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DRAFT FOR REVIEW

A Framework to Characterize Air Quality Impacts of Transportation Activities due to Shale Oil and Gas Extraction

Prepared by the Texas A&M Transportation Institute

Prepared for the Texas Department of Transportation

July 2014

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Air Quality and Conformity Inter-Agency Contract

Subtask 2.3 Air Quality Performance Measures– FY 2014

Prepared for

Texas Department of Transportation

By

Texas A&M Transportation Institute

July 2014

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CHAPTER 1 - INTRODUCTION

Oil and natural gas (O&G) extraction from shale formations (which includes horizontal drilling and hydraulic fracturing, widely known as fracking) has increased rapidly in the past decade. Overall, in the United States, the total natural gas production from unconventional sources has increased from 28% in 1998 to 46% in 2007 (*1*). Texas has a considerable share of the total national shale oil and gas reserves, and has been the site of significant O&G extraction activities. The Eagle Ford Shale Play represents a key and expanding area of these activities in Texas. Figure 1 is a map of the Eagle Ford Shale play that shows the permitted and completed O&G wells. Other areas of interest in Texas include the Anadarko Basin, the Barnett Shale, and the Bossier/Haynesville Shale (*2*).

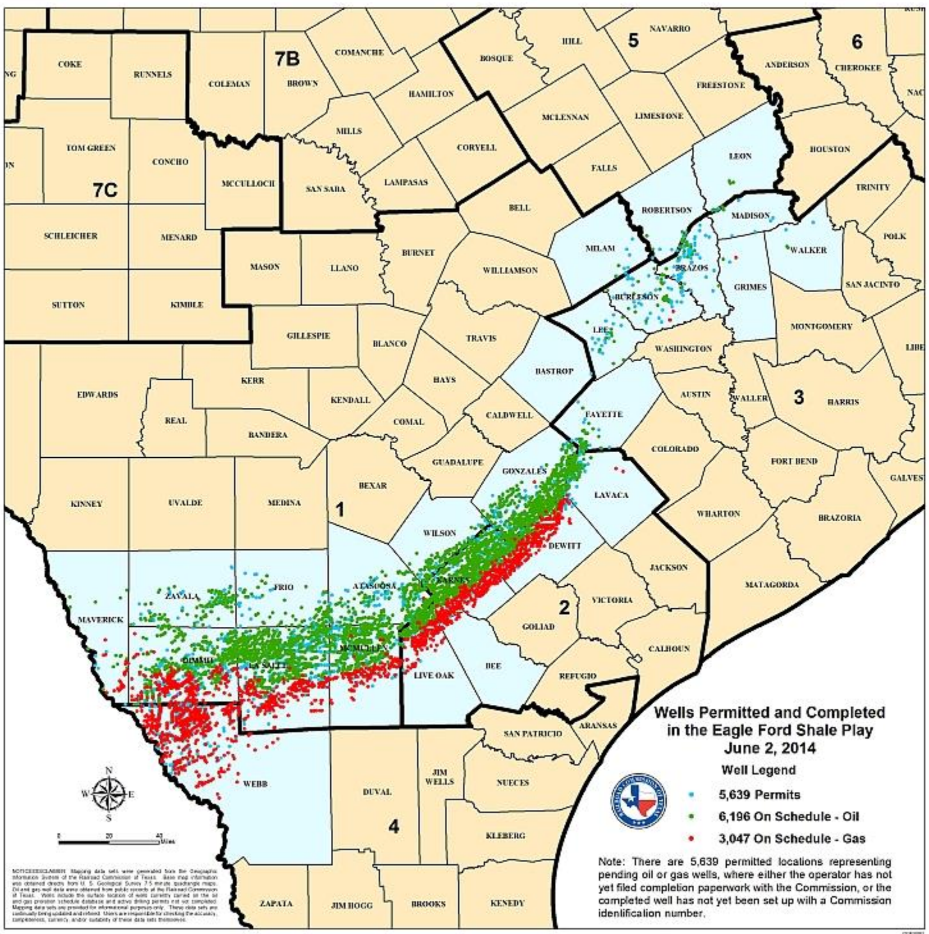

Figure 1. Eagle Ford Shale Play.
Source: Railroad Commission of Texas
http://www.rrc.state.tx.us/oil-gas/major-oil-gas-formations/eagle-ford-shale/

As the use of new and innovative extraction technologies has expanded the scope and scale of shale extraction, there has been increased attention from the public and regulatory agencies on the potential environmental, health and other impacts of these activities. The level of scrutiny and public concern has been specifically high with regards to air quality and water quality impacts in urban areas such as Dallas-Fort Worth and San Antonio. From an air quality perspective in Texas nonattainment and near-nonattainment areas, there is a concern of possible increases in emissions and concentrations of Volatile Organic Compounds (VOCs) and Oxides of Nitrogen (NO_x), which are precursors to ground level ozone. From a transportation conformity and transportation air quality standpoint, the factors of interest are the additional transportation activity (i.e. truck traffic) and the associated emissions generated. The focus of this report is therefore only on this aspect of the shale extraction process, and does not discuss broader topics such as the air quality impacts related to well-head emissions, or emissions associated with other parts of the supply chain.

