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Critical Assessment of the Literature Regarding the Public Costs of Roadway Damage Due to Fracking

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by

Brent Ritzel

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A Research Paper
Submitted in Partial Fulfillment of the Requirements for the
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RESEARCH PAPER APPROVAL

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AN ABSTRACT OF THE RESEARCH PAPER OF

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TITLE: CRITICAL ASSESSMENT OF THE LITERATURE REGARDING THE PUBLIC COSTS OF ROADWAY DAMAGE DUE TO FRACKING

MAJOR PROFESSOR: Dr. LaShonda Stewart

Many government bodies have raised concerns regarding preservation of existing public roadway systems from infrastructure damage, and roadway degradation in particular, due to the impact of fracking-related truck traffic on roads that are simply not designed for that level and intensity of usage. This significant heavy usage imposes both immediate and long-term cost burdens on taxpayers, and can create unfunded liabilities for the wide range of levels of government (jurisdictions) responsible for maintaining the roadways (from township to federal). This acceleration in roadway consumption has manifested a financial need that is not easily funded by traditional fee mechanisms.

This paper’s purpose is to provide a critical assessment of the literature regarding the public costs of fracking-related roadway damage beyond what a given road system would sustain under normal traffic conditions, which would assist in accurate monetization of the roadway damage for assessment and predictive purposes. Utilizing the theoretical frameworks of prior published research studies and reports examined, relevant independent variables and their associated hypotheses are elucidated.

Fracking will continue to strain jurisdictional resources at all levels of government until accountability measures in the form of comprehensive infrastructure financing mechanisms are in place. This current research recommends the best practice approach to maintaining a community’s infrastructure during fracking while removing the tax payers from the equation is an industry-funded proactive armoring of the roadways. Resources at all levels of government will continue to be strained until accountability measures that require comprehensive infrastructure upgrades, prior to the inception of energy development, are put in place to hand full responsibility to the industry that plans on subjecting roadways to predictable undue heavy truck traffic weights and volumes.

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INTRODUCTION

On May 31, 2013, the Illinois Senate passed SB1715, the Hydraulic Fracturing Regulation Act, by a vote of 52-3, the day after it passed the House by a vote of 108-9. The passage of this bill, signed by then Illinois Governor Pat Quinn into law on June 17, 2013, will potentially open the doors to fracking of Southern Illinois once regulations and the regulatory infrastructure are in place (Kasper & Maloney, 2013). The initial draft fracking regulations, which are drafted by the Illinois Department of Natural Resources [IDNR] without the benefit of a single scientific study, received 35,000 public comments during a 45-day public comment period that ended on January 3, 2014. It took the IDNR more than nine months to edit the regulations to integrate the vast array of public input delivered during that public comment period, during which scores of peer-reviewed studies and scientific reports introduced by the general public were brought to bear on Illinois fracking regulations (Fortino, 2014).

Hydraulic fracturing, or fracking, is a mining technology that involves the extraction of natural gas and/or oil from a targeted shale deposit by forcing typically several million gallons of water (along with sand and chemicals) under high pressures to re-fracture the rock formation to allow gas/oil to flow through the fractures that are propped open with the sand. Approximately half of the water returns to the surface through the well as flowback from days to weeks following injection accompanied by the natural gas/oil (Howarth, Santoro, & Ingraffea, 2011). Although hydraulic fracturing was first patented by Halliburton in 1949, modern hydraulic fracturing is the result of the development and realization of four distinct technological advances that combined together has led to an explosion in shale oil and gas mining that started in 2003. These include the utilization of high volumes of water (2 to 8 million gallons per fracked well), slick water (chemical lubricants to decrease fracking fluid viscosity), horizontal drilling and multi-well drilling pads (Cantarow, 2013).

While hydraulic fracturing or *fracking* itself is technically one-step of the mining process that lies in-between the insertion of well casings and the removal of flowback waters that just lasts several hours to a couple of days, in popular parlance the term fracking is used to reference the entire process that accompanies this mining technology. This includes, but is not limited to, the "processes of excavation, drilling, dehumidification, compression, processing and pipeline transport" (Cantarow, 2013, p. 4). Anthony Ingraffea, Cornell University engineering professor and president of Physicians, Scientists and Engineers for Healthy Energy, clarifies that because fracking is "a spatially intense, heavy industrial activity which involves far more than drill-the-well-frack-the-well-connect-the-pipeline-and-go-away, it results in much more land clearing, much more devastation of forests and fields" (Cantarow, 2013, p. 4). Ingraffea continues that fracking requires the construction of many industrial facilities known as compressor stations, which compress natural gas in preparation for transport, in addition to construction of both fresh-water ponds and waste pits, and the heavy truck traffic that necessarily accompanies these various activities (Cantarow, 2013).

While the potential benefits of fracking for Southern Illinois have been frequently highlighted by the oil and gas industry, Illinois politicians, and mainstream media (e.g., jobs, lease fees, severance tax revenues, energy independence), the potential negative impacts of fracking on Southern Illinois have been de-emphasized by these parties. This launch of fracking does not particularly have popular public support in Southern Illinois, with 40.7% supporting it, 39.7% opposed, and 19.6% with no opinion (Leonard, 2013) or nationwide, with 44% favoring increased fracking and 49% being opposed. In the six-month period from March to September, 2013 public opposition to fracking grew by 11% (Pew Research Center, 2013). This nationwide public disfavor to expanding fracking has continued to grow, according to a November 2014 Pew Research Center poll, with 41% favoring increased fracking and 47% being opposed, with the greatest demographic shift occurring in the Midwest, which saw a 16% drop from March 2013 to November 2014 in those favoring increased fracking, from 55% to 39% (Pew Research Center, 2014).

This shift is at least in part due to increased public awareness of the many potential consequences that accompany fracking. Some of these consequences include threats to the environment, including habitat segmentation and ecosystem degradation (Burton et al, 2014), permanent removal of water from the hydrological cycle (Adgate, Goldstein, & McKenzie, 2014), and increased greenhouse gas emissions (Howarth, Santoro, & Ingraffea, 2011). Some of these consequences include threats to infrastructure, including fracking wastewater disposal induced earthquakes (Ellsworth, 2013) and roadway degradation accompanied by infrastructure destruction (Ridlington & Rumpler, 2013). Some of these consequences include threats to public health, including air pollution due to methane leakage and industrial equipment operation (Howarth, Santoro, & Ingraffea, 2011), water contamination from methane migration and leaks, spills and intentional dumping of frack fluid (Ridlington & Rumpler, 2013), and toxic and radioactive fracking flowback and produced water (Fair, 2014). And finally, some of these consequences include threats to communities, including social ills like increased crime, drugs, prostitution, homelessness (Schafft, Borlu, & Glenna, 2013), and the most dangerous workplace in the United States, featuring seven times the national on-the-job death rate of the average occupation (Goldstein et al, 2014).

Though readily monetizable, general efforts to attach price tags to these various economic, environmental and social ills have lagged immensely behind efforts to project potential revenues from fracking. One realm of public interest that has particularly faced these impacts is that of transportation, having experienced various challenges to safety (dangerous degraded roadway and bridge conditions, increasing gravelization of rural U.S.), quality of life (traffic congestion, dust and air pollution), and economic vitality (primarily rural taxpayers subjected to unfunded liabilities such a road repairs and reconstruction) (Tidd, 2003). As fracking continues to proliferate around the United States, these concerns are starting to become more and more of an issue nationwide.

Several State Departments of Transportation (including Montana, Wyoming, North Dakota, Texas, West Virginia, New York, and Ohio) have especially raised concerns regarding preservation of existing roadway systems from infrastructure damage, and roadway degradation in particular, due to the immense drilling and fracking-related truck traffic on roads that are simply not designed for that level and intensity of usage. This includes a variety of specific road damage issues, such as base failures, potholes, rutting, distress, edge damage, and shoulder degradation (Quiroga, Fernando, & Oh, 2012).

The volume of fracking-related truck traffic has greatly accelerated consumption of roadways that are the responsibility of a wide range of levels of government (jurisdictions from townships to federal), “creating a financial need not easily funded from traditional highway user fee mechanisms” (Boske, Gamkhar, & Harrison, 2013, p.1). This heavy use of public infrastructure and services in fact imposes both an immediate and long-term cost burden on taxpayers (Dutzik, Davis, Van Heeke, & Rumpler, 2013). This is especially true of rural roads designed for a low volume of traffic of less than 400 vehicles per day carrying loads far below that of the average 80,000 pound (40 ton) fracking-related truck traffic, at times tipping the scales at as much as 115,000 pounds (57.5 tons). These pavement surfaces generally have “base layers thicknesses that fail to provide adequate structural support for heavy truck traffic encountered on rural roads” (Miller & Sassin, 2013, p. 3). Under normal operating conditions persistent rehabilitation and reconstruction is not anticipated, and "complete pavement restoration costs" are not typically included in maintenance cost plans (Huntington & Ksaibati, 2009, p. 17). Rebuilding just a typical county paved road can cost in excess of $1 million per mile, and that amount alone can match the total for many rural counties' annual Road Departments budgets (Wilson, 2012).

There is a long history of studies that have explored the impact of heavy truck usage on U.S. roadways in industrial, extraction and agricultural development. Some of these key peer-reviewed analyses include Purnell, Yoder, & Sinha (1978), Mason (1983), Tolliver (1989), Stephens & Hafferman (1993), Russell, Babcock, & Mauler (1995), Prozzi, Harrison, & Prozzi (2003), and Babcock, Bunch, Sanderson, & Witt (2003). The Mason (1983) study in particular estimates the reduction in life of Farm-to-Market road pavement in Texas due to oil development related traffic, along with the associated "increase in annual cost due to a reduced pavement serviceability" (Mason, 1983, p. 16). However, this study only concerns Farm-to-Market roads in Texas, and additionally, predates the very atypical and intense comprehensive demands of shale oil and gas production that has only very recently come under the scrutiny of scientific study (Dybing, Lee, DeHaan, & Dharmadhikari, 2013).

