Fracking-related Commercial Motor Vehicle (CMV) Crash Risk

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

June 2021

FOREWORD

This final report documents a research study, conducted under the direction of the Federal Motor Carrier Safety Administration (FMCSA) Research Division, on commercial motor vehicle (CMV) crash trends in United States energy-producing regions that use hydraulic fracturing ("fracking") mining methods. The study sought to evaluate fracking-related CMV crash risk. To accomplish this, the study team reviewed existing research and conducted independent analyses on the temporal and spatial relationships between fracking activity and CMV safety in three States representing the primary fracking regions in the United States. The data reviewed spanned the years 2000 to 2016. Crash data were drawn from the Motor Carrier Management Information System (MCMIS) and State sources. For North Dakota, these data included exact spatial information. All studied crashes involved at least one CMV. The team found increases in crash risk associated with increases in fracking activity and potential for decreased safety performance by motor carriers associated with this activity. The overall findings of this study are applicable for use by a broad spectrum of industry and Government stakeholders concerned with fracking and public safety.

NOTICE

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16. Abstract

The combination of two energy extraction technologies, hydraulic fracturing ("fracking") and horizontal drilling, has transformed the U.S. energy system by providing a means of accessing natural gas and oil in tight shale formations. The consequent fracking boom has transformed the U.S. economy, especially in less developed geographic areas where tight shale formations are prevalent.

Review of the literature and geospatial analysis of CMV crash trends over time show an increase in CMV-involved crashes associated with fracking activity. This increase is not principally due to less safe carrier behavior, but rather to increased total volume of CMV traffic associated with fracking activity. This effect is most pronounced in areas where energy extraction had been declining and in less-developed areas with transportation infrastructure not designed to handle heavier CMV and other traffic. It is not possible to determine whether fracking-associated carriers require further regulation without more data.

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commercial motor vehicle crash, hydraulic fracturing, fracking, energy resource extraction and transport, oilfield	**No restrictions**

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Unclassified	**Unclassified**	**71**	

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SI* (MODERN METRIC) CONVERSION FACTORS

Symbol	When You Know	Multiply By	To Find	Symbol
Approximate Conversions to SI Units				
		Length		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		Area		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	Acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		Volume (volumes greater than 1,000L shall be shown in m^3)		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		Mass		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		Temperature (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		Illumination		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		Force and Pressure or Stress		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

Symbol	When You Know	Multiply By	To Find	Symbol
Approximate Conversions from SI Units				
		Length		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		Area		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
Ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		Volume		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		Mass		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		Temperature (exact degrees)		
°C	Celsius	1.8c+32	Fahrenheit	°F
		Illumination		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		Force and Pressure or Stress		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003, Section 508-accessible version September 2009.)

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

Acronym	Definition
AADT	average annual daily traffic
AIC	Akaike Information Criterion
BASICs	Behavior Analysis and Safety Improvement Categories
CI	confidence interval
CMV	commercial motor vehicle
EIA	Energy Information Administration
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
HOS	hours of service
HPMS	Highway Performance Monitoring System
IRR	incidence rate ratio
MCMIS	Motor Carrier Management Information System
mi/h	miles per hour
OOS	out-of-service
Play	shale formations with specific geologic and geographic properties that contain significant accumulations of natural gas
SMS	Safety Measurement System
TxDPS	Texas Department of Public Safety
USDOT	U.S. Department of Transportation
VMT	vehicle miles traveled

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EXECUTIVE SUMMARY

PURPOSE

The purpose of this report is to measure the relationship between hydraulic fracturing ("fracking") activity and increased commercial motor vehicle (CMV) crash risk in the United States.

BACKGROUND

The combination of two energy extraction technologies, fracking and horizontal drilling, has transformed the U.S. energy system by providing a means of accessing natural gas and oil in tight shale formations. Drilling one fracking well requires 1,200–2,300 total truck trips. Most of these trips occur in the initial drilling phase, creating a burst of CMV traffic when wells are initiated. Because fracking opens access to previously untapped energy resource reserves, some areas' transportation infrastructure is subjected to heavy commercial/industrial traffic for the first time, and fracking wells even in States with a history of energy production tend to be in rural areas. At present, there is not a systematic or consistent means of identifying carriers associated with fracking activity, but anecdotal evidence suggests that fracking has attracted smaller carriers without extensive energy-sector experience.

PROCESS

The study team reviewed relevant literature on the relationship between fracking activity and CMV crashes, interviewed Federal Motor Carrier Safety Administration (FMCSA) Division Office staff, and carried out detailed analyses of crash trends over time, crash locations relative to fracking wells, and characteristics of CMV carriers most closely associated with fracking activity.

FINDINGS

Review of the literature and geospatial analysis of CMV crash trends over time show an increase in crashes involving at least on CMV in times and places of increased fracking activity. The study team found this relationship across different States, and across small geographical regions within North Dakota, where finer-grained spatial analysis was possible. By assessing multiple metrics of carrier safety, the analysis found that fracking-associated carriers generally have lower safety performance, but these trends were not consistent across States and measures. While increased fracking for gas and oil leads to higher CMV crash rates, this correlation is due more to the uptick in volume of CMV traffic when wells are initiated, and less to specific behaviors of fracking-associated carriers.

This result does not prove or disprove a need for changes in regulations. More data on the behaviors of fracking-associated carriers will be required to determine whether such carriers warrant further regulation.

1. OVERVIEW

This report summarizes the results of the "Commercial Motor Vehicle (CMV) Fracking-related Crash Risk" project conducted by the John A. Volpe National Transportation Systems Center (Volpe) on behalf of the Federal Motor Carrier Safety Administration (FMCSA). The goal of the project was to identify and analyze CMV crash trends in the energy-producing regions of the country that are using hydraulic fracturing (fracking) mining methods. To capture these trends, the study team reviewed existing research, interviewed staff from FMCSA Division Offices, and conducted independent analyses.

This overview introduces the underlying research questions that directed the study team's review of the literature, which in turn provided background and context for the independent analyses explained in Section 2. The overview concludes with a summary of the extant literature's account of how fracking activity affects crash risk. The literature indicates a positive correlation between fracking activity and crash risk, but a complete treatment of this correlation's strength and how the effects are distributed across space and time is reserved for Section 2.

1.1 INTRODUCTION

The goal of this study was to assess how fracking for natural gas and oil affects crashes involving CMVs. This study also sought to identify differences in safety performance unique to motor carriers serving the fracking sector.

Specifically, the Volpe study team sought to answer the following research questions:

1. How can we formulate quantitative measures of fracking activity and CMV crash risk, and what data are available for these measurements?
2. How have fracking activity and CMV crash risk changed over time in the three studied regions?
3. How is fracking activity related to CMV crash risk according to location of that activity, accounting for the effects of other risk factors?
4. How is CMV crash risk different for carriers involved in fracking-related operations from those not involved?
5. Are CMV carriers that transport fracking materials being inappropriately granted hours-of-service (HOS) exemptions?

1.2 BACKGROUND: IMPACTS OF FRACKING ACTIVITY IN THE UNITED STATES

The following background information was gleaned from a review of the literature regarding the fracking process and its impacts on the transportation system in major fracking production areas of the United States, particularly the States of North Dakota, Pennsylvania, and Texas.

1.2.1 The Fracking Process

The combination of two energy extraction technologies, fracking and horizontal drilling, has transformed the U.S. energy system by providing a means of accessing natural gas and oil in tight shale formations. The U.S. Energy Information Administration (EIA) projects that shale gas production will increase from 5.0 trillion cubic feet in 2010 to 13.6 trillion cubic feet in 2035.(1) Currently, two-thirds of all natural gas and half of all crude oil produced in the United States derive from fracking.(1) Shale gas and shale oil development have impacted the transportation system, particularly the trucking industry, because these practices require transporting high volumes of water, sand, and chemicals as inputs, in addition to wastewater and crude oil as outputs. Even where pipelines and rail networks exist, "last-mile" delivery frequently depends on trucks. The impacts on CMV traffic and associated crashes have been notable in several locations around the country. This literature review assesses the state of knowledge of truck crashes associated with fracking in the United States since 2000.

Understanding how the fracking boom has affected the transportation system requires a general understanding of the process of hydraulic fracturing. Shale formations, known as "plays," develop from sedimentary rock with pockets of organic material that develop into natural gas and crude oil. To access shale gas and oil, modern techniques rely on horizontal drilling. First, a vertical well is drilled down 5,000–12,000 feet. During the vertical drilling, a series of steel casings are cemented into place to protect freshwater aquifers, which rest above the shale formations, from potential contamination. Horizontal drilling then extends the well several thousand feet at right angles to the original shaft, creating a large surface area to access the layers of gas and oil.

The horizontal portion of the well is punctured at specific locations using a perforation gun, and fracking fluids are forced into the well at high volume and pressure to break the shale. The fracking fluid contains sand or other proppants to hold the cracks open. The sand used is a fine-grained mix and usually needs to be transported by truck from specific quarries with suitable grain size. Once the rock is fractured, the gas and/or oil flows through the horizontal part of the well and up for collection. Shale gas and oil wells are typically fractured multiple times to maintain production.

The fluid used for fracking is 99.2 percent water, with chemicals added to serve various purposes. A national registry of chemicals used in fracking provides a clearinghouse for chemical disclosures.(2) Chemicals added to the fracking mixture may include acids such as hydrochloric acid to clean the pipes of residue; polyacrylamide gel to reduce friction; surfactants and gelling agents, such as guar gum, to keep sand in suspension; biocides to kill micro-organisms; and corrosion inhibitors, such as dimethyl formamide, to prevent pipe corrosion. (3) When transported to well pads, these chemicals must be carried by tanker trucks with appropriate hazardous material placards. Wastewater, which consists of up to 50 percent of the water pumped into wells, is in some circumstances treated as hazardous waste transported to disposal sites in tanker trucks with appropriate placards.

The water, sand, and chemicals are all required in the fracking and production phases of the well. Prior to that, equipment needs to be transported to the well pad for drilling and construction. In particular, the initial drilling requires hauling the drill rig and specialized rigging equipment, along with equipment to build access roads and the pad itself.

1.2.2 Resource Distribution

Fracking in the United States has occurred in several shale plays across the 48 contiguous States. Currently, the most productive plays are the Marcellus Shale play for natural gas and the Bakken and Eagle Ford Shale plays for crude oil. Historically, the Barnett Shale in Texas is also an important play; this was the first play where a combination of horizontal drilling and hydraulic fracturing was deployed at a commercial scale (see Table 1). The Marcellus Shale accounts for nearly half of all natural gas produced from shale in the United States, and the Eagle Ford and Bakken Shale plays account for half of all oil from shale (see Figure 1).

Production amounts listed in Table 1 are the daily total output for each shale play. These four plays are the focus of this literature review. The plays have different water and sand input requirements and different modes of transporting natural gas and oil outputs. These distinctions are critical to the study because they contribute to key similarities and differences in the ways fracking has impacted the transportation system across the three States studied.

Table 1. Focal States producing natural gas and crude oil by hydraulic fracturing for this review.

Shale Play	State	Dominant Energy Product	History of Production
Barnett	Texas	Natural Gas	Earliest fracking for natural gas, since 2000. Consistent large quantity of gas, recently diminishing in production, 3 billion cubic feet per day.
Bakken	North Dakota	Crude Oil	Production began in 2000, large variation between years. Nearly 1 million gallons per day.
Marcellus	Pennsylvania	Natural Gas	Production began in 2005. Nearly half of all shale gas in the United States, 16.8 billion cubic feet per day.
Eagle Ford	Texas	Crude Oil	Large-scale production began in 2010. Now largest oil region, 1 million gallons per day.

Source: EIA, Annual Outlook 2016.

While commonalities exist in the general number of truck trips for hauling, drilling, construction, and production materials, estimates of truck trips required for water transport vary greatly for the different plays, highlighting regional differences. Geography and the type of resources being recovered from the well create additional differences in the volume and type of truck traffic required.

Wells typically dispose of wastewater with deep well injection, or treat it at specialized wastewater treatment facilities. The locations of these disposal or treatment sites can vary in distance from the production wells but are typically over 100 miles away. For example, in one county in Pennsylvania, wastewater treatment facilities are 140–200 miles from the wells, and injection sites are typically several hundred miles away in Ohio.(4 5)

Pipelines for transport of fresh water have been proposed as an alternative to truck transport, potentially reducing the number of truck trips substantially.(4) Significant barriers to building water pipelines exist, however, including negotiations with property owners and the economics of building a pipeline which may be in use for only a few years.(6)

Infrastructure needs also differ for gas and oil. Depending on the geology of the region, wells may produce predominantly gas, predominantly oil, or a mixture of the two. Wells producing crude oil rather than natural gas require tanker trucks to haul the oil directly to a refinery, a rail terminal, or a pipeline pump station. Natural gas wells typically have small-diameter gathering pipelines at the well, with 95 percent of all natural gas transported to its final destination by pipeline.(7) The distinction between natural gas-producing and crude oil-producing wells is one of the most significant factors determining the type and volume of traffic in a given fracking area. Figure 1 and Figure 2 provide graphical displays of daily U.S. tight oil and dry shale production from selected plays, for calendar years 2002–16.

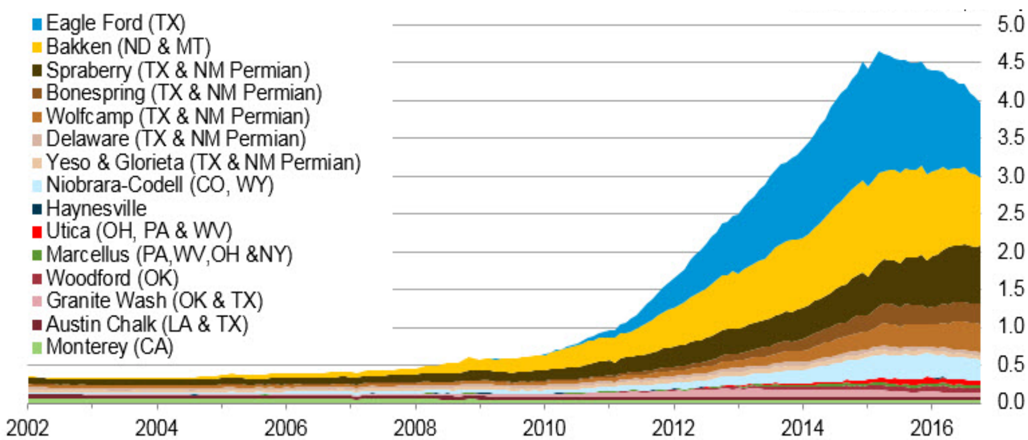

Figure 1. Graph. U.S. tight oil production from selected plays, million barrels of oil per day, 2002-2016.
Source: EIA.

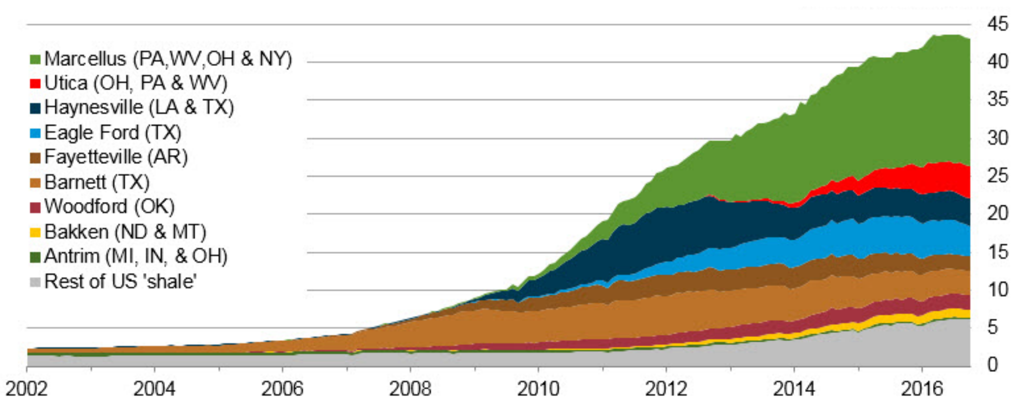

Figure 2. Graph. U.S. dry shale gas production from selected plays, billion cubic feet per day, 2002-2016.
Source: EIA.

1.2.3 Roadways and Traffic Volumes

Estimates of the total number of truck trips over the lifetime of a well vary by region due to differences in geology, drilling technology, and water needs. Typical estimates are 1,200–2,300 total truck trips per well.(8 9)

The bulk of these trips is transport of fresh water, with 2–5 million gallons of water required for fracking a single well.(10) In Texas, 685 loaded tanker trucks of freshwater are needed per well, in addition to 214 loaded trucks to remove wastewater.(7) Fresh and wastewater transport can account for up to 70 percent of the truck loads for each well.[11] These estimates are similar in North Dakota: 450 tanker trucks of freshwater and 225 tanker trucks for wastewater.[12] Estimates in Pennsylvania range higher: up to 1,220 truck trips for fresh water alone.[5 13]

The distribution of trips over time is not uniform. Approximately 75 percent of truck trips for each well occur in the first 2 or 3 months of development as access roads are built, well pads are constructed, and large quantities of water and sand are transported.[7] Fewer truck trips are required for ongoing production and maintenance. Ongoing maintenance operations may require as few as one truck trip per day over the remaining life of the well.

After some years, productivity of wells declines as the fractures in the shale become blocked by fracking sand and are depleted of gas and oil. For instance, Bakken Shale oil wells have been declining in productivity, down from approximately 425 to 190 barrels per day after the first 12 months of full production.[14] That amount of oil (190 barrels) would require two to eight tanker trucks per day per well, depending on truck capacity.

But wells can continue to have a significant impact on transportation systems after establishment. Wells are typically organized in dense formations, so even a small number of trucks per well can result in a large impact at the regional scale. Wells can also be re-fractured approximately 5 years after initial fracturing, requiring an additional 1,000 trips.[15]

Fracking activities can impact truck traffic beyond trucks directly delivering goods and services for the fracking industry. In interviews with FMCSA Division Offices, it has been noted that CMV traffic also increases due to supplying food and household goods to expanded worker populations in fracking areas.[i] For example, the population of North Dakota grew by 13 percent from 2007 to 2013, and the State achieved the highest population growth rate in the Nation for 2012 and 2013 despite a pre-fracking trend of slow growth or decline. Non-CMV traffic can also increase due to commuting and personal traffic by the increased worker population.

1.2.4 Impacts of Fracking Activities

Impacts of fracking activities include potential environmental impacts, road surface degradation, greater truck traffic, and higher vehicle crash rates. This review focuses on traffic volume and crash rates, touching briefly on other impacts.

Important regional differences in truck traffic emerge from differences in construction, equipment, and resource needs. The type of energy resources produced, the spatial distribution of inputs and outputs, and the history of production can all impact exactly how CMV traffic increases, which in turn produces different effects on crash rates.[ii]

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[i] http://www.census.gov/

[ii] It should also be noted that, while this report examines "fracking-associated carriers" via the fracking association methods described in Appendix C, the crash rates studied in the main body of the report are based on *all* CMV-related crashes at the times and places described. MCMIS does not distinguish fracking-associated carriers, and an underlying assumption of the report is that most new CMV traffic near a well-initiation site is related to that site. Given the remote locations of the sites studied, this is a reasonable assumption, but no claim is made that every single CMV crash

In regions where the "boom" cycle of gas and oil production is new, for example, FMCSA Division Offices have noted that the management of increased CMV traffic is much more challenging than in regions with a long history of gas and oil production.

This review focuses on the three States that account for the majority of gas and oil produced by fracking. Texas, North Dakota, and Pennsylvania were selected for their history of energy production, type of energy product, and the presence of transportation infrastructure before the advent of shale energy production.

1.2.4.1 Impacts of Fracking Activities in Pennsylvania

Pennsylvania is home to the largest swath of the Marcellus Shale formation, which produces natural gas almost exclusively. Figure 3 depicts cumulative counts of fracking wells up to calendar year 2015. Counts are summarized by county, with circles placed at the center of the county and sized proportionally to the number of wells. Data on well counts came from the Pennsylvania Department of Environmental Protection. Well counts are superimposed on the roadway network, shown with roads shaded by average annual daily traffic (AADT) rates in 2011. Traffic data came from the Highway Performance Monitoring System (HPMS) of the Federal Highway Administration (FHWA).

The resulting map shows that some of the areas with the most fracking activity, such as those in the northeastern part of the State, have sparse roadway networks with relatively low typical traffic volumes. The episodic large increases in CMV traffic associated with fracking may be especially significant for these areas.

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involves a CMV engaged in fracking-related operation. The report instead compares fracking and non-fracking counties, shows longitudinal comparisons for counties over time, and studies correlations between crash rates and location based on direct proximity to wells. Further, increases in general CMV traffic may accompany fracking activity for the same reason as increases in passenger vehicle traffic: an increase economic activity and population may reasonably be expected to increase general CMV traffic. The report therefore represents a faithful account of CMV crash risk associated with fracking activity—but this account must be read with care and in distinction from the separate discussion of fracking-associated carriers' safety practices and performance.

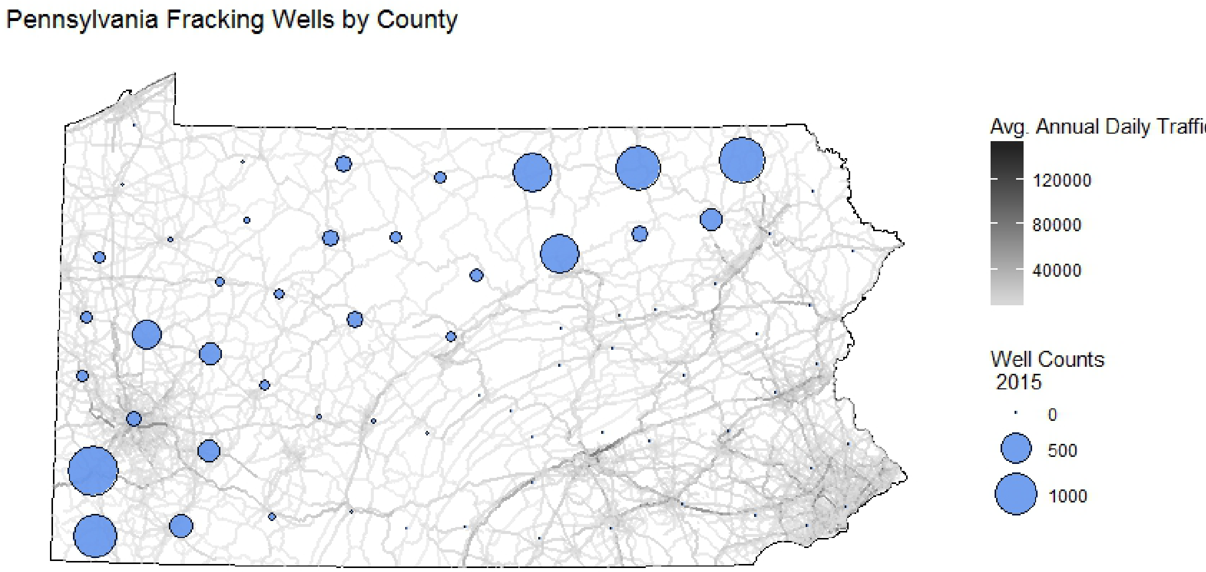

Figure 3. Map. Cumulative number of fracking wells in Pennsylvania as of 2015, superimposed over the roadway network showing average AADT rates as of 2011.

The natural gas production from the Marcellus Shale region now accounts for nearly half of all natural gas domestically produced, with the EIA predicting continued growth of production through 2040.[(1)] The production sites in Pennsylvania exist in a region of small, rural towns with relatively few highways connecting sources of freshwater and sand, the production sites, and the wastewater disposal sites. As is common for a natural gas producing area, pipelines convey nearly all of the energy product. CMV activity is therefore confined mostly to transporting drilling equipment, water, and sand rather than energy product outputs. Even so, the truck crash rate in gas-producing counties still peaked at 65 percent above the rate in non-gas producing counties.[(16)]

1.2.4.2 Impacts of Fracking Activities in North Dakota

Fracking activities in North Dakota differ from those in Pennsylvania in two crucial ways: the Bakken Shale formation of North Dakota mainly produces oil, not natural gas, and the transportation network comprises fewer roads and more distant locations (Figure 4). Because of the need for trucks to transport crude oil to rail terminals or directly to refineries, and the sparse nature of the road network, North Dakota's transportation system has been impacted by fracking more than Texas' and Pennsylvania's transportation systems. The advent of oil production in a rural area which had never previously experienced an energy boom resulted in a large increase in truck traffic on small roads.[(17)] The resulting traffic volume led one county with active fracking operations to close the entire road system to oil trucks to limit damage to road surfaces.[(18)]

Figure 4 maps cumulative counts of fracking wells in North Dakota up to calendar year 2015. Well counts are summarized at the county level, and each circle is sized proportionally to the number of wells in each county. Well data came from the North Dakota Department of Mineral Resources, and the roadway network data came from HPMS. Fracking activities in North Dakota are concentrated in the northwestern quarter of the State, a region with a sparse roadway network.

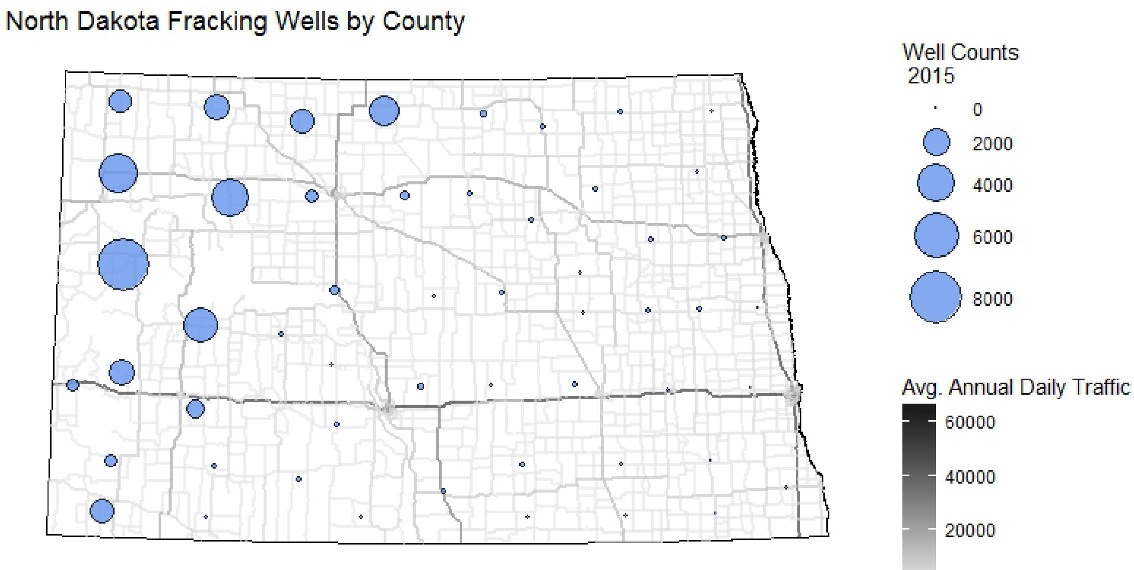

Figure 4. Cumulative number of fracking wells in North Dakota as of 2015, superimposed over the roadway network showing average AADT rates as of 2011.

1.2.4.3 Impacts of Fracking Activities in Texas

Texas contains multiple shale plays. The Barnett Shale play in northeast Texas and the Eagle Ford play, which spans southern and southwestern Texas, are historically the highest yielding for natural gas and crude oil production. More recently, Texas has had increased production from the Permian Basin in West Texas (Figure 5).

The Barnett Shale play has a long history of production, with the earliest natural gas production from hydraulically fractured wells in the early 1980s, reaching commercial-scale production in 2000. While production has plateaued in the Barnett Shale area, the truck traffic for maintenance activities continues to degrade road surfaces.(7) For each well that requires re-fracking in the Barnett Shale, approximately 1,000 truck trips are required over several weeks to maintain production.(19)

The Eagle Ford shale play was developed more recently, with oil production from fracked wells reaching commercial scale in 2010. With an exponential increase in the number of wells and associated truck traffic, the Eagle Ford area has become both the epicenter of oil production and the focus of road maintenance and road safety research in Texas.

Figure 5 maps cumulative counts of fracking wells in Texas up to calendar year 2015. Well counts are summarized at the county level, and each circle is sized proportionally to the number of wells in each county. Well data came from the national clearinghouse for hydraulic fracturing disclosures, FracFocus.org. The roadway network is shown with roads shaded by AADT rates in 2011 (HPMS).

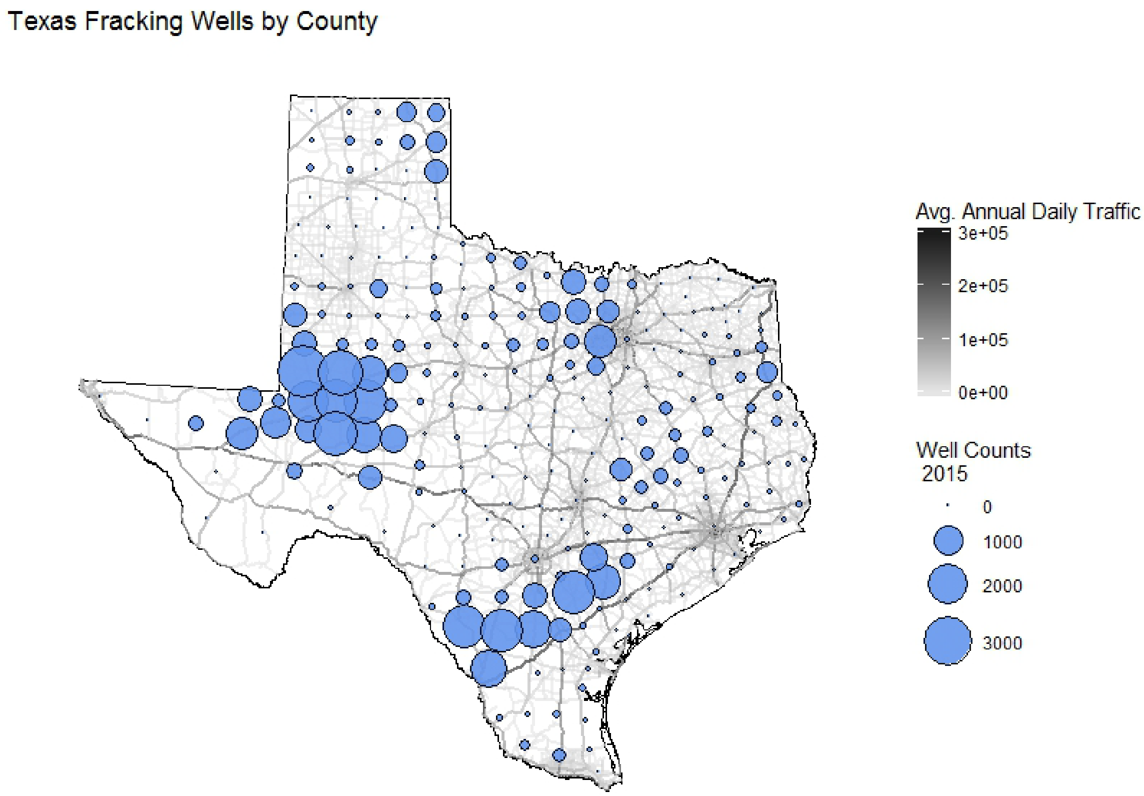

Figure 5. Cumulative number of fracking wells in Texas as of 2015, superimposed over the roadway network showing average AADT rates as of 2011.

1.3 FRACKING ACTIVITY AND CRASH TRENDS

Pennsylvania, North Dakota, and Texas provide case studies to illustrate general trends in CMV crashes resulting from fracking activities. In general, distinguishing fracking-related CMV crashes from other CMV crashes requires a level of analysis deeper than simply tracking statewide trends. Several complications must be considered, as described below.

As with many other energy production activities, fracking occurs in rural areas, and rural roads historically have fatality rates about 2.5 times higher than urban roads.(20) In 2017, rural roadways accounted for 62.3 percent of all fatal crashes involving trucks carrying hazardous materials, such as crude oil.(21) Analyses and any subsequent response must account for the disproportionate use of rural roads during fracking activities.

Incomplete records also pose a challenge. Records of fatal crashes in fracking areas are rare but still more complete than non-fatal crashes, which are historically underreported in a variety of sectors.(22) As such, fatal crash data provide a more reliable basis for measuring crash trends than crash data as a whole.

Identifying trucks involved in fracking activities is straightforward only in some cases. Initial fracking activities involve the hauling of specialized drilling rigs, whose unique configurations may require oversize or overweight permits.(23) Tanker trucks haul chemicals for initial fracking, and they may require hazardous material placards and permits. Sand trucks may have special configurations and haul large loads from known specialized sand facilities.(13 15) Thus, a study tracking CMV crashes resulting from fracking activity should attempt to identify CMVs involved in fracking by permits, placards, configurations, materials hauled, and CMV origin-destination.

In contrast, the construction of the well pad and access road involves general construction trucks. Water transport (500–1,000 truck trips) also uses trucks without known origins or special permits or configurations. To account for these CMVs, a study could compare areas with known fracking activities to areas without fracking (cross-sectional comparisons), or compare trends prior to and during fracking periods within the same area (longitudinal comparisons).

1.3.1 Pennsylvania – Marcellus Shale

Evidence indicates increased CMV crashes in areas of Pennsylvania with fracking activity. During the rise in fracking activity in the Marcellus Shale area (beginning in 2005), truck traffic increased in counties with fracking activity by 40 percent, with a commensurate 40 percent increase in crashes.(24) Separating fracking from other possible causes of increased traffic and crashes would require further study.

In the initial years of fracking activity, few direct negative safety effects were visible in specific counties.(25) This county-specific analysis was limited to a single pair of counties with and without active fracking, and excluded the 2010 boom in fracking activity. As such, other lines of evidence may offer more accurate and generalizable findings.

Comparing fracking counties to counties without fracking for shale gas from 1997 to 2011, the Pennsylvania Department of Transportation's Crash Reporting System showed a significant increase in the number of total crashes and crashes involving heavy trucks.(22) Based on such pairwise comparisons of fracking and non-fracking counties, the most heavily drilled counties showed a 15–23 percent increase in all vehicle crashes, and a 61–65-percent increase in heavy truck crashes.(15)

The risk of fatalities in CMV crashes from fracking activities is difficult to assess, but some researchers have extrapolated from previous trends to draw general conclusions. These extrapolations suggest that oil and gas workers are seven times more likely to suffer fatal accidents compared to the general industrial population, and one-third of fatalities in workplace accidents related to unconventional natural gas development result from vehicle crashes.(22 26)

The size of the CMV company also correlates with fatality rates; employees of small- and medium-sized companies are most at risk of suffering a fatal accident.(27) Anecdotal evidence from FMCSA enforcement officials indicates that the boom in Pennsylvania attracted many such smaller companies, especially for work which did not require specialized rigs, such as tanker truck services for hauling fresh water and wastewater.[iii] This skew toward smaller companies may help explain the rise in fatal accidents.

[iii] Jeff Jensen, FMCSA Division Office of North Dakota, *personal communication*

1.3.2 North Dakota – Bakken Shale

Like Pennsylvania, North Dakota experienced increases in CMV crashes during the fracking boom. With a fivefold increase in CMV crashes in the Bakken Shale region, and a commensurate fivefold increase in the injury crash rate in the 17 oil-producing counties of western North Dakota, North Dakota provides the clearest illustration of how increasing CMV traffic volume from fracking affects crash trends.(11) The rate of fatal crashes involving large trucks per vehicle-mile increased 250 percent, meaning the incidence of crashes increased more rapidly than traffic volume.(11) This suggests that some crashes were caused by factors other than heavier traffic.

Fatal crashes rose 189 percent from 2004 to 2013 in the 17 western oil counties, with the largest number (78) occurring during the peak of fracking in North Dakota in 2013. The increase in fatal crashes outpaced the increase in total vehicle miles traveled (VMT) in the same time period, again indicating some crashes were caused by factors other than heavier traffic.(17) In addition, crash rates showed the greatest increase in the four counties with the highest oil production in the State. In these four counties, large truck crashes increased 1,224 percent, from 25 in 2004 to 331 in 2011.(9) The per capita rate of CMV crashes for oil-producing counties has continued to exceed the rate elsewhere in the State, with 370 crashes involving large trucks per 100,000 individuals in oil-producing counties and 56 per 100,000 individuals elsewhere in 2014, despite a drop in the number of new wells drilled in 2014.(28)

Drivers of passenger cars seem aware of the risks posed by fracking-related CMV traffic on the rural roads of North Dakota. Surveys by the Upper Great Plains Transportation Institute show that passenger car drivers are willing to drive substantially longer routes to avoid interaction with fracking CMVs.(9 17 28) In Williams County, in the heart of the Bakken Region, truck traffic due to fracking increased traffic volume from 50 vehicles per day before the boom to over 1,000 vehicles per day at the peak.(29) Williams County responded by closing all town and county-level roads to oil trucks for a period in 2011.(18)

1.3.3 Texas – Barnett and Eagle Ford

Texas has a long history of drilling for energy production, unlike Pennsylvania and North Dakota, suggesting the State's infrastructure might be better suited to accommodate a fracking boom. Even so, correlations between fracking activity and roadway crashes in Texas are still visible. The Texas Department of Public Safety (TxDPS) recognized this; as such, the TxDPS Commercial Vehicle Enforcement Service had a stated goal of reducing the overall number of fatal crashes within the Eagle Ford Shale Region by 5 percent per year from 2014 to 2017. Initial data indicate a decline in crashes overall, but no decline in the number of fatal crashes.

Hydraulic fracturing differs from traditional oil development, notably in the geographical distribution of the energy resources. The Barnett Shale formation in north Texas abuts the city of Fort Worth, while the Eagle Ford Shale in south Texas stretches across a large area from south of Austin and San Antonio towards the Mexican border near Laredo. While oil fields existed in both regions prior to fracking, the number of wells developed in the boom between 2010 and 2013 outpaced previous booms, with a high density of wells developed along roads which had not previously supported drilling activities.

Associations between the fracking boom and the number of fatal roadway crashes in Texas have been noted by several sources. Statewide, the number of highway fatalities from CMV-involved accidents increased from 352 in 2009 to 532 in 2014, a 51-percent increase. The State saw a near-100-percent increase in all crashes between 2008 and 2011.(11)

Studies focused on counties with fracking activities have found similar increases in crashes, including CMV-related crashes. A 40-percent increase in crash fatalities was observed in the Eagle Ford Shale counties from 2008 to 2011.(22) A second analysis on the same counties found a 26-percent increase in all crashes, with a 49-percent increase in crashes resulting in fatalities and severe injuries from 2009 to 2013.(10) A more recent analysis found that these trends have continued, with one county experiencing a 216-percent increase in traffic accidents and 12 times as many fatal accidents compared to 2008.(30) Multiple-fatality accidents in the Laredo area rose from 72 in 2010 to 148 in 2013. Finally, the Texas Department of Transportation reported a 13-percent increase in crashes that resulted in serious injuries or fatalities from 2013 to 2014 in the Eagle Ford region.(31)

Overall, fatality rates in Texas on rural non-interstate roads are 2.76 per 100 miles, similar to the number in Pennsylvania. A high percentage of VMT related to fracking occurs on rural roads, which have fatality rates 2.5 times higher than urban roads.(20) The rise in fatality rates accordingly reflects an increase in CMV traffic in locations where new hazards are likely to be multiplied by existing conditions.

1.3.4 Other Impacts of Fracking Activity

1.3.4.1 Fracking, Seismic Activity, and Travel Requirements

The disposal of wastewater from fracked wells has most commonly been achieved by deep well injection. In areas where deep well injection has been concentrated, there is evidence of increased seismic activity.(19) By 2013, geologists had confirmed that at least eight earthquakes of magnitude 5–6 *Mw* were induced by deep well injection in areas such as Oklahoma and Alberta, locations far from fault lines where such activity typically occurs.(32) Trucks haul wastewater from fracking areas to injection sites, so the location of the injection sites has a substantial impact on the miles of truck traffic required for fracking activities. For example, fracking in the Marcellus Shale typically requires disposal of wastewater under sandstone layers in Eastern Ohio, where the depth, up to 3 km below the surface, and other geological features make it suitable for deep well injection. In the area around Youngstown, Ohio, a number of small earthquakes from 2–3 *Mw* have been detected since the initial surge in fracking activity in 2010.(21)

These increases in seismic activity may impact the suitability or availability of deep-injection disposal sites. Given the high volume of truck traffic dedicated to wastewater disposal, the location of these sites has a significant impact on geographic distribution of fracking-related traffic. If additional seismicity results in changes to the location or method of disposal of wastewater to require hauling to more distant locations, the volume of truck traffic required for Marcellus Shale operations could potentially increase dramatically.

1.3.4.2 Impacts of Fracking on Road Surfaces

A major focus of studies on CMV traffic resulting from fracking activities has been impact on road surfaces. Rapid deterioration of road surfaces has been observed in all fracking areas, from Wyoming to Arkansas, in some cases with roads planned to have a 20-year service exceeding the planned traffic loadings in just a few months.[29 30] The cost of repairing roads damaged by shale gas development is approximately $2–3 million dollars per mile.[33] Such high costs per mile add up to substantial totals at the State level; in the first 5 years of the fracking boom in North Dakota, the cost of road repairs was already $900 million.[18] The economic impact of road damage is substantial, but beyond the cost to States, it is possible that such road damage can have an impact on road safety.

In response to the challenge of maintaining roads in fracking areas, Pennsylvania has developed an unusual road-surface maintenance program. Nearly all significant roads in the State are maintained at the State level, nearly 40,000 miles of roadway.[35] Following the advent of fracking around 2005, Pennsylvania found that since trucks were the primary mode used to transport materials needed for drilling, truck traffic had increased dramatically and road surfaces were wearing down quickly.[34]

Pennsylvania instituted a posting and bonding requirement, in which companies responsible for overweight trucking on specific roads obtain a permit, post security, and submit a maintenance plan to use the roadway. In this system, one large energy company, Chesapeake Energy, invested nearly $300 million in 2013 to maintain 400 miles of roads.[35] The cost of maintaining roadways in the Marcellus Shale area for a single well has been estimated at $13,000-$23,000 per well.[36]

In Texas, road service life has been estimated to be reduced by 5.6 percent due to rigging, 29 percent due to construction, and 16 percent due to saltwater traffic.[7] Construction of well pads involves the heaviest trucks and causes the greatest damage, despite the duration of construction activities being limited to several weeks.

1.3.5 Summary of Fracking Activity and Crash Trends

The extant literature correlates fracking activity with increases in the number of CMV crashes (see Table 2). Additionally, there are indications that the rate of crashes for fracking-related CMV traffic may exceed that of other CMV traffic. Strong differences in the timing and number of crashes emerge between regions. Regions with less history of energy resource production, such as North Dakota, show the strongest trends of crash increases during rises in fracking activity. Table 2 summarizes these trends across the three focal regions, with the vast majority of findings across the literature indicating increased vehicle crash rates overall, along with increased rates of injurious or fatal crashes and increased rates for CMV crashes, specifically.

As oil prices fell in 2014–15, both fracking activity and related CMV traffic fell to low levels. Oil prices were rising as of 2017; therefore, a spike in CMV crashes may be expected if fracking activity also rises. Future research should focus on how to determine the effect of price changes on fracking activities on CMV crashes, taking into account regional differences, and work to predict where increased enforcement efforts may be needed.

Table 2. Summary of motor vehicle crash trends related to fracking activities since 2000.

Vehicle Type	Crash Type	State	Timeframe	Trends	Reference
CMV	Injury/ Fatal	ND	2007-2013	500% increase in injury crashes	1
CMV	-	ND	2004-2013	Increase in large truck crashes	2
CMV	-	ND	2005-2011	1,224% increase in large truck crashes	3
CMV	-	ND	2007-2013	500% increase in CMV crashes	1
CMV	-	ND	2007-2013	Increase in driver and vehicle out-of-service (OOS) rates	1
CMV	-	ND	2014	370 CMV crashes per 100,000 people in oil counties, 56 per 100,000 in non-oil counties	4
CMV	-	PA	2007-2009	* No increase in all crashes or CMV crashes	5
CMV	-	PA	2010-2013	61–65% increase in CMV crashes	6
-	Injury/ Fatal	ND	2005-2011	550–600% increase in injury and fatal crash rates	3
-	Injury/ Fatal	TX	2008-2011	40% increase in fatal motor vehicle accidents	7
-	Injury/ Fatal	TX	2008-2013	49% increase in fatalities and serious injuries	8
-	Injury/ Fatal	TX	2010-2013	Multiple fatality accidents more than doubled from 72 to 148	9
-	Injury/ Fatal	TX	2013-2014	13% increase in crashes resulting in serious injury or fatality	9
-	Injury/ Fatal	US	2003-2013	27.6% increase in work-related fatalities in oil and gas industry, despite overall decline in occupational fatalities	10
-	Injury/ Fatal	US	2003-2013	40% of fatalities attributed to transportation incidents	10
-	Injury/ Fatal	US	2003-2013	* 4% decrease in fatality rates across all oil and gas workers	11
-	Injury/ Fatal	US	2003-2013	40.3% of fatalities in oil and gas industry from transportation	11
-	-	ND	2004-2013	188.9% increase in all vehicle crashes	2
-	-	PA	2007-2009	* No increase in all crashes or CMV crashes	5
-	-	PA	2010-2013	15–25% increase in all vehicle crashes	6
-	-	TX	2003-2009	Total crashes, crash rates per 100 million VMT increased	12
-	-	TX	2008-2013	26% increase in all vehicle crashes	8

Note: All trends reported in the literature show increases in the total amount of vehicle crashes, with the exception of the three results indicated by an asterisk.

References: 1) FMCSA, 2015; 2) Kubas and Vachal, 2014; 3) Kubas and Vachal, 2012; 4) Kubas and Vachal, 2015; 5) Scheetz et al., 2013; 6) Graham et al. 2015; 7) Adgate et al., 2014; 8) Rahm et al., 2015; 9) Paraventi, 2015; 10) Mason et al., 2015; 11) Retzer et al., 2015; 12) Quiroga et al., 2012. See the References section at the end of the report for full bibliographic information.

2. ANALYSIS

This section presents Volpe's independent analyses of the relationship between fracking activity and CMV crash risk in three focal States, building off the literature review summarized in Section 1. These analyses use data on CMV crashes maintained by FMCSA (notably the Motor Carrier Management Information System (MCMIS)), data on fracking activity maintained by State agencies, data on road networks and travel from FHWA, and geographic and demographic data from the U.S. Census Bureau.

These analyses address four questions:

1. How much has fracking activity impacted CMV crash risk?
2. How strong is this relationship in different contexts?
3. What are the safety and violation rate profiles of carriers associated with fracking activity?
4. What spatial pattern emerges from the relationship between fracking activity and CMV crashes? That is, how are crash location distributions affected by the presence of fracking wells?

2.1 SCOPE AND OBJECTIVES

The analysis of fracking-related CMV crashes focuses on crashes that occurred in North Dakota, Pennsylvania, and Texas. As outlined in the literature review in Section 1, these three States can be taken as representative of fracking activity across the United States. North Dakota represents the regions where fracking for crude oil is a new economic activity, situated as it is in the upper Midwest where energy extraction had not been a large sector of the economy, and where the road network had not previously faced such a surge of trucking activity. Pennsylvania represents Appalachia, where fracking for natural gas has partially supplanted coal mining, but where energy extraction represents a small portion of overall trucking activity in a State dominated by a variety of industrial transportation. Finally, Texas has a long history of energy resource extraction over large geographic areas, with fracking for natural gas and crude oil adding to a mature oil extraction industry.

The next sections describe how the study team carried out each analysis in general and summarizes the major conclusions of each analysis. More details are available in the appendices.

2.2 ANALYSIS BY TOPIC

2.2.1 Measuring Fracking Activity and Crash Risk

Fracking activity can be measured by the number of fracking wells initiated at a given location over a specified time period. While wells vary in lifespan and total productivity, by far the largest portion of CMV-related activity for each well is associated with the initial preparation of a well site and the initial hydraulic fracturing. Accordingly, the study team focused on the initiation period and specific location of a fracking well. For example, the first analysis relies on a tabulation of fracking wells initiated in each county within each calendar year. A main assumption is that CMV activity related to wells is proportional to well initiation counts.

A more detailed analysis, which would have accounted for the volumes of equipment and material required for well construction and operation, and for the transport of gas or oil and waste materials generated by these operations, was not feasible given the lack of data.

Crash risk is measured by number of reported CMV-involved crashes, categorized by severity, within a location or time period. To determine crash risk associated with specific motor carriers, vehicles, or drivers, surrogate measures are often used. CMV carriers and drivers regulated by FMCSA are subject to frequent inspections for compliance with numerous safety regulations. Their violation profiles have been shown to reflect crash risk.[iv] The focus in these analyses is on the counts of CMV crashes, both fatal and non-fatal, at the county level or other geographical scales as appropriate.[v]

Producing accurate results requires care in the choice of units for time and location. This study uses calendar year increments, with the assumption that crashes associated with a fracking activity occur within the year of that activity. Similar determinations for location are more complex, particularly for spatial associations. For example, counts of crashes, or aggregate surrogate measures of crash risk, are useful for generalizations at the State level. But the underlying geographic associations between fracking and crashes rely not only on the specific locations of the fracking activity, but also on other factors dispersed within the State (and beyond its boundaries), such as CMV routes, roadway characteristics, traffic, population, and commercial development. Geolocated data (with points located by latitude and longitude) offer a means for defining and testing spatial relationships, but geolocated data is not always available.

Matching these considerations with a review of the data sources available, the study team compiled data on well locations, dates of initiation, location, and other relevant characteristics for each of the three focal States from 2000 to 2016. Well location and count data came from State and National sources. CMV carrier characteristics, including violation rates, were available in a consistent format for 2013–16. CMV crash data were available at the county level for all three States, and all CMV crash data (including non-fatal crashes) were available in a geolocated format for North Dakota for 2012–16. Given that the spatial resolution and available data years differ by source, the study years vary for the different analysis steps. Full details on data sources and preparation are available in Appendix D.

[iv] Crash risk associated with specific carriers, or groups of carriers, can be assessed using surrogate measures formulated for FMCSA's Safety Measurement System (SMS) which are enumerated and maintained in MCMIS. These include the carrier's Behavior Analysis and Safety Improvement Category (BASIC) percentiles, BASIC alert status, and Vehicle and Driver Out-of-Service (OOS) rates.

[v] Crash risk can be further expressed in terms normalized by exposure, for example by using amount of traffic on a roadway segment and length of a segment. Crashes per roadway mile (in a year) may be inherently more meaningful than simply crashes per year for a geographic area like a county, by providing estimates of crash risk associated with a particular road segment. For this study, the lack of available detailed crash data by road segment precluded such normalization.

2.2.2 Overall Trends in Fracking Activity and CMV Crash Risk

Increases in fracking wells are associated with increased CMV crashes. From 2000 to 2016, there is a clear pattern of increasing numbers of CMV crashes in a county with increasing numbers of wells drilled. Plotting the number of CMV crashes per new well drilled per county per year results in a nearly linear trend for North Dakota, and positive but less obvious trends for Pennsylvania and Texas, as shown in Figure 6.

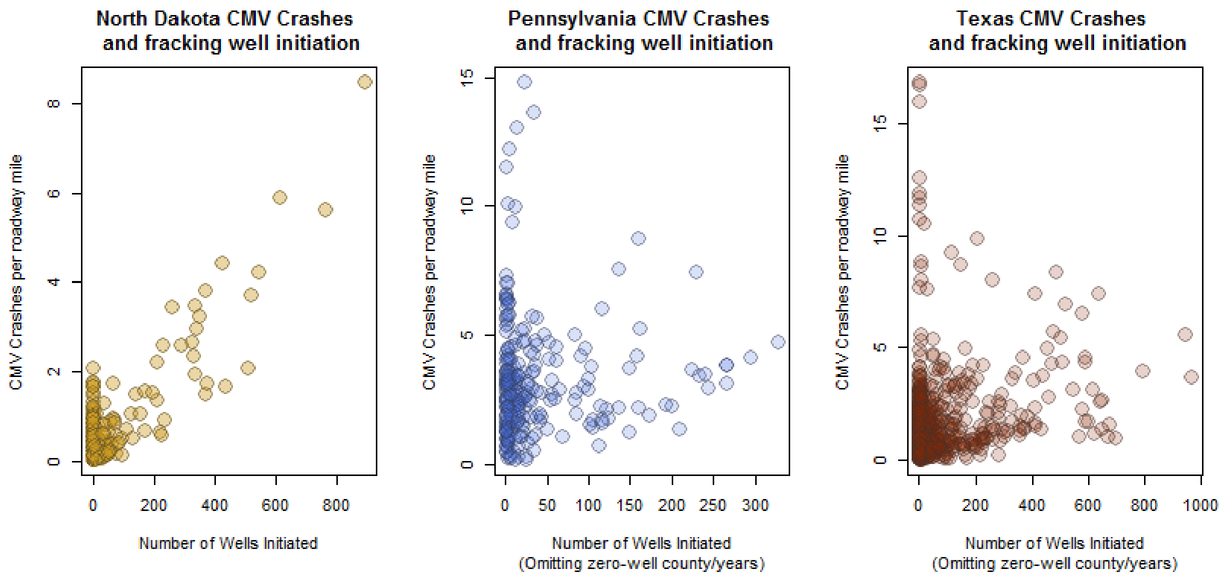

Figure 6. Scatterplot. Relationship between fracking wells initiated and total CMV crashes at the county level, 2000–16. The circles in each chart represent distinct counties in each State in one of the study years.

Across the three focal States, the number of CMV crashes varies by a factor of over 30 (6,187 to 214,243 crashes) and the number of fracking wells initiated varies by a factor of nearly 6 (9,540 to 55,757 wells, as shown in Table 3). Note that significant temporal factors (namely, the fracking boom from 2011 to 2014) and some aspects of spatial variation (such as the co-location of CMV crashes near areas of intensive fracking activity) are not captured in this summary table.

Table 3. Descriptive statistics for North Dakota, Pennsylvania, and Texas, for years where data were available for all States: 2004, 2005, 2008, 2010–16.

Metric	ND	PA	TX
Number of counties	53	67	254
Number of fracking wells initiated	14,071	9,540	55,757
Total CMV crashes	6,187	88,624	214,243
Total fatal CMV crashes	317	2,440	6,554
Crashes per well	0.44	9.29	3.84
Fatal crashes per well	0.02	0.26	0.12

Table 4 groups counties by number of fracking wells initiated in the noted years, with three categories: zero (0) fracking wells, 1–250 wells, and more than 250 wells. These broad categories were selected for illustrative purposes; detailed analyses of number of crashes and number of fracking wells initiated per county per year are presented in Appendix A.

Table 4. Demographic, CMV crash count, and CMV crash risk statistics for counties in North Dakota, Pennsylvania, and Texas.*

State	Well Group	Number of Counties	Total Population	Average Population per County	Total CMV Crashes	Average CMV Crashes per County	Road Miles	Average Road Miles per County	Average CMV Crashes per 1,000 Miles	Total AADT	Average CMV Crashes per 10,000 AADT
ND	0	36	504,690	14,019	201	5.58	41,292	1,147	4.87	2,003,489	1.00
ND	1–250	9	114,315	12,702	45	5.00	11,233	1,248	4.01	510,412	0.88
ND	>250	8	53,586	6,698	22	2.75	8,661	1,083	2.54	314,099	0.70
PA	0	34	8,712,222	256,242	5,586	164.29	34,700	1,021	160.98	35,541,714	1.57
PA	1–250	24	2,793,944	116,414	1,756	73.17	21,324	888	82.35	11,154,631	1.57
PA	>250	9	1,196,213	132,913	724	80.44	11,174	1,242	64.79	4,858,661	1.49
TX	0	62	4,564,522	73,621	1,839	29.66	113,071	1,824	16.26	19,744,052	0.93
TX	1–250	148	16,816,047	113,622	8,008	54.11	299,049	2,021	26.78	74,908,249	1.07
TX	>250	44	3,764,992	85,568	1,771	40.25	99,891	2,270	17.73	20,315,594	0.87

*Counties within each State are summarized by groupings of fracking well activity ("Well Group"), for the number of fracking wells initiated in each county for years where data are available for all States: 2004, 2005, 2008, 2010–16.

Table 4 indicates that, in general, counties with higher amounts of fracking activity do not show higher CMV crash risk within these broad categories, but the summary data do not account for other variable crash risk factors associated with each county.

2.2.3 County-level Relationship between Fracking Activity and CMV Crash Risk

Within each State, counties vary widely in the number of fracking wells initiated, from zero to 325 (PA), 896 (ND), or 966 (TX) wells per county per year. Geology, accessibility, and economic conditions for industrial-scale production all influence fracking well sites.

Counties also have different crash risk due to non-fracking factors, including properties of the road network, existing traffic levels, and non-fracking determinants of travel demand. Still, a statistically significant and strong positive relationship between number of fracking wells and CMV crashes was detected across all three States, accounting for AADT, roadway miles, county population, and other factors which differ between counties. A detailed description of this analysis is provided in Appendix A.

In a typical county in North Dakota, for every 100 wells initiated, 18.2 more CMV crashes per year occurred. Given that some counties initiated nearly 900 wells at the peak of the boom, this would result in an estimated 163.8 more truck crashes in such counties due to fracking activities. In a typical county in Pennsylvania, the relationship was also significant, with every 100 wells initiated corresponding to an additional 12.3 CMV crashes per year. In a typical county in Texas, 11.4 more CMV crashes occurred per year, per 100 wells initiated. In all three States, other variables (sum of roadway miles, population, and AADT) were significant predictors of CMV crashes, but to different extents for each State.

2.2.4 Spatial Relationships between Fracking Activity and CMV Crash Risk in North Dakota

The county-level analysis presented above showed statistically significant relationships between fracking activity and CMV crashes for all three States. It did not account for precise locations of individual wells and crashes, which could clarify relationships between fracking activity and CMV crash risk. More precise location data could differentiate between direct impacts (crashes at well sites, crashes by CMVs engaged in fracking transportation) and indirect impacts (crashes resulting from increased general traffic or overburdened infrastructure).

Well locations by latitude and longitude are available for all wells in each of the States. Only North Dakota provided similar geolocated data for CMV crashes, with Police Accident Reports provided by FMCSA's North Dakota Division Office. Therefore, only North Dakota supported this additional layer of analysis.

This analysis used both grid-based and point-based approaches to associate locations of fracking activity and locations of CMV crashes. For the "grid-based" approach, grids of 10, 25, and 100 square miles were created over the State of North Dakota. These correspond to 5,133 grid cells sized 10mi^2, 2,645 grid cells sized 25mi^2, and 823 grid cells sized 100mi^2 to cover the State of North Dakota. The estimated number of crashes, as predicted by count of fracking wells initiated, was modeled for each grid cell over the time period of interest. The second approach used a "point-based" method to assess the relationship between the distance from a fracking well and the number of CMV crashes. In both approaches, tests of all crashes, fatal crashes, and non-fatal crashes were conducted separately. Details of these analyses are provided in Appendix B.

The grid-based model found that the number of wells initiated in an area accounted for 1–7 percent more crashes overall, depending on the size of the grid cell and the type of crash. Focusing on fatal crashes, at the smallest grid cell size (10 mi^2), fracking well initiation accounted for 7.1 percent more fatal crashes. At the largest grid cell size (100 mi^2), this effect was more muted, at 1.9 percent more fatal crashes, but still statistically significant. Non-fatal crashes followed a different pattern, with the strongest effect at 25 mi^2 grid cells, with well initiation accounting for 4.5 percent more non-fatal crashes.

The point-based analysis considered the number of fatal and non-fatal crashes that occurred in a 1- or 5-mile radius around a fracking well location. Considering the raw counts of crashes near well and non-well locations alone, with no statistical modeling, there is no increase in non-fatal crashes observed near fracking wells within either distance, as shown in Table 5.

Table 5. Average number of crashes (non-fatal and fatal) within different radii around non-well or well locations in North Dakota, 2012–16.

Crash Type	Location	Average Number of Crashes in a 5-mile Radius	Average Number of Crashes in a 1-mile Radius
Non-fatal	Non-well	7.664	0.517
Non-fatal	Well	2.608	0.084
Fatal	Non-well	0.034	0.002
Fatal	Well	0.036	0.002

However, well and non-well locations differ in their roadway characteristics. After correcting for this difference in the exposure to roadway traffic using the AADT provided by HPMS, the point-based statistical models found that proximity to a fracking well location increased the risk of both fatal and non-fatal crashes, mirroring the grid-based results. Within 5 miles of a fracking well, there was a 51.9-percent greater chance of a fatal crash occurring compared to a non-well location with similar roadway characteristics. There was also a 22.3-percent greater chance of a non-fatal crash occurring within 5 miles of a fracking well compared to a non-well location. The model showed mixed results at a 1-mile radius. At the smaller radius, fatal crashes were rare for all cases. The small sample size may account for the mixed results.

2.2.5 Differences in CMV Crash Risk between Motor Carriers in the Fracking Sector and Other Carriers

Our analysis of carriers associated with the fracking sector found mixed results on whether safety and compliance issues were elevated compared to non-fracking-associated carriers.

2.2.5.1 Identification of Motor Carriers in the Fracking Sector

The study group considered several approaches for identifying motor carriers operating in the fracking sector, including carrier domicile location and dates, types of vehicles operated, commodities hauled, carrier operating locations and dates, and interviews with FMCSA enforcement personnel in fracking regions.

It was not possible to identify industrial sectors simply from cargo transported or vehicle type because many of the materials used in fracking are common to multiple industries (e.g., sand and water). Therefore, the study team developed a methodology based on the proportion of a carrier's activity (as reflected in their inspections and crashes) that occurred within a certain distance of a fracking well. Details of this methodology are laid out in Appendix C. The results of this methodology were cross-checked with data from interviews with FMCSA enforcement personnel in fracking regions to validate the approach.

Table 6. Number of carriers operating, by fracking association.*

State	Associated Carriers	Non-associated Carriers
ND	1,666	16,424
PA	4,076	123,461
TX	16,230	213,674

*See Appendix C for details on association scoring.

2.2.5.2 Regulatory Compliance of Fracking-associated and Non-associated Carriers

The study team used three methods of assessing regulatory compliance:

1. **Behavior Analysis and Safety Improvement Category (BASIC) Percentiles.** These scores accurately show how a carrier ranks against a comparable set of carriers based on number of power units, VMT, and other factors. These values provide the most detailed look into how fracking-associated and non-associated carriers compare. It should be noted that the majority of carriers do not receive a BASIC percentile score.

2. **BASICs in alert status.** Carriers can be assigned to alert status in a BASIC when they have a percentile above a certain threshold in that BASIC (see Table 7 for thresholds). Carriers with a percentile above the threshold are flagged as potentially unsafe in a specific BASIC. The majority of carriers are not in alert status across the BASICs.

3. **Vehicle and driver OOS rates.** These indicate the rate of vehicle- or driver-focused inspections that resulted in an OOS violation.

Note that BASICs are calculated at the carrier level; for carriers with large operations spanning multiple States, percentiles and alert status may reflect a national average of regulatory compliance, not regulatory compliance within the particular State. In comparison, OOS rates are calculated per carrier per inspection and therefore accurately reflect the results of inspections for a given carrier within a State.

BASIC Percentiles

According to BASIC percentiles, fracking-associated carriers did not show a clear and consistent difference in safety performance relative to non-fracking-associated carriers. Fracking-associated carriers had significantly lower BASIC percentiles for "Unsafe Driving" across all three States, indicating better safety records. After accounting for carrier size, VMT, and other factors included in percentile calculations, carriers assessed as consistently associated with fracking activity had fewer unsafe driving violations than non-associated carriers.

Other results varied. In North Dakota, fracking-associated carriers performed significantly worse in “Driver Fitness” than non-associated carriers. In Texas, fracking-associated carriers were significantly better in “Vehicle Maintenance” than non-associated carriers. Table 7 shows carrier outcomes by fracking association, along with the odds ratio for each BASIC and OOS rate as a predictor of fracking association. Odds ratios are statistical associations from a logistic regression, and show the direction and strength of a relationship—in this case, between fracking association and the corresponding BASIC percentile. Odds ratios greater than one indicate a positive relationship (worse performance); values less than one indicate a negative relationship (better performance). Statistically significant relationships are marked with an asterisk.

Table 7. Mean BASIC percentiles and modeled odds ratios by BASIC and by fracking association, 2013–16.

BASIC and percentile threshold for "alert" status	ND Fracking-associated Carrier: BASIC Percentile	ND Non-associated Carrier: BASIC Percentile	ND Odds Ratio	PA Fracking-associated Carrier: BASIC Percentile	PA Non-associated Carrier: BASIC Percentile	PA Odds Ratio	TX Fracking-associated Carrier: BASIC Percentile	TX Non-associated Carrier: BASIC Percentile	TX Odds Ratio
1. Unsafe Driving 65%	20.35	41.73	0.91*	30.48	49.36	0.93	28.17	46.54	0.96*
2. HOS Compliance 65%	55.34	57.81	1.01	50.27	62.82	1.01	53.67	63.44	1.01
3. Driver Fitness 80%	75.94	61.35	1.06*	69.83	69.77	1.01	82.54	72.91	1.03
4. Controlled Substances/ Alcohol 80%	34.45	27.94	1.07	30.93	35.16	1.01	43.93	40.01	0.99
5. Vehicle Maintenance 80%	58.85	51.82	0.95	45.98	53.56	0.99	67.15	66.51	0.95*
6. Hazardous Materials Compliance 80%	79.69	65.34	1.14	72.55	64.25	1.01	79.46	65.87	1.01

Note: Odds ratios of less than 1 indicate fracking-associated carriers had lower (better) scores in this BASIC.

*Statistically significant differences. Statistical significance accounts for the variability in percentiles, in addition to the difference in the mean values.

BASIC Alerts

Examination of BASICS in alert status for all States shows substantially fewer fracking-associated carriers in alert status for the "Unsafe Driving" and "Driver Fitness" BASICs (as shown in Table 8). These results are consistent with the mean "Unsafe Driving" percentile results in all States for "Unsafe Driving." Only in Texas did fracking-associated carriers have a significantly higher mean percentile for "Driver Fitness," indicating worse performance. Otherwise the results are not consistent for any of the BASICs across the three States. For "Vehicle Maintenance," significantly more fracking-associated carriers were in alert status in all States, while the mean percentile was significantly lower in Texas and not different in North Dakota and Pennsylvania. For "Controlled Substances," significantly more fracking-associated carriers were in alert status in North Dakota and Texas, while there were no differences in mean percentile in any of the States. These inconsistencies make it difficult to infer distinctions in the safety profile of carriers in the fracking sector based on BASICs in alert status.[vi]

Table 8. Number of carriers in alert status (above percentile threshold) for each non-crash BASIC, by fracking association, 2013–16.

BASIC and percentile threshold for "alert" status	ND Associated Carriers	ND Non-associated Carriers	PA Associated Carriers	PA Non-associated Carriers	TX Associated Carriers	TX Non-associated Carriers
1. Unsafe Driving 65%	30	1,523	124	10,078	256	10,028
2. HOS Compliance 65%	273	3,343	373	19,395	1,442	34,022
3. Driver Fitness 80%	103	652	174	3,681	706	5,464
4. Controlled Substances/ Alcohol 80%	21	217	25	1,329	178	3,425
5. Vehicle Maintenance 80%	193	1,268	245	10,371	3,295	37,994
6. HM Compliance 80%	67	235	80	558	268	886

[vi] BASIC percentiles provide a more accurate representation than BASIC alerts, since alert status is a binary classification based on the continuous values for percentiles.

Vehicle and Driver Out-of-Service Rates

An alternative to using BASICs to assess carriers is to look at the vehicle and driver OOS rates. This metric is the number of vehicle inspections which resulted in an OOS violation divided by the total number of vehicle inspections for that carrier, and the same for driver inspections. Unlike the calculations using the BASICs, those for OOS rates can be limited to OOS violations within the State of interest.

In North Dakota and Texas, fracking-associated carriers had significantly higher Vehicle and Driver OOS rates than did non-fracking carriers (see Figure 7 and Table 9), indicating worse performance. In Pennsylvania, there was no significant relationship between vehicle OOS rates and fracking association; further, fracking-associated carriers had significantly lower driver OOS rates, indicating better performance. Figure 7 shows high variability in these relationships (as indicated by the large error bars.

Table 9. Vehicle and driver OOS rates and modeled odds ratios, by fracking association.

Category	ND Fracking-associated Carrier: OOS Rate	ND Non-fracking Associated Carrier: OOS Rate	ND Odds Ratio	PA Fracking-associated Carrier: OOS Rate	PA Non-fracking Associated Carrier: OOS Rate	PA Odds Ratio	TX Fracking-associated Carrier: OOS Rate	TX Non-fracking Associated Carrier: OOS Rate	TX Odds Ratio
Vehicle	0.116	0.073	2.00*	0.254	0.212	0.96	0.537	0.385	1.80*
Driver	0.084	0.054	1.53*	0.064	0.094	0.56*	0.147	0.095	1.52*

Note: Odds ratio values greater than 1 indicate fracking-associated carriers had higher OOS rates.

*Significant relationships.

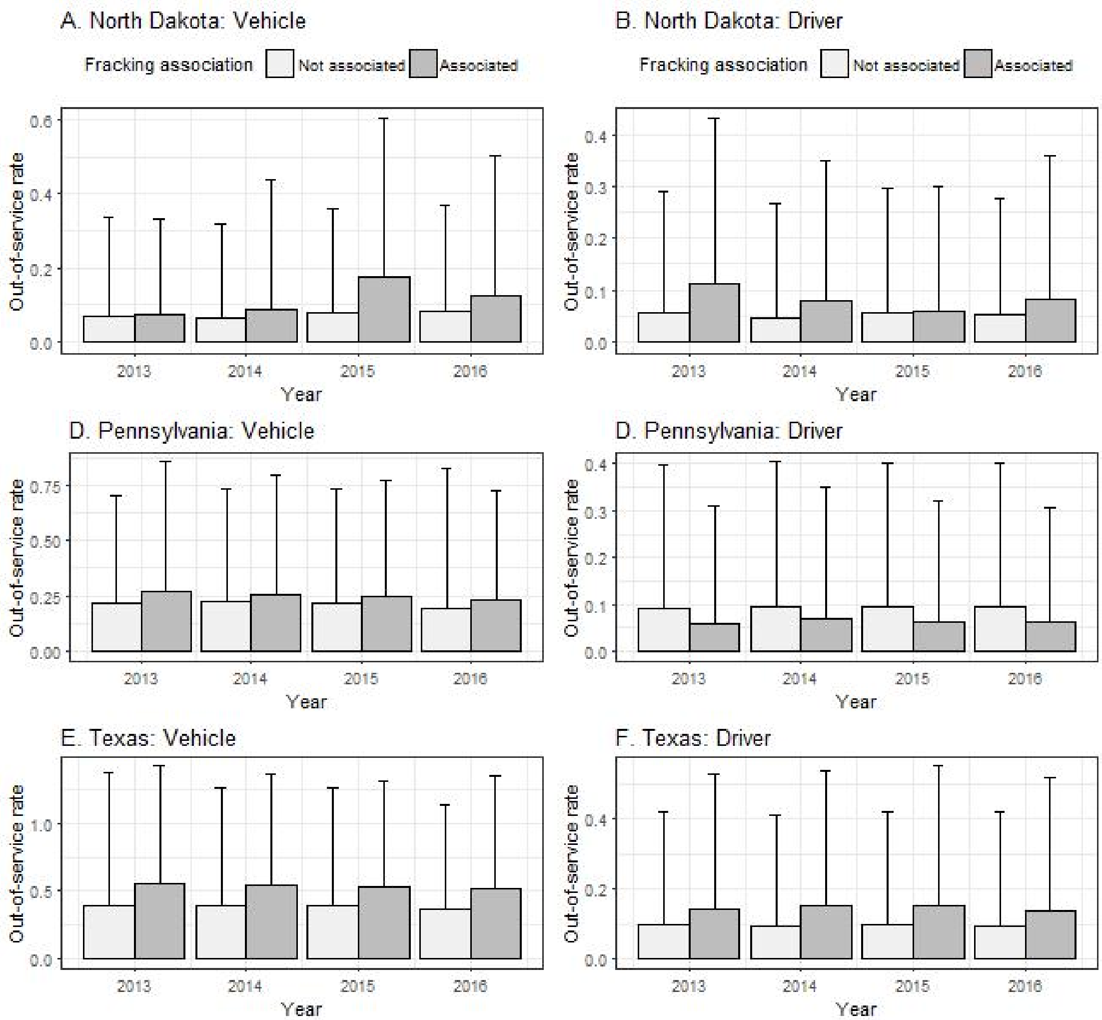

Figure 7. Grouped bar chart. Vehicle and driver OOS rates for fracking-associated and non-associated carriers, for North Dakota, Pennsylvania, and Texas, 2013–16.

Notes: Higher OOS rates indicate relatively worse safety performance. Mean values and one standard deviation are shown; the height of the bar represents the mean OOS, and the whisker represents one standard deviation above the mean.

2.2.6 Indications of Possible Misuse of Special Hours-of-Service Exemptions by Carriers Involved in Fracking Activity

Currently, FMCSA does not receive any inspection or investigation data indicating when an HOS exemption has been granted. This makes it impossible to consistently determine which carriers have requested such exemptions, along with whether they were appropriately granted and when.

State officials provided some anecdotal information on general compliance with HOS regulations and the practice of granting HOS exemptions. Motor carriers in the fracking sector are familiar with and make appropriate use of the "24-hour restart" provision provided by Section 395.1(d)(1). They are also aware of the "waiting time" provision in Section 395.1(d)(2).

Enforcement officials have observed some carriers trying to apply the "waiting time" provision outside its intended purpose.[vii] North Dakota officials observed compliance issues on this topic, particularly from 2009 to 2011, but found that motor carrier compliance with the intent of the "waiting time" provision improved following heightened enforcement.

Analysis of the HOS compliance of the fracking sector, as reflected in the HOS BASIC percentiles of fracking-associated carriers, shows that the fracking sector exhibits lower HOS compliance than other motor carrier sectors, but this trend was not statistically significant (see Figure 8). For all three States, HOS BASIC percentiles for fracking-associated carriers were not statistically significantly different from non-associated carriers.

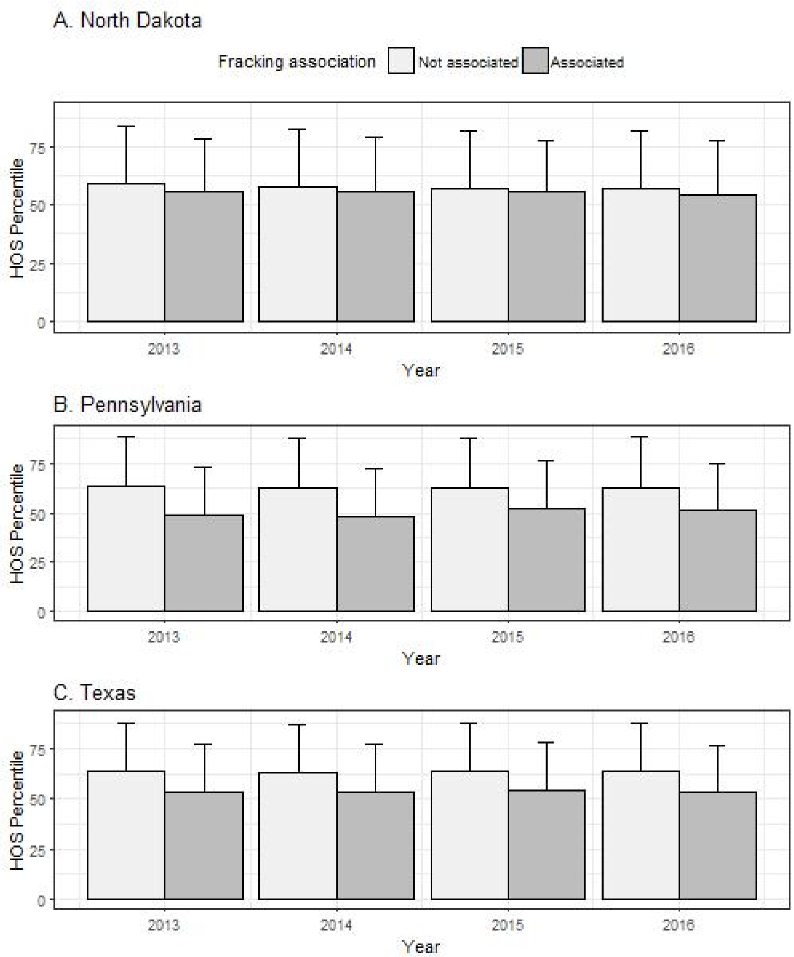

Figure 8. Bar chart. Carrier HOS BASIC percentiles, by fracking association, for carriers in North Dakota, Pennsylvania, and Texas, 2013–16.

Notes: Mean values +1 standard deviation are shown. Lower values indicate lower performance relative to peer carriers. Height of the bar represents mean percentiles, and the whisker represents one standard deviation above the mean.

[vii] The "specially constructed" CMVs in Section 395.1(d)(2) are a narrower category than the "oilfield equipment" in Section 395.1(d)(1)).

2.3 SUMMARY OF FINDINGS

The analyses show that fracking wells significantly increase the risk of CMV crashes occurring in the vicinity of these wells, with fatal crashes being of particular concern. Geospatial analysis of CMV crash trends over time shows a distinct increase in crashes associated with fracking activity. The study team found this relationship across all focal States and across smaller geographic scales for North Dakota, where finer-grained spatial analysis was possible; the North Dakota data included precise latitude and longitude coordinates for crashes, allowing exact measurement of distances between crash locations and well sites. As in other States' data, the North Dakota data represented all reported CMV-involved crashes in all locations, not only on highways.

There were significantly more crashes near fracking wells than other locations, and fatal crashes were substantially more frequent in close proximity to fracking wells for North Dakota. The grid-based spatial analysis approach, which considers all areas of the State and tests the effect of fracking well initiation on crash counts, shows a consistent, statistically significant, but small positive causal relationship between fracking wells and crashes of all types. The point-based approach takes a more narrow focus, and examines just the regions in the immediate vicinity of fracking well locations, compared to similar areas not centered on fracking wells. It found mixed results, possibly due to the small sample size.

This increase in crashes associated with fracking activity is not principally due to less safe carrier behavior, but rather to increased total volume of CMV traffic associated with fracking activity. Carriers involved in fracking activity showed some differences in safety performance compared to non-fracking carriers, but these differences did not describe a single nationwide trend. When assessing multiple metrics of carrier safety, the study team found fracking-associated carriers tended to have lower overall safety performance, but these trends were not consistent across States and measures. The most consistent trend showed higher vehicle and driver OOS rates for carriers in the oil-producing States of North Dakota and Texas, but carriers in Pennsylvania did not show the same trend.

An analysis of HOS compliance did show that carriers in the fracking sector showed lower rates of compliance than other carriers, which suggests that there may be incentives for circumventing regulations (such as the 24-hour restart and waiting time rules), but these differences were small and not statistically significant.

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3. CONCLUSIONS

The review of the literature and independent analyses of the data find that there is a clear and statistically significant relationship between increased fracking activity and increased CMV crash risk, due largely to the increased volume of CMV traffic in times and places of intense fracking activity. The spatial pattern of CMV crashes showed significantly more crashes near fracking wells than other locations, and fatal crashes were significantly more frequent in close proximity to fracking wells for North Dakota (the one State in this study with enough detailed data to support fine-grain spatial analysis).

Carriers involved in fracking activity showed some measurable differences in safety performance compared to non-fracking carriers, with unsafe driving and HOS violations tending to be more prevalent with fracking-associated carriers. Although there is anecdotal evidence of carrier misuse of special exemptions from HOS rules requiring 24-hour restart and waiting time, the study team could not find statistical data with which to identify these exemptions or sufficiently detailed operational data to verify their applicability.

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APPENDIX A: ANALYSIS DETAILS—CRASHES AND FRACKING WELLS INITIATED, BY COUNTY

The main analysis presented in this report is the county-level analysis of well initiation and CMV crashes. This analysis examines the association between CMV crashes and the number of new fracking wells initiated in each county each year for North Dakota, Pennsylvania, and Texas.

This analysis is based on Motor Carrier Management Information System (MCMIS) CMV crash records for counties in North Dakota, Pennsylvania, and Texas from 2000 to 2016. Well count data are from State and national sources. See Appendix D for more details.

Counts of wells initiated in a given year in a given county were used as a predictor for total CMV crashes, with county, year, AADT, miles of roadway, and population serving as additional predictors. The statistical approach employed is known as a mixed-effect linear model, where fixed effects (traditional statistical predictors) are mixed with random effects, which are grouping variables allowing for management of differences between groups of observations. In this analysis, county and year are used as random effects, essentially analyzing the trend in CMV crashes for each county over multiple years, with the other predictors as covariates.

This analysis includes moderating variables: the population size in each county and the total length of the roadway network in each county. Those variables are positively but not linearly related for the three focal States. Population information came from the U.S. Census Bureau's 2010 American Community Survey, while total roadway network length derived from FHWA's HPMS (HPMS, Appendix D).

In the 17-year period from 2000 to 2016, there is a clear pattern of CMV-involved crashes increasing with the number of wells drilled. Plotting the number of CMV crashes per new well drilled per county per year results in a nearly linear trend for North Dakota, and positive but less obvious trends for Pennsylvania and Texas, as shown in Figure 9.

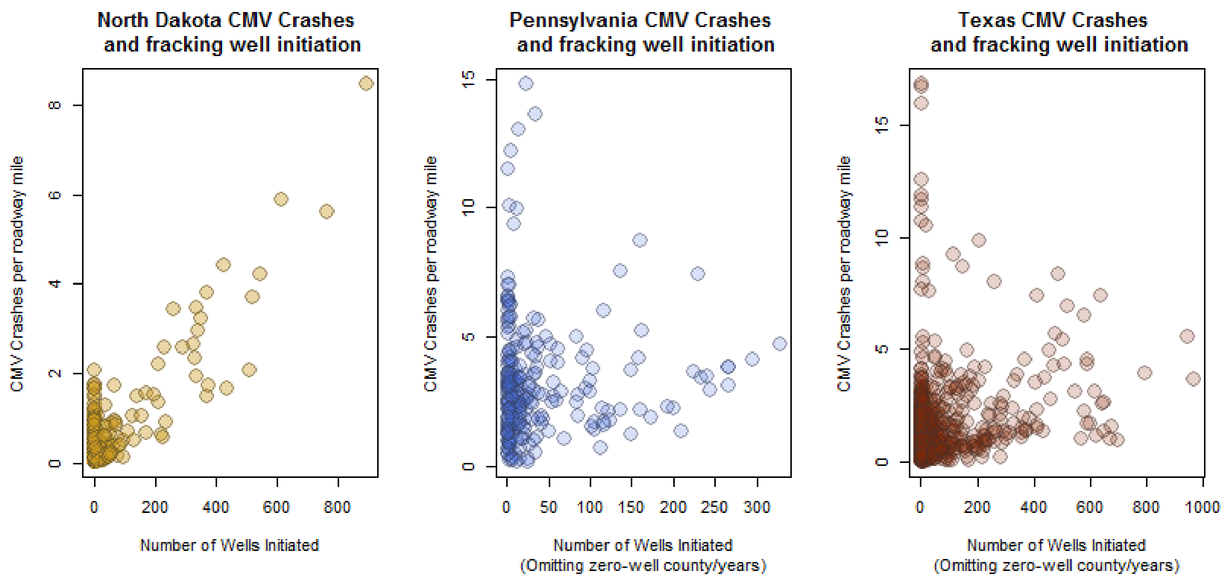

Figure 9. Scatterplot. Relationship between fracking wells initiated and total CMV crashes at the county level, 2000–16.

Distinct patterns emerge for each State over time, as shown in Figure 10. For each of the 53 counties of North Dakota over this 17-year period, the counties with the highest numbers of CMV crashes in a given year also had a large number of fracking wells initiated. For Pennsylvania and Texas, the relationships are less clear because of the high background number of CMV crashes. Still, the time periods corresponding to fracking activities are notable. Note that only State-level data on crashes are available for 2003–05 in North Dakota.

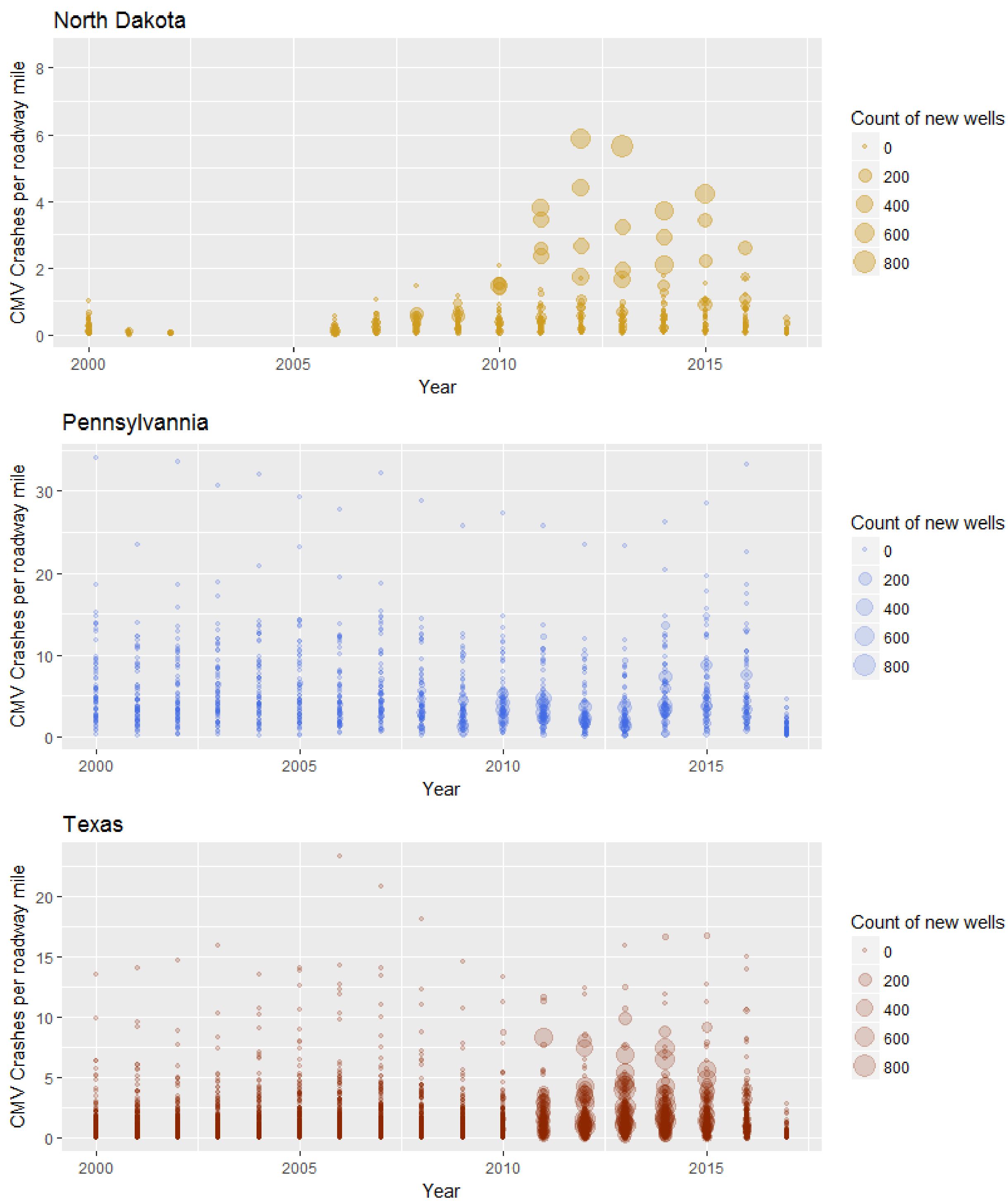

Figure 10. Scatterplot. Patterns of CMV crashes per roadway mile and fracking well initiation by county, over the study period 2000–16, for North Dakota, Pennsylvannia, and Texas.

The data being analyzed are the counts of new wells initiated in a given county in a given year and the corresponding number of CMV crashes. To account for the differences between counties, while producing a model which is general across all counties, we used a mixed-effect model with counties as “random effect” grouping variables. This type of model is appropriate when groups (counties) are heterogeneous, as is the case here. The model fits a separate regression for each county and takes into account the temporal relationship between years. Both features are important, because counties may differ widely in population, road density, and governance, and the year-to-year nature of the data means that data points for consecutive years are not independent. "Fixed effects" refers to predictor variables in the model that are directly measured for each county.

The full model is shown in Figure 11:

$$y_i = \beta_0 + \beta_1 Well\ count + \beta_2 Year + \beta_3 Population + \beta_4 Road\ miles + \beta_5 AADT + U_i + e_i$$

Figure 11. Equation. Mixed-effect model.

i indexes the county, and y_i is the response variable for the number of CMV crashes in that county, in that year, from MCMIS. β_0 refers to the overall intercept, while the terms β_1 to β_5 refer to the coefficients for each of the predictor variables:

- *Well count*: the number of new fracking wells initiated in that county in that year.
- *Year*: year of measurement.
- *Population*: 2010 Census total population of the county.
- *Road miles*: sum of the total roadway network length in the county, based on HPMS.
- *AADT*: sum of the average annual daily traffic (AADT) for the roadway segments in the county, based on HPMS.

A summary of the North Dakota county-level analysis output is shown in Table 10. The results reflect all 53 counties and 589 observations.

Table 10. Summary of North Dakota mixed-effect model of CMV crashes by fracking activity, year, population, and roadway characteristics for each county.

Variable	*B*	*CI*	*std. B*	*CI*	*p*
Intercept	**-6.6283**	-10.632 – -2.624	-	-	**.002**
Fracking well count	**0.1824**	0.173 – 0.192	**0.8140**	0.770 – 0.858	**<.001**
Year	**0.3794**	0.201 – 0.558	**0.0880**	0.047 – 0.129	**<.001**
Population	0.0001	-0.000 – 0.000	0.1145	-0.195 – 0.424	.471
Road miles (sum)	**0.2899**	0.080 – 0.500	**0.1120**	0.031 – 0.193	**.009**
AADT (sum)	<0.0001	-0.000 – 0.000	0.1070	-0.233 – 0.447	.540

This and the following summary tables (Table 11 and Table 12) show the outputs of the statistical models with two representations of the effect sizes. The effect size (*B*) and confidence interval (*CI*) are shown first in the original units of each predictor, like the number of wells. The value of *B* shows how each unit of the predictor results in one additional CMV crash in the average county for this State.

The following two columns show outputs of the effect sizes in standardized units (*std. B*) and the associated confidence interval. The standardized coefficients, also known as "*z*-scored" coefficients, are unitless. These are calculated by subtracting the mean and dividing by the standard deviation for each predictor. These values allow better comparison between predictors with very different scales, such as well count (0–896) and population (727–149,778). A larger value on the standardized scale exerts greater influence over the response variable.

The estimate of 0.182 indicates that for each additional well initiated within a generic county of North Dakota, 0.182 more CMV crashes can be expected each year; equivalently, every 100 wells initiated resulted in 18.2 more CMV crashes per year, for the typical county. Given that some counties initiated nearly 900 wells at the peak of the boom, this would result in an estimated 163.8 more truck crashes due to fracking activities.

Population, roadway network size, year, and AADT exert statistically significant but smaller effects on total CMV crash count. While greater population size and greater total miles of roadway do increase CMV crashes, these factors account for only 1/4 to 1/6 as much of the variance in CMV crashes created by new fracking wells.

County-level effects in North Dakota are generally in line with expectations based on which counties have the highest amounts of well activity. The population and roadway network variables explain discrepancies. For instance, Burleigh County has a high offset for crashes despite low fracking activity. Mountrail County, conversely, is in the heart of the Bakken Shale region, but has many fewer truck crashes than would be expected. These may be explained by non-fracking related truck patterns: Burleigh County has I-94 running through it and is the home of Bismarck, the capitol city, while Mountrail County is in the sparsely populated northwestern portion of the State. This analysis controls for these factors by accounting for population size, total roadway network length, and AADT in each county.

A summary of the Pennsylvania county-level analysis output is provided in Table 11. The results reflect all 67 counties and 1200 observations.

Table 11. Summary of Pennsylvania mixed-effect model of CMV crashes by fracking activity, year, population, and roadway characteristics for each county.

Variable	*B*	*CI*	*std. B*	*CI*	*p*
Intercept	**43.5799**	23.047 – 64.113	-	-	**<0.001**
Fracking well count	**0.1226**	0.047 – 0.198	**0.0331**	0.013 – 0.053	**0.002**
Year	**-2.3485**	-2.970 – -1.727	**-0.1023**	-0.129 – -0.075	**<0.001**
Population	**0.0002**	0.000 – 0.000	**0.4622**	0.288 – 0.636	**<0.001**
Road miles (sum)	0.9614	-0.257 – 2.180	0.0589	-0.016 – 0.133	0.125
AADT (sum)	**<0.0001**	0.000 – 0.000	**0.2412**	0.053 – 0.429	**0.013**

In Pennsylvania, there were 0.123 more truck crashes per fracking well initiated. With a maximum of over 300 new wells within a county at the peak, that corresponds to an estimated 40.2 more truck crashes due to fracking activities in the most active fracking county. The standardized coefficients show that the factors of population and roadway network size are much stronger predictors of total CMV crashes in Pennsylvania. While all factors are statistically significant, population size is the largest driver of CMV crashes in the State. In addition, there is a statistically significant decline in CMV crashes over time, with a negative coefficient for the predictor year. This negative coefficient for the predictor year indicates an overall downward linear trend in CMV crashes over time.

A summary of the Texas county-level analysis output is provided in Table 12. The results reflect all 254 counties and 4470 observations.

Table 12. Summary of Texas mixed-effect model of CMV crashes by fracking activity, year, population, and roadway characteristics for each county.

Variable	*B*	*CI*	*std. B*	*CI*	*p*
Intercept	-0.6292	-11.546 – 10.288	-	-	0.910
Fracking well count	**0.1137**	0.084 – 0.143	**0.0361**	0.027 – 0.045	**<0.001**
Year	-0.3136	-0.668 – 0.041	-0.0083	-0.018 – 0.001	0.084
Population	**0.0004**	0.000 – 0.000	**0.7092**	0.604 – 0.815	**<0.001**
Road miles (sum)	0.2916	-0.039 – 0.622	0.0290	-0.004 – 0.062	0.085
AADT (sum)	**<0.0001**	0.000 – 0.000	**0.1776**	0.066 – 0.290	**0.002**

For Texas, the similar coefficient of 0.114 for fracking well initiation corresponds to 110.1 more truck crashes at the peak of the boom for a county with over 900 new wells initiated.

As in Pennsylvania, county population is the largest single predictor of total CMV crashes. Total roadway network size is not as strong a predictor of CMV crashes in Texas as in Pennsylvania, and the number of fracking wells remains a statistically significant predictor of CMV crashes.

APPENDIX B: ANALYSIS DETAILS – SPATIAL ANALYSIS FOR NORTH DAKOTA

In addition to the county-level CMV crashes analyzed in Appendix A, geolocated CMV crash data were available for North Dakota for 2012–16, provided by the FMCSA Division Office in North Dakota. These data, shown in Table 13, represent 84,119 CMV crashes, sorted by crash severity. These data allow finer-grained spatial analysis of the association between fracking activity and CMV crashes.

Table 13. CMV crashes by year and severity for North Dakota, 2012-2016.

Crash Severity	2012	2013	2014	2015	2016
Fatal	147	133	121	111	102
Incapacitating Injury	487	445	424	443	353
Non-incapacitating injury	1,268	1,213	1,180	1,142	1,447
PDO	14,477	14,973	12,240	11,506	11,671
Possible Injury	2,002	2,246	2,270	2,094	1,624
Total	**18,381**	**19,010**	**16,235**	**15,296**	**15,197**

The study team combined these data with fracking well initiation data from North Dakota, sorted by year of well initiation (spud year).

Table 14. Fracking wells initiated in North Dakota, 2005–17.

Year	Number of Fracking Wells Initiated
2005	240
2006	348
2007	351
2008	637
2009	515
2010	1,183
2011	1,551
2012	2,136
2013	2,313
2014	2,653
2015	1,370
2016	619
2017	40

Both well and crash data are geolocated. To answer the question of how fracking activity informs crash locations, the study team took two approaches. First, a grid was created over the State of North Dakota, using three levels of resolution: 10, 25, and 100 square miles. These produce 5,133, 2,645, and 823 grid cells, respectively, to cover the State of North Dakota. The estimated number of crashes, as predicted by count of fracking wells initiated, was modeled for each grid cell over the time period of interest.

Second, a point-based method was used to assess how the distance from a fracking well affects the number of CMV crashes. This approach assessed the number of CMV crashes within a given radius (1 or 5 miles) around each well and compared those numbers with similar values for non-well locations. In both approaches, tests of all crashes, fatal crashes, and non-fatal crashes were conducted separately. Details for the statistical models used follow below. This analysis was conducted only for North Dakota because it is the only one of the three focal States for which consistent location data were available for all CMV crashes.

Grid-based approach

Grid cell size impacted the effect of well count on the number of crashes estimated, but the effect remained within a narrow range. In all cases, the number of wells initiated accounted for 1–7 percent more crashes over all. Focusing only on fatal crashes, at the smallest grid cell size (10 mi^2), fracking well initiation accounted for 7.1 percent more fatal crashes. At the largest grid cell size (100 mi^2), this effect was more muted, at 1.9 percent more fatal crashes, but it was still statistically significant. Non-fatal crashes followed a different pattern, with the strongest effect at 25 mi^2 grid cells, where well initiation accounted for 4.5 percent more non-fatal crashes.

We obtained these results by testing three types of statistical models, applied over three spatial resolutions, for all CMV crashes, fatal crashes only, and non-fatal crashes. Altogether, 18 statistical models were employed. We describe the structure, choice, and application of these models in the following section.

For the grid-based approach, the three types of statistical models were as follows:

- Poisson regression, which accounts for the integer nature of the response variable with random effects for grid cell IDs repeated across time periods. The random effect accounts for the non-independence of the same grid cell repeated over time. This is referred to below as the Poisson mixed-effect model.
- Poisson regression with an additional zero-inflated term to account for the large number of grid cells with zero crashes. Zero-inflated models are commonly used in analysis of crash data.(37) These models separate two processes: whether a crash occurred (a binomial process), and then how many more crashes are due to each of the predictor variables (a Poisson process). This is referred to below as the zero-inflated Poisson model.
- Poisson regression with zero-inflated term and random effect of grid cell, resulting in a zero-inflated Poisson mixed-effect model.

For each of these models, the main relationship of interest is how crashes (all, fatal, and non-fatal) are affected by the number of fracking wells in a given time period within a grid cell. In addition, measures of exposure were included, using AADT and the sum of roadway miles within a grid cell—data extracted from FHWA's HPMS.

Overall, the zero-inflated Poisson mixed-effect models (the third option) did not perform substantially better than non-zero inflated models. The models were compared using Akaike

Information Criterion (AIC), a commonly used metric that evaluates how well the model estimates fit the data after taking into account a penalty for adding additional parameters. Zero-inflated non-hierarchical models performed substantially worse than non-zero inflated mixed-effect models (the first option). Therefore, the focus of this analysis is on the Poisson mixed-effect models.

The best statistical model, the Poisson mixed-effect model, is shown in Figure 12:

$$CrashCount_i = \frac{e^{\beta_0 + \beta_1 Year(continuous)_i + \beta_2 WellCount_i + \beta_3 AADT_i + \beta_4 RoadMiles_i}}{1 + e^{\beta_0 + \beta_1 Year(continuous)_i + \beta_2 WellCount_i + \beta_3 AADT_i + \beta_4 RoadMiles_i}} + U_i + \varepsilon_i$$

Figure 12. Equation. Poisson mixed-effect model.

The error term ε_i has a Poisson distribution, and U_i is the random effects associated each county. Year, well count, AADT, and roadway miles are the fixed effects for this analysis.

The statistical analysis results of crash rates using a Poisson model produces coefficients called incidence rate ratios (IRRs). Values above 1 indicate a positive relationship between the predictor (well count) and the response (crashes); values below 1 indicate a negative relationship. Across all grid cell sizes, the relationships were significant and positive for all types of crashes.

Table 15. Summary of IRRs for effect of well count on crash count from Poisson mixed effect models.

Response	Grid Size = 100	Grid Size = 25	Grid Size = 10
All	1.0117	1.0246	1.0331
Fatal only	1.0195	1.0457	1.0714
Non-fatal only	1.0119	1.0250	1.0333

*All effects are significant.

10 mi² grid cell

In the average grid cell, there were 0.535 crashes over the years analyzed. The Poisson mixed-effect model showed that fracking wells caused a 2.85-percent increase in crashes, which was a statistically significant effect. This can be found by taking the exponent of the Poisson coefficient: e^0.0281 = 1.0285, which is the IRR for this effect and denotes a 2.85-percent increase.

The zero-inflated Poisson model is a poor fit to the data because it does not include the grouping effect of grid ID. The presence of a well was associated with a 6-percent reduction in the likelihood of a crash (IRR of well count on crash presence = 0.94, $p < 0.001$). Each additional well led to a further 6-percent decrease in the chance that additional crashes would occur (IRR of well count on crash count = 0.941, $p < 0.001$). In addition, 58.8 percent of the grid cell / year combinations had no crashes, and 91.4 percent of the grid cells had no wells.

The zero-inflated Poisson mixed-effect model is a reasonably good fit to the data but is not superior to the Poisson mixed-effect model. The coefficients are similar to the non-mixed effect zero-inflated model, but coefficients for the zero-inflation component are not statistically significant.

Looking at the fatal and non-fatal crashes using the Poisson mixed-effect model, we found well count led to a small but significant increase in the number of fatal/incapacitating injury crashes. The increase in serious crashes due to fracking wells was 4.64 percent (IRR of well count on crash count = 1.0464, $p < 0.001$). Well count correlated with a small but significant increase in non-fatal crashes, an increase of 3.3 percent (IRR of well count on crash count = 1.033, $p < 0.001$).

25 mi² grid cell

At the 25-mile resolution, the average grid cell had 0.98 crashes over the years analyzed. The mixed-effect Poisson regression found that fracking activity caused a 2.2-percent increase in crashes.

The zero-inflated Poisson regression without mixed effects found that the presence of a well was associated with a 9-percent decrease in the likelihood that a crash would occur (IRR of well count on crash presence = 0.904, $p < 0.001$). However, each additional well led to a 3.2 percent greater chance that one additional crash would occur (IRR of well count on crash count = 1.032, $p < 0.001$). Of the grid cell / year combinations, 45.7 percent had no crashes, and 89.6 percent had no wells.

When including the random effect of county in a mixed-effect zero-inflated Poisson regression model, the coefficients are similar to the non-mixed effect zero-inflated model, but the coefficient for the zero-inflated portion was not statistically significant.

Applying the Poisson mixed-effect model to fatal and non-fatal crashes showed that well count drove a small but significant increase in the number of fatal/incapacitating injury crashes, an increase of 3.3 percent (IRR of well count on crash count = 1.033, $p < 0.001$). Well count had a small but significant effect on non-fatal crashes, an increase of 2.5 percent (IRR of well count on crash count = 1.025, $p < 0.001$).

100 mi² grid cell

In the average grid cell, there were 1.36 crashes over the years analyzed, and each additional well added 1.01 percent more crashes based on the mixed-effect Poisson regression model. This is a small but statistically significant increase.

The zero-inflated Poisson regression model continued to be a poor fit to the data at this resolution. This model showed that each additional well after the first led to a 1.015 percent greater chance that one additional crash would occur (IRR of well count on crash count = 1.015, $p < 0.001$). Of the grid cell / year combinations, 19.9 percent had no crashes, and 85.9 percent had no wells.

The zero-inflated Poisson mixed-effect model showed similar coefficients to the non-mixed effect zero-inflated model, but the coefficient for the zero-inflated portion was not statistically significant. The chance that any crash occurs is (non-significantly) reduced by the presence of a well, but each additional well does increase the chance of an additional crash.

Finally, examining the fatal and non-fatal crashes separately using the Poisson mixed-effect model, we found well count caused a small but statistically significant increase in number of fatal/incapacitating injury crashes, an increase of 1.9 percent (IRR of well count on crash count = 1.019, $p < 0.001$). Well count caused a small but significant increase in non-fatal crashes, an increase of 1.1 percent (IRR of well count on crash count = 1.011, $p < 0.001$).

Point-based approach

The point-based approach compared locations where fracking wells were initiated to locations without fracking wells by counting crashes of different severity within a range of distances from both types of location. See below for details on how non-well locations were generated and how statistical models were constructed. Without any statistical modeling, non-fatal crashes were not more common near fracking wells, at any distance (see Table 16). Within the smaller radius, non-fatal crashes occurred more frequently near non-well locations. For fatal crashes, the difference between fracking well locations and non-well locations was minimal.

Table 16. Average number of crashes (all, non-fatal, and fatal) within different radii around non-well or fracking well locations in North Dakota, 2012–16.

Crash Type	Location	Average Number of Crashes in a 5-mile Radius	Average Number of Crashes in a 1-mile Radius
Non-fatal	Non-well	7.664	0.517
Non-fatal	Well	2.608	0.084
Fatal	Non-well	0.034	0.002
Fatal	Well	0.036	0.002

Well and non-well locations also differed in their roadway characteristics. Based on AADT and roadway miles from HPMS, fracking well locations had fewer roadway miles and less total traffic within a 1- and 5-mile radius (see Table 17). Thus, simply counting the number of crashes near well locations without taking exposure into account would not accurately reflect crash risk associated with proximity to a well.

Table 17. Summary of AADT and average roadway miles adjacent to different radii around non-well or fracking well locations in North Dakota, using 2015 HPMS data.

Characteristic	Location Type	Average Roadway Miles in a 5-mile Radius of Location	Average Roadway Miles in a 1-mile Radius of Location
AADT	Non-well	536.7	208.4
AADT	Well	364.0	97.6
Roadway Miles	Non-well	9.0	4.4
Roadway Miles	Well	6.2	2.2

Correcting for this difference in the exposure to roadway traffic, the statistical model partly confirms the results of the grid-based approach, where fracking wells increased the risk of fatal crashes within both distances, and increased the risk of non-fatal crashes within 5 miles of a well.

Within 5 miles of a fracking well, there was a 51.9-percent greater chance of a fatal crash occurring (IRR of well presence = 1.519) compared to a non-well location of similar roadway characteristics. Similarly, there was a 22.3-percent greater chance of a non-fatal crash occurring (IRR of well presence = 1.223) within 5 miles of a fracking well compared to a non-well location. At the nearer distance, there was a 34.1-percent reduction in non-fatal crashes within 1 mile of fracking well locations (IRR of well presence = 0.659, 1-0.659=0.341) compared to non-well locations.

Only the coefficients for the intercept and the well indicator are shown below in Table 18. The intercept can be interpreted as the average count of crashes of one type within one distance of a typical location in North Dakota. The coefficient of the well indicator is a ratio rather than an additive coefficient. For the 5-mile radius, there were 1.519 times as many fatal crashes near fracking wells than near non-well locations.

Table 18. Summary of Poisson regression models of crash counts at 1-, 5-, and 25-mile radii around locations in North Dakota.

Crash type	Distance (mi)	Intercept	IRR of well
Fatal	5	0.043	1.519
Fatal	1	0.003	1.304
Non-fatal	5	12.756	1.223
Non-fatal	1	0.391	0.659

Notes: Coefficients for year, month, AADT, and roadway miles are not shown for conciseness. IRR shown for fracking well indicator.

Taken together, these results show there is a significant effect of fracking wells on risk of CMV crashes in general and on fatal crashes in particular. The grid-based approach, which considers all areas of the State and tests the effect of fracking well initiation on crash counts, shows a consistent and statistically significant but small positive effect of fracking wells on crashes of all types. The point-based approach takes more narrow focus and examines only regions in the immediate vicinity of fracking well locations, comparing these regions to similar areas not centered on fracking wells. This approach shows an increase in both fatal and non-fatal crashes in the vicinity of fracking wells when accounting for roadway characteristics and looking within a 5-mile radius of a well. Within a 1-mile radius, the point-based approach shows a reduction in non-fatal crashes near wells.

Point approach detailed methods

For a given set of fracking wells, an equal number of non-well points were generated across the State of North Dakota. Non-well points were generated to have the same distribution of distances from the major roads in the State. Generating these reference non-well points involved the following steps:

- Filter the road segments of North Dakota to only those with the upper 25th percentile of AADT, using the 2015 HPMS of FHWA (see Figure 13).

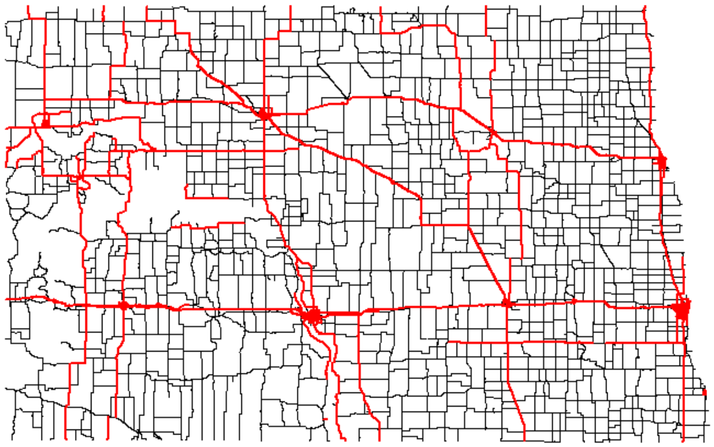

Figure 13. Map. Major roads of North Dakota in 2015, as defined by segments with the upper 25th percentile of AADT.

Note: Major roads are shown in red, all other roads are shown in black.

- For these roads, calculate the minimum distance between each fracking well in a given month of data and all road segments.
- Generate a random uniform distribution of points across the State of North Dakota.
- For the given month of data, retain only the same number of non-well points as there were fracking wells, and only those whose distances to the major roads have the same properties as the fracking wells. This means keeping only those non-well points with similar distance to the road network so that the mean, variation, and shape of the distance distribution is the same.

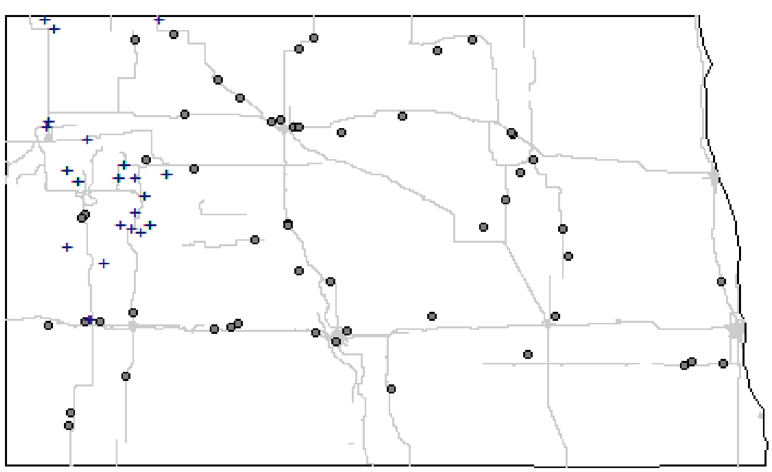

Figure 14. Map. Sample month of data (October 2016), with observed fracking wells and generated non-well points having the same distance to the roadway network.

Notes: Only major roads are shown. Observed fracking wells are indicated with a plus sign (+) and generated non-well points are indicated with filled circles.

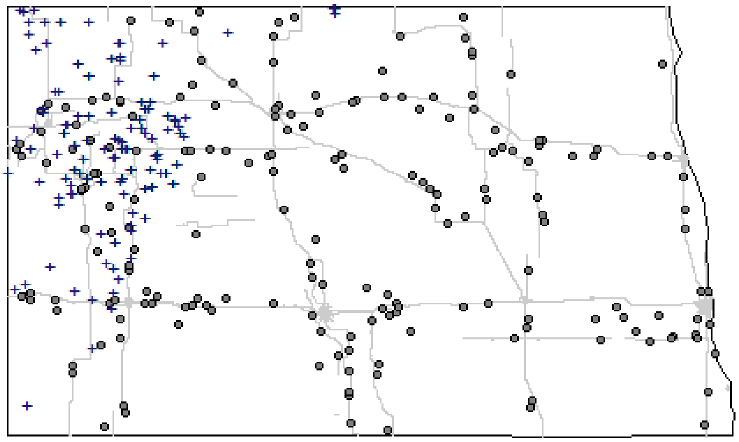

Figure 15. Map. Sample month of data (October 2013), with observed fracking wells and generated non-well points having the same distance to the roadway network.

Notes: Only major roads are shown. Observed fracking wells are indicated with a plus sign (+) and generated non-well points are indicated with filled circles.

Figure 14 and Figure 15 visualize some results of this process. After generating the non-well points, we counted crashes occurring within 1- and 5-mile radii of each well and non-well point. These radii produce areas of 3.1 and 78.5 square miles. We counted all crashes, non-fatal crashes, and fatal crashes. In addition, using the same circular buffer around each point of 1 and 5 miles, we mapped roadway characteristics from the HPMS product to each well and non-well location. This spatial overlay of HMPS data allowed extraction of the AADT and length for all the roadway segments which intersected with a buffer. The segment AADT and lengths were summed up and associated with each buffer for each of the 9,091 well and non-well points.

Model specification

For each radius, several possible model specifications were considered, including linear, Poisson, zero-inflated Poisson regression, and mixed-effect models with roadway characteristics as grouping variables. Unlike the gridded or county approaches, there was no between-time-period variable considered; each well or non-well point and each count of crashes was independent in time. Specifications of year and month as continuous or factor variables were considered as well. Models were compared by AIC, with the best-fitting model for all crashes within a radius retained and applied to all crash types within that radius. The mixed-effect Poisson regression model was the best model for fatal and non-fatal crash types within both 1 and 5 miles of each point (see Figure 16).

$$CrashCount_i = \frac{e^{\beta_0 + \beta_1 Year(continuous)_i + \beta_2 WellIndicator_i}}{1 + e^{\beta_0 + \beta_1 Year(continuous)_i + \beta_2 WellIndicator_i}} + \mathrm{U}_i + \varepsilon_i$$

Figure 16. Equation. Mixed-effect Poisson regression model.

The error term ε_i has a Poisson distribution, and U_i is the random effects associated with each point, accounting for the roadway characteristic variable AADT for each point type.

In all models, the predictor variables are the same: “Year” as a continuous variable expressed from 0 to 4 for the years 2012–16, and “WellIndicator” as a categorical variable, with 0 indicating non-well points and 1 indicating fracking wells.

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APPENDIX C: CARRIER FRACKING ASSOCIATION SCORE METHODOLOGY

Carrier-level data were available for North Dakota, Pennsylvania, and Texas for calendar years 2013–16. Data on fracking well initiation were available at the county level for all these years as well (see Figure 17).

The total number of carriers varies by State and year (see Table 19), with the three focal States varying by nearly an order of magnitude in number of carriers.

Table 19. Total number of motor carriers by State and year.

State	2013	2014	2015	2016
ND	9,462	9,044	8,912	7,544
PA	69,172	67,782	66,611	61,773
TX	168,698	157,352	164,978	172,238

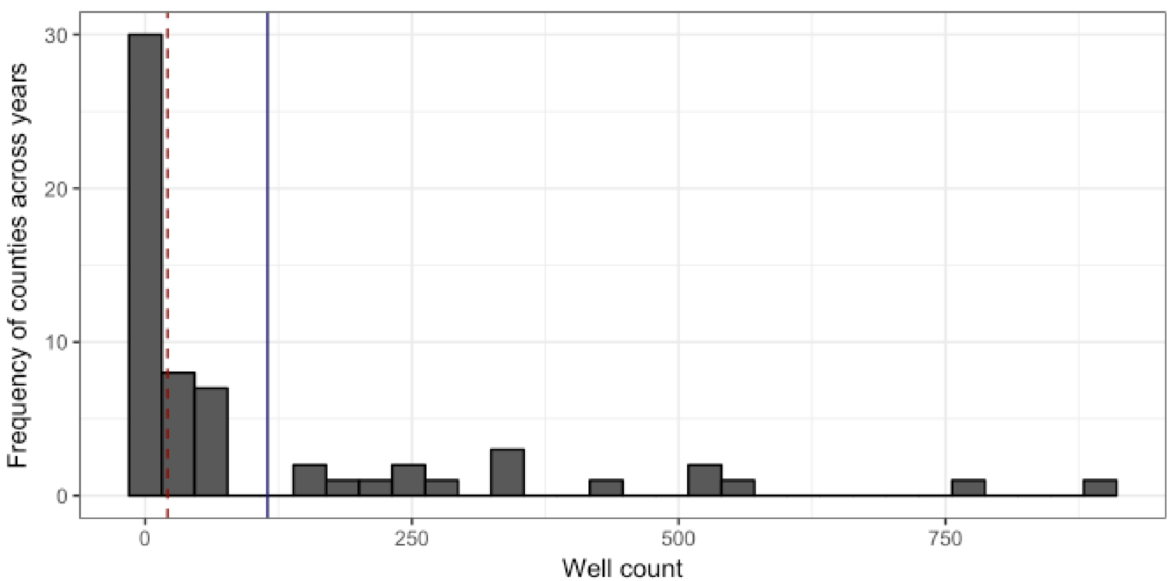

Figure 17. Bar graph. North Dakota well counts by county.

Both fracking well counts and carrier events by county are skewed in their distribution. The distribution of these data is an important factor in deciding how to associate fracking activity at the county level with carriers. The long skew to the right reflects that many counties had no fracking activity during this time period, while a few counties had very high fracking activity. The median value of 21 is well below the mean value of 114.7; these are indicated with the red dashed line (median) and blue solid line (mean) in Figure 17.

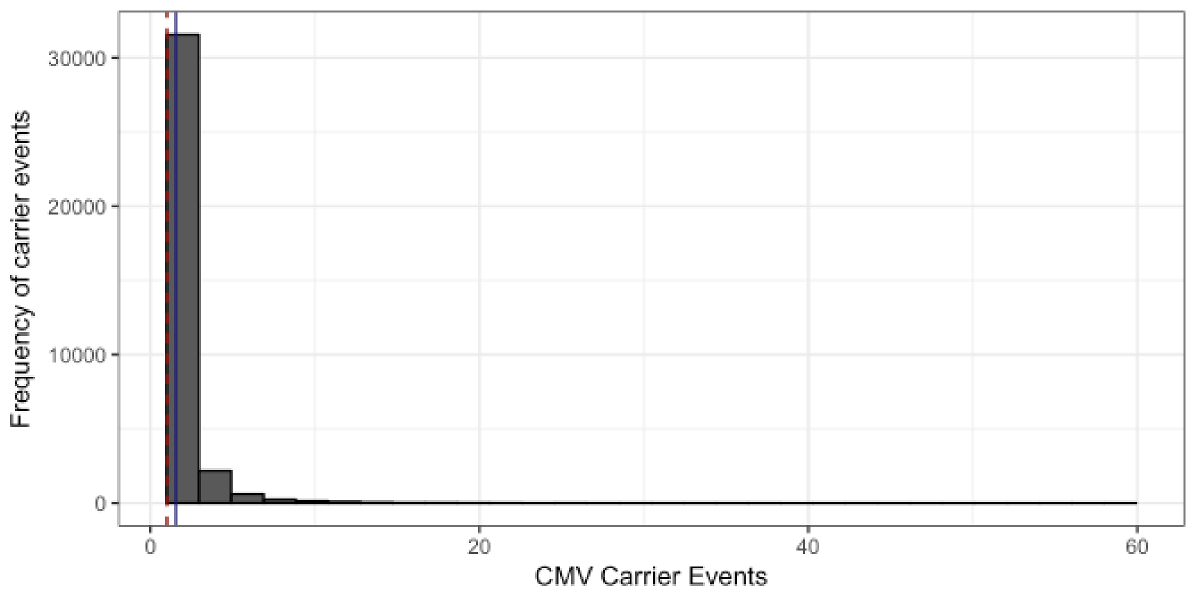

Figure 18. Map. Frequency of North Dakota CMV carrier events.

Similarly, carrier events are highly skewed, with a few carriers accounting for the majority of events (see Figure 18). The median value of 1 is slightly below the mean value of 1.6; these are indicated with the red dashed line (median) and blue solid line (mean). It should be noted that the "events" being counted are the number of inspections or crashes for a given carrier in each county in each year. These events are used to locate counties where carriers were active, and as a measure of the level of activity for each carrier each county.

There are typically two ways to associate data like this. One is to use all the data as continuous numeric variables, and to associate the two variables with each other. This approach has the advantage that each unit difference matters; counties with a difference of even a few wells can be distinguished, as can carriers differing by a few events. In addition, the impact of each additional well on crashes can be quantified. In this case, the association score would be a continuous variable.

The second approach is to use categories to group the variables into "bins" and then use simpler metrics of association to split carriers into fracking-associated or non-fracking-associated groups. The resulting association score would be a binary variable.

Binary association score

To more simply associate fracking activity with carrier activity, we took the following approach:

- Divide counties into "fracking counties" and "non-fracking counties," using the mean number of wells for each year as the dividing point.
- For each year, count the number of events that a carrier experienced in fracking counties and in non-fracking counties.
- Give a score of zero to carriers that did not haul any fracking-related cargo (machinery, oil equipment, chemicals, construction, water).

- Limit inputs to U.S.-based carriers. For Texas, it became clear that omitting Mexican carriers is necessary, even with cargo flags. Many border-crossing inspections were being counted as "events," distorting the association score.

There are two parts to the binary fracking association score: the sum of the events in fracking counties, and the proportion of events in fracking counties compared to all events. Using North Dakota as an example, we calculated 18,090 fracking association scores for carriers with an inspection or crash in North Dakota in 2013–16. Table 20 shows some results of this analysis, listing the carriers most associated with fracking under this estimation method. These are just 15 of the 1,666 carriers ultimately determined to be "fracking-associated" by the binary methodology; any statements made about the safety performance of fracking-associated carriers do not necessarily reflect these individual carriers. The carriers' legal names are displayed here to help show the validity of the methodology at face value—most of the names indicate that the carriers are involved in transportation for the oil or natural gas sectors.

Table 20. Top 15 carriers in North Dakota by binary fracking association score.

Rank	Fracking Association Score	Fracking Association Proportional Score	DOT Number	Legal Name
1	43.00	72.50	1432084	BADLANDS POWER FUELS LLC
2	20.25	72.00	100351	BLACK HILLS TRUCKING INC
3	19.00	100.00	1800269	DEER VALLEY TRUCKING INC
4	17.75	63.00	731020	MANN ENTERPRISES LLC
5	16.50	47.75	812071	HOFMANN TRUCKING LLC
6	15.50	68.75	606058	IOWA TANKLINES INC
7	15.00	65.00	1681446	CASCADE TANKS LLC
8	13.75	46.00	2255800	QC ENERGY RESOURCES NORTHWEST LLC
9	12.00	94.75	1290947	NATURAL RESOURCES TRANSPORTATION LLC
10	12.00	86.00	1370472	M & K HOTSHOT & TRUCKING INC
11	11.75	83.00	1212424	MIKE PALMER PETROLEUM SERVICES INC
12	11.75	73.25	2263045	QC ENERGY RESOURCES TEXAS LLC
13	11.67	63.00	1605289	CRESTWOOD CRUDE TRANSPORTATION LLC
14	11.50	69.50	1681446	CASCADE INTEGRATED SERVICES LLC
15	11.50	90.00	2114259	CREEK ENERGY SERVICES LLC

The advantage of this approach is its simplicity compared to the continuous fracking association score. It is easy to calculate a binary score for each carrier each year. The disadvantage is that there are two additional decisions to be made independently of observed data: first, deciding on the well count that distinguishes fracking from non-fracking counties, and second, deciding what combination of total score and proportional score should be used to assign carriers to fracking and non-fracking-associated groups. In short, the dividing line between fracking and non-fracking categories is subjective.

In this report, we use both parts of the binary association score and developed thresholds to consider carriers "fracking-associated." Carriers with a proportional score of at least 25 and at least one score in association were considered fracking-associated. The following conditions led to a carrier being categorized as fracking-associated within a given State in a given year:

- Only carriers based in the United States were considered.
- Carriers hauled at least one type of potentially fracking-related cargo.
- Carriers had at least one inspection or crash in a county with an above-average number of fracking wells initiated.
- Carriers had 25 percent or more of their recorded inspections or violations in counties with an above-average number of fracking wells initiated.

For a summary of the resulting number of fracking-associated and non-associated carriers by State, see Table 6.

APPENDIX D: DATA SOURCES

Data on CMV crashes came from the FMCSA's Motor Carrier Management Information System (MCMIS), and location-specific crash data came from the Fatality Analysis Reporting System (FARS) maintained by NHTSA. Police Accident Report summaries were made available by FMCSA's North Dakota Division Office.

Data for this research were compiled from several State and national sources. Data pertained to fracking well locations and dates, roadway network and characteristics, CMV crash locations, and carrier characteristics. These data are summarized in Table 21, with additional details following.

Table 21. Summary of data sources used in this report.

Spatial Extent	Data Type	Source Name	Temporal Extent	Notes
National	Roadway	FHWA Highway Performance Monitoring System	2011–15	Roadway classifications, AADT.
National	CMV Crashes	MCMIS	2013–16	County-level location only.
National	CMV Carrier Characteristics	MCMIS	2013–16	Violations, inspections, and BASICS by carrier.
North Dakota	CMV Crashes	FMCSA Division Office of North Dakota	2012–16	Geolocated, including fatal and non-fatal.
North Dakota	Wells	North Dakota Department of Mineral Resources	1922–2017	Includes active and inactive, drilling date.
Pennsylvania	Wells	Pennsylvania Department of Environmental Protection	Annual since 2001; monthly since 2015	Includes active and inactive, gas production volume, drilling date.
National	Wells	FracFocus	Current	County name only, no coordinate information. Used for Texas analysis.
National	Counties	U.S. Census Bureau	2016	Includes population.

TRANSPORTATION NETWORK

Highway Performance Monitoring System

Features: Traffic counts, roadway classification, geospatial locations of all roadways, by segment. Provides AADT, for each road segment. For 2015, truck volume counted separately (combination and single-unit trucks).

Reference: https://www.fhwa.dot.gov/policyinformation/hpms/fieldmanual/HPMS_2014.pdf.

Source: https://www.fhwa.dot.gov/policyinformation/hpms/shapefiles.cfm.

Extent: State-level, by year (2011–15).

CRASHES

MCMIS (Motor Carrier Management Information System)

Features: For crashes: county name, number of CMV crashes, number of fatalities, injury, and towaway crashes. For carrier information: BASIC percentiles and alert status, vehicle and driver out-of-service rates, number of inspections by county, and other carrier characteristics.

Source: MCMIS.

Extent: Statewide for North Dakota, Pennsylvania, and Texas. Crashes from 2000–16, carrier information 2013–16.

FARS (Fatal Accident Reporting System)

Features: Fatal accidents, with number of vehicles involved, CMV involvement, time, and location with latitude and longitude. FARS data were used to assess the feasibility of the grid- and point-based spatial analysis described in Appendix B.

Source: NHTSA.

Extent: Nationwide.

Police Accident Reports

Features: All CMV crashes in North Dakota. Provides the location and time of each CMV crash, including non-fatal and fatal. These data were used in the grid- and point-based spatial analysis described in Appendix B.

Source: FMCSA Division Office of North Dakota

Extent: Statewide, 2012–16

FRACKING WELLS

National

Features: The FracFocus chemical disclosure registry is the national clearinghouse for fracking wells. The data on well location, start date, and chemicals used are available for download in MS SQL Server 2012 format. The data have been reformatted by a third party, Frackingdata.org, and provided as a Microsoft Access database.

Wells are organized by county only, without latitude and longitude. These were the best data readily available for Texas.

Source: http://fracfocusdata.org/digitaldownload/fracfocusdata.zip.

Secondary Source: https://frackingdata.org/fracfocus-data/.

Extent: National, 2014–2016.

North Dakota

Features: Shapefile (geospatial data file format) of all wells drilled, with spud date, back to 1922. No production data. Geolocated.

Source: North Dakota Department of Mineral Resources, https://www.dmr.nd.gov/.

Extent: Statewide, 1922–2016.

Pennsylvania

Features: Historical well location and production data available, with latitude and longitude, operator, and quantity. Monthly data since 2015, annual back to 2001. The December 2016 report was used for this analysis.

Source: Department of Environmental Protection, http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?%2fOil_Gas%2fOil_Gas_Well_Historical_Production_Report.

Extent: Statewide, annual and monthly frequency.

Texas

Railroad Commission of Texas has jurisdiction over oil and gas wells.

Data are not freely available, so the national data from FracFocus were used for Texas.

CENSUS DATA

Features: Population number and county shapefiles for year 2015, from the U.S. Census Bureau.

Source: https://www.census.gov/geo/maps-data/data/cbf/cbf_counties.html.

Extent: National, year 2015. At 1:500,00 scale, largest scale (highest resolution) available.

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