The aim of this report is to provide a general framework and a systematic approach to understanding and quantifying the air quality impacts due to transportation activities associated with shale O&G extraction. This report builds on a 2012 report submitted as part of the Air Quality and Conformity Interagency Contract (*2*), in which the Texas A&M Transportation Institute (TTI) summarized preliminary information regarding traffic and air quality impacts of natural gas drilling in Texas, including information regarding Texas' natural gas resources, and environmental concerns associated with shale gas supply.

Background and Existing Literature

The rapid increases in O&G extraction from fracking can be credited to innovations in horizontal drilling, which allowed for the industry to become profitable and increase production in the U.S. (*3*). Since the horizontal drilling and fracking industry is relatively new, there is limited research evaluating impacts of the industry in general, or transportation sector impacts in particular. The transportation activities associated with shale gas drilling are generally discussed with regards to their impacts on safety, infrastructure condition, emissions, and air quality.

A recent study in Pennsylvania found a significant increase in the number of accidents involving heavy trucks in shale O&G development areas as compared to other areas. It was shown that one additional well drilled in a county could lead to 0.6% increase in the number of accidents involving a fatality (*4*). In addition, the active truck traffic associated with shale gas extraction also causes accelerated damages to transportation infrastructure. In a 2011 presentation, TxDOT estimated annual impacts of $2 billion for state highway system and $1 billion for local roads due to truck traffic (*5*). Additionally, emissions from the trucks are potentially creating health risks to the population living or working in or near shale O&G development areas. The duration of exposure to increased traffic emissions was estimated to span the entire shale gas development duration, at this time expected to be at least five years (*6*). A study by the North Central Texas Council of Governments (NCTCOG) found that the additional truck trips due to natural gas extraction activities can result in up to 4.07 tons per day (tpd) of NO_x and 2.79 tpd of CO in 2012 in the Dallas-Fort Worth area(*7*). These emissions are comparable to the NO_x emissions from other major vehicle types such as diesel transit buses and diesel school buses whose contributions in the region are of a similar order of magnitude at 2.68 tpd and 3.27 tpd, respectively(*8*).

This Report

Following this introductory chapter, the next chapter of the report (Chapter 2) discusses an approach and overall framework for assessing air quality impacts due to transportation activities associated with O&G extraction. Chapter 3 discusses the estimation of the emissions impact in further detail, including discussion of activity data that are needed for air quality assessments, and further details of parameters from other studies of traffic activity for O&G extraction locations. Chapter 4 provides concluding remarks.

CHAPTER 2 - APPROACH AND FRAMEWORK FOR ASSESSING AIR QUALITY IMPACTS

As discussed in the introductory chapter, the impacts due to transportation activity generated by shale O&G extraction have been the focus of a limited number of studies, covering infrastructure impacts, safety impacts, and air quality impacts. In the context of air quality, the emissions generated can be viewed as a function of vehicle activity and vehicle emissions characteristics. These emissions not only have implications from a conformity perspective, but also can potentially affect a region's attainment of the National Ambient Air Quality Standards (NAAQS), as well as cause local health impacts. Figure 2 provides a framework to conceptualize these various issues.