While there have been several scattered reports from State Departments of Transportation, counties, and universities in the past decade aimed at estimating the long-term costs of road damage associated with fracking, there has generally been a dearth of peer-reviewed studies analyzing this relationship. The disparate and diverse reports and studies that do exist on this topic, however, focus on variety of different infrastructure and roadway jurisdictions (township, municipality, county, farm-to-market, state, interstate, federal) in a number of different states (Texas, Pennsylvania, New York, West Virginia, Arkansas, Ohio, North Dakota, Wyoming, Montana, Colorado). Additionally, each of these reports and studies often explores its own unique variables or combination of variables, often dependent upon the data available, the theoretical framework of those conducting the research, or the specific research question being pursued by the report/study principle(s).

The current research addresses the gap in the literature by developing a critical assessment of the literature regarding the public costs of fracking-related roadway damage. Freilich and Popowitz (2012) indicate that both the "isolated and cumulative adverse effects and impacts" of fracking "on the traffic shed need to be understood regarding the existing and future required capacity of the county and state road system" (Freilich & Popowitz, 2012, p. 570). However, one of the challenges of this current research, as noted by Quiroga et al (2012), is that "many short-term and long-term impacts on the state's transportation infrastructure are not properly documented" (Quiroga, Fernando, & Oh, 2012, p. 134). Critical assessment of literature will assist in the development of a model that may provide the tools necessary to determine the degree and intensity of roadway damage due to fracking in a particular region over a specific time period, beyond what that given road system would sustain under normal traffic conditions, and to accurately monetize that damage for evaluatory or predictive purposes.

The research question of the current research paper is *what are the total cost burdens on the public of roadway damage due to fracking in a given region over a given period of time*? The purpose of the current study is to provide a critical assessment of the literature regarding the public costs of fracking-related roadway damage, based upon the theoretical frameworks of prior research studies and reports examined regarding this issue, in order to render a useful system of roadway-related infrastructure harms for the purposes of establishing economic accountability. The methodology of the current study is to conduct an inventory of existing literature to determine potentially relevant independent variables.

CHAPTER 2

LITERATURE REVIEW

Scale of Fracking

The most comprehensive list of total high-volume hydraulic fracturing [HVHF] (fracking) wells by state has been compiled by Ridlington and Rumpler (2013), who find that between 2005 and 2012 more than 82,000 fracking wells are drilled or permitted in 17 states, with 22,326 fracking wells being drilled in 2012, 13,540 of which are drilled in Texas.

Current industry plans for continued fracking nationwide include the drilling of one to two million wells over the next 10 to 20 years, with production at each well running for approximately 30 years. The estimate for total projected wells for individual states include 100,000 in Pennsylvania (Yeoman, 2013), 26,450 to 50,000 in North Dakota (Tolliver & Dybing, 2010; Scheyder, 2013), and 40,000 for the State of New York (Kennedy & Gallay, 2012). In terms of total fracking wells already drilled, Texas has more than 33,000 wells, followed by Colorado with in excess of 18,000, and Pennsylvania with nearly 7,000 (Ridlington & Rumpler, 2013). The rate of growth of drilled wells in Pennsylvania has been accurately described as “exponential,” with Marcellus shale fracking wells increasing from 2 drilled in 2005, to 11 drilled in 2006, to 34 drilled in 2007, to 210 drilled in 2008, to 768 drilled in 2009 and 1454 drilled in 2010 (Pifer, 2011; Meng, 2014).

With more than $250 million invested in buying up drilling leases on a half million acres of private land in southeastern Illinois (Yeagle, 2013), the oil and gas industry is planning on fracking 50,000 to 100,000 wells in a 19-county area of state’s southeast corner including Jasper, Crawford, Clay, Richland, Lawrence, Wayne, Edwards, Wabash, Franklin, Hamilton, White, Williamson, Saline, Gallatin, Johnson, Pope, Hardin, Pulaski and Massac Counties (Bieneman, 2013).

High Density of Well Placement

The cause of greatest harm is not particularly the high volume hydraulic fracturing (HVHF) or "fracking" technology itself, as it is the scale of mining required to engage in this form of fossil fuel extraction. As Columbia University's Dr. Anthony Ingraffea relates, the problem with shale gas and oil is that it is fundamentally distributed everywhere equally throughout a shale play, which means that the industry has to drill *everywhere* to access it (Law & Hays, 2013).

Everywhere can mean a five to fifteen-acre drilling pad, with each one supporting six to twelve wells and spacing of one well for every 40 (in the Marcellus Shale Play) to 65-acre (in the Eagle Ford Shale Play) area in a given county to be fracked (Arthur, Bohm, & Layne, 2009; Dukes, 2012). With the industry standard of fracking 70% of targeted counties, individual rural counties in southeastern Illinois in the *sweet spot* of the New Albany Shale Play could conservatively be looking at upwards of 3,500 wells each. This total is based upon one well for every 65-acres, clustered in 6-well drilling pads over 70% of a county, with an average of 14 townships per county and each township averaging 36 square miles in area (Podulka, S. G. & W. J. Podulka, 2010).

Intensity of Fracking-Related Truck Traffic

The amount of truck traffic required to service each individual fracking well is immense, though it does indeed vary from site to site according to "well type and depth, geology, drilling technology, and water need" (Quiroga, Fernando, & Oh, 2012, p. 5). Other factors that can impact total truck trips required are whether water delivery and/or waste water disposal is by truck or pipeline, how many wells are being drilled per well pad, the specific equipment and materials that are required for each site, and the relative location of additional key inputs like fracking sand and chemicals (Tidd, 2013; Abramzon, Samaras, Curtright, Litovitz, & Burger, 2014).

Truck traffic generally consists of a fully loaded 80,000 pound (40 ton) inbound trip in the case of fracking well inputs (or outbound trip in the case of fracking well outputs such as waste water disposal or rig removal), and an ‘empty’ 35,000 pound (17.5 ton) outbound trip upon completion of delivery of inputs (or inbound trip once again in the case of the fracking well outputs of waste water disposal or rig removal) (Schiller, 2008). Special overweight truck load permits are often readily available for a very low cost (Wilson, 2012), meanwhile, drilling-rig related truck traffic can consist of oversized loads weighing as much as 115,000 pounds (57.5 tons) (Locher, 2012). Roads facing that kind of truck traffic can have 20-year life spans reduced to days, as “all it takes is one pass of 6 million pounds of drilling equipment to destroy a road like that” (Fowler, 2012, p. 1)

S. G. Podulka & W. J. Podulka (2010) estimate that it takes between 1,760 and 1,904 truck trips hauling equipment, materials and water to build, drill and high volume hydraulically fracture a single well. A typical Marcellus fracked well requires 5.6 millions gallons of water during the hydraulic fracturing of the shale, of which approximately half returns to the surface as flowback and produced wastewater, which is summarily shipped away in tanker trucks to disposal wells. Currently more than 95% of fracking wastewater produced in the United States is injected into deep disposal wells (Clark & Veil, 2009).

Moss (2008) estimates that it can require more than 3,000 truck trips to bring water to and remove waste from a single typical fracking well, with an additional 220 to 364 trips being necessary for hauling equipment, materials and employees. The New York State Department of Transportation (2011) finds that while the drilling phase can require 290 truck trips over a 28 day period, due to total water and waste needs, the hydraulic fracturing of a single well can require more than 2,300 truck trips in just a 3 day period. The New York State Department of Environmental Conservation [NYSDEC] estimates a single well requires 1,800 to 2,600 total truck drive-bys (truck trips) through all phases, with an 8 well site requiring 14,400 to 20,800 total truck trips. A “Revised Draft Supplemental Generic Environmental Impact Statement” from NYSDEC (2011) estimates that early horizontal well pad development generates 1,148 heavy truck and 831 light-truck one-way loaded trips, and peak well pad development generates 625 heavy truck and 795 light-truck one-way loaded trips. This results in 3,950 one-way trips in early well pad development and 2,840 one-way trips during peak well pad development, for a total of 6,790 one-way trips per fracked well (ALL Consulting, 2010).

A report prepared by Underbrink (2012) of Naismith Engineering for the DeWitt County Texas Commissioners utilizes Equivalent Axle Load Factors (EALF), roughly equivalent to both a truck trip and an Equivalent Single Axle Load (ESAL), to define traffic demand in the Eagle Ford Shale region. One ESAL represents a single axle load of 18,000 pounds (PDOT, 2010). The roadway damage caused by a given load is roughly a function of pavement characteristics, number of axles, and load per axle by a power of four (AASHTO, 1993). A typical country road will last about twenty years when being subjected to about 500 EALF’s per year, requiring reconstruction after a total of 10,000 EALF’s. Underbrink estimates that the total EALF’s in the first year of a single fracking well’s development and production is 2,430, with annual EALF total of 1,250 thereafter, for a total of 26,680 EAFL’s for one single well in production over 20 years. This means that a county road designed to last 20 years would only last 7 years when subjected to the typical fracking of just one single well.

[See Appendix C for a state-by-state breakdown of research on fracking-related roadway degradation costs.]

CHAPTER 3

METHODOLOGY

In order to create a critical assessment of the literature regarding the public costs of fracking-related roadway damage, an inventory of existing literature is conducted to determine potentially relevant independent variables. At the time of this research, only six peer-reviewed studies explain factors that influenced the total cost of roadway damage due to fracking in the following states where such activities are taking place or are projected to take place: Texas, Pennsylvania, New York, West Virginia, Arkansas, Ohio, North Dakota, Wyoming, Montana and Colorado. These peer-reviewed studies include Abramzon, Samaras, Curtright, Litovitz, & Burger (2014); Huntington & Ksaibati (2009); Mason (1983); Mitra, Tolliver, & Dybing (2012); Sathaye, Horvath & Madanat (2010); and Wynveen (2011). Though conducted prior to the advent of modern fracking that launched approximately in the year 2003, the Mason study is utilized in the current study as it pertains to behaviors (road damage related to truck traffic from oil development) still relevant to the research being conducted regarding fracking traffic in this study.

Several search terms are used on the full text of each study and report to identify potentially relevant sections for detailed review. The search terms include “shale,” “gas,” “oil,” “fracking,” “road,” “highway,” “damage,” “truck traffic,” “wells,” “repair” and “reconstruct.” Independent variables are functionally organized according to the following categories: Physical Factors (truck trips, fracked wells, well development phase, roadway type, roadway condition and roadway improvement required) and Fiscal Factors (Road User Maintenance Agreement, bonding, impact fees, and additional appropriations).

Given the dearth of relevant peer-reviewed studies published on the topic on roadway damage due to fracking, eighteen relevant reports and engineering studies commissioned by counties and state departments of transportation conducted by universities and private firms are included. The purpose of this research paper is to provide a critical assessment of the literature regarding the public costs of fracking-related roadway damage through which oil and gas companies engaged in shale oil and gas drilling and the high volume hydraulic fracturing (HVHF) process can be held accountable for the full extent of infrastructure harms in the form of roadway damage (and its total associated costs) for which it is responsible. This model will allow for the most accurate evaluation and/or prediction of roadway costs due to fracking in a specific area or region over a particular time frame. This will be accomplished through identification of variables and their associated hypotheses that embody the theoretical backbone of the previously published literature on the subject.

CHAPTER 4

INDEPENDENT VARIABLES

Physical Factors

Truck Trips

According to prior research studies and reports the physical factor that has the most direct impact on the cost of road damage due to fracking is that of total truck trips to a given well site. Quiroga et al (2012) identifies several factors determinant of the total number of truckloads in evaluating the total cost of road damage on U.S. and interstate highways and state maintained roadways in Texas, including well type and depth, local geology, drilling technology utilized and total water needed (Quiroga, Fernando, & Oh, 2012)

Abramzon et al (2014) examines the number of heavy truck trips required to construct and operate a single well, and determines that whether water is delivered or disposed of via truck or pipeline clearly has a significant impact on overall heavy truck traffic, and thus the total cost of road damage on state highways, along with the number of wells per well pad (which can vary between four and sixteen) and the specific equipment, materials and total water required for each site (Abramzon, Samaras, Curtright, Litovitz, & Burger, 2014).

Dybing (2012), who engages in projecting the degree of increased traffic on Montana highways, utilizes GIS-based build-out analysis to estimate the location and degree of potential oil development. Specifically, Dybing utilizes historic oil production databases to predict the flow from oil production zones to final destinations, in addition to previous traffic data and truck survey results, to predict future costs of road damage. Based upon this prior research, the current research hypothesizes that the greater the number of total truck trips to a given well site, the greater the cost of road damage.

Total Wells

According to prior research studies and reports the total number of fracking wells in a given region over a given time frame, a.k.a. the distribution of well activity, has a significant impact on the cost of road damage, primarily due to its direct impact on associated heavy truck traffic. Dybing (2012) utilizes GIS-based build-out analysis to project future drilling locations and production levels in order to estimate the total number of fracking wells and the associated heavy truck traffic that Montana is facing in the coming years.

Likewise, Tidd (2013) utilizes GIS-based build-out analysis on a number of factors, including location of key inputs (water, sand and chemicals) and outputs (waste disposal); regulatory minimum spacing requirements; mineral leasing activity; pace of well development; and total well permits issued to project future well locations along with total well-development in a particular area. In the current research it is hypothesized that the greater the number of total fracking wells in a given region the greater the cost of road damage.

Well Development Phase

While most reports and studies on fracking identify several unique developmental stages in regards to the nature of truck traffic, various researchers model this phenomenon differently. Indeed truck traffic in each of these phases varies and has to be looked at distinctly, as different combinations of jurisdictional roadways are utilized and different loads exist for each of these stages, and traffic carrying inputs are fully loaded inbound and empty outbound, while traffic carrying outputs are empty inbound and fully loaded outbound, and thus have varying impacts on the cost of roadway damage according to prior research.

Prozzi et al (2011) conceives of fracking truck traffic as falling within one of three general categories, those of construction traffic (that occurs during the well development process, including rig-related traffic), fracking traffic, and saltwater removal traffic. Specifically, "construction traffic is generated during the five-step well development process: site preparation, rigging up, drilling, hydraulic fracturing, and rigging down" (Prozzi, Grebenschikov, Banerjee, & J. A. Prozzi, 2011, p. 36). Miller & Sassin (2013) conceives of the development phase of the oil and gas well process expansively as consisting of the inbound hauling to drilling site of cranes and rigging, heavy machinery, drilling equipment, pipe and other construction materials, sand and water (Miller & Sassin, 2013).

A peer-reviewed study by Mitra et al (2012) presents a more comprehensive, functional model in determining that fracking-related truck traffic consists "largely of five types of movements" each of which require independent analysis, including:

> 1) Inbound truck traffic consisting of movement of cement, gravel, fuel, drilling mud, sand and water.
> 2) Inbound truck traffic consisting of movement of fracking chemicals.
> 3) Outbound truck traffic consisting of movement of oil and gas, and their byproducts.
> 4) Outbound truck traffic consisting of movements of fracking flowback wastewater.
> 5) Inbound and outbound truck traffic consisting of primarily rig-related movements, including specialized vehicles such as utility vehicles, fracturing rigs, work-over rigs and cranes (Mitra, Tolliver, & Dybing, 2012).

Given the various truck traffic differences identified in prior studies and reports in each stage of the fracking life cycle, the current research hypothesizes that the phase of well development impacts the cost of road damage, with the phases consisting of greater truck traffic and greater truck weights having a greater impact on the cost of road damage than phases consisting of lesser truck traffic and lesser truck weights.

Roadway Type

Prior research studies and reports indicate that the cost of roadway damage is significantly influenced by the type of roadway traveled on by heavy truck traffic related to fracking. Mitra et al (2012) examines projected impacts and funding needs for county and township roads in North Dakota related to three different types of road structures: paved, gravel, and graded and drained. GIS-based build-out analysis was applied to well production forecasts, traffic data, and county road survey data sources to evaluate estimated costs of roadway improvements such as structural overlays and reconstruction. Abramzon et at (2014) similarly evaluates four different types of road structures, including paved, low type, oil/gravel and earth to render cost of road damage estimations.

Dybing (2012) takes matters a step further beyond road composition in evaluating the specific physical characteristics of roadway types, including such factors as structure and geometry. Roadway structure, and therefore a roadway's associated "structural number," is calculated from a combination of layer thickness, material types and specific structural coefficients. Roadway geometry includes such factors as lane width, shoulder type and shoulder width. These various structural and geometric elements are significantly determinant of pavement condition following fracking-related heavy truck traffic, and thus of reconstruction and replacement costs of a particular roadway. Given the findings of prior research studies and reports, the current research hypothesizes that the specific roadway type impacts the cost of road damage, with degraded high volume paved roadways having the greatest impact on road damage costs, degraded moderate volume gravel roadways having a moderate impact on road damage costs, and degraded lower volume graded and drained roadways having the least impact on road damage costs.

Roadway Condition

Prior research studies and reports demonstrate that not only does roadway type and design have an impact on the cost of road damage, but the heavily correlated element of roadway condition does too. Two fundamental approaches to this impact-laden factor in the prior literature is to either examine the total reduction in useful roadway life, a measure of the degree to which the roadway has already been diminished *(glass half empty)*, or to explore the estimated useful remaining roadway life *(glass half full)*.

Early research by Mason (1983) takes a look at the impacts of oil field development on lower volume Farm-to-Market roads in Texas. This peer-reviewed study finds that the estimated pavement life reduction, which has a direct impact on costs insofar as the greater the pavement life reduction due to heavy truck traffic the greater the cost of roadway damage, is determined by a combination of truck weight and traffic volume. Prozzi et al (2011) also examine reductions in service life of roadways in Texas, concluding that such traffic-induced reductions manifest "shorter time intervals between maintenance cycles, resulting in increased maintenance expenses by the TxDOT districts" (Prozzi, Grebenschikov, Banerjee, & J. A. Prozzi, 2011, p. 106). The study frames its results in terms of "terminal distress value," which is the total estimated road life until roadway maintenance or repair intervention is required. This research also determines that the overall reduction in service life varies according to phase of well completion, with rig traffic causing a 5.6% decrease in service life, construction traffic leading to a 29.5% reduction, and saltwater disposal traffic decreasing service life by 15.7% (Prozzi, Grebenschikov, Banerjee, & J. A. Prozzi, 2011, p. 126).

According to the Texas Department of Transportation, unexpected or unplanned heavy truck traffic consumes pavement life faster than what roadways are originally designed for, as "Pavements are designed to carry the amount of traffic expected to travel that roadway over a specific period of time, usually 20 years, without significant deterioration or damage" (TxDOT, 2012). Given that standard, other studies choose to examine estimated useful remaining roadway life. Like Mason (1983), Abramzon et al (2014) limit their analysis to weight and frequency of truck traffic, while acknowledging that other studies examine factors such as the thickness of pavement structure layers, drainage characteristics, predicted loading patterns of truck traffic, and road maintenance schedule (Quiroga, Fernando, & Oh, 2012; Abramzon, Samaras, Curtright, Litovitz, & Burger, 2014).

The equivalent single axle load (ESAL) approach is utilized by the North Dakota Department of Transportation (NDDOT, 2006) to determine that heavy truck traffic related to fracking produces very high ESAL values per mile, so high (3.95 to 9.94 ESALs per mile) that one four-axle workover rigs could potentially account for a year's worth of roadway wear in just a few passes on a county or township road (Dybing, Lee, DeHaan, & Dharmadhikari, 2013). The Gas Drilling Task Force (2009) specifically refers to this American Association of State Highway Transportation Officials (AASHTO) standard as being "useful in establishing the percentage of road damage attributable to truck traffic resulting from gas development and may provide baseline data for establishing the costs associated with this type of development" (Gas Drilling Task Force, 2009, p. 37). Due to the conclusions of prior studies and reports, this research hypothesizes that the greater the reduction in useful roadway life, the greater the increase in diminished road capacity, the greater the cost of road damage.

Roadway Improvements Required

The final key physical factor, according to prior research studies and reports, to determining the cost of road damage associated with fracking is that of the particular roadway improvement required by a given degraded strip of pavement. Several studies, including Huntington & Ksaibati (2009), Tolliver & Dybing (2010), Wray (2011), Underbrink (2012), Quiroga, Fernando, & Oh (2012), Huntington, Pearce, Stroud, Jones, & Ksaibati (2013) and Stroud & Ksaibati (2013) identify three major categories or levels of roadway improvement, from lowest cost to highest cost, and least extensive to most extensive: 1) Maintenance, 2) Rehabilitation, and 3) Reconstruction (see Table 1 below). Tolliver (2010) specifically frames these road improvement levels as being the result of fracking-related heavy truck traffic reduction in pavement life, and further distinguishes between levels 2 and 3 as being roads with lower traffic volumes (the former) versus paved routes with the greatest direct traffic impacts (the latter). Due to the clear findings of prior research studies and reports, the results of which are included in Table 1, this research hypothesizes that the greater the need for road

Table 1. Roadway Improvement Categories – Average Cost Per Mile of Roadway *(all figures adjusted to 2014 dollars)*

		Underbrink (2012)	**Huntington et al (2013)**	**Quiroga (2012)**	**Stroud & Ksaibati (2013)**	**Tolliver & Dybing (2010)**
State:		*Texas*	*Wyoming*	*Texas*	*Wyoming*	*North Dakota*
Road type:		*County paved*	*County paved*	*Farm-to-Market paved*	*County gravel*	*County & Town paved*
Maintenance	*Renewal*					$2,919
	Drain Repair				$15,243	
	Seal Coat			$21,840		$12,594
	Regravel				$30,487	
	Maintenance	$82,489		$3,157		$47,124
Rehabilitation	*Structural Overlay*			$243,040		$173,254 to $325,700
	Minor Rehab.		$257,777			
	Restoration			$288,048		
	Preventative Rehabilitation		$61,866 to $360,887			
	Rehabilitation			$537,546	$152,483	
	Major Rehab.		$670,220			
Reconstruction	*Basic Recon.*	$948,619				
	Reconstruction					$1,232,443 to $1,357,083
	Full Recon.		$1,237,329			
	Major Recon.	$1,959,103				

improvements, the greater the cost of road damage, with reconstruction having the greatest impact, rehabilitation having a moderate impact, and maintenance having the least impact on the cost of road damage.

Fiscal Factors

Maintenance Agreements

The reality of infrastructure financing mechanisms related to fracking is very different in the Marcellus shale region than that of other regions like the Barnett and Eagle Ford Shale of Texas. A peer-reviewed study by Abramzon et al (2014) find that shale gas and oil development companies make repairs and often reconstruct roadways that are visibly damaged as required through Excess Use Maintenance Agreements (EUMAs) with the State and local municipalities in Pennsylvania (Abramzon, Samaras, Curtright, Litovitz, & Burger, 2014; Boske, Gamkhar, & Harrison, 2013). Boske et al (2013) also find in their report that states like Ohio and West Virginia have a proven successful mechanism for funding necessary road repairs due to fracking in the form of "Road Use Maintenance Agreements (RUMAs), "a legal agreement between the well operator and the state or local authority," which varies from Pennsylvania's mechanism in requiring energy companies make improvements to insufficiently prepared roads *prior* to fracking beginning, along with repairing and maintaining roads throughout the entire process (Boske, Gamkhar, & Harrison, 2013, p. 3).

Ohio municipalities are free, but not required to, negotiate RUMAs with fracking companies (Locher, 2012), as in Ohio RUMAs are established between these companies directly with counties, municipalities and townships, and not the Ohio Department of Transportation. These fracking road improvement projects have ranged between $50,000 to $3 million (Boske, Gamkhar, & Harrison, 2013). Given what prior research has determined regarding use of maintenance agreements in Pennsylvania, Ohio and West Virginia, the current research puts forth the hypothesis that the greater the utilization of maintenance agreements the lower the cost of road damage to municipalities, counties and the state net of the maintenance agreements.

Bonding

Both Ohio and West Virginia utilize the financial mechanism of bonding to complement the use of RUMAs. Boske et al (2013) reveal that while bonding in Ohio is an optional component of RUMAs, they are not widely utilized, as if a fracking company engages in making improvements upfront, a bond is not a required aspect of the RUMA. However, as a “home rule” state, Ohio municipalities are responsible for both the construction and maintenance of state highways that pass through their borders (Wray, 2011). In order to provide assurance for these added responsibilities, local governments in Ohio can and do pursue road bonds. When bonds are utilized, companies are assessed $150,000 to $400,000 per mile, contingent upon the road type (Boske, Gamkhar, & Harrison, 2013, p.3).

Fracking companies are required by West Virginia state law to meet with highway engineers and discuss roadway maintenance needs for their heavy truck routes, and to post bonds that are capped at $100,000 per mile of paved roads and $25,000 per mile of unpaved roads (Mattox, 2012). Dybing, Lee, DeHaan and Dharmadhikari (2013) point out that there are shortcomings to bonding in West Virginia, as the bond is limited to secondary roads, not applying to state and federal highways (Associated Press, 2011), and an operator can even further reduce their fiscal responsibility for road repairs by covering their liabilities across a single District for $250,000, or across the entire state of West Virginia for a $1,000,000 bond (Mattox, 2012; Dutzik, Ridlington, & Rumpler, 2012).

Pennsylvania also requires that fracking companies post bonds for their routes in addition to entering in Excess Use Maintenance Agreements (Boske, Gamkhar, & Harrison, 2013). In fact, "whenever there is an excess maintenance agreement there is an associated bond" (Christie, 2010a). The State of Texas, in contrast to the aforementioned states, has no requirements for systematic road bonding (Wilson, 2012). While according to prior research studies and reports there are distinct challenges to the utilization of bonding as a fiscal tool in relation to fracking in Pennsylvania, Ohio, West Virginia, this research hypothesizes that the greater the utilization of bonding the lower the cost of road damage to municipalities, counties and the state net of the bonding.

Impact Fees

According to prior research studies and reports, Pennsylvania is a state that has taken the lead with implementation of this fiscal tool that "charges an impact fee for each drilled well" (Boske, Gamkhar, & Harrison, 2013, p. 3) to offset the cost of road damage incurred as result of fracking with the passage of a Senate and House of Representatives approved bills in November 2011 (Negro, 2012), which was signed into law as the Unconventional Gas Well Impact Fee Act (Act 13) on February 12, 2012. The impact fees imposed on companies producing gas via unconventional horizontal wells follow a 15-year fee schedule and are based upon the average annual market price of natural gas. With the average price falling between $2.26 and $2.99 per Mcf in 2013, this results in companies being assessed a *per well* impact fee of $45,000 for the first year of production, $35,000 for the second year of production, $30,000 for the third year of production, $15,000 for the fourth through tenth year of production, and $5,000 for the eleventh through fifteenth years of production (Sacavage, 2013). Of the total $204 million in fees collected in 2012, $25.5 million (12.5%) go to specific earmarked state agencies, and 60% of the remaining funds go directly to counties and municipalities to finance the cost of roadway damage via the Unconventional Gas Well Fund, with 40% ending up in the Marcellus Legacy Fund for statewide initiatives "with potential local impacts and value" (Sacavage, 2013, p. 8).

Colorado made it legal for counties and municipalities to charge such impact fees for new growth projects with the passage of SB15 in 2001 (RPI Consulting, 2008). These impact fees can be negotiated into lease agreements and provide counties with as much as $9,000 per well (Sassin, 2009). Ohio Governor Kasich introduced a similar plan in March 2012 that would have allowed for "100 percent of the proceeds staying at the local level for road maintenance" (Fields, 2012, p. 1). What became Ohio HB 59 would have levied a $25,000 fee per well pad prior to start of construction, with all proceeds going to the treasurer of the county the drilling is taking place in, which can be utilized for any purpose (Hickman, 2013). Ultimately, Governor Kasich's proposal is rejected by the Ohio General Assembly and is not included in the HB 59 that is adopted on June 30, 2013 (Atlas Resource Partners, L.P., 2014). Given the conclusions of prior literature regarding application of impact fees on roadways damaged by fracking, this research puts forth the hypothesis that the greater the utilization of impact fees the lower the cost of road damage to municipalities, counties and the state net of the impact fees.

Voluntary Participation

Traditionally, Texas has been dependent upon the voluntary participation of the industry to finance road repairs, and Dewitt County Judge Daryl Fowler indicates that his county does consistently receive economic contributions from two fracking companies for each well drilled, with others contributing on an ad hoc basis (Fowler, 2012). However, a peer-reviewed study of two Texas counties located in the Barnett Shale region conducted by Wynveen (2011) finds that fracking related road repairs funded by industry revenues are "disparately undertaken, neglecting certain areas and attending to others," identifying an unequal distribution of revenue that favored the oil companies and their employees, in addition to lease holders, as "the only benefactors of the natural gas industry in Wise County" (Wynveen, 2011, p. 17). As Dutzik et al (2013) elucidates, "Voluntary donations from fracking companies are far from reliable sources of revenue to repair and maintain crumbling roads," referencing the reality of large fracking operations like Devon Energy Corp. and Chesapeake Energy (Dutzik, Ridlington, & Rumpler, 2012, p. 24). Described by Johnson County (Texas) Judge Roger Harmon as being "early to voluntarily cover repairs to roads if presented with before-and-after assessments," Johnson County Commissioner Rick Bailey finds that as drilling activity slowed, natural gas prices declined, and smaller subcontractors moved in to service wells, it becomes difficult to get anyone to cover further road maintenance costs (Shlachter, 2012, p. 1). Due to the inconsistency and arbitrariness of this mechanism in prior studies and reports, the current research did not include voluntary participation as a potential independent variable.

