

IMPACTS OF ENERGY DEVELOPMENT ON TEXAS ROADS

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ABSTRACT

The production and exploration of oil and gas in Texas has been ongoing for many years. Recently, Texas has seen a tremendous increase in the exploration and production of energy resources. The number of completed oil and gas wells has almost tripled since 2011. The increase in energy-related activity has greatly benefited the state economy, however, the production of oil and gas generates large numbers of heavy trucks traveling on roads which were not originally designed to handle high-intensity truck traffic. Over time, the large volumes of heavy truck traffic have damaged the roads and significantly reduced their service life. The problem is particularly acute in the counties that have experienced the oil and gas drilling boom. These counties have experienced a more than ten percentage point drop in their percentage of lane miles in “Good” or better condition in just one year. Due to the lack of adequate funding, it is a challenge to maintain existing infrastructure and ensure the transportation system can serve the energy sector in the future. This paper illustrates the impacts of the energy development activities on the state maintained roads, and compares the differences between proactive and reactive maintenance approaches using a case study on a typical Farm-to-Market road. In addition, some of the mitigation strategies implemented in Texas were documented in this paper. The analysis methodology, findings, and strategies documented in this paper can be used by other transportation agencies to mitigate damages caused by the energy sector.

INTRODUCTION

Texas has experienced a significant increase in energy-related activities recently, especially in development of oil and natural gas wells, and the construction of wind farms. According to a new report from the Energy Information Administration (EIA), Texas is now the largest producer of wind power, oil, and natural gas in the country (1).

A large number of areas around Texas have had oil and gas drilling activities going on for many years, including the Permian Basin area in West Texas which has been active since the 1920s. Besides this West Texas area of the state, Texas has four other major areas of shale oil and gas activities: the Barnett Shale in the Fort Worth region, the Granite Wash in the Panhandle stretching into Oklahoma, the Haynesville-Bossier Shale in East Texas, and the Eagle Ford Shale in South Texas. These four shale formations only recently became economically viable because of two innovative drilling technologies: horizontal drilling and hydraulic fracturing. The Permian Basin has re-emerged incorporating advanced drilling techniques with drilling in multiple geologic horizons. According to the Railroad Commission of Texas (RRC), the total number of completed oil and gas wells almost tripled since 2011(2). Oil production per day from the Eagle Ford Shale has increased more than five folds in the last four years (3).

In addition, the wind energy industry in Texas has created thousands of jobs and provided billions of dollars in economic benefits. Texas has 12,000 megawatts of wind generation, more than double any other state (4). Most wind farms are located in areas overlapping oil and gas development.

The energy sector has been a major contributor to the local and state economies in Texas. However, the energy sector is placing significant financial and operational demands on both the state and local transportation systems. Wind farm developments require delivery of very large and heavy components to the sites by oversize and overweight trucks. Additionally, concrete, gravel and other construction materials and equipment must be delivered to build the foundation for the turbines, which causes most pavement damages. Once the wind turbine is erected, the pavement damage caused by wind farm maintenance traffic is minimal. The oil and gas development requires the movement of heavy equipment, site prep materials, fracking sand, water to the drilling sites, and transportation of brine water from the sites. This movement generates a large amount of truck traffic on the Texas roadway network, especially on the rural roads which were not designed and constructed to accommodate heavy truck loads. Compared to oil and gas development, the wind farm construction only causes localized and short term impact on the state roadway network. Therefore, only impacts associated with the oil and gas well development activities are investigated and estimated in this study.

This paper illustrates the impact of oil and gas development activities on the state maintained road network. A pavement performance measure was presented to demonstrate the overall condition trends using the annual pavement evaluation data. In addition, a project level case study was conducted to show the difference between the proactive and reactive maintenance/repair approaches. Finally, this paper shares some mitigation strategies used in Texas.

OIL AND GAS DRILLING ACTIVITIES IN TEXAS

RRC regulates the oil and gas industry, gas utilities, pipeline safety, safety in the liquefied petroleum gas industry, surface coal and uranium mining in Texas. RRC maintains an extensive database of oil and gas well permits in the state. This database includes both spatial and non-spatial data, part of which contains the latest permits and completion information of the oil and gas wells in the state. Figure 1 shows the general trend of issued drilling permits and completed oil and gas wells (2). The trend clearly shows Texas has experienced an oil and gas drilling boom in the last two years. The completed oil and gas wells set a new record in 2013, even though the number of permits slightly decreased.

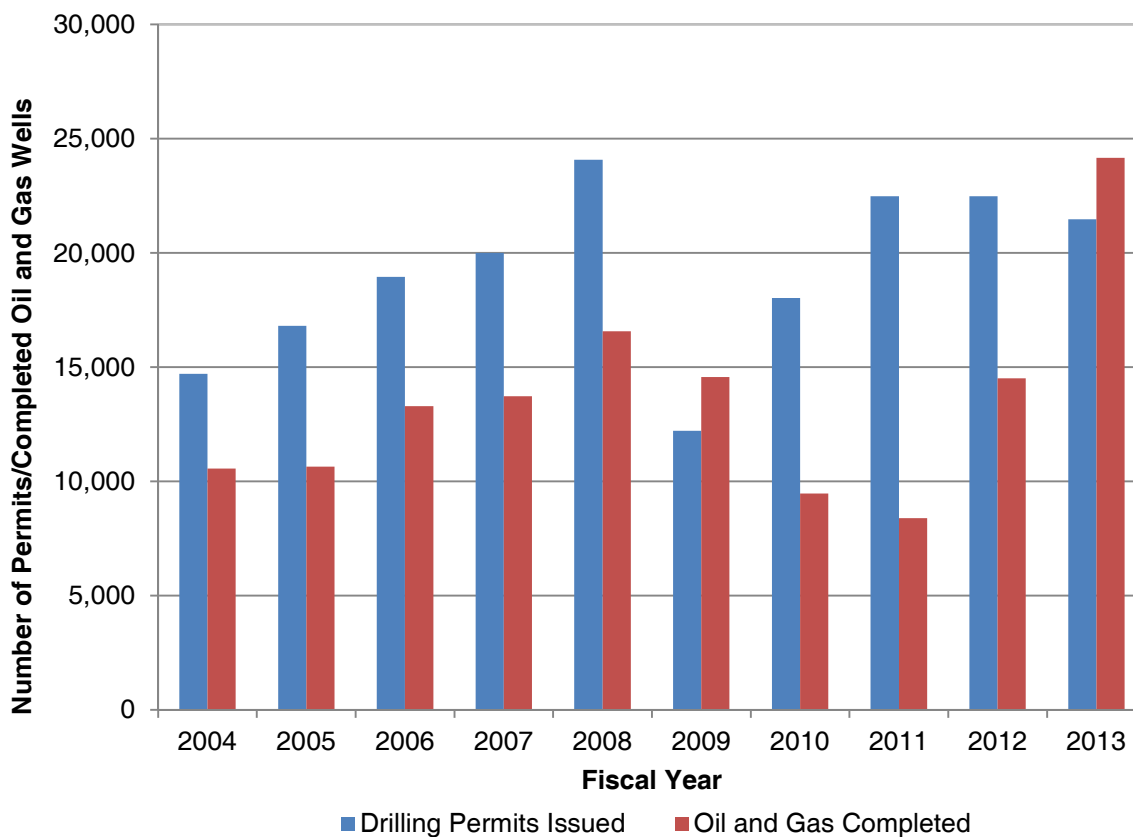


FIGURE 1. Drilling Permits vs. Completed Oil and Gas Wells

The creation and life of an oil or gas well can be divided up into five phases: planning, drilling, completion, production, and abandonment. After drilling, a well must be completed. The completion process enables a well to produce oil and/or gas (5). The production phase is the most important phase of a well's life, which can last many decades. Therefore, wells completed 20 or 30 years ago could still be actively producing if operating companies decide that the well operation remains commercially viable. Figure 2 shows the locations of completed oil and gas wells between 2004 and 2013. The dark blue dots show completed well locations before 2011, while the red dots show completed well locations between 2011 and 2013. This map illustrates the extent of oil and gas drilling activities for the entire state in the last ten years. Many recently completed wells are located in the traditional Permian Basin and Granite Wash areas, but a large

number of completed wells are also located in the recently booming shale formations such as Barnett Shale and Eagle Ford Shale.

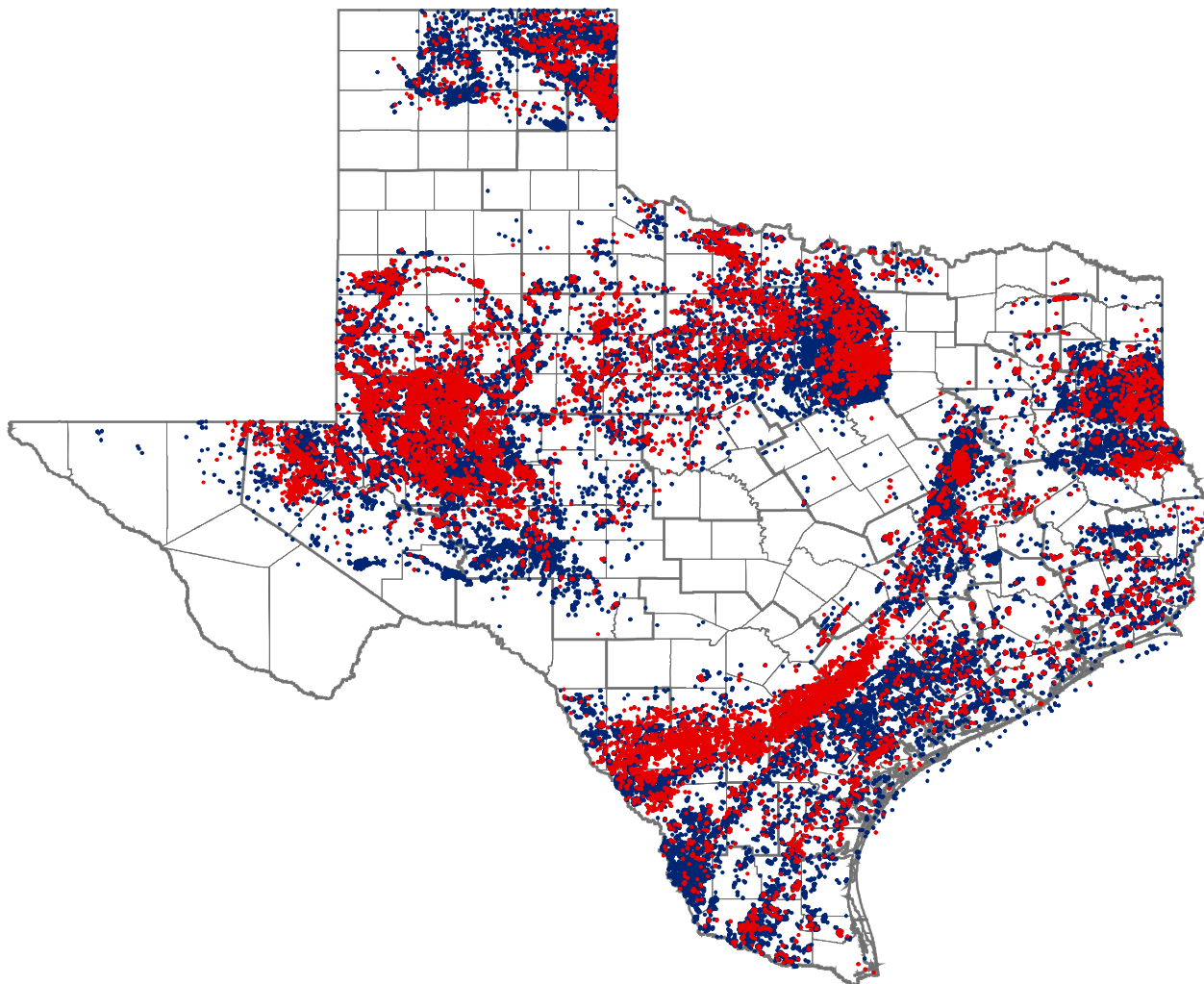


FIGURE 2. Completed Oil and Gas Well Locations in 2004-2013

THE STATEWIDE PAVEMENT CONDITION TREND

The pavement performance measure for the state maintained pavement is the percent of lane miles in “Good” or better condition. The “Good” or better condition is defined to have pavement condition scores of 70 or above. Texas Department of Transportation (TxDOT) collects pavement evaluation data on the entire highway network annually. Pavement distresses are rated by certified visual raters every September to December. Inertial profiler vans collect ride quality and rutting data from September to February. The pavement evaluation data is stored into a Pavement Management Information System (PMIS) database that is used to monitor the overall

pavement condition trend and help pavement managers to select projects and identify feasible pavement maintenance and rehabilitation options.

Oil and gas development activities generate large amounts of heavy truck traffic causing pavement damages and reduction in service life. This problem is particularly acute in the counties of South and East Texas where the Pavement condition is deteriorating rapidly due to the oil and gas drilling activities in those areas. The following counties experienced a more than ten percent drop in their percent of “Good” or better condition in just one year: Hansford, Lipscomb, Roberts, La Salle, Winkler, and Dimmit. Figure 3 shows the detailed change in percent of lane miles between FY2010 and FY2013 for all Texas counties. Hansford, La Salle and Karnes County experienced a more than 20 percent drop, and 24 Counties showed a more than 5 percent drop in the last four years.

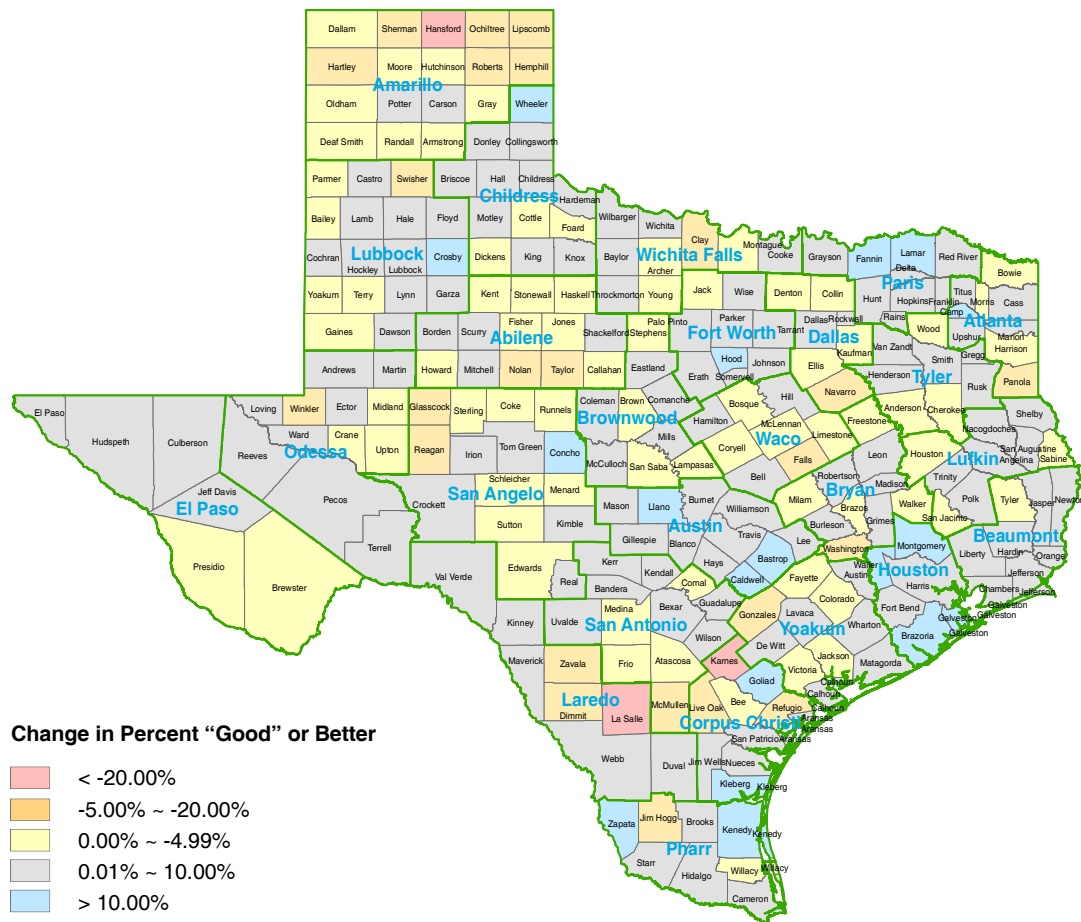


FIGURE 3. Texas County Percent Change “Good” or Better between FY2010 and FY2013

TRUCK TRAFFIC FROM ONE SINGLE WELL DEVELOPMENT ACTIVITIES

Traffic data plays a critical role on estimating the impact associated with oil and gas development activities. TxDOT has 32 Weight-in-Motion (WIM) data sites installed on interstates or major routes. However, most of the damages caused by the energy development activities occur on the rural roadways which do not have WIM stations. The TxDOT PMIS database contains traffic data, but the problem is that the traffic data in the PMIS database is normally two years behind, which makes it difficult to use for this purpose. In addition, traffic volumes generated by the energy-related activities increase dramatically during development stages and decreases significantly during production when pipeline systems are in place. It is very challenging to capture reliable traffic information related to the drilling and completion of oil and gas wells using the TxDOT statewide traffic data collection program (6).

TxDOT collected traffic data from the oil and gas companies in the Barnett Shale (7) and Eagle Ford Shale areas which included the detailed number of trucks, gross vehicle weights and axle configurations from drilling to production phases. These truck loads are converted to standard 18-kip Equivalent Single Axle Loads (ESAL) based on the American Association of State Highway and Transportation Officials (AASHTO) standard (8). Table 1-2 show the number of truck traffic in each phase of the oil or gas well development and their corresponding ESALs in these two shale formation areas.

TABLE 1. Truck Traffic Produced by One Single Well in Eagle Ford Shale

Type of Vehicle	Number of Axles	Loaded Weight (in pounds)	One-Way Trips (per Wellsite)	18-k ESAL (per Truck)	18-k ESAL (per Wellsite)
Construction Wellsite					
Ingress Overweight Loads	6	108,000	1	4.083	4.083
Ingress Overweight Loads	6	118,000	1	5.719	5.719
Egress Overweight Loads	6	108,000	1	4.083	4.083
Egress Overweight Loads	6	118,000	1	5.719	5.719
7-Axle Truck Trailer Combo Lowboy Trailer	7	141,000	14	3.562	49.868
1/2-3/4-1 ton Truck	2	10,000	94	0.016	1.504
5-axle Semi Tractor Trailer	5	80,000	206	2.451	504.906
Subtotal			318		575.882
Drilling Wellsite					
Ingress Overweight Loads	6	110,000	4	4.395	17.58
Ingress Overweight Loads	6	95,000	2	2.469	4.938
Ingress Overweight Loads	6	90,000	1	3.959	3.959
Ingress Overweight Loads	6	80,000	1	2.451	2.451
Egress Overweight Loads	6	110,000	4	4.395	17.58
Egress Overweight Loads	6	95,000	2	2.469	4.938
Egress Overweight Loads	6	90000	1	3.959	3.959
Egress Overweight Loads	6	80,000	1	2.451	2.451
5-axle Semi Tractor Trailer low boy	5	80,000	144	2.451	352.944
9-axle Semi Tractor Trailer	9	148000	80	4.673	373.84
Subtotal			240		784.64
Fracturing					
5-axle Semi Tractor Trailer	5	80000	560	2.451	1372.56
Subtotals			560		1372.56
Production					
5-axle Semi Tractor Trailer	5	80000	2190	2.451	5367.69
Subtotals			2190		5367.69

TABLE 2. Truck Traffic Produced by One Single Well in Barnett Shale

Type of Vehicle	Number of Axles	Loaded Weight (in pounds)	One-Way Trips (per Wellsite)	18-k ESAL (per Truck)	18-k ESAL (per Wellsite)
Drilling Wellsite					
Rock Hauler	5	84,000	70	2.99	209.30
Rig (install)	5	100,000	2	6.21	12.42
Rig (removal)	5	100,000	2	6.21	12.42
Bob-Tail	5	80,000	20	2.45	49.00
Bob-Tail	5	80,000	20	2.45	49.00
Bob-Tail	5	80,000	8	2.45	19.60
Bob-Tail	5	80,000	6	2.45	14.70
Bob-Tail	5	80,000	9	2.45	22.05
Subtotals			137		388.49
Fracturing					
Work-over Rig	5	80,000	2	2.45	4.90
Work-over Rig	5	80,000	2	2.45	4.90
Tank Truck	5	80,000	70	2.45	171.50
Water Tanker	5	80,000	685	2.45	1,678.25
Water Tanker	5	80,000	214	2.45	524.30
Bob-Tail	5	80,000	24	2.45	58.80
Subtotals			997		2,442.65
Production					
Tank Truck	5	80,000	353	2.45	864.85
Subtotals			353		864.85

When truck traffic from different phases in the first year are added together, the total number of ESALs generated from the Barnett Shale area is 3,696 while the total number of ESALs is 8,101 from the Eagle Ford Shale area. The total number of ESALs for the site construction, drilling, and fracturing is very close in these two shale formations. The biggest ESAL difference exists in the production phase. Eagle Ford shale formation requires much more production truck loads than Barnett Shale formation, because the Eagle Ford doesn't have the pipeline system to transport the oil or natural gas product yet. Most of the oil or natural gas produced has to be trucked out to the nearest collection sites. On average, five extra trucks per day are needed to transport the oil and gas product from one single well. Trucking out oil or gas products is also observed in some of the Permian Basin areas, even though the pipeline system has been established for years. The current record high oil and gas production has exceeded the capacity of the current pipeline system in some of the Permian Basin areas.

These oil and gas wells need to be refractured every 5-10 years after they are completed. The extra 2,443 ESALs generated due to refracturing would be applied to the pavement in the Barnett Shale area compared to 1,372 refracturing ESALs in the Eagle Ford area. If a five year refracture cycle is assumed in this analysis, 27,456 ESALs would be generated per one single well in the 20 year pavement design life in the Barnett Shale area compared to 114,205 ESALs from the Eagle Ford Shale area.

Please note that the truck loads collected in these two shale formation areas may not be applicable in other areas because the number of truck loads depends on a variety of factors such as well type and depth, geology, drilling technology, water need, and product transportation.

Truck traffic impacts on the road segment around the locations where well drilling takes place depend on the number of wells drilled and fractured each year, the distribution of these activities around the shale formation area, and truck trip generation at each well.

CASE STUDY OF PROACTIVE VERSUS REACTIVE MAINTENANCE/REPAIR APPROACH

Energy-related activities cause various kinds of pavement damages and result in increased roadway maintenance needs. These increased needs pose a huge financial burden on TxDOT especially when the agency is already facing funding shortfalls. A cost effective maintenance strategy can help the state stretch the limited amount of funding and improve pavement condition. In order to assess the difference between proactive and reactive approaches, a hypothetical analysis was conducted using a typical FM road in South Texas.

The reactive approach is to fix and maintain roads after pavement damage has occurred, while the proactive approach includes reconstructing or resurfacing a road to preserve it before damage occurs. In other words, the proactive approach armors up the pavement structure to make it capable of carrying a high volume of heavy truck traffic loads. In this analysis, the reactive approach is to maintain or repair the pavement without changing the current pavement structure.

The reduction in pavement life was calculated based on the accumulated truck traffic generated by the nearby permitted wells. Then the additional annual replacement cost was calculated. For simplicity, the additional annual replacement cost is assumed to be the reactive maintenance/repair cost for the road to hold it together. The shorter the pavement life is, the more money it needs to restore the road condition.

The case study evaluated FM2688, a 12.6 mile 2-lane rural highway located in Dimmit County. This typical FM road has a structure of chip seal (seal coat) on top of 6 inch flexible base. It was originally designed and constructed to last 20 years and carry a total of 197,000 18-kip ESALs.

There were 47 oil and gas drilling permits issued along FM2688 in 2012, due to the oil and gas boom in the Eagle Ford Shale area. According to the traffic data collected in the Eagle Ford area, the total 20-year ESAL generated by one single well could reach 114,204 ESALs. 47 drilling permits could potentially generate 5 million ESALs in 20 years which far exceeds the design capacity of this FM road. Since the pipeline system is expected to be put into place in the Eagle Ford Shale area, the traffic loads model for the Barnett Shale area is used in this analysis.

In order to estimate the proper maintenance needs, this 12.6 mile of road was divided into five segments based on the connecting point to the access road. Each segment handles the traffic generated by the nearby oil and gas wells. The number of wells served by each segment and their designed 20-year ESALs are shown in Table 3.

TABLE 3. FM 2688 Road Segments and Their Design ESALs

Segment	# of Wells	Length	20-Year Design ESALs
1	13	2.00	197,000
2	23	3.96	197,000
3	30	2.02	342,000
4	42	1.97	342,000
5	47	2.66	342,000

These 47 wells were assumed to be completed with 100 percent success rate in the coming year. The total number of traffic generated by these wells was calculated and assigned to

each segment. This extra amount of heavy truck traffic should cause the premature failure of the road requiring significant maintenance.

The annualized additional cost was assumed to be used to fix the road to its original condition. Based on the historical data, the average reconstruction cost is \$156,905 per lane mile for a typical FM road. Table 4 shows the expected life and additional cost needed every year.

TABLE 4. Expected Life and Additional Annual Replacement Cost per Lane Mile

Segment	Expected Life	Annualized Additional Cost
1	6.09	\$ 17,986
2	4.44	\$ 27,753
3	5.36	\$ 21,554
4	4.18	\$ 29,979
5	3.62	\$ 35,873

Since the number of completed wells in the future is unknown, the 20-year ESALs have to be estimated in order to properly armor up the road to meet future needs. In this analysis, 0, 5, and 10 more wells were assumed to be completed each year. The different pavement structures were proposed to meet the TxDOT pavement design requirements (9). Cost for each structure is shown in Table 5.

TABLE 5. Proactive Versus Reactive Approach Over 20 Years

Number of Additional Well Permits	20-Year ESAL	Proposed Plans	Total Proactive Cost	Total Reactive Cost
0 more	1.63 million	2" Thin Overlay	\$ 2,004,536	\$ 13,756,000
5 more	3.05 million	5" Thick Overlay	\$ 4,654,149	\$ 23,303,952
10 more	4.47 million	Thick ACP Reconstruction	\$ 5,723,533	\$ 27,452,880

As shown in Table 5, the proactive approach is more cost effective than reactive approach for the next 20 years. However, determining how adequate the new pavement structure should be is another challenge because the oil and gas drilling activities have a boom-and-bust cycle. It is not wise to overinvest in a rural road where the energy development activities may diminish in a few years. At the same time, the reconstructed road structure should be strong enough to meet the energy sectors' transportation needs for the next foreseeable years. How to strike the balance is very important when proactively upgrading the pavement structure.

TxDOT has adopted both reactive and proactive approaches to prepare for energy development activities. Proactive approaches that armor roads in preparation for energy development activities may one day be the standard approach, but as of yet reactive approaches seem to dominate the state of practice.

MITIGATION STRATEGIES

The extent of the oil and gas development activities is significant on Texas roads. In March 2012, a task force on Texas's Energy Sector Roadway Needs was formed to find ways to address and mitigate the impacts (10). Some of the mitigation strategies from the engineering perspectives are shared as follows:

Preventing damage before it happens by posting load limits

Overweight vehicles can accelerate pavement deterioration and reduce the life of the pavement very rapidly on pavements with weak structure. Texas has developed standard operations for oversize and overweight vehicles and lowered the maximum loads limits on roads for restricted access by large energy-related loads. An emergency load posting is used by TxDOT if the road condition deteriorates too rapidly.

Pavement preservation treatments

Texas has adopted both reactive and proactive approaches to prepare for energy development activities. These approaches include revisiting the roadway maintenance methods, frequency and providing different levels of rehabilitation depending upon the level of damage sustained.

At the same time, pavement preservation is emphasized and implemented throughout the entire state. TxDOT requires every district to produce a 4-year pavement preservation and maintenance plan which help the district to plan out their work ahead of time instead of being reactive to it. In the meantime, TxDOT also has a series of peer reviews of each district's pavement maintenance program to improve the effectiveness of pavement maintenance.

Updating design standards

TxDOT has funded several research projects to understand the impact of the growing energy sector on Texas pavements. One of the engineering tools generated by the research project is the geodatabases of energy and transportation-related datasets. Researchers (6) recommended using the Texas triaxial design check in current pavement design, and nondestructive testing tools to help determine maintenance and repair strategies. In addition, guidelines for the cross-sectional width on the rural two-lane highways were suggested to reduce shoulder and edge damages. Another research project funded by TxDOT is underway to study and evaluate the state's current maintenance and construction activities, as well as to update the pavement design standard for impacted FM roads.

Legislation

Funding shortage is the major issue in these heavily impacted areas. Districts face a shortage of construction funds to upgrade pavement sections, and maintenance funds to repair problem areas. During the 83rd legislative session, the Texas Legislature passed several bills to allocate additional funds specifically to the road and bridge infrastructure impacted by energy development. HB 1025 allocated \$450 million to be divided between state roads and county roads damaged in the energy development areas. \$225 million was allocated to TxDOT projects, and \$225 million was distributed to counties through grants (11). SB 1747 created a grant program for county roads in the energy development areas and authorized TxDOT to administer the program (12). In addition, a constitutional amendment has been approved by eighty percent

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of Texas voters during the November 2014 general election to dedicate a portion of Texas revenues from the oil and gas industry, instead of the Rainy Day fund, to TxDOT to help repair the impacted roadways.

CONCLUSIONS

This paper demonstrated the extent of the oil and gas development activities in Texas. The oil and gas drilling activities reached a record high in 2013 and impacted 50% of Texas counties. As a result, pavement performance measures in six heavily impacted counties dropped significantly within one year.

Oil and gas development activities generate large amounts of heavy truck traffic. This type of traffic data is not recorded in the current databases. This paper presented truck traffic data collected in Barnett Shale and Eagle Ford Shale and converted that data into standard ESALs. By comparing these two sets of truck traffic data, it was found that the method of how the oil and natural gas product was transported had a significant impact on the pavements.

A case study on a typical FM road was conducted to compare the difference between proactive and reactive maintenance/repair approaches. The results clearly show the proactive approach is much more cost effective than the reactive approach in the long term. However, the initial cost of upgrading the pavement structure of a FM road could be prohibitive, especially when TxDOT is facing financial shortfalls. The reactive approach still dominates the current practice. In addition, engineers should be cautious not to overbuild the pavement structure due to the boom and bust cycle that happens in energy sectors.

Posting load limits, updating maintenance strategies, and modifying design standards could help mitigate the energy development related impact. Another research project funded by TxDOT is under the way to further investigate the problem, and find innovative ways, to reduce the risk and help serve the needs of energy sectors and stake holders.

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REFERENCES

1. U.S. Energy Information Administration (EIA), <http://www.eia.gov/>, Accessed August 11, 2014.
2. Railroad Commission of Texas, Texas Drilling Statistics, <http://www.rrc.state.tx.us/media/19846/txdrillingstats.pdf>, accessed August 8, 2014.
3. U.S. Energy Information Administration (EIA), <http://www.eia.gov/petroleum/drilling/pdf/eagleford.pdf>, Accessed August 19, 2014.
4. American Wind Energy Association (AWEA), <http://awea.files.cms-plus.com/FileDownloads/pdfs/Texas.pdf>, Accessed August 19, 2014.
5. Wikipedia, http://en.wikipedia.org/wiki/Oil_well, accessed August 27, 2014.
6. Quiroga, C., E. Fernando, and J. Oh, “Energy Developments and the Transportation Infrastructure in Texas: Impacts and Strategies.” Texas Transportation Institute, Report No. 0-6498-1, March 2012.
7. Schiller R., Barnett Shale Gas Exploration, Presented at 2008 TxDOT Maintenance and Traffic Conference.
8. Huang, Y. *Pavement Analysis and Design* (2nd Edition). Prentice Hall, Englewood Cliffs, New Jersey, 2003.
9. Texas Department of Transportation, *Pavement Design Guide*, Austin, Texas, January 2011. <http://onlinemanuals.txdot.gov/txdotmanuals/pdm/index.htm>, Accessed August 9, 2014.
10. Wilson, P. Impact of Energy Development Activities on the Texas Transportation Infrastructure, Texas Department of Transportation, Testimony Before the House Committee on Energy Resources, Texas department of Transportation, June 26, 2012.
11. House Bill 1025, 83rd Legislative Regular Session, Austin, Texas, Signed into Law, June 14, 2013.
12. Senate Bill 1747, 83rd Legislative Regular Session, Austin, Texas, Signed into law June 14, 2013.