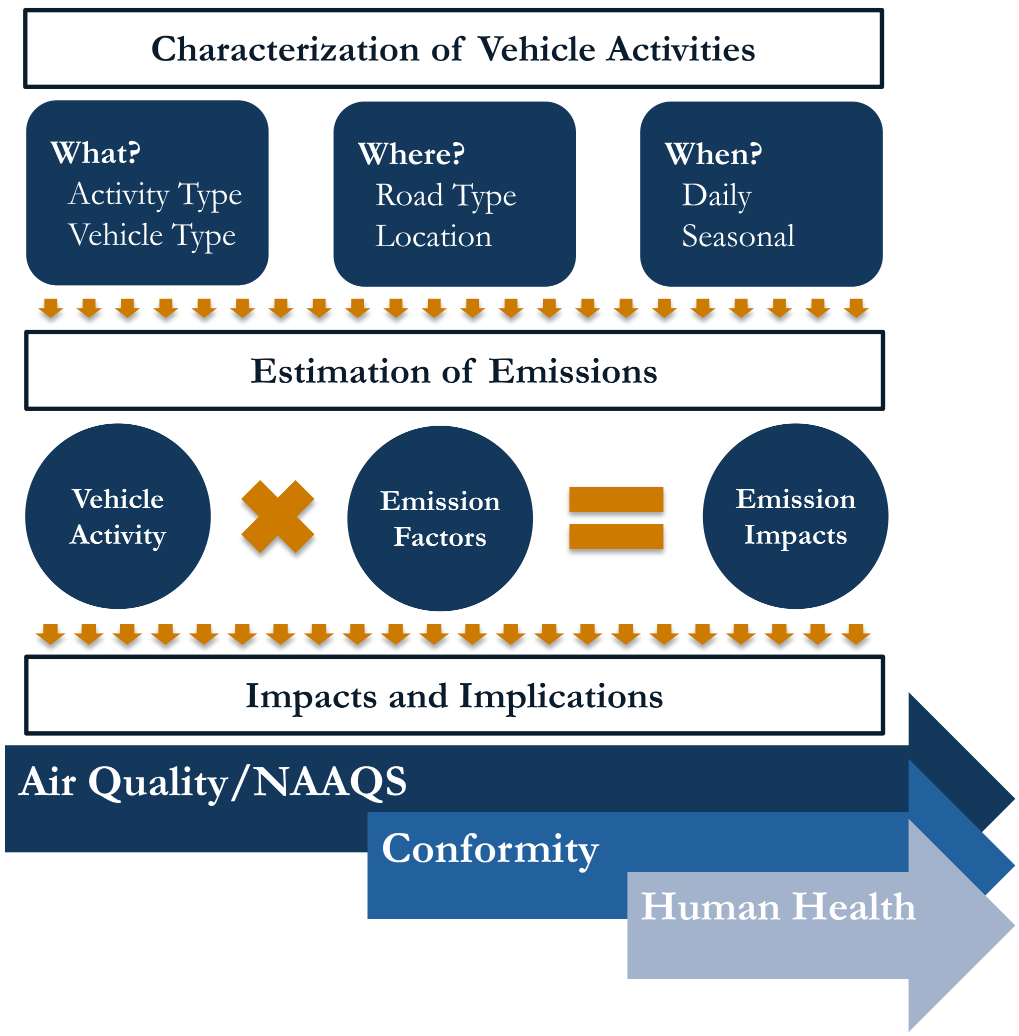

Figure 2. Framework for Understanding Emissions and Air Quality Impacts of Transportation Activities due to Shale Gas Extraction.

As seen in the figure, the framework covers three major areas:

- Characterization of Vehicle Activities
- Estimation of Emissions
- Impacts and Implications

The vehicle activity characterization forms the basis of the analytical component of the framework. The analysis begins with estimating vehicle (truck) activities due to shale gas extraction by activity type, vehicle classification, road type, and other relevant factors. Next, for the estimation of emissions, emission factors can be applied to the activity estimation to calculate the emissions impact. The broader impacts and implications of the vehicle activity and associated emissions could include effects on local or regional air quality (potentially also affecting an area's nonattainment status), which in turn has implications on transportation conformity and the transportation planning process, specifically on the travel demand modeling front. There are other indirect impacts, such as health impacts, which can also be assessed based on these emissions estimations, combined with other factors or local information.

The next chapter in this report provides further details on the estimation of the required inputs/data needed in the application of this framework in order to estimate the vehicular emissions due to shale O&G development activities. The focus of Chapter 3 is therefore on the first two parts of the framework (i.e. the characterization of vehicle activity and the estimation of emissions).

CHAPTER 3 –VEHICULAR EMISSIONS FROM SHALE OIL AND GAS DEVELOPMENT

As discussed in Chapter 2, understanding vehicle activities associated with shale O&G extraction is one of the main components of estimating the emissions impacts. This chapter discusses past studies covering different aspects of O&G extraction as well as estimation of truck activity in the absence of a travel demand model. This is a topic which is highly relevant to rural or exurban areas (which are not covered by metropolitan travel demand model networks) where majority of oil and gas drilling activities occur. This chapter also discusses emissions factors and gaps in knowledge associated with these, as well as possible data sources that Texas agencies can use in the estimation of vehicular emissions from shale extraction activities.

