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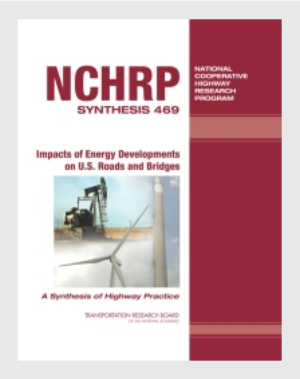

Impacts of Energy Developments on U.S. Roads and Bridges

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 469

Impacts of Energy Developments on U.S. Roads and Bridges

A Synthesis of Highway Practice

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Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2015
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Cover figure: North Dakota's transportation system plays a vital role in the development and movement of the state's energy resources. (*Source*: Courtesy of North Dakota Department of Transportation.)

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FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Jo Allen Gause
Senior Program Officer
Transportation Research Board

This report documents the economic impact of heavy truck traffic related to energy development on the nation's roads and bridges. Strategies used by transportation agencies to minimize and pay for the damage caused by heavy loads are also documented.

Information used in this study was acquired through a review of the literature, a survey of state transportation agencies, and interviews with selected federal and tribal agencies. Follow-up interviews with multiple agencies in five states selected for further study provided additional information.

Leslie Ann McCarthy, Seri Park, and Paul Casazza, Villanova University, and Anthony R. Giancola, Washington, D.C., collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable with the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

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IMPACTS OF ENERGY DEVELOPMENTS ON U.S. ROADS AND BRIDGES

SUMMARY

As outlined in the 2013 TRB report *Critical Issues in Transportation*, the changing energy supply is also affecting freight services. The report found that the geographic shifts in oil and gas supply greatly expand the transport of oil by truck and rail. In addition, the drilling of new oil and gas wells calls for the movement of heavy equipment, fracking sands, water, and other supplies to rural locations, which may have roads and bridges that are especially susceptible to heavy traffic. States in many areas of the country have increased their capacity for both wind and solar energy, which has required movement of oversized industrial parts for the construction of these facilities. A number of places in the middle portion of the United States are harvesting crops for biofuel energy and creating new opportunities for what was once a primarily agricultural sector.

As a result of these activities, the energy sector is placing significant financial and operational demands on state and local transportation systems. Hundreds of millions of dollars are spent each year on road repairs necessitated by energy development. Rural roads and bridges that were designed to provide land access, with little thought given to high traffic or heavy loadings, are now subjected to loads and traffic beyond their design limits owing to energy development. Transportation agencies are challenged to address the increased damages resulting from energy development–related traffic. In addition, the U.S.DOT reported that the increased number of large trucks involved in fatal crashes, injury crashes, and property-damage-only crashes in energy development areas are creating safety concerns.

Among the factors underlying the legislative requirements in the Moving Ahead for Progress in the 21st Century Act (known as MAP-21), the facilitation of energy independence appears in Section §167 Section D.1.B.vi, calling for the designation of primary freight network and critical rural freight corridors. There is further emphasis on the responsibility of the transportation community to provide access to energy development areas in Sections 1118 and 1120 of the legislation.

This synthesis documents the economic and infrastructure impacts of the energy sector on roads and bridges and provides an overview of state-of-the-practice strategies to minimize the impacts of heavy loads. The synthesis provides examples of engineering tools and design standards used to address the challenges of energy development impacts on roads and bridges, methods to assess costs, tools to document and improve safety, and state and local legislation and regulations. The findings of this study will help federal, state, local, and tribal transportation managers and agencies to plan strategies and better communicate the impacts of energy development activities on roads and bridges.

The information for this synthesis was gathered through a comprehensive literature review, survey of state departments of transportation (DOTs), and subsequent interviews with selected federal and tribal agencies, as well as interviews with multiple organizations in five states selected for further study. The survey was sent to the 50 states and the District of Columbia and Puerto Rico. Forty-one DOTs (40 states and the District of Columbia) responded to the survey, a response rate of 79%. After reviewing documentation in the literature and the detailed survey responses, the study team used criteria outlined in chapter one to select

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Colorado, Iowa, North Dakota, Pennsylvania, and Texas for more detailed interviews. The following observations were made based on the DOT survey data, detailed interviews, and literature review.

- Twenty of the 41 DOTs responding to the survey indicated an increase in damage or congestion on roads and bridges near areas where energy-related truck transportation is under way.
- In a number of rural areas infrastructure damage from energy development is an issue for state and local transportation agencies. The types of development associated with longer-term infrastructure damage were reported to be those with sustained hauling activities such as oil, natural gas, and biofuels. Low-volume roads nearer to urban areas were found to be generally less affected than those in rural counties, as a result of differences in roadway design, funding levels, and frequency of maintenance applications. However, in some urban locations an increase in pavement or bridge damage has been reported, particularly near intermodal transfer centers.
- The study found economic costs associated with providing energy development companies with adequately performing roadway and bridge infrastructure. There are significant costs to energy developers as well, including user delay costs resulting from work zone areas necessitated by repairs to infrastructure damage, and longer haul times owing to detour routing from energy development activities.
- An engineering method most commonly used by DOTs to assess the heavy loads and high traffic volumes created by energy development is determination of the pavement's remaining service life. Approaches that were reported for gathering data to compute the remaining service life include (1) portable and virtual weigh-in-motion devices for identifying traffic volumes and load levels; (2) falling weight deflectometer and ground penetrating radar to determine existing structural capacity of pavement layers; and (3) the automated road analyzer and related equipment to collect automated geographically related pavement condition information on routes traveled by heavy trucks.
- Some practices reported to address damage created by energy development included (1) stabilization of unpaved roads; (2) use of full depth reclamation of existing pavements; (3) addition of paved shoulders; (4) use of superstructure temporary "jumper" bridges; and (5) placement of geosynthetics for strengthening gravel or dirt roads.
- The literature review, survey responses, and interviews all indicated that an increase in roadway degradation, bridge deterioration, and/or increased risks to roadway safety have been observed in areas where energy development activities are occurring.
- A number of tools are being used by agencies to assess costs and pay for damages to roads and bridges related to energy development, such as (1) identifying more accurate truck volumes and their associated payloads; (2) assessing a variety of taxes, fees, adequate public facility ordinances, and other reimbursement mechanisms; and (3) applying the truck traffic percentage or the vehicle miles traveled as a factor for use in a cost formula. Some states reported using an increase in applications for oversize and/or overweight vehicle permits and more frequent requirements for roadway or bridge maintenance as the basis for a cost formula.
- Continuous communications and collaboration with energy development companies by state and local government entities have fostered constructive relationships. This has resulted in more effective planning for improvements, restoration and maintenance, and funding agreements and reimbursements to state and local roadways.

The responses indicated a need for future research in the areas of safety, environmental, and social impacts associated with energy development on state and local roads and bridges. Of particular interest will be holistic and international views on the allocation of resources, education, and welfare. Equally important will be how the increasing need for addressing impacts of energy development in the future will affect the amount of funding available to support other highway programs. The integration of planning techniques with how the energy industry approaches the mapping of future development is a potential area for consideration.

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Suggested areas of future research also include the collection of safety and crash statistics on impacted rural roads, improved methods for both pavement and geometric design of impacted rural roads, and engineering-based methods for detour routing during periods of high-activity energy development. Because of the continually evolving nature of energy sector activities, technology, regulations, and implementation of research and strategies, this topic is one that requires frequent updating.

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CHAPTER ONE

INTRODUCTION

This chapter introduces background information and highlights the impacts from energy development on roads and bridges, including a description of types of energy development. The survey and interview processes and organization of the report are also described.

BACKGROUND

The energy sector (i.e., oil, natural gas, wind, biofuels, etc.) has been a major contributor to many state economies in the United States. These states' infrastructures have played a critical role in meeting the transportation needs for supporting and further developing the nation's energy reserves. The energy sector is placing significant financial and operational demands on both state and local transportation systems. Hundreds of millions of dollars are spent each year on road repairs that are attributed to energy development activities. For example, the oil and natural gas industries require the movement of aggregate, equipment, and water to drilling sites, as well as flowback fluids from the well sites. As a result, rural roads and bridges that were designed to provide land access for residential and agricultural purposes are now subjected to heavy loads and increased traffic that are well beyond their design limits.

Public agencies at the state, county, and municipal levels are challenged to address the increased damages resulting from energy-related traffic. Initial measures that have been taken to address this challenge have included requiring surety instruments, permits, and excess maintenance agreements from energy companies. Concerns about the impacts of these trucks on roadway infrastructure and has led to many local jurisdictions requiring bonds from energy companies. Similarly, rural roads have seen an increased number of oversized and overweight (OS/OW) trucks generated by the development of wind farms. The term oversized (OS) has to do with the height and width dimensions of trucks, and overweight (OW) relates to a maximum weight. Each state has its own definition of what constitutes an OW vehicle, but in many cases it is any truck weighing more than 80,000 pounds. In addition to experiencing the energy sector's impacts on infrastructure durability, roadway networks are sustaining environmental impacts. Some roads are being strengthened to carry the increased applications of heavy loads, but at the same time, air and water quality in many areas have been negatively impacted, with issues such as such as dust control, erosion, and impacts to endangered species (Environmental Protection Agency 2009).

Federal Perspective

In 2012, the Moving Ahead for Progress in the 21st Century Act (MAP-21) was signed into law to fund surface transportation programs at more than $105 billion for federal fiscal years 2013 and 2014 (Public Law 112-141 2012). The MAP-21 Act includes a number of provisions to (1) improve the condition and performance of the national freight network and (2) support investment in freight-related surface transportation projects (Federal Highway Administration 2013). One of the factors listed in §167 Section D.1.B.vi for the designation of the primary freight network is the access to energy exploration, development, installation, or production areas. Another related item in the MAP-21 Act includes the establishment of critical rural freight corridors, in which a state may designate a road within its borders as a critical rural freight corridor if the road provides access to energy exploration, development, installation, or production areas.

The legislation also requires the establishment of a national freight strategic plan that identifies freight planning routes providing access to energy areas, and directs the U.S.DOT to develop this plan within three years of MAP-21's enactment, in consultation with states and other stakeholders, and to update the plan every five years. Section 1118 of MAP-21 requires a comprehensive long-range plan that describes improvements that may be required to reduce or impede the deterioration of roadways on which travel by heavy vehicles (including mining, agricultural, energy cargo or equipment, and timber vehicles) is projected to deteriorate the roadways' condition substantially. Section 1120 deems projects that improve roadways vital to national energy security are eligible as projects of national and regional significance, and cites eligible applicants for these projects to include a state DOT or a group of DOTs, a tribal government or consortium of tribal governments, a transit agency, or a multistate or multijurisdictional group of agencies.

SYNTHESIS OBJECTIVE

The objective of this synthesis is to document the impacts of the energy sector on roads and bridges and the state-of-the-practice strategies to minimize the impacts of heavy loads.

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The report will help federal, state, and local transportation managers and agencies better understand and communicate the energy development impacts on roads and bridges, and select the appropriate strategies for managing them. Other aspects of the impacts of energy development on roadway infrastructure that are explored in this study include:

- Areas of the country where road infrastructure damage from energy development are an issue for state and local transportation agencies;
- Types of development associated with infrastructure damage;
- Economic costs associated with supporting energy development companies with adequate and sustained infrastructure;
- Current design standards (or amended standards, if any) used by states and local jurisdictions to address the increased frequency and weights of heavy truck traffic traveling these roads and bridges;
- Engineering methods used by federal, state, or local agencies to assess and address the heavy truck loads and high traffic volumes created by energy development, including the metrics currently used to evaluate these impacts;
- Tools being used by agencies to assess costs and pay for damages to roads and bridges related to energy development, such as taxes, fees, adequate public facility ordinances, and other reimbursement or contractual mechanisms;
- Agency practices that address the safety implications of increased vehicle volumes related to energy development, including speed, roadway geometry, and conflicts with local traffic; and
- Examples of agency and industry collaboration to address roadway issues (i.e., sample agreements, state laws and regulations, etc.).

Various efforts have been made in recent years by some states and local public agencies to address the impacts of energy development within those states. There is a need to quantify these efforts and garner examples of practices that are reported to be effective, to facilitate the exchange of information and to help other states. This study will provide DOTs and their local agencies with useful information and ideas for alternative options to address more effectively the impacts of energy development on their roads and bridges.

The synthesis also includes suggestions for future research, based on existing gaps identified through the literature review, survey, and agency interviews. This report provides a reference to transportation agencies regarding existing engineering practices, funding approaches, and contractual mechanisms for dealing with the impacts of energy development.

STUDY APPROACH

A multifaceted approach was taken to document various efforts made in recent years by some states and local public agencies to address the impacts of energy development within those states. The approach to this study included a literature review, survey of state transportation agencies, and interviews with state and local transportation agencies, consultants, and universities in states identified as having existing practices that are effective for dealing with energy impacts on public roads. The following sections provide more detail on each step in the approach.

Literature Review

A literature review was conducted to identify practices used by federal, state, tribal, and local agencies. In every state, management of the impacts of energy development activities involves a vast number of staff from municipal, state, and federal government, consultants, universities, and state resource agencies. Because of the large number of people involved, the study panel opted for a more in-depth investigation of five individual state programs. This detailed focus on a small sample of states could obtain more explanation and details on various procedures. In-depth information was gathered from focus states Colorado, Iowa, North Dakota, Pennsylvania, and Texas. The criteria for selecting these five states are explained further in a subsequent section.

A comprehensive literature review of U.S. sources established the background information on the range and impact on public roads and bridges from energy development projects. The consultants used a number of resources, including the Transport Research International Documentation, Internet and web searches, FHWA and DOT internal reports, journal publications, conference proceedings, other published media including newspaper and magazine articles, and resources of professional associations.

Additionally, the review of programs online and interviews with key federal agencies—Bureau of Indian Affairs (BIA), U.S. Forest Service (USDA-FS), FHWA Federal Lands, and Bureau of Land Management (BLM)—were conducted to determine their experience and research associated with energy development. Particular attention was paid to references suggested in the Project Scope and other related resources. Some of these resources were guidance manuals drafted by several federal agencies to address the design of infrastructure on rural roadways.

Survey of State Transportation Agencies

The survey consisted of 62 questions and was sent to members of the AASHTO Standing Committee on Highways, with a suggestion for distribution through the chief engineer's office to the DOT local agency program coordinators to complete the survey. The survey was sent to contacts in each of the state DOTs, Washington, D.C., and Puerto Rico. Seventy-nine percent of the DOTs responded to this synthesis survey; the survey questions and results are included in Appendix A of this report.

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Interviews of Transportation Practitioners in Focus States

Based on the results of the survey and literature review, five states were selected for additional data gathering on practices used related to managing the impacts of energy development. A number of criteria were considered in selecting the five focus states to be interviewed. The criteria included:

1. The geographical distribution of states to reflect varying climatic conditions and varying rural/urban road configurations;
2. Distribution of the types and extent of energy development industries to reflect the uniqueness of impacts on roads and bridges;
3. Inclusion of states in which roads and bridges owned and managed by local agencies are significantly impacted;
4. Inclusion of states in which significant impacts have been observed through the increase in maintenance and repair dollars and/or large percentage of increases in maintenance and repair budgets;
5. A range of safety data, such as an increase in the total number of truck-related crashes and the number of crashes that resulted in fatalities; and
6. Use of innovative solutions on roads and bridges for mitigating the impacts from energy development.

DOT offices, local agencies, consultants, and universities in the states of Colorado, Iowa, North Dakota, Pennsylvania, and Texas were interviewed. As a result of some of the pertinent findings from the survey, additional interviews were conducted with individuals in Mississippi and New Jersey. More than 41 representatives from several agencies or organizations involved at various levels with the locally administered federal aid process contributed to this synthesis effort. Additionally, multiple members of federal agencies and tribal nations were interviewed to gain their perspective on the topic, including the U.S. Forest Service, the Federal Lands Highway (FLH), the BLM, the BIA, the Tribal Technical Assistance Program, and the Southern Ute and MHA (Mandan, Hidatsa, Arikara) Tribal Nations.

Multiple representatives from the organizations shown in Table 1 were interviewed in person, over the phone, or by e-mail to gather their input on issues and practices in their state related to impacts of energy development on their roads and bridges. A list and sampling of documents obtained as examples of current practice are included in Appendix B (available at www.trb.org; search NCHRP Synthesis 469).

ORGANIZATION OF REPORT

This synthesis report is organized into five chapters. The balance of chapter one presents the report's structure and defines key terms. The report structure is summarized with brief explanations of each chapter's content. This chapter also includes brief introductions to major types of energy development that use the nation's highways.

Chapter two describes energy development activities in the United States as documented in published literature and online state and local resources (e.g., county engineers associations, energy councils, etc.). There are sections on the strategies used by states for addressing engineering challenges, financing repairs, and quantifying the extent of damages induced by heavy trucks affiliated with energy development. The chapter concludes with information from interviews and website review conducted with four federal agencies and two tribal nations that have experienced the impacts of energy development.

Chapter three presents the impacts of energy industry development on state and local roads and bridges, as reported by the DOTs in their survey responses. The chapter describes the state of the practice in many states, on the extent to which the roadway system infrastructure design and maintenance, traffic operations, and safety are impacted. An overview of the various engineering practices, funding strategies, and cross-organizational tools reported by DOTs that are currently used to address energy development impacts on state and local roads and bridges is presented.

Chapter four examines the specific practices of organizations that were collected through published literature, survey responses, and a series of detailed interviews with individuals listed in Table 1 in each of the five states selected for further study. The chapter is organized to describe the road system impacts as well as the most effective practices for addressing engineering design challenges, assessing costs, using contractual agreements, and mitigating impacts on safety. Organizational efforts at the state and local levels for dealing with energy developers are also described.

Chapter five concludes the synthesis with a summary of findings and suggestions for further study. The evaluation techniques for assigning the safety, infrastructure, and economic impacts of increased heavy vehicles owing to energy development activities are discussed, along with the current and evolving state of the practice for effectively mitigating impacts of energy development on the roadway network. A number of suggestions for future research are also presented in this chapter.

Each topic within a chapter follows a similar format: (1) the impacts of energy development on roads and bridges; (2) the practices used to address engineering challenges; (3) the tools to assess costs and contractual agreements; and (4) practices to mitigate for impacts on safety. These chapters are followed by a glossary, references, bibliography, and four appendices. Appendix A includes a copy of the survey questions and results. Appendix B (available at www.trb.org; search NCHRP Synthesis 469) presents several sample documents that were offered by agencies as a result of the interviews for sharing as examples. Appendix C includes links to resources identified

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TABLE 1
AGENCY OR ORGANIZATION REPRESENTATIVES WHO CONTRIBUTED TO SYNTHESIS DEVELOPMENT

State, Federal, or Tribal	Agency or Organization	Departments or Role
Colorado	Local agencies	County Engineering, Public Works
	Southern Ute Tribal Nation	Planning
	State DOT	Bridge Unit, Permits Office
	U.S. Forest Service	Road Operations and Maintenance
Iowa	Local agencies	County Engineering
	State DOT	Bridges and Structures Office, Local Programs Office, Office of Design, Planning Office, Safety Office
	University transportation center	Local Roads Safety Liaison
Mississippi	Local agencies	County Engineering
New Jersey	State DOT	Freight Management Office, Pavement Management and Technology
	University transportation center	Transportation Institute
North Dakota	Local agencies	County Engineering
	State DOT	Deputy Director of Engineering
	Three Affiliated Tribes	Consultant to tribal government
	University transportation center	Transportation Institute
Pennsylvania	Consultant to energy developer	Construction Management, Engineering Inspections
	Local agencies	County Planning
	State DOT	District Engineering, District Maintenance, District Pavement Management, District Posted and Bonded Roads Unit, Maintenance Programs, Municipal Services, Pavement Asset Management
	U.S. Forest Service	Engineering and Oil, Gas, and Minerals Program
Texas	Local agencies	County Engineering
	State DOT	Bridge Division, District Maintenance, District Bridge Design
	University transportation center	Pavement and Infrastructure Research
Tribal Governments	Tribal Technical Assistance Program, Southern Ute and MHA (Mandan, Hidatsa, Arikara) Tribal Nations	Engineering
Federal Highway Administration	Federal Lands Highway	Planning
U.S. Department of the Interior	Bureau of Land Management	Planning and Engineering

through the literature review or by the agencies interviewed. Appendix D includes a table that shows examples of practices in each topic area identified by the contacts in each of the five focus states.

DEFINITIONS

Some key terms are defined here that pertain to the synthesis scope. Additional terms are defined within the context of their relevant sections. A glossary is also included in the report that further defines acronyms and organizations discussed in the report.

Equivalent Single Axle Loads (*ESALs*): The ESAL is a common measure to convert damage from wheel loads of various magnitudes and repetitions from mixed traffic into damage from an equivalent number of standard or equivalent loads. The most commonly used equivalent load in the United States is the 18,000-pound equivalent single axle load (normally designated as ESAL). The design ESAL is a cumulative traffic load summary statistic. The statistic represents a mixed stream of traffic of different axle loads and axle configurations predicted over the design or analysis period and then converted into an equivalent number of 18,000-pound single axle loads summed over that period.

Flowback fluids: Flowback is a water-based solution that flows back to the surface during and after the completion of hydraulic fracturing. The fluid contains clays, chemical additives, dissolved metal ions, and total dissolved solids.

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Horizontal and vertical drilling: Horizontal wellbores allow for far greater exposure to a formation than a conventional vertical wellbore. This is particularly useful in shale formations, which do not have sufficient permeability to produce economically with a vertical well. Such wells, when drilled onshore, are now usually hydraulically fractured in several stages. The type of wellbore completion used will affect how many times the formation is fractured, and at what locations along the horizontal section of the wellbore. Horizontal drilling is a process in which the well is turned horizontally at depth. It is normally used to extract energy from a source that runs horizontally, such as a layer of shale rock. Because the horizontal section of a well is at great depth, it must include a vertical part as well. Thus, a horizontal well resembles an exaggerated letter "J." When examining the differences between vertical wells and horizontal wells, it is easy to see that a horizontal well is able to reach a much wider area of rock and the natural gas that is trapped within the rock. A drilling company using the horizontal technique can reach more energy with fewer wells.

Hydraulic fracturing: Hydraulic fracturing is the fracturing of rock by a pressurized liquid. Some hydraulic fractures form naturally—certain veins or dikes are examples. Induced hydraulic fracturing (also hydrofracturing, fracking, and fraccing) is a well-stimulation technique in which a high pressure fluid (usually water mixed with sand and chemicals) is injected into a wellbore to create small fractures (usually less than 1.0 mm wide) in the deep-rock formations to allow natural gas, petroleum, and brine to migrate to the well. When the hydraulic pressure is removed from the well, small grains of hydraulic fracturing proppants (either sand or aluminum oxide) hold open the small fractures once the deep rock achieves geologic equilibrium.

Local public agency (*LPA*): Any organization that is directly or indirectly affiliated with a government body under federal, state, or local jurisdiction. Such entities have administrative and/or functional responsibilities including the authority to finance, build, operate, or maintain public infrastructure facilities. Although such entities are most often associated with county, municipal, town, township jurisdictions, etc., and their related public works authorities, the term LPA covers a broader context to include quasi-governmental entities such as port authorities, water districts, public utilities, and other agency representatives of governmental entities associated with all levels of government, including tribal sovereignties.

Shale gas formation: Shale gas is natural gas that is present in shale rocks. Shale rocks usually have low permeability, making gas production more complex and costly. Shale gas is considered an "unconventional gas." Although both conventional and unconventional deposits host natural gas, it is the more elaborate production methods that distinguish unconventional from conventional deposits; hydraulic fracturing is often applied to unconventional natural gas deposits. Like oil and coal, natural gas in shales has essentially formed from the remains of plants, animals, and microorganisms that lived millions of years ago. Although there are different theories on the origins of fossil fuels, the most widely accepted is that they are formed when organic matter (such as the remains of a plant or animal) is buried, compressed and heated in the earth's crust for a long time. In the case of natural gas, this is referred to as thermogenic methane generation.

Shale play: The term "play" in the oil and gas industry refers to a geographic area that has been targeted for exploration because of favorable geoseismic survey results, well logs, or production results from a new or "wildcat well" in the area. An area comes into play when it is generally recognized that there is an economic quantity of oil or gas to be found.

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CHAPTER TWO

LITERATURE REVIEW OF ENERGY DEVELOPMENT ACTIVITIES IN THE UNITED STATES

INTRODUCTION

This chapter provides an overview of the specific industries involved with energy development and their activities related to transportation throughout the United States. The information reported will assist in defining context to the types of energy development, the magnitude of their activities, and the extent to which they are impacting roads and bridges both on and off the National Highway System. This is accomplished through a review of the literature and insight provided through interviews with officials of federal agencies and tribal representatives that present examples of effective practices to address impacts on infrastructure.

Table 2 provides a summary of the major findings presented in chapter two. Table D1 in Appendix D includes a more detailed summary of practices reported by the five focus states.

SUMMARY OF ENERGY DEVELOPMENT INDUSTRIES IN THE UNITED STATES

The following sections highlight various approaches to extract or generate energy sources in the United States. The development of these industries is impacting transportation infrastructure managed by federal, state, and local governments, and this section provides examples of how these energy input materials or output products are transported.

Ever since the Industrial Revolution began in the 18th century, vast quantities of fossil fuels have been used to power the economy and deliver unprecedented affluence to huge numbers of people. Petroleum, coal, and natural gas are major fossil fuels. During the Industrial Revolution, fossil fuels appeared to be the ideal energy source. Steam locomotives, the quintessential machines of the Industrial Revolution, used coal as an early fuel source to compensate for a shortage of firewood and charcoal. Not only was a seemingly inexhaustible supply of coal available from easily exploited seams near the surface, but it could be used in its natural form. Since the modest beginnings of the oil industry in the mid-19th century, petroleum has risen to global prominence. Initially, kerosene, used for lighting and heating, was the principal product derived from petroleum. However, the development of drilling technology for oil wells in mid-19th century America put the petroleum industry on a new footing, leading to mass consumption of petroleum as a highly versatile fuel. Oil-powered automobiles, ships, airplanes, and other forms of transportation helped generate electricity, and were used for heating and hot water. The usage of fossil fuels increased in step with economic growth.

Types of Current and Emerging Energy Development Industries

Oil

Crude oil is a nonrenewable fossil fuel formed when the remains of prehistoric plants, animals, and aquatic life were compressed by heat and pressure under the bed of seas or lakes over many years, and finally evolved into a fossil fuel. The oil is drilled and pumped from massive underground pockets and is processed by means of a system called distillation. Oil traffic can be classified into five types of movements: (1) inbound movement of sand, water, cement, scoria/gravel, drilling mud, and fuel; (2) inbound movement of chemicals; (3) outbound movement of oil and byproducts; (4) outbound movement of saltwater; and (5) movements of specialized vehicles such as workover rigs, fracturing rigs, cranes and utility vehicles (North Dakota State University 2013).

Natural Gas

Natural gas is a nonrenewable fossil fuel that is closely related to oil and is drilled from the same wells as crude oil or is removed during the distilling process. Shale gas refers to natural gas that is confined within shale formations. The production of natural gas from shale formations has revitalized the natural gas industry in the United States. Natural gas well development requires large volumes of moderately heavy trucks over rural roads (Wilke and Harrell 2011). Many low-volume local secondary roads with thin pavement sections can fail within hours of the heavy loading associated with energy-related activities. The new developments in drilling methods have allowed for higher rates of production compared with vertical drilling methods. With advancements leading to horizontal drilling and hydraulic fracturing, it is now possible to drill in locations that were previously too difficult. A study by Pearce (2013) found that oil and gas drilling production is associated with increased traffic volumes and heavy truck traffic and that the increases are attributable to the substantial damages caused by increased heavy loads on flexible pavements.

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TABLE 2
SUMMARY OF MAJOR PRACTICES REPORTED TO ADDRESS ENERGY DEVELOPMENT IMPACTS

State or Organization	Practice(s) Reported to Address Energy Development Impacts
Arkansas	Use of AASHTO Pavement Design equation to predict asphalt pavement performance on low-volume roads subjected to heavy loads from energy development activities.
	ARAN measurement of low-volume pavement conditions, along with mapping of existing and permitted wells.
	Development of crack index for all routes accessed by energy developers and analysis of all roads with rut depths greater than 1 inch.
Minnesota	Heavy Traffic Generation tool to estimate pavement damage and associated repair and reconstruction costs on local roads affected during the construction of wind turbine developments.
	Truck weight education classes hosted by Minnesota DOT Local Technical Assistance Program (LTAP) for energy company haulers, law enforcement officers, and local agencies.
	State legislation allows for special hauling permits for heavy vehicles with added axles, enabling permit fees to be deposited into a special account at Minnesota DOT for use in bridge inspections and signage.
Missouri	Permit fees applied to energy developers reflect the number of permits issued by Missouri DOT.
Montana	State legislation to address funding and operations demands on roads with infrastructure degradation.
	Planning forecast studies identified high-use corridors for energy development to facilitate design modifications and accelerate reconstruction projects to satisfy forecasted demands.
	Facilitation of multimodal shift (use of rail and pipeline for oil industry) and consolidation of shipping locations (for energy and non-energy commodities) to higher demand locations.
New Jersey	Retrofit of WIM sites to virtual WIMs for law enforcement officials to collect real-time weight data from trucks active passing on highways.
	Researching the impacts of OS/OW loads on pavements and bridges to quantify the structural damage these vehicles cause. Damage translated to cost over time revises the fee structure for OS/OW permits. Deterioration modeling tool developed to assist DOT in decision-support and planning capacities.
Three Affiliated Tribes (TAT)	Lump sum royalty payments and maintenance agreements with energy companies; 5% gross value tax applied to oil produced from an American Indian holding within the boundary of a reservation.
U.S. Forest Service	Road Use Permits for energy development activities can require energy developers to pay for repair or reconstruction of roads directly or through donation of materials and/or equipment.
	Generation of traffic volume statistics and speed studies; load postings on roads and bridges during thaw period (February to April); upgrade to full two-lane roads in areas where pavements are continually damaged.
Wisconsin	Traffic impact analyses; use of road upgrade maintenance agreements with developers; truck tonnage projections; and use of FWD and GPR to establish seasonal load restrictions for roads.
Wyoming	Funds appropriated to assess current county road conditions to develop transportation asset management systems.

Sources: Literature review and interviews with federal agencies.

Fracturing proppants (i.e., sand, man-made ceramic materials, etc.) are a necessary component in hydraulic fracturing, as is the hauling in and out of water. The tonnage of sand required per well is commonly estimated to be 150 tons per segment and up to 20 segments per horizontal well, resulting in 3,000 tons per well. As the natural gas drilling industry continues to expand, the possible annual demand is between 40 and 60 million tons of fracking sand. In addition, approximately 6 million gallons of water are generally needed to frack a well, and this water is primarily hauled to the site by a significant number of trucks. A study by Hart et al. (2013) reported that the American Petroleum Institute established standards for the fracking sand based on mesh sizes and added more mesh sizes in June 2012. More than 100 mines produce this type of sand in Wisconsin, and there are at least eight such mines in Minnesota. Some of the sand mines are all-inclusive, meaning that the mine, processing plant, and rail access are all in one location. In other mines the three components are in different locations, and the truck traffic is contained within the mining site, limiting the impacts primarily to local grade crossings with rail lines.

Coal

Coal is a nonrenewable fossil fuel produced worldwide, formed when millions of years of pressure and heat turn the remains of prehistoric forests and swamps into coal (Commonwealth of Pennsylvania 2014). Coal is obtained from the earth either by deep mining or strip mining. Most coal is used by domestic power plants to generate electricity.

Biofuel and Wood

Biofuel contains energy from a geologically recent carbon fixation and is produced from living organisms. Good examples of biofuel include those used for transportation, such as ethanol and biodiesel (made from biomass materials), which are generally combined with the petroleum fuels (ZME Science 2007).

Wood is a renewable resource that is considered the historic and traditional source of energy (Commonwealth of Pennsylvania 2014). Wood is considered a form of a biofuel arising from multiple sources, including forests, other

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wooded areas and trees outside forests, co-products from wood processing, post-consumer recovered wood, and processed wood-based fuels.

Nuclear

Nuclear energy is generated by a nuclear reaction, the splitting of uranium atoms referred to as fission (Commonwealth of Pennsylvania 2014). This fission process is then applied to generate heat to transform water into steam, which ultimately turns a turbine and generates electricity. There is not a significant amount of transportation required for activities related to nuclear energy.

Solar and Wind

Solar energy is a renewable energy derived from the sun's rays and is converted directly into electricity by solar photovoltaic panels (Commonwealth of Pennsylvania 2014). Another form of renewable energy comes from wind movement and rotation, and activates an electricity generator. These sources of renewable energy are free of emissions and are constantly available with continuous wind flow and solar activity. There has been a recent increase in the development of natural gas and other alternative energy sources, including wind farms, throughout North America (Wilke and Harrell 2011). Wind farms require movement of heavy equipment over low-volume, rural roads that were often not designed for the heavy loadings associated with this equipment.

Examples of Energy Development Industries in the United States

According to the U.S. Energy Information Administration (2013), an extensive variety of energy development is occurring across the United States. Table 3 presents the types of energy development occurring in the states.

COSTS AND REVENUE SOURCES FOR PUBLIC AGENCIES

A recent economic study from Duke University on shale public finance revealed some relevant figures related to the fiscal impacts of shale and natural gas energy development on eight states (Raimi and Newell 2014). Table 4 shows a summary of eight states that were included in the study and indicated that the major costs to local governments involve the upkeep of roads. The major sources of revenue are also listed and the table shows that, although a variety of sources exist to address costs related to roads and staff (defined as government employees who spend time devoted to oil- and gas-related issues that divert them from other priorities), some states such as Colorado and North Dakota are paying out more than they are generating. The report stated that the economic impacts tend to incur less substantial costs for local governments with stronger pre-existing infrastructure compared with the rural roads originally designed for the movement of light traffic or farm equipment. The study concluded that, on the whole, recent energy development has provided net fiscal benefits to local governments. It also points out that the use of in-kind operation agreements with developers can help to mitigate potential roadway maintenance and repair costs for local governments.

IMPACTS ON PUBLIC ROADS AND BRIDGES AS A RESULT OF ENERGY DEVELOPMENT

The 2013 report on *Critical Issues in Transportation* stated that the changes in energy supplies are affecting freight services (Transportation Research Board 2013). The report found that geographic shifts in oil and gas supply have greatly expanded the transport of oil by truck and rail. In addition, the drilling of new oil and gas wells implies the movement of heavy equipment, fracking sands, water and other supplies to rural locations, which may have roads and bridges that are susceptible to the heavy traffic. Shale plays are all over the country, so municipalities nationwide are facing issues and receiving benefits from the burgeoning domestic oil and gas industry. Energy development directly contributed $545 billion to the U.S. economy in 2011 and, of that, the Eagle Ford shale play in South Texas contributed nearly $25 billion that year (Tunstall et al. 2012).

Information found in the published literature is summarized in the next several sections, organized by state.

Arkansas

Beginning in 2006, the central part of Arkansas began seeing a boom in horizontal natural gas well drilling. The activity was primarily concentrated in Arkansas State Highway and Transportation Department (Arkansas DOT) Districts 5 and 8 (Wright-Kehner 2008; Meadors and Wright-Kehner 2013). In 2008, the state had a little more than 2,800 wells. By 2010, more than 4,000 wells were scattered throughout the two districts.

There are natural gas developments in the Fayetteville shale of Arkansas. The *Shale Public Finance* study (Raimi and Newell 2014) reported that the leading revenue source for county governments in the Fayetteville shale region has stemmed from property taxes. Although the counties also incurred new road maintenance and repair costs, the costs were limited to a large extent by agreements between the counties and a number of energy companies who assisted in repairing roads damaged during operations.

The Arkansas DOT started to monitor the increase in truck traffic and associated pavement damages and determined that low-volume roads were experiencing 20-year accumulated traffic loadings within a few months of exposure to energy-related traffic. A study by Meadors and Wright-Kehner (2013)

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TABLE 3
ENERGY SECTORS BY STATE

State	Coal Mining	Natural Gas	Oil	Biofuels	Wind	Solar	Nuclear
Alabama	X	X	X	X			X
Alaska	X	X	X	X	X		
Arizona	X	X	X	X	X	X	X
Arkansas	X	X	X	X			X
California		X	X	X	X	X	X
Colorado	X	X	X	X	X	X	
Connecticut				X			X
Delaware				X	X	X	
Florida		X	X	X		X	X
Georgia				X		X	X
Hawaii				X	X	X	
Idaho				X	X		
Illinois	X	X	X	X	X	X	X
Indiana	X	X	X	X	X	X	
Iowa				X	X		X
Kansas	X	X	X	X	X		X
Kentucky	X	X	X	X	X		
Louisiana	X	X	X	X			X
Maine				X	X		
Maryland	X	X		X	X	X	X
Massachusetts				X	X	X	X
Michigan		X	X	X	X		X
Minnesota				X	X		X
Mississippi	X	X	X	X			X
Missouri	X	X	X	X	X		X
Montana	X	X	X		X		
Nebraska		X	X	X	X		X
Nevada		X	X	X	X	X	
New Hampshire				X	X		X
New Jersey				X	X	X	X
New Mexico	X	X	X	X	X	X	
New York		X	X	X	X	X	X
North Carolina				X		X	X
North Dakota	X	X	X	X	X		
Ohio	X	X	X	X	X	X	X
Oklahoma	X	X	X	X	X		

(*continued on next page*)

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TABLE 3
(*continued*)

State	Coal Mining	Natural Gas	Oil	Biofuels	Wind	Solar	Nuclear
Oregon		X		X	X	X	
Pennsylvania	X	X	X	X	X	X	X
Rhode Island				X			
South Carolina				X			X
South Dakota		X	X		X		
Tennessee	X	X	X	X	X	X	X
Texas	X	X	X	X	X	X	X
Utah	X	X	X	X	X	X	
Vermont				X	X	X	X
Virginia	X	X	X	X			X
Washington				X	X		X
West Virginia	X	X	X	X	X		
Wisconsin				X	X		X
Wyoming	X	X	X		X		

Source: U.S. Energy Information Administration (2013).

assessed the structural capabilities of pavements on low-volume roads and found that the increased loadings associated with oil and gas operations would substantially increase the rate of pavement deterioration. The study compared local paved roads to the state's secondary, primary, and Interstate pavements and found local roads more vulnerable to increased traffic loadings. Using the AASHTO pavement design equation for structural number and the nomographs, it was estimated that most pavements on low-volume roads would service truckloads from the oil and gas activities, suitable for approximately 40 trucks per day average daily truck traffic (ADTT), for less than one year.

TABLE 4
SUMMARY OF MAJOR REVENUE SOURCES AND COSTS FOR LOCAL GOVERNMENTS IN STATES WITH SHALE ENERGY DEVELOPMENT

State	Major Revenue Source(s)	Major Cost(s)	Net Fiscal Impact
Arkansas	Property taxes, in-kind contributions (road repairs)	Roads	Medium to large net positive
Colorado	Property taxes, severance tax revenue, in-kind contributions (road repair)	Roads, staff costs	Small net negative to large net positive
Louisiana	Lease revenue, sales taxes	Roads, staff costs	Medium to large net positive
Montana	Severance tax revenue	Roads, staff costs	[insufficient data]
North Dakota	Severance tax distributions, sales taxes	Roads, staff costs	Small to medium net negative
Pennsylvania	Act 13 distributions	Staff costs	Small to large net positive
Texas	Property taxes	Roads, staff costs	Neutral to large net positive
Wyoming	Property taxes, sales taxes	Roads, staff costs	Large net positive

Source: Adapted from Raimi and Newell (2014).
Note: Pennsylvania Major Revenue: In 2012 Pennsylvania enacted legislation, Act 13, which imposes an "impact fee" on each new unconventional gas well drilled in the state.

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The Arkansas DOT did not encourage the piping of water to wells because the pipes would be run through highway rights-of-way (ROW); thus, the majority of wells were hauled water wells (Meadors and Wright-Kehner 2013). A well drilled vertically (an older technology) resulted in approximately 1,100 equivalent single axle loads (ESALs) per well on local roadways, whereas piped water wells each resulted in approximately 1,800 ESALs per drilling, and hauled wells resulted in more than 2,800 ESALs per drilling. It was found that none of the non-Interstate roadways in central Arkansas were designed to carry this level of ESALs. The public reported to the Arkansas DOT increased incidences of broken axles resulting from a large number of sizable potholes. Arkansas DOT investigated pavement conditions and found that 812 miles of roadway were affected.

Colorado

The Douglas County (Colorado) Oil and Gas Production Transportation Impact Study considered high, medium, and low development scenarios to quantify range of the impacts of energy development (Felsburg Holt & Ullevig, and BBC Research & Consulting 2012). The study team randomly selected pad sites based on existing lease data, travel demand modeling of impact on specific roads, roadway repair cost assessment, and tax revenue assessment. The study identified a major issue with revenue lag in that it takes one to three years between the timing of existing infrastructure needs and the identification of capital revenues. This finding was corroborated by the conclusion drawn in the Raimi and Newell (2014) study on shale public finance, which indicated that in some counties in Colorado, the roadway costs had increased faster than the revenues.

Iowa

Variations in traffic patterns have been observed when energy industry developers use low-volume roads. In Iowa, the trucks that tended to haul to elevators and river accesses in the past have now changed, as the plants have relocated to new areas (Nahra 2013). During wind farm construction, construction loads are severe and were noted to cause roadway damages. To address large loads delivering wind farm components, some temporary road embankments were built to accommodate the movement of machinery as a result of tight turning radii at rural intersections. The major damage occurs during construction activities and on gravel or unpaved roads. In addition to routine maintenance repairs, additional damage caused by the hauling of heavy transformers, turbine parts, moving cranes, and multiple loads of construction materials is observed within one to one and a half years after construction. The transportation of heavy electrical transformers to towers is reported to be more damaging to the roadways when there is wet weather or frost in the spring. For example, after moving one of the heavy transformers, an 8.5-inch thick asphalt pavement on a county road was observed to have developed rutting more than 1 inch deep.

For biofuel plants, road damage occurs not only during plant construction but is ongoing as a result of the continual hauling of raw product to the plant and finished products to market. Pavement and gravel road repairs were more numerous in the year or two years following the beginning of operations of a biofuel plant (Gkritza et al. 2011). The damage to county roads was attributed to biofuel operations (construction and hauling), and deterioration of the unpaved roads around plants was more rapid, often exhibiting a significant amount of damage within the first year of plant operation, when combined with the effects of bad weather.

A follow-up to the September 2010 report *Investigation of the Impacts of Rural Development on Iowa's Secondary Road Systems* (Taylor et al. 2010) outlined the impacts of specific types of rural development, rural residential subdivisions, and livestock production. Although not directly related to energy development, the report did detail several relevant findings that address issues also faced by local governments when dealing with the impacts of energy development activities. Table 5 summarizes the local ordinances, county codes, and state legislation that was reported in interviews to be useful by the agencies in Iowa that have noticed impacts from energy development in their jurisdictions.

Montana

Counties in Montana were reported generally to have received large revenues from the state's severance tax. However, municipalities in Montana face more infrastructure costs than they have the revenue to address (Raimi and Newell 2014), a circumstance attributed to municipalities' limited share of severance tax revenue share.

New York

A study in New York state estimated that 1,148 one-way loaded truck trips are generated per well, assuming that all water is brought in by truck and that using pipelines instead of trucks to move water reduces this dramatically (Tidd 2013). The report indicated that shale development will result in both increased heavy traffic and increased employment and population, which also generate traffic demand. The implications for transportation planning include economic vitality, safety, congestion, system preservation, financial resources, linking transportation and land use, air quality, transportation conformity, and environmental justice. The report mentioned that the New York State Department of Environmental Conservation has a revised 2012 draft Shell Gas Environmental Impact Study on the oil and natural gas mining regulatory program. The Nature Conservancy also produced an assessment of the potential impacts of high-volume hydraulic

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TABLE 5
LEGISLATION OR CODES POTENTIALLY USEFUL FOR ADDRESSING ENERGY IMPACTS ON SECONDARY ROADS IN IOWA

Code or Legislation	Impacts on Secondary Road System in Iowa
Iowa Code Chapter 311	• Permits counties to establish secondary road special assessment districts for the improvement of secondary roads. The usefulness of this authority is limited by the necessity for a petition of affected landowners to initiate a district, and the geographic limitation on the reach of the special assessment district.
County Zoning Act	• Permits counties to place conditions on rezoning requests and site plan approvals that are "reasonable and imposed to satisfy public needs which are directly caused by the requested change." • Permits county boards of adjustment to grant special exceptions/conditional use permits "subject to appropriate conditions and safeguards."
Subdivision Act	• Permits counties that have adopted subdivision ordinances to place conditions on plat (subdivision) approval that "require the installation of public improvements in conjunction with approval." • Permits cities that have adopted subdivision ordinances to exercise extraterritorial jurisdiction over subdivisions and plats of survey within 2 miles of their borders. This is the case in all counties (counties with or without subdivision regulations).
Iowa Legislature	• Not yet adopted legislation authorizing local governments to charge impact fees to offset the burdens placed on public infrastructure by new developments.
Iowa Supreme Court	• Ruled that local government monetary charges associated with permit approvals are limited to charges that cover administrative expenses, in the absence of impact fee-enabling legislation, and do not allow for compensation of the local government for any development impacts on public infrastructure.

Source: Adapted from Taylor et al. (2010).

fracking on forest resources in Tioga County, New York, in 2011.

North Dakota

A study by the Upper Great Plains Transportation Institute at the North Dakota State University (2013) reported that the size and mass difference between 80,000-pound trucks and 4,000-pound passenger vehicles, combined with operational differences such as acceleration and deceleration rates and turning radii, heighten the risk for crashes to occur. Truck crashes that involved injuries (per vehicle miles traveled, or VMT) increased by 80% between 2002 and 2012. The study also found that 62% of truck crashes that resulted in injuries occurred between July and December and 82% of them occurred during weekdays. Approximately 86% of the severe truck crashes involved multiple vehicles and of those, 23% occurred on hills and 36% at intersections. Furthermore, 68% of the crashes at intersections were a result of left-hand turns. In most crashes, weather was the most common contributing factor. In observing the trends in truck crashes involving injuries, the number of crashes in oil regions has increased steadily since 2002, whereas the crashes in non-oil regions have remained constant with only a slight increase in recent years.

Pennsylvania

Bloser and Ziegler (2013) reported that environmental concerns arise as a result of roadway deterioration resulting from energy development, including surface water problems. Surface water issues may pose greater environmental or health safety risk, resulting from accelerated erosion and potential chemical spills. Sediment is reported to be the largest pollutant by volume to inland waters, and the study concluded that more research is necessary to quantify the road impacts on watershed level variations in flow, water quality, and aquatic ecological changes.

A study by Koser (2013) reported that during Marcellus shale developments, the associated truck trips generated are on average 1,450 trucks per well development, considering all of the trucks required for pad development, drilling operations, fracking, and reclaiming. Pennsylvania DOT can post weight restrictions on its roadways, thus requiring the heavy user to obtain a permit with an Excess Maintenance Agreement (EMA). The Pennsylvania DOT EMA requires (1) an initial inspection to establish the base condition of roadway; (2) user responsible for excess maintenance; (3) approval of the maintenance plan; (4) routine roadway condition surveys for heavy users; and (5) a security, which is typically

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bonding. Municipalities in Pennsylvania can pass ordinances allowing posting and bonding of roadways or can elect to use the Roadway User Maintenance Agreements.

Also in Pennsylvania, the brine produced from oil and gas wells and other sources, such as brine treatment plants and brine wells, have been used as a dust suppressant and road stabilizer on unpaved secondary road systems. The Pennsylvania Department of Environmental Protection (2013) reported that there are some environmental concerns with the usage of brine because of the potential for contaminants from brine to leach into surface or ground waters.

South Dakota

Wind and ethanol energy development projects in northeast South Dakota have led to significant damage and are affected by the geometry of the roads, as reported by a study conducted by Skorseth (2013). A major problem was that existing roads were too narrow for trucks, resulting in added routes to keep trucks from simultaneously utilizing roads. These added routes consequently increased the number of miles of roads affected by the transportation of energy sectors. The result was that local agencies were struggling to determine the most effective road restoration alternatives. It was also reported that existing road conditions, such as the depth of gravel to asphalt surfacing, roadway width, general surface conditions, and damage should be noted before any heavy truck traffic begins and continue to be inspected at reasonable intervals thereafter, after heavy or prolonged rainfall, and at the end of the project. The study suggested that to reduce impacts on local roads, local agencies should be proactive when these energy development projects are permitted—the impact on local roads is invariably greater than anticipated. The documentation of existing road conditions and preemptive planning for additional impacts are to be conducted in advance and the energy industry required to participate in any road improvements and restorations as a result of their activity, the study recommended.

Texas

The Center for Transportation Research at the University of Texas at Austin reported that the truck traffic impacts of the wind industry on the transportation system is causing increased damage to the pavement structure when shifting from higher to lower functional roadway classes (Prozzi et al. 2011, 2012). The transportation of wind turbine components on Interstate highways represents approximately 0.03% of additional damage, whereas it represents about 4% on U.S. highway sections. The development of natural gas wells results in a significant increase in truck traffic owing to the movement of materials and equipment, building the pad site and access roads, the drilling and fracking operations, and saltwater disposal from the site. The crude oil supply chain traffic consists of well development, oil production, and petrol gasoline distribution that all have different transportation impacts. The construction phase of an oil well development involves building access roads to the site, rigging up, drilling, rigging down, and well completion. The entire operation involves numerous truck trips to and from the well site to bring materials and equipment necessary for constructing of oil or gas wells. The mobilization of the rotary rig requires OS/OW permits, whereas all the remaining loads are transported on conventional combination trucks. It was observed that the VMT of the construction traffic was more or less evenly distributed among U.S. highways, state highways, and farm-to-market roads, with a slightly lower utilization of the Interstate system. The production traffic associated with crude oil development is mostly responsible for the transportation of oil from tank batteries located near the well site to the pipeline breakout stations. Table 6 presents transportation and operational features of energy development activities in Texas, and how raw goods and exhumed energy products are moved logistically on roadway networks. The study concluded that activities related to natural gas extraction results in an average reduction in pavement service life of 30% in the presence of construction traffic. The activities related to oil were reported to result in approximately an average of 2% reduction in pavement service life owing to

TABLE 6
MOVEMENT OF ENERGY-RELATED COMPONENTS AND PRODUCTS ON TEXAS ROADWAY NETWORK

Energy Type	Pavement Service Life Reduction
Natural Gas	Due to truck traffic associated with: • Rig movements: 1% to 16% reduction • Saltwater disposal: 1% to 34% reduction • Construction: 4% to 53% reduction
	Overall (average) reduction in pavement service life: 30% from construction traffic
Crude Oil	Due to truck traffic associated with: • Construction: 1% to 3% reduction • Production: 2% to 16% reduction
	Overall (average) reduction in pavement service life: 2% due to the construction traffic and 9% due to the production traffic

Sources: Adapted from Barton (2013) and Prozzi et al. (2011).

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construction traffic. An average of 9% reduction in pavement service life was reported as a result of oil production traffic (Prozzi et al. 2011).

The distribution of truck traffic attributable to energy development activities in Texas was researched in Quiroga et al. (2012). Heavy truck traffic was observed on all corridors used for oil and gas activities, and these developments sustained a significant number of truckloads during both drilling and production. The truck traffic associated with the increased number of wind farms was present only during active construction and consisted of hauling both construction materials and wind turbine parts. The truck traffic associated with ethanol plants shipped grains, ethanol, and by-products to and from the plants, but some ethanol developers are targeting the use of railroads to transport ethanol and by-products and have reduced the volume of trucks in some farm-to-market areas. It was also observed that some drivers frequently selected routes to and from energy developments based on the avoidance of weigh stations and law enforcement in favor of better pavement or geometric conditions and/or preferred routes.

As a result of energy-related activities, the main safety concerns for bridges in Texas include inadequate bridge widths for safely accommodating the drilling rigs and other OS/OW loads along with the large volumes of truck traffic. A report by Wilson (2012) showed that more than 1,000 Texas bridges are exposed to OS/OW conditions and are concentrated in areas where there are energy developments. Texas DOT has found that proactive approaches to addressing roadway impacts have been more cost-effective in maintaining the infrastructure because permit fees are too low to recoup the costs of potential damage. Other damages to pavements are creating safety hazards for drivers, who drive across potholes, badly cracked asphalt, and damaged shoulders. These poor pavement conditions, and the drilling-related traffic that causes the damage, were reported by Batheja (2013) to be increasing the numbers of accidents on farm-to-market roads. In an attempt to increase safety, speed limits, signs, and traffic signals have been implemented.

Wyoming

In anticipation of increasing oil and gas drilling traffic on low-volume county roads in southeastern Wyoming, the Wyoming state legislature appropriated funds to assess current county road conditions and develop transportation asset management systems that counties could implement. Huntington et al. (2013) reported that unpaved roads can be rehabilitated more easily and less expensively than paved roads in Wyoming. Wyoming DOT estimates a need of $2.7 million for improvements to unpaved roads, but there is currently $145 million in outstanding recommended improvements for county paved roads impacted by energy development activities. The study concluded that there is more benefit in investing in the condition of paved roads because these roadways can deteriorate more quickly and irrecoverably.

Advancements in oil and gas technology have led to an increase in oil and gas production in the Niobrara shale formation located in parts of Colorado and Wyoming. Owing to the nature of the growth in this industry and the type of traffic associated with it, pavements on local county roads have exhibited rapid degradation. The *Gravel Pavement Surface Evaluation and Rutting Manual* (in Stroud 2013) presents a system for rating and evaluating gravel roads. Thus far, the counties in Wyoming have reported little difference in the condition of non-impacted roads compared with energy development–impacted roadways, primarily a result of efforts by counties to sustain all of their roads in the same good conditions.

LITERATURE REVIEW OF STRATEGIES USED BY FEDERAL AGENCIES AND STATES

Table 7 provides examples from the review of published literature on strategies for addressing the impacts of energy development, as reported by federal agencies.

The following sections present detailed information from the literature review on strategies published by state agencies and their affiliates, for addressing the impacts of energy development. The information from these states was found in the literature review and can be of interest to other states with similar circumstances or geographic features.

Arkansas

The Arkansas DOT interviewed all district engineers and some maintenance employees about the condition of the roads. The agency also increased its frequency of taking traffic counts using pneumatic tubes (previous counts predated the drilling boom) and found that some routes experienced three-fold increase in average daily traffic (ADT) over just three years (Meadors and Wright-Kehner 2013). The Arkansas DOT also mapped all existing and permitted wells, began a procedure of biannual field evaluations, and ran the Auto Road Analyzer (ARAN) over each mile of roads in the study. The ARAN provided pavement smoothness measurements, rutting and cracking information, pavement serviceability ratings, and pavement edge conditions at intervals of ⅒ of a mile. Likewise, the DOT staff performed a windshield survey every ⅒ of a mile in areas where the data were incomplete and developed a crack index for the routes (mostly block and alligator cracking) and analyzed all routes where the rut depths exceeded 1 inch.

Pavement edges were a particular problem, as a large proportion of the road edges were so degraded that the white lines delineating the lanes had been worn down. Many of the affected routes were never designed to have shoulders

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TABLE 7
LITERATURE PUBLISHED THROUGH FEDERAL AGENCIES RELATED TO ADDRESSING IMPACTS FROM ENERGY DEVELOPMENT ACTIVITIES

Agency	Strategies	Reference
Federal Highway Administration	Defined design mechanisms for aggregate surfacing; Developed a model for use in native surfacing design, while considering the effects of maintenance and road management; Provided a set of procedures for surfacing design for low-volume roads.	*Earth and Aggregate Surfacing Design Guide for Low Volume Roads* (Bolander et al. 1996)
Federal Highway Administration	Explained geosynthetic-reinforced soil (GRS) technology and its fundamental characteristics as an alternative to other construction methods.	*Geosynthetic Reinforced Soil Integrated Bridge System Synthesis Report* (Adams et al. 2011)
Federal Highway Administration, National Highway Institute	Manual to guide highway engineers in correctly identifying and evaluating potential applications for geosynthetic materials.	*Geosynthetic Design and Construction Guidelines* (Holtz et al. 1998)
Federal Highway Administration and South Dakota LTAP	Manual to provide clearer understanding of the design and maintenance of gravel roads.	*Gravel Roads Maintenance and Design Manual* (Skorseth and Selim 2000)
United States Environmental Protection Agency	Manual assists rural road owners in using natural systems and innovative technologies to reduce erosion, sediment, and dust pollution; Guidance for effective and efficient maintenance of dirt and gravel roads.	*Environmentally Sensitive Maintenance for Dirt and Gravel Roads* (Center for Dirt and Gravel Road Studies 2014)

and had lanes that were only 9 or 10 feet wide. A significant number of large and heavy trucks were not adhering to speed limits and were flipping over when their wheels went off the edge of road. After reviewing the roadways for this study, the DOT divided the roads into six conditions: slight, intermittent, or major damage, and with or without shoulder needs. Slight damage was indicative of reasonable condition where no repair work was needed. Intermittent damage was for pavements that required overlays, and the major damage required full reconstruction of the pavement and underlying layers. Approximately one-third of the miles studied fell into an intermittent damage with shoulder needs category.

Sections of pavement on horizontal curves were the first pavement sections to show issues when heavy and frequent truck traffic began. Most of the trucks were measured at more than 120,000 pounds and were braking when entering the curves, leading to washboarding and shoving of the pavement. In these cases, the pavement failures were measured down to the subgrade layer.

Idaho

Case histories from Poland, Canada, and American Falls, Idaho, were reported in an article by Gale et al. (2013). The study found that ground support conditions of access roads are generally not considered in the development of wind energy sites and lead to soft subgrades that must be dealt with during construction. The use of geosynthetics is becoming more prevalent in stabilizing renewable energy access roads throughout the world. These roads must withstand the short-term heavy loading and sustain low-volume maintenance vehicle access more than 25 to 50 years. The use of geosynthetics materials in low-volume roadways successfully reduces maintenance concerns during construction and enhances the longevity of the roads. The study suggested that roadway agencies can seek compensation in the form of a development impact fee, based on the magnitude of the development, or a user fee based on measured damage to specific roads used by the developer. If development impact fees are adopted by roadway agencies, the fee is to be determined according to the reduction in pavement life expected as a result of energy development–related traffic.

Iowa

Nahra (2013) presented an approach to measure the incremental maintenance costs on pavement for new traffic generated as a result of energy development. The approach consists of calculating the total ESALs resulting from energy development, comparing that total to the number of ESALs for which the road was designed, and basing the pavement deterioration rate on this value. The effects of overweight vehicle loads, such as road rutting, are causing counties to upgrade pavement design standards to better accommodate the heavier loads in areas of anticipated growth. Using this approach, some counties now design for 10 million ESALs for pavements that connect cooperatives to biofuel plants.

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Other counties have designed for triple the level of ESALs compared with the previous design standard. One county instituted a Road Preservation Ordinance that issues permits as a source of funds for the repair of road damages caused by the renewable energy industry.

Minnesota

Interstates, state highways, county state-aid highways, and county roads are all utilized to transport wind turbine components in Minnesota. Pavements that are designed to carry lower levels of traffic were not intended to carry these heavy loads. A report by the Minnesota Department of Transportation developed a Heavy Traffic Generation tool that allows users to estimate the damage that may be caused to pavements on local roadways during the heavy construction traffic associated with wind turbine developments (Minnesota DOT 2012). The tool allows for the estimation of repair and reconstruction costs on affected roadways.

Mississippi

In an interview, the county engineer for three counties in Mississippi described two counties that have experienced impacts from oil and gas production. Jasper County houses the largest petroleum producer in Mississippi, and a state-of-the-art power plant was being constructed in Kemper County. Oil production has been ongoing since the mid-1940s using conventional drilling techniques. Energy companies are now using carbon dioxide injection to recover an additional 30% to 40% of the oil. This has increased activity and caused more damage to county roads.

The counties receive part of a severance tax from petroleum that is extracted within their jurisdictional limits. New legislation recently passed by the state of Mississippi is expected to increase the county severance tax allocation up to $600,000 per year. Although the entire amount is not allocated to roads and bridges, a significant portion is. Carbon dioxide facilities are classified as green energy activities. As a result, energy developers receive significant tax benefits and exemptions, in accordance with both state and federal laws. Therefore, many of the facilities that the energy developers construct are tax exempt.

In Kemper County, the Mississippi Power Company (MPC) is constructing a new power plant that will be fueled by recovering gas from natural lignite. The new power plant is based on an innovative technology and employs 6,000 to 7,000 personnel on the site. Although a great deal of heavy traffic is not expected once the plant is operational, a tremendous influx of both construction traffic and employee traffic has been observed on low-volume county roads.

The interview cited an example in which the Mississippi DOT upgraded a state highway for primary access to the energy production site. Because this was not the shortest route, considerable traffic began using other county roads as shortcuts, and although most of the loaded trucks used the appropriate state route to the site, they returned along county roads which were not designed for the loads carried. Even though the loads were lighter, the increased ADT increased the deterioration of the roadway pavements.

The MPC projects about $8 million per year of increased revenue, about $3 million of which will be placed in Kemper County's general fund for multiple purposes. About $5 million will go into a capital improvements fund; $3 million per year will be budgeted for upgrading roads and bridges. Kemper County reported that the MPC is also providing some benefits, starting with the upgrade of a 4-mile segment of county road that connects two state highways, estimated to cost approximately $2.6 million, and improving the strength of the pavements on county road connectors to state highways. The MPC will take a number of lower-quality dirt roads and low-volume paved roads out of service as part of their mining. The company has committed to restoring those roads to the current design standards for both gravel and paved roads, which will be a significant enhancement over what is in place currently. When a road is taken out of service, other local roads will be more heavily traveled, and the MPC has committed to spend about $100,000 to improve the riding surface on these roads.

Montana

Montana DOT monitors population and subsequent traffic growth to ensure roadway quality, safety, sensitivity to the environment, and economic vitality, according to a comprehensive study regarding the impacts of Bakken Region Oil development on Montana's transportation and economy (Brown et al. 2013). Figure 1 depicts the overall monitoring process used by Montana DOT.

New York

In New York, uncertainty about the timing and location of future shale gas development limits the ability of transportation agencies to consider shale gas–related impacts in long-range planning (Tidd 2013). Approaches used to forecast land use change for planning (build-out analyses, scenario planning, expert panels/Delphi method, etc.) may be adaptable to shale gas well development. Planning organizations can attempt to address uncertainty with a range of possible outcomes and monitoring, and examples are available for metropolitan planning organizations (MPOs) to alter as needed to fit their situation.

The study cited a few effective practices, starting with the idea that planning organizations should generate a complete set of baseline data on any existing activities, in order to characterize any trends. In doing so, the planning organiza-

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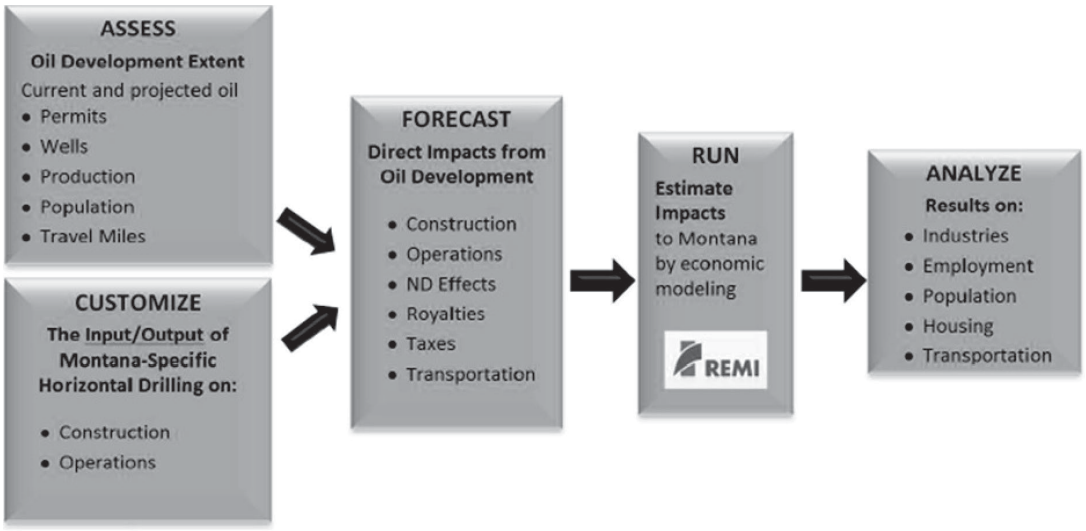

FIGURE 1 Montana DOT monitoring process (*Source*: Brown et al. 2013).

tions can determine whether shale gas development impacts are significant enough to require special consideration when developing the population and employment totals for transportation modeling. In addition, planners are recommended to include the full range of shale gas–related impacts on transportation, including air quality, congestion, safety, socioeconomics, and system maintenance.

North Dakota

A study by North Dakota State University (2010) concluded that load limits must be imposed during the spring thaw as a result of soils being unable to effectively support heavy loads. This is because the modulus of poor soils may drop below 5,000 psi, causing a drastic change from the approximately 12,000 psi (frozen) modulus and, as a result, the relative damage from loads increased up to 400%. Spring load restrictions were reported to typically last six to eight weeks, depending on the soil conditions. Ideally, roads that are most heavily traveled by heavy trucks would be free from seasonal load restrictions. The study reported that the North Dakota DOT has developed a predictive model for use in the western part of the state that could be adaptable to other states and provinces.

Pennsylvania

The Pennsylvania DOT (PennDOT) performs routine roadway condition surveys on roads impacted by energy development activities (Koser 2013). If survey results show damage levels to be significant, a five-day notification letter is issued (through certified mail) and, if not satisfactorily handled, the energy company's permit is suspended. If the roadway conditions are very degraded, then the permit is immediately suspended. The goal is to maintain the roadway to a condition at least equivalent to the original conditions throughout the period during which hauling activities take place. When a heavy hauler wishes to exit its EMA, it must return the roadway to either the original condition or a better condition. PennDOT defines a heavy user as a hauler that has substantial risk for causing excess damage to the roads, generally defined as having more than 700 loads or greater per year. The natural gas industry and larger coal operations were reported to generally fall into this category in Pennsylvania.

In terms of cost recovery, PennDOT invoices heavy users for costs such as the initial and final inspections, periodic construction inspections, road condition surveys, and plans review.

Texas

Texas state bill SB 1747 gives counties the ability to create County Energy Transportation Reinvestment Zones. The legislation was widely supported by the oil and gas industry. A formula was created for grant distribution for counties that designate an energy transportation reinvestment zone. The formula appropriates 20% to counties based on weight tolerance permits issued in the preceding fiscal year, 20% according to oil and gas production taxes in the preceding fiscal year, 50% determined by well completions in the preceding fiscal year, and 10% according to the volume of oil and gas waste injected in the preceding fiscal year. It includes requirements for an advisory board and for holding a public hearing on the creation of the zone, and on its benefits to the county and to the property in the proposed zone. It also established an ad valorem tax increment account for the zone, funded by the taxes collected on property in a zone, to be used for transportation projects located in the zone. An alternative exists that allows a county to create a road utility district (with the same boundaries as the zone) which may issue bonds.

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The bill also created a transportation infrastructure fund that consists of eligible federal and state funds, gifts, and grants for funding for transportation projects, including those for county energy transportation reinvestment zones. It granted the Texas DOT the authority to develop policies and procedures to administer a transportation infrastructure grant program to counties located in areas of the state affected by increased oil and gas production.

A study by Oh et al. (2013) recommended that agencies enforce the use of triaxial design checks in the current flexible pavement design method, especially for energy-related corridors. Nondestructive testing tools such as ground penetrating radar (GPR) and falling weight deflectometer (FWD) were suggested to evaluate existing pavement structural conditions and for early identification of weak or potentially problematic sections. Other suggestions in the study included guidelines for strengthening cross-sectional elements on rural two-lane highways and modifications to include requirements that are tied to the actual ADT traffic range. The study described a need for widening the cross-sections of farm-to-market roads that are subjected to frequent truck traffic, and a need to avoid moisture-susceptible base materials in cross-section widening applications.

A paper by Miller et al. (2014) presented various partnership approaches between energy companies, county officials, and other organizations. The proactive, performance-based approach aims to strengthen pavements in advance of energy development. The reactive, performance-based approach assesses the impact fees based on the cost of roadway maintenance after the damage. A third approach imposes impact fees on energy developers that are not attached to actual measured deterioration. A fourth approach considers policy changes at the state level to allow counties to promote transportation infrastructure projects affected by energy production activities.

A research project funded by Texas DOT, reported on in Conner et al. (2012), measured the impacts of increased levels of energy-related traffic on infrastructure. Research activities included the creation of a geodatabase of energy developments; assessment of pavement and roadside impacts; operational, safety, and economic impacts; stakeholder meetings; and, strategy recommendations. An ideal pavement assessment methodology was reported to consist of four steps: (1) determine the pavement condition/strength, (2) estimate the pavement life consumed by projected heavy vehicle traffic, (3) determine pavement replacement cost, and (4) charge the developer for the costs of the increased heavy vehicle traffic. An analysis was conducted that created buffer zones around both existing and permitted future wells within a 5-mile radius. Using these buffers, researchers determined what portion of the highways would be impacted, assuming that roadways outside of the buffer would not be impacted. Because the road network is much less dense in South Texas than in North Texas, the impacts were suggested to be more significant on each road mile. Using this buffer analysis, it was estimated that the oil and gas industry is having a $1 billion annual impact on secondary roads.

Wisconsin

Wisconsin DOT reported that it uses a few tools for managing the impact of the sand mining on roads: traffic impact analyses, statutes (specifically, Chapters 348 and 349), and permitting local areas to handle road upgrade maintenance agreements (Hart et al. 2013). The highway commissioner of Chippewa County was able to negotiate on behalf of the county, and the county treated the sand mines as any other traffic-generating enterprise. Baseline condition measurements for the roads were taken using FWD, GPR, pavement surface evaluation rating, and Minnesota DOT TONN (a tool that uses FWD deflection data to determine both the Seasonal Load Restriction and to calculate the subgrade's R-value). The county also projected truck tonnage from issuing mining permits and in some areas have mandated that the heavy truck traffic must avoid school bus routes.

PRACTICES REPORTED BY FEDERAL AGENCIES

Information gathered from online content and through interviews with staff indicated that there are many federal lands impacted by activities related to energy development. Several agencies associated with national forest, recreational, or tribal roadways have adopted practices to help adapt to the new transportation needs for the purposes of energy development.

United States Department of the Interior, Bureau of Indian Affairs

The Bureau of Indian Affairs (BIA) website describes the Office of Indian Energy and Economic Development, whose mission is to provide technical advice to tribes in exploration and development of nearly 2 million acres of energy and mineral resources. An additional 15 million acres of undeveloped lands could hold the potential for further energy and mineral exploration. In addition to oil and minerals, renewable energy development exists with priorities for wind, solar, geothermal, and biomass activities.

The website showed that an Office of Indian Services also exists, with a Division of Transportation at the BIA. This division is responsible for approximately 29,500 miles of roadway and 930 bridges that are identified as BIA roads and are included in the National Tribal Transportation Facility Inventory. Under the operation and maintenance of BIA roads, transportation facilities located on Indian reservations and within tribal communities are maintained. It is the policy of the BIA Road Maintenance Program to preserve, repair, and restore the BIA system of roadways and transportation

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facilities in accordance with federal, state, tribal, and local laws, as applicable. The BIA is mandated to maintain roads and transportation facilities constructed with Highway Trust funds. Many of these BIA roads are in failing to fair condition, are not built to an adequate design standard, and have safety deficiencies. In fiscal year 2012, approximately 5,150 miles, or 17%, were considered to be in acceptable condition, based on the BIA Service Level Index condition assessment criteria. The 23,850 miles of remaining roads, or 83%, were in unacceptable condition.

In an interview with a transportation consultant, representatives of the MHA Nation (Mandan, Hidatsa, and Arikara Tribes), which comprise the Three Affiliated Tribes (TAT) of North Dakota, described their situation. There are a number of state, local, and tribal roads that were not designed to handle the volume and composition of the energy-related traffic that has increased in recent years, and pavement surface failures were observed to increase the number of reported crashes. The transportation system on the Fort Berthold Reservation, located within the Bakken play where drilling is under way, consists of state-owned paved highways as well as county and tribal unpaved roads. In 1995, the TAT assumed the road maintenance system from the Bureau of Indian Affairs, and since that time the Fort Berthold Reservation has experienced unprecedented heavy truck traffic resulting from the oil exploration in northwestern North Dakota. A 2011 Road Safety Audit of the BIA Roads on the reservation, conducted by the FHWA Office of Federal Lands (Indian Reservation Roads) Program, the TAT, North Dakota DOT, FHWA North Dakota Division, and BIA Great Plains Region, revealed poor pavement conditions, inadequate sign maintenance and visibility, and obsolete horizontal and vertical alignments and speed management for the current traffic volumes and composition (Loegering 2012). A comprehensive list of recommendations was compiled to improve safety on these roads.

The interview also uncovered that currently the TAT and individual tribal landowners receive lump sum royalty payments through leases with the energy companies. Additionally, the TAT have turned over about 100 miles of road for ongoing maintenance and repair through separate maintenance agreements with the energy companies. The companies have used chemical stabilizers in the unpaved road surfaces to keep the roads operational.

United States Department of the Interior, Bureau of Land Management

A review of its website found that the Bureau of Land Management (BLM) administers more than 245 million surface acres of public land, which is more than any other federal agency in the United States. Most of this land is located in the 12 western states, including Alaska. The BLM also manages 700 million acres of sub-surface mineral estate throughout the nation. The BLM's multiple-use mission manages public land resources for a variety of uses, such as energy development, livestock grazing, recreation, and timber harvesting, while protecting a wide array of natural, cultural, and historical resources, many of which are found in the BLM's 27 million-acre National Landscape Conservation System.

The website also showed that the BLM has a source document entitled the *Surface Operating Standards and Guidelines for Oil and Gas Exploration and Development*, commonly referred to as "The Gold Book" for use by the U.S. Forest Service (USDA-FS) and BLM (Bureau of Land Management 2007). The topics in the guidance document include guidance for filing plans, conducting environmental analysis and on-site inspections, and presentation of best practices; geophysical operations; permitting and approval of lease operations; construction and maintenance (roads and access ways, transportation planning, road design/construction/maintenance, drainage, pipelines and flow lines); drilling and production operations; reclamation and abandonment; and, appeals. The document was developed to assist energy operators by providing information for them on the requirements for obtaining permit approvals and conducting environmentally responsible oil and gas operations on federal lands and on private surface access over federal minerals.

United States Department of Agriculture, Forest Service

A review of its website and interviews conducted with staff found that the United States Forest Service (USFS) Engineering Division provides engineering technical assistance for the management of about 200 million acres of national forests, lakes, mountains, and prairie lands. The USFS manages an extensive road and trail transportation system and provides for the planning, management, maintenance, and capital improvement of 7,500 bridges and 375,000 miles of National Forest System (NFS) roads. Twenty percent of the roads are open without restriction to all vehicle types (including passenger cars), 58% are open to pickups and other high-clearance vehicles, and 22% are closed. Additionally, the Minerals and Geology Management department manages energy and mineral resources into development, production, and reclamation according to specific authorities, legislation, rules, and regulations. The program is also responsible for authorization of ancillary projects, such as roads and pipelines that are part of the energy and minerals development projects. The value of energy and mineral production from NFS lands typically exceeds $2 billion per year. More than 5 million acres of NFS lands are leased for the oil, gas, coal, and phosphate types of energy.

Energy industry activities range from oil and gas leases, methane, timber, geothermal, and biomass projects, which require Road Use Permits (RUP), the key regulating permit for energy development activities. The RUP template is provided in Appendix B (available at www.trb.org; search

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TABLE 8
PRACTICES USED TO ADDRESS IMPACTS OF ENERGY DEVELOPMENT IN ALLEGHENY NATIONAL FOREST

Impact of Energy Activity	Strategy or Practice to Address Issue	Notes on Practice
Recovery of funds for maintaining forest road condition	Road use permits: initial fee payment followed by an annual fee for hauling brine and oil	Fee structure is based on level of activity (charged on per mile basis) and depends on the number of sites
Need for improvements at intersection of ANF and state roads	Sight distance, brushing, signing, markings, and pavement resurfacing	Energy developers must pay or fund through working with Pennsylvania DOT
Unpaved roads with ruts holding water or entrenched, resulting in poor condition	Use higher quality aggregate in areas with unconventional wells and build to a higher USFS road design standard	Some roads have been treated with full depth reclamation (FDR) of pavements to enhance road surface's ability to handle truck loads from unconventional well sites
Dust spread from passage of trucks to and from well sites	Use of conventional binders, emulsifying oils, or water trucks to wet road surface	ANF is a relatively wet forest; thus, dust control has not been a major issue
Trucks are too large for the forest roads, which are single lane roads with turnouts	Reconstruct roads to a full two-lane highway after conversion to FDR surface is no longer resisting damage	Energy company must pay for the upgrade to a two-lane road

NCHRP Synthesis 469). The USFS generally regulates access through RUP and can modify permits to reflect the specific situations. The USFS policy is to bring the roads up to standard before their use by energy developers and to maintain them during use. Reimbursement is through the specific items outlined in the RUP with funds provided to the specific National Forest.

In the Grand Mesa Uncompahgre and Gunnison National Forests in Colorado, the USFS has installed 40 traffic counters and has commenced collecting traffic volume statistics. For areas where traffic exceeds the normal range of 150 to 200 vehicles per day, the USFS is considering mitigation measures to reduce the speeds and to increase the strength of the roadway subbase or subgrade.

In interviews with staff at the Allegheny National Forest (ANF), it was explained that there are two types of oil and gas development, designated as conventional and unconventional drilling, in the ANF in northwestern Pennsylvania. The conventional drilling consists of shallow vertical wells (ranging from 500- to 2,000-feet depths), an activity which has taken place in the forest since the 19th century and attracts approximately 300 trucks per year to the area. Approximately 60% to 70% of the forest roadway system is being used by conventional energy operators and other multiple operators within the same year.

The unconventional deep well extraction is still in the exploratory stage in the ANF but has already attracted about 3,000 trucks per year to the area and is expected to expand more. The majority of the roads in the ANF are unpaved (dirt and gravel), and the emergence of heavy trucks operating to the exploratory sites has significantly accelerated pavement damage, sometimes in a couple of hours.

The USFS works with the gas and oil operators to fix major structural damage (e.g., ruts in aggregate-surfaced roads that are deeper than 3 inches) and restore the roadway surface to the USFS road standards. Because many of the operators use the same roads, RUPs can allow the energy companies to pay for the reconstruction directly or allow them to donate equipment or materials for the repair of the roads. If there are impacts to water quality, the Pennsylvania Department of Environmental Protection may also be involved negotiating fund allocations with the energy companies.

Load postings are in effect on ANF roads and bridges during the thaw period (February through April); otherwise, the state legal load is the standard. However, USFS engineers continually inspect whether the ANF roads and bridges can withstand the loads in unconventional well areas and seek cooperation with the energy developers in controlling their loads on roads with sensitive bridges. A number of effective practices have been used by the USFS in ANF and are summarized in Table 8.

PRACTICES REPORTED BY TRIBAL NATIONS

In interviews with a representative of the Southern Ute Tribal Nation, the significance and importance of the 2006 Ignacio Area Corridor Access Plan was outlined. The plan involves collaboration between the Southern Ute Tribal Nation, La Plata County, the town of Ignacio, and the Bureau of Indian Affairs. This plan was developed to address the sustained growth resulting from the new Ute Casino, Museum, and Cultural Center, and the energy development activities in the region. One key factor was the gas and oil field development anticipated with the high probability of significant gas/oil field expansion to the east of the Ignacio. The project team used historic truck traffic growth volumes to determine future traffic impacts on the corridor resulting from new wells planned in the area. The weblink is provided in Appendix C for accessing and viewing this plan.

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CHAPTER THREE

SURVEY ON ENERGY DEVELOPMENT IMPACTS ON STATE AND LOCAL ROADS AND BRIDGES

INTRODUCTION

A survey was distributed to the chief engineers (or equivalent position) at the DOTs in the 50 states, District of Columbia, and Puerto Rico. Forty-one DOTs (40 states and the District of Columbia) responded, resulting in a survey response rate of 79%, and provided input on impacts of energy industry development on state and local roads and bridges. The DOT survey questions and summary of results are presented in Appendix A.

The survey found that more than half of the DOTs reported an increase in congestion and/or damage on roads and bridges near energy development areas. The survey results show that, for the majority of DOTs, energy development impacts are primarily observed on the rural secondary roadways; however, there are a few states that said more than half of their freeways and primary roadway systems are impacted by the increased number of heavy trucks serving energy developers. In the case of DOTs that use a proactive approach in addressing impacts to infrastructure from energy developments, the use of pavement preservation treatments were identified as very effective, along with the continuous updating of design standards. The posting of load limits was considered somewhat effective. Partnership with energy development companies was also observed by DOTs to be an effective in resolving infrastructure issues. Many DOTs reported the most common challenges related to energy development activities to be the issuance and tracking of permits, accelerated roadway and bridge degradation, and the shortage of maintenance funding. Some efforts to resolve these challenges were reported by DOTs, including assigning permit fees that are relative to the level of energy development activity, the funding of inspection fees assigned to energy companies, and collaboration between railroad companies and current or future energy sectors to shift some transporting activities from roads to the railway network.

IMPACT ON INFRASTRUCTURE: ROADWAYS AND BRIDGES

Thirty-two DOTs reported that their state experienced a sustained and/or expanded level of energy development activities in recent years. When asked whether the increased level of energy development activities is impacting either state or local roads, 32 DOTs indicated that roads have been impacted. The energy development types that have increased and/or sustained levels within these 32 states include predominantly wind energy, followed by natural gas energy. Both oil and mining energy types showed the same increase and/or sustained level (14 states). Biofuel (nine states), solar (four states), and nuclear (one state) energy types were also reported.

Twenty-seven DOTs indicated that they observed an increase in the amount of truck traffic volumes and heavy loads as a result of the energy development activities. In Wisconsin, a continual escalation in wind tower loads was observed over the past five years, with an anticipated 1,600 wind tower loads by 2015. The total number of OS/OW permits issued has risen accordingly. Maine DOT reported short-term impacts during the transport of windmill towers or heavy power generation equipment to sites. However, once these projects were completed, Maine DOT did not observe a sustained increase in traffic nor any related infrastructure damage. In Minnesota, rural traffic patterns have changed with the increase of corn and ethanol shipments. In addition, the wind energy sector has contributed to the increase in OS/OW shipments through and to Minnesota. In Vermont, wind industry–related OS/OW permits and new trip patterns have been observed, although they were not statistically significant. In Pennsylvania, several thousand miles of the roadway system are posted with weight restrictions as a result of the significant increase in energy-related truck traffic. Although seven states reported no increase in truck traffic, two states foresee a potential for growth. In North Carolina, preliminary seismic testing is being done currently to account for the legislation that will allow drilling starting in March 2015. Therefore, even though the energy development industry is not currently active, it is plausible that this industry may expand in North Carolina. In a couple of states the increase in the amount of truck volumes and heavy loads is hard to decipher. For example, in New Jersey, the ethanol and oil sand facilities are located where truck volumes are already high, making it difficult for the DOT to measure the exact portion that results from energy development activities. A few states (Alabama, Hawaii, Maryland, and New Hampshire) noted a truck traffic pattern change as opposed to an increase.

Both Illinois and Alabama reported that more than 60% of their roadway system is impacted by the increased presence of trucks, particularly the interstate/freeway and primary roadway systems. Figure 2 summarizes the reported

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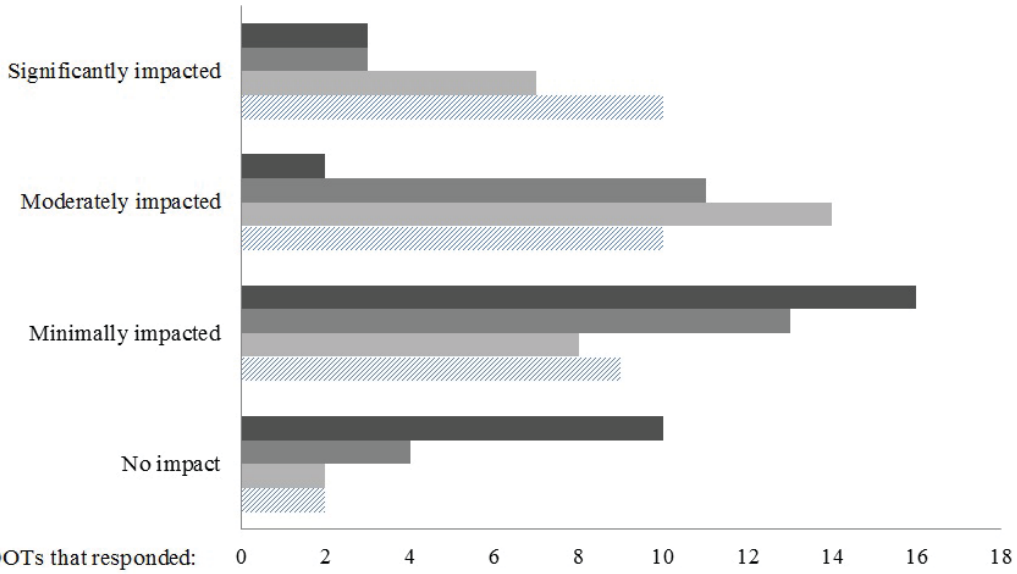

	No impact	Minimally impacted	Moderately impacted	Significantly impacted
Interstates or freeways	10	16	2	3
Primary (National Highway System or state highway system)	4	13	11	3
Secondary (minor arterials or collectors/distributors)	2	8	14	7
Secondary (local roads)	2	9	10	10

FIGURE 2 Rating of energy development impact level by facility type.

impact level, based on the roadway type. Secondary roadways that include minor arterials, collectors/distributors, and local roads were reported as most impacted by the truck traffic resulting from energy development activities. Ten states noted a significant impact level for local roads, whereas seven states reported a significant level also for minor arterials or collectors/distributors. Approximately twice as many DOTs rated the impact on minor arterials and local roads at a moderate level, with Interstates or freeways reported to be least impacted.

Twenty-three of the DOT respondents answered that local agencies, DOT District maintenance offices, or the Division of Motor Carriers have reported an increase in damage or congestion on roads and bridges near areas where the transport of energy-related commodities occurs. Windshield inspections or visual observations were the most widely reported measure for assigning these impacts, along with complaints logged from the public, commercial business owners, or the energy industry. Noticeable changes in recorded road condition survey data from detailed inspection reports from local agency public works, law enforcement, or engineering departments were also identified as commonly applied methods for identifying impacts. In Montana, both internal DOT and consultant contract research (by the Upper Great Plains Transportation Institute) was conducted to study the effects of energy development and extraction on state highways. Both studies focused on the development of a truck traffic forecasting model with specific attention to oil development–related truck movements in the Bakken formation in eastern Montana and western North Dakota. They also addressed the assessment of differences in impacts under various development scenarios. Montana DOT also performed pavement analysis and population estimation to analyze the effects on pavement condition, roadway capacity, safety, and operations by forecasting extent and magnitude of truck traffic increases.

In Alabama, rural and local roadways are within a county's survey and maintenance jurisdiction near mining operations sites. At intersections with state route facilities, it is expected that either the municipalities or the county will perform scheduled maintenance condition surveys of the adjacent state routes and then report the survey findings to the state DOT. In urban areas, either the local government or the DOT monitors the condition of the roadway infrastructure and take action when repairs are warranted.

A number of DOTs reported their approaches to addressing the damages done to infrastructure by energy-related activities.

- Reactive: Two DOTs reported using a reactive approach that potentially included OW/OS vehicle fees assigned; recouping payment after damages for fixing roads; extended duration closures of local

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roads or bridges; and/or an increased presence of law enforcement along heavily used roadways.
- Proactive: Three DOTs reported using a proactive approach that covered preventing damage before it happens by posting load limits; applying pavement preservation treatments; improving structural capacity of pavements; designating truck routes; other mitigation strategies; and continuously updating design standards.
- Legislative: No DOT reported using a legislative approach that included road ownership responsibilities (interjurisdictional); local ordinances; state laws on energy development; permitting restrictions; roadway usage fee scaled to vehicle load or type; or modal shifts of freight dictated legislatively.
- Partnering with energy development companies: Two DOTs reported partnering with energy development companies, an approach that potentially included having energy companies design new roads; having energy companies pay for reconstruction of local roads; using Concessionaire agreements (public–private partnerships); or having procedures in place for recouping damage costs.

Twelve states used a combination of approaches. Examples from these states are presented in the following sections.

Alabama

Alabama DOT is preparing a 2014 Statewide Alabama Freight Network that will be intermodal and include a critical rural freight corridor component. This proposed network is in addition to the U.S.DOT-designated national freight network. The objective of this network designation is to establish a freight network that is independent of a national designation, to better benefit the taxpayers in Alabama.

In Alabama, bridges are replaced and/or rebuilt based on periodic inspections. In the Birmingham urban area, where facilities must be improved because of the area's noncompliance for air quality conformity, the roadway structures were widened or improved to meet mitigation requirements regardless of the availability of Congestion Mitigation and Air Quality (CMAQ) funding.

Minnesota

In Minnesota, the DOT assists local agencies by coordinating the OS/OW permits as well as posting load limits on roads and bridges. Although the Minnesota DOT has updated the design standards to require a stronger pavement cross-section for the impacted roads, funding limitations are hindering local agencies from rebuilding the roadways to meet these higher standards. As a result, a practice to use preservation overlays fits better within the limited budgets. Minnesota DOT developed and has offered truck weight education classes to haulers and local agencies at an affordable cost for several years. These courses are offered by former state patrol officers and are coordinated by the DOT Local Technical Assistance Program center. In 2013, the Minnesota DOT extended class coverage to include specific classes for law enforcement officers and the special challenges they encounter. From a legislative perspective, a law has passed that allows special hauling permits for vehicles that have an added axle to moderate the extra weight for timber and agriculture products. This enables these collected permit fees to go into a special account to be used for bridge inspection and signing. The legislature also passed a law to eliminate the immunity previously extended to implements of husbandry for damage done in crossing weight-posted bridges. It is anticipated that a similar approach could be implemented for dealing with the impacts of energy development in the future.

Missouri

In Missouri, the presence of law enforcement is reported to be very effective. Most of the issues were concentrated on low-volume state roadways during the construction of wind farms.

Montana

The Montana DOT has applied both reactive and proactive approaches. The survey response provided some examples of proactive approaches, including updating its design standards and plans. Some state agencies and local agencies have worked with the state of Montana (and national) legislature to establish legislation to address the infrastructure degradation, funding, and operations demands. As a proactive approach, the forecasted high-use corridors were identified, which facilitated project acceleration and design modifications to satisfy the forecasted demand.

South Dakota

In South Dakota, the pavement conditions for state highways are continuously monitored and proactive treatments such as seal coats, mill and overlay, and the like are completed routinely to preserve the facilities.

West Virginia

West Virginia has partnered with energy development companies by entering into voluntary road maintenance agreements to restore infrastructure to existing conditions, with bonding to assure compliance.

Table 9 summarizes information provided by seven state DOTs that use one or a combination of approaches to addressing issues that have arisen as a result of energy development activities. The information in Table 9 indicates that the application of pavement preservation treatments was reported by state DOTs to be very effective. The posting of load limits was reported to be somewhat effective.

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TABLE 9
APPROACHES IDENTIFIED AS EFFECTIVE TO A CERTAIN DEGREE FOR ADDRESSING IMPACTS FROM ENERGY DEVELOPMENT ACTIVITIES

State	Type of Reactive Approach	
	Recouping payment after damages for fixing roads	Increased presence of law enforcement along heavily used roadways
Maine	Somewhat effective	Not using
Missouri	Not using	Very effective

State	Type of Partnership Approach	
	Energy companies design new roads	Energy companies pay for reconstruction of local roads
Kansas	Not using	Somewhat effective
West Virginia	Very effective	Very effective

State	Type of Proactive Approach			
	Preventing damage before it happens by posting load limits	Pavement preservation treatments used	Designating truck routes	Continuously updating design standards
Alabama	Somewhat effective	Very effective	Shows promise, too soon to tell	Somewhat effective
Nebraska	Somewhat effective	Very effective	Not using	Not using
South Dakota	Somewhat effective	Very effective	Somewhat effective	Somewhat effective

Four states (Arkansas, Montana, North Dakota, and Pennsylvania) indicated there has been a decrease in the bridge rating or performance during recent bridge inspections that is directly attributable to energy development activities. Figure 3 presents the most frequently reported damage to bridge superstructures or decks, culverts on a particular route, superficial damage to pavements (e.g., raveling, aggregate stripping, or pop-outs), and structural damage to pavements (e.g., cracking, rutting, potholes, shoulder degradation). One reported challenge was that even though a significant increase in OS/OW permits was observed, it was hard to attribute the infrastructure degradation solely to energy extraction activities.

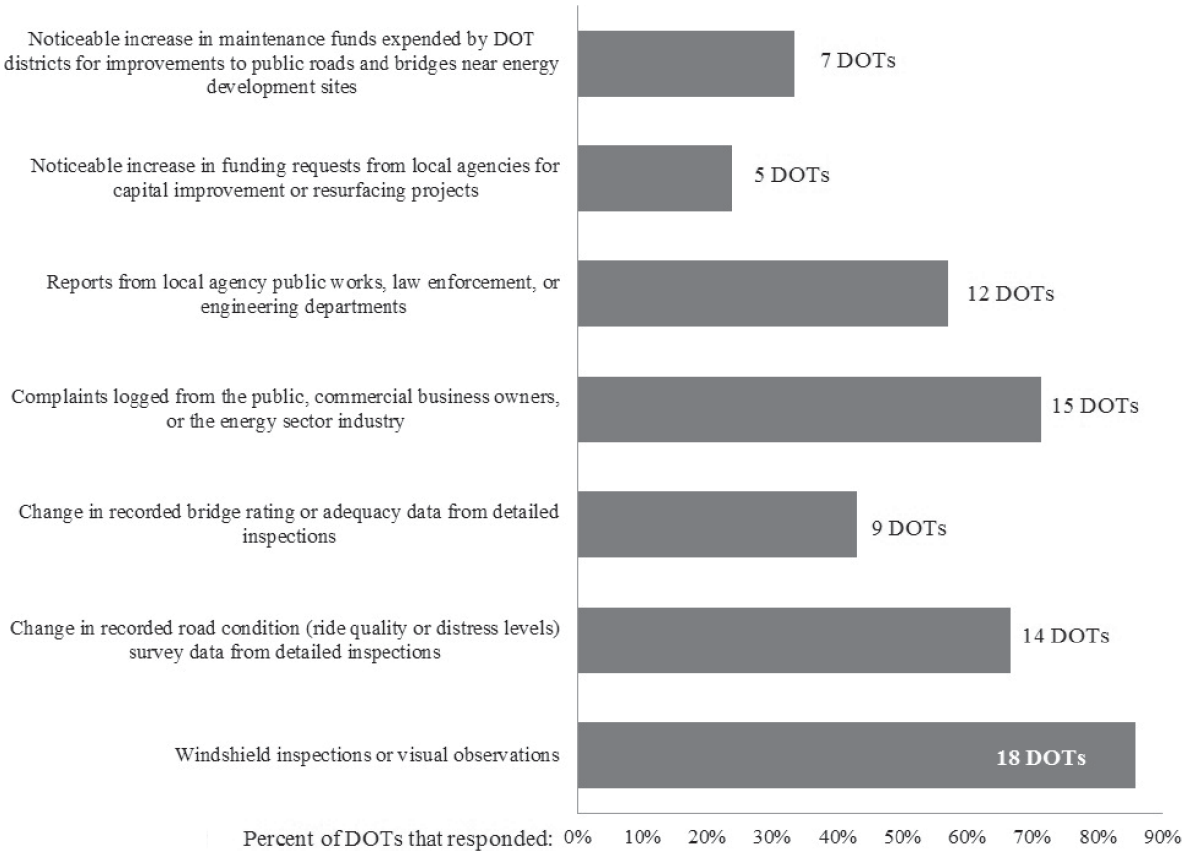

FIGURE 3 Damage or performance-related issues on infrastructure due to energy development activities.

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The detailed review of the state DOT survey data led to the selection of five states (Colorado, Iowa, North Dakota, Pennsylvania, and Texas) to be contacted for in-depth interviews. The details from these states are presented in chapter four.

The survey data showed that 16 states that experienced an increase in damage or congestion on roads and bridges near areas resulting from energy-related transportation, also reported a noticeable increase in the issuance of OS/OW permits. Montana DOT reported a 50% to 75% increase, and Arkansas and Iowa DOTs noted a 75% to 100% increase in OS/OW permit requests.

ENGINEERING TOOLS AND DESIGN STANDARDS

Figure 4 was generated based on survey responses from nine DOTs concerning damage on roadways exposed to freeze/thaw or heave conditions, and any related regulations in place to address the damage. In three states (North Dakota, Ohio, and Pennsylvania), roadways are exposed to freeze/thaw, and a related acceleration in pavement damage has been observed. As a result, these states have put policies in place to limit the amount of hauling activity during the spring thaw periods. In contrast, the Nebraska, Nevada, and South Dakota DOTs did not place restrictions on their roadway pavements exposed to freeze/thaw or heave conditions, because increased damage was not observed.

As shown in Table 10, the state DOT design standards and specifications were primarily reported to be somewhat or very effective in addressing roadway and bridge damage resulting from energy development activities. The most widely used assessment method reported was the observation and management of the pavement structure, such as in Pennsylvania, where routine roadway inspections are conducted on all posted roads. The importance of an accurate forecast of the anticipated truck traffic volumes in the energy development areas was also identified by North Dakota, Missouri, and Texas DOTs. In Montana, pavement design modifications have been made based on the truck traffic volumes forecasted. In West Virginia, the longevity of repairs and the effectiveness of preventative measures have been used for assessing the effectiveness of design standards. In Arkansas, the natural gas drilling activities within the Fayetteville Shale Play Area were reported to result in rapid pavement deterioration, and periodic site visits along with photographic documentation were used to assess these low-volume roadways. The South Dakota DOT noted that although it does not approve the design standards used for roads repaired or built by energy developers, it appears that the pavement materials and designs currently in use have been effective in handling the resulting energy-related truck loads.

Nineteen DOTs responded to the question of which engineering approaches they used to address the increase in damage or congestion on roads and bridges associated with energy-related activities. The posting of bridges by limiting weight and/or height restrictions was reported to be the most widely used method by all 19 states. There were 16 states that reported that posting bridges on the basis of a reduction in structural ratings (based on engineering inspections done by the DOT or local agencies) was an effective practice, whereas eight states

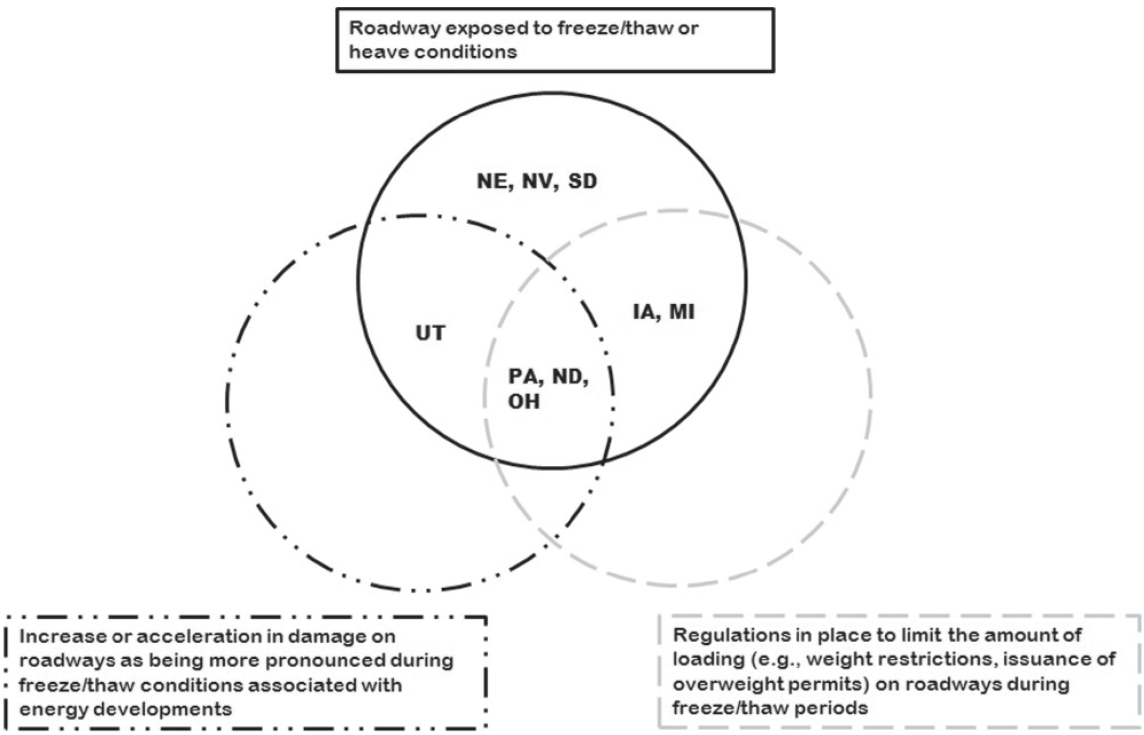

FIGURE 4 Roadway exposure conditions and amount of damage reported.

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TABLE 10
NUMBER OF DOTs REPORTING DESIGN STANDARDS USED AND RATED EFFECTIVENESS

Standards Reported	Not Effective	Not Sure Since Roads Are Not Currently Monitored	Somewhat Effective	Very Effective	Research or Monitoring Currently Under Way to Determine Effectiveness
Not sure, since they are not approved by state DOT		1		1	1
State DOT design standards and specifications	1	1	4	2	1
Local agency design standards and specifications	1	1	1		1
No requirement for design standards currently in place with energy developers		3		1	1

reported seasonal road postings as a strategy. Texas DOT uses an emergency load zone posting when the pavement conditions are rated as significantly poor owing to the extra amount of heavy trucks generated by the energy developers.

There were 12 DOTs that provided information or website links to their roads and bridges posting procedures, shown in Table 11. A sample of the posting policy from Iowa DOT is included in Appendix B.

The New Jersey DOT is in the process of upgrading or retrofitting 12 weigh-in-motion (WIM) sites to become virtual WIM sites. Virtual WIMs allow an enforcement official to wirelessly tie into real-time data to capture weight data while trucks pass on the highway.

ECONOMIC IMPACTS OF ENERGY DEVELOPMENT ON ROADS AND BRIDGES

The analysis of economic impacts on roads and bridges was reported by 14 states as being centered on the cost of repair or rehabilitation. The cost of reconstruction was also identified by ten states as a major cost. The Colorado DOT is currently researching cost identification, whereas Alabama

TABLE 11
STATE ROAD AND BRIDGE POSTING INFORMATION

State	Posting Description or Link
Alabama	http://www.dot.state.al.us/maweb/bridge_inspection.htm
Colorado	Bridge unit performs checks on bridges and, based on the unit's rating, structural restrictions are assigned.
Iowa	Posting information is based on the Iowa DOT Instructional Memorandum #2.120 and the Iowa DOT Policy and Procedures Manual #610.03.
Minnesota	http://www.mrr.dot.state.mn.us/research/seasonal_load_limits/sllindex.asp
Missouri	Bridges are posted using normal posting practices, which are based on legal loads within the state.
Montana	Analysis is done by the Montana DOT while local agencies post bridges based on the inspection and resultant load rating. Load ratings and bridge performance are reviewed regularly. In addition, energy extraction activities in Canada have required the movement of OS/OW items across bridges in the western and northern parts of the state. These traffic patterns were assessed, and bridges were shored up to enable the OS/OW loads to pass.
Nebraska	Bridges are all rated when the structural condition rating drops below a threshold and loading is posted if needed.
Pennsylvania	Follow National Bridge Inspection Standards (NBIS) and AASHTO (see the Bridge Posting Memorandum in Appendix B). Road posting and bonding website: www.papostedroads.pa.gov
South Carolina	Bridge ratings are based on the Load Factor Method and the Load and Resistance Factor Method. Results are factored in determining a safe load, posting levels, and in issuing OS/OW truck permits.
South Dakota	Any state highway that does not handle legal loads has a posted load limit. South Dakota DOT also conducts frost projection models to predict the thaw periods. Structures are inspected based on the NBIS.
Texas	http://www.txdot.gov/business/resources/construction/load-zoning.html
Virginia	Virginia DOT issues temporary load restrictions on roads for a limited number of days per year.

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DOT noted that energy-associated costs typically would be a result of environmental studies and/or air quality mitigation requirements. Eight states indicated that cost factors are associated with a unit cost. For example, South Dakota DOT noted that costs for rehabilitation are based on treatment type. North Dakota DOT stated that cost information is for in-house use only. Colorado DOT is in the process of identifying the most effective way to assess these unit costs. Alabama DOT listed several unit cost items such as cost per mile, cost per hour, cost per man-day, fuel reimbursement per mile cost, subsistence cost, percent overhead rate, and the percent fringe rate that would be presented in cost estimates either by DOT staff or by consultants on specific projects. Iowa DOT reported that the unit costs are determined on a county-by-county basis.

Truck traffic percentage was identified as the most widely applied factor for use in a cost formula by six states. Five states reported using the VMT in establishing a cost formula. Other states reported using the number of OS/OW vehicle permits issued and increased frequency in roadway or bridge maintenance as bases for a cost formula. Alabama DOT noted that rather than applying a formula, costs are derived from documented operational needs. For example, the VMT factor is used to determine the traffic volume and roadway capacity information that are then applied in both roadway design and designation of areas that require air quality mitigation.

TOOLS USED TO ASSESS COSTS

This section explores specific tools used to assess cost and the current reimbursement mechanisms in place to recover costs. Five states reported details on the use of tools to assess the costs of damage resulting from energy development activities. Table 12 presents the states and their practices for assessing costs to roads and bridges.

A review was conducted to identify the strategies used by state DOTs to address sources of damage to pavements and roadway infrastructure from husbandry, agricultural, or other heavy industries that share the same network of roads and bridges with energy companies.

Four states identified methods for the quantification of the costs of damage from energy development activities. These were methods that differed from those already in place to deal with damage to pavements and roadway infrastructure from husbandry, agricultural, or other heavy industries that use the same network of roads and bridges. Colorado has no method to assess non-energy activities related to roadway impacts, and in Arkansas the analysis of non-energy industries is not comprehensive. In Kansas, energy development contractors supplied the road rock to resurface roads damaged by their own activities. Montana DOT reported that the relatively new energy industries that operate year-round require different strategies, such as the use of significantly different pavement degradation models, as opposed to more predictable or seasonal non-energy industries. One strategy that Montana DOT applies is the encouragement and facilitation of multimodal shift, such as the use of rail and pipeline for the oil industry, as well as the consolidation of energy and non-energy industries shipping to higher demand locations. For the states that share strategies to address damages by both non-energy and energy industries, the use of standard permits, a maintenance program, and periodic surveys and data collection were most often applied. In North Dakota, truck traffic and VMT are integrated into the design of roadway improvements.

As presented in Figure 5, some states reported the percentage of costs shared between their agency and the energy companies. Alabama and Iowa DOTs indicated that 100% of the costs for repairs are covered by energy companies. In Pennsylvania, generally the energy companies pay 100% of the repair costs, although in a few cases some cost-sharing was done between both the agency and energy companies. Both Arkansas and Utah DOTs reported a cost-sharing of 75% to the agency and 25% to the energy company. West Virginia DOT reported cost sharing as 25% by the agency and 75% by the energy company.

Some DOTs (four states) indicated that energy developers are required to repair impacted roads and bridges to the

TABLE 12
METHODS REPORTED TO ASSESS COSTS OF DAMAGE DUE TO ENERGY DEVELOPMENT ACTIVITIES

State	Practices for Assessing Infrastructure Costs
Iowa	Permit cost quantification
Minnesota	Web-based road wear cost calculator
Montana	Continuous monitoring of population and traffic growth
Texas	Ad-hoc method (http://www.roadsfortexasenergy.com). In March 2012, a task force, composed of representatives from state agencies, local governments, and the energy industry, was formed to find ways to address the impact on the state's infrastructure of increased energy development activities.
Utah	Asset management and maintenance system

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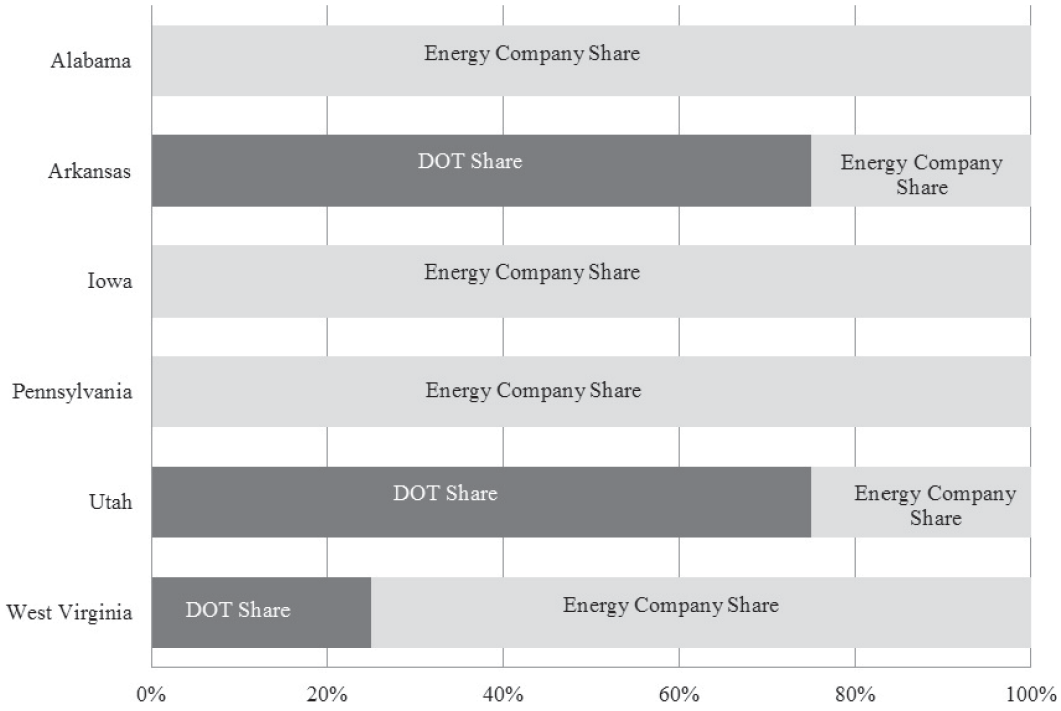

FIGURE 5 Level of cost sharing between DOTs and energy companies, as reported by the DOTs.

previously existing conditions, whereas two states currently specify no requirement. For the types of contracts, permits, or partnering agreements between energy developers and state/local agencies, various types were identified. For instance, Arkansas applies maintenance assessment and fee calculations. West Virginia uses more project-specific infrastructure improvement agreements. In Pennsylvania, there are maintenance, cooperative, and contribution agreements. Local agencies primarily use the Road Use Maintenance Agreement, whereas Pennsylvania DOT mainly uses the EMA and occasionally uses either the contribution or cooperative agreement for the partnering of repair work with heavy users. Additional information on contribution and cooperative agreements can be found in Chapter 15 of Pennsylvania DOT Publication 23. In Utah, a different agreement approach is applied to state and local facilities. The local agencies use energy developers for maintaining local roads and bridges, whereas Utah DOT takes full responsibility for state roads. In Iowa, agreements are usually between the counties and the energy developers and include a pre- and post-roadway assessment associated with each energy expansion project.

The New Jersey DOT has funded a research project to predict the impacts of freight loads on highway infrastructure. The purpose of the project is to provide information for the decision-making process in allocating the limited funds for the repair, maintenance, and rehabilitation of New Jersey's infrastructure network. The scope is to investigate the impacts of overweight loads on the pavements and bridges in New Jersey and to quantify the impact of overweight vehicles on structures or the roadway in terms of structural damage. Traffic data collected will be used to model and predict the life cycle of pavements and structures on New Jersey highways. Traffic data measured from WIM sites in the state will be used for analysis modeling of a variety of load scenarios on the pavement and bridge sections located at or near the WIM sites. The WIM sites provide monthly downloads of truck weights, some axle weights, and truck volumes. The damage will then be translated to cost over time, which will be used to influence the fee structure for overweight permits (currently set at $5.00 per ton for vehicles weighing more than 80,000 pounds). A deterioration modeling tool will then be integrated into a user interface that will enable New Jersey DOT to use the tool in decision-support and planning capacities. Findings from the study may also eventually influence the structure that New Jersey DOT uses to assign fines related to enforcement of overweight vehicles.

IMPACTS ON ROADWAY SAFETY AND OPERATIONS

Nineteen states reported an increase in conflicts with local traffic (e.g., school buses, regional transit, agricultural, and husbandry vehicles) by energy development heavy vehicles. Traffic conflicts with other modes (e.g., pedestrians, bicycles) were reported as safety-related issues, as were increases in the number of head-on collisions and run-off-the-road incidents. Both North Dakota and Texas DOT reported increases in both fatality crashes and rear-end collisions. The leading causes of these crashes, according to law enforcement in Texas, were the failure to control speed and driver inattention. Table 13 summarizes the effective measures reported

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TABLE 13
SAFETY STRATEGIES USED AND RATED EFFECTIVENESS

Measures Reported	States	
	Measure Rated as Very Effective	Measure Rated as Somewhat Effective
Reinforcement of roads (e.g., use of geotextiles, stabilization of aggregates or subgrade)	West Virginia	Iowa, Nebraska, Pennsylvania, Utah
Roadway geometric feature modifications (e.g., widening paved shoulder, horizontal curve re-alignment, etc.)	Arkansas, Colorado, Iowa, Kansas, Texas	Alabama, Montana, North Dakota, Pennsylvania, Utah
More frequent use of law enforcement (e.g., limit traffic, especially during periodic heavy rainfall)	Colorado	Arkansas, Montana, Pennsylvania, Texas, Utah
Encourage or require use of detours and alternate routing for heavy trucks	Colorado, Iowa, West Virginia	Minnesota, Nebraska, Pennsylvania, South Carolina, Utah
Install additional signage to warn motorists of heavy truck traffic volumes in the area	West Virginia	Alabama, Pennsylvania, Utah
Lower the posted speed limit		Colorado, Montana, Pennsylvania
Specific state or local legislation or regulations that apply to specific energy development industries (e.g., adequate public facilities ordinances, specific road and bridges design standards, etc.)	Colorado	Alabama, Pennsylvania
Temporary measures such as roadway embankments	Kansas	Pennsylvania
Campaigning and public outreach (e.g., ProgressZone in state of North Dakota)	North Dakota	Colorado, Pennsylvania, Texas, Utah
Use of intelligent transportation systems (e.g., advance warning systems)	Alabama, Colorado	Pennsylvania, Utah

to address identified safety issues. Two measures reported as very effective were roadway geometric feature modifications and the use of detours or alternate routing for heavy trucks.

The North Dakota and Texas DOTs indicated that the increase in crashes with incapacitating injuries and fatalities was attributable to the effects of energy development in the area.

Alabama, Utah, and West Virginia DOTs reported increases in the number of property-damage-only crashes. Montana DOT reported an increase in crashes characterized as possible injury and non-incapacitation injuries.

Twelve states noted that the congestion level on public roads with heavy truck volumes could be primarily attributed to roadway geometric issues. Congestion on adjacent roads and conflicts with infrastructure (vertical clearance issues) were reported as other noticeable congestion patterns. Even though congestion resulting from the increased truck traffic from energy development activities was observed in Montana and South Dakota, these DOTs reported that it is manageable under current roadway capacity. Table 14 describes and ranks the effective measures reported by DOTs to address observed congestion issues.

DEFINING THE CHALLENGES TO AGENCIES

Figure 6 introduces the challenges reported by DOTs and shows that land permits, leases, other load permits, maintenance, and accelerated degradation were the most highly ranked challenges. The tools used to assess and pay for the damages ranged from taxes and user fees to adequate public facilities laws and/or local ordinances and reimbursement mechanisms, as shown in Table 15. Some states that reported using other approaches include Colorado, Missouri, Nebraska, North Dakota, Pennsylvania, and Texas.

Seventeen of 19 states reported that they are responsible for repairing public roads in the vicinity of energy development, using state funds. Colorado, Iowa, Michigan, Ohio, Utah, and West Virginia DOTs reported that the energy developers lead the repair of public roads. In Pennsylvania, responsibility for repairs is determined by whether a roadway has been posted when it is a state-owned and -maintained roadway. Municipalities in Pennsylvania can pass ordinances to allow posting and bonding of roadways or can choose to use Roadway User Maintenance Agreements, under which the heavy hauler is responsible for repairs. In South Dakota, each jurisdiction is responsible for its own roads. The repair and maintenance of functionally classified

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TABLE 14
TRAFFIC OPERATIONS STRATEGIES USED TO ADDRESS OBSERVED CONGESTION ISSUES AND RATED EFFECTIVENESS

Measures	States	
	Measure Rated as Very Effective	Measure Rated as Somewhat Effective
Encourage use of detours or alternate routing for heavy trucks	Iowa	Pennsylvania, South Carolina
Install increased signage to warn motorists of heavy truck traffic volumes	Utah	Alabama, Pennsylvania, Texas
Use of intelligent transportation systems (e.g., advance warning system)	Utah	Alabama, Colorado, Pennsylvania
Collaborate with energy development companies to adjust the timing and logistics of truck movements (e.g., staged truck routing schedule)	Iowa, West Virginia	Colorado, Pennsylvania, South Carolina

roads is assigned to state and federal funds in Alabama, but local agencies are responsible for any other roadway repairs using state or local funds.

Colorado, Iowa, Minnesota, Pennsylvania, and Utah DOTs reported that the metropolitan planning organizations (MPOs) and/or regional planning organizations (RPOs) are engaged in the process of working with energy developers on managing the damage to public roads. In Colorado, the MPOs and RPOs are actively working to define roadways that are appropriate for energy development use. In Pennsylvania, the DOT avoids posting major traffic routes with weight restrictions and thereby works together with the MPOs and RPOs to program these roadways for repairs. The RPOs are responsible for long-range capacity planning in South Carolina, whereas the DOT is responsible for improving pavement and bridge conditions. In Alabama, the role of MPOs includes not only proposing and prioritizing roadway improvement projects, but also requesting funding if the energy development access needs align with the projects identified by the MPOs.

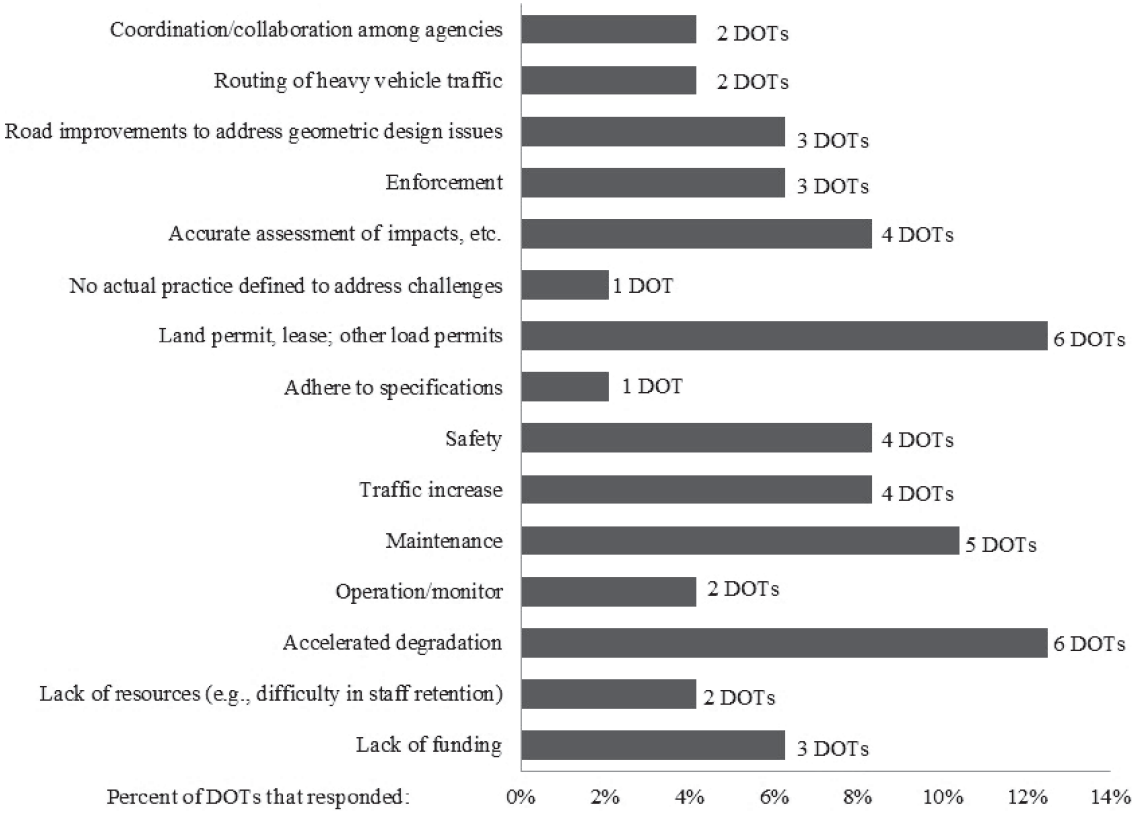

FIGURE 6 Identified challenges related to energy development activities.

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TABLE 15
TOOLS USED TO ADDRESS CHALLENGES AS REPORTED BY AGENCIES

State	Tools Reported to Address Challenges
Colorado	Local agencies are developing fees to address issues with infrastructure damage.
Missouri	An approach where the permit fee applied is commensurate with the number of permits issued to address funding issues.
Nebraska	Cost is being extracted from corresponding annual budget, as the amount is not significant.
North Dakota	State legislature has provided general fund money from the oil extraction fund to the DOT and local jurisdictions for road and bridge improvements.
Pennsylvania	Energy development sector is responsible for excess maintenance costs, inspection fees, and roadway condition survey costs.
Texas	A unique relationship between the current/future energy sectors and railroad commission has been developed. This unique collaboration enabled Texas DOT to plan for the increased impacts to highway, rail, and ports. Other identified practices from Texas DOT are development of standard lease agreement with an associated fee, as well as temporary use of water lines in state right-of-way to reduce roadway truck volumes.

There are 13 states that share data related to the impacts on public roadways with local agencies when energy development issues are identified. Local agencies communicate the most with energy developers (in 18 states), as does the DOT (in 15 states), or engineering consultants to the DOT or local agencies (in six states).

Alabama DOT noted that the location of an energy facility is the factor that designates who leads the communications with the energy company. For example, if an interaction is required with a federal agency involving an environmental or operational issue relating to the type of energy facility (e.g., nuclear power), Alabama DOT would take the lead. Fifteen DOTs reported that the use of state or local permits is the most common type of contractual agreement allowing public roads to be used by energy developers. State laws or local ordinances were also widely reported by many DOTs as a typical practice. For example, Appendix B (available at www.trb.org; search NCHRP Synthesis 469).contains an example from Iowa, the Delaware County Ordinance #32, which is a local ordinance that regulates the placement of wind energy conversion systems on property located in the unincorporated areas of Delaware County, Iowa.

Alabama and Ohio DOTs also use Memoranda of Agreement as a type of contractual agreement with energy developers.

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CHAPTER FOUR

CASE EXAMPLES OF STATE AND LOCAL PRACTICES

INTRODUCTION

The information in the following sections was taken primarily from detailed interviews with individuals from several organizations in five states. In addition, detailed information from the published literature and survey responses for each of the five states has been incorporated into this chapter.

The chapter is organized by (a) road system impacts that agencies have observed and are addressing and (b) effective practices that generally come in the form of (1) techniques for addressing engineering design challenges; (2) tools to assess costs; (3) use of contractual agreements; and (4) methods to mitigate for impacts on safety. These topic areas comprise the different subsections within each of the sections in this chapter. The findings are also summarized by state and topic area in Table D1 of Appendix D.

Because of the continually evolving nature of energy sector activities, technology, regulations, and implementation of research and strategies, the information in this chapter is such that it requires frequent updating.

Selection Criteria for Focus States

Colorado, Iowa, North Dakota, Pennsylvania, and Texas were the five states selected for more detailed investigation. There were a number of reasons these states were selected to be focus states. One reason is that they represent a geographic distribution that includes both cold and warm climates. The states of North Dakota, Pennsylvania, and Texas have all witnessed a significant growth in energy development, and their respective responses in the DOT survey indicated that significant impacts have been observed on their state and local highways and bridges. Although North Dakota, Pennsylvania, and Texas have experienced major oil, gas, and coal energy development, the state of Iowa was selected because of its major activities in the wind and biofuel energy sectors. In the west, Colorado represents a variety of energy development sectors, as well as significant state laws and organizational focus on revenue generation through severance taxes. The states of Pennsylvania and Iowa are both unique in that their use of contractual agreements has placed the responsibility for funding or making repairs to roadway infrastructure on the energy companies. North Dakota and Texas reported an increase in energy development truck–related crashes and fatalities associated with energy-related traffic and have developed methods to quantify the economic impacts of energy development.

Summary of Findings from Focus States

The interviewees from the five focus states consistently observed that, as a result of a shortage in state or local funds for maintaining and rehabilitating roadways used by the energy industry, the energy developers also sustain significant costs to maintain their vehicles that operate on the damaged roadways and also suffer increased haul times for the construction, development, and maintenance of their operations. The most frequently reported engineering approach employed by both DOTs and local agencies for addressing pavement damage is to (1) increase the lane widths (and add a paved shoulder); (2) increase the pavement thickness; and (3) stabilize the surface layers of unpaved roadways. There are examples of both local agencies and DOTs that have adjusted their pavement design standards or construction specifications to provide for conveyance of the heavy loads associated with energy development activities. A need for increased resources and funding was reported to address pavement and bridge deterioration and roadway improvements at intersections by adding turning lanes, seasonal posting of roads and bridges, strengthening of pavement structures, and the increase of turning radii at intersections.

PRACTICES USED TO ADDRESS ENERGY DEVELOPMENT IMPACTS IN COLORADO

Introduction

According to the Colorado DOT, energy development activities related to coal, natural gas, oil, wind, solar, and biofuels are impacting the state's roadways. The U.S. Energy Information Administration (2013) reported that Colorado's vast fossil fuel resources include the Niobrara shale, with resource estimates running as high as two billion barrels of oil. Between 2007 and 2012, crude oil production in Colorado rose 89% and marketed natural gas production rose 38%. In 2013, 64% of the electricity generated in Colorado came from coal, 20% from natural gas, and 17% from renewable energy resources. The greatest concentration of energy power plants and development activities are in the Denver area and in western Colorado.

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As a result of the significant amount of energy activity, the Colorado Oil and Gas Conservation Commission (COGCC) was established to foster the responsible development of Colorado's oil and gas natural resources and administer a regulatory program. Through the program, each county has a Local Governmental Designee (LGD) who is the recognized individual at that local government to receive copies of all state oil and gas permit applications. The LGD may make comments to the COGCC regarding any permit applications and serves as a liaison between the COGCC, the Colorado Oil and Gas Association (COGA), local government, the oil and gas industry, local oil and gas operators, and the public (Colorado Oil and Gas Conservation Commission 2014).

Road System Impacts

Energy development activities use all available roads, including those owned by the state, county, and other local jurisdictions. Colorado DOT has reported an increase in the amount of truck traffic impacting approximately 31% to 60% of roads, with most of the impacts concentrated on secondary roads. Colorado DOT has observed damage to both pavements and bridge structures as a result of the heavy loads and increased volume of truck traffic, both on the state and local road networks.

Colorado DOT

The Colorado DOT is initiating a more extensive study on oil and gas energy development impacts through its Planning Office.

Colorado DOT enforces OS/OW load permit requirements. The legal gross load limit on the secondary road system is 85,000 pounds. There are annual permits, including one that allows up to 200,000 pounds gross and 17 feet width, which require no reporting. In the absence of recorded violations, their impacts on the roads remain unknown. The number of permit requests has risen by 3% to 8% since 2009. Samples of two local agency OS/OW permits (Special Transport Permit and Weld County Access Permits) are presented in Appendix B. Colorado DOT reported observing incidences of overstressing under-capacity bridges because of the existence of heavy loads, but there is a lack of data that attribute this damage to the energy industry. Generally, Colorado DOT has not yet entered into any maintenance agreements with energy companies for the repairs and maintenance of state roads. An exception is a 10-mile section of State Highway 317 in northwest Colorado that has an agreement between Colorado DOT Region 3, Moffat County, and Shell Energy Company covering the repairs, restoration, and improvement of the road. The posting of bridges is done on a regular basis according to the load limits as outlined in the Colorado DOT bridge rating manual (Colorado DOT 1995) and bridge design manual (Colorado DOT 2012).

Routt County

Routt County reported that transportation related to the oil and gas industries has impacted its 900 miles of road (of which only 170 miles are paved). Routt County reported the addition of four new wells per year over the past few years, with five more projected in the near future. The county has seen the development of a total of 80 wells over the past 50 years. Routt County began energy development relatively recently, and it has instituted mitigation measures such as increasing the pavement thickness in preparation for energy development activities. Truck traffic volumes have increased, and movement of large pieces of equipment has been impacting roadway widths, intersections, and curve design elements. A structural analysis of geotechnical requirements was identified as a need, as was a permit from the Planning Department that would require mitigation efforts including improvements to the roadway structure based on traffic impacts. The permit request also addresses impacts on wildlife in the county. Because of the need for pavements as thick as 8 or 9 inches, and the restrictions on roadway width, the county is still analyzing the optimal way to increase pavement strength while using thinner pavement lifts, possibly by the use of geosynthetics.

The Colorado DOT is involved with Routt County in assessing access and turning movements at intersections with state roads because new movements are exceeding the thresholds at which acceleration/deceleration and turning lanes would be required. Many of the added lanes could be temporary; therefore, the locations where improvements are most needed will be determined. It was reported that the energy companies are expected to pay for these improvements, including any signage improvements associated with these operations. For instance, the county is blading (emulsion skimming) more frequently on gravel roads and maintaining signs that the energy companies have placed, although on a few occasions the energy company has been asked to repair a damaged road associated with its operations. The county pointed to the need for a long-term maintenance requirement; however, currently the county has no established method of counting the amount of traffic generated by the energy development industry.

The county conducts both pre- and post-inspections of road and bridge conditions, but reported that adequate staffing could become a constraint as the energy development expands. Exhibit 111 included in Appendix B (available at www.trb.org; search NCHRP Synthesis 469) outlines the permit requirements for oil and gas exploration in Routt County for energy development companies. Both the Routt County and Colorado DOT have OS/OW permit requirements, and the energy companies are required to mitigate for dust on unpaved roads through dust stabilization.

El Paso County

El Paso County reported implementing a process to provide limited regulations to address the impacts of energy

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development to county roads and bridges. Several companies have drilled by fracking, but to date damages have not been reported on impacted county roads because the energy companies have cooperated in maintaining gravel roads that will be involved when production commences. After operations cease, the county will require the roads to be returned to original conditions, but in some cases roadway improvements may be required if the original condition involved a road that was already planned for rehabilitation. Afterwards, any rehabilitated roads would be eliminated from the network of potential haul routes. Energy companies are required to provide a haul route plan to the county and to obtain a permit, which would include a maintenance agreement between the county and the company.

Load postings are used at present to warn motorists of the danger from trucks in the area. Daily inspections of roadways used by energy developers occur, depending on the activity and type of work permitted in the right-of-way (ROW). The county has a designated LGD for oil and gas and a page on the county website that contains the regulations and the specific El Paso County Oil and Gas permit form application.

La Plata County

La Plata County includes 220 miles of paved road and 440 miles of gravel or unpaved roads and witnessed oil industry growth and impact on roads in the 1990s and mid-2000s. Although the oil industry has departed for other areas of the country, the county reported pavement failures such as rutting, potholes, alligator cracking, and shoulder deterioration during the period when energy activities were under way. Initially, La Plata County performed the pavement repairs, but later memoranda agreements for maintenance were executed for the oil companies to perform maintenance. Samples of memoranda of agreements can be viewed at the links provided in Appendix C. A sample Colorado Special Transport Permit is included in Appendix B (available at www.trb.org; search NCHRP Synthesis 469).

La Plata County did lose one bridge to an overweight water truck. Bridge postings are primarily identified in its normal inspections. The county administers an OS/OW permit system and, until two years ago, used the state weight limit and design criterion of 85,000 pounds before increasing it to the current 110,000 pound limit.

Practices for Addressing Engineering Design Challenges

In the survey, Colorado DOT identified three challenges: increased maintenance needs on secondary roads; the lack of funds to repair poor roads and bridges; and systematic methods to determine impacts on roads. Additional challenges included routing/permitting, geometric improvements to the roads especially for turning radii at key intersections, and structural damage assessment of roads and bridges.

Colorado DOT

Pavement research is being done at Colorado DOT with the AASHTOWare Pavement ME Design® software to predict the expected pavement performance at the various loads and truck axle configurations on affected highways near energy development areas. Similar research has been conducted to analyze the pavement remaining service life by the eastern Federal Lands Highway Division of the Federal Highway Administration (Eastern Federal Lands Highway Division 2008).

At the county level, additional staffing for pre-and post-inspection of infrastructure conditions will be necessary if expanded energy development occurs, as well as a staffing expansion to address the increase in permitting activity.

Tools to Assess Costs and Contractual Agreements

The Colorado shale oil boom is increasing revenues for oil companies and counties in which the drilling takes place, but was reported to have mostly minimal benefit to the state on the whole. Although thousands of wells are being drilled, mainly in Weld County in the Niobrara shale formation, many tax payments are being reduced by tax credits, which equal up to $208 million a year (Lewandowski and Wobbekind 2013). The size and role of energy taxes vary across the western U.S., with Colorado having one of the lowest rates.

In contrast, some states have raised more and turned it into a statewide benefit. For example, the state of Wyoming collects about $1 billion a year and uses the money to fund highway and water projects and to provide grants to all cities and towns based on population. A portion goes to a trust fund, now valued at $6.2 billion, whose interest, dividends, and capital gains go to the Wyoming general fund. Montana is using oil and gas taxes for statewide property tax relief. However, in Colorado half of the state severance tax is distributed to the state Department of Natural Resources, while the other half is distributed to the counties impacted by oil and gas development. The severance tax also funds water and wildlife projects across the state, and contributes to covering the cost of state oversight of oil and gas and minerals. Colorado produced 49 million barrels of oil in 2012, worth an estimated $4.1 billion, and approximately 80% of the oil was derived from Weld County.

The Colorado Legislative Council study stated that the state tax on oil and gas in 2012 was $118.3 million, which represents a small portion of the $10.6 billion in overall state tax collections. The Colorado severance tax is a tax imposed on nonrenewable natural resources that are removed from the earth in Colorado. The tax is calculated based on the

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gross income from crude oil, natural gas, carbon dioxide, oil (including shale oil), and gas severed from the earth in Colorado (Colorado State Department of Revenue 2012).

A study by the University of Colorado in 2012 quantified the economic and fiscal contributions of Colorado's oil and gas industry in 2012 (Lewandowski and Wobbekind 2013). The oil and gas industry generated $29.6 billion output in Colorado's economy and directly contributed almost $1.6 billion to public revenue in 2012. Weld County receives the largest share of the severance money, as a result of receiving 60% of the drilling permits issued in the state in 2013.

The severance tax is Colorado's main levy on oil and gas and ranges from 3% to 5% of sales. However, energy producers absorb the bulk of local property taxes (referred to as the ad valorem tax) as a credit against the state tax.

The Colorado Department of Local Affairs provided grants through the Energy Impact Grant program. The funds were provided for the maintenance and improvements of impacts resulting from the development of oil and gas. In La Plata County, additional funding was made available through the board of county commissioners to address the impacts of energy development. Funds were obtained through the property taxes on revenues occurring from the production of oil and gas.

La Plata County

In La Plata County, approximately 100 oil and gas companies have created a coalition that coordinates closely with the county. The coalition, which has a manager, was reported to have a constructive relationship with the county for many years. When road damage was recorded by the county, discussions were initiated with the coalition and resulted in repairs being made to the roads or a cooperative approach being established to resolve the issue. Additionally, memoranda of understanding were developed to enhance communications. As part of this, former farm-to-market roads were assessed as to their potential to be used as haul roads to allow for programming improvements in capital improvement programs.

La Plata County reported a population growth that occurred adjacent to roads that were built on private land by oil and gas companies. Although the residents expected that these roads would be eventually incorporated into the county road system, the county passed a resolution that absolves it of the responsibility for maintaining these private roads.

Practices to Mitigate for Impacts on Safety

In Colorado, the State Patrol collects and monitors crash statistics. To date, the counties of Routt, La Plata, and El Paso have not observed any significant truck traffic crashes.

El Paso County

El Paso County reported concerns with the increase in frequency and volume of traffic and the resulting impact on degrading roadway surface conditions. Deteriorated surface conditions could become a safety issue by causing traffic to cross over into oncoming lanes of traffic. As a result, El Paso County has instituted both public service and other media announcements to warn the traveling public.

La Plata County

Although it reported observing higher ADT on narrow two-lane roads, La Plata County has not witnessed a significant increase in crashes. The county deployed regulatory warning signage and also expanded an aggressive dust stabilization program to help prevent the loss of gravel on unpaved roads.

PRACTICES USED TO ADDRESS ENERGY DEVELOPMENT IMPACTS IN IOWA

Introduction

In addition to its long-standing agriculture and husbandry industries, Iowa has had significant growth in the wind and biofuels industries, which have been impacting both state and local roads and bridges. According to the Energy Information Administration, energy development activities are distributed throughout the state of Iowa (Iowa DOT 2013).

Iowa leads the nation in percentage of total wind energy generation. According to the Iowa Wind Energy Association (2013), Iowa in 2013 produced approximately 27% of all the electricity generated in the state by means of wind turbines, a national record. Iowa has 3,198 utility scale wind turbines in operation, along with 100 wind projects producing electricity. Iowa landowners with wind turbines on their land have more than $16 million dollars annually in lease payments (Iowa Wind Energy Association 2014).

According to the U.S. Energy Information Administration (2013), Iowa is the largest producer of ethanol in the United States and in 2013, Iowa was ranked third nationally for the generation of net electricity from non-hydroelectric renewable energy resources.

The Center for Transportation Research and Education at Iowa State University reported that Iowa has become a leader in renewable energy, particularly biofuels (e.g., crop-based ethanol) and wind energy (2010). Large, heavy turbine components and machinery that are used to construct wind farms in Iowa must be transported along rural roads and bridges. The turbine components are continually increasing in size and weight, and the next generation of biofuels (e.g., cellulosic biofuels made from switchgrass and corn cobs) will increase the quantity of raw material being shipped on the

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roads. As a result, a need was reported for turning radii on local roads to be considered thoroughly, as the length of wind turbines increases.

The costs of renewable energies for Iowa's transportation system were reported to include both the costs for maintaining roads and the costs of enticing a company to build a biofuels plant or wind farm within a jurisdiction, paid for by both cities and counties.

The study also reported survey findings from 96 counties regarding the types of biofuels production plants or wind energy farms in place, under construction, or in the planning stage. Key findings of the study included:

- County-owned, paved roadways typically deteriorated within a couple years of the biofuels facility opening. Likewise, expenditures for pavement repairs and maintenance increased both during and after facility construction.
- For wind farms, the major damage occurred during construction activities and predominantly on gravel roads.
- Counties lacked adequate revenues to continue full maintenance on all roads and to address the reduced pavement life resulting from additional haul loads.
- The impact calculator estimates the number of truckloads and maintenance costs, but does not factor in the impacts of construction/plant maintenance traffic or safety-related costs (e.g., addition of turning lanes).
- County road maintenance expenditure data reporting is not standardized, which sometimes complicated the estimation process.

Road System Impacts

Much of Iowa's rural transportation infrastructure is near or beyond its original design life. It is estimated that the demand of total intercity freight by all modes will grow significantly from 19.3 billion tons to 37.2 billion tons in 2035, greatly impacting Iowa's transportation infrastructure. Trucks are the dominant transportation mode of corn to ethanol plants, traveling mostly on the secondary road system. Therefore, the increased traffic volume could deteriorate the infrastructure, as there has been a steady increase of vehicles and large truck traffic on secondary and local roadways.

Johnson County

Energy development activities use all available roads, including those owned by the state and counties or local jurisdictions. Johnson County, home of the University of Iowa, is the third most populated county in the state. Wind farm energy companies have purchased many properties for future development and, in preparation, the Johnson County engineer contacted other counties impacted by wind farm activities in order to benefit from any lessons learned. The County Commission has been proactive by passing predevelopment planning and zoning regulations to avert some impacts from energy development activities. The Resolution Approving Conditional Use Permit Fees for Wind Energy Facilities in Johnson County and Ordinance Amending the Johnson County Unified Development Ordinance to Permit Private Wind Generators as Accessory Uses and Distributed Wind Generators as Conditionally Permitted Uses outline the proactive county ordinances and regulations, and are shown in Appendix B (available at www.trb.org; search NCHRP Synthesis 469).

Story County

Story County roads have been impacted by the construction of wind farms since 2008. More than 100 turbines have been installed, with impacts primarily occurring during their installation owing to the large amounts of gravel deliveries for the concrete pads and side roads. In order to sustain operations, the county turned maintenance over to the energy company. Dust control was needed and ongoing during construction. As an example, the concrete pavement on a 4-mile stretch of road was damaged during installation of a wind farm and required ongoing maintenance to be executed by county forces. However, after completion of construction the energy company provided Story County with $500,000 for permanent pavement repairs to remedy the actual damage. The County Planning and Zoning staff had executed an agreement that includes a pre- and post-inspection, entitled the Story County Conditional Use Permit. A sample of a Planning and Zoning Conditional Use Permit is included in Appendix B and details the restrictions and requirements for wind farms as well as the compensation to be received by the county. The county did not experience damage to bridges except for some smaller timber structures, because the bridges had been posted with load limits, and the energy company had complied.

Additionally, Story County has had a corn ethanol plant in operation for more than eight years and another energy company has begun the construction of a major cellulosic ethanol plant in the nearby city of Nevada. The energy company indicated their emphasis will be on educating farmers within approximately 35 miles of their plant on how to most effectively gather, transport, and store the cornstalks to be used in the cellulosic production process because of all the issues with transporting and storing the bulky product (i.e., cellulosic ethanol from corn stover is fundamentally different than the corn-ethanol process in that the corn is easier to transport and store).

Delaware County

Delaware County also reported impacts, mostly on gravel roads, from the construction of wind farms over the past two years. The county conducted both pre- and post-inspections

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of roadways, and the energy company then reimbursed the county for resulting damages through the issuance of a building permit and an agreement. An ordinance was developed to require each wind farm site to have a permit, the ordinance regulating the placement of wind energy conversion on properties in unincorporated areas of Delaware County through the Maintenance Agreement for Elk Farm-Elk Wind Energy LLC Delaware County, Iowa, as well as the Delaware County One-Stop Permit, included in Appendix B. An example of a building permit (Commercial Wind Energy Conversion System Building Permit Application) for the Delaware County is also included in Appendix B (available at www.trb.org; search NCHRP Synthesis 469).

The city of Dyersville annexed a portion of the county where the ethanol plant was constructed to gain revenue through property taxes. The road adjacent to the ethanol facility is a county road that for a limited time was restricted to a 10-ton weight limit. However, Iowa counties can only embargo roads for 90 days; this is done typically during spring thaw periods. The county reported that historically the husbandry industry with manure hauling has had a greater impact on roads and bridges than the energy industry.

Iowa DOT

At the state level, Iowa DOT is involved with the routing of truck traffic onto roads known to have better-paved surfaces. The Iowa DOT recently implemented an automated truck OS/OW permitting system that considers and reviews all bridges and pavement conditions and restrictions associated with energy plant locations, to recommend preferred routes. The permit outlines which routes developers should use for transport; however, the industry's transport requirements are continuously evolving. Permits are tracked by payload on OS/OW vehicles, but not by a specific industry. The permitting system will have the capability of reporting by energy industry, with permits structured as a flat fee.

Practices for Addressing Engineering Design Challenges

Iowa DOT

Iowa DOT reported that the establishment of effective communications between state and local jurisdictions with the energy companies can create a constructive and collaborative environment, which enhances pre- and post-construction and operations. Some of the approaches reported by Iowa DOT to address engineering design challenges included (1) systematic routing of trucks combined with permitting, (2) geometric improvements to the roads (especially for turning radii), and (3) assessing the structural damage to roads and bridges. It was reported that additional staffing is needed at Iowa DOT to handle the large growth in providing permits, although the new automated permitting system is helping. However, once off the state highway system, trucks are required to have a county road permits. Iowa DOT has a goal of integrating local jurisdiction truck permitting into the automated state system, to allow for more effective routing of heavy trucks on roads that can handle the weight and volume of energy industry activities.

Although the Iowa DOT has identified geometric improvements for improving the turning radii at key intersections, the lack of adequate funding remains a challenge. The wind turbine blades are large and require a large radius. The need for additional rights-of-way presents further challenges. Although Iowa DOT is also exploring the use of intersection alterations such as roundabouts, these innovations do not address the issue of geometric restrictions resulting from the size requirements of vehicles moving equipment. The Iowa DOT has increased pavement structural capacity on its state roads to address the impacts of the ethanol industry, such as on US 20, a major route that has experienced an increase in grain-hauling traffic.

Gkritza et al. (2011) reported that county engineers in Iowa have adjusted pavement design standards to a higher level, at an additional cost, to provide for increased heavy loads associated with renewable energy. Counties offered financial concessions to biofuel companies such as cash, infrastructure matches, tax abatements, and funds to get biofuel plants to build within their jurisdictions. In addition, the counties used any available federal funds for economic development to pave needed routes and roadways.

Johnson County

Johnson County has about 900 miles of road network, of which 250 miles are paved. The maintenance budget is approximately $300,000 annually. In order to serve the agricultural and husbandry industries over the years, pre- and post-inspections of roads have been institutionalized as routine practice. At impacted locations such as intersections, the county has increased the concrete pavement thickness. An aggressive dust control program using calcium and magnesium chloride for stabilization has been incorporated for unpaved roads. During freeze/thaw periods, the county posts roads to a maximum of 8-ton loading.

Delaware County

Delaware County has increased pavement widths, pavement thickness, and shoulder stabilization to address impacts from the energy industry. Geosynthetics on county gravel roads and cement stabilization of subbases are among the practices being implemented. In the wind farm area, dust stabilization was necessary during construction and costs were reimbursed by the energy industry.

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Tools to Assess Costs and Contractual Agreements

Although there are not specific partnerships between the energy industry and Iowa DOT, the state does maintain communications with energy industries. The state does not have maintenance agreements with energy companies; however, these agreements exist at the county level. Although there is not currently any state-level funding to support energy industry development, the Rural Energy for America program offers grants for projects that support economic development and job creation and growth. In addition, counties are using Tax Increment Financing (TIF) to finance projects. The Iowa DOT is not collecting data on social or environmental impacts, but does track the increased tax base.

Many kinds of authorities levy property taxes in Iowa, including counties, cities, school districts, townships, community college districts, hospital districts, fire protection districts, and sanitary sewer districts. Each geographic area is subject to a unique set of taxing authorities that constitute a property tax district, and there are nearly 13,000 such districts in Iowa. A city or county can establish a TIF area to direct property tax revenue toward investments in one or multiple property tax districts in which they have jurisdiction. TIF is a practice in which municipalities can use anticipated increases in property tax revenues to finance infrastructure improvements for public purposes. Iowa state legislation permits cities and counties to designate TIF areas for the purposes of promoting economic development. For example, Story County established a TIF for wind farms (although the funds are not exclusively for use on infrastructure repairs, pavement improvements, and road improvements). Approximately $30 million over 20 years will be generated.

Once a TIF area is established, subsequent increases in property value in the area are designated as the increment. Property tax revenues associated with the value of the increment, including those taxes levied by all contributing jurisdictions such as school districts, are diverted to the city or county that established the TIF. The purpose of the TIF is to enable the city or county to incur debt in order to fund local infrastructure improvements. These improvements are expected to then spur economic development that results in increases in property value over the base year. Such increases are intended to increase the tax base of all overlapping jurisdictions once the TIF expires, while the debt is paid off over time using the taxes diverted to the TIF. In Iowa, TIFs may be financed through issuance of general obligation bonds, whereby a municipality pledges its full faith and credit to repayment. The use of TIF in Iowa has expanded markedly in the last decade, and the number of TIF urban renewal areas increased by 43% (Girardi 2013). The amount of taxable value in TIF increments has more than doubled during the same period, accounting for nearly $300 million in property tax revenues in fiscal year 2014 and 5.9% of total property tax revenues in Iowa.

Property Tax Assessed Value

Wind turbine property can be assessed at a maximum of 30% of the total acquisition and construction cost. A tax abatement period of six years allows 5% of the assessed value to be added to the county tax rolls each year. The increase in assessed value after the abatement period passes for turbines currently operating in Iowa is estimated at $2.6 billion.

Practices to Mitigate for Impacts on Safety

Iowa Department of Transportation

The Iowa DOT reported that they have not witnessed any significant increase in crashes and fatalities associated with the growth of the energy industry activities. The Iowa DOT safety office, several counties, and the Iowa State University Center for Transportation Research and Education have confirmed that the energy industry (especially wind and biofuels), along with the long-standing agricultural and husbandry industries, have not generated a significant increase in safety crash statistics.

The Iowa DOT district offices proactively review proposed facilities along with local jurisdictions and attempt to provide appropriate improvements in intersections to handle large blade and turbine/energy cell deliveries and the use of signage enhancements. Each Iowa DOT district includes the Safety, Engineering Design, and Bridge offices in planning improvements. However, the OS/OW equipment and the increase in volume of activity have necessitated resources to address several factors: pavement and bridge deterioration and road improvements at intersections; the addition of left- and right-hand turn lanes; strengthening of pavements and bridges; seasonal bridge and road postings; and improvements to intersections to increase turning radii. The Avenue of the Saints Corridor, which runs through 13 counties in Iowa, was recently upgraded to a four-lane corridor from a two-lane road and added capacity that is generating many positive benefits for the state (Iowa Department of Transportation 2013).

PRACTICES USED TO ADDRESS ENERGY DEVELOPMENT IMPACTS IN NORTH DAKOTA

Introduction

The state of North Dakota has experienced an unprecedented and exponential growth in energy development over the past several years in the coal, oil, natural gas, biofuels, and wind sectors. The western portion of North Dakota is sustaining energy industry expansion and economic prosperity because of ongoing development of shale oil formations in the Bakken and Three Forks formations, which geographically cover half of the entire state. As a result, many roads that were once used only for local access and agricultural purposes are now being exposed to high truck traffic volumes serving the

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energy sector. A presentation by Tolliver (2014) reported that the development also has had a significant impact on infrastructure, estimated at $340 million of additional road and bridge investments over the next 20 years. The North Dakota Pipeline Authority (2013) reported that the vast majority of oil is currently being transported by truck. The annual oil production in fall 2013 was reported to be 930,000 barrels/day with a projection of nearly 1.5 million barrels/day in the next 30 years. The projected Bakken/Three Forks development was estimated to be 1,100 to 2,700 wells per year with 40,000 to 70,000 wells in the next 30 years. Truck traffic movements associated with a Bakken well include about 2,300 loaded and empty trucks carrying fresh and waste water, fracking tanks, sand, and scoria/gravel (Tolliver 2014). Other truck movements include rigging and drilling equipment as well as transporting mud, cement, and pipes (Tolliver 2014).

Despite the county governments and municipalities in North Dakota having received revenues from severance and sales taxes, the demand for repair of roads, bridges, and staff costs (i.e., hiring more employees to handle issues related to energy development impacts) was reported to significantly exceed the amount of funding these local agencies are generating (Raimi and Newell 2014).

Road System Impacts

North Dakota DOT reported that all available roads are being used by energy developers, including roads owned by the state, county, other local jurisdictions, and tribal roads. Oil-related traffic patterns are dynamic and vary spatially and temporally. Different modes may be used more or less intensively in different stages of energy development. Rural collectors and the local road system are heavily impacted, with road infrastructure frequently inadequate to handle the increased truck traffic. These roads require substantial initial and ongoing investment (Tolliver 2014).

Upper Great Plains Transportation Institute

Although the North Dakota DOT is heavily involved with the planning and programming of improvements to state and local roads, the state legislature has taken the lead in the oversight and funding of impact studies from the energy development using the Upper Great Plains Transportation Institute (UGPTI) at North Dakota State University. An interview conducted with the UGPTI staff indicated that these studies have included detailed forecasts of traffic to and from individual spacing units; annual truck traffic estimates over 20 years; models calibrated with observed traffic data for a base year; estimated truck ADT converted to ESALs for pavement analysis; and annual paved road condition forecasts. The UGPTI conducts these studies and will provide an update for the North Dakota State and Local Road Needs spanning 2013 to 2015. A large-scale investment state highway program is estimated at $2.5 billion over two years, and approximately $930 million is identified for county and township roads. Other critical needs were identified, such as enforcement resources, safety in the presence of heavy vehicles, grade crossing safety, two-lane roadway capacity, and hazardous and emergency response.

An article by Oldham (2012) stated that one road in Mountrail County, North Dakota, was originally designed to carry 10 tractor-trailers a day. Recently, county officials counted 800 trucks, most of which were related to the oil drilling in the Bakken shale formation, within a 24-hour period. The Bakken Formation runs from Canada through North Dakota and Montana. Oil companies pay a combined 11.5% in annual taxes on oil extraction and production, supplying state coffers with $2.6 billion since 2008. North Dakota sends roughly 30% of the oil tax receipts back to energy-producing counties and cities. Significant sinkholes have developed on heavily traveled energy transport routes. The county needs an estimated $600 million to rebuild and pave the 1,600-mile system.

Practices for Addressing Engineering Design Challenges

Agencies in North Dakota have been incorporating various strategies to address engineering challenges with reconstruction, widening and resurfacing, unpaved roads analysis based on increased frequencies of blading and graveling and increased gravel costs, and higher routine maintenance for both paved and unpaved roads. Adjustments have been made on an experimental basis to traditional pavement designs by county engineers in an attempt to armor roads that are experiencing heavy truck traffic.

Ward County

As an example, Ward County has used cement-treated subbases, surface treatments from 12 to 16 inches thick on major collectors, and geosynthetic materials such as geogrids. Although Ward County is not a major oil-producing county, a significant volume of through-traffic has been present on county roads, because of the gravel support from suppliers in the City of Minot area and wind farm development. A particular challenge was reported to occur during the traditional freeze and thaw periods annually between March and June.

Upper Great Plains Transportation Institute

The UGPTI reported in an interview that it will research the feasibility of an energy collection road system, aimed at alleviating congestion and improving safety. Part of the study is to track the truck distributions and to develop prediction models for their trip distributions in the future, to better predict the impacts to infrastructure and to better assign appropriate truck routes. The study will focus on defining the artery of

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the county's major collector systems network in the four major oil-producing counties of Williams, Dunn, McKenzie and Mountrail, and then maximize access to the oil development fields by means of parallel, periodically spaced paved roads. The study aims to then identify the roads that are to be reconstructed first and to suggest these roads be designed to standards such that they would be able to accommodate 105,500-pound vehicles during the entire year The idea is to start with an optimally planned roadway infrastructure system and assign the most resources to that first. Subsequently, the majority of the heavy trucks would be channeled onto these reconstructed roads in order to minimize impacts on other roads.

The UGPTI also analyzed state highway construction data and reported that the difference in the cost of pavement overlay repairs is estimated to be approximately 30% of total reconstruction costs.

Tools to Assess Costs and Contractual Agreements

In North Dakota, the state legislature imposes oil and gas gross production tax and an oil extraction tax in lieu of property taxes on oil and gas producing properties. A brief description of the various financing techniques used in North Dakota is presented in Table 16 and comes from the Office of State Tax Commissioner: State of North Dakota (2014).

Practices to Mitigate for Impacts on Safety

In fall 2013, the UGPTI issued a briefing that indicated that western North Dakota continues to experience an economic boom resulting from energy industry expansion (UGPTI 2013). The report found that traffic safety issues are resulting on roads that were once used only for local access and agricultural purposes and are now experiencing high truck volumes to serve the expanding oil sector. Approximately half of the counties, within a 17-county area affiliated with oil production, are above the state average for crash risk considering all crash types on rural roads. The details on the North Dakota Traffic Safety: Oil Counties document are presented in Appendix B. In addition, the estimated cost of all crashes in the region more than doubled between 2008 and 2012. During this period, the total crashes and fatalities have increased from 2,959 crashes, 651 injuries, and 38 fatalities to 5,535 crashes, 1,287 injuries, and 83 fatalities. The total estimated cost has risen from $125.9 million to

TABLE 16
TYPE OF FINANCING AND OPERATING AGREEMENTS USED IN NORTH DAKOTA

Type of Financing and Operating Agreement	Description
Oil Gross Production Tax	A 5% rate is applied to the gross value at the well of any oil that is produced, except on royalty interest on oil produced from a state, federal, or municipal holding and/or from an American Indian holding within the boundary of a reservation.
Gas Gross Production Tax	The tax on gas is an annually adjusted flat rate per million cubic feet of all nonexempt gas produced in North Dakota. The annual adjustments are made according to the average producer price index for gas fuels.
Oil Extraction Tax	The oil extraction tax is levied on the extraction of oil from the earth. The gross value of oil production at the well is taxed at 6.5%, except for any parts that are specified as being exempt.
Coal Conversion Facilities	The coal conversion facilities privilege tax is imposed on electrical generating plants that have at least one generating unit with a capacity of 10,000 kilowatts or more. The tax is also levied on other coal conversion facilities that consume 500,000 tons or more of coal per year and on coal beneficiation plants. The tax is applied in lieu of property taxes on the plant itself, but the land upon which the coal plant is located would still be subjected to the property tax.
Coal Severance Tax	The coal severance tax is imposed on all coal severed for sale or industrial purposes. Some exceptions to the tax include coal used for heating buildings in the state, coal used by the state or any political subdivision of the state, and coal used in agricultural processing and sugar beet refining plants in the state or in adjacent states. The tax is applied in lieu of sales and use taxes on coal production and in lieu of property taxes on minerals in the earth. The coal is taxed at a flat rate of 37.5 cents per ton and an additional 2 cents per ton tax is levied for the Lignite Research Fund in North Dakota. A 50% reduction in the 37.5 cent tax is permitted for coal burned in a cogeneration facility designed to use renewable resources in order to generate 10% or more of its energy output. Counties may grant a partial or complete exemption from the 70% portion (attributable to the counties) of the 37.5 cent tax for coal that is shipped out of state.
Tribal/State Oil and Gas Tax Revenue Sharing Agreement	Beginning in fiscal year 2009, the North Dakota state legislature authorized the Governor to enter into an agreement that shared tax revenue from oil and gas production within the Fort Berthold Indian Reservation. This agreement resulted in $183.6 million in revenue to the Mandan, Hidatsa, and Arikara tribes between 2011 and 2013.
Legacy Fund	The constitution in North Dakota requires that 30% of all oil and gas tax revenues are deposited into the state's Legacy Fund for the future. The Legacy Fund received $1.271 billion between 2011 and 2013.

Source: Office of State Tax Commissioner, State of North Dakota (2014).

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$257 million. Severe injury truck crashes in the oil region increased by more than 1,200% between 2008 and 2012, whereas the remainder of the state experienced a 147% increase over the same period.

Rural road crashes involving large trucks in the oil counties has also risen between 2008 and 2012, representing about one-third of all crashes in the region in 2012 as shown in Figure 7.

The marked increase in traffic and crashes that result in serious injuries and fatalities prompted a group of safety stakeholders including the North Dakota Department of Transportation, the North Dakota Petroleum Council, the North Dakota Highway Patrol, and other groups to encourage roadway safety through the development of a public awareness campaign. The campaign is entitled ProgressZone, and since 2011 has been reminding motorists in the oil-producing part of the state to be patient and exercise caution with five core messages (North Dakota Petroleum Council 2012).

PRACTICES USED TO ADDRESS ENERGY DEVELOPMENT IMPACTS IN PENNSYLVANIA

Introduction

The energy sector in Pennsylvania has grown exponentially in the past several years in the extraction of natural gas. For example, 20% of the total Marcellus shale wells drilled in Pennsylvania are found in Lycoming County and in 2012, the county led the state in number of wells drilled for that year. The municipal and state roads in the region were never designed to carry the level of truck loading, exacerbated by the dynamic loading from water trucks that transport water to and from the well sites, associated with natural gas well development and operations. As a result, the Pennsylvania Department of Transportation (Pennsylvania DOT) and municipalities are reporting pavement deterioration in the form of rutting, cracking (both alligator and longitudinal), poor ride quality, base failures, and potholes.

The locations of Marcellus shale deposits and gas wells in Pennsylvania run through state parks and forests and federal lands, such as the Allegheny National Forest, and a number of maps can be viewed on the Penn State Marcellus Center for Outreach and Research website (2010).

The Duke University *Shale Public Finance* report (Raimi and Newell 2014) discussed that a large portion of the state's impact fee for unconventional natural gas well drilling is directed to the municipalities and counties impacted by the energy development activities. The report also cited that roadway repair costs were relatively minor for townships owing to the road maintenance agreements they have in place with energy companies.

Road System Impacts

Energy developers in Pennsylvania use available roads including the interstate and those owned by the state and municipalities. A report by Scheetz et al. (2013) investigated the condition of seven bridges exposed to increased heavy truck traffic and found the presence of deterioration in the wearing surfaces, decks, and parapets. The report also concluded that pavement rutting significantly increased with an associated increase in energy activity and was the most common form of deterioration encountered. This damage was noted to be especially pronounced on secondary and municipal roads because of the increase in heavy truck traffic.

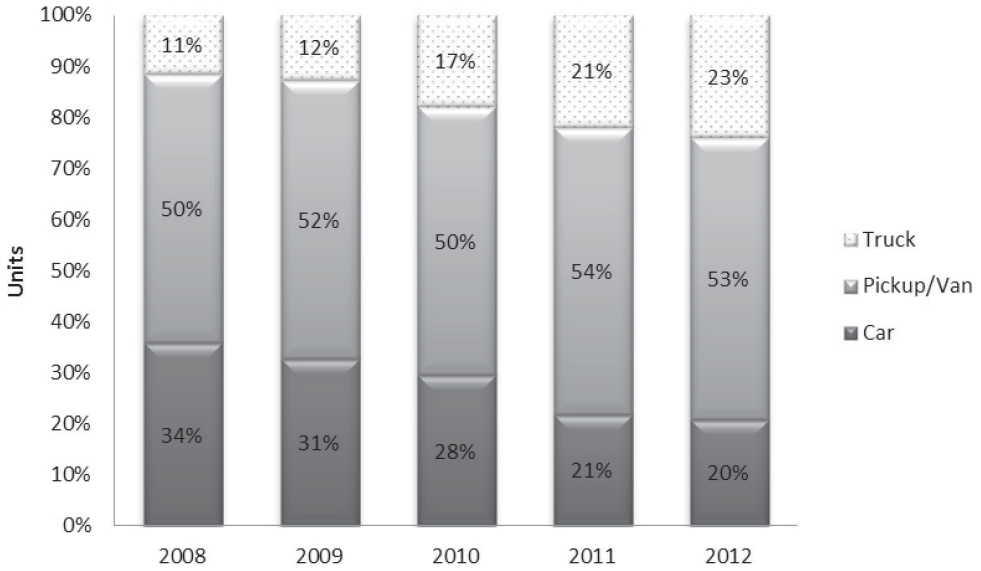

FIGURE 7 Oil county crashes in North Dakota organized by vehicle type (*Source*: UGPTI 2013).

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Lycoming County

An interview with staff in Lycoming County indicated that the municipalities own approximately two-third of the roadways and 200 of the 700 bridges and have varying levels of abilities to deal with the impacts of energy development on their infrastructure. In order to address this issue, the Pennsylvania LTAP offered a posting and bonding course to educate local agencies on how to legally enforce weight limits and to collect costs from energy developers for the infrastructure damages. Pennsylvania DOT can post its roadways with a weight restriction and then for the user to haul on the roadway, it must obtain a permit which requires an EMA (including a maintenance plan and security). Municipalities can pass ordinances in order to allow posting and bonding of roadways or can choose to use Roadway User Maintenance Agreements.

Bradford County

Information from interviews indicated that in Towanda in Bradford County, there was more damage observed on 20-feet wide roads as opposed to 22-feet wide roads, as a result of the width of truck axles and where their wheel paths lined up in the lane. The 22-feet wide roads included roadway embankments, some paved shoulders, drainage infrastructure, and culverts. The county did report that residents did report congestion resulting from the number of trucks present on the main roads and intersections because of the sizeable growth in population.

Pennsylvania DOT

At the state level, it was reported that one major issue is the impact to interstates and other National Highway System routes that are not posted and bonded which are also experiencing an increase in truck traffic. The state is limited in terms of methods for collecting funding from energy developers to address repairs or reconstruction of these roadways, which are the most expensive to rebuild. For example, an ongoing project on US 15, a route heavily used by the natural gas energy sector, is projected to cost $20 million to reconstruct the concrete pavements after only a 20-year service life.

For roadways posted with weight restrictions, the Pennsylvania DOT issues road use permits and occasionally must suspend, and possibly revoke, the permits when the repairs (necessitated by the excess maintenance they have caused) are not made on the roadways. One energy company in Cameron County had a permit issued for moving its drilling trucks and other equipment over a state route and it was revoked because the company failed to deal with severe damage of the roadway in a timely manner (Pennsylvania Department of Transportation 2010). Under the terms of the energy company's EMA, it must proactively monitor pavement conditions and immediately begin repairs as needed to keep the road safe. The permits are generally restored once the company makes the roadway repairs necessary and after the road is inspected and approved by Pennsylvania DOT.

Practices for Addressing Engineering Design Challenges

Pennsylvania DOT

The Pennsylvania DOT reported that partnering with the Marcellus Shale Coalition is a practice that it considers being greatly effective. The Pennsylvania DOT and the Marcellus Shale Coalition have been meeting every one to two months since 2010 and share perspectives on issues related to energy development and Pennsylvania DOT's policies and infrastructure, ideas for addressing problems, and evaluation of the ideas and solutions proposed. The consistent communication between both parties has helped to resolve many issues. The information from the meetings is shared with the Pennsylvania State Association of Township Supervisors (PSATS) through the Pennsylvania DOT Municipal Services Manager. In addition, the Pennsylvania DOT Bureau of Municipal Services has staff that is dedicated to ensuring local agencies are using safe practices and the appropriate standards on roadways impacted by energy development activities.

For state roadways posted with weight restrictions, the Pennsylvania DOT establishes the initial condition of the posted roads through pre-hauling inspections (which generally include photos and videos) and also regularly monitors roadway conditions and safety through routine roadway condition surveys which are not typically video recorded.

As part of the EMA used for posted roads, the energy companies are responsible for inspecting the roads that they use and have built, reconstructed, or repaired. An interview with an engineering consultant to one of the energy companies operating in Bradford County reported that in order to prioritize roadways for the energy company to repair, the consultants conducted monthly visual inspections and photographic documentation of the roadways using a three-tiered pavement distress condition rating system. The Pennsylvania DOT surveys the roadways as quality verification and invoices the user for the cost incurred. The roadway condition surveys are performed on a routine basis by the Pennsylvania DOT District and a 2014 average cost of $10.83 per mile is assigned.

Another practice which has been reported as effective by Pennsylvania DOT for the repair of low-volume roadways is the use of full depth reclamation (FDR) of pavements, a process in which an emulsified asphalt or Portland cement was used to strengthen the existing roadway structure after it has been pulverized. This mode of repair resulted from a study funded by Pennsylvania DOT that specifically sought to develop standards, specifications, and a standard practice for use in FDR projects (Morian et al. 2012). The study collected information from two separate FDR projects (one using chemical stabilization and another using emulsion stabilization)

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to develop a best practices manual for Pennsylvania DOT. The conclusions of the study resulted in the development of a process for identifying future FDR candidate projects and in establishment of criteria to choose which method is best suitable, including general mixture design suggestions for use in future projects. As a result of this report, Pennsylvania DOT is currently in the process of implementing a FDR specification for Pennsylvania DOT Publication 408 Construction Specifications in order to ensure consistent quality for its use on low-volume roads impacted by energy development activities, as well as all state-owned roadways within the Commonwealth. Some energy companies reported use of cement-soil stabilization with an asphalt overlay to be more economical as compared with Pennsylvania DOT standards. The pavement repair process consisted of excavating down 12 to 15 inches to crush any existing aggregate and to rototill. Another 12 to 15 inches of aggregate was then mixed with cement and water, placed, and compacted with a drum roller. Finally, a 4.5-inch asphalt overlay was constructed and covered by another 1.5 inches of an asphalt wearing course.

Lycoming County

The interview with Lycoming County reported that in many cases, the energy companies are building and repairing the roadways beyond the minimum requirements in the Pennsylvania DOT design standards in order to prevent the need for continual maintenance. For example, many locally owned roadways in the county have been upgraded and paved by the energy companies to limit the amount of required maintenance and to eliminate environmental impacts such as dust control.

Additionally, Lycoming County was reported to be unique in that it is routinely inspecting locally owned bridges with spans that are shorter than 20 feet. The county began inspecting bridges and culverts of all sizes coincidental with the initiation of energy development locally and found that approximately 35% of bridges were structurally deficient. The Pennsylvania ACT 89 Legislation is a funding mechanism used by municipalities in the county to address the backlog of structurally deficient bridges since the energy companies generally are not repairing bridges. The Pennsylvania DOT Posted and Bonded Roads program is referred to and included as an example document in Appendix B (available at www.trb.org; search NCHRP Synthesis 469). One unique practice observed in Lycoming County was the use of jumper bridges. Some energy companies built new temporary bridge decks over existing older bridges in order to bypass the permitting process. Although this was not observed to be a widespread practice, the energy companies were able to dismantle the jumper bridges after drilling was complete and post-inspection by the county found that the roadways underneath were relatively undamaged.

Pennsylvania Department of Environmental Protection

The Pennsylvania Department of Environmental Protection has developed guidelines for the spreading of brine on unpaved roads to control dust. These guidelines can be found under the authority of Clean Streams Law, the Solid Waste Management Act, and Chapters 78 and 101 of the Rules and Regulations (Pennsylvania Department of Environmental Protection 2013). Another source of guidance is the *Environmentally Sensitive Road Maintenance Practices for Dirt and Gravel Roads* manual (Bloser et al. 2012) that addresses reducing the runoff and sediment pollution to nearby vegetation and forests from low-volume transportation corridors, such as rural roads and trails. The practices in the manual are also designed to reduce the long term maintenance costs on the roads.

Southwest Pennsylvania Commission

The Southwest Pennsylvania Commission is the regional planning agency that serves the Pittsburgh ten-county area. In the SPC's 2040 Transportation and Development Plan, a discussion exists on shale development that addresses items such as regional conditions, the number of permits issued, and the influence on local economy and the roadway and railway transportation system (Southern Pennsylvania Commission 2011). The Northern Tier Regional Planning and Development Commission has produced a Marcellus shale freight transportation study that contains both a quantitative analysis of truck traffic impact and also a qualitative analysis of routes most likely to be impacted. The projections show a peak traffic year of 2022, in which there will be double the existing quantity of daily truck traffic; however, the trips are not assigned to specific roadways to assess VMT, pavement damage, and other indicators.

Tools to Assess Costs and Contractual Agreements

The Commonwealth of Pennsylvania has various means to assess costs through three types of agreements: maintenance; cooperative; and, contribution. The municipalities generally use the Road Use Maintenance Agreement. The Pennsylvania DOT uses the EMA and occasionally uses either the contribution or cooperative agreement for the partnering of repair work. It is also unique in its use of maintenance agreements between the energy development companies and the Pennsylvania DOT.

Posting and Bonding Ordinances

In Pennsylvania, the regulations related to any posted and bonded roads in Chapter 189 of the 67 Pa. Code apply to haulers from most industries including energy development (Commonwealth of Pennsylvania 2012). Additionally, Pennsylvania DOT's Statement of Policy for Letters of Local Determination (Commonwealth of Pennsylvania

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2012) applies to at-risk (distressed) industries and small local haulers (Commonwealth of Pennsylvania 2012). The regulations are managed through the Pennsylvania DOT maintenance manual (Publication 23), as presented in Chapter 15 (Pennsylvania Department of Transportation 2013). Out of the 40,000 miles of state-maintained roadways, almost 30% (11,300) miles are posted with a weight restriction. Typically around 5,000 miles of these roadways are bonded, of which approximately 2,400 miles of roadways are bonded by unconventional oil and gas energy developers. The Chapter 189 regulations apply to municipalities; however, the Chapter 190 Letters of Local Determination do not. The Pennsylvania DOT provides helpful information, forms, and geographic information systems (GIS) mapping of posted roads and bridges on its website, which are listed in Appendix C. Also, a sample of the Pennsylvania DOT's New Bridge Posting Memorandum is presented in Appendix B.

Legislation on Financing

Pennsylvania DOT and local agencies in Pennsylvania have been partnering with energy development companies and have reported this practice to be effective in minimizing the amount of roadway damage induced by heavy trucks. Posting the roadway with weight restrictions, as well as entering into agreements with energy development companies for the roadway maintenance, are used. In addition, the Pennsylvania DOT reported that the ACT 89 Legislation, that states the utilization of user fees to establish a funding source for transportation needs and assists in addressing the backlog of roads and bridges needing repairs.

As part of the comprehensive Pennsylvania ACT 13 legislation passed in 2012, an impact fee on energy companies was levied based on the level of drilling activity (PA ACT 13 2012). The fees collected are deposited to the Pennsylvania Utility Commission and then distributed to municipalities and Commonwealth of Pennsylvania programs. As an example, Lycoming County and their 52 local municipalities collectively received approximately $25 million from PA ACT 13.

Maintenance Agreements

The interviews with Pennsylvania DOT explained that in Pennsylvania, an excess maintenance agreement, security bond, and permit are all required from an energy development company in order to ensure that it repairs damages caused to infrastructure. The excess maintenance agreement requires the energy development company to restore and maintain the condition of the roads and bridges used for transportation that support energy development activities to its pre-hauling activity condition or better. Some energy developers choose to upgrade the roadway prior to beginning their hauling operations.

Energy development companies are required to annually submit a roadway maintenance plan to inform Pennsylvania DOT of how they will repair damages when they occur and who will be contacted in order to evaluate and complete the work. The process for submission and review of the maintenance plan is illustrated in Figure 8 and is presented in Form M4902-MP in Appendix B (available at www.trb.org; search NCHRP Synthesis 469).

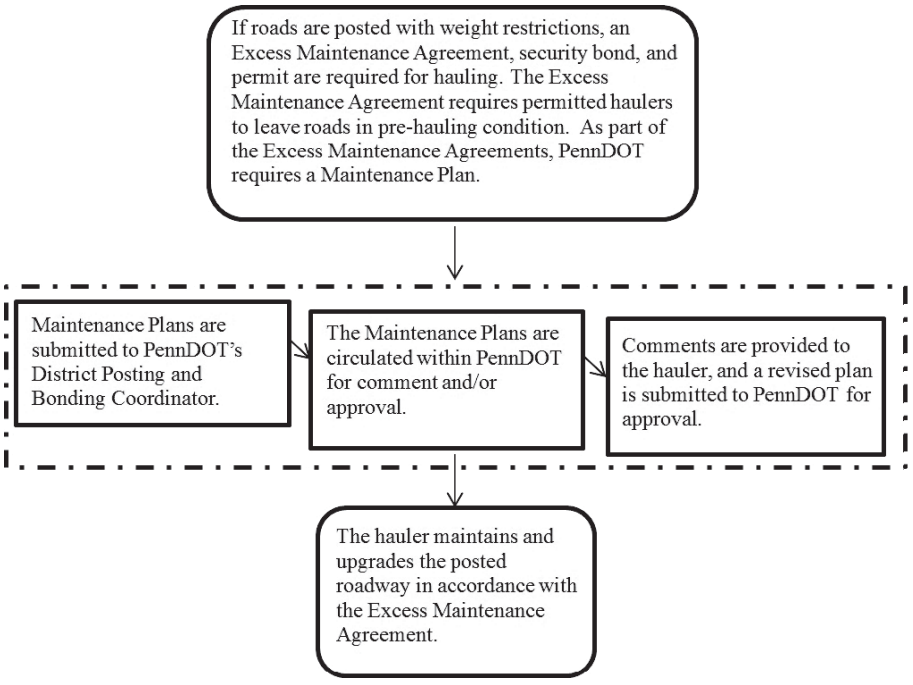

FIGURE 8 Steps in the process for maintaining roads bonded by unconventional energy industries in Pennsylvania.

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The Pennsylvania DOT Publication 23 Chapter 15 provides information on the contents of a Maintenance Plan. Because of the freeze/thaw seasonal limitations on many roads and bridges between February and April, the excess maintenance agreements and maintenance plans must show the materials that will be used for repairs of roads during the thaw period, when the repairs will be made, by whom the repairs will be made, the notification plan for communicating the need for repairs to Pennsylvania DOT and the action plan for addressing any roadway damage. In addition, any trucks that hauled on the weight-restricted roads were required to have documentation and authorization (i.e., a permit issued after the maintenance agreement was official) that they were hauling for the energy companies.

Practices to Mitigate for Impacts on Safety

In Pennsylvania, it was reported that the counties generally do not record accident data. In the Scheetz et al. report (2013), the findings related to safety showed that the enhanced heavy truck traffic has a weak correlation to increased severity of traffic accidents. The report went on to conclude that limited data and a lack of a good baseline for comparison were the reason behind the limited strength of associated observations. In addition, the Marcellus Shale Coalition has a safety subcommittee that hosts an annual Safety Day conference. Pennsylvania DOT also remarked that the use of training has been effective for improving safety in impacted regions.

Lycoming County

Lycoming County reported that its observation in recent years was that the number of accidents increased slightly because of the significant increase in truck traffic. It was also reported that some energy developers have been observed to not respect the established speed limits, even when there are obvious challenges created by either insufficient roadway geometry or by inclement weather conditions. In order to address this safety issue, Lycoming County created a natural gas task force partnership with the local chamber of commerce and other community representatives that are impacted by energy development activities, in order to offer information and suggestions to the energy companies operating inside the county.

PRACTICES USED TO ADDRESS ENERGY DEVELOPMENT IMPACTS IN TEXAS

Introduction

The energy sector in Texas is a significant contributor to the state and national economy with approximately one-half of the oil and gas drilling rigs in the United States located in Texas. In the last decade, an annual average of approximately 12,000 new or reworked wells are being drilled. According to a study by Fry et al. (2013), the energy sector is a crucial and integral part in the economy of Texas as it provides a large number of jobs in a number of different industries (exploration, drilling, production operations, material production, equipment manufacturing, technology development dealing with the energy industry). Between 2000 and 2012, there were approximately 16,650 drilling permits issued annually corresponding to an average of 13,413 wells drilled annually during the same 12-year period.

Recently, Texas has experienced a boom in energy related activities as a result of the extraction of oil and natural gas as well as wind power generation (Boardman et al. 2012). Many short and long term impacts of the state's transportation infrastructure are not properly documented as a result of this boom in energy related activities. The U.S. Energy Information Administration (2013) reported that the majority of energy activity is taking place in eastern Texas with some concentrated developments also in west Texas and along the northern border with Oklahoma.

The majority of counties in Texas that have experience with energy development within their jurisdictions must fund roadway repairs that essentially equal the amount of new revenue gained from property taxes (Raimi and Newell 2014). For the most part, the municipalities have been capable of maintaining the condition of their roads with revenues from sales taxes depending on the size of the municipal roadway network. However, both counties and municipalities in Texas have had to address the costs of hiring more staff to deal with issues related to energy development.

Road System Impacts

The numerous damaging impacts to infrastructure in Texas have been documented in a number of studies that were discussed in chapter two. In Texas, the impacts of heavy machinery used in energy production are observed not only on the lower volume roadway networks but also onto the interstate highways in Texas. In a report by the Texas DOT, trucks weighing in excess of 80,000 pounds were reported to already be impacting farm-to-market roads in areas such as the Eagle Ford Shale region and the effects are extending to major highways (Texas Department of Transportation 2013). Overweight permitted trucks and conventional trucks carrying loads such as water and sand used for hydraulic fracturing utilize rural, state maintained roads that were not designed for those loading scenarios. There are projects currently underway and planned for the future to address, repair, and rehabilitate the major freeways that are being impacted.

In 2013, there were 709,123 OS/OW permits issued by the Texas Department of Motor Vehicles (up from 527,453 permits in 2009) which represented a significant increase. Likewise, the number of investigations into illegal and unpermitted loads has increased between 2012 and 2013.

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Texas DOT

Interviews with Texas DOT indicated that the majority of pavement damage has occurred through premature fatigue cracking failures and problems with the unpaved shoulders. One example provided was the Texas state route SR-72, where four to six inches of asphalt pavement deteriorated excessively (due mostly to fatigue cracking and pumping of fines) and required major rehabilitation within six to eight months. Texas DOT is funding research to determine how wide the pavement cross section should be and whether using 2- to 4-foot shoulders would be an effective practice to reduce shoulder damage in the continual presence of 11-foot wide trucks. There are no shoulders on some of the impacted farm-to-market roads and Texas DOT is considering whether to eventually widen these roads to 28 feet.

A report from Quiroga et al. (2012) estimated that the heavy traffic associated with energy development in Texas is incurring approximately $1 billion dollars in roadway repairs annually to rural roads managed by Texas DOT and another $1 billion dollars annually to locally owned roadways. These estimates do not include cost estimates of any additional related damage to state or U.S. arterials and freeways. The report also projected that vehicle operating costs are expected to increase by between $0.5 and $1.5 billion dollars annually for energy companies and that haul times are expected to increase the cost of well development and service an additional $1 to $2 billion annually.

One interview indicated that a significant challenge for practitioners and researchers in Texas is to determine with a certain level of accuracy how heavy the truck loads really are. The traffic load data from the Railroad Commission, Department of Public Safety, and the Texas DOT WIM stations has been collected. However, in the case of the WIM data, the majority of the traffic data was measured on interstates or major routes in Texas as opposed to the rural roadways which are most often damaged first.

The significant impacts to bridges by heavy trucks that support energy development activities have been frequently documented in recent years in Texas. One of the Texas DOT districts interviewed stated that even if trucks hauling in heavy equipment are able to find a path that does not use or cross over a bridge, the workers and other vehicles associated with energy activities will use a route that is the shortest, and in most cases, will cross bridges. The bridges are being damaged by the increased volume in heavy trucks as in the case of the pavements and as a result, there is a lot of superstructure damage being observed, especially on timber bridges.

Tarrant County

In Tarrant County, which contains an urbanized road network within its jurisdiction and is nearby Fort Worth, they have not done any permitting and rely on Texas DOT for the permitting of OS/OW trucks. A few of the county bridges have deteriorated over time and the county observed during their biannual inspections that the heavy trucks affiliated with energy development have accelerated the bridge deterioration process. In terms of roadway impacts, the county has not experienced any catastrophic types of damage as a result of energy development in the area and thus, it does not have a system in place to prioritize roadway work and perform maintenance on an as-needed basis.

Practices for Addressing Engineering Design Challenges

The interviews indicated that the Texas DOT District Maintenance offices are responsible for the design and repairs of impacted roadways on the state highway network that service the energy sector.

Texas DOT

Pavements A two-part Texas A&M University Transportation Institute study is currently under way that will last approximately three years and is funded by the Texas DOT Maintenance Division. The first part of the study is concerned with establishing and evaluating which practices are currently used by the Texas DOT Maintenance personnel considering both routine (e.g., patching, shoulders, etc.) and non-routine (e.g., strengthening roadways, chip seals, new base layer materials, etc.) maintenance and reconstruction activities. The second part of the study focuses on aspects of pavement design (including the cross-sectional width, layer thickness, and shoulder materials and widths) for the impacted farm-to-market roads. Expanding the cross-sectional width would be beneficial to these roadways because their current narrow footprint is not able to handle the size and loadings of the trucks serving the energy industries. The Texas DOT intends to widen pavements a certain amount along horizontal curves and to design for enhanced drainage on the vertical curves. As part of the study, the performance of repairs and rehabilitation strategies will be tracked to use in the development of a decision tree that will tie together pavement performance and life-cycle cost.

In terms of the pavement strategies, the agencies in Texas normally add gravel on top of a base layer and then two additional courses on top for farm-to-market roads. The two-course surface treatment (or application of seal coats) has been used both in southern and western Texas in the vicinity of the energy fields. Through interviews it was stated that in some areas, the asphalt or concrete pavements have been reconstructed to gravel in order to reduce the long-term maintenance costs for local agencies.

Recently, the use of stabilizers has been done for unbound layers on roadways impacted by energy development activi-

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ties. The applications include the addition of portland cement concrete or lime (for areas in southern Texas where there is mostly clay subgrade soil) and asphalt emulsions. Stabilization of the base layer has been done by taking the existing base material and adding 2% to 3% cement, which is then overlaid by new gravel or the two-course chip seal surface treatments. The use of a cement-treated base was reported as being effective; however, the application method and layer thickness are not yet standardized. Other places have used cold in place recycled pavement or FDR, both of which are more environmentally friendly maintenance strategies.

Training workshops conducted by Texas DOT technical specialists and Texas A&M University are planned for every three to six months with Texas DOT maintenance personnel both in the southern and western Texas districts impacted by energy development. The workshops and associated meetings will be focused on roadway improvement techniques and to discuss topics such as subgrade performance, pavement stabilization methods, etc.

Recently, the Texas A&M Transportation Institute was funded by the Texas DOT to measure the economic, operational, and safety impacts of increased levels of energy-related activities on infrastructure within the state highway network ROW and to develop recommendations for mitigating and managing risks to infrastructure. One engineering tool developed is a geodatabase that consists of existing and anticipated energy developments (Boardman et al. 2012). Part of the research project was to develop a methodology to assess the cost impacts of energy development based on the predicted reduction in pavement life and average trends in construction and maintenance expenditures. Research was conducted on pavements near energy development areas in three Texas DOT districts (Abilene, Fort Worth, and Lubbock) using field testing equipment, the FWD and a ground penetrating radar device. The results from the field tests were compared with two different pavement life models [MODULUS (Liu and Scullion 2001) and OTRA (Fernando and Oh 2004)] in order to estimate the remaining life of pavements on roads impacted by energy developers. The researchers concluded that the extra trucks and weights associated with energy development have significantly shortened the life of pavements on roads in those areas. Figure 9 illustrates the impact of the research conducted by Boardman et al. (2012) and indicates that the majority of pavements have a remaining service life of two years or less.

Bridges The Texas DOT reported that of the $250 to $260 million a year it receives for funding infrastructure projects, approximately 25% of this amount is directed to off-system bridges. As a result, the 5.8% of bridges which were structurally deficient in 2000 has now been reduced to less than 2% of structurally deficient bridges in 2014.

If a bridge is unable to withstand the state's legal load limit (20,000 pound single axle, 34,000 pound tandem axle, and 80,000 pounds gross vehicle weight), then it will be posted. If equipment going to or coming from the oil fields is overweight, the energy companies can request a permit to run OS/OW; however, they would not be permitted to cross a posted bridge, including bridges off of the Texas DOT network (approximately one-third of all of the 53,000 bridges in Texas).

Because the issue of trucks being over height has been more prevalent in Texas [e.g., in Odessa (near the Permian Basin) 37 DOT bridges were impacted with over height issues within one year], one practice was to launch a publicity campaign, providing both pamphlets at truck stops, broadcasting by radio, and printing billboards in both English and Spanish to remind drivers about overpass height restrictions. Other practices used to address the issue of over height trucks include signing all bridges under 18 feet height on the Texas DOT system and accelerating the raising

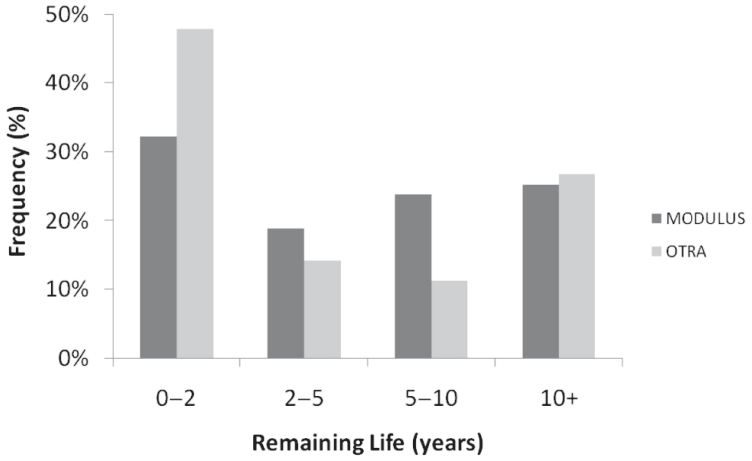

FIGURE 9 Analysis of remaining service life of pavement near energy development areas in Texas (*Source*: Boardman et al. 2012).

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of bridges (by six to 12 months) in the Texas DOT's work program in order to accommodate energy activities in the Eagle Ford shale region.

The engineering standards for bridges depends mostly on the origination of funds; that is, if Texas DOT funds a bridge repair or reconstruction project then the Texas DOT standards are used and its website includes all of the design standards and plans.

Tarrant County

In Tarrant County, many of the locally owned roadways do not have shoulders and therefore the pavement edges have been deteriorated quickly by the heavy truck traffic. In areas that were most problematic, the county addressed these impacts by widening the roadways with a stabilized base and an asphalt surface or with a two-course asphalt surface.

Gonzalez County

It was reported in an interview that an issue in Gonzalez County in which a bridge collapsed was a result of a truck driver finding (and using) an alternate route that had a shorter haul distance. As a result, the truck drove over a bridge that was posted and the overloaded bridge collapsed. Another bridge approximately two miles away was also destroyed in a similar manner, whereas a third bridge which was already scheduled for rehabilitation was collapsed by a heavy truck before the Texas DOT was able to start construction to repair the bridge.

In order to address these findings, some counties and energy companies came in to reinforce bridges on these routes, but without conducting a full set of engineering analysis to strengthen the bridge. In some cases, timber bridges have been replaced by concrete culverts and, for shorter simple span bridges, energy companies have placed a jump bridge, defined by Texas DOT as essentially a sizable steel box that is laid across and over the bridge that prevents any damage structurally to the bridge itself. When energy companies are finished working in the area, they generally will remove the jump bridge and take it to the next location in which they will be impacting bridges.

Tools to Assess Costs and Contractual Agreements

In recent years, the state of Texas has established various means to assess costs through permitting, along with legislation related to the financing of activities for handling impacts resulting from energy development. Some counties in Texas have reported in interviews that they used both informal and formal maintenance agreements with the energy development companies.

An August 2013, the Texas DOT commissioned a study to explore several partnership approaches between energy companies, county officials, and other organizations (Miller and Sassin 2014). It cited that in Texas the cost of energy development impact on the farm-to-market system is an additional $890 million of maintenance needs annually. The approaches included a proactive performance-based approach which strengthens pavements and armor roads prior to energy development; a reactive performance-based approach which assesses impact fees associated with road maintenance after the damage; a stand-alone impact fee not attached to actual deterioration; and, a final approach which considers policy changes to the Texas Transportation Code, which allows counties to promote transportation infrastructure projects affected by energy production.

Posting and Bonding Ordinances

In Texas, the state and local agencies have adopted reactive, proactive, and legislative approaches to revisit roadway maintenance methods and frequency, as well as providing different levels of rehabilitation dependent upon the level of damage sustained. In addition, Texas Department of Motor Vehicles has developed standard permitting operations for OS/OW vehicles and lowered the maximum load limits on roads and bridges for restricted access by large energy-related loads.

Legislation on Financing

The Texas Legislature has established innovative methods of developing and financing transportation projects. One such tool used by local entities to advance transportation projects is a transportation reinvestment zone (Texas Department of Transportation 2014). The local governing body designates a zone in which it will promote a transportation project. Once the zone is created, a base year is established and the incremental increase in property tax revenue collected inside the zone is used to finance a project in the zone. For example, Tarrant County has applied for funding in this program and a proposed fee system is being developed to tie excessive road degradation to vehicles causing the damage which are directly involved in the energy extraction industry (Fry et al. 2013).

The mechanism for charging fees is proposed to be based on actual vehicle weight with variations, such as different axle configurations and other factors that would influence the distribution of the loads. The proposed weight-distance fee system includes a few key elements. For example, fees are applied to all commercial vehicles with a destination within counties comprising an energy zone; however, the fees are not for application to any travel outside of these counties or through these counties. The Texas Department of Motor Vehicles Division of Commercial Vehicle Enforcement would be responsible for managing the fee system using the same

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administrative systems already established for the permitting of OS/OW vehicles. In this way, truck owners would be given the option of applying for a travel permit (for a certain period of time for a destination within an energy zone) directly through the Division of Commercial Vehicle Enforcement or to use a certified in-vehicle device through in-vehicle telematics service providers (a third-party service who collect reporting information and payments for Texas DOT) as their method of reporting mileage to pay the fee. Fry et al. (2013) also suggested that in order to account for the truck weight, Texas DOT could consider mandating the use of technologies that differentiate the truck from the load being hauled and subsequently charge a fee to each entity of the truck (i.e., the truck itself and the load) separately.

The state legislature's bill SB 1747 is expected to allocate additional funds specifically to infrastructure (State of Texas 2013). Texas DOT is funded through the state legislation, of which there is currently $225 million for road and bridge infrastructure impacted by energy development, and $150 million has been allocated to a major design-build contract in south Texas. During the November 2014 election, an amendment will be voted on that would obligate the $1 to $1.3 billion to Texas DOT which has been held in the Rainy Day Fund (intended for a period of economic challenges) to be used to help repair the impacted roadways.

A copy of the Texas DOT County Transportation Infrastructure Fund Grant Agreement is presented in Appendix B (available at www.trb.org; search NCHRP Synthesis 469). This grant program was created by the 83rd Legislature in Senate Bill 1747 and is solicits counties to apply for eligible grant awards for all eligible applicant counties. Eligible counties for transportation infrastructure projects are those located in areas of Texas that are impacted by increased oil and gas production.

Maintenance Agreements

Thus far, the state of Texas does not have any agreements with energy companies; however, there are a number of counties that do have agreements for the rebuilding of roadways to prior conditions before the energy activities existed. For example, in the past Tarrant County would present the energy companies with evidence of damages resulting from the heavy trucks and then partner with the companies (i.e., the county performed the road maintenance and then invoiced the energy company for the effort and materials) on a project-by-project basis.

LaSalle County

Texas DOT announced a resolution to manage the maintenance of roads heavily used in the energy sector of LaSalle County, Texas (Texas Department of Transportation 2013). The county and Texas DOT agreed to share responsibly in repairing roads in need and to maintain the roads over time. The relationship between the Texas DOT and county is as follows; the county is responsible for the purchasing of all materials necessary to address road issues while Texas DOT performs the repairs and provides the labor needed to complete the projects. It is then the responsibility of the county to maintain the roads for five years or until energy activity in the area decreases.

Tarrant County

Tarrant County is unique because it is a metropolitan county in the Fort Worth area and therefore it has a good funding base from taxes for their roadways, which are considered to be in good condition. There are 350 road miles in the county which serves the Barnett Shale energy development fields surrounding Fort Worth. Tarrant County reported that it will receive $2.5 million (out of the total $225 million) from the state fund that is generated by taxing the energy companies.

Practices to Mitigate for Impacts on Safety

A number of reports were found in the literature review that pointed to the safety problems and proposed solutions for roadways impacted by energy development in Texas. A summary of these includes:

- Texas Transportation Commission awarded a $150 million contract for much needed road work resulting from the states oil and gas boom. This money came from the $225 million that the legislature passed through the house bill 1025 for energy sector road improvements. The bill 1025 permits for the Texas DOT to begin repairing and rehabilitating roadways damaged by heavy trucks and increased traffic in the region.
- In 2012, reported crashes rose by 6% and fatalities rose by 13% in Texas's five energy areas of Eagle Ford Shale, Permian Basin, Barnett Shale, Granite Wash, and Haynesville/Bossier.
- A $150 million design–build contract has been let by Texas DOT and will address safety concerns by widening damaged roadways to better accommodate the increasing levels and volumes of heavy vehicles and by improving mobility.
- In September 2013, $75 million was awarded for repairs in Amarillo, Corpus Christi, Lubbock, Odessa, and San Angelo districts as a result of the state of Texas identifying more than $400 million in immediate roadway safety needs for severe damage caused by the increased traffic associated with oil and gas industries.
- In addition to the $400 million for immediate safety issues, an additional $1 billion per year is needed to restore roadways that have been heavily impacted by energy developments to "good" or "better" conditions.

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Texas DOT

From the interviews, it was reported that on state highways where there are increasing traffic volumes on narrow (20 to 24 feet wide) bridges, heavy trucks have been observed to impact each other (by smacking mirrors) as they pass. In some instances on other roadways this is causing an increase in accidents in general (including fatalities) and particularly in the number of run-off-the-road incidents. In many cases, the bridges were already programmed for repairs before the accidents occurred.

The Yoakum region (Texas DOT District 13) of Texas is not far from San Antonio and includes mostly rural areas with nearly 4,000 bridges. In this area, there have been multiple bridge collapses and accidents related to the width and height of bridges. It was reported that a large number of narrow one-lane bridges exist that require drivers to wait until a truck or vehicle is completely crossed in order to advance and cross over the bridge. It was noted that communities are now calling in complaints about trucks on narrow bridges and as a result, the Texas DOT has increased signage on narrow bridges.

Tarrant County

In Tarrant County, there have been very few safety issues and the county law enforcement monitors truck speeds which may prove effective for reducing the incidences of speeding.

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CHAPTER FIVE

CONCLUSIONS AND KNOWLEDGE GAPS

INTRODUCTION

Information from both published literature and the responses provided by 40 state departments of transportation (DOTs) and the District of Columbia DOT provided valuable insight into how the impacts of energy development transportation activities are affecting roadway and bridge infrastructure. Detailed interviews were conducted with DOTs, local agencies, and other organizations in five states. The information obtained in the interview sessions was used to acquire a more precise idea of the concerns and effective practices for managing the impacts of energy development on transportation infrastructure, safety, and operations across the five focus states.

CONCLUSIONS

Based on the work carried out in this synthesis, the following conclusions can be made:

- The literature review, survey responses, and interviews all indicated a strong correlation between the increase in negative impacts on road safety and road and bridge deterioration in and around the areas in which energy development activities are under way.
- The most frequently reported engineering approach employed by both DOTs and local agencies for addressing pavement damage is to increase the lane widths (and adding a paved shoulder), increasing pavement thickness, and stabilization of unpaved roadway surface layers.
- Some tools reported to address damage created by energy development included (1) the stabilization of unpaved roads; (2) use of full depth reclamation of existing pavements; (3) addition of paved shoulders; (4) use of superstructure temporary "jumper" bridges; and (5) placement of geosynthetics for strengthening gravel or dirt roads. The use of geosynthetic materials in low volume roads was reported to be particularly effective for enhancing the lives of unpaved roadway surfaces and for reducing issues with constructability.
- Most often the compensation to state and local agencies for damage to roads and bridges includes a variety of mechanisms, such as: development impact fees based on the magnitude of the development or a user fee based on measured damage to specific roads; use of donation agreements with energy developers; use of energy-related permit fees; application of severance, property, production, and/or sales taxes; use of lease revenues; and, implementation of maintenance agreements.
- Thirty-two DOTs (78%) reported that their state experienced a sustained and/or expanded level of energy development activities in recent years with 32 DOTs reporting that activity impacting either state and/or local roads. Of those, 27 DOTs indicated they observed an increase in the amount of truck traffic volumes and heavy loads as a result of the energy development activities.
- Secondary roadways that include minor arterials, collectors/distributors, and local roads were reported as most impacted by the truck traffic resulting from energy development activities. Ten states noted a significant impact level for local roads, whereas seven states reported a significant level also for minor arterials or collectors/distributors. Approximately twice as many DOTs rated the impact on minor arterials and local roads at a moderate level and the interstates or freeways were reported to be the types of roads that were least impacted.
- Most of the states that reported an increase in damage or congestion on roads and bridges near energy development activities also noted an increase in the issuance of oversize and/or overweight (OS/OW) permits.
- Most DOTs that reported observing damage on roads because of energy development activities indicated that they are addressing the repairs of these public roads with a combination of state and local funding. Only six DOTs reported that they have established agreements with energy companies to pay for the repairs on the public roads that they use. Another example of a funding model is that of the United States Forest Service, which requires energy developers to purchase Road Use Permits. This process regulates access to forest roads by the developers, provides flexibility to modify permits for specific situations, and requires energy companies to improve and maintain the condition of existing forest roads to standard before and during use for energy development activities. Fifteen of the 41 DOTs reported that the use of state or local permits is the most common type of contractual agreement that allows public roads to be used by energy developers. State laws or local ordinances were also widely reported by many DOTs as a typical practice.
- The truck traffic percentage was identified as the most widely applied factor for use in a cost formula by six states. Five states reported using the vehicle miles

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traveled. Some states reported use of the number of OS/OW vehicle permits issued and increased frequency in roadway or bridge maintenance to serve as the basis for a cost formula.
- The specific portion of damage that is attributable to heavy vehicles used for energy development activities was reported as difficult to quantify in rural areas, although some DOTs such as Arkansas, New Jersey, North Dakota, and Texas have sponsored detailed research to define this factor.
- The most common quantification of damage reported in the literature or through the interviews was by calculation of a remaining service life for pavements (or structural analysis for bridges). The reduction in service life for pavements was reported in some cases to be up to 30% for those state highways involved in the study. There are plans in some states to use the remaining service life as a parameter to which a DOT can assign a user fee structure for roads used by energy development.
- Roadway bridges are being impacted because of trucks that are taller than the vertical clearances of some bridges resulting in a number of expensive repairs and closures. Other safety concerns are related to the thousands of bridges that do not have adequate width to safely accommodate drilling rigs and other oversized loads combined with increased volumes of truck traffic.
- In Iowa, both the state and local jurisdictions have separate OS/OW vehicle permitting systems. The Iowa DOT OS/OW permitting requirements are now being used successfully in monitoring and scheduling the volume of truck traffic resulting from energy development particularly since the system's automation. This study found that other impacted state DOTs may want to explore the combinations of state and local permitting into one automated system.
- Interstates, state highways, county state-aid highways, and county (secondary) roads are all utilized to transport wind turbine and other energy sector components on pavements which were not designed to withstand these heavy loads. Many state DOTs and local jurisdictions do not have an accurate predictor for pavement life nor an accurate means of estimating damage on secondary roads. One effective tool reported is the Minnesota DOT's Heavy Traffic Generator tool that allows the users to estimate the damage that may be caused on pavements on local roadways during the heavy construction traffic associated with wind turbine developments. The tool also allows for the estimation of costs to repair and/or reconstruct any impacted roadways.

SUGGESTED FUTURE RESEARCH

The following section outlines some knowledge gaps that stemmed from the DOT survey and agency interviews. The responses indicated a need for future research in the areas of safety, environmental, and social impacts associated with energy development on state and local roads and bridges. Of particular interest will be the holistic and international view on the allocation of resources and how the increasing need for addressing the impacts of energy development in the future will affect the amount of funding available to support other highway programs.

Based on the work carried out in this synthesis, the following future activities are suggested for research in order to address the many gaps in knowledge that were identified as part of this study:

- In detailed interviews with local government jurisdictions in Colorado, Iowa, North Dakota, Pennsylvania, and Texas, it was reported that there is little quantitative information being collected (or statistical analyses being conducted) on the specific economic and social impacts resulting from energy development activities. The state DOTs observed that the primary impacts are typically noted on roadways off of the state highway system (i.e., secondary roads), which they view as the responsibility of local jurisdictions. It appears that this is an area of opportunity for future data collection and could consider the existence of adequate staff resources and available electronic databases.
- The findings of this study indicated that there is a general lack of information on safety and crash statistics, particularly on low volume roads, that have resulted as a result of energy development activities. Methods for the efficient and comprehensive collection of this critical information are an area for future research.
- Many state DOTs and local jurisdictions do not have an accurate predictor for pavement life nor an accurate means of estimating damage on secondary roads. There is a need for research on the prediction of road and bridge service life reductions as a result of the impacts in increased heavy truck traffic.
- Investigation into detour routing is an area of opportunity for states and local agencies. It was reported that the length of detour routes are not considered in the context of the decision-making process used for route selection by the operators of heavy trucks. The intended benefits of avoiding at-risk bridges or deteriorated pavements may be offset by the negative impacts of increased congestion or reduced safety when the length of detour routes are too long, indirectly encouraging trucks to seek out shorter haul distances.
- It was reported to be of interest to transportation agencies to review the contribution levels to funding repairs and upholding of maintenance agreements in terms of the size of the energy companies. Although many large companies were reported to be contributing a share of the funding that are commensurate to the repairs required for roads and bridges, it is currently unknown whether the same level of cooperation can be accomplished with smaller independent energy companies that are or will be doing development.

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- In order to gain a more complete picture of energy development impacts on state and local roadway infrastructure, input is required from several divisions within the DOTs as well as from other state agencies that manage economic development, public safety, motor vehicle registration, etc. Because of the organizational structure of the DOTs and of some state governments, the flow of information within the organizations can be restricted and cross-organizational communications sometimes inhibited. The findings suggest that future research might include reviewing the ability of DOTs to adapt to programs which will involve multiple divisions and agencies be explored, such as the successes witnessed in the implementation of the improved Local Public Agency programs for contract administration of federal-aid projects.
- The ability of local agencies to collect and analyze traffic, economic, and social data and information on the impacts of energy development activities is severely limited by the lack of adequate resources and templates of proven measurement tools. Future research could explore the identification and/or development of generic tools to assist LPAs in collecting and analyzing this information.
- The focus for the impacts of energy development activities has been on secondary roads in primarily rural locations. One need identified by the DOTs interviewed was to quantify the extent of damage induced on more high-type roadways such as freeways, interstates, and major arterials. This is particularly of interest in areas near any port facilities or modal shift locations.
- The focus of this study was on the domestic impacts of energy development activities on roadway networks in the United States. However, there are many other countries (such as Canada, Australia, and China, to name a few) internationally that have been experiencing rapid changes and/or expansion in energy development. One suggestion is to research to what extent the energy development activities have impacted the roadway infrastructure, traffic, and safety in these nations and how the impacts have been addressed.

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GLOSSARY

ADT	Average daily traffic
ADTT	Average daily truck traffic
ANF	Allegheny National Forest
ARAN	Auto Road Analyzer
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
CMAQ	Congestion Mitigation and Air Quality
COGA	Colorado Oil and Gas Association
COGCC	Colorado Oil and Gas Conservation Commission
DEP	Department of Environmental Protection
DOT	Department of Transportation (state highway agency)
EMA	Excess Maintenance Agreement
EPA	U.S. Environmental Protection Agency
ESAL	Equivalent single axle load
FDR	Full depth reclamation of flexible pavements
FLH	Federal Lands Highway
FLHP	Federal Lands Highway Program
FLMA	Federal Land Management Agencies
FWD	Falling weight deflectometer
Geocell	A three-dimensional structure filled with soil, thereby forming a mattress for increased stability when used with loose or compressible soils.
Geogrid	Any geosynthetic material used to reinforce soils and similar materials. Geogrids are commonly used to reinforce subbases or subgrades below roads or structures.
Geonet	A netlike polymeric material formed from intersecting ribs integrally joined at the junctions used for drainage with foundation, soil, rock, earth, or any other geotechnical-related material.
Geosynthetic	The generic classification of all synthetic materials used in geotechnical engineering applications; it includes geotextiles, geocells, geogrids, geomembranes, and geocomposites.
GIS	Geographic information systems
GMUG	Grand Mesa Uncompahgre and Gunnison
GPR	Ground penetrating radar
GRS	Geosynthetic-reinforced soil
HACP	Hot asphalt concrete pavement
LGD	Local Government Designee
LPA	Local public agency (borough, city, county, town, township, village, etc.)
LTAP	Local Technical Assistance Program
MAP-21	Moving Ahead for Progress in the 21st Century
MHA	Mandan, Hidatsa, and Arikara Tribes
MPC	Mississippi Power Company
MPO	Metropolitan planning organization
NBIS	National Bridge Inspection Standards
NDHP	North Dakota Highway Patrol
NFS	National Forest Service
OS/OW	Oversize and Overweight Vehicles
PDO	Property damage only
RMA	Roadway maintenance agreement
ROW	Right-of-way
RPO	Regional planning office
RUMA	Road upgrade maintenance agreements

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RUP	Road User Permits
SOL	Strike-off Letter
Spacing units	A legally described boundary designated by a governmental agency as a common source of supply of oil and gas, done for purposes of dividing fairly among the various owners, the production from a particular well or wells.
TAT	Three Affiliated Tribes
TIF	Tax increment financing
UGPTI	Upper Great Plains Transportation Institute
USDA-FS	U.S. Department of Agriculture, Forest Service
VMT	Vehicle-miles traveled
WECS	Wind Energy Conversion System
WIM	Weigh-in-motion

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REFERENCES

Adams, M., J. Nicks, T. Stabile, J. Wu, W. Schlatter, and J. Hartmann, *Geosynthetic Reinforced Soil Integrated Bridge System Synthesis Report*, FHWA-HRT-11-027, Federal Highway Administration, Washington, D.C., 2011.

Barton, J.A., Presentation to House Appropriations Subcommittee Committee on Budget Transparency and Reform, Texas Department of Transportation, Austin, Mar. 11, 2013 [Online]. http://ftp.dot.state.tx.us/pub/txdot-info/energy/presentation_031113.pdf [accessed May 5, 2014].

Batheja, A., "A New Boom for Oil, but a Bust for Texas' Rural Roads," *The New York Times*, Sep. 12, 2013 [Online]. Available: http://www.nytimes.com/2013/09/13/us/a-new-boom-for-oil-but-a-bust-for-texas-rural-roads.html?_r=1& [accessed Nov. 10, 2013].

Begley, D., "Lawmakers Look for Energy Roads Repair Solutions," *Houston Chronicle*, Oct. 10, 2013 [Online]. Available:http://www.houstonchronicle.com/news/houston-texas/texas/article/Lawmakers-look-for-energy-road-repair-solutions-4883106.php [accessed Oct. 30, 2013].

"Biofuel," *ZME Science*, 2007 [Online]. Available: http://www.zmescience.com/tag/biofuel/ [accessed May 10, 2014].

Bloser, S., D. Creamer, C. Napper, B. Scheetz, and T. Zigler, *Environmentally Sensitive Maintenance Practices for Dirt and Gravel Road*s, 1177 1802-SDTDC, National Technology Development Program, Forest Service, U.S. Department of Agriculture, Washington, D.C., Apr. 2012.

Bloser, S. and T. Ziegler, "Infrastructure and Environmental Impacts of Energy Development on Low Volume Roads in Pennsylvania," *Compendium of the 92nd Annual Meeting of the Transportation Research Board Annual Meeting*, Transportation Research Board of the National Academies, Washington, D.C., Jan. 2013.

Boardman, M.S., et al., *TxDOT Administration Research: Tasks Completed FY 2012*, FHWA/TX-13/0-6581-TI-4, Texas A&M Transportation Institute, College Station, Oct. 2012.

Bolander, P., D. Marocco, and R. Kennedy, *Earth and Aggregate Surfacing Design Guide for Low Volume Roads*, FHWA-FLP-96-001, U.S. Forest Service and Federal Highway Administration, Washington, D.C., 1996.

Brown, N., H. Fossum, A. Hecht, C. Dorrington, and D. McBrown, *Impacts of Bakken Region Oil Development on Montana's Transportation and Economy*, Montana Department of Transportation, Helena, Jan. 31, 2013 [Online]. http://www.mdt.mt.gov/other/research/external/docs/research_proj/oil_boom/TRANSPORTATION-ECONOMY_IMPACTS.pdf [accessed Apr. 2, 2014].

Bureau of Land Management (BLM), *Surface Operating Standards and Guidelines for Oil and Gas Exploration and Development*, Fourth Edition, BLM, U.S. Department of Interior, Washington, D.C., 2007 [Online]. Available: http://www.blm.gov/pgdata/etc/medialib/blm/wo/MINERALS__REALTY__AND_RESOURCE_PROTECTION_/energy/oil_and_gas.Par.18714.File.dat/OILgas.pdf [accessed Apr. 16, 2014].

Center for Dirt and Gravel Road Studies, *Environmentally Sensitive Maintenance for Dirt and Gravel Roads*, Pennsylvania State University, University Park, 2014.

CH2M Hill, *North Dakota Strategic Highway Safety Plan*, North Dakota Department of Transportation, Bismarck, Sep. 2013 [Online]. Available: http://www.dot.nd.gov/divisions/safety/docs/ND_SHSP_final_2013-09-09.pdf [accessed Jun. 10, 2014].

Colorado Department of Transportation (CDOT), *Bridge Design Manual*, CDOT, Denver, 2012 [Online]. Available: http://www.coloradodot.info/library/bridge/bridge-manuals/bridge-design-manual [accessed Feb. 10, 2014].

Colorado Department of Transportation (CDOT), *Bridge Rating Manual*, CDOT, Denver, 1995 [Online]. Available: http://www.coloradodot.info/library/bridge/bridge-manuals/bridge-rating-manual [accessed Feb. 10, 2014].

Colorado Department of Transportation (CDOT), *Colorado Integrated Safety Plan 2012–2015*, CDOT, Denver, 2012 [Online]. Available: http://www.coloradodot.info/programs/safety-data-sources-information/2012-2015%20ISP.pdf/view [accessed June 10, 2014].

Colorado Department of Transportation (CDOT), *Colorado Strategic Highway Safety Plan 2006*, CDOT, Denver, 2006 [Online]. Available: http://www.coloradodot.info/library/traffic/traffic-manuals-guidelines/safety-crash-data/problem-id-annual-reports/FY2007_SPIRS_20061001.pdf [accessed June 10, 2014].

"Colorado Oil and Gas Conservation Commission: Home," Colorado Oil and Gas Conservation Commission, Denver, Colo., 2003 [Online]. Available: http://cogcc.state.co.us/ [accessed Mar. 10, 2014].

Commonwealth of Pennsylvania, The Pennsylvania Code, Hauling in Excess of Limit, Section 189, *Hauling in Excess of Posted Weight Limit*, 67 § 189.1, Commonwealth of Pennsylvania, Aug. 12, 2012 [Online]. Available: http://www.pacode.com/secure/data/067/chapter189/067_0189.pdf [accessed Apr. 15, 2014].

Commonwealth of Pennsylvania, The Pennsylvania Code, Letter of Local Determination, Section 190, *Letter of Local Determination—Statement of Policy*, 67 § 190.1, Commonwealth of Pennsylvania, Aug. 12, 2012 [Online]. Available: http://www.pacode.com/secure/data/067/chapter190/067_0190.pdf [accessed Apr. 15, 2014].

Commonwealth of Pennsylvania, The Pennsylvania Code, Oil and Gas, Title 58, *House Bill No. 1950*, Commonwealth of Pennsylvania, 2012 [Online]. Available: http://www.legis.state.pa.us/WU01/LI/LI/US/HTM/2012/0/0013.HTM [accessed Apr. 28, 2014].

"Condition of U.S. Roadways by Functional System," Bureau of Transportation Statistics, Research and Innovative Technology Administration, U.S. Department of Transpor-

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tation, Washington, D.C., Oct. 2013 [Online]. Available: http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_01_27.html [accessed Nov. 24, 2013].

Eastern Federal Lands Highway Division, *Hole-in-the-Donut Substrate Disposal Hauling—Everglades National Park*, Pavement Report Number FY 08-20, Eastern Federal Lands Highway Division, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., July 2008.

"Fatality Analysis Reporting System (FARS) Encyclopedia," National Highway Traffic Safety Administration, Washington, D.C. [Online]. Available: http://wwwfars.nhtsa.dot.gov/Trends/TrendsLargeTruckRel.aspx [accessed Nov. 20, 2013].

Felsburg Holt & Ullevig and BBC Research & Consulting, *Douglas County Oil & Gas Production Transportation Impact Study*, FHU Reference No. 11-091-01, Douglas County, Colo., 2012 [Online]. Available: http://www.douglas.co.us/planning/documents/oil-and-gas-production-transportation-impact-study.pdf [accessed Mar. 20, 2014].

Fernando, E.G. and J.H. Oh, *Guidelines for Evaluating Routine Overweight Truck Routes*, FHWA/TX-04/0-4184-P2, Texas A&M Transportation Institute, College Station, May 2004.

Fry, G., B. Stockton, G. Goodin, T. Baker, J.A. Epps, D. Newcomb, and T. Freeman, *TxDOT Administration Support: FY2013*, FHWA/TX-14/0-6581-TI-5, Texas A&M Transportation Institute, College Station, Oct. 2013.

Gale, S., M. Kurtz, F. Chuck, and D. Janse, "Use of Geosynthetics in Wind Farm Access Roads," *Geosynthetics Magazine*, Apr. 2013 [Online]. Available: http://geosyntheticsmagazine.com/articles/0413_f1_access_roads.html [accessed Oct. 10, 2013].

Girardi, A.G., *Iowa Tax Increment Financing Tax Credits Program Evaluation Study*, Iowa Department of Revenue, Ames, Dec. 2013 [Online]. Available: http://www.iowa.gov/tax/taxlaw/TIF2013.pdf [accessed Mar. 15, 2014].

Gkritza, K., I. Nlenanya, W. Jiang, R.B. Sperry, and D.E. Smith, "Infrastructure Impacts of Iowa's Renewable Energy," *Transportation Research Record: Journal of the Transportation Research Board, No. 2205*, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 238–246.

Gkritza, K., D.E. Smith, R.B. Sperry, I. Nlenanya, and W. Jiang, *Iowa's Renewable Energy and Infrastructure Impacts*, IHRB Project TR-593, Iowa Highway Research Board, Iowa Department of Transportation, Apr. 2010 [Online]. Available: http://www.iowadot.gov/research/reports/Year/2010/fullreports/TR-593%20Final.pdf [accessed Mar. 15, 2014].

Hart, M.V., A. Teresa, and A. Schwartz, "Shifting Sands: Emerging Transportation Impacts of 2 Fracking Sand Mining and Sahle Gas Drilling." *Compendium of the 92nd Annual Meeting of the Transportation Research Board Annual Meeting*, Transportation Research Board of the National Academies, Washington, D.C., Jan. 2013.

Holtz, R.D., B.R. Christopher, and R.R. Berg, *Geosynthetic Design and Construction Guidelines: Participant Notebook*, NHI Course No. 13213, National Highway Institute, Federal Highway Administration, Washington, D. C., Apr. 1998.

Huntington, G., J. Jones, and K. Ksaibati, "Risk Assessment of Oil and Gas Drilling Impacts on County Roads," *Compendium of the 92nd Annual Meeting of the Transportation Research Board Annual Meeting*, Transportation Research Board of the National Academies, Washington, D.C., Jan. 2013.

"Introduction to Major Energy Sources," Pennsylvania Historical & Museum Commission, Commonwealth of Pennsylvania, 2014 [Online]. Available: http://www.portal.state.pa.us/portal/server.pt/community/types_of_energy/4568 [accessed Apr. 2, 2014].

Iowa Department of Transportation, *Iowa Strategic Highway Safety Plan 2013–2016*, Iowa DOT, 2013 [Online]. Available: http://www.iowadot.gov/traffic/shsp/pdf/SHSP.pdf [accessed June 10, 2014].

Iowa Department of Transportation, "Avenue of the Saints Benefits" [Online]. Available: http://www.iowadot.gov/saints/Benefits.html [accessed Dec. 15, 2013].

"Iowa State Profile and Energy Estimates," U.S. Energy Information Administration, 2013 [Online]. Available: http://www.eia.gov/state/?sid=IA [accessed May 21, 2014].

Koser, S., "Marcellus Shale Developmental Impacts to PennDOT's Roadways," *Compendium of the 92nd Annual Meeting of the Transportation Research Board Annual Meeting*, Transportation Research Board of the National Academies, Washington, D.C., Jan. 2013.

Lewandowski, B. and R. Wobbekind, *Assessment of Oil and Gas Industry 2012 Industry Economic and Fiscal Contributions in Colorado*, Leeds School of Business, University of Colorado, Boulder, July 2013.

Liu, W. and T. Scullion, *MODULUS 6.0 for Windows: User's Manual*, FHWA/TX-05/0-1869-2, Texas A&M Transportation Institute, College Station, Oct. 2001.

Loegering, J., "Memorandum—2013 HSIP Safety Project Request—Fort Berthold Indian Reservation—Bureau of Indian Affairs (BIA) Roadways," Office of Federal Lands, U. S. Department of Interior, Washington, D.C., Mar. 27, 2012.

"MAP-21—Moving Ahead for Progress in the 21st Century: Significant Freight Provisions," Federal Highway Administration, Washington, D.C., 2013 [Online]. Available: http://www.fhwa.dot.gov/map21/factsheets/freight.cfm [accessed Apr. 4, 2014].

Marcellus Center for Outreach and Research, Pennsylvania State University, University Park, 2010 [Online]. Available: http://www.marcellus.psu.edu/ [accessed July 27, 2014].

Mason, J.M., *Investigation of the Effects of Oil Field Traffic on Low Volume Roadways*, Ph.D. Dissertation, Texas A&M University, College Station, 1981.

Copyright National Academy of Sciences. All rights reserved.

Meadors, A. and E. Wright-Kehner, "Accelerated Damage to Low Volume Highways Due to Natural Gas Well Drilling Activity in Arkansas," *Compendium of the 92nd Annual Meeting of the Transportation Research Board Annual Meeting*, Transportation Research Board of the National Academies, Washington, D.C., Jan. 2013.

Miller, T. and J.M. Sassin, "Preliminary Energy Development Partnership Case Studies for Rural Texas Highway Infrastructure," *Compendium of the 93rd Annual Meeting of the Transportation Research Board Annual Meeting*, Transportation Research Board of the National Academies, Washington, D.C., Jan. 2014.

Morian, D., M. Solaimanian, B. Scheetz, and S. Jahangirnejad, *Developing Standards and Specifications for Full Depth Pavement Reclamation*, FHWA-PA-2012-004-090107, Bureau of Planning and Research, Pennsylvania Department of Transportation, Harrisburg, May 2012 [Online]. ftp://ftp.dot.state.pa.us/public/pdf/BPR_PDF_FILES/Documents/Research/Complete%20Projects/Extending%20Pavement%20Life/FDR%20Final%20Report.pdf [accessed May 8, 2014]

Nahra, M., "County Engineer Perspective on Energy Sector Road Use in Iowa," *Compendium of the 92nd Annual Meeting of the Transportation Research Board Annual Meeting*, Transportation Research Board of the National Academies, Washington, D.C., Jan. 2013.

"NDDOT to Install Traffic Signal at Intersection of ND Highway 40 and US Highway 2 south of Tioga," North Dakota Department of Transportation News Release, Bismarck, June 2, 2011 [Online]. Available: http://www.dot.nd.gov/dotnet2/news/docs/2011releases/20110602NDDOTtoinstalltrafficsignalatintersectionofNDHighway40andUSHighway2southofTioga.pdf [accessed Dec. 15, 2013].

"North Dakota: An Economy on the Move," Office of State Tax Commissioner: State of North Dakota, Bismarck, 2014 [Online]. Available: http://www.nd.gov/tax/coal/ [accessed Apr. 4, 2014].

North Dakota State University, Upper Great Plains Transportation Institute (UGPTI), *Additional Road Investments Needed to Support Oil and Gas Production and Distribution in North Dakota*, North Dakota Department of Commerce, Bismarck, Dec. 9, 2010 [Online]. Available: http://www.transleader.org/media/materials/2010-12_AddRoadInvToSupportOil.pdf [accessed Jan. 28, 2014].

"North Dakota Traffic Safety: Oil Counties," North Dakota State University, Upper Great Plains Transportation Institute, Fargo, Fall 2013 [Online]. Available: http://www.ugpti.org/rtssc/briefs/downloads/2013_TrafficSafety.pdf [accessed Jan. 28, 2014].

Oh, J., E. Fernando, and C. Quiroga, "Assessment of Pavement Impacts Due to Energy Developments in Texas," *Compendium of the 92nd Annual Meeting of the Transportation Research Board Annual Meeting*, Transportation Research Board of the National Academies, Washington, D.C., Jan. 2013.

"Oil/Gas Development and Production: Roadway Damage and Repair Workshop Agenda," Corpus Christi District Office, Texas Department of Transportation, Mar. 5, 2014.

Oldham, J., "North Dakota's Oil Boom Strains Its Infrastructure," *Bloomberg Businessweek Magazine*, Feb. 2, 2012 [Online]. Available: http://www.businessweek.com/magazine/north-dakotas-oil-boom-strains-its-infrastructure-02022012.html [accessed Dec. 9, 2013].

Oskin, B., "Fracking-Linked Earthquakes May Strike Far from Wells," *LiveScience*, May 2, 2014 [Online]. Available: http://www.livescience.com/45322-fracking-waste water-farther-earthquakes.html [accessed May 8, 2014].

Pearce, A., *Pavement Condition Assessment to Plan for Energy Development on Local Roads*, Ph.D. Dissertation, Department of Civil and Architectural Engineering, University of Wyoming, May 2013.

Pennsylvania Department of Transportation (PennDOT), *Pennsylvania Strategic Highway Safety Plan*, PennDOT, Harrisburg, 2013 [Online]. Available: http://www.justdrivepa.org/Resources/Strategic%20Highway%20Safety%20Plan.pdf [accessed June 10, 2014].

Pennsylvania Department of Transportation (PennDOT), "Weight Restrictions on Highways (Posted Highways)," Chapter 15, *PUB 23—Maintenance Manual*, PennDOT, Harrisburg, 2013 [Online]. Available: ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/PUB%2023/Pub%2023-Chapter%2015.pdf [accessed Apr. 20, 2014].

"ProgressZone," North Dakota Petroleum Council, Bismarck, 2012 [Online]. Available: http://ndoil.org/?id=232&page=ProgressZone [accessed Jan. 15, 2014].

Prozzi, J., S. Grebenschikov, A. Banerjee, and J.P. Prozzi, *Impacts of Energy Developments on the Texas Transportation System Infrastructure*, 0-6513-1A, University of Texas at Austin, Center for Transportation Research, 2011 [Online]. Available: http://ftp.dot.state.tx.us/pub/txdot-info/energy/impacts_energy.pdf [accessed Mar. 15, 2014].

Prozzi, J., et al., *Oversize/Overweight Vehicle Permit Fee Study*, FHWA/TX-13/0-6736-2, University of Texas at Austin, Center for Transportation Research, Dec. 2012.

Prozzi, J., A. Banerjee, S. Grebenschikov, and J.P. Prozzi, "Energy Sector Impacts on Road Infrastructure in Texas," *TR News*, No. 290, Jan.–Feb. 2014, p. 39.

Public Law 112-141, "Moving Ahead for Progress in the 21st Century Act (MAP-21)," 112th Congress, 126 STAT. 405, July 6, 2012 [Online]. Available: http://www.dot.gov/map21 [accessed Mar. 1, 2014].

"Public Road Length, Miles by Ownership: 2008," Bureau of Transportation Statistics, Research and Innovative Technology Administration, U. S. Department of Transportation, Washington, D.C., 2011 [Online]. Available: http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/state_transportation_statistics/state_transportation_statistics_2010/html/table_01_02.html [accessed Nov. 5, 2013].

Quiroga, C., E. Fernando, and J. Oh, *Energy Developments and the Transportation Infrastructure in Texas: Impacts and*

Copyright National Academy of Sciences. All rights reserved.

Strategies, FHWA/TX-12/0-6498-1, Texas A&M Transportation Institute, College Station, Mar. 2012 [Online]. Available: http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/0-6498-1.pdf [accessed Dec. 8, 2013].

Raimi, D. and R.G. Newell, *Shale Public Finance: Local Government Revenues and Costs Associated with Oil and Gas Development*, Duke University Energy Initiative, Durham, May, 2014 [Online]. Available: http://energy.duke.edu/sites/energy.duke.edu/files/files/Shale%20Public%20Finance%20Local%20Revenues%20and%20Costs%20Report%20Final.pdf [accessed May 31, 2014].

"Rep. Blumenauer Introduces Bills to Raise Gas Tax, Set up VMT Pilot Program," *AASHTO Journal*, Dec. 6, 2013 [Online]. Available: http://www.aashtojournal.org/Pages/120613Blumenauer.aspx [accessed Dec. 9, 2013].

"Road Spreading of Brine for Dust Control and Road Stabilization," Pennsylvania Department of Environmental Protection, Harrisburg, Feb. 2013 [Online]. Available: http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-92873/8000-FS-DEP1801.pdf [accessed Dec. 16, 2013].

Scheetz, B., D. Linzell, T. Murtha, E. Donnell, P. Jovanis, and M. Pietrucha, "The Impact of Marcellus Gas Development on the Rural Transportation Infrastructure," PSU-2010-05, Pennsylvania State University, University Park, 2013.

Skorseth, K., "Recent Impact of Wind Energy and Biofuel Production on Local Roads," *Compendium of the 92nd Annual Meeting of the Transportation Research Board Annual Meeting*, Transportation Research Board of the National Academies, Washington, D.C., Jan. 2013.

Skorseth, K. and A.A. Selim, *Gravel Roads Maintenance and Design Manual*, Federal Highway Administration, Washington, D.C., Nov. 2000.

Southern Pennsylvania Commission, *2040 Transportation and Development Plan for Southwestern Pennsylvania*, Pittsburgh, 2011 [Online]. Available: http://www.spcregion.org/pdf/lrp2040/2040Plan.pdf [accessed Mar. 9, 2014].

Stroud, N.K. and K. Ksaibati, *Quantifying the Impact of Energy Traffic on Local Unpaved Roads*, MPC 13-263, Mountain Plains Consortium, Fargo, Dec. 2013.

Taylor, G., R. Souleyrette, and C. Albrecht, *Investigation of the Impacts of Rural Development on Iowa's Secondary Road Systems*, IHRB Report TR-548, Institute for Transportation, Iowa State University, Ames, Sep. 2010 [Online]. Available: http://www.intrans.iastate.edu/reports/tr-548_rural_impacts_report_w_cvr1.pdf [accessed Feb. 12, 2014].

"Texas 83rd Legislative Session Recap: Water, Energy & Roads," *Texas Star Alliance*, July 2013 [Online]. Available: http://texasstaralliance.com/blog/2013/07/25/texas-83rd-legislative-session-recap-water-energy-roads/ [accessed Dec. 9, 2013].

Texas Association of Counties, *2013 Legislative Analysis Report*, Texas Association of Counties, Austin [Online]. Available: http://www.county.org/member-services/legislative-updates/presentations/Documents/2013%20Legislative%20Conference%20Docs/LegisAnalysisReport.pdf [accessed Dec. 9, 2013].

Texas Department of Transportation (TxDOT), *2013 Texas Strategic Highway Safety Plan*, TxDOT, Austin, 2013 [Online]. Available: http://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/gov/shsp.pdf [accessed June 10, 2014].

Texas Department of Transportation (TxDOT), "*TxDOT* Partners with Eagle Ford Shale Counties for Solution to Maintain Damaged Energy Sector Roads," *Statewide News Releases*, Media Center, Austin, Nov. 26, 2013 [Online]. Available: http://www.txdot.gov/inside-txdot/media-center/statewide-news/2013-archive/068-2013.html [accessed Dec. 5, 2013].

Thompson, C., "Aging Bridges, Maintenance, Congestion Relief Are Among Transportation's Top Priorities, PennDOT Secretary Says," *The Patriot News*, Dec. 04, 2013 [Online]. Available: http://www.pennlive.com/midstate/index.ssf/2013/12/penndot_secretary_barry_schoch.html [accessed Dec. 5, 2013].

Tidd, L., "Consideration of Shale Gas Development Impacts in Long-Range Transportation Planning," *Compendium of the 92nd Annual Meeting of the Transportation Research Board Annual Meeting*, Transportation Research Board of the National Academies, Washington, D.C., Jan. 2013.

Tolliver, D. "Transportation Systems for Oil & Gas Development: Case Study of the Bakken Shale," *Compendium of the 93rd Annual Meeting of the Transportation Research Board Annual Meeting*, Transportation Research Board of the National Academies, Washington, D.C., Jan. 2014.

"Traffic Safety Facts," Upper Great Plains Transportation Institute, North Dakota State University, Bismarck, 2013 [Online]. Available: http://www.ugpti.org/rtssc/briefs/downloads/2013_TruckCrashFacts.pdf [accessed Feb. 2, 2014].

Transportation Research Board, *Critical Issues in Transportation*, Transportation Research Board of the National Academies, Washington, D.C., 2013 [Online]. Available: http://onlinepubs.trb.org/Onlinepubs/general/criticalissues13.pdf [accessed Dec. 8, 2013].

"Truck Weights and Highways," South Dakota Department of Transportation, Pierre, Sep. 2003 [Online]. Available: http://www.sddot.com/resources/Brochures/sddot_truck_briefing_2d.pdf [accessed Dec. 15, 2013].

"TxDOT Enhancing Roadway Safety in Oil and Energy Boomtowns," Texas Department of Transportation, Austin, Mar. 7, 2013 [Online]. Available: http://www.txdot.gov/inside-txdot/media-center/statewide-news/2013-archive/010-2013.html [accessed Dec. 15, 2013].

"TxDOT Partners with Eagle Ford Shale Counties for Solution to Maintain Damaged Energy Sector Roads," Texas Department of Transportation, Austin, Nov. 26, 2013 [Online]. Available: http://www.txdot.gov/inside-txdot/media-center/statewide-news/2013-archive/068-2013.html [accessed Dec. 5, 2013].

Tunstall, T., et al., *Economic Impact of the Eagle Ford Shale*, Institute for Economic Development, University of Texas at San Antonio, May 2012.

Copyright National Academy of Sciences. All rights reserved.

"U.S. Energy Mapping System," U.S. Energy Information Administration, Washington, D.C., 2013 [Online], Available: http://www.eia.gov/state/maps.cfm [accessed Oct. 20, 2013].

"Using Geotextiles in Unpaved Low Volume Roads," Local Highway Technical Assistance Council, Vol. 12, No. 11, 2005.

Walsh, B., "The Challenges of America's Energy Revolution," *Time Magazine*, Oct. 2013 [Online]. Available: http://content.time.com/time/magazine/article/0,9171,2153104,00.html [accessed Oct. 20, 2013].

Wilde, W.J., *Traffic Generating Development and Roadway Life Consumption*, 2012RIC11, Minnesota Department of Transportation, St. Paul, Aug. 2012 [Online]. Available: http://www.lrrb.org/media/reports/2012RIC11.pdf [accessed Mar. 22, 2014].

Wilke, P.W. and M. Harrell, "Assessment of Impact of Energy Development Projects on Local Roads," *Proceedings of 2011 Annual Conference of the Transportation Association of Canada*, Edmonton, AB, Canada [Online]. Available: http://conf.tac-atc.ca/english/annualconference/tac2011/docs/p2/wilke.pdf [accessed Dec. 8, 2013].

Wilson, P., *Impact of Energy Development Activities on the Texas Transportation Infrastructure: Testimony Before the House Committee on Energy Resources*, Texas Department of Transportation, Austin, June, 2012 [Online]. Available: http://ftp.dot.state.tx.us/pub/txdot-info/energy/testimony_062612.pdf [accessed Apr. 5, 2014].

"Wind Power Facts," Iowa Wind Energy Association, Milford, 2013 [Online]. Available: http://www.iowawindenergy.org/whywind.php [accessed May 21, 2014].

Wright-Kehner, E., "Evaluating Pavement Damage in the Fayetteville Shale Play Area," Transportation Research Committee, Mar. 2008 [Online]. Available: http://www.ltrc.lsu.edu/ltc_11/pdf/2010%20Fayetteville%20Shale1.pdf [accessed Feb. 20, 2014].

Copyright National Academy of Sciences. All rights reserved.

BIBLIOGRAPHY

Bachman, J., "North Dakota's Downside to the Oil Boom: Traffic Deaths," *Bloomberg Businessweek*, June 9, 2014 [Online]. Available: http://www.businessweek.com/articles/2014-06-09/north-dakotas-downside-to-the-oil-boom-traffic-deaths [accessed June 9, 2014].

Begos, K. and J. Fahey, "Traffic Deaths Rise in Fracking Boom," *The Durango Herald*, May 5, 2014 [Online]. http://www.durangoherald.com/article/20140505/NEWS03/140509731/Traffic-deaths-rise-in-fracking-boom [accessed May 8, 2014].

Brunswick, M., "Evacuation Ends for N.D. City Near Crude Oil Inferno," *StarTribune*, Dec. 31, 2013 [Online]. http://www.startribune.com/local/238272931.html [accessed Jan. 24, 2014].

Bumpy Roads Ahead: America's Roughest Rides and Strategies to Make our Roads Smoother, TRIP, Washington, D.C., Oct. 2013 [Online]. Available: http://www.tripnet.org/docs/Urban_Roads_Report_Oct_2013.pdf [accessed Mar. 1, 2014].

Burka, P., "Road to Nowhere," *Texas Monthly*, Nov. 16, 2013 [Online]. Available: http://www.texasmonthly.com/story/why-texas-needs-to-spend-the-money-to-repair-its-roads?fullpage=1 [accessed Nov. 25, 2013].

Chandler, B. and R. Anderson, *Implementing the High Risk Rural Roads Program*, FHWA-SA-10-012, Office of Safety, Federal Highway Administration, Washington, D.C., Mar. 2010.

Chowdhury, M., B. Putman, W. Pang, A. Dunning, K. Dey, and L. Chen, *Rate of Deterioration of Bridges and Pavement as Affected by Trucks*, FHWA-SC-13-05, Clemson University, Clemson, S.C., Dec. 2013.

"Court Rejects Motion to Allow Mega-loads of Oil Field Equipment on Idaho Highway," The Bureau of National Affairs Inc., Washington, D.C., Oct. 18, 2013 [Online]. Available: http://www.bloomberglaw.com/public/document/Nez_Perce_Tribe_v_US_Forest_Serv_Case_No_313CV348BLW_2013_BL_2812 [accessed Jan. 15, 2014].

"Dalrymple Dedicates Opening of Williston's Temporary Bypass," North Dakota Department of Transportation News Release, Bismarck, Aug. 20, 2012 [Online]. Available: https://www.dot.nd.gov/dotnet2/news/docs/2012releases/20120821Willistontemporarybypass.pdf [accessed Dec. 15, 2013].

"Federal Transportation Safety Agency Chief says Washington Bridge Collapse is wake-up call," *Daily News*, May 2013 [Online]. Available: http://www.nydailynews.com/news/politics/federal-transportation-safety-agency-washington-bridge-collapse-wake-up-call-article-1.1355031 [accessed Dec. 15, 2013].

Fitzsimmons, E.J., T. Mulinazzi, and S.D. Schrock, "Economic Impact of Closing Structurally Deficient or Functionally Obsolete Bridges on Very Low-Volume Roads," *Compendium of the 93rd Annual Meeting of the Transportation Research Board Annual Meeting*, Transportation Research Board of the National Academies, Washington, D.C., Jan. 2014.

"Governor Jindal Highlights $2.3 Million Rural Highway Project in Caldwell Parish," Louisiana Department of Transportation and Development, Baton Rouge, Dec. 2013 [Online]. Available: http://www.dotd.la.gov/pressreleases/Release.aspx?key=2510 [accessed Dec. 5, 2013].

Henning, T.F.P., D. Alabaster, G. Arnold, and W. Liu, "The Relationship between Traffic Loading and Environmental Factors to Low Volume Road Deterioration," *Compendium of the 93rd Annual Meeting of the Transportation Research Board Annual Meeting*, Transportation Research Board of the National Academies, Washington, D.C., Jan. 2014.

Horwath, B., "Transportation Institute Pitches Oil Field Road Plan," *Prairie Business*, Mar. 2014 [Online]. Available: http://www.prairiebizmag.com/event/article/id/18308/ [accessed Mar. 20, 2014].

Jaffe, M., "Oil and Gas Companies Playing, but Pay to Colorado Counties Is Uneven," *The Denver Post*, Apr. 13, 2014 [Online]. Available: http://www.denverpost.com/business/ci_25551329/oil-and-gas-companies-playing-but-pay-colorado#ixzz32MeizRhw [accessed Apr. 14, 2014].

"Large Truck and Buses Crash Facts 2011," Federal Motor Carrier Safety Administration Analysis Division, U.S. Department of Transportation, Washington, D.C., Oct. 2013.

Lorand, R., J. Cohen, J. Mello, and D. Panich, *NCHRP Report 751: Renewable Energy Guide for Highway Maintenance Facilities*, Transportation Research Board of the National Academies, Washington, D.C., 2013 [Online]. Available: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_751.pdf [accessed Dec. 27, 2013].

"Marcellus Shale En Banc Hearing, Docket No. 1-2010-2165," Pennsylvania State Police, Harrisburg, June 2010 [Online]. Available: http://www.puc.pa.gov/pcdocs/1082570.pdf [accessed Feb. 15, 2014].

Middleton, D., Y. Li, J. Le, and N. Konez, *Accommodating Oversize and Overweight Loads: Technical Report*, 0-6404-1, Texas A&M Transportation Institute, College Station, 2012 [Online]. Available: http://ftp.dot.state.tx.us/pub/txdot-info/energy/osow_technical.pdf [accessed Jan. 20, 2014].

Montana Department of Transportation Pavement Analysis Section, *Northeastern Montana Oil Boom Study*, Montana Department of Transportation, Helena [Online]. http://www.mdt.mt.gov/other/research/external/docs/research_proj/oil_boom/pavement_impact.pdf [accessed Mar. 30, 2014].

Murawski, M., *Transportation Patterns and Impacts from Marcellus Development*, presentation for Freight Planning, Federal Highway Administration, Washington, D.C., Sep. 13, 2013.

Copyright National Academy of Sciences. All rights reserved.

Nahra, M., "Ethanol Production and Wind Energy, Challenging Low-Volume Roads in Iowa," *TR News*, No. 290, Jan.–Feb. 2014, p. 44.

Newcomb, D., E. Fernando, and J. A. Epps, *An Economic Analysis of Four Options for Dealing with Low-Volume Roads in Energy-Impacted Areas of Texas*, 0-6806-TTI, Texas A&M Transportation Institute, College Station, Oct. 2013.

"News for Immediate Release Cameron County," Pennsylvania Department of Transportation, Harrisburg, Apr. 22, 2010 [Online]. Available: http://www.dot.state.pa.us/penndot/districts/district2.nsf/a49f8addf0b73b1585256863004ed760/0d5d369d39abecd38525783f00625086?OpenDocument [accessed Dec. 16, 2013].

"New Funds Approved for Critical Repairs to Damaged Roads in Booming Energy Areas Experiencing Unprecedented Growth," Texas Department of Transportation, Austin, Dec. 19, 2013 [Online]. Available: http://www.txdot.gov/inside-txdot/media-room/news/statewide/073-2013.html [accessed Dec. 27, 2013].

"Oil and Gas Producers Join Truckers for Improved Road Safety," Consumer Energy Alliance, Apr. 22, 2013 [Online]. Available: http://consumerenergyalliance.org/oil-gas-producers-join-truckers-for-improved-road-safety/ [accessed Dec. 15, 2013].

Olson, J., "Understanding, Calculating and Applying the Impact of Oil-Related Traffic," FHWA's Talking Freight, Planning Asset Management Division, North Dakota Department of Transportation, Bismarck, May 2012.

Oskin, B., "Oklahoma Earthquake Risk Prompts Rare Warning," *Huffington Post*, May 5, 2014 [Online]. Available: http://www.huffingtonpost.com/2014/05/05/oklahoma-earthquake-risk_n_5269280.html [accessed May 8, 2014].

Prozzi, J., A. Dumais, M. Cline, L. Otway, and E. Seaborne, *Texas Energy Sector: Past and Future*, 0-6513-1B, Center for Transportation Research, University of Texas at Austin, 2011 [Online]. Available: http://ftp.dot.state.tx.us/pub/txdot-info/energy/energy_past_future.pdf [accessed Jan. 21, 2014].

Quiroga, C., *Fracking-based Energy Developments and Transportation Impacts and Needs*, Presentation for Freight Planning, Federal Highway Administration, Washington, D.C., Sep. 13, 2013.

Ryan, M., "Massive Methanol Plant Planned for Beaumont," Houston BizBlog, Nov. 21, 2013 [Online]. Available: http://www.bizjournals.com/houston/resources/ [accessed Nov. 22, 2013].

Scheyder, E., "Insight: To Flee Ohio Oil Boom, Amish Cash Out by Selling Royalties," *Reuters*, Dec. 20, 2013 [Online]. Available: http://www.reuters.com/article/2013/12/20/us-energy-ohio-amish-insight-idUSBRE9BJ15120131220 [accessed Dec. 30, 2013].

Spigelmyer, D., "PA's Shale Industry Is Investing in Infrastructure," *Penn-Live*, Nov. 17, 2013 [Online]. Available: http://www.pennlive.com/opinion/index.ssf/2013/11/pas_shale_industry_is_investing_in_infrastructure_dave_spigelmyer.html [accessed Aug. 7, 2014].

Texas Department of Transportation, *Task Force on Texas' Energy Sector Roadway Needs*, Texas Transportation Commission, Austin, 2012 [Online]. Available: http://ftp.dot.state.tx.us/pub/txdot-info/energy/final_report.pdf [accessed Mar. 3, 2014].

Torres, C., *Freight Management Office Peer-To-Peer Program*, presentation for Freight Planning, Federal Highway Administration, Washington, D.C., Sep. 18, 2013.

"What Can Be Done to Enhance HVUT Revenues?" Federal Highway Administration, Washington, D.C. [Online]. Available: http://www.fhwa.dot.gov/policy/091116/03.htm [accessed Dec. 9, 2013].

White, D.J. and P. Vennapusa, *Low-Cost Rural Surface Alternatives: Literature Review and Recommendations*, IHRB Project TR-632, Iowa Highway Research Board, Iowa Department of Transportation, Ames, Dec. 2013 [Online]. Available: http://www.intrans.iastate.edu/research/documents/research-reports/rural_surface_alternatives_w_cvr2.pdf [accessed Apr. 2, 2014].

"Why Texas Needs to Spend the Money to Repair its Roads?" *Texas Monthly*, Apr. 2014.

Wind, K., "Natural Gas Industry Fixing State Roads," *Citizens Voice*, July 22, 2013 [Online]. Available: http://citizensvoice.com/news/natural-gas-industry-fixing-state-roads-1.1523883 [accessed Aug. 7, 2014].

Ziegler, T., "Repairing Damaged Rural Roads in Pennsylvania, Gas Companies Learn to Add Environmental Sensitivity to Durability," *TR News*, No. 290, Jan.–Feb. 2014, p. 46.

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APPENDIX A

Summary of Survey Results

The responses to the DOT survey questionnaire are presented in this appendix.

TABLE A1
SURVEY RESPONSE TO QUESTION 2: "HAS YOUR STATE EXPERIENCED A SUSTAINED LEVEL AND/OR AN EXPANSION IN ENERGY DEVELOPMENT ACTIVITIES IN RECENT YEARS?"

Response Type	Response Rate
Yes	78%
No	22%

TABLE A2
SURVEY RESPONSE TO QUESTION 3: "HAVE ANY OF THE FOLLOWING INDUSTRIES SEEN A SUSTAINED OR INCREASED LEVEL OF ACTIVITIES WHICH ARE IMPACTING EITHER STATE OR LOCAL ROADS?—BIOFUELS (E.G., FROM WOOD, CORN, ETC.)—MINING—NATURAL GAS—NUCLEAR—OIL—SOLAR—WIND."

Response Type	Response Rate
Yes	78%
No	22%

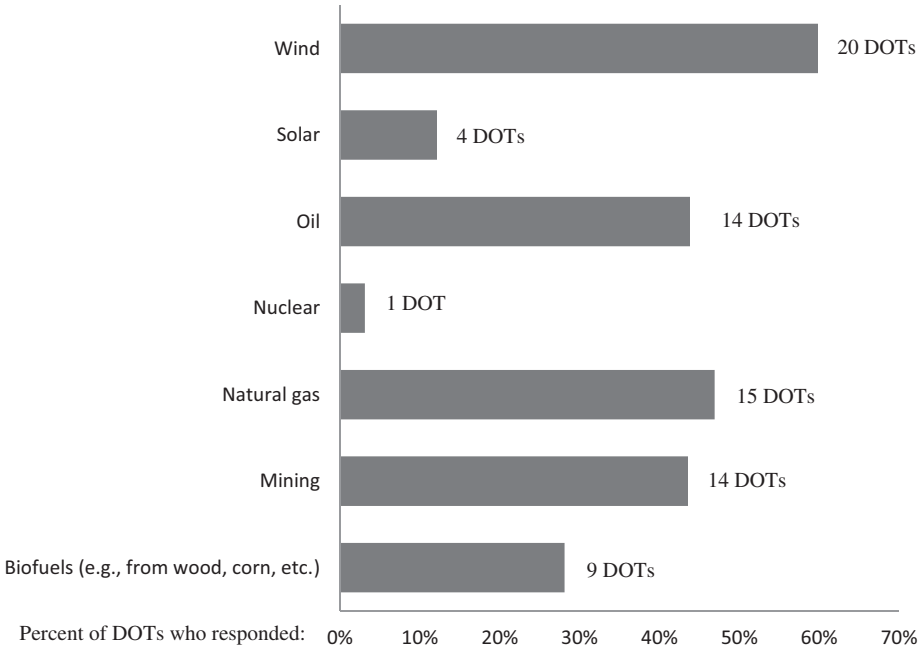

FIGURE A1 Survey response to Question 4: "Which industries have seen a sustained or increased level of activities which are impacting either state or local roads?"

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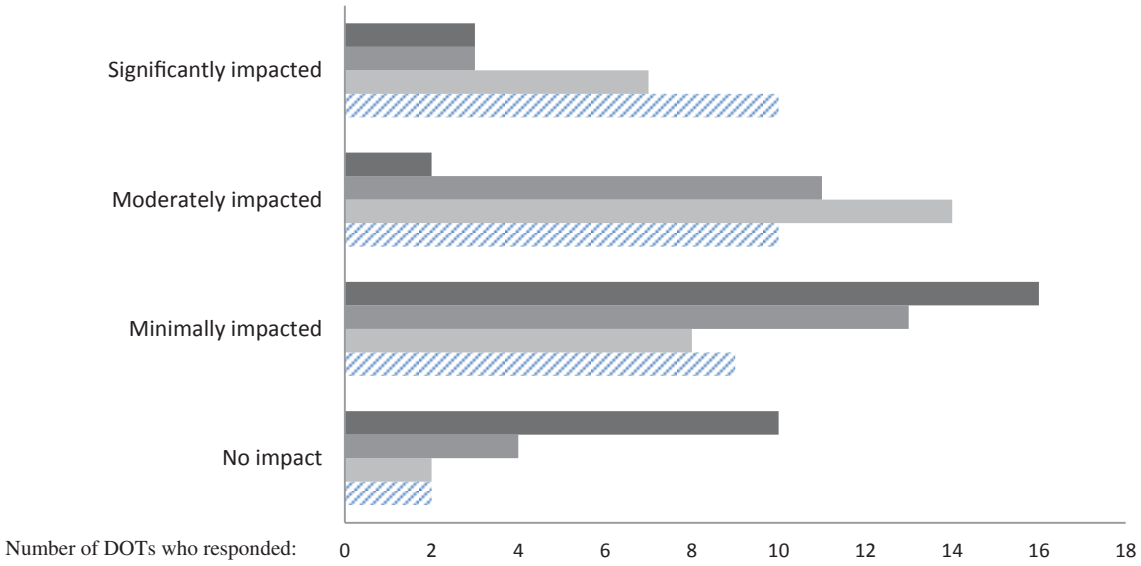
TABLE A3
SURVEY RESPONSE TO QUESTION 5: "HAS THERE BEEN AN INCREASE IN THE AMOUNT OF TRUCK TRAFFIC VOLUMES AND HEAVY LOADS AS A RESULT OF THESE ACTIVITIES ON THE PUBLIC ROAD SYSTEM IN YOUR STATE?"

Response Type	Response Rate
Yes	68%
No	18%
I don't know	5%
Other	10%

TABLE A4
SURVEY RESPONSE TO QUESTION 6: "ESTIMATE WHAT PERCENTAGE OF ROADS IN YOUR STATE THAT ARE IMPACTED BY THE INCREASED PRESENCE OF TRUCKS."

Response Type	Response Rate
0–15%	45%
16–30%	36%
31–60%	13%
61–80%	3%
81–100%	3%



	No impact	Minimally impacted	Moderately impacted	Significantly impacted
Interstates or freeways	10	16	2	3
Primary (National Highway System or state highway system)	4	13	11	3
Secondary (minor arterials or collectors/distributors)	2	8	14	7
Secondary (local roads)	2	9	10	10

FIGURE A2 Survey response to Question 7: "Estimate the distribution of roads impacted by the increased presence of trucks in terms of their functional class or ownership. *Note*: Impacts in this case are considered in terms of the level of the combined effects on budget, truck volume, congestion, and increased maintenance."

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TABLE A5
SURVEY RESPONSE TO QUESTION 8: "HAVE LOCAL AGENCIES, DOT DISTRICT MAINTENANCE OFFICES, OR THE DIVISION OF MOTOR CARRIERS REPORTED AN INCREASE IN DAMAGE OR CONGESTION ON ROADS AND BRIDGES NEAR AREAS WHERE THE TRANSPORT OF ENERGY-RELATED COMMODITIES OCCURS?"

Response Type	Response Rate
Yes	50%
No	50%

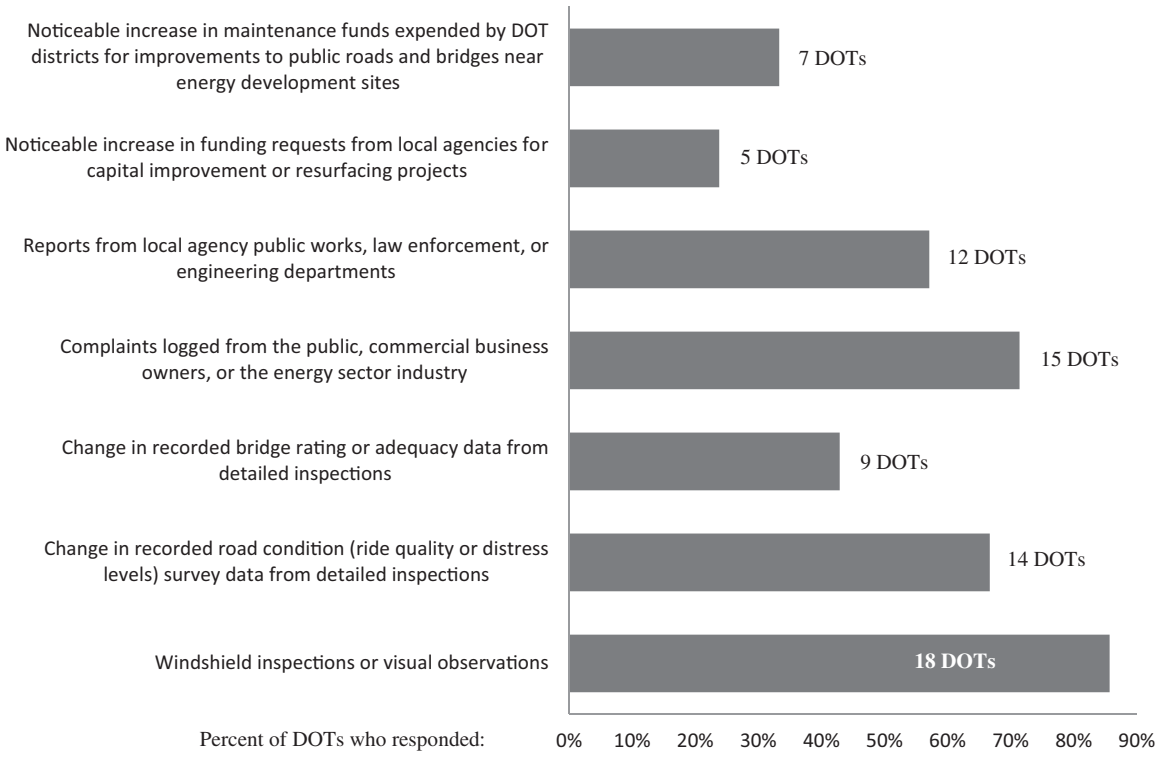

FIGURE A3 Survey response to Question 9: "How have the increased impacts due to heavier loading on roads and bridges, due to energy development activities, been reported and measured?"

TABLE A6
SURVEY RESPONSE TO QUESTION 10: "PLEASE SELECT THE APPROACH THAT BEST DESCRIBES HOW YOUR AGENCY, OR ANY LOCAL AGENCIES, IS TAKING TO ADDRESS THE DAMAGE DONE TO INFRASTRUCTURE (E.G., PREMATURE CRACKING IN PAVEMENTS, PREMATURE DECREASE IN BRIDGE SUFFICIENCY RATING, MORE FREQUENT PAVEMENT PATCHING REQUIRED, INCREASED FREQUENCY OF POTHOLE OR WASHBOARDING DEVELOPMENT IN UNPAVED ROADS, ETC.) BY ENERGY SECTOR TRANSPORTATION ACTIVITIES?"

Response Type	Response Rate
Proactive	14%
Reactive	10%
Partnering with energy development	10%
A combination of more than one of the approaches	57%
No action	10%

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TABLE A7
SURVEY RESPONSE TO QUESTION 11: "DESCRIBE THE REACTIVE APPROACH THAT YOUR STATE OR LOCALS ARE TAKING TO ADDRESS THE DAMAGE DONE TO INFRASTRUCTURE BY ENERGY SECTOR TRANSPORTATION ACTIVITIES."

Rating of Effectiveness of Approach						
	Not using	1 - not effective	2 - shows promise too soon to tell	3 - somewhat effective	4 - very effective	Total
Overweight or oversized vehicle fees assigned	100% 2	0% 0	0% 0	0% 0	0% 0	2
Recouping payment after damages for fixing roads	50% 1	0% 0	0% 0	50% 1	0% 0	2
Extended duration closures of local roads or bridges	100% 2	0% 0	0% 0	0% 0	0% 0	2
Increased presence of law enforcement along heavily-used roadways	100% 2	0% 0	0% 0	0% 0	0% 0	2
Other (please describe details in text box below)	50% 1	0% 0	0% 0	0% 0	50% 1	2

TABLE A8
SURVEY RESPONSE TO QUESTION 12: "DESCRIBE THE PROACTIVE APPROACH THAT YOUR STATE OR LOCALS ARE TAKING TO ADDRESS THE DAMAGE DONE TO INFRASTRUCTURE BY ENERGY SECTOR TRANSPORTATION ACTIVITIES."

Rating of Effectiveness of Approach						
	Not using	1 - not effective	2 - shows promise too soon to tell	3 - somewhat effective	4 - very effective	Total
Preventing damage before it happens by posting load limits	0% 0	0% 0	0% 0	100% 3	0% 0	3
Pavement preservation treatments used	0% 0	0% 0	0% 0	0% 0	100% 3	3
Designating truck routes	33.33% 1	0% 0	33.33% 1	33.33% 1	0% 0	3
Other mitigation strategies	66.67% 2	0% 0	0% 0	33.33% 1	0% 0	3
Continuously updating design standards	33.33% 1	0% 0	0% 0	66.67% 2	0% 0	3
Other (please describe details in text box below)	66.67% 2	0% 0	0% 0	33.33% 1	0% 0	3

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TABLE A9
SURVEY RESPONSE TO QUESTION 13: "DESCRIBE THE LEGISLATIVE APPROACH THAT YOUR STATE OR LOCALS ARE TAKING TO ADDRESS THE DAMAGE DONE TO INFRASTRUCTURE BY ENERGY SECTOR TRANSPORTATION ACTIVITIES."

Rating of Effectiveness of Approach						
	Not using	1 - not effective	2 - shows promise too soon to tell	3 - somewhat effective	4 - very effective	Total
Road ownership responsibilities (interjurisdictional)	0% 0	0% 0	0% 0	0% 0	0% 0	0
Local ordinances	0% 0	0% 0	0% 0	0% 0	0% 0	0
State laws on energy development	0% 0	0% 0	0% 0	0% 0	0% 0	0
Permitting restrictions	0% 0	0% 0	0% 0	0% 0	0% 0	0
Roadway usage fee scaled to vehicle load or type	0% 0	0% 0	0% 0	0% 0	0% 0	0
Modal shifts of freight dictated legislatively	0% 0	0% 0	0% 0	0% 0	0% 0	0
Other (please describe details in text box below)	0% 0	0% 0	0% 0	0% 0	0% 0	0

TABLE A10
SURVEY RESPONSE TO QUESTION 14: "DESCRIBE THE PARTNERING WITH ENERGY DEVELOPMENT COMPANIES APPROACH THAT YOUR STATE OR LOCALS ARE TAKING TO ADDRESS THE DAMAGE DONE TO INFRASTRUCTURE BY ENERGY SECTOR TRANSPORTATION ACTIVITIES."

Rating of Effectiveness of Approach						
	Not using	1 - not effective	2 - shows promise too soon to tell	3 - somewhat effective	4 - very effective	Total
Energy companies design new roads	50% 1	0% 0	0% 0	0% 0	50% 1	2
Energy companies pay for reconstruction of local roads	0% 0	0% 0	0% 0	50% 1	50% 1	2
Use of Concessionaire agreements (e.g., public-private partnerships)	50% 1	0% 0	0% 0	50% 1	0% 0	2
Procedures in place for recouping damage costs	50% 1	0% 0	0% 0	50% 1	0% 0	2
Other (please describe details in text box below)	50% 1	0% 0	0% 0	0% 0	50% 1	2

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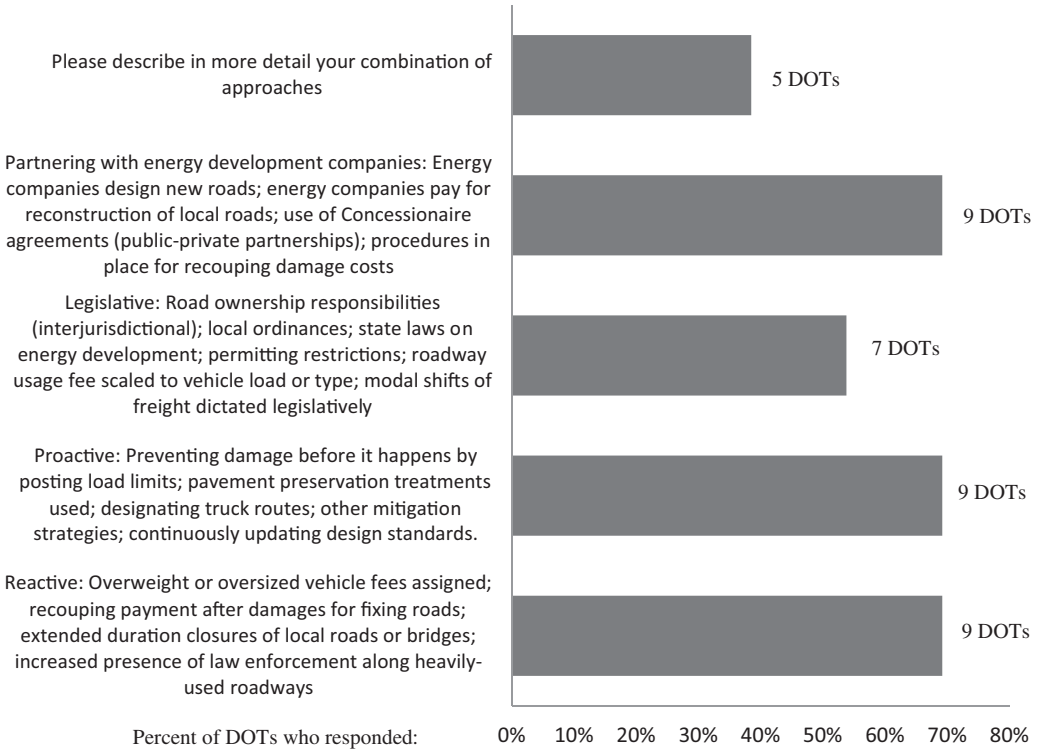

FIGURE A4 Survey response to Question 15: "Select all that are being used. Check all that apply."

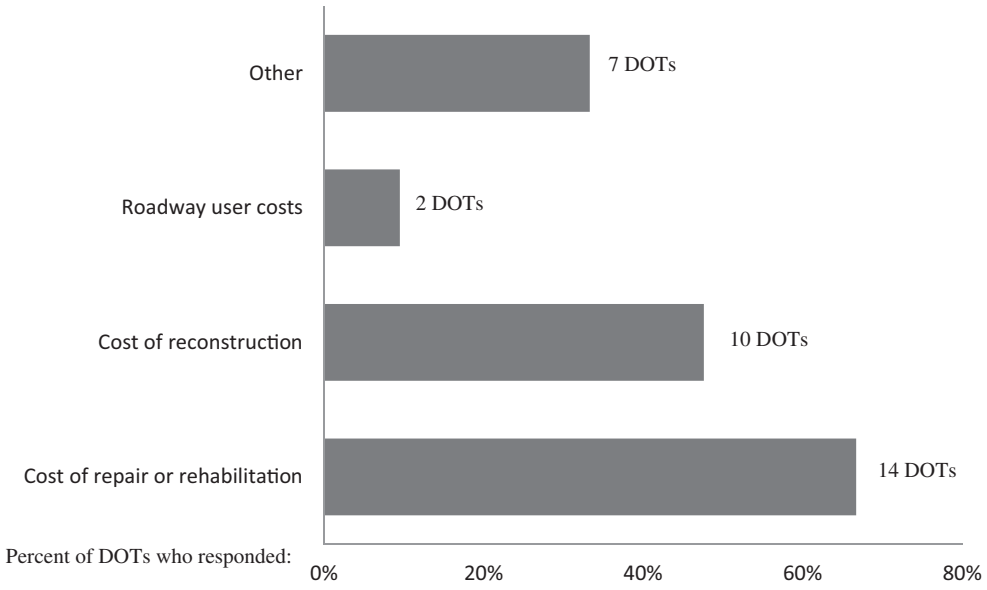

FIGURE A5 Survey response to Question 16: "Which costs have you identified in an economic impact analysis on roads and bridges?"

TABLE A11
SURVEY RESPONSE TO QUESTION 17: "ARE ANY OF THESE FACTORS CONSIDERED THROUGH A UNIT COST (I.E., COST/MILE, EXTENDED TRAVEL TIME TO DESTINATION ETC.)?"

Response Type	Response Rate
Yes	38%
No	62%

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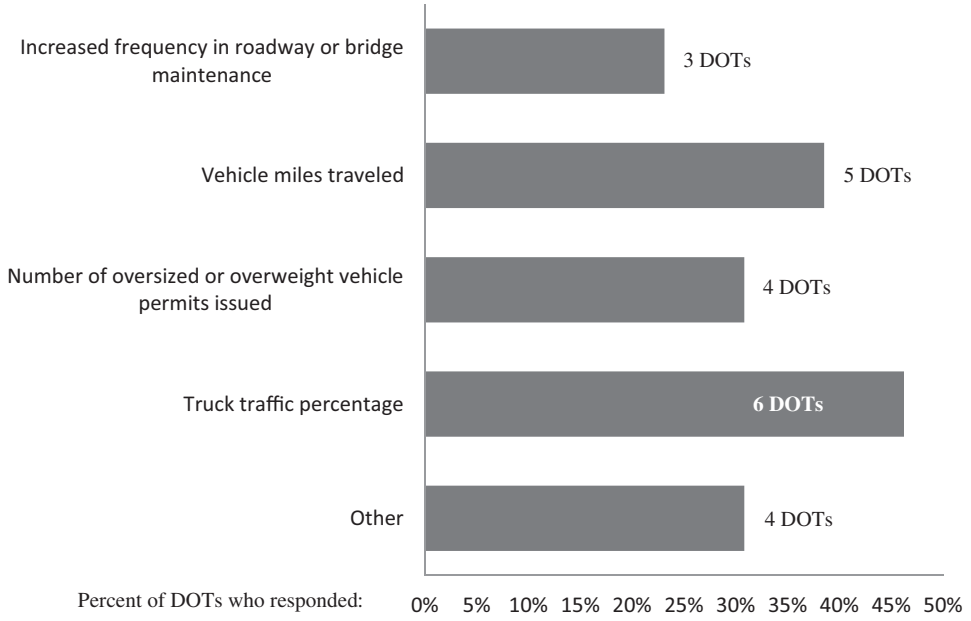

FIGURE A6 Survey response to Question 18: "If the factors are part of a cost formula, is the formula based on any of the following items?"

TABLE A12
SURVEY RESPONSE TO QUESTION 19: "DOES YOUR AGENCY (OR DO LOCAL AGENCIES IN YOUR STATE) HAVE A STRATEGY OR METHOD IN PLACE FOR QUANTIFYING ANY OF THESE COSTS?"

Response Type	Response Rate
Yes	29%
No	71%

TABLE A13
SURVEY RESPONSE TO QUESTION 20: "DO THESE STRATEGIES OR METHODS DIFFER FROM THOSE IN PLACE TO DEAL WITH SOURCES OF DAMAGE TO PAVEMENTS AND ROADWAY INFRASTRUCTURE FROM HUSBANDRY, AGRICULTURAL, OR OTHER HEAVY INDUSTRIES THAT USE THE SAME NETWORK OF ROADS AND BRIDGES?"

Response Type	Response Rate
Yes	19%
No	81%

TABLE A14
SURVEY RESPONSE TO QUESTION 23: "ARE ANY OF THE ENERGY DEVELOPERS IN YOUR STATE CONTRACTUALLY RESPONSIBLE FOR THE MAINTENANCE AND REPAIRS OF ROADWAYS?"

Response Type	Response Rate
Yes	26%
No	74%

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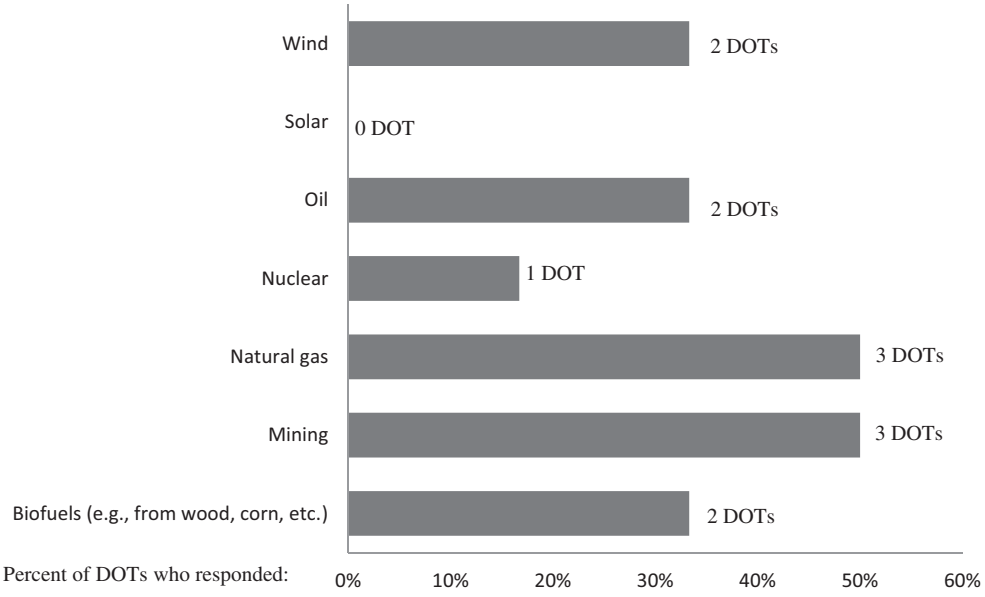

FIGURE A7 Survey response to Question 24: "Which energy sectors are contractually responsible for design, construction, maintenance and/or repairs of roadway damage? Check all that apply."

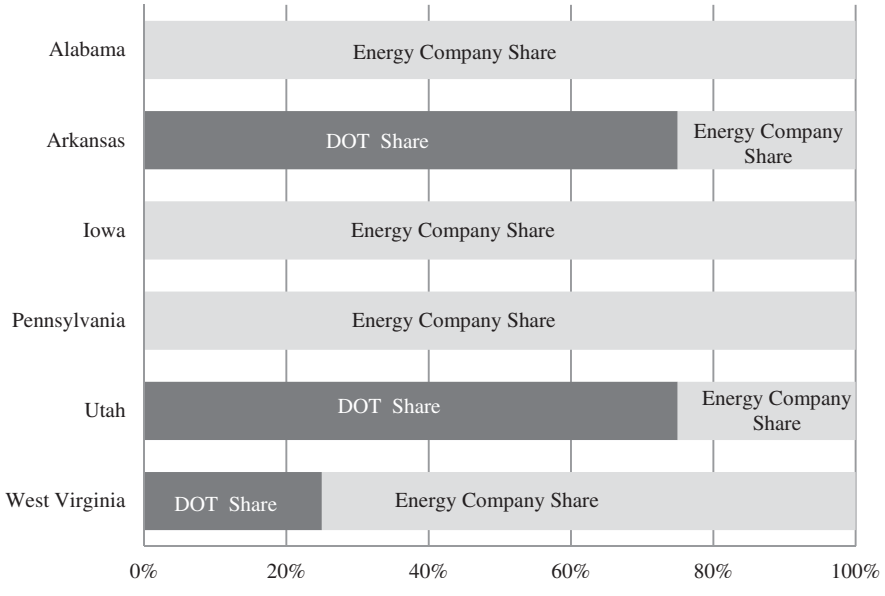

FIGURE A8 Survey response to Question 25: "Please estimate how much have you spent and/or will be spending on roadway and bridge repairs as compared to the portion which the energy company is responsible for."

TABLE A15
SURVEY RESPONSE TO QUESTION 26: "CHARACTERIZE TO WHICH CONDITIONS THE ENERGY DEVELOPERS ARE GENERALLY REQUIRED TO MAINTAIN AND/OR REPAIR THE ROADWAYS AND BRIDGES."

Response Type	Response Rate
Previously existing conditions	3%
Not required	97%

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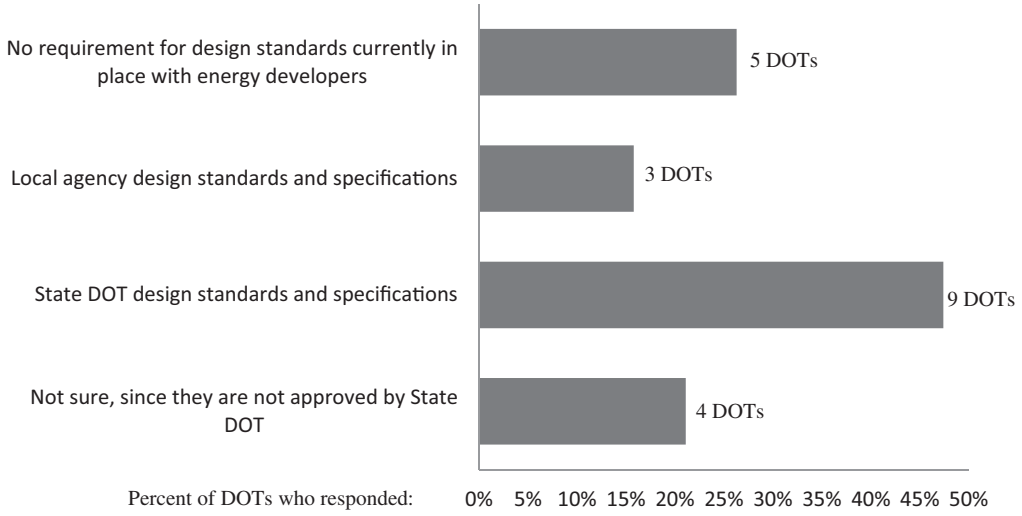

FIGURE A9 Survey response to Question 28: "Which design standards are used for roads repaired or built by energy developers? Check all that apply."

TABLE A16
SURVEY RESPONSE TO QUESTION 29: "HOW EFFECTIVE ARE THE DESIGN STANDARDS FOR ADDRESSING THE DAMAGE INCURRED BY THE INCREASED HEAVY TRUCK TRAFFIC?"

Response Type	Response Rate
Very effective	21%
Somewhat effective	21%
Not effective	11%
Research or monitoring currently underway to determine effectiveness	16%
Not sure since roads are not currently being monitored	32%

TABLE A17
SURVEY RESPONSE TO QUESTION 31: "IN THE DOCUMENTATION OF RECENT BRIDGE INSPECTIONS, HAVE THERE BEEN ANY DECREASES IN EITHER BRIDGE RATINGS OR PERFORMANCE THAT CAN BE DIRECTLY ATTRIBUTABLE TO ENERGY DEVELOPMENT ACTIVITIES IN THE AREA?"

Response Type	Response Rate
Yes	21%
No	79%

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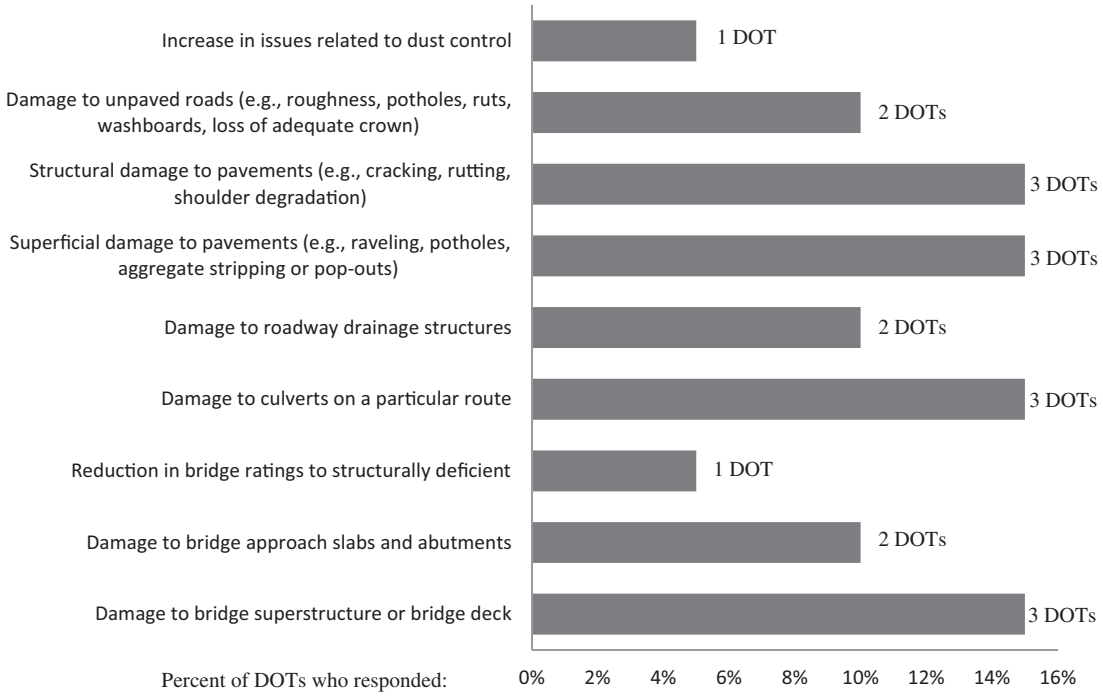

FIGURE A10 Survey response to Question 32: "Which types of damage or performance-related issues have arisen on roads and bridges due to energy development activities? Check all that apply."

TABLE A18
SURVEY RESPONSE TO QUESTION 33: "ARE THE ROADWAYS IN YOUR STATE EXPOSED TO FREEZE/THAW OR HEAVE CONDITIONS FOR A PROLONGED DURATION DURING THE YEAR?"

Response Type	Response Rate
Yes	79%
No	21%

TABLE A19
SURVEY RESPONSE TO QUESTION 34: "HAVE YOUR AGENCY OR THE LOCAL AGENCIES OBSERVED AN INCREASE OR ACCELERATION IN DAMAGE ON ROADWAYS AS BEING MORE PRONOUNCED DURING FREEZE/THAW CONDITIONS ASSOCIATED WITH ENERGY DEVELOPMENTS?"

Response Type	Response Rate
Yes	56%
No	44%

TABLE A20
SURVEY RESPONSE TO QUESTION 35: "ARE THERE ANY REGULATIONS IN PLACE TO LIMIT THE AMOUNT OF LOADING (E.G., WEIGHT RESTRICTIONS, ISSUANCE OF OVERWEIGHT PERMITS) ON ROADWAYS DURING FREEZE/THAW PERIODS?"

Response Type	Response Rate
Yes	44%
No	56%

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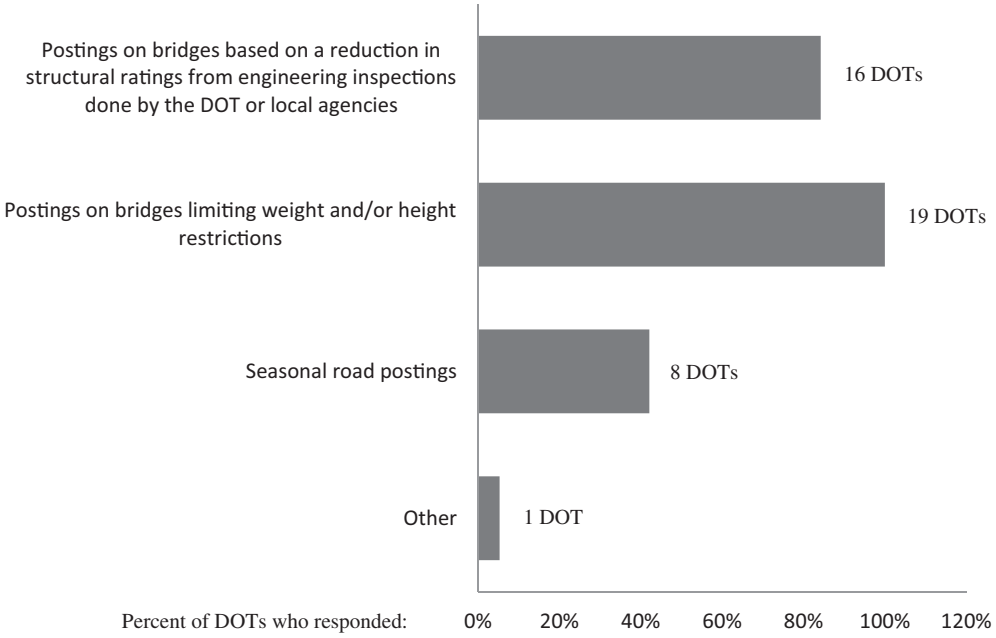

FIGURE A11 Survey response to Question 36: "What type of posting do you use for your roads and bridges in your state? Check all that apply."

TABLE A21
SURVEY RESPONSE TO QUESTION 38: "HAS THERE BEEN A NOTICEABLE INCREASE IN CRASHES INVOLVING LARGE OR HEAVY TRUCKS THAT ARE ATTRIBUTABLE TO CHANGES IN TRAFFIC COMPOSITION AS A RESULT OF ENERGY DEVELOPMENT IN RECENT YEARS IN YOUR STATE?"

Response Type	Response Rate
Yes	26%
No	74%

TABLE A22
SURVEY RESPONSE TO QUESTION 39: "PLEASE GENERALLY RATE THE LEVEL OF INCREASE IN CRASHES."

Response Type	Response Rate
Low	50%
Moderate	17%
Severe	33%

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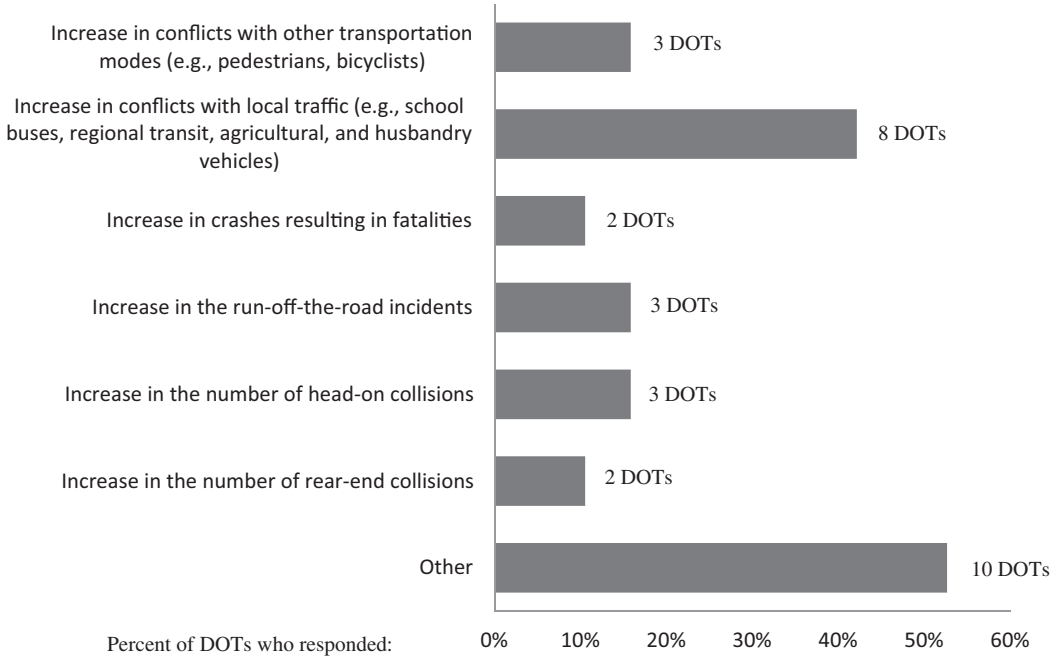

FIGURE A12 Survey response to Question 40: "Which of the following items best describes the nature in which the level of safety has been affected? Check all that apply."

TABLE A23
SURVEY RESPONSE TO QUESTION 41: "HOW IS YOUR AGENCY, OR THE LOCAL AGENCIES, ADDRESSING THE SAFETY ISSUES ATTRIBUTABLE TO THE INCREASE IN HEAVY TRUCK TRAFFIC? WHICH ONE(S) WOULD YOUR AGENCY RECOMMEND AS THE MOST EFFECTIVE PRACTICE(S)? CHECK ALL THAT APPLY. ALSO, PLEASE RATE EACH APPROACH'S LEVEL OF EFFECTIVENESS (FROM 1 TO 5, WHERE 1 IS NOT EFFECTIVE AND 5 IS VERY EFFECTIVE). PLEASE CHECK N/A IF THE PROVIDED OPTION DOES NOT APPLY TO YOUR AGENCY OR TO THE LOCAL AGENCIES."

	1	2	3	4	5	N/A	Total	Average Rating
Not addressing the issues at this time	10.53% 2	0% 0	21.05% 4	5.26% 1	0% 0	63.16% 12	19	2.57
Reinforcement of roads (e.g., use of geotextiles, stabilization of aggregates or subgrade)	10.53% 2	5.26% 1	21.05% 4	21.05% 4	5.26% 1	36.84% 7	19	3.08
Roadway geometric feature modifications (e.g., widening paved shoulder, horizontal curve re-alignment, etc.)	0% 0	0% 0	15.79% 3	26.32% 5	26.32% 5	31.58% 6	19	4.15
More frequent use of law enforcement (e.g., limit the traffic especially during the periodic heavy rainfall)	0% 0	21.05% 4	10.53% 2	26.32% 5	5.26% 1	36.84% 7	19	3.25
Encourage or require the use of detours and alternate routing for heavy trucks	0% 0	10.53% 2	15.79% 3	26.32% 5	15.79% 3	31.58% 6	19	3.69
Install additional signage to warn motorists of heavy truck traffic volumes in the area	15.79% 3	0% 0	15.79% 3	15.79% 3	5.26% 1	47.37% 9	19	2.90
Lower the posted speed limit	10.53% 2	15.79% 3	5.26% 1	15.79% 3	0% 0	52.63% 10	19	2.56
Specific state or local legislation or regulations that apply to specific energy development industries (e.g., adequate public facilities ordinances, specific road and bridges design standards, etc.).	15.79% 3	5.26% 1	5.26% 1	10.53% 2	5.26% 1	57.89% 11	19	2.63
Temporary measures such as roadway embankments	15.79% 3	5.26% 1	5.26% 1	5.26% 1	5.26% 1	63.16% 12	19	2.43
Campaigning and public outreach (e.g., ProgressZone in state of North Dakota)	5.26% 1	0% 0	10.53% 2	21.05% 4	5.26% 1	57.89% 11	19	3.50
Use of intelligent transportation systems (e.g., advance warning systems)	0% 0	21.05% 4	5.26% 1	10.53% 2	10.53% 2	52.63% 10	19	3.22

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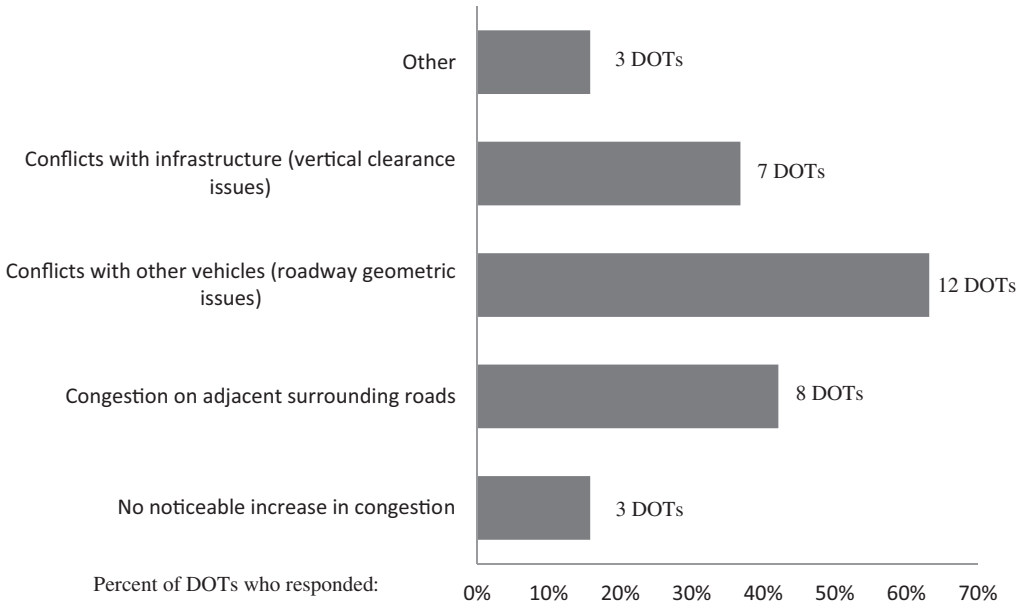

FIGURE A13 Survey response to Question 42: "Has your agency, or the local agencies, noticed any increase in the level of congestion on public roads due to the heavy truck volumes associated with energy development? Check all that apply."

TABLE A24
SURVEY RESPONSE TO QUESTION 43: "HOW IS YOUR AGENCY, OR THE LOCAL AGENCIES, ADDRESSING ANY ISSUES RELATED TO INCREASED ROADWAY CONGESTION? CHECK ALL THAT APPLY. ALSO, PLEASE RATE EACH APPROACH'S LEVEL OF EFFECTIVENESS (FROM 1 TO 5, WHERE 1 IS NOT EFFECTIVE AND 5 IS VERY EFFECTIVE). PLEASE CHECK N/A IF THE PROVIDED OPTION DOES NOT APPLY TO YOUR AGENCY OR TO THE LOCAL AGENCIES."

	1	2	3	4	5	N/A	Total	Average Rating
Encourage use of detours or alternate routing for heavy trucks	12.50% 2	12.50% 2	18.75% 3	12.50% 2	6.25% 1	37.50% 6	16	2.80
Install increased signage to warn motorists of heavy truck traffic volumes	18.75% 3	6.25% 1	0% 0	18.75% 3	6.25% 1	50% 8	16	2.75
Use of intelligent transportation systems (e.g., advance warning system)	18.75% 3	6.25% 1	6.25% 1	18.75% 3	6.25% 1	43.75% 7	16	2.78
Collaborate with energy development companies to adjust the timing and logistics of the truck movements (e.g., staged truck routing schedule)	6.25% 1	18.75% 3	0% 0	18.75% 3	12.50% 2	43.75% 7	16	3.22

TABLE A25
SURVEY RESPONSE TO QUESTION 44: "HAS THERE BEEN A NOTICEABLE INCREASE IN THE ISSUANCE OF OVERSIZE/OVERWEIGHT (OS/OW) PERMITS FROM YEAR TO YEAR IN YOUR STATE?"

Response Type	Response Rate
Yes	84%
No	16%

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TABLE A26
SURVEY RESPONSE TO QUESTION 45: "PLEASE GENERALLY RATE THE LEVEL OF INCREASE IN THE ISSUANCE OF OS/OW PERMITS."

Response Type	Response Rate
0–25% increase	53%
25–50% increase	29%
50–75% increase	6%
75–100% increase	12%

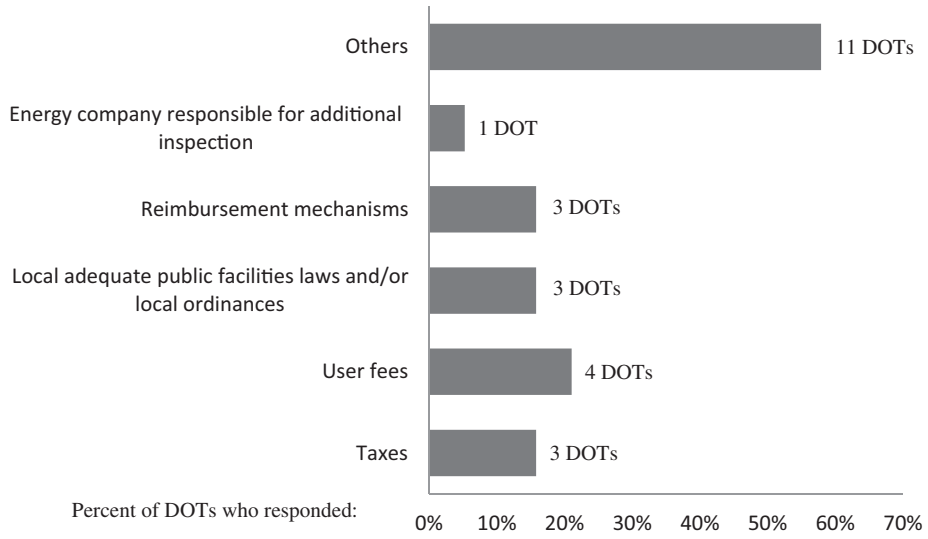

FIGURE A14 Survey response to Question 47: "In order to deal with the challenges listed in the previous question, please share some tools that have been used in your state to assess and pay for damages to roads related to energy development. Check all that apply." Question 47 also required an open-ended response, and the responses received are synthesized within the body of the report.

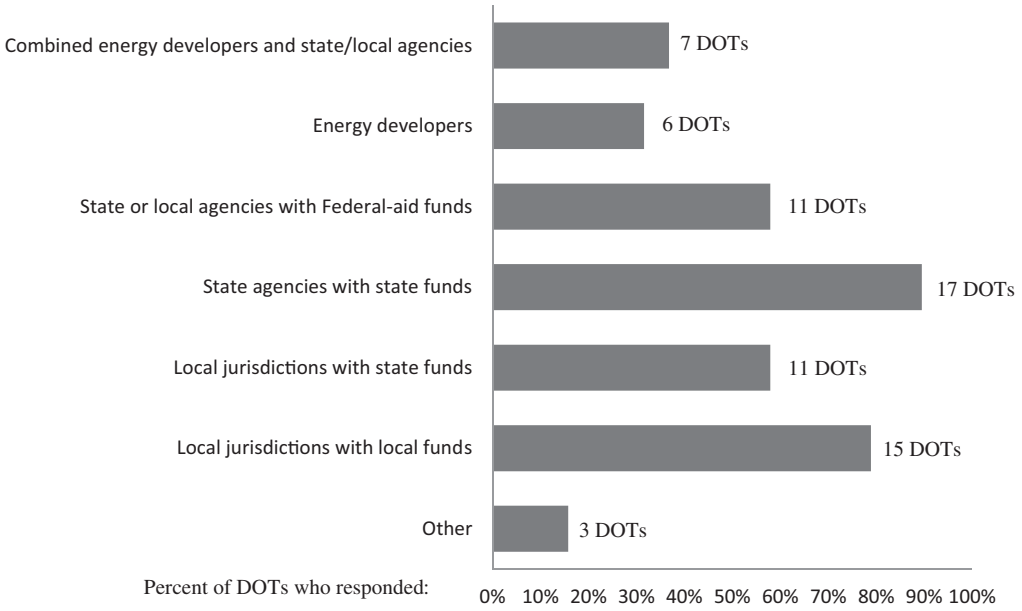

FIGURE A15 Survey response to Question 48: "Who funds the repairs of public roads in the vicinity of energy development areas? Check all that apply."

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TABLE A27
SURVEY RESPONSE TO QUESTION 49: "ARE THE METROPOLITAN PLANNING ORGANIZATIONS (MPOS) AND/OR REGIONAL PLANNING ORGANIZATIONS (RPOS), OR EQUIVALENT PLANNING GROUPS, ENGAGED IN THE PROCESS OF WORKING WITH THE ENERGY DEVELOPERS ON MANAGING THE DAMAGE TO PUBLIC ROADS?"

Response Type	Response Rate
Yes	26%
No	74%

TABLE A28
SURVEY RESPONSE TO QUESTION 50: "DOES YOUR AGENCY SHARE DATA WITH THE LOCAL AGENCIES RELATED TO THE IMPACTS ON PUBLIC ROADWAYS WHEN ENERGY DEVELOPMENT ISSUES ARE IDENTIFIED?"

Response Type	Response Rate
Yes	68%
No	32%

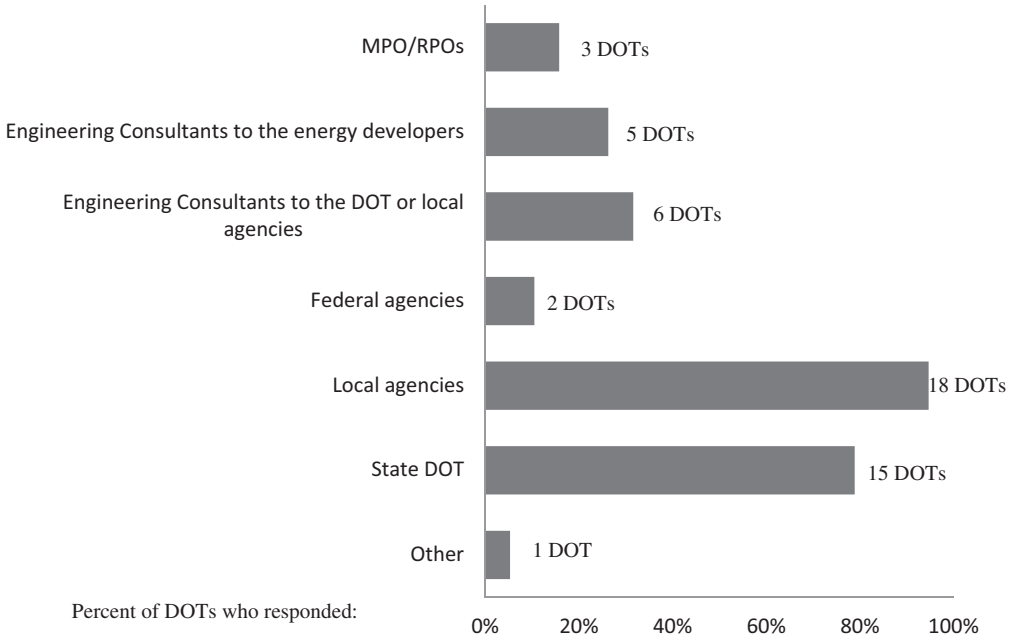

FIGURE A16 Survey response to Question 51: "Which entities communicate the most often with the energy developers when issues are identified or in approving development and operational plans? Check all that apply."

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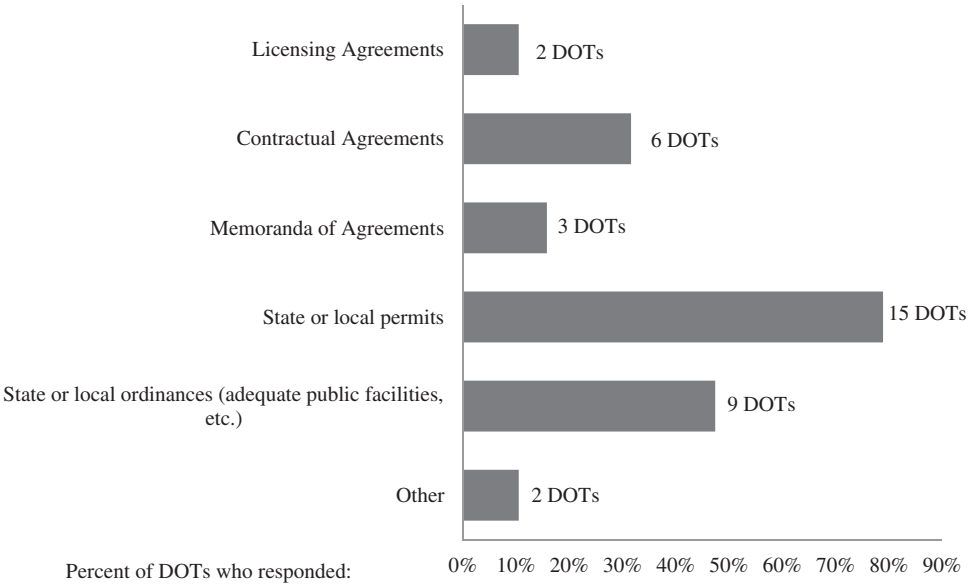

FIGURE A17 Survey response to Question 52: "Which types of contractual agreements exist in your state to allow the public roads to be used by energy developers? Check all that apply."

TABLE A29
SURVEY RESPONSE TO QUESTION 53: "ARE YOU AWARE OF PRACTICES BEING USED EFFECTIVELY BY FEDERAL AND TRIBAL AGENCIES IN DEALING WITH THE ISSUE OF INCREASED DAMAGE TO THEIR ROADWAYS?"

Response Type	Response Rate
Yes	0%
No	100%

TABLE A30
SURVEY RESPONSE TO QUESTION 54: "IS YOUR AGENCY OR ARE LOCAL AGENCIES TRACKING OR QUANTIFYING OTHER IMPACTS DUE TO ENERGY DEVELOPMENT, SUCH AS SOCIAL, ENVIRONMENTAL, OR FINANCIAL RAMIFICATIONS?"

Response Type	Response Rate
Yes	26%
No	74%

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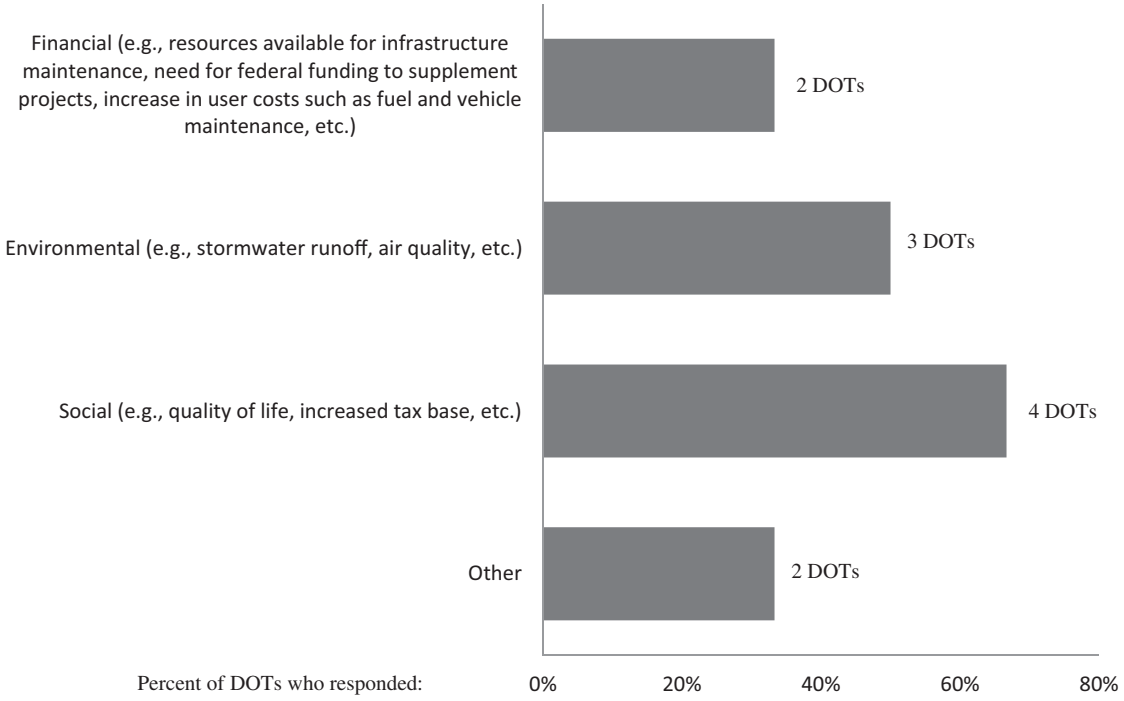

FIGURE A18 Survey response to Question 55: "You answered YES to the question 'Is your agency or are local agencies tracking or quantifying other impacts due to energy development, such as social, environmental, or financial ramifications.' Please check all that apply."

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APPENDIX B

Sample Documents that Support Practices Addressing Impacts of Energy Development on Transportation Infrastructure

Appendix B is web-only and can be found at www.trb.org, search "NCHRP Synthesis 469."

Colorado

Weld County Special Transport Permit Application
Weld County Access Permit Application Form
Routt County Special Use Permit
La Plata County Special Transport Permit

Iowa

Instructional Memorandums to Local Public Agencies #2.120
Delaware County Ordinance #32
Johnson County Resolution Approving Conditional Use Permit Fees for Wind Energy Facilities
Johnson County Ordinance Amending the Johnson County Unified Development Ordinance to Permit Private Wind Generators as Accessory Uses and Distributed Wind Generators as Conditionally Permitted Uses
Story County Conditional Use Permit
Delaware County Maintenance Agreement
Delaware County One Stop Permit
Delaware County Commercial Wind Energy Conversion System Building Permit Application

North Dakota

Road Design, Construction and Maintenance Agreement
ND Traffic Safety: Oil Counties

Pennsylvania

M-4902-MP (8-13) Maintenance Plan
Strike-off Letter, Posted and Bonded Roads Program
Bridge Posting Memorandum

Texas

County Transportation Infrastructure Fund Grant Agreement

U.S. Department of Agriculture Forest Service

Non-Federal Commercial Road Use Permit
Permit for Use of Roads, Trails, or Areas Restricted by Regulation or Order

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APPENDIX C

Links to Resources Identified

Several findings contained in this synthesis report can also be found online at the various agency websites. A series of links to the online resources are presented here.

Colorado

El Paso County Oil and/or Gas Application Permit http://www.elpasoco.com/OilAndGas/Documents/Oil%20and%20Gas%20Application.pdf

La Plata County Memoranda of Agreement http://www.co.laplata.co.us/sites/default/files/departments/planning/documents/2014%20Samson%20Mesaverde%20Infill%20MOU%20Executed.pdf

Pennsylvania

PennDOT Posted and Bonded Roadway Program www.papostedroads.pa.gov

PennDOT Publication 23 Maintenance Manual ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/PUB%2023/PUB%2023.pdf

PennDOT Publication 408 Highway Construction Specifications ftp://ftp.dot.state.pa.us/public/bureaus/design/pub408/pub%20408-2011.pdf

Texas

Oversize/Overloading Permit http://ftp.dot.state.tx.us/pub/txdot-info/energy/osow_technical.pdf

House Bill 1025 http://www.capitol.state.tx.us/tlodocs/83R/billtext/pdf/HB01025F.pdf#navpanes=0.pdf

State Bill 1747 http://www.capitol.state.tx.us/tlodocs/83R/billtext/pdf/SB01747F.pdf

Tribal Nations

Southern Ute Indian Tribe Long Range Transportation Plan http://www.southernute-nsn.gov/wp-content/uploads/2013/04/Final_Corridor_Plan.pdf

U.S. Department of Agriculture Forest Service

Surface Operating Standards and Guidelines for Oil and Gas Exploration and Development: http://www.blm.gov/pgdata/etc/medialib/blm/wo/MINERALS__REALTY__AND_RESOURCE_PROTECTION_/energy/oil_and_gas.Par.18714.File.dat/OILgas.pdf

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APPENDIX D

Specific Effective Practices Identified by Focus States

Examples for practices reported from each of the five focus states are presented here.

TABLE D1
SPECIFIC PRACTICES FOR ADDRESSING THE IMPACTS OF ENERGY DEVELOPMENT ACTIVITIES ON ROADS AND BRIDGES AS IDENTIFIED BY FOCUS STATES

Topic	State	Description of Practice
Practices for Addressing Engineering Design Challenges	Colorado	Use of Pavement ME Design® software that evaluates the roadways and develops performance curve
	Iowa	Systematic routing of trucks combined with permitting, geometric improvements to the roads (especially for turning radii), assessing the structural damage to roads and bridges, adjust pavement design standards to a higher level, aggressive dust control program, shoulder stabilization, and use of geosynthetics on county gravel roads and cement stabilization of subbases
	North Dakota	Accurate forecast of the anticipated truck traffic volumes in the energy development areas
		Experimental basis pavement design for roads that are experiencing heavy truck traffic
		Use of cement-treated subbases, surface treatment with increased thickness (12 to 16 inches) on major collectors, and geosynthetic materials such as geogrids
		Predictive model developed to analyze capabilities (based on both average and frozen moduli) of various subgrade soils to support heavy loads
	Pennsylvania	A biweekly roadway inspection on all posted roadways
		Consistent communication between PennDOT and Marcellus Shale Coalition
		Energy companies' responsibility for inspecting roads they use and have built, reconstructed, or repaired
		Use of FDR and cement-stabilization of pavements
	Texas	Developing best practices for pavement structural design and assessment, nondestructive testing tools (FWD, GPR) to evaluate existing pavement structural conditions
		Monitoring effectiveness of structures being built with proposed design methods
		Use of emergency load zone posting when pavement conditions are rated as significantly poor due to the extra amount of heavy trucks generated by energy developers
State and Local Legislation and Regulations	North Dakota	The state legislature has provided general fund money from the oil extraction fund to DOT and local jurisdictions for road and bridge improvements
		One Stop permit, building permit, and conditional use permit
	Pennsylvania	Chapter 189 of the 67 Pa. Code applies to haulers from all industries, including energy development, associated with any posted and bonded roads
		Comprehensive Pennsylvania ACT 13 legislation, a tax on energy companies based on level of drilling activity
Tools to Assess Costs and Contractual Agreements	Colorado	A portion of energy tax going to trust fund Local agencies are developing fees to address issues with infrastructure damage
		Application of severance tax, which is imposed on non-renewable natural resources removed from the earth in Colorado. Calculated based on gross income from crude oil, natural gas, carbon dioxide, oil (including shale oil), and gas severed from the earth in Colorado
	Iowa	Base pavement deterioration rate on measurement of incremental maintenance costs on pavement for new traffic generated as a result of energy development; consists of calculating the total ESALs resulting from energy development, then comparing it to the number of ESALs for which the road was designed.
		Permit cost quantification and county Road Preservation Ordinances that permit collection of funds for repair of road damage caused by renewable energy industry
		Establishment of Tax Increment Financing (TIF) counties that are financed through issuance of general obligation bonds
	North Dakota	Various financing and operating agreements such as Oil Gas production tax, and Oil Extraction tax
	Pennsylvania	Energy developers responsible for necessary Pennsylvania DOT inspection fees Requirement for energy development companies to submit an annual roadway maintenance plan to inform Pennsylvania DOT, an excess maintenance agreement, security bond, and permit
	Texas	Formula for counties through SB 1747 that designates energy transportation reinvestment zone Ad-hoc method (http://www.roadsfortexasenergy.com)
		In March 2012, a task force, composed of representatives from state agencies, local governments and the energy industry, was formed to find ways to address the impact on the state's infrastructure of increased energy development activities
		Other identified practices from Texas DOT are the development of standard lease agreement with an associated fee, as well as the temporary use of water lines in state right-of-way in order to reduce roadway truck volumes

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TABLE D1
(*continued*)

Topic	State	Description of Practice
Practices to Mitigate for Impacts on Safety	Colorado	Institution of both public service and other media announcements to warn the traveling public Deployment of regulation signage Application of an aggressive dust stabilization program to help prevent the loss of gravel on unpaved roads
	Iowa	Modify roadway geometric features such as building temporary road embankments. Encourage or require the use of detours and alternate routing for heavy trucks. Proactively review any proposed facilities along with local jurisdictions and attempt to provide appropriate improvements
	North Dakota	Campaigning and public outreach (ProgressZone)
	Pennsylvania	LTAP offered courses to educate local agencies on how to legally enforce weight limits and to collect costs from energy developers for the infrastructure damages
		Revoke of road use permit when repairs are not made. Proactive roadway monitoring and roadway repair responsibility assignment to energy companies
	Texas	Roadway geometric feature modifications, revision of speed limits, and addition of signs and traffic signals
Practices to Mitigate for Impacts on Operations	Iowa	Encourage use of detours or alternate routing for heavy trucks and collaborate with energy development companies to adjust timing and logistics of truck movements
		Upgrade of two-lane roads to four-lane corridors to add capacity
	Texas	Install increased signage to warn motorists of heavy truck traffic volumes, and use of intelligent transportation systems
Program Organization	Colorado	Colorado Oil and Gas Conservation Commission to administer regulatory process on oil and gas development
		Energy Impact Grant program
Manuals and Training	Pennsylvania	Pennsylvania DOT implementing FDR specification for DOT Publication 408 Construction Specifications in order to ensure consistent quality for its use on low-volume roads impacted by energy development activities, as well as all state-owned roadways within the Commonwealth
		DEP has developed guidelines for the spreading of brine on unpaved roads used to control dust, found under the authority of Clean Streams Law, the Solid Waste Management Act, and Chapters 78 and 101 of the Rules and Regulations
		Penn State University published the Environmentally Sensitive Road Maintenance for Dirt and Gravel Roads manual that provides information on practices that are designed to reduce the long-term maintenance costs on low-volume rural roads and to address runoff and sediment pollution to nearby vegetation and forests
	Texas	Training workshops conducted by Texas DOT technical specialists and Texas A&M University held every 3 to 6 months with Texas DOT maintenance personnel in Districts impacted by energy development, focusing on pavement improvement techniques and issues related to topics such as subgrade performance, pavement stabilization methods, etc.

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Abbreviations used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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