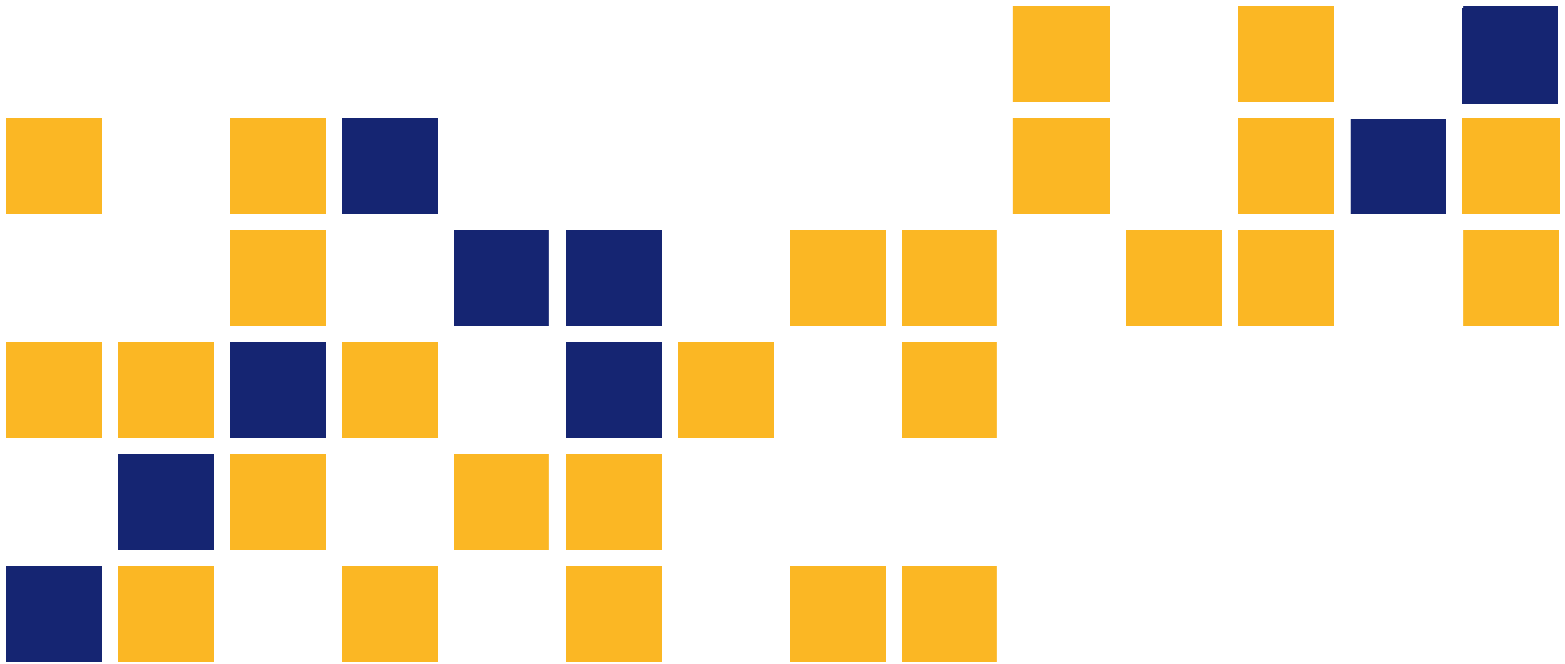


Pavement Deterioration Due to Horizontal Hydraulic Fracturing and Wind Farm Development in Kansas

Steven D. Schrock, Ph.D., P.E., F.ITE
Mazharali Udaipurwala
Jie Han, Ph.D., P.E., F.ASCE
Robert Parsons, Ph.D., P.E.

The University of Kansas



1 Report No. KS-16-18	2 Government Accession No.	3 Recipient Catalog No.	
4 Title and Subtitle Pavement Deterioration Due to Horizontal Hydraulic Fracturing and Wind Farm Development in Kansas		5 Report Date March 2017	6 Performing Organization Code
		7 Performing Organization Report No.	
7 Author(s) Steven D. Schrock, Ph.D., P.E., F.ITE, Mazharali Udaipurwala, Jie Han, Ph.D., P.E., F.ASCE, Robert Parsons, Ph.D., P.E.		10 Work Unit No. (TRAIS)	
9 Performing Organization Name and Address The University of Kansas Department of Civil, Environmental and Architectural Engineering 1530 West 15th St Lawrence, Kansas 66045-7609		11 Contract or Grant No. C1953	
		13 Type of Report and Period Covered Final Report January 2013–August 2014	
12 Sponsoring Agency Name and Address Kansas Department of Transportation Bureau of Research 2300 SW Van Buren Topeka, Kansas 66611-1195		14 Sponsoring Agency Code RE-0616-01	
		15 Supplementary Notes For more information write to address in block 9.	
<p>The purpose of this research was to determine the impact on pavements and roadbeds due to the increase in truck traffic from oil and gas fracking activities, as well as from expansion of the wind energy industry, and estimate the resulting reduction in roadway service life for typical two-lane KDOT roadways. In addition to KDOT roadways, this research can also be used as a proxy for county-level or other local jurisdiction-level paved roadways.</p> <p>This research used the Mechanistic-Empirical Pavement Design Guide software to estimate the shortening of useful life of typical Kansas two-lane rural roadways using both the International Roughness Index (IRI) and total rutting as measures of deterioration. Five roadways from south central Kansas were modeled. It was found that even for large increases in truck traffic, the IRI values only showed a reduction in service life of from 1 to 2 years. However, total rutting showed much larger reductions of from 9 to 19 years, which reflected a shortening of pavement life of from 35 to 50 percent.</p>			
17 Key Words Pavement Damage, Mechanistic Empirical Pavement Design Guide, Wind Farms, Oil and Gas Fracking		18 Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service www.ntis.gov .	
19 Security Classification (of this report) Unclassified	20 Security Classification (of this page) Unclassified	21 No. of pages 60	22 Price

Form DOT F 1700.7 (8-72)

This page intentionally left blank.

Pavement Deterioration Due to Horizontal Hydraulic Fracturing and Wind Farm Development in Kansas

Final Report

Prepared by

Steven D. Schrock, Ph.D., P.E., F.ITE
Mazharali Udaipurwala
Jie Han, Ph.D., P.E., F.ASCE
Robert Parsons, Ph.D., P.E.

The University of Kansas

A Report on Research Sponsored by

THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

and

THE UNIVERSITY OF KANSAS
LAWRENCE, KANSAS

March 2017

© Copyright 2017, **Kansas Department of Transportation**

NOTICE

The authors and the state of Kansas do not endorse products or manufacturers. Trade and manufacturers names appear herein solely because they are considered essential to the object of this report.

This information is available in alternative accessible formats. To obtain an alternative format, contact the Office of Public Affairs, Kansas Department of Transportation, 700 SW Harrison, 2nd Floor – West Wing, Topeka, Kansas 66603-3745 or phone (785) 296-3585 (Voice) (TDD).

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or the policies of the state of Kansas. This report does not constitute a standard, specification or regulation.

Abstract

The purpose of this research was to determine the impact on pavements and roadbeds due to the increase in truck traffic from oil and gas fracking activities, as well as from expansion of the wind energy industry, and estimate the resulting reduction in roadway service life for typical two-lane KDOT roadways. In addition to KDOT roadways, this research can also be used as a proxy for county-level or other local jurisdiction-level paved roadways.

This research used the Mechanistic-Empirical Pavement Design Guide software to estimate the shortening of useful life of typical Kansas two-lane rural roadways using both the International Roughness Index (IRI) and total rutting as measures of deterioration. Five roadways from south central Kansas were modeled. It was found that even for large increases in truck traffic, the IRI values only showed a reduction in service life of from 1 to 2 years. However, total rutting showed much larger reductions of from 9 to 19 years, which reflected a shortening of pavement life of from 35 to 50 percent.

Acknowledgements

The authors would like to thank the Kansas Department of Transportation for sponsorship of this project, and for the technical assistance provided by Mr. Brent Terstriep (District Construction Engineer, District 5), Mr. Don Schneider (Area Engineer, Harper County), and Mr. Rick Miller (State Pavement Management Engineer).

Table of Contents

Abstract	v
Acknowledgements	vi
Table of Contents	vii
List of Tables	viii
List of Figures	ix
Chapter 1: Introduction	1
1.1 Overview	1
1.2 Problem Statement	8
1.3 Organization	8
Chapter 2: Literature Review	9
2.1 Highway Impacts Due to the Oil and Gas Industry	9
2.2 Wind Farms	13
2.3 Summary of Literature Review	16
Chapter 3: Methodology and Experimental Design	17
3.1 Use of the MEPDG	21
3.1.1 Methodology for Adding Truck Trips due to Oil and Gas Fracking Activities	25
3.1.2 Methodology for Adding Truck Trips due to Wind Farm Activities	28
Chapter 4: Research Findings	30
4.1 Results of Estimated Pavement Damage due to Oil and Gas Fracking Activity	30
4.2 Results of Estimated Pavement Damage due to Wind Farm Traffic	36
Chapter 5: Discussion	43
References	45
Appendix: Kansas Wind Farm Data	47

List of Tables

Table 2.1:	Assumed Heavy Truck Trips used for the Construction and Operation of a Single Well in Pennsylvania.....	11
Table 2.2:	Characteristics of Roads Assumed to be used for Construction and Operation of Shale Gas Wells in Pennsylvania	12
Table 2.3:	Estimated Consumptive Road Use	12
Table 2.4:	Estimates of Truck Traffic Associated with Site Preparation for a Single Typical Wind Turbine (Siemens 2.3 MW).....	15
Table 2.5:	Specialized Vehicles used for Moving Wind Turbine Components	15
Table 2.6:	Overall Impact on Texas Highway Infrastructure due to Wind Farm Traffic.....	16
Table 4.1:	Service Life Reductions Due to Additional Oil and Gas Fracking Traffic and Wind Farm Construction Traffic	42
Table A.1:	Kansas Wind Farm Data.....	47

List of Figures

Figure 1.1:	Number of Oil and Gas Wells in Kansas by Year.....	1
Figure 1.2:	Top 10 Kansas Counties for Oil and Gas Production	2
Figure 1.3:	Example of Horizontal Hydraulic Fracturing to Extract Oil and/or Gas	3
Figure 1.4:	Diagram Showing Multiple Fracking Wells from a Single Drill Site.....	4
Figure 1.5:	United States Annual Average Wind Speed at 80 m	5
Figure 1.6:	View of Elk River Wind Farm in Butler County	6
Figure 1.7:	View of Smoky Hills Wind Farm in Ellsworth and Lincoln Counties	6
Figure 1.8:	Counties with Wind Farms in Operation or Under Construction.....	7
Figure 1.9:	Counties with Wind Farms Under Consideration	7
Figure 2.1:	Flow Chart of Analysis Procedure for Determining Pavement Serviceability	10
Figure 3.1:	Reported Composition of K-1 in Comanche County South of US-183.....	19
Figure 3.2:	Reported Composition of K-42 between Rago and Norwich	19
Figure 3.3:	Reported Composition of K-44 East of Anthony.....	20
Figure 3.4:	Reported Composition of K-179 South of Anthony	20
Figure 3.5:	Reported Composition of US-160 South of Coldwater	21
Figure 3.6:	Approximated Composition of K-1 used for Analysis.....	22
Figure 3.7:	Approximated Composition of K-42 used for Analysis.....	23
Figure 3.8:	Approximated Composition of K-44 used for Analysis.....	23
Figure 3.9:	Approximated Composition of K-179 used for Analysis.....	24
Figure 3.10:	Approximated Composition of US-160 used for Analysis	24
Figure 3.11:	Choosing the Suitable Layer Configuration and Setting the IRI Parameter	26
Figure 3.12:	Selection of Binder for the Asphalt Pavements	27
Figure 3.13:	Creation of a Virtual Climate Station near Wichita	27
Figure 3.14:	Traffic Inputs.....	28
Figure 4.1:	IRI Results for K-1 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic	31
Figure 4.2:	Pavement Rutting Depth Results for K-1 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic	32

Figure 4.3: IRI Results for K-42 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic	32
Figure 4.4: Pavement Rutting Depth Results for K-42 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic	33
Figure 4.5: IRI Results for K-44 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic	33
Figure 4.6: Pavement Rutting Depth Results for K-44 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic	34
Figure 4.7: IRI Results for K-179 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic	34
Figure 4.8: Pavement Rutting Depth Results for K-179 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic	35
Figure 4.9: IRI Results for US-160 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic	35
Figure 4.10: Pavement Rutting Depth Results for US-160 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic	36
Figure 4.11: IRI Results for K-1 for Different Amounts of Wind Farm Traffic	37
Figure 4.12: Pavement Rutting Depth Results for K-1 for Different Amounts of Wind Farm Traffic	38
Figure 4.13: IRI Results for K-42 for Different Amounts of Wind Farm Traffic	38
Figure 4.14: Pavement Rutting Depth Results for K-42 for Different Amounts of Wind Farm Traffic	39
Figure 4.15: IRI Results for K-44 for Different Amounts of Wind Farm Traffic	39
Figure 4.16: Pavement Rutting Depth Results for K-44 for Different Amounts of Wind Farm Traffic	40
Figure 4.17: IRI Results for K-179 for Different Amounts of Wind Farm Traffic	40
Figure 4.18: Pavement Rutting Depth Results for K-179 for Different Amounts of Wind Farm Traffic	41
Figure 4.19: IRI Results for US-160 for Different Amounts of Wind Farm Traffic	41
Figure 4.20: Pavement Rutting Depth Results for US-160 for Different Amounts of Wind Farm Traffic	42

Chapter 1: Introduction

1.1 Overview

Kansas has a long history of energy production. In some of the earliest surveys of the state, it was clear that petroleum products were present near the surface, with recorded instances of oil seeping to the surface through rock faces noted by settlers. Kansas's first oil well was drilled in 1860 (Skelton, 2011). From this modest start, the oil and gas industry in Kansas expanded, and as shown in Figure 1.1, by the 1950s there were over 25,000 wells in the state. By 2015, this had increased to 77,821 wells (Kansas Geological Survey, 2016).

Figure 1.2 shows that rather than being distributed evenly across the state, oil and gas production is concentrated predominantly in western Kansas, with the most active areas located in the Kansas Department of Transportation's (KDOT) Districts Three, Five, and Six.

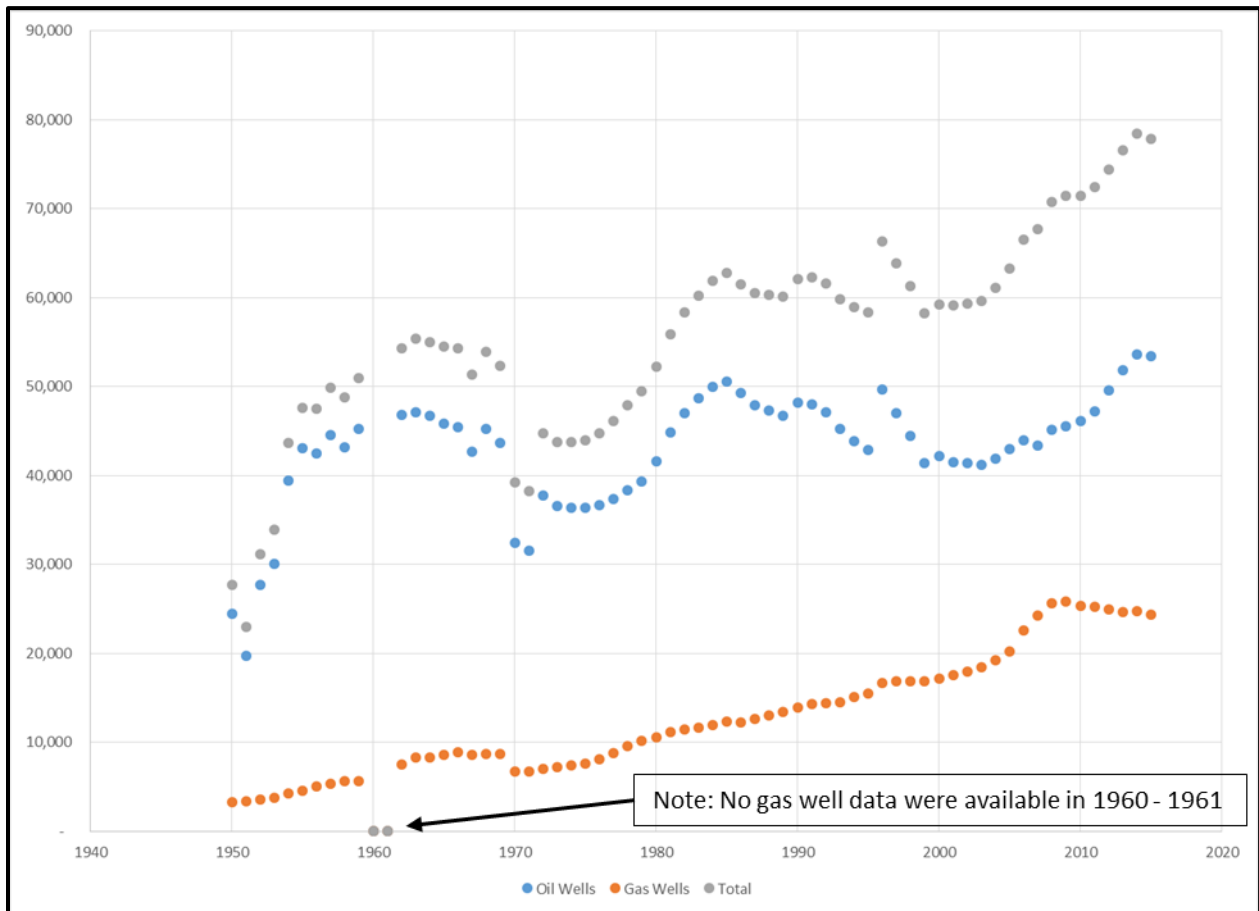


Figure 1.1: Number of Oil and Gas Wells in Kansas by Year

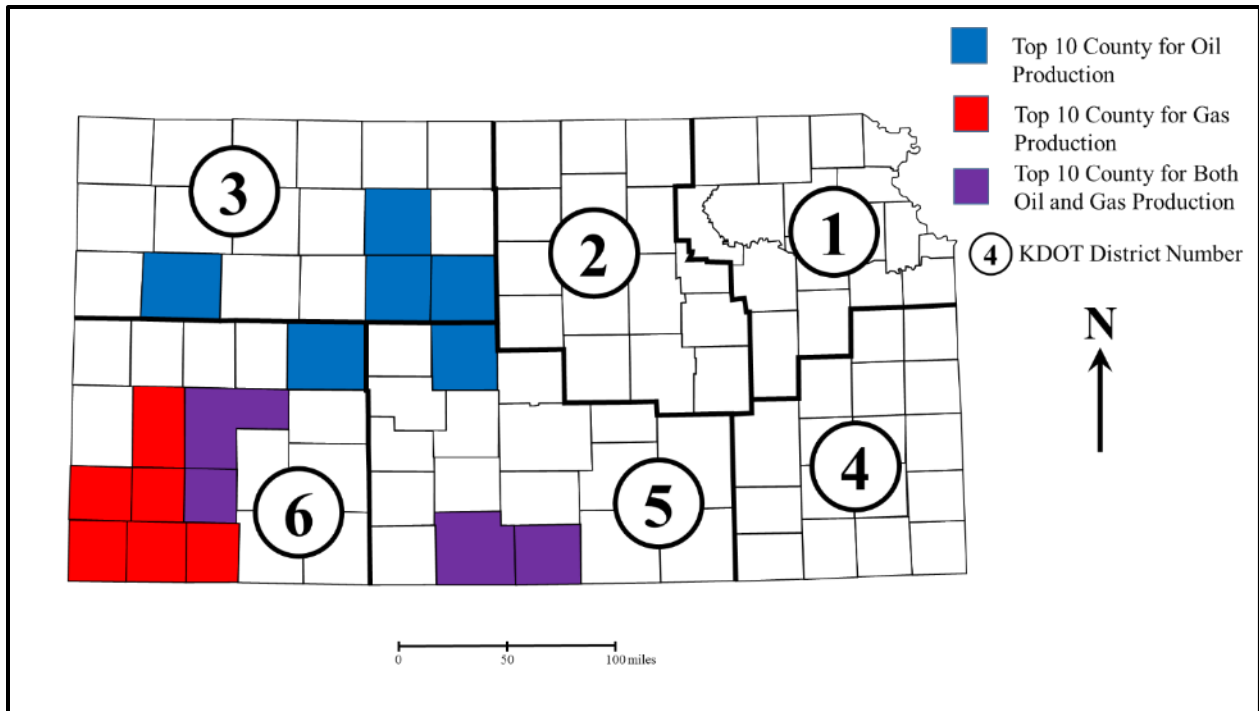


Figure 1.2: Top 10 Kansas Counties for Oil and Gas Production

Adapted from Kansas Geological Survey (2016)

In recent years, several developments have occurred in the energy industry that have the potential to negatively impact the roadway infrastructure in Kansas. The first is an innovation in the oil and gas industry which greatly increases the truck traffic for the construction and operation of each well: horizontal hydraulic fracturing. Known more generally as “fracking,” this is a process of drilling horizontally in order to extract oil and/or gas from a particular layer of rock such as shale (Suchy & Newell, 2012). A diagram depicting this process is shown in Figure 1.3. Fracking has existed as a technique for decades (the first well to experiment with fracking was actually in Grant County, Kansas, in 1947), but it was not economically feasible until the 2000s. Once it was possible to profitably drill using fracking techniques, its use spread rapidly worldwide; by the year 2000, there were over 2,000 fracked wells in Kansas and by 2015 there were over 7,000 such wells (Chow, 2015).

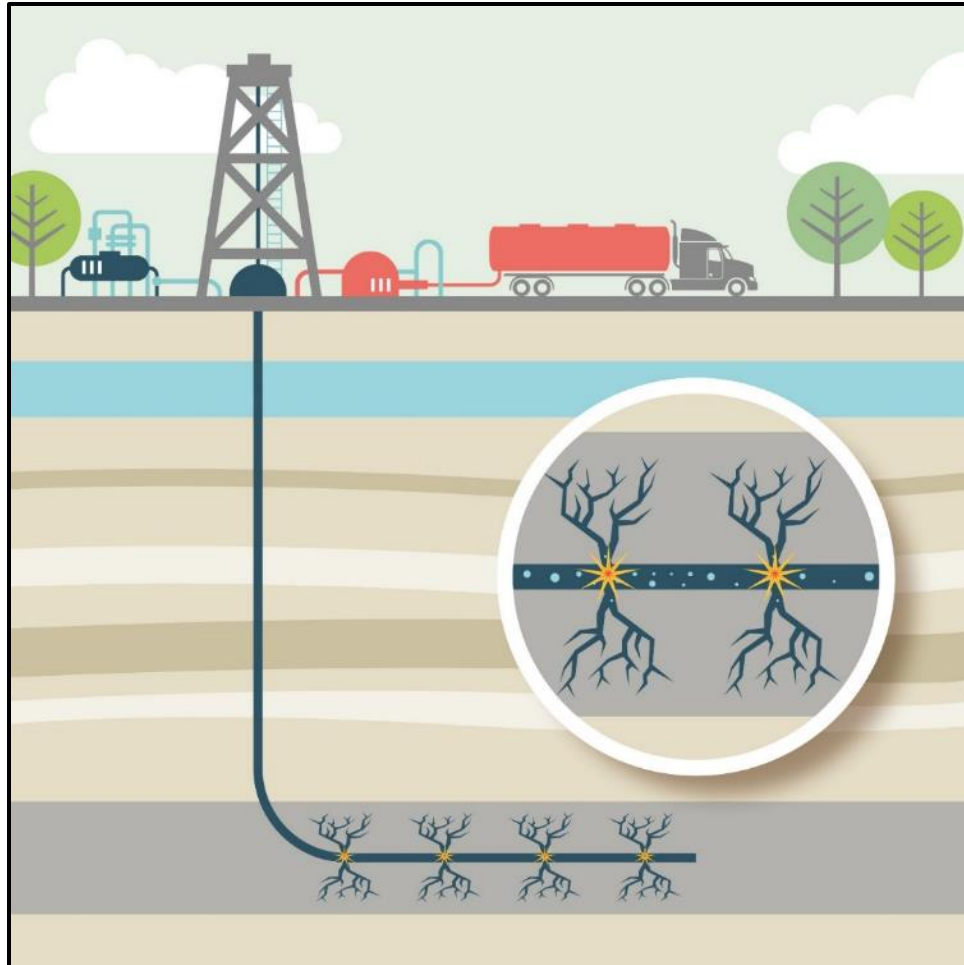


Figure 1.3: Example of Horizontal Hydraulic Fracturing to Extract Oil and/or Gas
Source: University of Michigan Energy Institute (2013)

While fracking can increase the ability of the oil and gas industry to increase production in previously non-viable locations, it is achieved only through an increased intensity of the amount of material delivered to the well site. Multiple wells are drilled from a single location, reaching out horizontally in many directions from the drilling location, as shown in Figure 1.4. This requires many miles of pipe and other materials for each location, all delivered by heavy trucks. Once the wells are drilled, the fracturing step takes place, which consists of forcing water into the wells at great pressure to create cracks in the rock layer so the oil and/or gas can flow to the well. In order to keep the cracks open, proppant (usually sand or ceramic beads) is injected into each well. Again, the proppant must also be delivered to the drilling site, further increasing the truck volume on the adjacent roadway network.

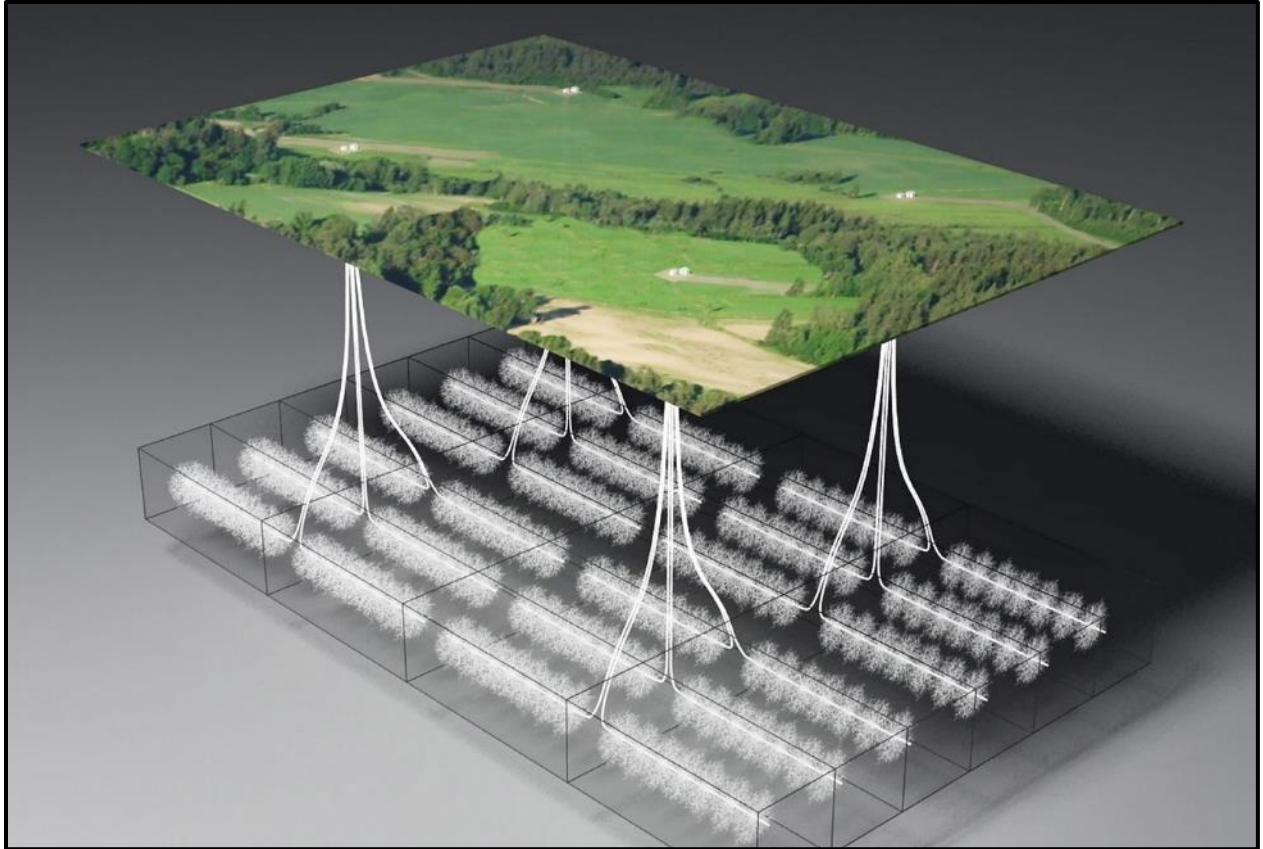


Figure 1.4: Diagram Showing Multiple Fracking Wells from a Single Drill Site

Source: Linley (2011)

The second innovation in the energy industry is the concentration of wind turbines to produce electricity. While windmills have been used since antiquity for mechanical purposes such as pumping water and grinding grain, wind turbines became useful in electricity generation in 1887 when a Scottish electrical engineering professor equipped a wind turbine to an electric turbine (Price, 2009). Due to the relatively cheap and abundant existence of oil and gas products, the development of wind as an alternative energy source did not develop until the 1970s, as a response to both the energy crisis from the Organization of the Petroleum Exporting Countries (OPEC) and the growing demand for alternatives to nuclear power (ProCon.org, 2013). In order to maximize the return on investment for each wind turbine, it is clear that the wind turbine should be located in an area of consistently high winds. As shown in Figure 1.5, Kansas is part of a swath of the United States stretching from North Dakota to Texas that is considered economically attractive for the placement of these wind turbines. The National Renewable

Energy Laboratory (NREL) rates Kansas as second only to Texas in wind electricity generation potential (NREL, 2011).

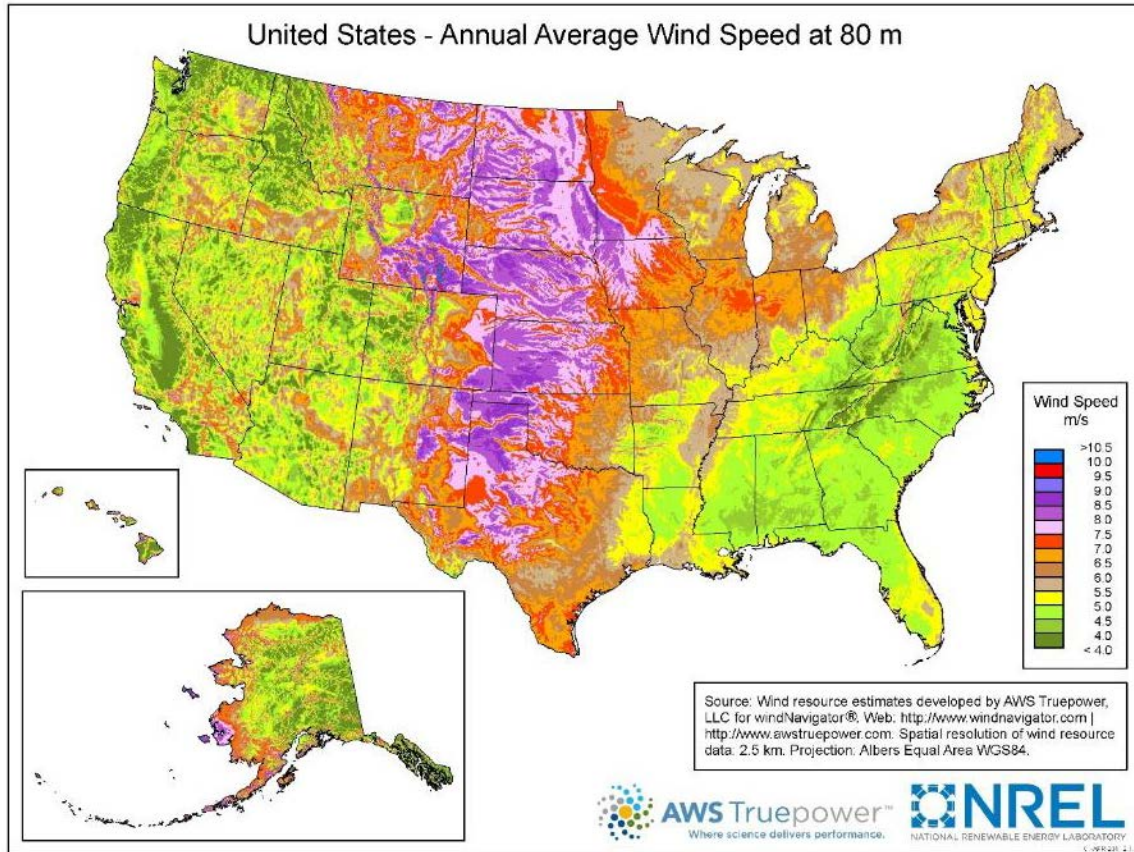


Figure 1.5: United States Annual Average Wind Speed at 80 m
Source: NREL (2011)

In addition, there is an advantage to grouping wind turbines together to minimize the infrastructure of the electricity collection network. These concentrations are known as “wind farms.” Examples of wind farms in central Kansas are shown in Figures 1.6 and 1.7. The types of wind turbines shown in Figure 1.6 and 1.7 must be brought to the wind farm in sections, and many of these sections exceed the standard load of a heavy vehicle, meaning that several “super heavy load” vehicles must travel on the highway network for each wind turbine installation. At the time of this report, there were 28 wind farms in operation or under construction in 25 Kansas counties (Kansas Energy Information Network, 2016). While all six KDOT districts contained at least one wind farm, they were predominantly located in Districts Three, Five, and Six as shown

in Figure 1.8. Additionally, as shown in Figure 1.9, there were an additional 33 locations being studied across 35 Kansas counties (several projects under consideration were located in more than one county), concentrated mostly in the western portion of the state.



Figure 1.6: View of Elk River Wind Farm in Butler County
Source: Kansastravel.org (2015)



Figure 1.7: View of Smoky Hills Wind Farm in Ellsworth and Lincoln Counties

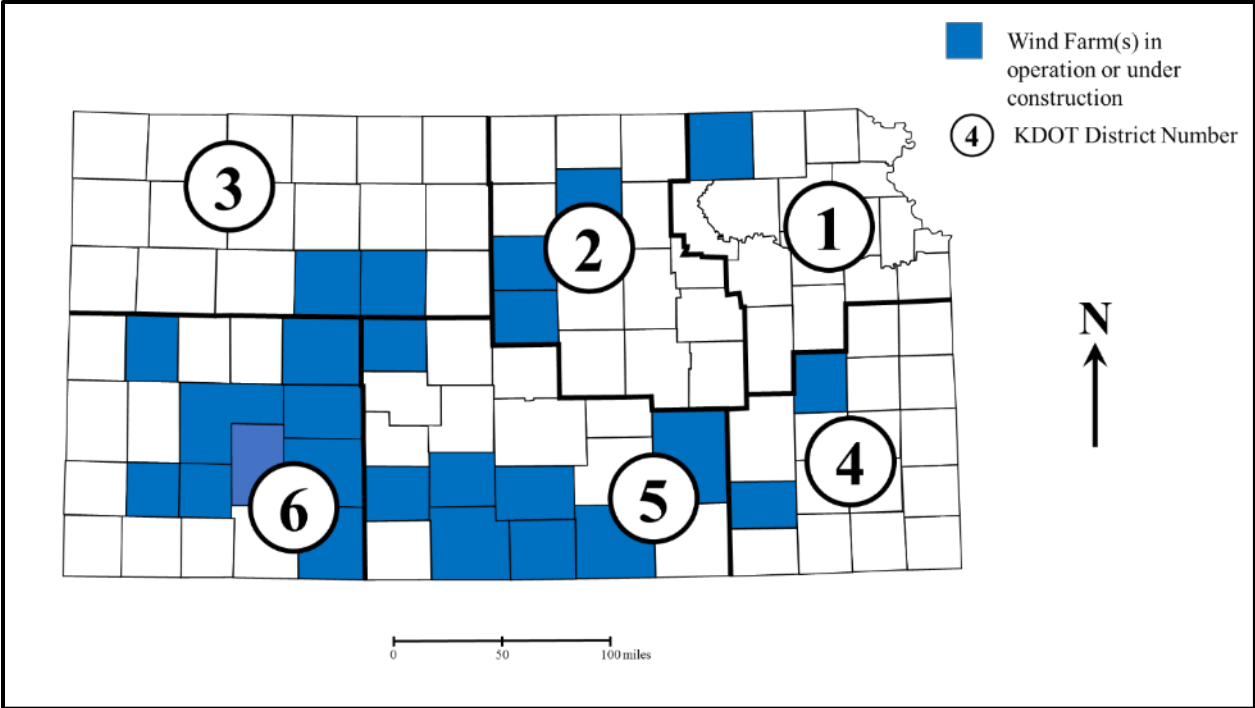


Figure 1.8: Counties with Wind Farms in Operation or Under Construction

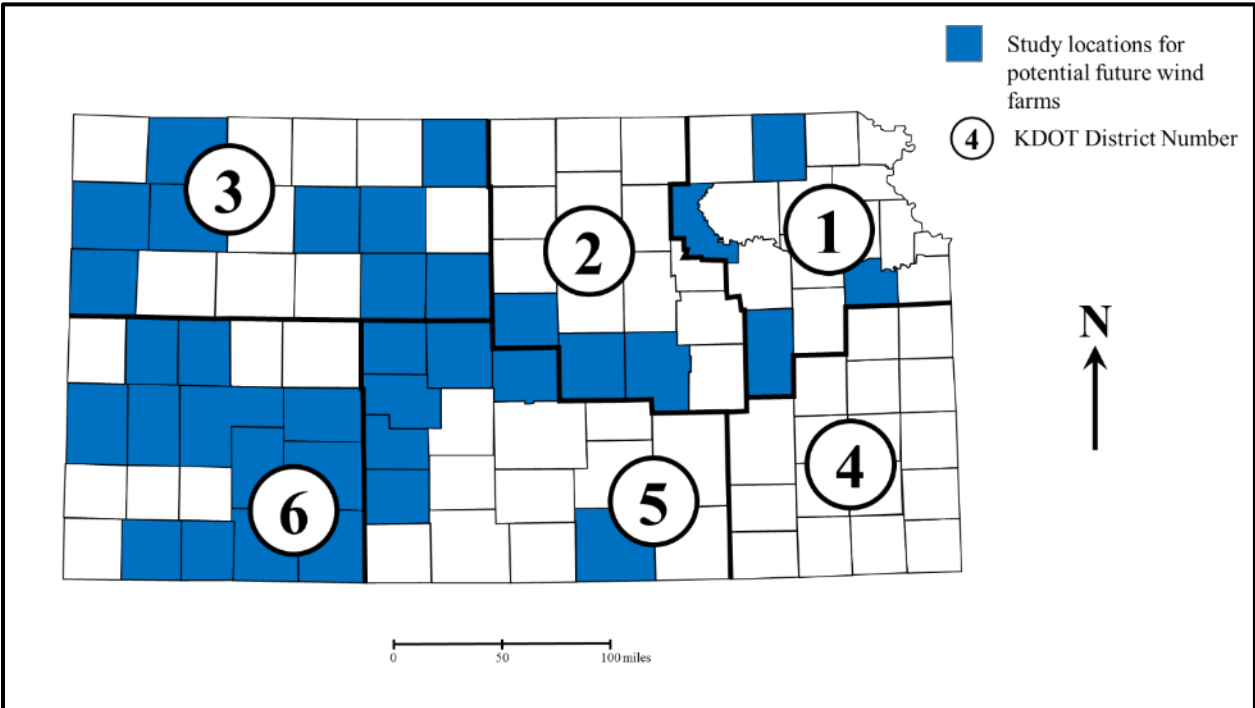


Figure 1.9: Counties with Wind Farms Under Consideration

1.2 Problem Statement

The oil and gas industry and wind farms have several things in common that can be detrimental to the state and local highway networks. First, the loads that they are bringing tend to concentrate on a few locations, bringing the potential for pavement damage and a shortening of the useful life of the adjacent roadways. Second, as these tend to be concentrated away from populated areas, they are more likely to be adjacent to lower-volume two-lane roadways that were not designed for high volumes of truck traffic. Third, as previously discussed these activities are more likely to be found in the western districts of the state, which can place an additional burden on the resources of those districts in order to maintain the affected roadways. Some of these projects require routing super heavy vehicle loads on these low-volume roadways. There is a need to better understand the effect on roadway pavement life in Kansas to determine if a change is needed in design and/or maintenance of the affected facilities.

At present, there is no standard mechanism employed to estimate the costs to the state and local jurisdictions that may be incurred due to fracking wells or wind farm sites. As the fracking industry and wind farms continue to expand in Kansas, these roadways may experience an increase in heavy truck traffic that could significantly decrease the pavement service life of nearby roadways. As these types of developments tend to occur in rural areas, it is the older, lower-volume paved roadways where any damage will be concentrated. The purpose of this research was to determine the impact on pavements and roadbeds due to this increase in truck traffic and correlate that to a reduction in roadway service life for typical two-lane KDOT roadways. In addition to KDOT roadways, this research can also be used as a proxy for county-level or other local jurisdiction-level paved roadways.

1.3 Organization

This research included several tasks, and this report discusses each in turn. Chapter 1 includes the history of fracking and wind farms in Kansas, and also presents the research problem statement. Chapter 2 discusses previous research that has been done in the area of pavement damage with respect to the energy industry. Chapter 3 discusses the methodology used to research the issues. Chapter 4 discusses the results of the analysis, and Chapter 5 presents the findings and avenues for future research. Appendix A presents background data regarding the energy industry in Kansas.

Chapter 2: Literature Review

This literature review summarizes available literature on the subjects of pavement and other infrastructure damage due to heavy truck traffic associated with the oil and gas industry and/or the wind energy industry. Where necessary, additional background into each industry is also provided. This literature review was conducted by searching WorldCat - FirstSearch, the Transportation Research Board's Transportation Research Information Database (TRID), and Google.

2.1 Highway Impacts Due to the Oil and Gas Industry

Mason, Metyko, and Rowan (1982) reported on a study to determine the effect of oil field trucks on light pavements. For this study, one oil well in the state of Texas was monitored for a total period of 73 days with the help of a camera actuated by pneumatic tubes. With the help of this device, accurate counts on the number of vehicles and the number of axles required for each stage of oil well development (preparation, rigging-up, drilling, completion, and production) were determined. For all the stages of oil well development, a total of 10,353 vehicles were recorded and a total of 22,923 single-axle repetitions were recorded. The average daily traffic for one oil well during development was found to be 150 vehicles per day with various combinations of 2-axle, 3-axle, semi and full trailers, and comprised 14 percent of the daily trips.

The evaluation of these low-volume roadways (known in Texas as Farm-to-Market, or FM, roadways) roads was done on the basis of serviceability. Costs comparisons were made between intended-use design traffic volume and observed oil field demand volume. Figure 2.1 depicts the conceptual framework of their analysis. The three main components of the analysis were pavement analysis, traffic analysis, and an estimate of traffic generated by an oil well. It was found from the study that the expected life of a road with regular design volume was 7.5 years. The effect of developing one well on this road resulted in a reduced service life of 4.2 years. Therefore, the first rehabilitation would be required in Year 1, rather than Year 3.2, and second rehabilitation would be required in Year 3.3 instead of Year 7.5. From the cost analysis, it was found that maintaining a typical FM road of 250 annual daily traffic (ADT) was about \$14,000 per mile, and the cost for same FM road with typical ADT and the addition of one well's

traffic was \$26,500 per mile; therefore, the estimated cost difference to maintain the roadway as a result of adding one well was \$12,500 per mile annually.

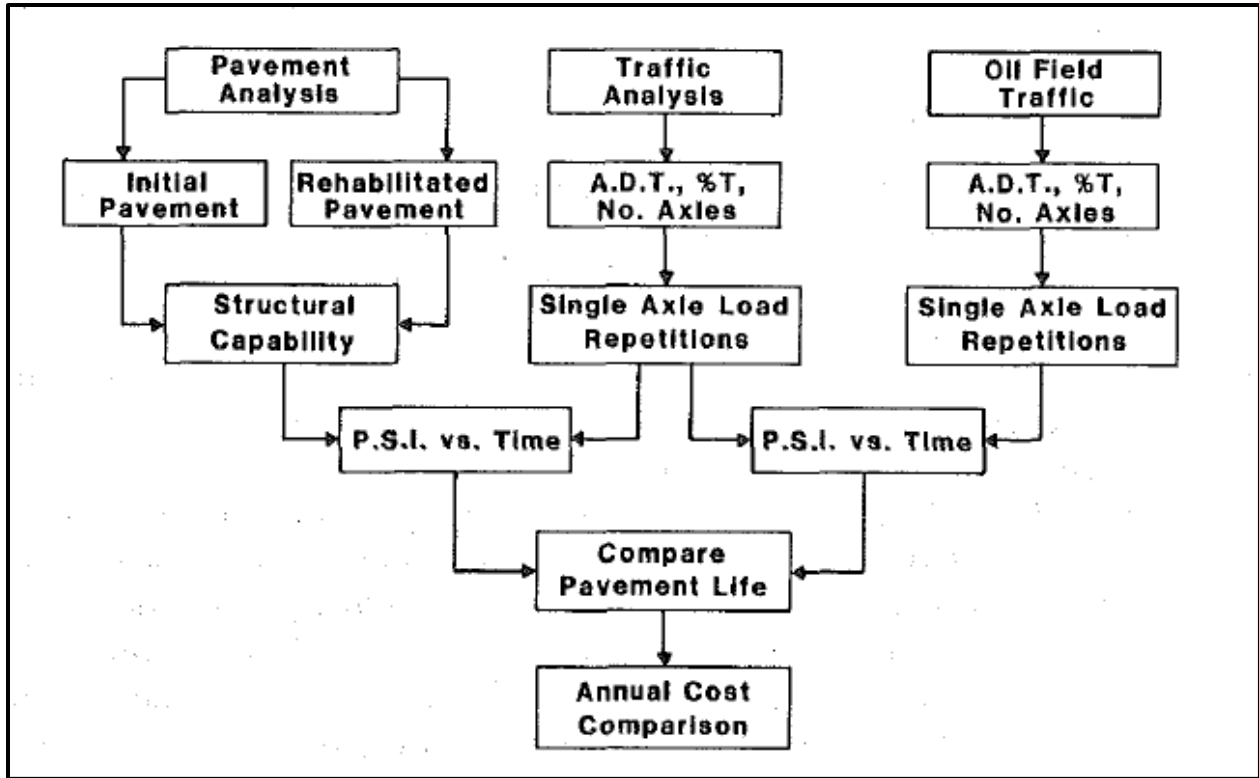


Figure 2.1: Flow Chart of Analysis Procedure for Determining Pavement Serviceability
 Source: Mason et al. (1982)

Recent development of natural gas extraction in the Marcellus Shale formation has resulted in additional drilling activities in Pennsylvania. Increased truck traffic associated with this shale gas development was used to determine deterioration rates on low-volume state roadways. Major contributors to road damage include: the number of trucks, weight of trucks, traffic patterns, construction material, drainage, and environmental conditions (Abramzon, Samaras, Curtright, Litovitz, & Burger, 2014). They recommended a three-point methodology to study this type of truck damage:

1. Determine the total number of trucks required to construct and operate a single well. The number of trucks required predominantly depends on whether water for hydraulic fracking is transported by pipes or trucks, if the waste is disposed of by pipes or trucks, the number of wells in a single

well pad, and the amount of materials and equipment needed at the site. Table 2.1 shows the estimate of heavy truck trips required for the construction and operation of a single well in Pennsylvania (New York State Department of Environmental Conservation, 2011).

Table 2.1: Assumed Heavy Truck Trips used for the Construction and Operation of a Single Well in Pennsylvania

Well pad activity	High range	Low range
	Number of heavy truck trips for early well pad development	Number of heavy truck trips for peak well pad development
Drill pad construction	45	45
Rig mobilization	95	95
Drilling fluids	45	45
Non-rig drilling equipment	45	45
Drilling (rig crew, etc.)	50	50
Completion chemicals	20	20
Completion equipment	5	5
Hydraulic fracturing equipment (trucks and tank)	175	175
Hydraulic fracturing water hauling	500	60
Hydraulic fracturing sand	23	23
Produced water disposal	100	17
Final pad prep	45	45
Miscellaneous	0	0
Total one-way, loaded heavy truck trips per well	1,148	625

Source: New York State Department of Environmental Conservation (2011)

- Estimates of roadway life and reconstruction costs were obtained. This was done with the help of the Pennsylvania Department of Transportation (PennDOT). The useable life of roadways was predicted in terms of the number of equivalent single axle loads (ESALs) converted from the assumed truck traffic. For this, the entire road network of Pennsylvania was classified from Interstates (Class A) to local roads (Class E) and the share of heavy truck vehicle miles traveled for gas development on each type of roadway class in Pennsylvania was estimated, as shown in Table 2.2.

Table 2.2: Characteristics of Roads Assumed to be used for Construction and Operation of Shale Gas Wells in Pennsylvania

PennDOT road maintenance class	A	B	C	D	E
Assumed description	Interstate	NHS	NHS	Non-NHS > 2000 ADT	Non-NHS < 2000 ADT
Design pavement life in ESALs	65,000,000	25,000,000	25,000,000	21,000,000	6,000,000
Lane mile reconstruction costs (in 2012 dollars)	\$3,175,182	\$2,684,376	\$2,684,376	\$2,571,398	\$2,333,664
Average distribution of shale gas activity in vehicle miles traveled (%)	2	2	22	46	28

Source: Abramzon et al. (2014)

- Truck travel and repair costs were combined to predict the consumptive roadway costs of the shale gas extraction industry, as shown in Table 2.3.

Table 2.3: Estimated Consumptive Road Use

Truck trip assumptions	Road class	A	B	C	D	E	Total
Low truck trip range	Consumptive roadway use per well (%)	0.0001	0.0001	0.0015	0.0036	0.0077	
	Damage cost per lane mile for each well	\$2	\$3	\$40	\$92	\$180	\$315
High truck trip range	Consumptive roadway use per well (%)	0.0001	0.0002	0.0027	0.0066	0.0142	
	Damage cost per lane mile for each well	\$3	\$5	\$72	\$168	\$331	\$580

Source: Abramzon et al. (2014)

The study found that shale gas development in Pennsylvania cost \$13,000–\$23,000 per well for state roadways, or \$5,000–\$10,000 per well if the state roads with lowest volumes are excluded. Further, the report stated that these results were sensitive to the types of trucks used. It was assumed for the study that the proportion of truck traffic was 50 percent 4-axle single unit trucks (FHWA Classification 7) and 50 percent 6-axle single trailer (FHWA Classification 10). If this ratio were changed from 50/50 to 60/40, then the cost of roadways would increase by 14 percent. A proportion of 70/30 would further increase the cost by 29 percent. It was also found that the estimated road costs were sensitive to the road used by the trucks. If the usage of higher

class roads (Classes A, B, and C) was increased by 26 percent in total usage, then the damage costs dropped 9 percent across all roadways in Pennsylvania, as those roads were better designed to withstand additional heavy truck traffic. This finding suggests that keeping heavy truck traffic on roads with a higher design as often as possible can help minimize overall costs.

According to Prozzi, Grebenshikov, Banerjee, and Prozzi (2011), traffic associated with oil development originates from a four-step well development process:

- Site preparation;
- Rigging up;
- Drilling; and
- Rigging down.

Development of a single well takes about 35 to 40 days. The average daily truck traffic (ADTT) was estimated as 27 trucks per day, with the total of 527 truck visits during the drilling process. For site selection purpose, 50 permitted routes were randomly selected for the truck traffic related to one oil well. After monitoring the miles traveled on each of these routes, it was determined that the average trip length for hauling oil well equipment was about 86 miles (Prozzi et al., 2011). Trucks mainly consisted of tankers for movement of bulk sand and water, and flatbed trucks for hauling drilling and other equipment.

It was found from this research that traffic associated with the construction of an oil well had little to no impact on Texas's highway infrastructure. Damage done by this traffic was in the range of 0.5 to 4 percent depending on the distress mechanism, reducing the life of pavements by 1.8 percent on average for one well. However, the traffic associated with production and operating the oil well (e.g., the traffic that occurred after drilling was completed) had far more impact on the pavement, causing damage ranging from 24 percent from a fatigue perspective and 3 percent from a rutting perspective. Impact on service life of these pavements due to production traffic was estimated up to a 9 percent reduction (Prozzi et al., 2011).

2.2 Wind Farms

In 2011, Prozzi et al. studied the impacts of energy development on the Texas transportation system. They performed extensive research and studied the impacts of traffic

generated due to the wind energy industry, the natural gas industry, and the crude oil industry individually on roads in Texas. The American Association of State Highway and Transportation Officials' (AASHTO) Mechanical-Empirical Pavement Design Guide (MEPDG) software was used for evaluating the service life of pavement cross-sections. Rutting depth, longitudinal cracking, and alligator cracking were the measures of distress used to evaluate the pavements.

Their report assessed the damages done by oversized and overweight (OS/OW) trucks on the pavement, with emphasis on the trucks that were transporting wind turbine components. According to the Texas OS/OW database, 10 trips were required for the construction of a single wind turbine. The researchers randomly selected 97 permitted routes from the Texas Department of Transportation (TxDOT) OS/OW database for further study. Similar to oil and gas drilling, the generation of traffic for wind turbine construction can be divided into several stages:

- Site preparation;
- Wind turbine foundation installation;
- Wind turbine delivery and assembly; and
- Underground cable installation.

For the purpose of site preparation and the construction of the wind turbine foundation, the estimated number of truck trips was determined to be approximately 336 truck trips as shown in Table 2.4. According to report and these presented statistics, a 200-unit wind farm development would generate 67,200 truck trips over a 6- to 12-month period. For assembly of the wind turbines, eight OS/OW components are typically needed to be delivered to the site, as shown in Table 2.5. The researchers found that the additional damage done by the movement of these OW/OS vehicles was less than 1 percent on interstate sections over a 20-year period life, however, higher values of damage were observed for rural roads with less robust pavement designs.

Table 2.4: Estimates of Truck Traffic Associated with Site Preparation for a Single Typical Wind Turbine (Siemens 2.3 MW)

	Quantity	Truck hauls
Concrete for pad	600–710 tons	35
Base material for pad	5,000 tons	223
Service Road material	1,000–2,250 tons	78
Total estimated truck trips		336

Source: Prozzi et al. (2011)

Table 2.5: Specialized Vehicles used for Moving Wind Turbine Components

Vehicle	Component	Weight (lbs)
13-axle Schnabel a/ 6-axle steerable dolly	Tower, main section	232,000
11-axle Schnabel w/ 6-axle steerable dolly	Tower, mid-section	199,000
Schnabel dolly	Tower, mid-section	128,800
5-axle stretch lowboy	Tower, mid-section	112,000
Dolly trailer	Tower, top section	91,000
13-axle trailer	Nacelle	218,000
Specialized blade trailer	Blade	78,000
Double drop trailer	Hub/rotor	85,000

Source: Prozzi et al. (2011)

The overall estimated damage on Texas roadways from wind farm activity is shown in Table 2.6. Using the MEPDG software, the research team estimated the additional rutting, longitudinal cracking, and alligator cracking that would result from the wind farm traffic. The analysis of this research was based on the MEPDG through its transfer function. Based on rutting, longitudinal cracking, and alligator cracking, the team of researchers estimated the damage on the pavement along with the transfer functions. It was estimated that the additional damage done by the movement of the components on US Highways was about 5 percent, resulting in a reduction of service life of 1.9 percent for the Interstate highways, 15.2 percent on US highways, and 20.2 percent on state highways. The overall reduction average on the pavement was found to be 9.1 percent.

2.3 Summary of Literature Review

The following points can be taken from the preceding literature review:

- Damage done by the truck traffic associated with the construction of oil wells is less compared to that done by traffic associated with operation of oil wells.

Table 2.6: Overall Impact on Texas Highway Infrastructure due to Wind Farm Traffic

Distress Type	Impact on Interstate Highways	Impact on US Highway	Impact on State Highways	Overall Impact
Longitudinal cracking	0.3%	2.3%	58%	+11.4%
Alligator cracking	0.2%	4.1%	4.1%	+2.1%
Rutting	0.4%	4.8%	7.6%	+3.0%
Roughness	0.2 inches/mile	1.2 inches/mile	1.3 inches/mile	+0.7 inches/mile

Source: Prozzi et al. (2011)

- Damage by OS/OW vehicles carrying wind turbine parts on rural roads is higher than the damage done by total ESAL repetitions for constructing oil and gas wells.
- Interstate highways show little to no damage or reduction in service life due to traffic related to the construction of oil wells and wind farms. This is most likely because these highways are designed to withstand a large number of ESALS during their lifetimes, and are also specifically designed as OS/OW routes.
- Rural roads show a reduction in average service life due to oil industry. Typically, these roadways are not designed to the same standard as Interstate or other high-volume truck routes.

There is a need to determine the extent to which the oil and gas industry, as well as the wind farm industry, impact the low-volume roadways in Kansas. The next chapter presents the methodology used in this research.

Chapter 3: Methodology and Experimental Design

The objective of this research project was to develop an understanding of how the oil and gas production industry and the wind farm electricity generation industry impact the roadways in Kansas. The tool used to provide answers was AASHTO's MEPDG software. The MEPDG was developed in 2004, with the goal to "Identify the physical causes of stresses in pavement structures and calibrate them with observed pavement performance" (Pavement Interactive, 2012). The MEPDG software incorporates empirical observations that AASHTO has been collecting since the 1950s on long-term pavement performance. By using initial assumed pavement designs and traffic loadings as inputs, MEPDG software can estimate how the pavement design might respond to the load and environmental stresses over time. This provides an estimated level of damage the pavement will sustain over time, represented in two forms: International Roughness Index (IRI) and pavement rutting.

It was beyond the scope of this project to collect long-term pavement performance data, or to collect field data of truck movements for specific oil and gas wells or for wind farm activities. Nor was the project meant to examine one specific roadway. Instead, the research team was tasked with providing a general understanding of how such activities could affect a typical Kansas roadway, either part of the state network or a local roadway. As shown in the literature review, little damage has been observed on the interstate-type highways, as these are typically designed to handle large quantities of heavy and super-heavy trucks. Therefore, this research focused solely on lower-volume two-lane roadways. Additionally, it was beyond the scope of this project to develop a Kansas-specific calibration for the MEPDG, and so the default values were retained in the modeling runs used this this research.

There was an expectation that information on the makeup of existing roadbeds would be greater on the state network, so the research team focused on finding lower-volume two-lane state roadways that could also serve as proxies for local roadways as well. A review of the state network to find viable sample sections for further analysis focused on finding roadways with the following attributes: two-lane roadways, low-to-moderate traffic volumes, and in Districts Five or Six. Districts Five and Six are representative of the area more likely to have energy

developments in the future, so these districts were focused on to simplify the search for appropriate examples for this research.

After searching available KDOT online maps, and using Google Earth to visualize many of the roadways, phone calls were placed to several KDOT engineers to gain their views on what would be considered a typical roadway. Some roadways had inadequate documentation on the various subsurface layers and so could not be used. However, Mr. Brent Terstrip (District Construction Engineer, District Five) suggested three roadway sections that were suitable and also had the required composition information. Upon inquiring more, Mr. Don Schneider (Area Engineer, Harper County) suggested two more roadways that could be used, and so these five roadway sections were selected for further study:

- K-1 (Comanche County south of US 183);
- K-42 (Kingman County between Rago and Norwich);
- K-44 (Harper County east of Anthony);
- K-179 (South of Anthony); and
- US-160 (South of Coldwater and West to Clark County).

Traffic counts for each location were taken from KDOT traffic count maps (KDOT, 2014). Mr. Rick Miller, KDOT's State Pavement Management Engineer, provided information regarding the type and thickness of the roadbed for each of these roadways, which are shown in Figures 3.1 through 3.5. As expected, these pavements represented somewhat thinner designs that might be expected on higher-volume roadways in the state, with overall pavement thicknesses (all layers above the subgrade) ranging from 3.0, 3.6, 4.5, and 5.5 inches, respectively. Also, reflecting that these surfaces are not new and have been resurfaced several times over their service life, the research team worked with KDOT to develop models that contained several asphalt pavement layers. The number of pavement layers modeled ranged from three (for K-44) to five (for K-1 and K-179).

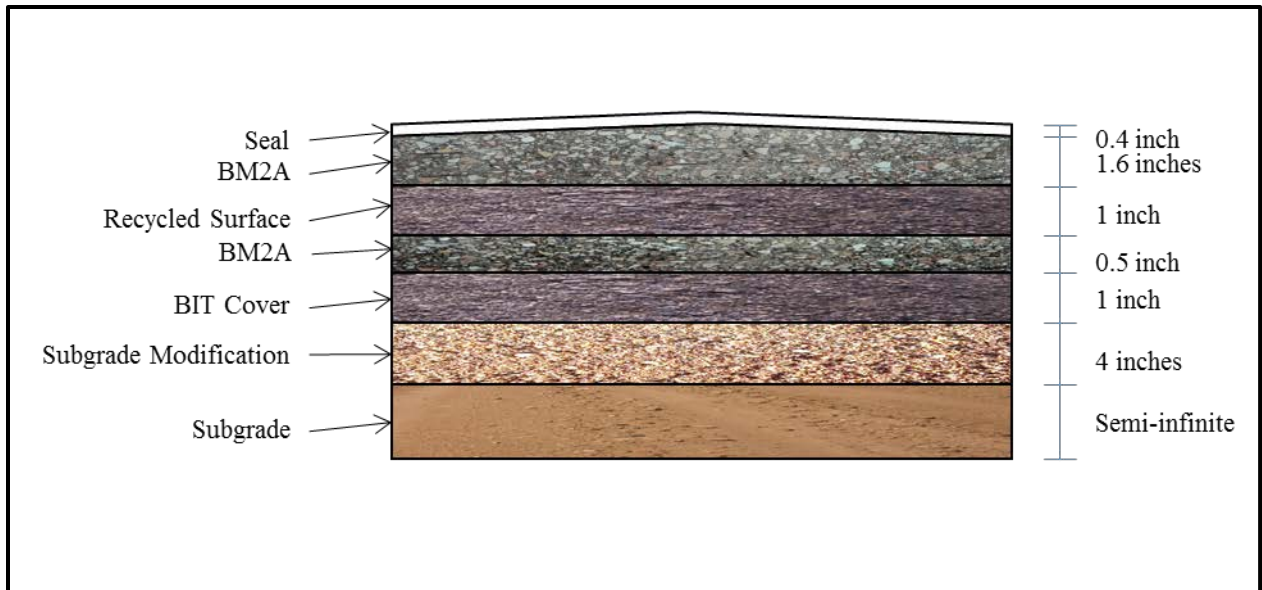


Figure 3.1: Reported Composition of K-1 in Comanche County South of US-183

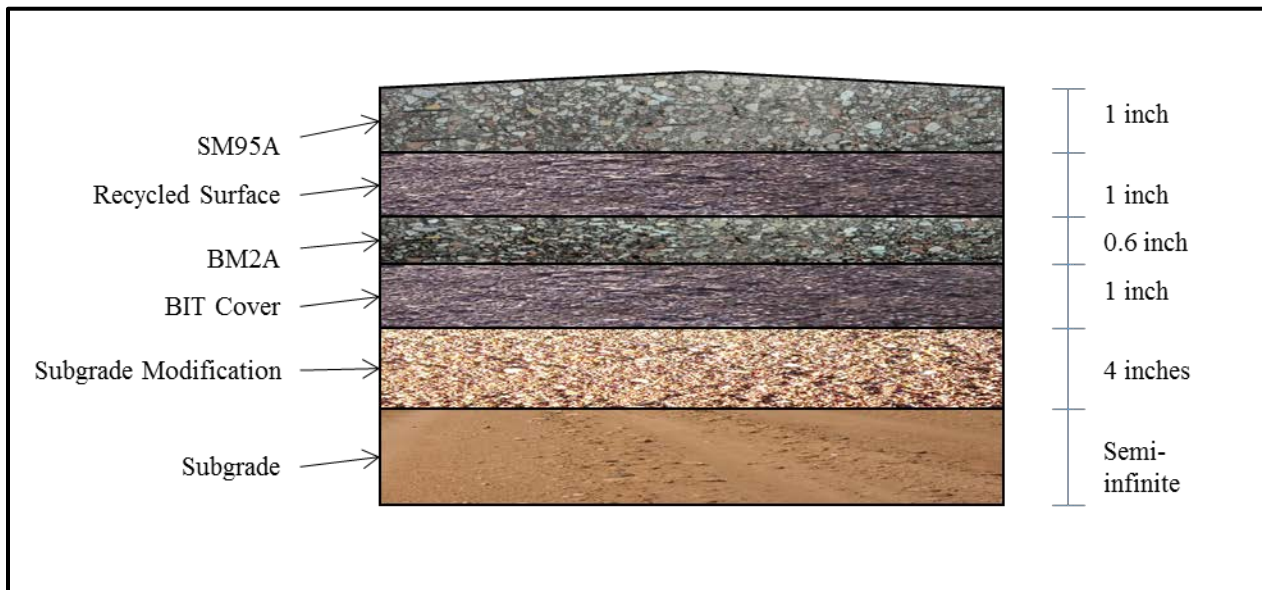


Figure 3.2: Reported Composition of K-42 between Rago and Norwich

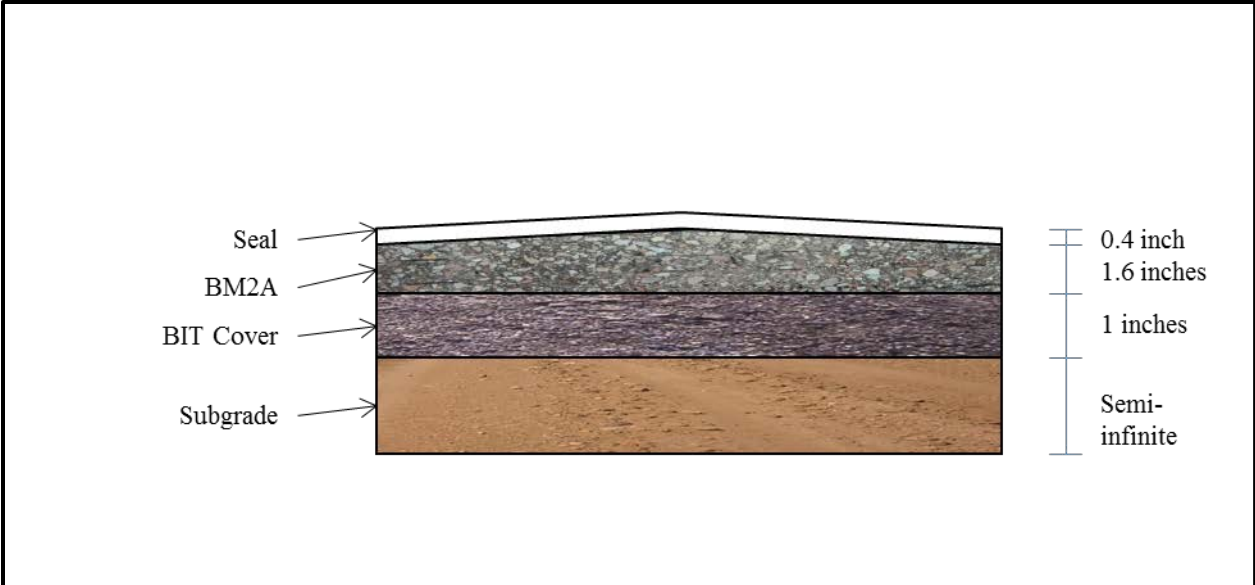


Figure 3.3: Reported Composition of K-44 East of Anthony

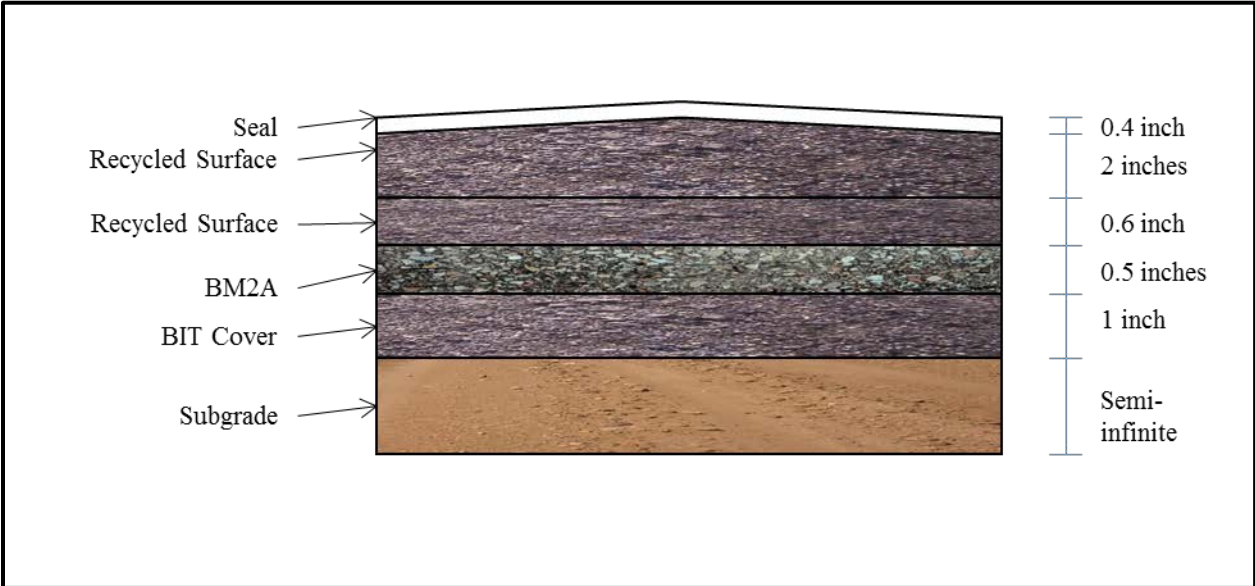


Figure 3.4: Reported Composition of K-179 South of Anthony

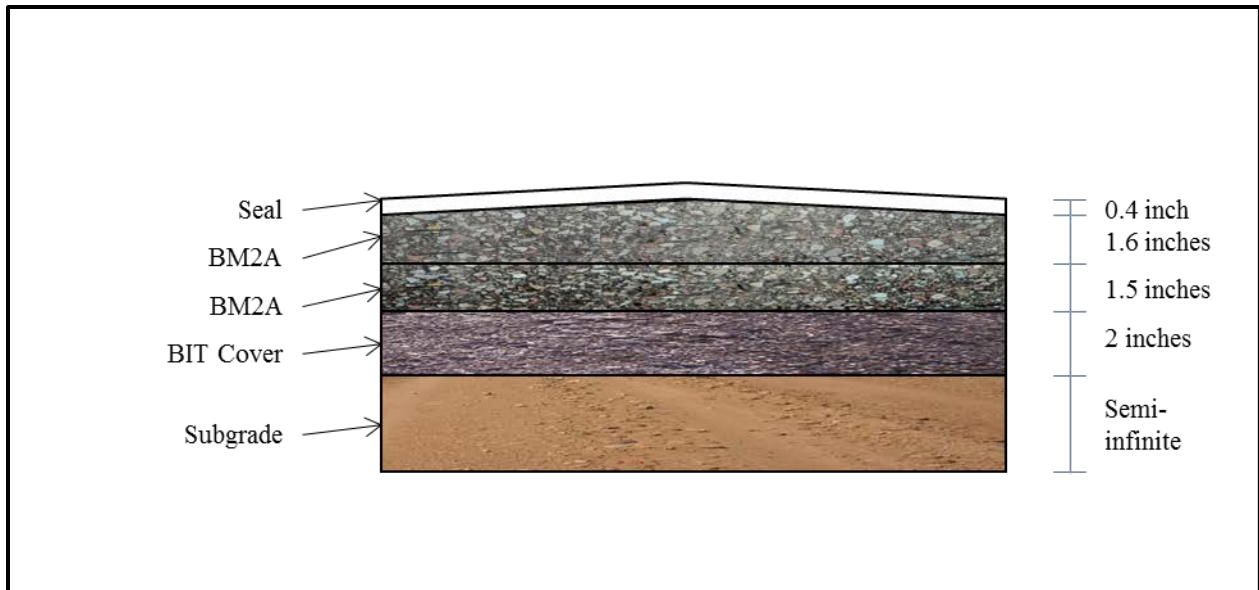


Figure 3.5: Reported Composition of US-160 South of Coldwater

3.1 Use of the MEPDG

The initial purpose of the MEPDG and its software was to answer design questions such as, “Does the predicted performance of the pavement satisfy criteria for the design, such as the desired service life of the pavement, based on the level of distress and potential maintenance and rehabilitation needs?” and, “Are there reasonable alternatives to the initial design assumptions that could generate better predicted performance or lower life-cycle costs?” (Pavement Interactive, 2012). These questions are meant to be asked during the pavement design phase of a project, with the software providing optimal solutions that can maximize pavement life while minimizing costs. This research project used the MEPDG software in a slightly different manner: the research team assumed that a pavement was already in existence and was interested what the net change would be if at some point in its life cycle additional traffic due to either (a) the oil and gas industry or (b) the wind energy industry began to travel on the roadway as it developed new resources.

In this research, only the overlay design and new flexible pavement design components in the MEPDG software were used. When the research team attempted to input the existing attributes of the five roadways selected for analysis, it was determined that the MEPDG was not able to completely model reality. The reason for this is that some of the components available in

the software did not match the existing roadways, because—as stated before—the MEPDG was developed to design new pavements, and so components related to overlays, seals, and the use of recycled materials were not sufficiently developed without using some simplifying assumptions. In order to use the MEPDG software to approximate the selected roadways, the following simplifying assumptions were used after conversations with Mr. Jon Routh of KDOT:

- Seal coats were not considered as part of the evaluation;
- Various asphalt mixes (e.g., BM2A, SM95A) were simply defined in the software simply as AC pavement;
- Without knowing more about the subgrade modifications of the roadways, A-2-1 material was assumed; and
- Without knowing more about the subgrades of the roadways, A-2-7 material was assumed.

The type and thickness of the roadbed for each of these roadways that were modeled are shown in Figures 3.6 through 3.10.

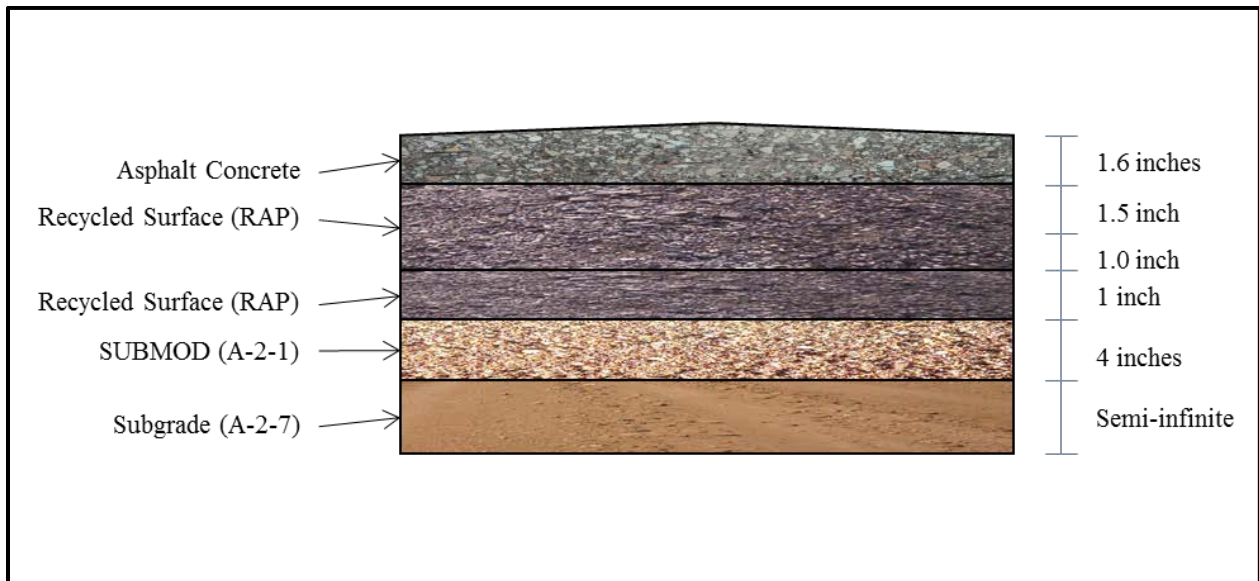


Figure 3.6: Approximated Composition of K-1 used for Analysis

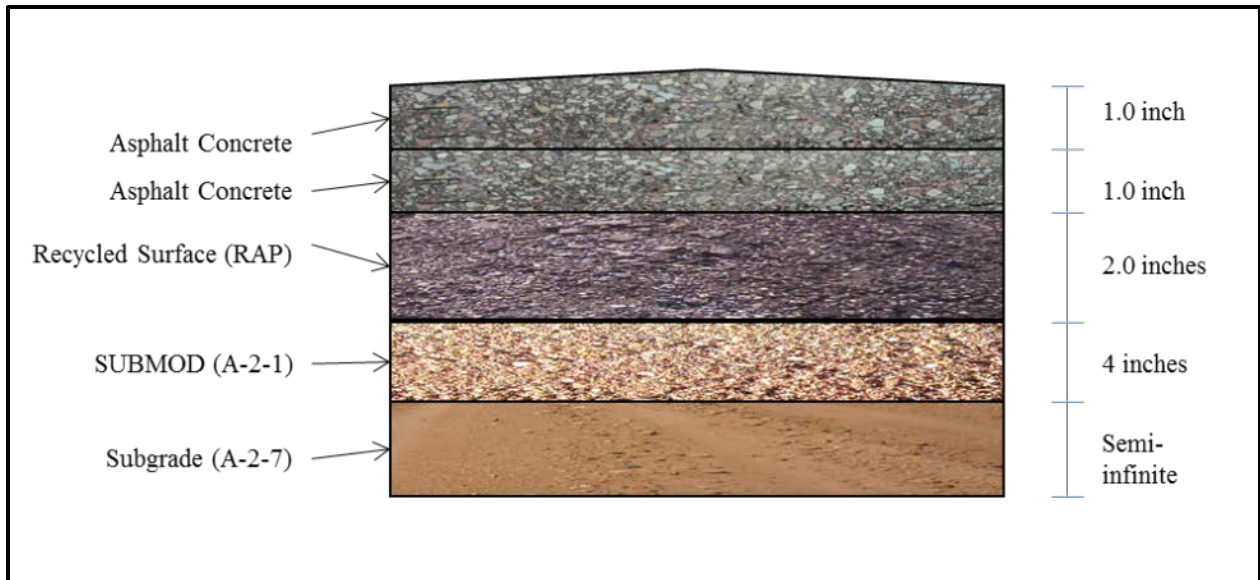


Figure 3.7: Approximated Composition of K-42 used for Analysis

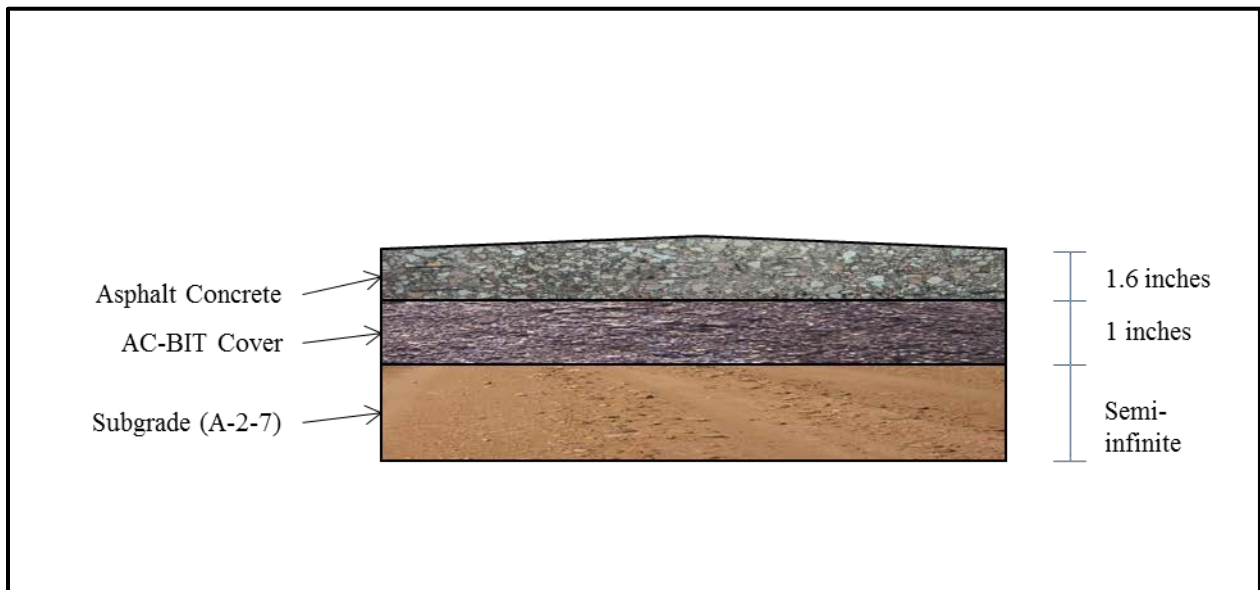


Figure 3.8: Approximated Composition of K-44 used for Analysis

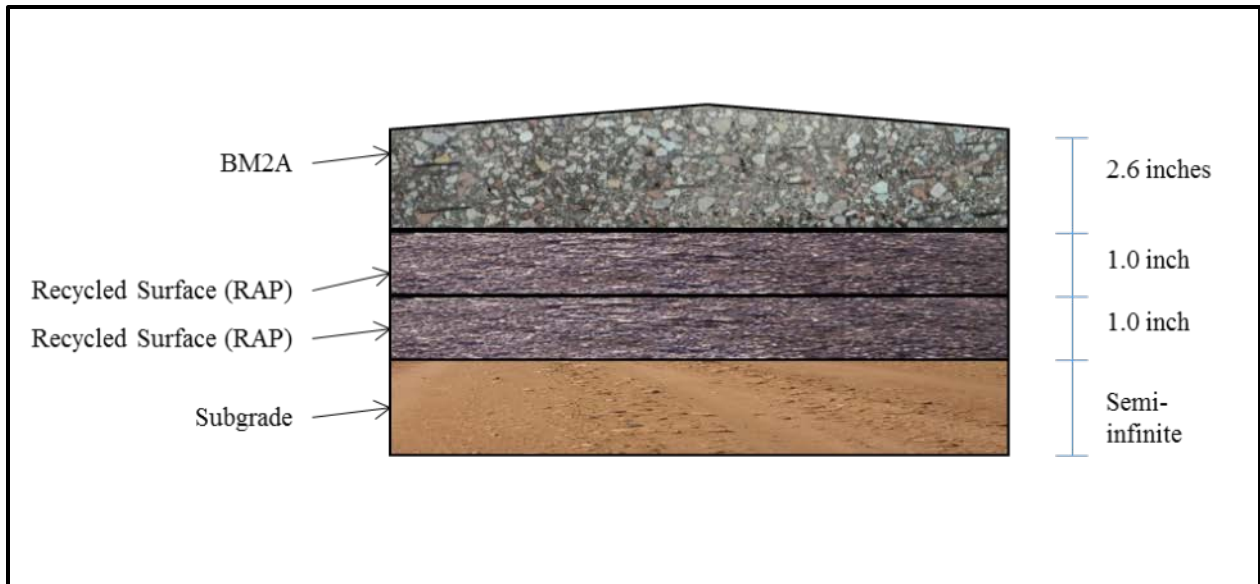


Figure 3.9: Approximated Composition of K-179 used for Analysis

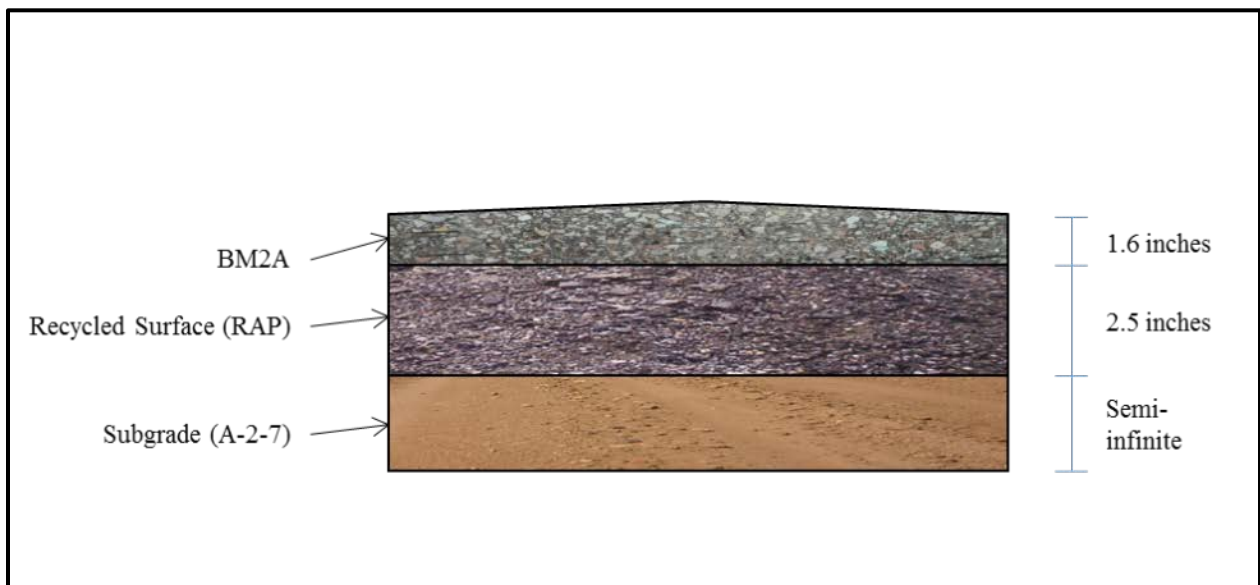


Figure 3.10: Approximated Composition of US-160 used for Analysis

In addition, the following inputs were used in the MEPDG software:

- Each roadway was assumed to be a two-lane roadway, even if portions of the roadways have more than two lanes; and

- Traffic volumes for the annual average daily truck traffic (AADTT) and the average daily truck traffic (ADTT) were taken from the KDOT pavement management record.

Additionally, each road section was input into the MEPDG software in the Overlay Design Section. The list of parameters used is as follows:

- Binder: Superpave;
- Initial IRI: 63;
- Terminal IRI: 163;
- Terminal pavement rutting depth: 0.75 inch;
- Original average annual daily truck traffic (AADTT): 10 percent of AADT;
- Axle weight distribution: Default from the MEPDG software;
- Vehicle class distribution: Default from the MEPDG software;
- Traffic annual growth factor: 2 percent; and
- Design Input Level: 2 or 3.

Note that it takes one mode of failure for KDOT to initiate a rehabilitation action, so once the IRI reaches 163, an appropriate repair, rehabilitation, or resurfacing action would take place. As will be shown, this point was reached in the model prior to 0.75 inch of rutting occurring. So in a practical sense only the IRI value controlled the result of the models.

3.1.1 Methodology for Adding Truck Trips due to Oil and Gas Fracking Activities

As discussed in the literature review, the daily truck traffic to be added to the roadway due to oil and gas activity was estimated to be the same as that reported from shale natural gas extraction in Pennsylvania, that is, a minimum of 625 and a maximum of 1,148 additional trucks per day (Abramzon et al., 2014).

Initially the model for each roadway was run with a desired service life of 20 years. With existing traffic conditions (e.g., no oil and gas truck traffic), the IRI value and total rutting depth were output by the MEPDG software. Each roadway model was then run again with additional truck traffic corresponding to 1, 2, 5, 10, 20, and 50 wells, respectively, and the IRI values and

total rutting depth were output for each run. All the roadway models were compared to their original model and the corresponding reductions in pavement life were determined for the various amounts of additional truck traffic. An example of this data input process is detailed for the K-1 roadway model and shown in Figures 3.11 through 3.14.

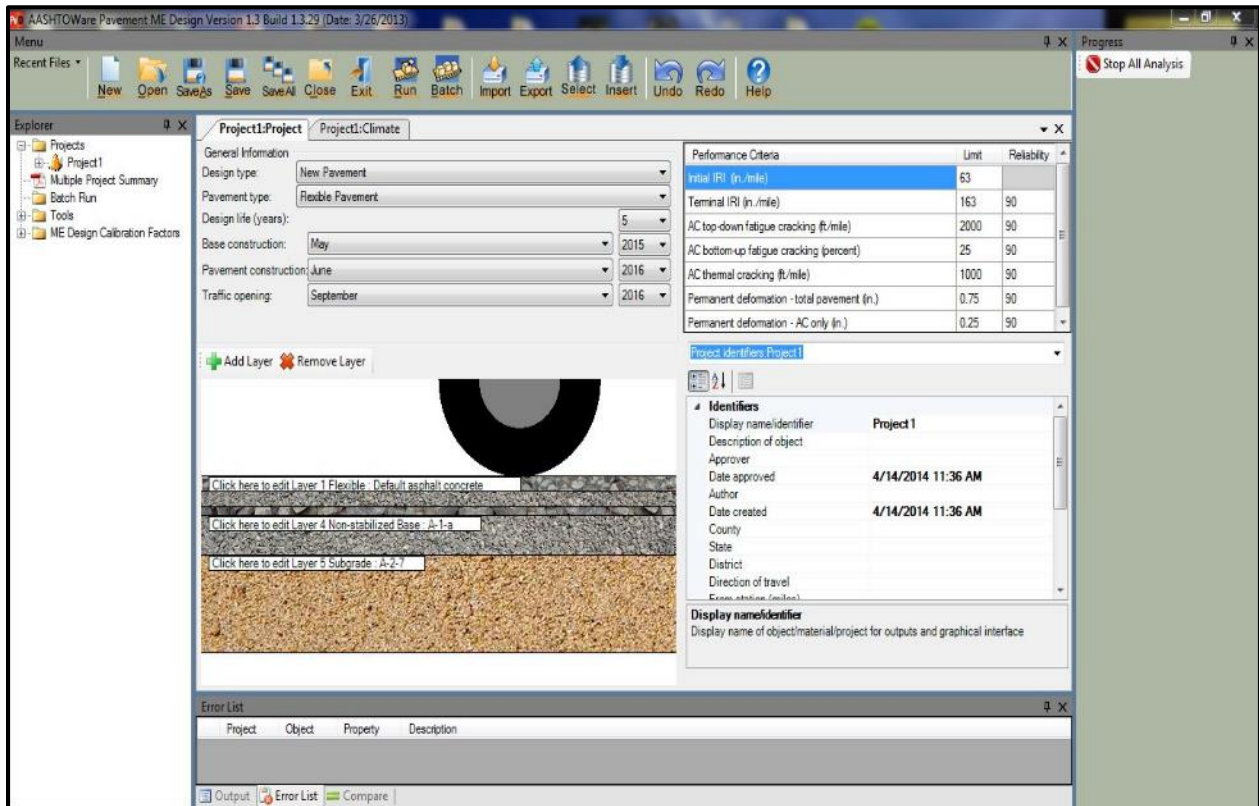


Figure 3.11: Choosing the Suitable Layer Configuration and Setting the IRI Parameter

A suitable layer system was selected under the new flexible pavement AC over AC. The terminal IRI was changed from the default value of 172 to a more conservative parameter of 163. The remaining terminal values were kept as default (input value 2 or 3).

The binder selected for all the asphalt pavements was Superpave with mix design of 64-22.

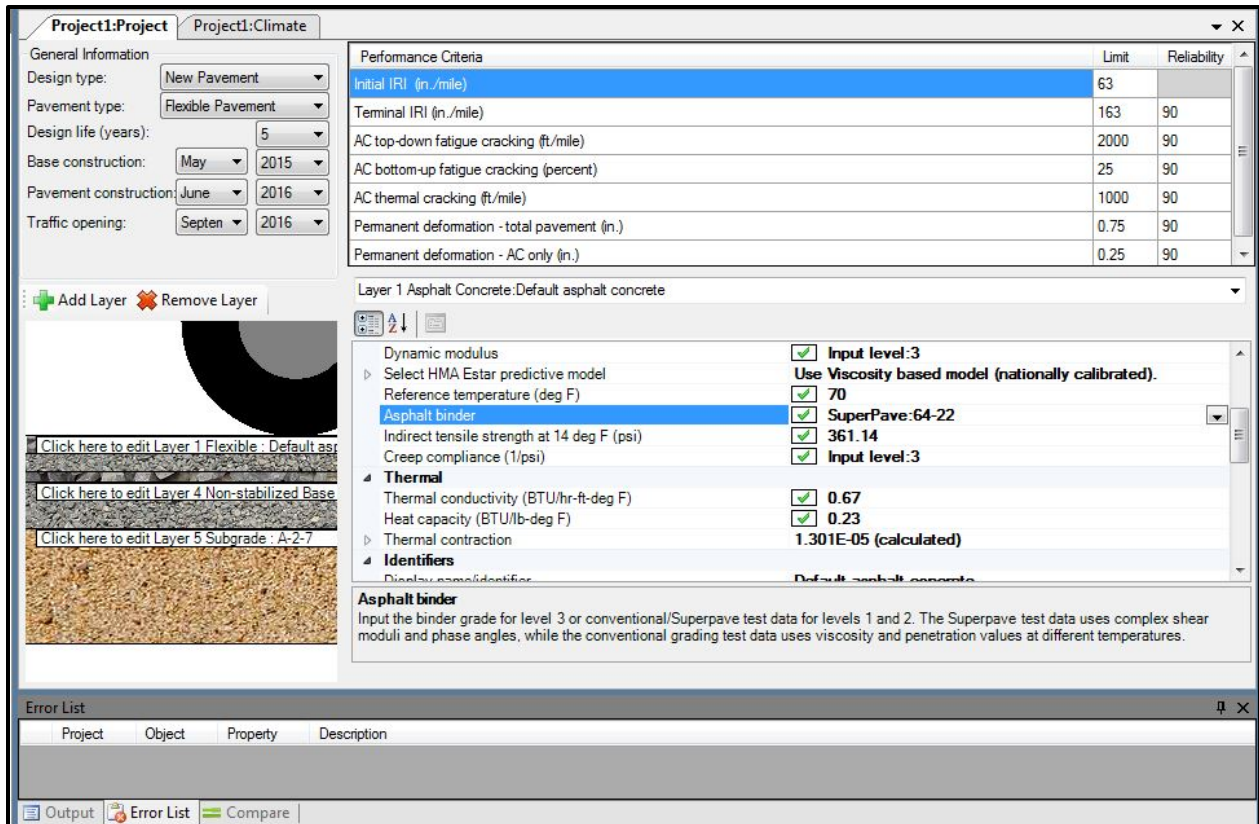


Figure 3.12: Selection of Binder for the Asphalt Pavements

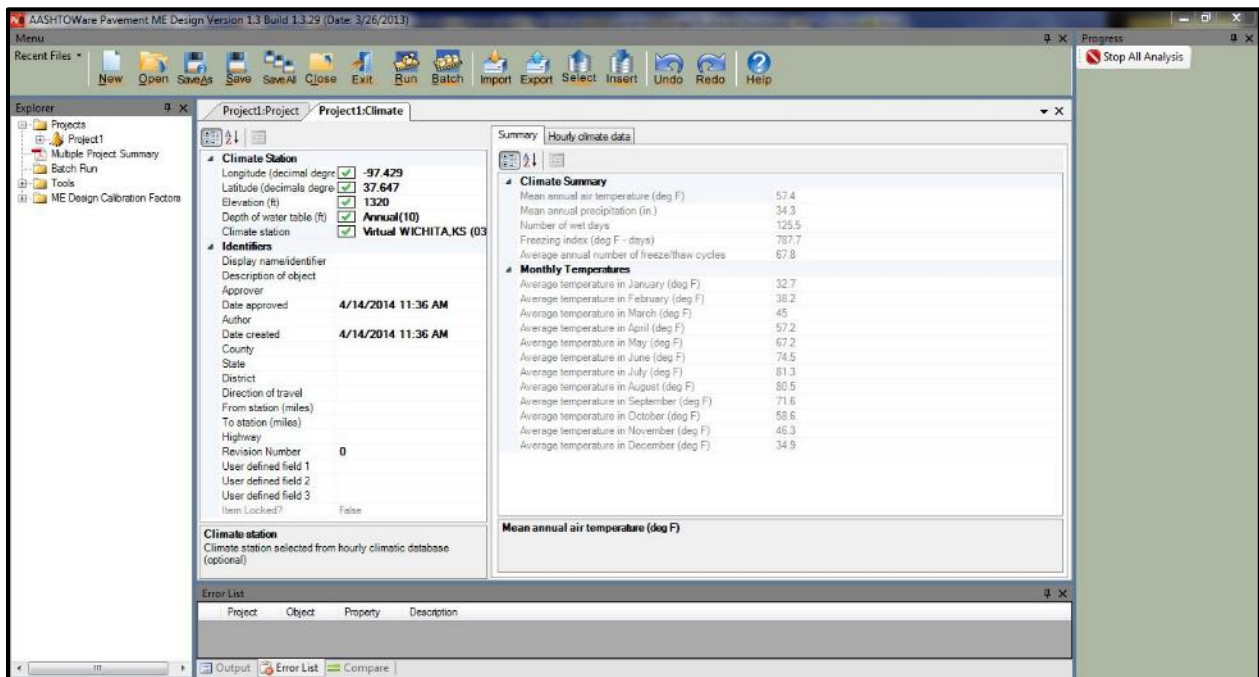


Figure 3.13: Creation of a Virtual Climate Station near Wichita

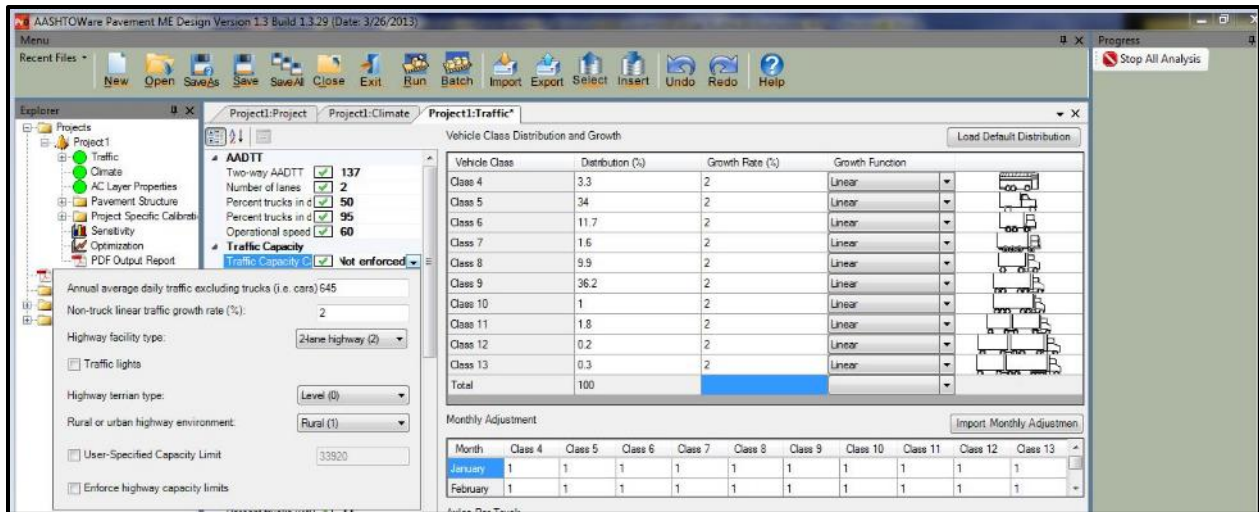


Figure 3.14: Traffic Inputs

Using the climate section of the program, a virtual station was created using Wichita as the location and interpolating the climate data from nearby areas.

Under the Traffic Capacity tab, the AADTT was entered. For the AADTT, 10 percent was assumed for the existing traffic load, and the growth rate factor was changed to 2 percent for all types of traffic growth.

Simulations were run for existing traffic levels for 5, 10, 15, 16, 17, 18, 19, and 20 years, and continued being rerun with increasing service life until the terminal IRI was reported to be 163 or higher. The year when the IRI value reached 163 was determined to be the point when the pavement had reached the end of its service life. For the fracking section of the analysis, this process was repeated with additional truck traffic representing 1, 2, 5, 10, 20, and 50 wells, respectively.

3.1.2 Methodology for Adding Truck Trips due to Wind Farm Activities

For the wind farm portion of the analysis, a new overall truck count was obtained by adding the existing trucks with the number of trucks required for pad construction, service road, and trucks required to haul the parts of wind turbine. The work done by Prozzi et al. (2011) and shown in Tables 2.4 and 2.5 indicated 344 trucks trips estimated for each wind turbine were used as a reasonable estimate for determining trips, and was used for this research. These figures were then scaled up to estimate the trips required for an entire wind farm. The trips used to prepare the

wind farm (such as pad preparation and hauling service road materials) tended to be standard loadings (less than or equal to 80,000 lb), but all of the trucks hauling wind turbine components exceed 80,000 lb. In order to reflect this mix in the inputs in the MEPDG software, the following process was used:

- The default proportions for each class of trucks were already given in the MEPDG software for the road section having major truck traffic.
- The newly-calculated AADTT was then used with the class proportions to calculate the adjusted number of trucks in each class.
- Axle loads for each of the wind turbine section-carrying trucks were converted to single axle 18,000-lb loads and then added to the proportion of Class 10 trucks. Class 10 was selected as it was the first truck type with more axles than a standard combination tractor-trailer truck (Type 9).

As with the oil and gas fracking scenarios, simulations for the wind farm were run for existing traffic levels for 5, 10, 15, 16, 17, 18, 19, and 20 years, and continued being rerun with increasing service life until the terminal IRI was reported to be 163 or higher. The year when the IRI value reached 163 was determined to be the point when the pavement had reached the end of its service life. This process was repeated with additional truck traffic representing wind farms of two different sizes: a large wind farm representing the largest Kansas wind farm at the time of this research (262 wind turbines), and the median wind farm in Kansas (67 wind turbines). A more detailed list of the wind farms in Kansas is shown in Appendix A.

The results and discussion of the MEPDG simulation runs are presented in the next chapter.

Chapter 4: Research Findings

In this chapter the findings of the MEPDG simulation runs are presented and their significance is discussed. In all, there were 280 simulation runs conducted in order to determine the additional roadway deterioration for both the oil and gas fracking activities, and an additional 80 simulation runs for wind farm activity, for a total of 360 simulation runs.

4.1 Results of Estimated Pavement Damage due to Oil and Gas Fracking Activity

Figure 4.1 shows the differences in pavement life depending on the modeled increase in well traffic on the K-1 roadway model. As shown, the reduction in service life due to 5, 10, 20, and 50 wells is not noticeably different than the existing traffic with no well traffic with respect to both IRI values. Similar performance can be observed in the output of total pavement rutting depth, as shown in Figure 4.2. These results are indications that a roadway constructed similar to the K-1 pavement model can successfully bear small to moderate amounts of oil and gas well traffic without loss of service life, but that for large oil fields rutting may become an issue much earlier when compared to existing traffic levels.

Output results for the K-42, K-44, K-179, and US-160 models are shown in Figures 4.3 through 4.10, and provide similar results. In all figures, it can be seen that for each of the tested scenarios up to 50 wells, all of the roadway models showed a negligible service life reduction based on IRI. Similarly, the total rutting depth was practically unchanged for all scenarios up to 50 wells. Therefore, these results can be interpreted that regardless of the roadway models tests, oil and gas exploration using fracking techniques do not appear to materially affect the lifespan of Kansas roadways with respect to overall roughness and rutting.

A natural extension to this result is: at what traffic levels would a service life reduction be observed based on IRI values? Although traffic from more than 50 wells concentrated onto a single roadway is highly unlikely, the research team increased these numbers even higher to determine when there would be so much truck traffic associated with oil and gas hydraulic fracturing that one full year of pavement life would be lost (compared with no such oil and gas traffic). It was found that an exceedingly high number of hydraulically fractured oil and gas wells would be needed (from between 425 and 500 wells). This is not likely to be a practical

value, as it is expected that this level of concentration in traffic would result in larger service life reductions. Development of a Kansas-specific MEPDG model that is properly calibrated to soil types and their resulting properties may provide results of a more expected nature.

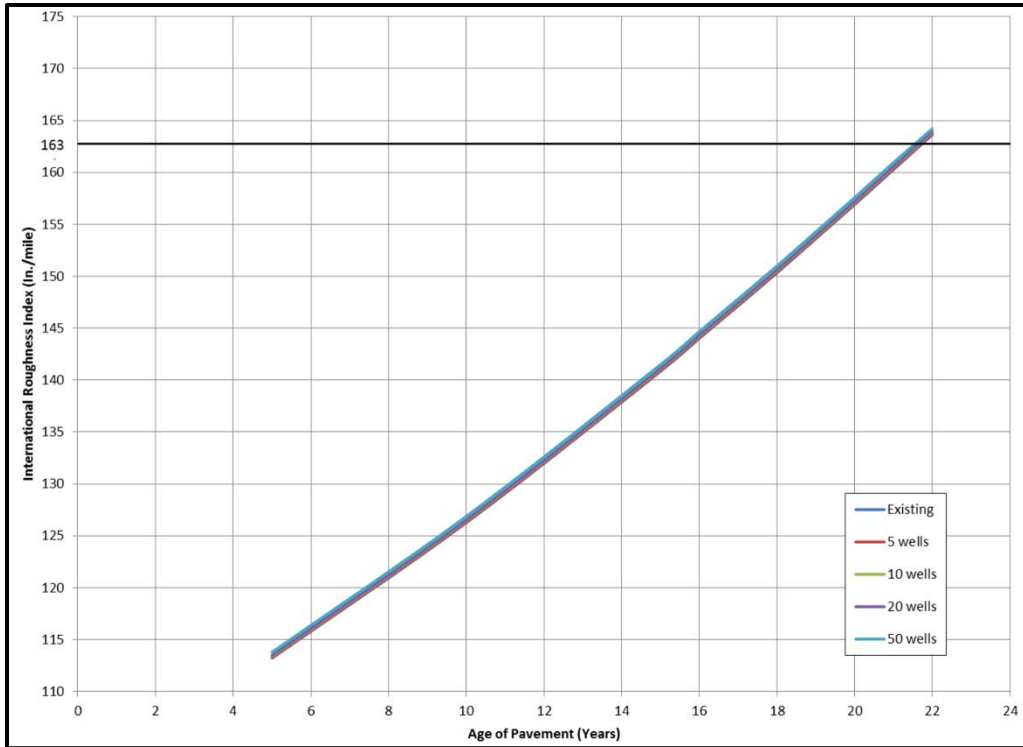


Figure 4.1: IRI Results for K-1 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic

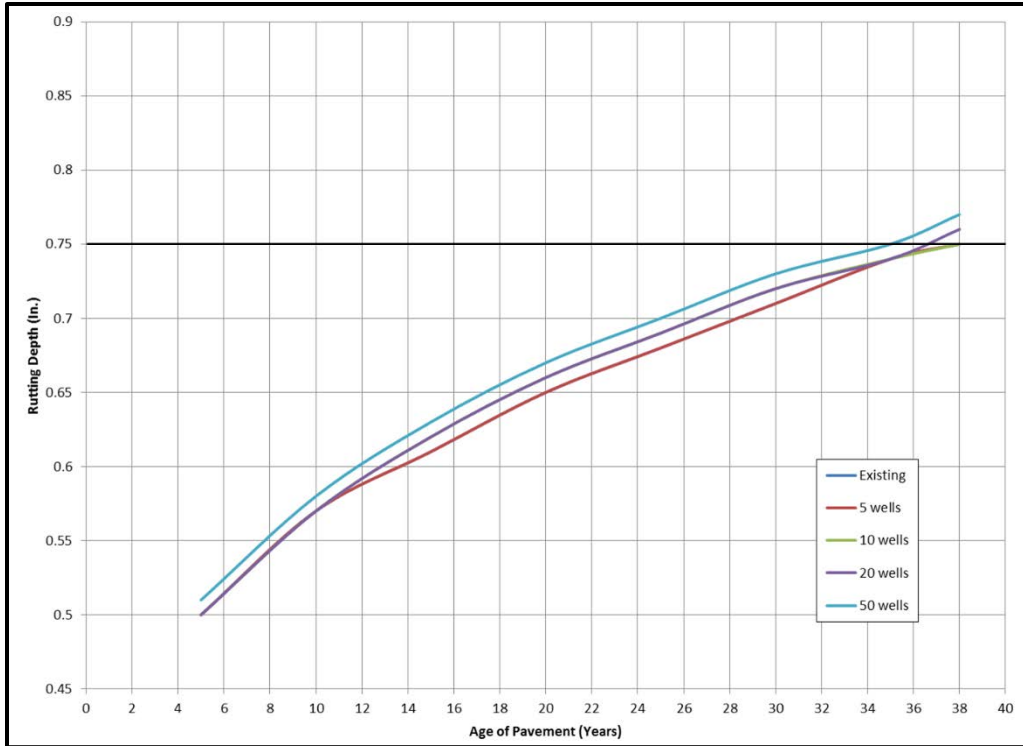


Figure 4.2: Pavement Rutting Depth Results for K-1 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic

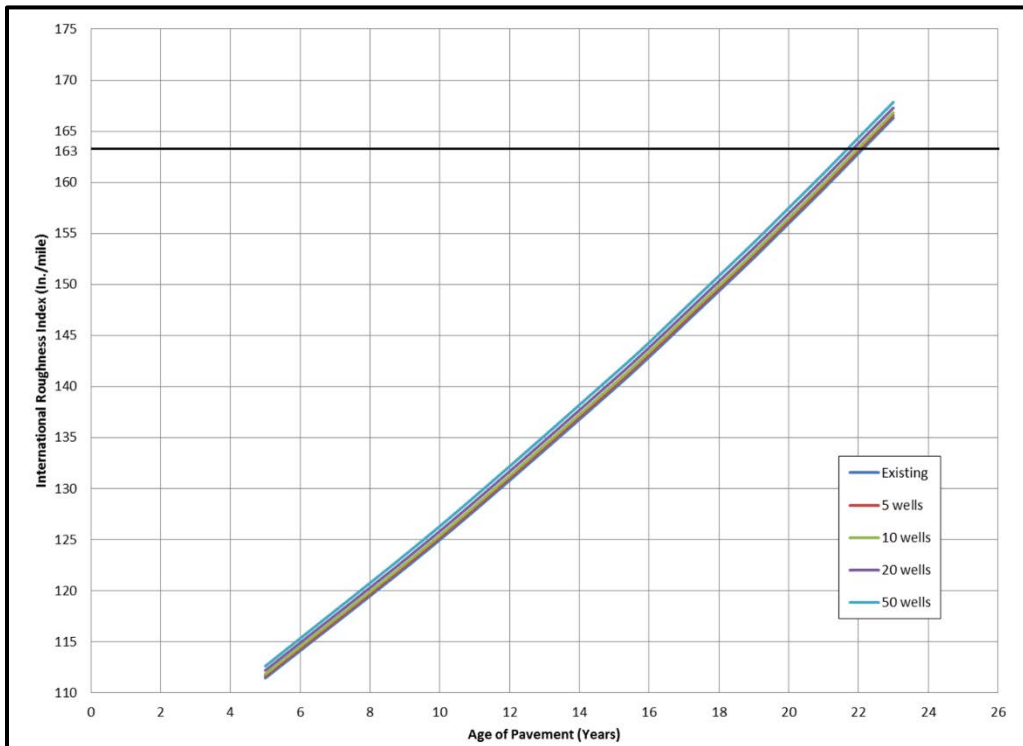


Figure 4.3: IRI Results for K-42 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic

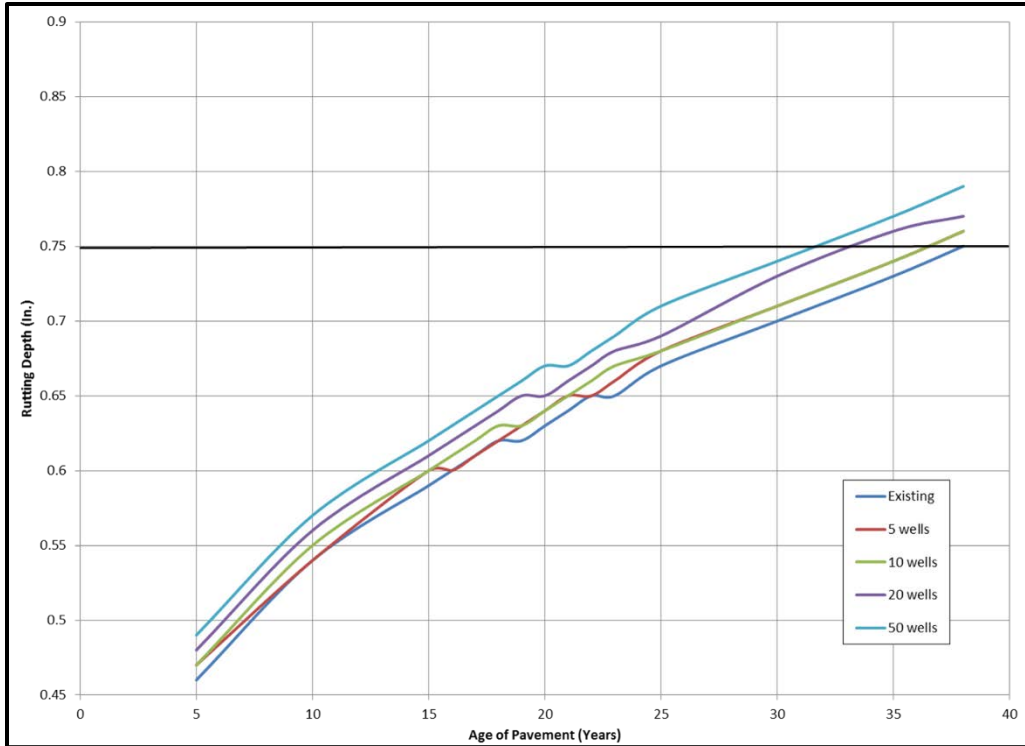


Figure 4.4: Pavement Rutting Depth Results for K-42 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic

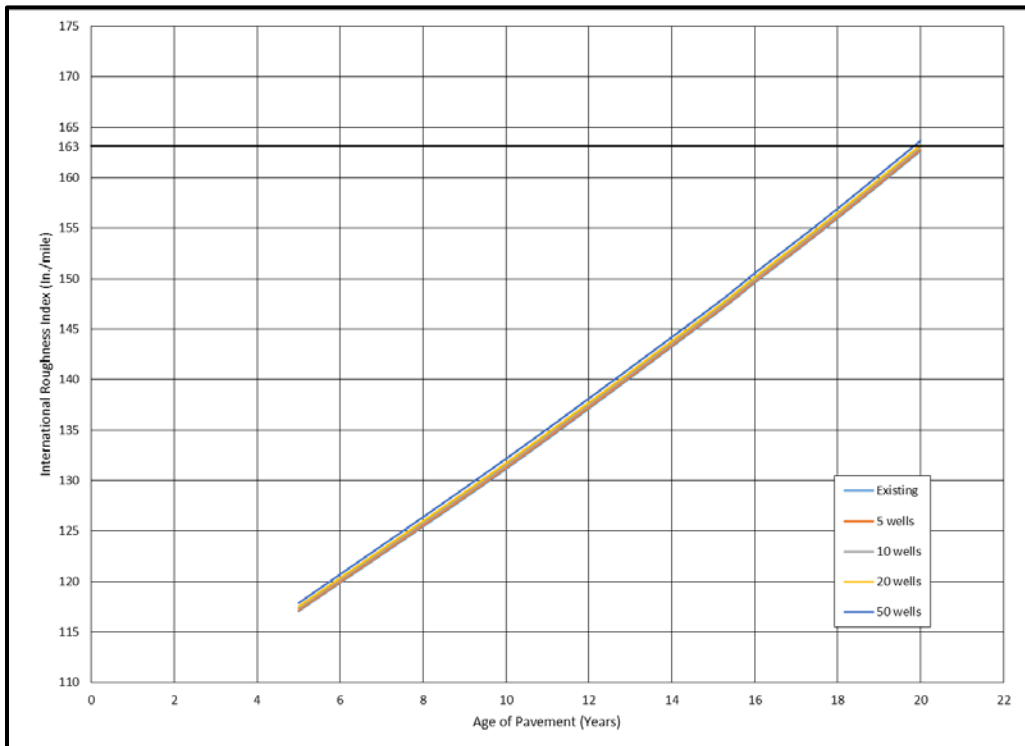


Figure 4.5: IRI Results for K-44 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic

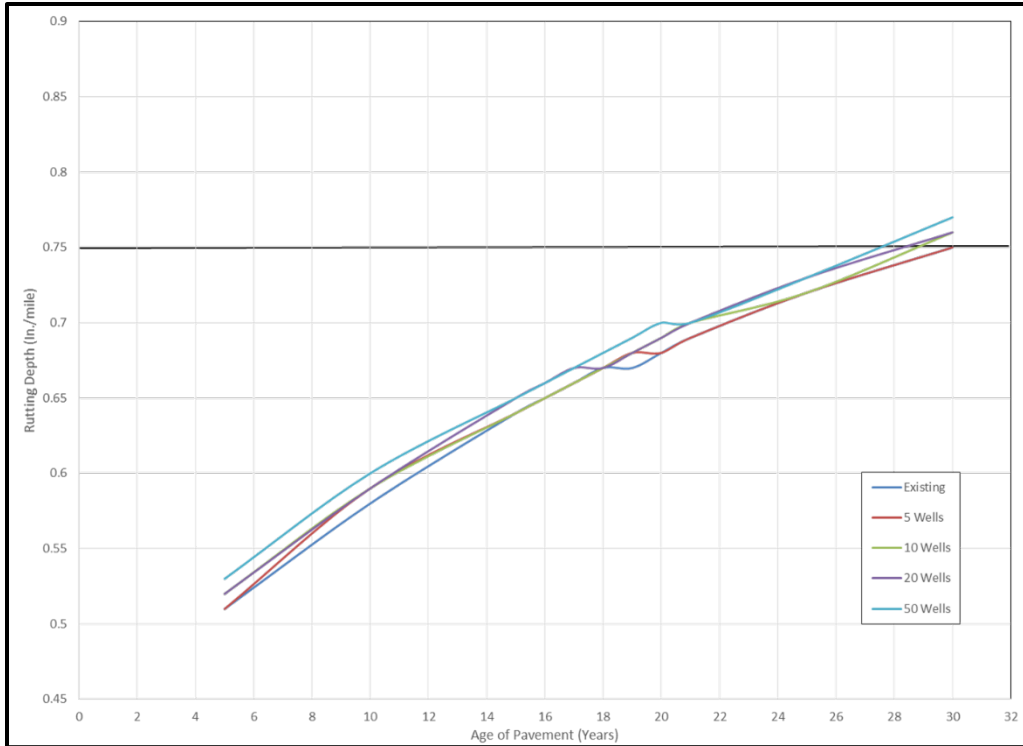


Figure 4.6: Pavement Rutting Depth Results for K-44 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic

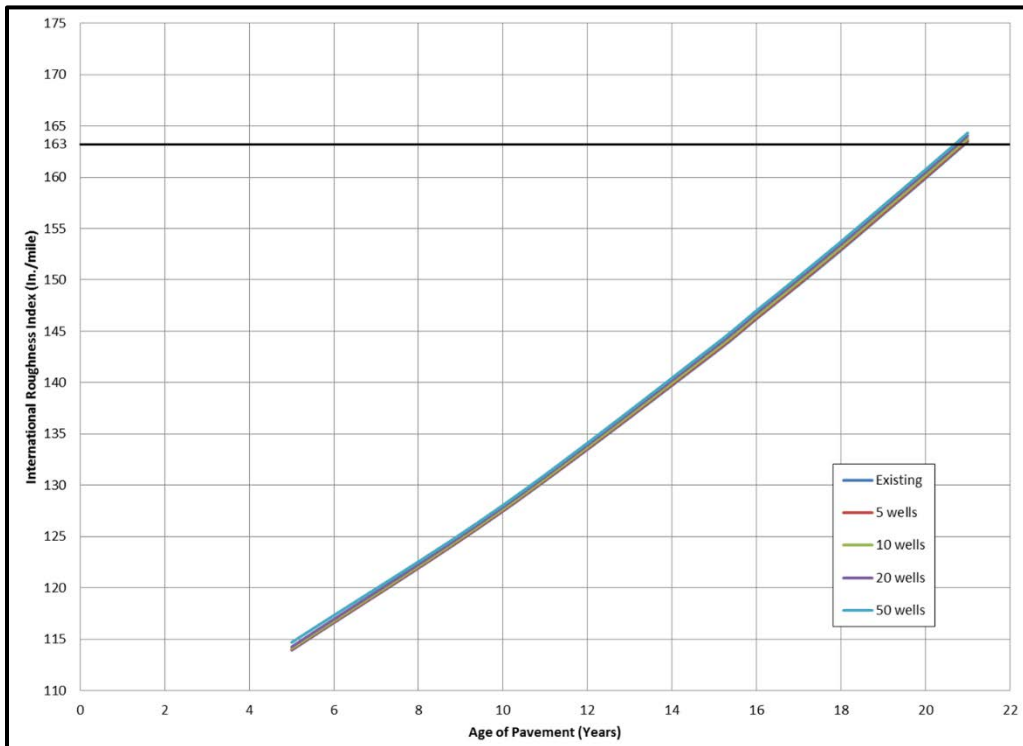


Figure 4.7: IRI Results for K-179 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic

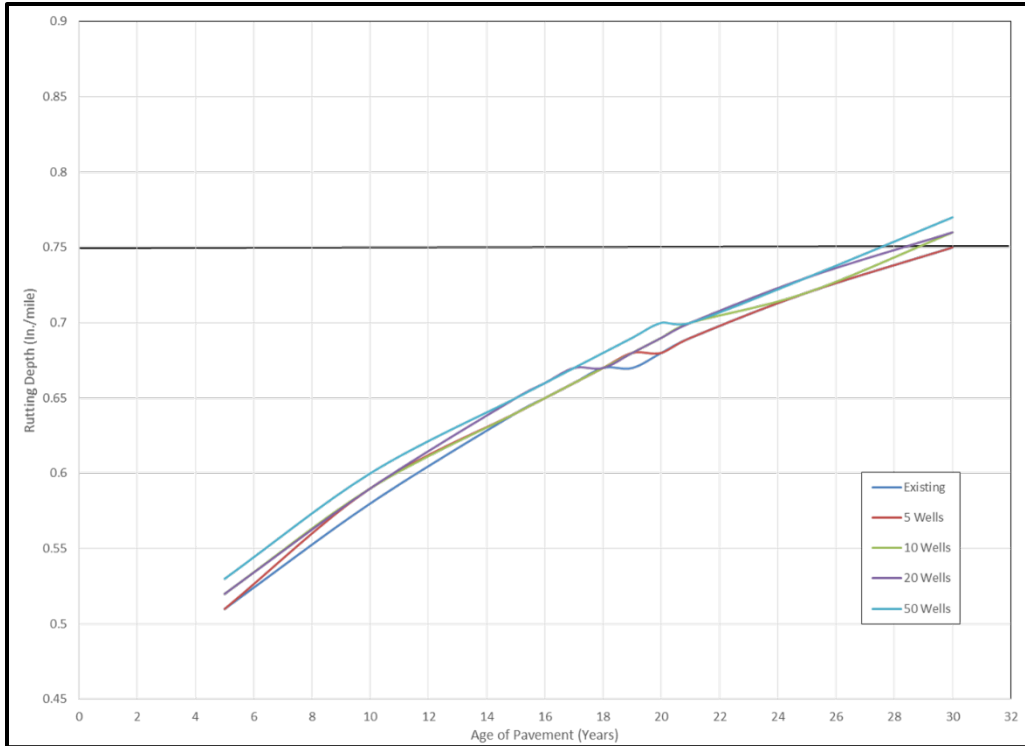


Figure 4.8: Pavement Rutting Depth Results for K-179 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic

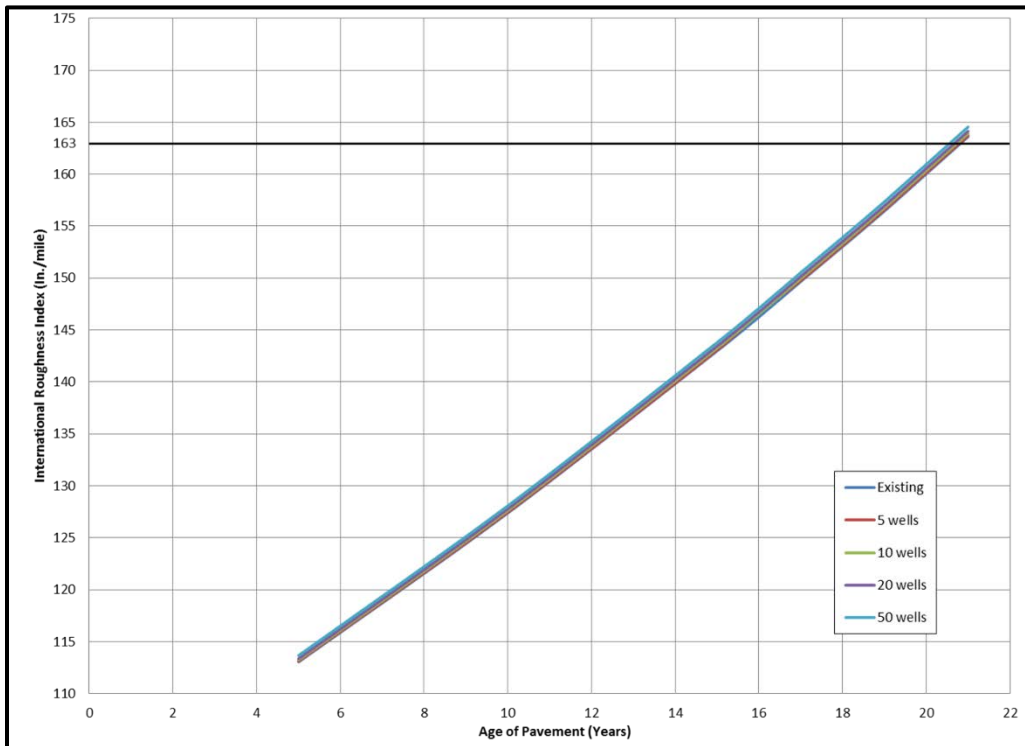


Figure 4.9: IRI Results for US-160 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic

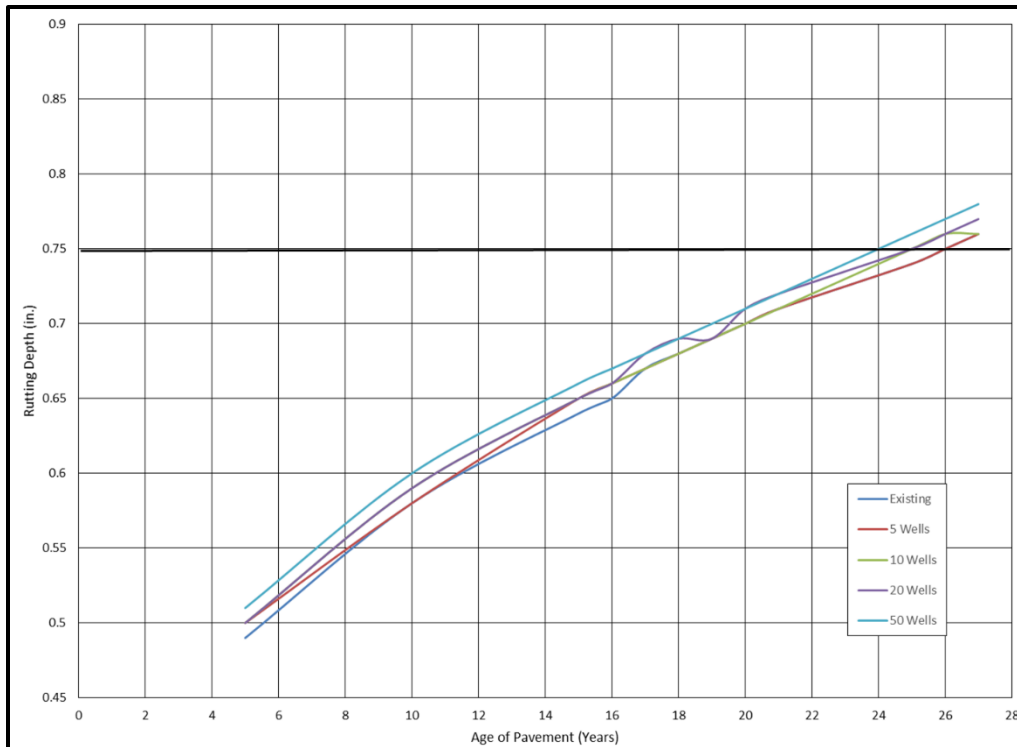


Figure 4.10: Pavement Rutting Depth Results for US-160 for Different Amounts of Oil and Gas Well Hydraulic Fracturing Traffic

4.2 Results of Estimated Pavement Damage due to Wind Farm Traffic

Similar to the oil and gas fracking portion of the analysis, Figure 4.11 shows the differences in pavement life depending on the modeled increase in wind farm traffic on the K-1 roadway model. As shown, the reduction in service life due to median (e.g., a 67-turbine wind farm) and high (e.g., a 262-turbine wind farm) is not noticeably different than the existing traffic with no wind farm.

However, a difference in performance was noted for the K-1 model when comparing the total rutting of the pavement when wind farm traffic was added. In both cases where wind farm traffic was added, 0.75 inch of rutting or greater was observed far sooner than if no wind farm traffic had been placed on the roadway—12 years sooner as shown in Figure 4.12, representing a reduction in pavement life of from about 38 years to about 26 years. These results are indications that a roadway constructed similar to the K-1 pavement model cannot bear the traffic due to a moderate-sized wind farm (67 wind turbines) or higher without a reduction in service life.

Output results for the K-42, K-44, K-179, and US-160 models are shown in Figures 4.3 through 4.10, and provide similar results. Namely, there were little estimated changes in IRI values for overall roughness, but large reductions in service life due to pavement rutting were observed in most of the roadway models when wind farm traffic was added. Table 4.1 shows the estimated service life reductions due to rutting for each of the modeled roadways.

While planning for a wind farm that equals or exceeds the largest in the state (262 wind turbines) may be overly conservative, planning for a median wind farm is not. As shown in Appendix A, most of the wind farms were either larger than the median, or else only slightly smaller in size. As discussed earlier in this report, there is also an economy of scale to be gained from larger wind farm projects from optimizing the creation of service roads and electricity collection and distribution infrastructure. As such, it is likely that when new wind farms are developed they will likely be either near the current median size or larger.

Further discussion on these results is found in the next chapter.

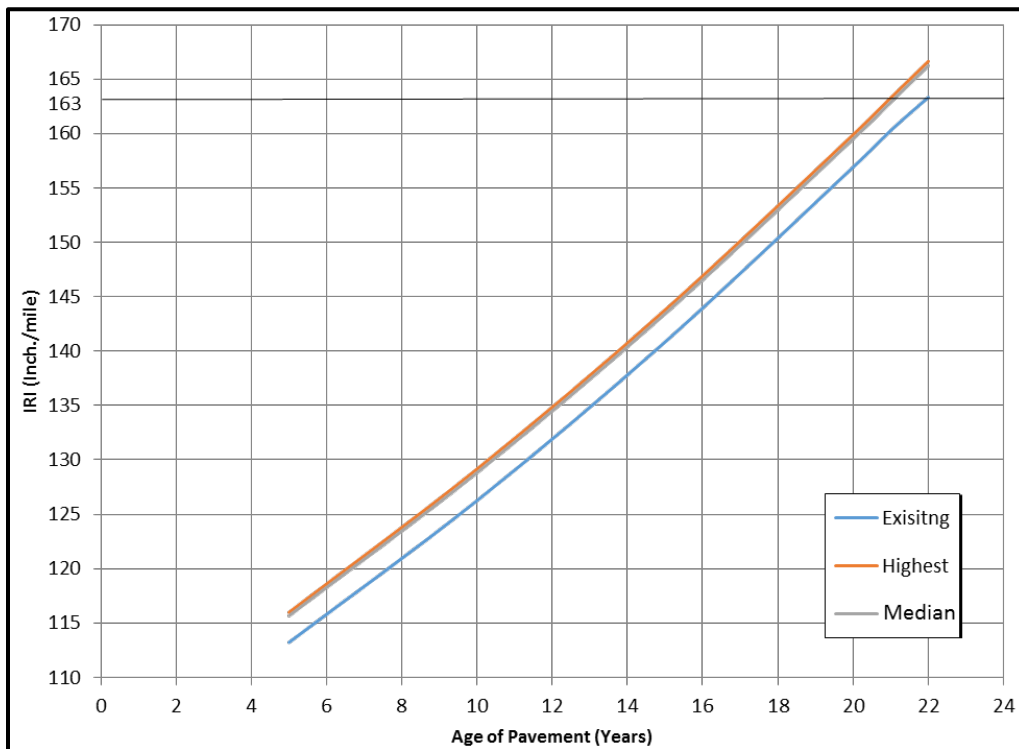


Figure 4.11: IRI Results for K-1 for Different Amounts of Wind Farm Traffic

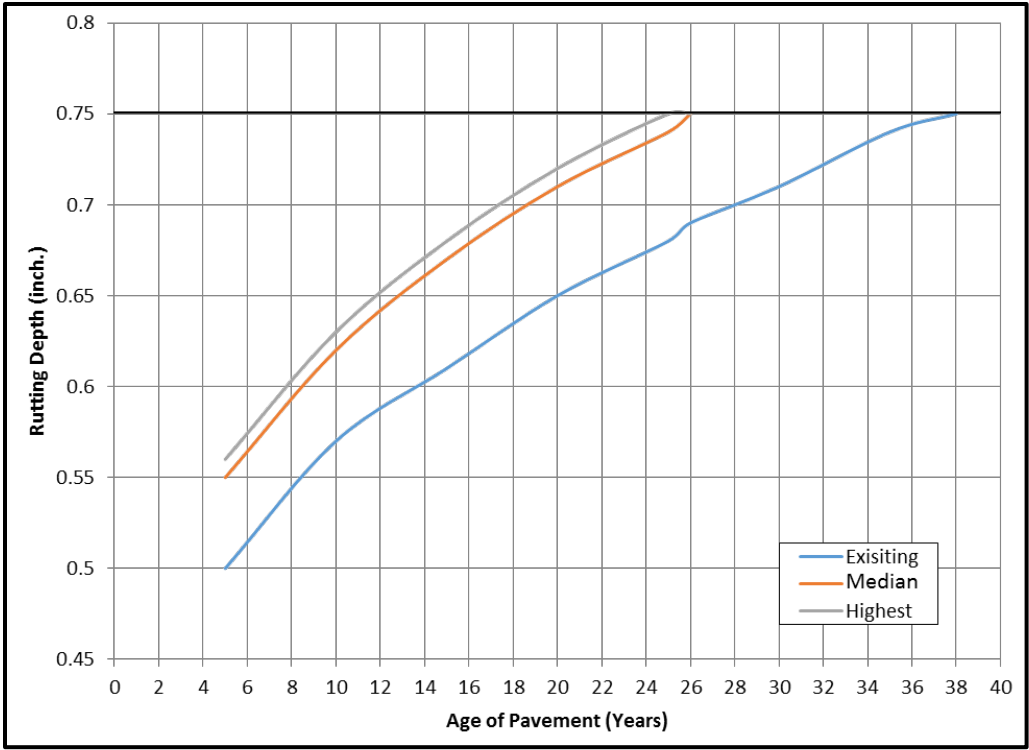


Figure 4.12: Pavement Rutting Depth Results for K-1 for Different Amounts of Wind Farm Traffic

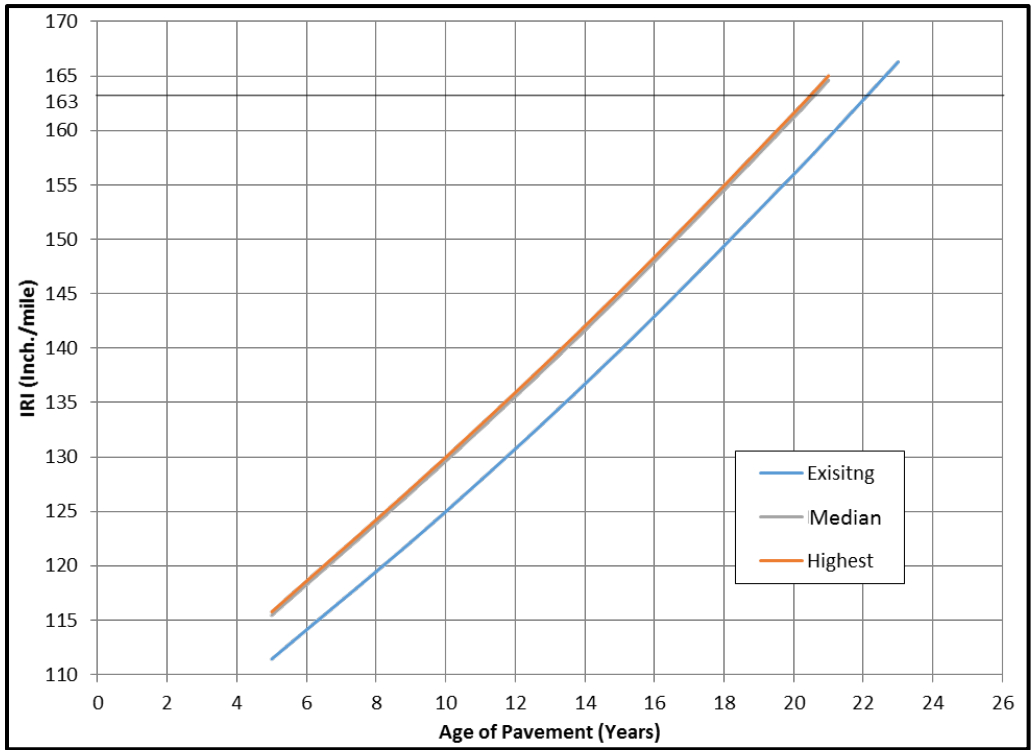


Figure 4.13: IRI Results for K-42 for Different Amounts of Wind Farm Traffic

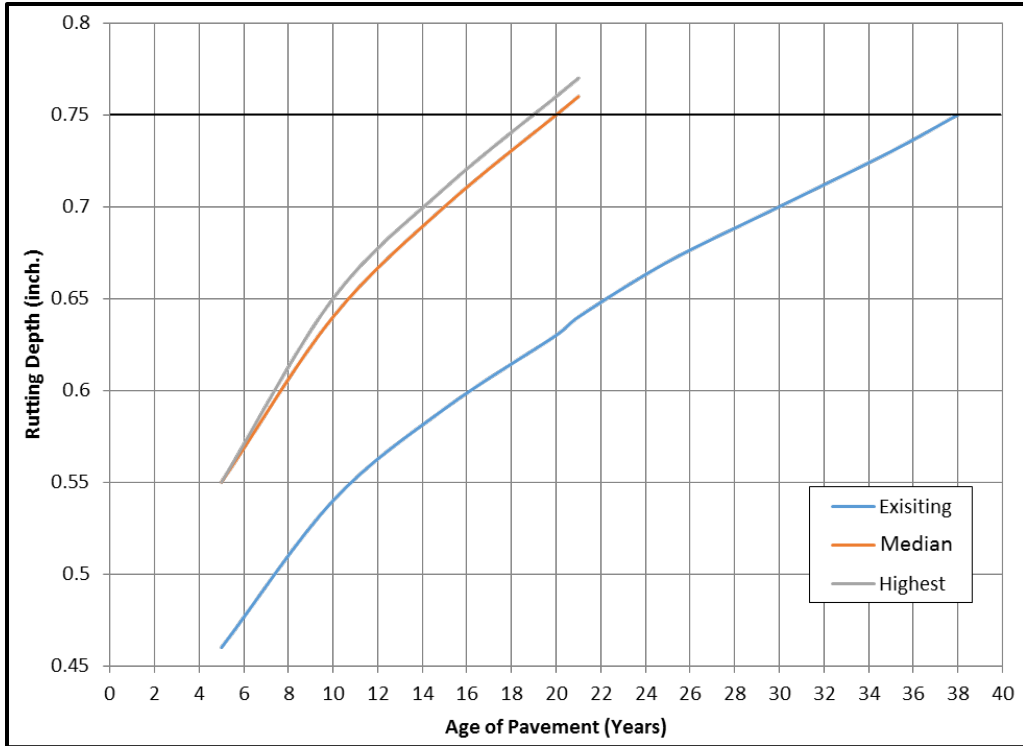


Figure 4.14: Pavement Rutting Depth Results for K-42 for Different Amounts of Wind Farm Traffic

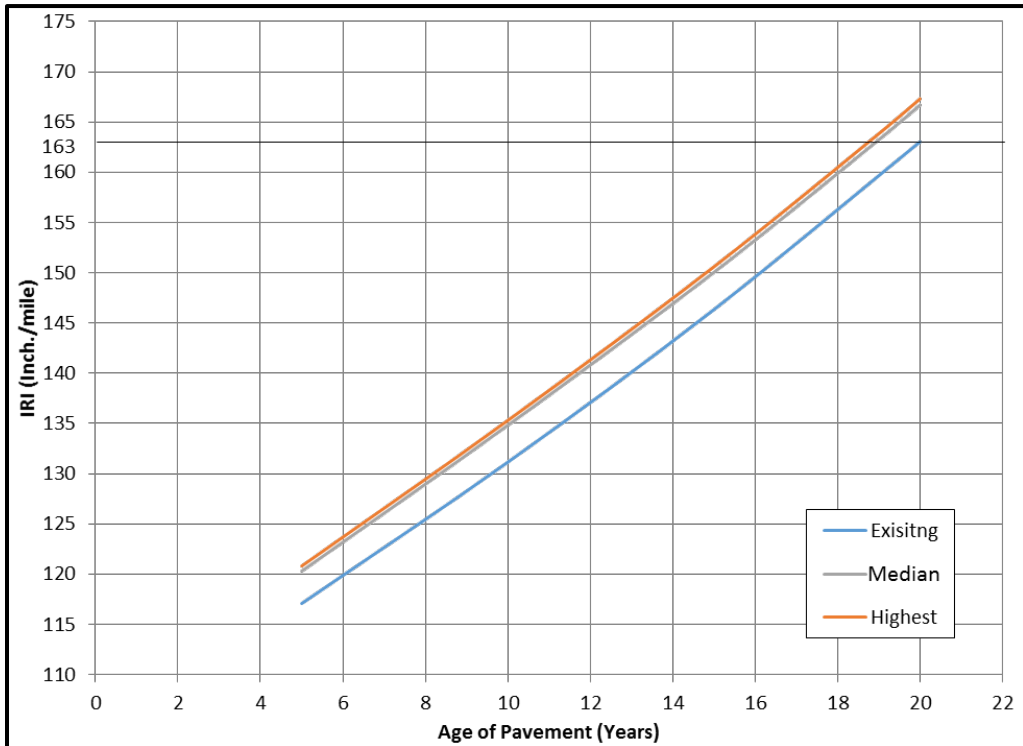


Figure 4.15: IRI Results for K-44 for Different Amounts of Wind Farm Traffic

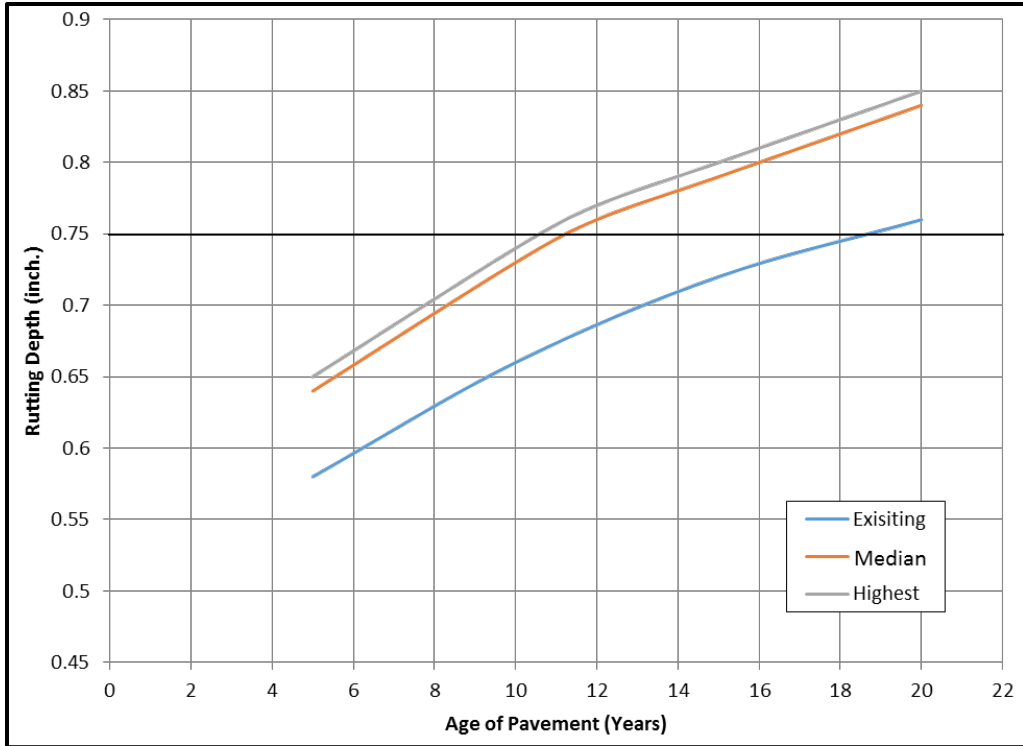


Figure 4.16: Pavement Rutting Depth Results for K-44 for Different Amounts of Wind Farm Traffic

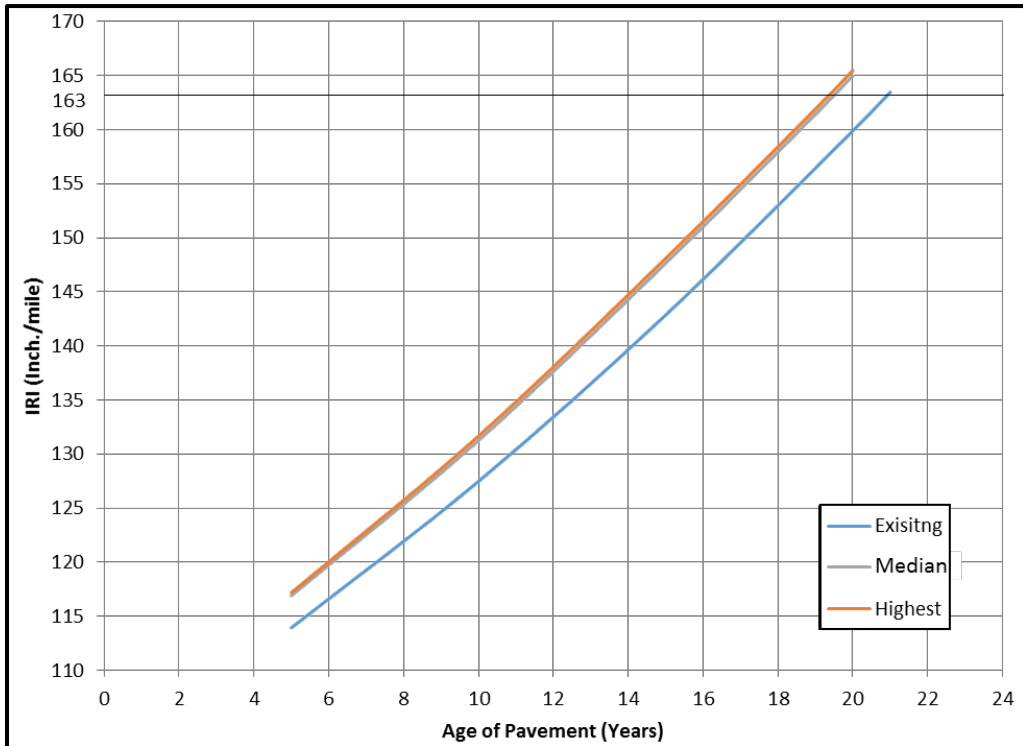


Figure 4.17: IRI Results for K-179 for Different Amounts of Wind Farm Traffic

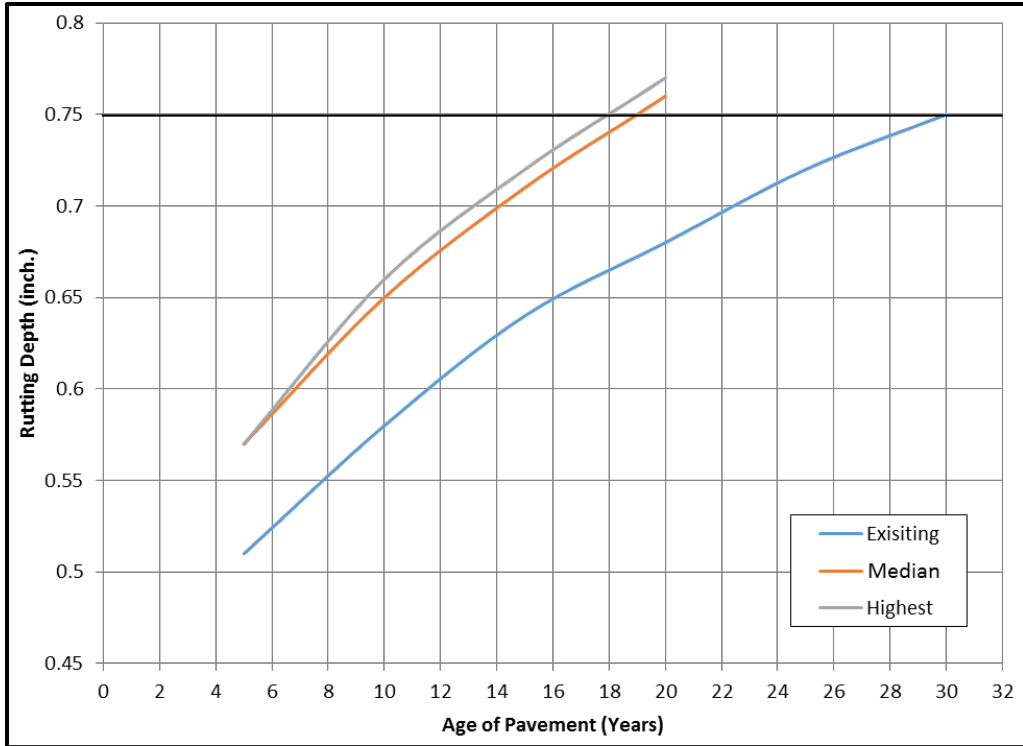


Figure 4.18: Pavement Rutting Depth Results for K-179 for Different Amounts of Wind Farm Traffic

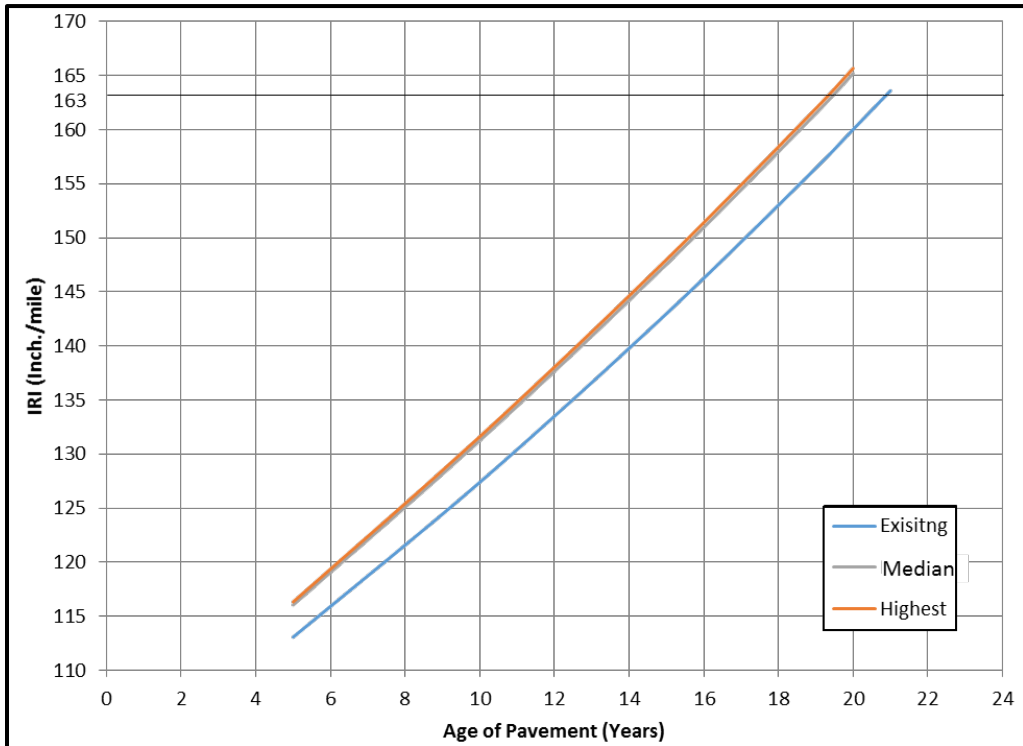


Figure 4.19: IRI Results for US-160 for Different Amounts of Wind Farm Traffic

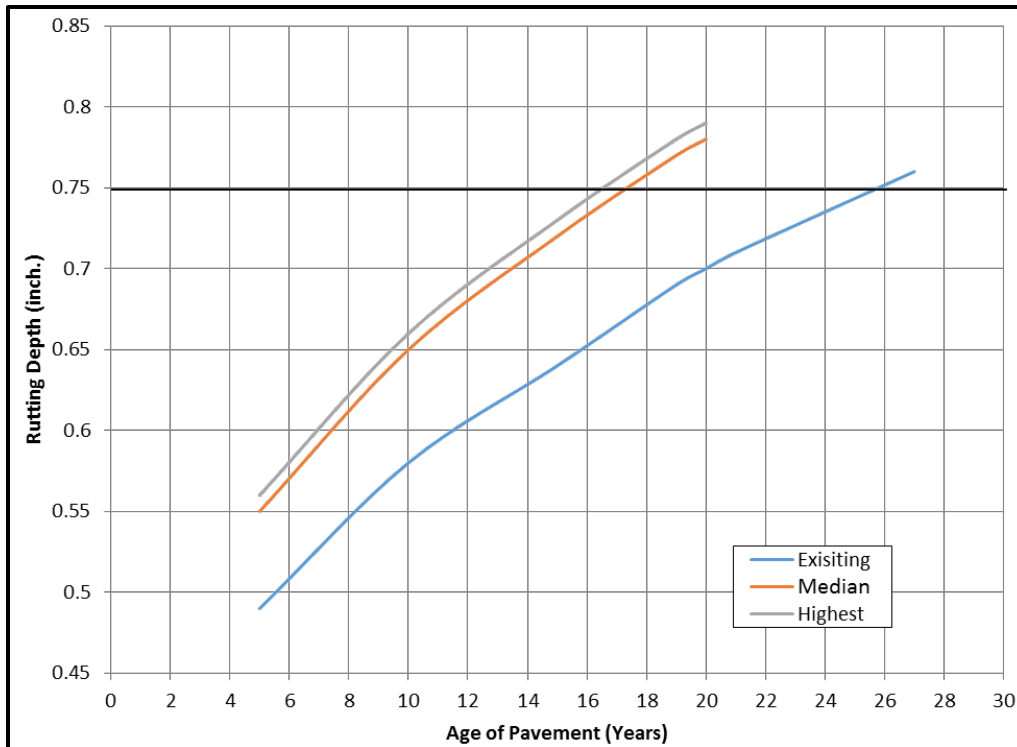


Figure 4.20: Pavement Rutting Depth Results for US-160 for Different Amounts of Wind Farm Traffic

Table 4.1: Service Life Reductions Due to Additional Oil and Gas Fracking Traffic and Wind Farm Construction Traffic

	Service Life Reductions (in Years)			
	Oil and Gas Fracking Truck Traffic (50 wells)		Wind Farm Truck Traffic (262 wind turbines)	
	From IRI	From Total Rutting	From IRI	From Total Rutting
K-1	<1	3	1	13
K-42	<1	6	1	18
K-44	<1	2	1	8
K-179	<1	2	1	12
US-160	<1	2	2	9

Chapter 5: Discussion

Five different roadway sections were developed based on existing rural two-lane roadways in southern Kansas. After discussions with KDOT, these roadways were considered typical roadways that would bear the impact of additional truck traffic due to expansion of the oil and gas industry and/or the wind energy industry. These roadways were also considered similar to two-lane paved roads maintained by local jurisdictions, which could also be impacted by additional truck traffic. The road sections were tested under two criteria, namely, for International Roughness Index (IRI) and total rutting depth using the MEPDG software.

For the oil and gas industry, the roadway sections were tested for 5, 10, 20, and 50 wells, and for the wind energy industry, the roadway sections were tested for the traffic resulting from the installation of wind farms with 67 and 262 wind turbines. None of the roadway models showed a reduction in pavement life of more than 2 years under any of the conditions when analyzing roughness on the IRI scale. However, as discussed in Chapter 4, large reductions in service life were noted under all conditions when looking at the point when total rutting reached 0.75 inch. As shown in Table 4.1, this level of rutting was reached between 9 and 19 years sooner depending on the roadway model. Put another way, this reflects between a 35 and 50 percent reduction in service life before this threshold is reached, depending on the roadway modeled.

These findings indicate that KDOT will bear an increased maintenance cost as roadways deteriorate due to rutting from truck traffic associated with these types of energy development projects. While these projects undoubtedly add to the tax base of Kansas, further analysis is needed to determine if the taxes paid to the state exceed the costs KDOT must bear in their development. Additionally, there needs to be an examination of state laws and budgeting processes to ensure that enough tax dollars are added to the KDOT maintenance budget to be able to adequately maintain the affected roadways. Possible solutions could include additional taxation on these industries, or a one-time up-front charge or bond for roadway repair and maintenance. These are both policy-level examinations that go beyond the scope of this research

project, but could prove beneficial for policy makers to put in place remedies for such roadway damage.

A second area of future research includes an examination of the most likely points of material generation. For example, where are the most likely points where wind turbine components originate from? This would require much more information on specific truck movements than was possible from this research project, but could shed additional information on whether there are Kansas roadways where a concentration of truck traffic may be concentrating, even if it is relatively far from the actual construction sites. A portion of this information is already collected and maintained by KDOT, as the majority of the wind turbine components consist of loads heavier than 80,000 lb, which requires special oversize permits obtained from the KDOT Bureau of Structures and Geotechnical Services.

Third, there is a need to explore the impacts of potential changes to these energy collection industries. For example, since oil and gas well fracking became common in many regions, there have been innovations in how the wells are developed, including an increase in the depth and length of individual horizontal wells, and the number of wells that can be drilled from an individual pad. These increases have resulted in an increase in materials brought to a single location. If this trend continues, there could be a corresponding increase in the amount of traffic on a single adjacent roadway. Similar changes could occur in the wind energy industry. These changes could also expand the areas where oil, gas, or electricity could be profitably produced in Kansas, which could bring these industries to new areas of the state. A planning-level assessment of how the state would deal with the expansion of one or both of these industries would help the state become better prepared for these kinds of changes.

Finally, it appears that the service lives calculated for the existing conditions for the five roadways may overstate the traditional experience KDOT actually achieves in practice. A Kansas-specific model for using the MEPDG may help improve the accuracy, and bring these values in line with traditional experience. In the absence of that, these results are still useful in showing the relative differences between the performances of different roadway and loading conditions.

References

- Abramzon, S., Samaras, C., Curtright, A., Litovitz, A., & Burger, N. (2014). Estimating the consumptive use costs of shale natural gas extraction on Pennsylvania roadways. *Journal of Infrastructure Systems*, 20(3), 1–11.
- Chow, L. (2015, October 28). Alarming uptick of earthquakes in Kansas linked to fracking with 52 in just last two weeks. *Ecowatch.com*. Retrieved from <http://www.ecowatch.com/alarming-uptick-of-earthquakes-in-kansas-linked-to-fracking-with-52-in-1882114801.html>
- Kansas Department of Transportation (KDOT). (2014). *KDOT historical state flow maps*. Retrieved from <http://www.ksdot.org/burtransplan/maps/mapstrafficdist.asp>
- Kansas Energy Information Network. (n.d.). *Kansas wind projects - Case studies*. Retrieved from http://www.kansasenergy.org/KS_wind_projects_case.htm
- Kansas Energy Information Network. (2016). *Kansas wind projects – List*. Retrieved from http://www.kansasenergy.org/wind_projects.htm
- Kansas Geological Survey (KGS). (2016). *Energy research section; Oil and gas data*. Retrieved from <http://www.kgs.ku.edu/PRS/petroIndex.html>.
- Kansastravel.org. (2015). Elk River wind project [Photograph]. *The Beaumont Hotel*. Retrieved from <http://www.kansastravel.org/beaumont hotel.htm>
- Linley, D. (2011). *Fracking under pressure: The environmental and social impacts and risks of shale gas development*. Retrieved from http://www.sustainalytics.com/sites/default/files/unconventional-fossil-fuel-shalegas_final.pdf
- Mason, J. M., Metyko, M. J., & Rowan, N. J. (1982). *The effects of oil field development on rural highways* (Report No. 299-1). College Station, TX: Texas Transportation Institute, Texas A&M University System.
- National Renewable Energy Laboratory (NREL). (2011). *United States – Annual average wind speed at 80 m*. Retrieved from <http://www.nrel.gov/gis/wind.html>

- New York State Department of Environmental Conservation (NYSDEC). (2011). *Supplemental generic environmental impact statement on the Oil, Gas and Solution Mining Regulatory Program: Well permit issuance for horizontal drilling and high-volume hydraulic fracturing to develop the Marcellus Shale and other low-permeability gas reservoirs*. Albany, NY: Author.
- Pavement Interactive. (2012). *What is Mechanistic-Empirical Design? – The MEPDG and you*. Retrieved from <http://www.pavementinteractive.org/2012/10/02/what-is-mechanistic-empirical-design-the-mepdg-and-you/>
- Price, T. J. (2009). Blyth, James (1839–1906). *Oxford dictionary of national biography*. Oxford, UK: Oxford University Press.
- ProCon.org. (2013). *Historical timeline: History of alternative energy and fossil fuels*. Retrieved from <http://alternativeenergy.procon.org/view.timeline.php?timelineID=000015>.
- Prozzi, J., Grebenshikov, S., Banerjee, A., & Prozzi, J. (2011). *Impacts of energy developments on the Texas transportation system infrastructure* (Report No. 0-6513-1A). Austin, TX: Center for Transportation Research, University of Texas at Austin.
- Skelton, L. H. (2011). *A brief history of the Kansas oil and gas industry*. Retrieved from http://archives.datapages.com/data/phi/v7_2006/skelton.htm.
- Suchy, D. R., & Newell, K. D. (2012). *Hydraulic fracturing of oil and gas wells in Kansas* (Public Information Circular 32). Retrieved from <http://www.kgs.ku.edu/Publications/PIC/pic32.html>
- University of Michigan Energy Institute. (2013). *Diagram of horizontal hydraulic fracturing*. Retrieved from <http://www.energy.umich.edu>.

Appendix: Kansas Wind Farm Data

Table A.1: Kansas Wind Farm Data

Wind Farm Name	County Location	Number of Wind Turbines
Flat Ridge II	Barber, Harper, Kingman, and Sumner	262
Gray County	Gray	170
Smoky Hills	Ellsworth and Lincoln	155
Post Rock	Ellsworth and Lincoln	134
Buckeye	Ellis	112
Caney River	Elk	111
Cedar Bluff	Ness and Trego	111
Elk River	Butler	100
Waverly	Coffey	95
Buffalo Dunes	Haskell, Grant, and Finney	90
Slate Creek	Sumner	75
Ironwood	Ford and Hedgeman	73
Spearville III	Ford	72
Spearville	Ford	67
Meridian Way	Cloud	67
Western Plains	Ford	66
Ninnescah	Pratt	65
CPV Cimarron REC	Gray	57
Bloom Wind	Clark and Ford	54
Ensign	Gray	43
Shooting Star	Kiowa	42
Flat Ridge I	Barber	40
Marshall	Marshall	36
Alexander	Rush	33
Central Plains	Wichita	33
Spearville II	Ford	32
Greensburg	Kiowa	10

Source: Kansas Energy Information Network (n.d.)