Summary of Past Studies

Montana's State Department of Transportation (*9*) developed a truck traffic forecasting model for truck traffic generated due to the oil development in the Bakken formation in eastern Montana and western North Dakota. The model uses an approach that is based on the traditional four step travel forecast modeling without the mode choice step.

In a 2011 presentation by TxDOT, it was shown that almost 1,200 loaded trucks are required to bring one gas well into production; over 350 are required per year for maintenance of a gas well; and almost 1,000 are needed every five years to re-fracture a well (*5*). According to a 2012 study conducted by Naismith Engineering, Inc. of Corpus Christi (*10*), the anticipated oil field traffic demand, including public usage, will require the construction of stronger and wider roads in DeWitt County. The cost includes $70,000-80,000 per mile per year to maintain the road, and up to $1.9 million per mile to rebuild the road.

The New York State Department of Environmental Conservation (NYSDEC) in 2011 conducted an elaborate study on the environmental impact of oil, gas and mining industry[11]. Their data indicate that horizontal well with high-volume hydraulic fracturing, i.e. one of current technology in shale O&G extraction, was found to generate 2 to 3 times higher truck traffic compared with vertical wells.

Researchers at the Center for Transportation Research (CTR) at The University of Texas at Austin (*12*) performed a study which focused on the Barnett shale area. The study aimed to quantify the overall impacts of energy sector, including shale oil and gas industry, on Texas' transportation system and predict its future growth. Particularly, this study focuses on pavement impacts of shale gas extraction with no emphasis on air quality aspect.

One of a few studies focusing on the air quality impacts of shale O&G extraction was conducted by NCTCOG in 2012 (*7*). The study estimated emissions from shale gas extraction activity for three analysis years: 2006, 2012 and 2018 in the 12 county Metropolitan areas. EPA's MOVES model emission rates for heavy duty vehicles were applied to VMT estimation based on NCTCOG's activity model to calculate emission estimation. As discussed in the introductory chapter, the NOx emissions estimated from this activity was found to be of a comparable order of magnitude to vehicle categories such as diesel school buses or diesel transit buses.

Transportation Activity Associated with the Oil and Gas Extraction

This section provides an overview of the characteristics of the characteristics of the transportation activities associated with the O&G extraction. The discussion of findings and estimates of transportation activity in this section are taken primarily from two sources, NCTCOG's Barnett Shale inventory (*7*), referred to as the NCTCOG study, and CTR's study on energy developments and impacts on Texas infrastructure (*12*), referred to as the CTR study. The shale O&G extraction activities can generally be divided into three major phases as follows:

<u>*Seismic exploration phase*</u> is conducted to determine where to drill for oil and gas. Typically, seismic exploration involves using of seismic trucks to create artificial vibrations and seismologists determining natural gas formations location by reflection of vibration waves. The seismic trucks activities are limited in duration; therefore, most of studies do not consider their air quality impacts, though their damage to pavement condition is widely considered. According to the NCTCOG study, the seismic phase consists of a very low number of truck trips and hence low air quality impacts.

<u>*Construction phase*</u> - includes the setting up of well site, assembly, drilling of the wellbore and disassembly of rig equipment. Usually a 10000 foot well is drilled using the rig, and after this if the well seems economically viable then hydraulic fracturing is initiated. This phase goes on for a short period lasting up to 2-3 weeks, but it includes truck traffic which has the highest negative impact on the pavement and potentially air quality.

<u>*Production phase*</u> - includes the actual extraction or production of natural gas and spans 20-40 years depending on the amount of shale O&G reserves. The truck trips in this phase are mostly generated to dispose of water that comes up the wellbore during the extraction of the shale oil and gas.

Keeping in line with previous studies or discussions of the air quality impacts of shale development, the remainder of this chapter focuses on the production and construction phases only, and does not consider emissions due to the relatively lower impact seismic exploration phase.

Number of Truck Trips

Table 1 shows a comparison of truck trips frequency estimates for two phases based on the CTR and NCTCOG studies. NCTCOG divided construction phase further into drilling and completion phase, but in order to compare, those two sub-phases' results are combined in the table. Table 2 shows more detailed estimates of overall truck trips from the CTR study, while Table 3 shows the duration and trip estimates (along with data sources/assumptions) for the NCTCOG study. The results indicate similar truck trip patterns from the two studies for construction phase. For production phase, NCTCOG's estimates of trip frequency are seen to be 3~10 times higher than CTR's study.

Table 1. Trip Frequency Estimates from CTR and NCTCOG Studies.

Phase	CTR	NCTCOG
Construction	Min: 14~21.1 trips/day Max: 21.7~32.5 trips/day	20.2~21.7 trips/day
Production	0.03~0.08 trips/day	0.33 trips/day

Table 2. Truck Trip Estimates from CTR Study.

Phase	Well Pad Traffic	Minimum Truck Trips	Maximum Truck Trips
Construction	Drilling Pad and Road Construction Equipment	10	45
	Drilling Rig	35	45
	Drilling Fluids and Materials	25	50
	Drilling Equipment (casing, drill pipe, etc.)	25	50
	Completion Rig	15	15
	Completion Fluids and Materials	10	20
	Completion Equipment (casing, drill pipe etc)	5	5
	Hydraulic Fracturing Equipment (pump trucks and tanks)	150	200
	Hydraulic Fracturing Sand Trucks	20	25
	Phase 1 Total	295	455
Production	**Phase 2 total**	400	600
	Total	**695**	**1055**

Table 3. Duration and Trips Estimates from the NCTCOG Study.

Phase		Source	Duration	Number of trips	Final Assumption
Construction	Drilling	Chesapeake	17-24 days	62 for equipment	187 based on TxDOT (more detailed) data
		TxDOT	25 days	187 (for site preparation, for equipment, for mud/water/cement)	
	Completion	Chesapeake	3-5 days	Up to 400 water trucks, another 20 truckloads for other items	420 truckloads, based on Chesapeake information which is a moderate assumption compared to other sources
		City of Fort Worth	Approx. 1 month	Ranges from 150-400 truckloads	
		TxDOT	Approx. 14 days	997 truckloads; can be reduced to 655 truckloads if half of freshwater needed for hydraulic fracturing is piped in	
Production		Chesapeake		13-17 trips on the first day of production around 8 trips/day during the second week of production around 4 trips/day after 60 days. Less than on trip/day after 90 days/ or Less than 1 per day for lifetime of well	0.33 trips/day per well
		City of Fort Worth		219-2,847 lifetime trips or 0.03-0.39 per day	
		TTI		88 trips/year or 0.24 per day	
		TxDOT		353 trips/year or 0.97 per day	

Trip Distance

Trip distance is mainly dependent on the ongoing phase of the shale gas extraction. The first phase, i.e. the construction phase, consists of the trips aimed at bringing equipment and material to the site for setting up of the well site including: sand, cement, drilling, and rig equipment. For the production phase the truck trips are mainly to dispose of water produced at the wellbore while extracting shale O&G to a Saltwater Disposal (SWD) site. Pipeline or onsite water disposal sites may also be used to dispose of the produced water, but some portion is always transferred by the trucks. Due to the basic difference in the goods being carried, the trip lengths for the two phases are also different. Tables 4 and 5 list the data sources and assumptions of trip distance from the two studies.

For the construction phase, the study done by the CTR based its estimation of the length of the haul on the TxDOT OS/OW (oversize/overweight) database, which was collected for years 2007 and 2009 for the oil-based industry. The OS/OW traffic data was filtered out to best match the trucks fleet in the Barnett shale area, and was found to provide a good reference for truck fleet in Barnett shale area. In addition, the OS/OW dataset recorded start and end location of each route. Google Maps was used to estimate average trip lengths based on 50 permit routes in the analysis. The average trip length based on this method is 32.88 mile per trip (Table 4).

NCTCOG tried to estimate the construction phase trip length on the basis of the truck contractor survey. Although the response rate of these surveys was quite low, they were still helpful in getting a good enough estimate of the length of the trip during this phase. They found out that the average length of the trip will be around 50 miles (Table 5).

CTR Researchers used the ArcGIS software to come up with the average trip length for the truck trips in the Production phase. For this study they used the Rail Road Commission (RRC) of Texas data to locate the 3756 gas wells and 57 disposal sites in the Barnett Shale region. Almost all the gas wells and the disposal sites were completed in 2007 and 2008. The estimate from this study for average trip length came out to be approximately 10 miles with rather high standard deviation.

NCTCOG developed a synthetic module of the Dallas-Fort Worth Regional Travel Model for the Expanded Area, to estimate the trip length and the demand for the truck traffic. Since, the associated traffic was recurring and repetitive, they opted for travel demand modeling. From the synthetic traffic demand model, the estimate for the average trip length was 26 miles for 2006 and 22 miles for the year 2012 and 2018. From the year 2012 and 2018, it was assumed that no new wells were dig which is consistent with the historical emission inventories for use in SIP modeling and transportation conformity analysis.

Table 4. