicle owners reported that the inspection station failed their vehicle, but they went elsewhere for repairs (out of either choice or necessity), then returned to the station for a second inspection before passing.

  This results in 37% of vehicle owners having never failed an inspection and 63% of vehicle owners having failed an inspection at least once over the programmatic time span.

- When using only the data from the vehicle owner surveys, the true first-time failure rate is unknown. However, by using two methods of statistically analyzing the data available, the CTR team developed estimates of the first-time failure rate that agree closely. Method 1 produced an estimated range of 7.5% to 12.5% and Method 2 produced an estimated average of 10.3%. These values are all in the same range and are higher than the 2.63% captured in the TxDPS database system currently.
- Retaining the Inspection Program allows an opportunity to improve future inspection processes. Stakeholders identified the following potential improvements to the Inspection Program:
  - Incorporate information about vehicle recalls in the inspection report. This is currently done in the 17 emissions counties, but not in the 237 safety-only counties. States that have incorporated notice of vehicle recalls, including the Takata Airbag, in the safety inspection reports have seen an increase in the number of serviced recalls. Texas has approximately 1,000,000 vehicles still on the road with Takata Airbags and is at a higher risk of airbag explosions due to high heat and humidity.
  - Tire age should be considered in addition to tread depth as an inspection factor. The National Transportation Safety Board and tire manufacturers have indicated that tires deteriorate with age and can contribute to severe crashes.
  - Retaining the Inspection Program will support future enhancements that allow new inspection procedures, yet to be determined, for autonomous and connected

vehicles. In any case, these vehicles will have physical components that wear out, just as current and older vehicles do.

- Eliminating the Inspection Program will also mean that high-mileage taxis, limos, and personal vehicles used for ride-sharing services are no longer inspected.

7.2. Recommendations

The results of the analyses conducted in this report indicate that the Inspection Program saves lives and enhances vehicle safety. The CTR study team strongly recommends the following:

- Retain the Inspection Program for PVs.
- Conduct a further study to consider whether potential additional inspection items, such as tire age and recall information, should be included in the Inspection Program to further enhance highway safety in Texas.

References

Asander, S., 1993. Vehicle safety inspection systems. In Wheels' 92: Conference and Workshop; Proceedings (p. 63). Institution of Engineers, Australia.

Berg, G., Danielsson, S. & Junghard, O., 1984. Trafiksäkerhet och periodisk fordonskontroll (Traffic safety and periodic vehicle inspections).

Case, M., De Forest, R. & Youngman, J.H.R., 1991. Compulsory Periodic Vehicle Inspections (No. 912587). SAE Technical Paper.

Christensen, P. & Elvik, R., 2007. Effects on accidents of periodic motor vehicle inspection in Norway. Accident Analysis & Prevention, 39(1), pp.47-52.

Crain, W.M., 1980. Vehicle safety inspection systems. How effective? American Enterprise Institute for Public Policy Research: Washington DC.

Ebeling, C.E., 2004. An introduction to reliability and maintainability engineering. Tata McGraw-Hill Education.

Fazzalaro, J., 2007. Periodic Motor Vehicle Safety Inspections. Connecticut General Assembly Office of Legislative Research.

FHWA, 2018. Online reference. Available at: https://www.fhwa.dot.gov/policyinformation/statistics/2016/dl22.cfm. Accessed on October 25, 2018.

Fosser, S., 1992. An experimental evaluation of the effects of periodic motor vehicle inspection on accident rates. Accident Analysis & Prevention, 24(6), pp.599-612.

Fuchs, V.R. & Leveson, I., 1967. Motor accident mortality and compulsory inspection of vehicles. Journal of the American Medical Association, 201(9), pp.657-661.

GAO, 2015. United States Government Accountability Office. Vehicle Safety Inspections. Improved DOT Communication Could Better Inform State Programs. Report to the Honorable Claire McCaskill, U.S. Senate. Report No. GAO-15-705.

Gardner, B., 1995. Vehicle roadworthiness. From Proceedings of Vehicle Accidents: Their cause, reconstruction, law. Grzebieta, R.H., de Forest, R. & Rechnitzer, G. (Editors). Melbourne. pp 83-90.

Grandel, J., 1985. Investigation of the technical defects causing motor vehicle accidents. Field Accidents: Data Collection, Analysis, methodologies, and Crash Injury Reconstructions. SAE International Congress and Exposition, Detroit, February 25-March 1, 1985.

Haworth, N., R. Smith, I. Brumen and N. Pronk. 1997a. Case-control study of motorcycle crashes. Report CR 174, Federal Office of Road Safety, Australia.

Haworth, N., Vulcan, P., Bowland, L., & Pronk, N., 1997b. Estimation of Risk Factors for Fatal Single Vehicle Crashes. Reports No. 121, Monash University Accident Research Centre, Australia.

Holdstock, J., Zalinger, D. & Hagarty, D., 1994. Review of a mandatory vehicle inspection program: project report.

Keall, M.D. and Newstead, S., 2013. An evaluation of costs and benefits of a vehicle periodic inspection scheme with six-monthly inspections compared to annual inspections. Accident Analysis & Prevention, 58, pp.81-87.

Little, J.W., 1971. Uncertainties in evaluating periodic motor vehicle inspection by death rates. Accident Analysis & Prevention. 2, pp.301-313.

Loeb, P.D. & Gilad, B., 1984. The efficacy and cost-effectiveness of vehicle inspection: a state specific analysis using time series data. Journal of Transport Economics and Policy, pp.145-164.

Manitoba Infrastructure, 2018. Online reference. The official website of Manitoba Province, Canada. Retrieved on June 22, 2018. Available at: http://www.gov.mb.ca/mit/mcd/mcs/index.html.

McLean, A.J., Aust, H.S., Brewer, N.D., & Sandow, B.L., 1979. Adelaide In-depth Accident Study. Part 6: Car accidents. The University of Adelaide.

McLean, A.J., Brewer, N.D., Hall, T., Sandow, B.L., & Tamblyn, P.J., 1979. Adelaide In-depth Accident Study. Part 4: Motorcycle accidents. The University of Adelaide.

Merrell, D., Poitras, M. & Sutter, D., 1999. The effectiveness of vehicle safety inspections: An analysis using panel data. Southern Economic Journal, pp.571-583.

NHTSA (1989). Study of the effectiveness of state motor vehicle inspection programs: Final report. Report of the US Department of Transportation: USA.

Peck, D., Matthews, H.S., Fischbeck, P., & Hendrickson, C.T., 2015. Failure rates and data driven policies for vehicle safety inspections in Pennsylvania. Transportation Research Part A: Policy and Practice, 78, pp.252-265.

Poitras, M. & Sutter, D., 2002. Policy ineffectiveness or offsetting behavior? An analysis of vehicle safety inspections. Southern Economic Journal, pp.922-934.

RACQ Submission to Travelsafe Committee, 1990. Does Queensland need compulsory periodic inspections of passenger vehicles? RACQ: Queensland.

Rompe, K. & Seul, E., 1985. Advantages and disadvantages of conducting roadworthiness tests to monitor the mechanical condition for private cars, the impact of such tests on road safety, environmental protection and the renewal of the vehicle fleet and the scope for introducing roadworthiness testing throughout the European community. Final report commissioned by the Directorate-General for Transport. VII/G-2 of the Commission of the European Communities. Drawn up by the TUV Rheinland.

Schroer, B.J. & Peyton, W.F., 1979. The effects of automobile inspections on accident rates. Accident Analysis & Prevention, 11(1), pp.61-68.

Sutter, D. and Poitras, M., 2002. The political economy of automobile safety inspections. Public Choice, 113(3-4), pp.367-387.

Treat, J.R., 1977. Tri-level study of the causes of traffic accidents: an overview of final results. In Proceedings: American Association for Automotive Medicine Annual Conference (Vol. 21, pp. 391-403). Association for the Advancement of Automotive Medicine.

TxDOT, 2015. Highway Safety Improvement Program Manual. http://onlinemanuals.txdot.gov/txdotmanuals/hsi/hsi.pdf. pp.1-13

TxDOT, 2018. Highway Safety Improvement Program Call. http://ftp.dot.state.tx.us/pub/txdot-info/trf/hsip/2018/program-call.pdf. p.9.

Vaughan, R., 1993a. Vehicle ageing and safety. In Wheels' 92: Conference and Workshop; Proceedings, p.47. Institution of Engineers, Australia.

Vaughan, R.G., 1993b. Safety maintenance of road vehicles. In proceedings of the Institution of Mechanical Engineers. Braking of road vehicles. International conference held 23-24 March 1993 at Birdcage Walk, London (paper number C444/007/93).

Vlahos, Nicholas J., Samuel T. Lawton, Anurag K. Komanduri, Yasasvi D. Popuri, & Danena L. Gaines, 2009. Pennsylvania's Vehicle Safety Inspection Program Effectiveness Study (070609) Summary of Findings. The Pennsylvania Department of Transportation. Report No. PA-2009-004-070609. Prepared by Cambridge Systematics.

White, W.T., 1986a. Does periodic vehicle inspection prevent accidents? Accident Analysis & Prevention, 18(1), pp.51-62.

White, W.T. 1986b. Relaxation of PMVI: Scenario selection. Traffic Research Branch, Ministry of Transport: Wellington, NZ.