Additional Appropriations

Fracking will continue to strain jurisdictional resources until accountability measures in the form of infrastructure financing mechanisms are in place (Miller & Sassin, 2013). While Texas currently lacks a statewide strategy for managing roadway damage due to fracking (Boske, Gamkhar, & Harrison, 2013), the Texas Department of Transportation requested an additional $400 million in appropriations in 2012 to repair existing roadway and bridge damage to State highways and Farm-to-Market roads due to fracking. These are the findings of studies conducted by the Texas A&M University Transportation Institute and the University of Texas Center for Transportation Research. Six hundred million will follow each year of the proceeding biennium to further prepare roadways and bridges for projected fracking truck traffic related degradation (TxDOT, 2012). The Texas State legislature set aside an additional $225 million in early 2013 for a two-year grant program administered by the Texas Department of Transportation targeted at county roadways in west and south Texas, marking the first time that state has been utilized in the repair of county roads (Dukes, 2013).

Judge Fowler reiterates, “It is high time to do something about the inequity” in the Eagle Ford Shale region of Texas. Fowler offers that the same fiscal year only $112,000 is returned from the state in appropriations towards fracking-related impacts for his county via Overweight Axle Fees and gasoline tax collections, the State of Texas collected more than $57.5 million in severance tax from his county for fracking-related activities (Dukes, 2012, p. 2). The fact is that while fracking companies can receive overweight load permits from the Texas Department of Transportation, the permits themselves specifically state that revenue from the permits will not necessarily go back to the counties that are facing the related industry caused road damage: “It is expressly understood that the Texas Department of Transportation shall not be responsible in any way for any damage of whatever nature that may result from the movement of the described vehicle and load over state highways” (TxDOT, 2008, p.1). Given the results of prior research studies and reports, this study hypothesizes that the cost of road damage decreases as the additional appropriations to assist in covering those costs increases.

CHAPTER 5

THE MODEL

The dependent variable of Cost of Road Damage on the public in this critical assessment breaks down into four distinct dimensions in terms of unit of measurement (per well, per lane mile of roadway, per year and per roadway lifetime), and seven distinct dimensions of roadway jurisdictions by level of governments responsible for maintaining the given infrastructure (U.S. highways, Interstate highways, State highways, Farm-to-Market roadways, County roadways, Municipal roadways and Township roadways). Each of these dimensions illustrates further interrelationships between the ten independent variables discussed above, and the dependent variable of Cost of Road Damage due to fracking that is the subject of this critical assessment. The bottom line is the cost of road damage, as illustrated by the prior research, can be framed according to a number of different unit measurements each responsive to its own unique set of independent variables, as well as being analyzed from a number of unique jurisdictions when it comes to levels of government physically and fiscally responsible for maintaining the impacted roadways.

Unit Factors

Cost of Road Damage Per Well

In 2008 Rio Blanco County enlisted RPI Consulting to produce a report regarding new growth road impact fees in light of Colorado's 2001 SB15 allowing for the legal imposition of such fees by counties and municipalities. This study estimates that the per well cost of road impact for a gas or oil well is $22,032 in 2014 dollars, with it being reduced to $13,194 in 2014 dollars per well with on-site produced water disposal (thus eliminating all outbound wastewater heavy truck traffic), with a further reduction to $12,821 in 2014 dollars per shallow well less than 5,500 feet deep, due to fewer inbound and outbound water deliveries being required (RPI Consulting, 2008).

The RAND Corporation published the study "Estimating The Consumptive Use Costs of Shale Natural Gas Extraction on Pennsylvania Roadways" in 2014 that estimates the consumptive use costs on Pennsylvania state-maintained roadways of additional heavy truck traffic due to fracking of the Marcellus Shale during 2011. Abramzon et al (2014) determines that the cost of road damage per well for all state roadway types is between $13,682 and $24,206 in 2014 dollars, while if the lowest heavy truck traffic volume state roads are excluded the cost is $5,262 to $10,524 in 2014 dollars per well. This is because the bonded higher volume traffic state roadways generally do not have reconstruction agreements in place and thus "are typically not charged for consumptive use; only visual damages to the roadway require repairs under the excess maintenance agreements" (Abramzon, Samaras, Curtright, Litovitz, & Burger, 2014).

The DeWitt County Commissioners Court enlisted Naismith Engineering to create a "Road Damage Cost Allocation Study" to estimate the total cost of providing a County Road system that will serve both public and fracking industry needs in the face of their plans to drill 3,250 wells. Their conclusion is that based on 45 miles of anticipated Road Maintenance at $82,489 in 2014 dollars per mile per year, 187 miles of anticipated Basic Reconstruction at $949,619 in 2014 dollars per mile of road, and 99 miles of anticipated Major Reconstruction at $1,959,103 in 2014 dollars per mile of road, that the total cost to provide a County Road system for DeWitt County is $445,582,620 in 2014 dollars, or approximately $137,137 in 2014 dollars per well (Underbrink, 2012).

Table 2. Cost of Road Damage Per Well (Dependent Variable Unit Factor Dimension #1)
(all figures adjusted to 2014 dollars)

Cost Per Well	State	Road Type(s)	Source
$22,032	Colorado	Rio Blanco County roads	RPI Consulting (2008)
$13,682 to $24,206	Pennsylvania	State maintained roadways	Abramzon et al (2014)
$137,137	Texas	Dewitt County roads	Underbrink (2012)

Cost of Road Damage Per Mile

A peer-reviewed study, Abramzon et al (2014), examines consumptive roadway use costs due to shale has activity for all types of roadways in Pennsylvania and derives that the total road damage for each well per mile of travel across all roadways is $558 in 2014 dollars for a low number of truck trips scenarios, and $1,221 in 2014 dollars for a high number of truck trip scenarios above normal background road damage. An early study by Mason (1983) entitled "Effects of Oil Field Development on Low Volume Roadways: An Overlooked Energy Related Cost" concludes that the increase in annual additional pavement cost due to oil industry activities on light duty, low volume Farm-to-Market roads in Texas is $30,665 in 2014 dollars per mile.

A Huntington and Ksaibati (2009) study of Carbon, Johnson and Sheridan Counties in Wyoming analyzes unpaved county roads impacted by unconventional shale oil and gas development and reports that those roads subjected to fracking require an average $14,824 in 2014 dollars in improvements per mile, while baseline unpaved and non impacted road require only an average of $2,260 in 2014 dollars in improvements per mile, for a difference of an additional cost of $12,564 in road damage per mile. 69% of the improvements on fracking damaged roads are due to potholes, 20% of the improvements are due to rutting distress, and 10% of recommended improvements are due to a combination of the distresses of washboards, drainage or dust.

A report prepared for the City of Keller, Texas by Belcheff and Associates (2010) analyzes eight different city road types by total ESALs available on each based upon the total number of heavy truck trips required to construct and operate a single fracking well. From these calculations they derive a fee to cover the cost of roadway reconstruction, and thus total road damage, per lane-mile for each of these roadways (for this research these totals are doubled to match the unit measurement of two-lane roadways utilized throughout the other prior studies reviewed). Their examination renders the results of a per mile fee of $115 to $43,427 in 2014 dollars to cover expected damages, contingent upon the type of roadways and trucking methods utilized.

Utilizing full replacement cost per lane mile, the Denton County Oil and Gas Task Force Summary Report (2005) places the cost of damage due to fracking to full county roadways to be $100,259 in 2014 dollars per mile per well for this Texas county (DCOGTF, 2005). In addition to anticipating the full replacement cost for 99 miles of roadway they project to have to undergo Major Construction, Naismith Engineering also accounts for how many miles of DeWitt County, Texas roadway they anticipate will have to undergo Road Maintenance (45 miles) and Basic Reconstruction (187 miles) in order to create sufficient infrastructure for heavy truck traffic to construct and operate 3,250 fracking wells. The total estimated project cost of $445,583,000 in 2014 dollars to create the DeWitt County road system necessary to meet the demands of fracking, when factored out over 331 total miles of roadway and 3,250 total wells, results in a total cost of road damage of $416 in 2014 dollars per well per mile (Underbrink, 2012).

Table 3. Cost of Road Damage Per Mile (Dependent Variable Unit Factor Dimension #2)
(all figures adjusted to 2014 dollars)

Cost Per Mile	State	Road Type(s)	Wells	Source
$663 to $1,221	Penn.	All road types	1	Abramzon et al (2014)
$12,564	Wyoming	Unpaved county roads	1	Huntington & Ksaibati (2009)
$30,665	Texas	Farm-to-Market roads	1	Mason (1983)
$115 to $43,427	Texas	City of Keller roads	1	Belcheff & Associates (2010)
Full replacement $100,259	Texas	Denton County roads	1	DCOGTF (2005)
Road maintenance $82,489 *Basic Reconst.* $948,619 *Major Recon.* $1,959,103 $443	Texas	Dewitt *45 mi* County *187 mi* Roads *99 mi*	3,250 ——— 1	Underbrink (2012)

Cost of Road Damage Per Year

Scott Christie, Deputy Secretary for Highway Administration at the Pennsylvania Department of Transportation, reports for the Pennsylvania House Transportation Funding Hearing on June 10, 2010 that the total required for road repairs due to fracking of the Marcellus Shale is $288 million in 2014 dollars. This cumulative (rather than annual) total is based upon the estimation that for the 1,711 miles of roadway that already have an excess maintenance agreement with Marcellus Shale companies that 10% require full reconstruction, 20% require major base repair, and 50% require minor repairs and maintenance, in combination with the same proportionate assumption regarding fracking-related roadway repairs for the "planned to be posted roadways" (Christie, 2010b, p. 3). Just three short years later, in 2013, the Pennsylvania Department of Transportation estimated that more than $3.6 billion in 2014 dollars is needed to maintain all state roadway assets, due to cumulative damage from both unconventional oil and gas-related heavy truck traffic and baseline, pre-existing roadway vehicle traffic (Rogers, 2013).

In 2011 the New York State Department of Transportation (NYSDOT) produced the discussion paper "Transportation Impacts of Potential Marcellus Shale Gas Development," where they report that the annual projected costs of road damage from fracking to New York would range from $98 to $169 million in 2014 dollars for State roads and $131 to $241 million in 2014 dollars for local roadways (NYSDOT, 2011). These figures are based upon the estimation that even a lower level of development than that experienced in Pennsylvania would result in a heavy truck trip increase of up to 1.5 million during peak year, while increasing peak hour heavy truck trips by as many as 36,000 per hour throughout the New York Marcellus Shale region. This draft paper also explicitly concludes “there is no mechanism in place allowing State and local governments to absorb these additional transportation costs without major impacts to other programs and other municipalities in the State,” and that the NYSDOT and “local governments currently lack the authority and resources necessary to mitigate such problems” (NYSDOT, 2011, p.3).

The State of Arkansas has determined that the cumulative impact from 2009 to 2012 of fracking of the Fayetteville shale play is $464 in 2014 dollars in additional damage to Arkansas state highways (Heinberg, 2013). The Texas Department of Transportation, through partnerships with Texas A&M University Transportation Institute (TTI) and the University of Texas Center for Transportation Research, has conducted several research studies to quantify the annual total cost of road damage on Texas roads due to fracking in the Barnett and Eagle Ford shale plays. Results of the research indicates that the total annual cost of road damage in 2014 dollars is more than $2 billion on the Texas state highway system, $1 billion on Texas farm-to-market roadways, and $1 billion on local transportation systems, including city and county roads, for a grand total of more than $4 billion in 2014 dollars annually (TxDOT, 2012).

Table 4. Cost of Road Damage Per Year (Dependent Variable Unit Factor Dimension #3) ***(all figures adjusted to 2014 dollars)***

Damage Cost	Time Frame	State	Road Type(s)	Source
$288 million	*cumulative to 2010*	Pennsylvania	State highways	Christie (2010b)
$98 to $169 million $131 to $241 million	*annual estimate* *annual estimate*	New York	State highways Local roadways	NYSDOT (2011)
$464 million	*cumulative 2009 to 2012*	Arkansas	State highways	Heinberg (2013)
*$3,557 million	*cumulative to 2013*	Pennsylvania	State roadway assets	Rogers (2013)
$2,062 million $1,031 million $1,031 million	*annual estimate* *annual estimate* *annual estimate*	Texas	Interstate/State hwys. Farm-to-Market rds. County/City roads	TxDOT (2012)

* *Includes both unconventional oil & gas-related and baseline (pre-existing) roadway traffic damage*

Cost of Road Damage Lifetime

Naismith Engineering has determined for DeWitt County, Texas that the upfront costs of preparing the county roadway infrastructure for 20 years (2013-2032) of fracking of 3,250 wells to be in excess of $445 million in 2014 dollars for 331 miles of county roads (Underbrink, 2012). The Upper Great Plains Transportation Institute produced the report “Additional Road Investments Needed to Support Oil & Gas Production and Distribution in North Dakota” that estimates the total projected roadway infrastructure investment needs over 20 years (2011-2030) due to fracking for all county and town road systems to be $907.1 million in 2010 dollars ($984.8 in 2014 dollars). This projection, based on existing and future drill rig locations in 2010, represents $340.1 million in total paved road damage costs and $567 in total unpaved road damage costs. A 3% inflation rate renders a 20-year total cost of $1,099 million, while a 5% inflation rate renders a 20-year total cost of $1,266 million (Tolliver & Dybing, 2012).

Table 5. Cost of Road Damage Lifetime (Dependent Variable Unit Factor Dimension #4)
(all figures adjusted to 2014 dollars)

Damage Cost	Time Frame	State	Road Type(s)	Source
$445 million	*2013 to 2032*	Texas	Dewitt County roads	Underbrink (2012)
	2011 to 2030	North Dakota	County & town roads	Tolliver & Dybing (2010)
$369.2 million			paved roads	
$615.6 million			unpaved roads	

Jurisdiction Factors

In order to accurately determine the overall cost of roadway damage that has occurred or will occur over a given region in a specific time frame, it is not enough to consider just one or two jurisdictional dimensions. As fracking ultimately impacts the roadways of all levels of government, the total cost within each jurisdiction must be determined, and then summed together to derive the overall total cost according to this critical assessment. Not one single prior research study or report took into consideration all seven jurisdictional dimensions identified by the current research (see Table 7 below), however the report from the Center for Transportation Research at the University of Texas at Austin by J. Prozzi, Grebenschikov, Banerjee, & J. A. Prozzi (2011) comes closest by taking six jurisdictional dimensions into consideration.

The report compiled by Prozzi et al (2011) sponsored by the Texas Department of Transportation, has come closer than any other study located to researching the full range of roadway jurisdictions in relation to fracking, categorizing total mileage traveled according to the following types: Interstate highways; U.S. highways; Texas State highways; Farm-to-Market roads; beltways, spurs, loops, and business roads; and local and county roads (J. Prozzi, Grebenschikov, Banerjee, & J. A. Prozzi, 2011).

In Texas, highways maintained by the state carry 73% of the overall traffic, while comprising only 26% of the total roadway mileage. These include both State Highways and

Farm-to-Market roadways. In excess of half of this state maintained system is comprised of Farm-to-Market (and Farm-to-Ranch) roads, which with nearly 41,000 miles of roadway is the most extensively developed of all rural highway systems in the United States (Purcell, 2012). The Prozzi et al (2011) report finds the average vehicle miles traveled [VMT] for moving drill rigs to be 33 miles, and when it comes to the movement of related construction traffic in Texas's Barnett Shale, Prozzi et al (2011) determines the roadway usage to breakdown among jurisdictions as follows: State Highways 28%, Farm-to-Market roads 27%, U.S. Highways 23% and Interstates 19%. Likewise the same study finds that the average VMT for fracking wastewater disposal (from gas/oil well to disposal well) is 9.4 miles, with 30.7% of truck traffic occurring on city streets and 24.8% of the traffic happening on Farm-to-Market roads (J. Prozzi, Grebenschikov, Banerjee, & J. A. Prozzi, 2011).

The reports and studies analyzed in this research focus on the jurisdictions in Table 6.

Table 6. Cost of Road Damage (Dependent Variable Jurisdiction Factor Dimensions #5–#11)

Jurisdiction Factors	Sources
U.S. highways	J. Prozzi, Grebenschikov, Banerjee, & J. A. Prozzi (2011) and Quiroga, Fernando, & Oh (2012)
Interstate highways	J. Prozzi, Grebenschikov, Banerjee, & J. A. Prozzi (2011) and Quiroga, Fernando, & Oh (2012)
State highways	NDDOT (2006); NYSDOT (2011); J. Prozzi, Grebenschikov, Banerjee, & J. A. Prozzi (2011); TxDOT (2012); Dybing (2012); Quiroga, Fernando, & Oh (2012); and Abramzon, Samaras, Curtright, Litovitz, & Burger (2014)
Farm-to-market roads	Mason (1983); J. Prozzi, Grebenschikov, Banerjee, & J. A. Prozzi (2011) and Quiroga, Fernando, & Oh (2012)
County roadways	DCOGTF (2005); RPI Consulting (2008); GDTF (2009); Huntington & Ksaibati (2009); Tolliver & Dybing (2010); J. Prozzi, Grebenschikov, Banerjee, & J. A. Prozzi (2011); Underbrink (2012); TxDOT (2012); Mitra, Tolliver & Dybing (2012) and Tolliver (2012)
Municipal roadways	Belcheff & Associates (2010); NYSDOT (2011); J. Prozzi, Grebenschikov, Banerjee, & J. A. Prozzi (2011) and TxDOT (2012)
Township roadways	Tolliver & Dybing (2010); NYSDOT (2011); Mitra, Tolliver & Dybing (2012) and Tolliver (2012)

CHAPTER 6

DISCUSSION: WHO PAYS THE COSTS OF FRACKING?

Freilich and Popowitz (2012) relate the story of LaSalle County, Texas that is facing fracking-related truck traffic requiring infrastructure improvements in the range of $100 million that cost more than sixteen times the entire county's annual $6 million budget. The same year that DeWitt County, Texas determines that their roadway infrastructure needs to accommodate the planned degree of fracking would cost their county alone in excess of $445 million in 2014 dollars, while the total collected in severance taxes from the industry on production from all 24 Eagle Ford Shale counties combined was $333 million in 2014 dollars (Underbrink, 2012; Rogers, 2013). DeWitt County Judge Fowler adds further context to the issue by revealing that his county's contribution to that severance tax from fracking-related activities was $57.5 million in 2011, while the state only returned $112,000 to the county in appropriation support for the roadway infrastructure damage in the form of Overweight Axle Fees and gasoline tax collections (Dukes, 2012). Dewitt County's total annual budget stood at $15 million that year (Rogers, 2013).

During 2012 the State of Texas took in $3.6 billion in severance taxes for oil and gas production, approximately $1.5 billion from fracking of shale plays, while the Texas Department of Transportation made the determination that the total annual cost of road damage due to fracking for all roadways systems surpassed $4 billion (TxDOT, 2012; Rogers, 2013). A similar pattern has been revealed in the Fayetteville shale play of Arkansas, as between 2009 and 2012 the state took in $188 million in 2014 dollars in severance taxes from fracking activities, while experiencing what is estimated to be $464 million in 2014 dollars in road damage due to fracking, $412 million in 2014 dollars of which has been covered directly by taxpayers

(Heinberg, 2013; Kandlur, 2014).

As Freilich and Popowitz (2012) elucidate, while the liabilities associated with fracking are best managed by a combination of all levels of government, secondary impacts such as responding to and managing damage to local roadway infrastructure can only readily be dealt with through local regulation and intervention. Unfortunately, the notable gains that do often accompany this unconventional shale development in the form of severance taxes and other fiscal mechanisms generally do not find their way into the coffers of localities that are making the greatest sacrifices in terms of degraded infrastructure and loss in quality of life (Freilich & Popowitz, 2012). Severance taxes are thus not used exclusively, or even primarily, to compensate local counties, municipalities and townships for the direct impacts of fracking (Dutzik, Davis, B., Van Heeke, T., & Rumpler, 2013).

Simply put, “States distribute revenues in various ways, but typically, most of the collected taxes are deposited into the general fund,” with the extra revenue or remainder going to state permanent funds, or to finance environmental clean-up and conversation projects, and then finally in some cases distributed to local governments (Pless, 2012, p.1). For example, Wyoming follows the common practice of putting the vast majority of its total severance tax revenue into the state’s General Fund, Budget Reserve Account, and the Permanent Mineral Trust Fund, leaving 3% for Counties, Cities and Towns and Capital Construction, 1% for the Highway Fund, and 1% for State Aid County Roads. This provides very little for the local governments that face the immediate impacts of fracking on a daily basis (Wyoming Taxpayers Association, 2014).

Due to its utilization of the publically available roadway infrastructure, fracking imposes a unique and significant immediate and long-term burden on taxpayers (Dutzik, Davis, B., Van Heeke, T., & Rumpler, 2013). A study by Kelsey et al (2011) demonstrates how this reality has been playing out due to impacts of the Marcellus Shale fracking efforts in Pennsylvania: “Only 18 percent of the governments experiencing Marcellus development activity said their tax revenues had increased, which indicates that most local governments being affected are not seeing more tax revenue as a result. In comparison, 26 percent of the local governments indicated that their costs had increased, particularly related to road expenses” (Kelsey, Shields, Ladlee, & Ward, 2011).

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

The current research explores how the impact of heavy truck traffic due to fracking on seven unique roadway dimensions (according to governmental jurisdiction) is influenced by a mix of both physical and fiscal factors, and points towards the utility of conducting a critical assessment of the literature regarding the public costs of fracking-related roadway damage. The findings of this study additionally elucidate the imbalance between the accrued costs (liabilities) of fracking and the resources derived for the various jurisdictional dimensions to manage and mitigate those comprehensive and well-documented risks.

Several fiscal mechanisms have been brought into existence in an effort to manage the liabilities and compensate for loses, but all are met with inconsistent degrees of success from state to state, county to county, and municipality to municipality. While there is not a lot of means of controlling the physical factors, outside of some policy and regulation measures, the fiscal factors do present a variety of opportunities to create direct economic incentives to motivate fracking companies from engaging in roadway infrastructure degrading behaviors without specifically defined and transparent means to recompense and *to make whole*.

This research takes a look at four fiscal factor mechanisms that the prior literature discusses and demonstrates to have impacts and some degree of success in reducing the overall cost of roadway damage to the various jurisdictions responsible for management and upkeep of these public roadways. These include road maintenance agreements, bonding, impact fees and additional appropriations, most of which are tools utilized in combination, depending on state and local laws and standards. Abramzon et al (2014) in their report for the RAND Corporation put forth three policy mechanisms for how to mitigate fracking-related roadway damage and its associated costs. These include: 1) recovering the cost of roadway damage through fees or taxes; 2) reduce the road damage itself through incentives / regulations that compel fracking companies to change their activities in order to create less damaging outcomes; 3) build-up the roadway infrastructure prior to start of fracking to withstand the projected roadway damage (Abramzon, Samaras, Curtright, Litovitz, & Burger, 2014).

Abramzon et al's (2014) first policy mechanism of recovering the cost of roadway damage via fees or taxes embodies each the fiscal factors of this research study, in additional to utilizing severance taxes to assist in defraying the costs of roadway damage. It is a flexible category that includes the vast majority of fiscal mechanisms already in play or being pursued. Their second policy mechanism of reducing roadway damage by "compelling companies to engage in less damaging activities […] through regulations or incentives" (Abramzon, Samaras, Curtright, Litovitz, & Burger, 2014, p. 6), including such methods as limiting truck weights, limiting truck traffic, or requiring pipeline usage for water transport, is not addressed in this research due to the general lack of viable and productive examples of this approach at work. The third policy mechanism address by Abramzon et al (2014) is to build-up the roadways before inception of fracking, to "adjust the infrastructure system in a way that could absorb the expected damages at lower costs (Abramzon, Samaras, Curtright, Litovitz, & Burger, 2014, p. 6). This strategy is precisely embodied in the Road Maintenance User Agreements that are identified in Ohio and West Virginia, which require energy companies make improvements to insufficiently prepared roads *prior* to all drilling and extraction activities (Boske, Gamkhar, & Harrison, 2013, p.3), in order to be adjusted to support the heavier truck traffic weights and volumes from fracking.

This third policy mechanism represents a proactive partnership approach to assessment, and very favorably aligns with the first of three policy strategies that Miller and Sassin (2013, 2014) develop and elucidate as the "spectrum of policies currently being advocated" for in the realm of mitigating the cost of roadway damage due to fracking (Miller & Sassin, 2013, p. 4). This particularly proactive *armor-up* approach that strengthens roadway pavement prior to the inception of energy developments, is directly contrasted with two other *reactive* approaches, which include: 2) a performance-based assessing of impact fees for specific damages after they have already occurred, and 3) a non-performance based assessing of impact fees that bare no relation to the actual roadway degradation, i.e. donations of maintenance or repair materials by developer after the damage is already done (Miller & Sassin, 2013; Miller & Sassin, 2014).

The proactive approach not only ultimately removes tax payers from the equation, and puts the full cost of roadway degradation mitigation in the hands of the responsible parties, the fracking companies, but it also creates immense cost savings in the overall process of protecting roadways subjected to fracking. This armoring and reinforcement is essential to "maintaining health, welfare, and the quality of life in states where oil and gas resources can be reached by fracking" (Freilich & Popowitz, 2012), as the general public requires the continual functionality of public roadways for safe and efficient travel. Prior research also indicates that this proactive approach to managing roadway impacts, including "reconstructing or resurfacing a road to preserve it before damage occurs," reduces overall maintenance and repair costs by approximately 700% (Wilson, 2012, p. 9). As Boske et al (2013) surmise: "The main lessons learned by both West Virginia and Ohio are the cost effectiveness of upfront road improvements in regions developing shale gas reserves and the importance of early coordination with energy companies…" (Boske, Gamkhar, & Harrison, 2013, p. 8).

A recommendation of this current research is that the optimal approach to maintaining the roadways for both public and private usage in the face of fracking, with the added economic benefit of reducing costs due to road damage to the general public and the fracking industry alike, is a proactive armoring approach that puts the full responsibility of preparing roadways for the known risks of fracking in the hands of industry that plans on subjecting those roadways to undue heavy truck traffic weights and volumes, prior to the inception of energy development.

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APPENDICES

APPENDIX A

Operationalization of Dependent Variable Total Cost of Road Damage

Dimensions	Definition	Measurement
Per well	Cost of road damage per well from fracking-related heavy truck traffic	Total cost of road damage in a given county divided by the total number of wells in that county (RAND Corporation, http://repository.cmu.edu/cgi/viewcontent.cgi?article=1065&context=ce
Per mile	Cost of road damage per lane mile of roadway from fracking-related heavy truck traffic	Total cost of road damage in a given county divided by the total number of road lane miles in that county (Wyoming Technology Transfer Center, http://trb.metapress.com/content/p2x287tw6k043753)
Per year	Cost of road damage per year from fracking-related heavy truck traffic	Annual estimated reconstruction costs of roads in a given region (RAND Corporation, http://repository.cmu.edu/cgi/viewcontent.cgi?article=1065&context=cee)
Per lifetime	Cost of road damage over 20 years of road lifetime from fracking-related heavy truck traffic	20-year anticipated expenditures with fracking development minus 20-year anticipated expenditures without (Texas Transportation Institute, http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6498-1.pdf)

APPENDIX A

Operationalization of Dependent Variable Total Cost of Road Damage (continued)

Dimensions	**Definition**	**Measurement**
To U.S. highways	Cost of road damage to U.S. highways from fracking-related heavy truck traffic	Total estimated cost of damage to roadways under U.S. highway jurisdiction (Center for Transportation Research, UT Austin, https://ftp.txdot.gov/pub/txdot-info/energy/impacts_energy.pdf)
To interstate highways	Cost of road damage to interstate highways from fracking-related heavy truck traffic	Total estimated cost of damage to roadways under interstate highway jurisdiction (Center for Transportation Research, UT Austin, https://ftp.txdot.gov/pub/txdot-info/energy/impacts_energy.pdf)
To state highways	Cost of road damage to state highways from fracking-related heavy truck traffic	Total estimated reconstruction costs of damage to roadways under state highway jurisdiction (RAND Corporation, http://repository.cmu.edu/cgi/viewcontent.cgi?article=1065&context=cee)
To farm-to-market roadways	Cost of road damage to farm-to-market roadways from fracking-related heavy truck traffic	Total estimated cost of damage to farm-to-market roadways (Center for Transportation Research, UT Austin, https://ftp.txdot.gov/pub/txdot-info/energy/impacts_energy.pdf)

APPENDIX A

Operationalization of Dependent Variable Total Cost of Road Damage (continued)

Dimensions	**Definition**	**Measurement**
To county roadways	Cost of road damage to county roadways from fracking-related heavy truck traffic	Total paved & unpaved road investment needs for county roads (Upper Great Plains Transportation Institute, http://www.ugpti.org/resources/downloads/2010-12_AddRoadInvToSupportOil.pdf
To municipal roadways	Cost of road damage to municipal roadways from fracking-related heavy truck traffic	Total estimated cost of damage to municipal roadways (Center for Transportation Research, UT Austin, https://ftp.txdot.gov/pub/txdot-info/energy/impacts_energy.pdf)
To township roadways	Cost of road damage to township roadways from fracking-related heavy truck traffic	Total paved & unpaved road investment needs for township roads (Upper Great Plains Transportation Institute, http://www.ugpti.org/resources/downloads/2010-12_AddRoadInvToSupportOil.pdf

APPENDIX B

Operationalization of Independent Variables

Variable	Definition	Measurement
Truck trips	Total number of loaded truck trips (and empty inbound/outbound trips) required to construct and operate a single well	Contributing factors include well type and depth, local geology, drilling technology and water need (Texas Transportation Institute, http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6498-1.pdf)
Fracked wells	Total fracked wells actual and projected in a given region in a specific time frame	Utilize GIS-based build-out analysis of several factors for projections: permits issued, current drilling locations, development pace, input and output locations, spacing requirements and leasing activity (Transportation Research Board, http://67.20.169.205/~/media/Files/LBG/PDF/Insights/Shale%20Gas%20Development.pdf)
Well development phase	The phase of well development in regards to the nature of heavy truck traffic	Categorization of the well development phase as 1) inbound cement, sand and water; 2) inbound chemicals; 3) outbound oil/gas and byproducts; 4) outbound wastewater; or 5) inbound and outbound rig movement (Transportation Research Board, http://trb.metapress.com/content/84188l60061643pj)

APPENDIX B

Operationalization of Independent Variables

Variable	**Definition**	**Measurement**
Roadway type	The composition of a roadway (paved, low type, oil/gravel, earth) along with structural/geometrical characteristics	Categorization of roadway's composition, structure (thickness, material types, coefficients) and geometry (lane and shoulder width, shoulder type) (North Dakota State University, http://phdtree.org/scholar/dybing-alan-gabriel/publication)
Roadway condition	Condition of road in terms of reduction in useful roadway life or estimated remaining useful roadway life	Measure a combination of impacts from truck weight/loads, traffic volume and pavement characteristics, including roadway type, structural damage and maintenance schedule (Federal Highway Administration, http://ntl.bts.gov/lib/18000/18700/18753/PB2002101769.pdf)
Roadway improvements required	Physical improvements to roadway required due to heavy truck traffic damage.	Categorization of roadway improvement needs into 1) maintenance, 2) rehabilitation, and 3) reconstruction (Upper Great Plains Transportation Institute, www.ugpti.org/resources/downloads/2010-12_AddRoadInvToSupportOil.pdf)

APPENDIX B

Operationalization of Independent Variables

Variable	Definition	Measurement
Maintenance agreement	An agreement a municipality, county or state has in place with fracking companies to guarantee coverage of particular roadway maintenance costs.	Categorization of presence of maintenance agreement and whether or not it requires armoring prior to development (Center for Transportation Research, http://library.ctr.utexas.edu/ctr-publications/0-6802-1.pdf)
Bonding	Financial assurance a municipality, county or state requires from industry to cover costs of roadway damage.	Per mile fiscal bonding requirements categorized by road type and enforcing jurisdiction (Center for Transportation Research, http://library.ctr.utexas.edu/ctr-publications/0-6802-1.pdf)
Impact fees	Fee assessed by municipality, county or state to cover costs of fracking-related roadway damage.	Categorization of presence of impact fee and related fee per well per year (Center for Transportation Research, http://library.ctr.utexas.edu/ctr-publications/0-6802-1.pdf)
Additional appropriations	Monies appropriated by the state legislature for utilization by municipalities, counties and/or the state to cover costs of fracking roadway damage.	Target and origin of total dollar amount appropriated to a designated jurisdiction in a given time frame (Center for Transportation Research, http://library.ctr.utexas.edu/ctr-publications/0-6802-1.pdf)

Appendix C

Research on Fracking-Related Roadway Degradation Costs

New York

The New York State of Transportation estimates that the total road maintenance costs to mitigate impacts from truck traffic to 40,000 proposed wells across New York State would total as much as $410 million annually in 2014 dollars. This total is based upon state roads having an estimated cost between $98 million and $169 million per year in 2014 dollars, and local roads having an estimated cost between $131 million to $241 million per year in 2014 dollars, due to projected fracking traffic (Barth, 2013; Kennedy & Gallay, 2012; NYSDOT, 2011).

Arkansas

The Arkansas state highway department estimates that the costs between 2009 and 2012 from road damage due to Fayetteville shale play fracking truck traffic are in excess $450 million ($464 in 2014 dollars), finding that roads designed to last 20 years require major repairs after only 5 years due to fracking's constant stream of overweight vehicles ferrying water and equipment to and from well sites (Heinberg, 2013; Rogers, 2013). More than $400 million ($412 in 2014 dollars) of this total cost has landed directly on the back Arkansas taxpayers (Kandlur, 2014).

Colorado

A report completed by RPI Consulting (2008) for Rio Blanco County, Colorado, utilizing well lifetimes of 40-years, estimates a county roadway improvement cost of $22,032 (in 2014 dollars) per well due to fracking. This estimated cost is actually a fee per well proposed by the RPI Consulting report based up maintaining level of service, and derived from a proposed fee per ESAL and the projected ESALs required over the estimated lifetime of the wells (Abramzon, Samaras, Curtright, Litovitz, & Burger, 2014).

North Dakota

According to David Flynn, the Director of the University of North Dakota Bureau of Business and Economic Research, North Dakota allocated more than $1 billion (in 2014 dollars) for infrastructure, primarily for roads damaged by heavy energy-related truck traffic (Gunderson, 2012; White, 2013). Alan Dybing, a researcher at the Upper Great Plains Transportation Institute, states, “Simply put, the roads are falling apart in many cases,” as each new well requires more than 2,000 truck trips, and the massive trucking rigs are demolishing the state’s roadways (Holeywell, 2011, p. 3). A study prepared for the North Dakota Department of Commerce projects that the county and township road repair costs alone in North Dakota’s seventeen oil and gas producing counties due to oil and gas development is $985 million over the next twenty years (Tolliver & Dying, 2010; Tidd, 2013), with $369 million required for paved roads and $616 million for unpaved roads (all figures in 2014 dollars) (Tolliver & Dying, 2010; Huntington, Pearce, Stroud, Jones, & Ksaibati, 2013).

Wyoming

An early three-county study of unpaved roads by the Wyoming Technology Transfer Center, which took place between 2004 and 2006, indicates that while non-impacted unpaved roads require an average of $2,260 (in 2014 dollars) in improvements per mile, unpaved roads that are impacted by oil and gas drilling require an average of $14,824 (in 2014 dollars) in improvements per mile. Potholes necessitated 69% of the improvements on drilling roads, with rutting being the road distress underlying 20% of the needed improvements on these same roads (Huntington & Ksaibati, 2009).

Pennsylvania

Pennsylvania Department of Transportation officials report that in 2010 more than $265 million ($288 million in 2014 dollars) was needed to repair roads damaged due to Marcellus Shale drilling (Christie, 2010b; Dutzik, Ridlington, & Rumpler, 2012). Related heavy truck traffic on all state maintained roadway types is estimated to cause an additional $13,000 to $23,000 of damage per well in 2011 ($13,682 to $24,206 in 2014 dollars) (Abramzon, Samaras, Curtright, Litovitz, & Burger, 2014). State officials also report that as their rural roads are not designed to withstand the volume or weight of the level of truck traffic, they have sometimes been degraded into impassability (Randall, 2010). By 2013, the state estimates that it would cost $3.5 billion ($3.6 billion in 2014 dollars) just to maintain the state's existing roadway assets, and an additional $8.7 billion ($8.8 billion in 2014 dollars) for necessary bridge repairs, from all wear and tear (Rogers, 2013), with fewer than 7,000 existing wells.

Texas

An engineering study from the Eagle Ford Shale Task Force regarding anticipated fracking-related truck traffic in DeWitt County, Texas indicates that with an estimate of 3,250 wells that will be accessed by county roads, the total cost for DeWitt County to provide a road system (331 miles) to meet projected industry and public needs is approximately $445 million in 2014 dollars, or almost $137,000 per well, over the next twenty years (Underbrink, 2012). This total accounts for the total needs in regards to county roads alone. LaSalle County chief administrator Joel Rodriguez estimates that build-up of the county's 230 miles of roads to withstand the influx of fracking-related heavy truck traffic in the heart of Eagle Ford Shale play would exceed $103 million in 2014 dollars, while the county's entire annual budget is a mere $6.2 million in 2014 dollars (Compoy, 2012).

A report completed for the City of Keller, Texas by Belcheff & Associates (2010) finds that a fee per lane-mile between \$53 to \$20,000 (\$58 to \$21,713 in 2014 dollars), contingent upon type of roadway and transportation methods, would be required to offset the cost of expected additional damages from fracking. An earlier study by Mason (1983) determines that the increased annual pavement cost-per-mile for a Farm-to-Market road servicing one oil well is \$29,711 in 2014 dollars.

The Texas Department of Transportation [TxDOT] estimates that the cost of maintaining the roadway infrastructure degraded by the fracking traffic statewide is more than \$4 billion a year in 2014 dollars (Heinberg, 2013; Rogers, 2013). That includes \$1 billion for farm-to-market roads, \$1 billion for local city street and county roads, and \$2 billion for interstate and state highways (Barth, 2013; Sprow, 2013; TxDOT, 2012). TxDOT additionally estimates that more than \$2 billion of that total is road damages to the East Ford Shale region of South Texas alone (Remington, 2013). Due to the overwhelming extent and expense of the destruction in that area, the TxDOT plans to convert at least 83 miles of asphalt roads into gravel roads in those areas experiencing increased fracking-related truck traffic (Batheja, 2013).

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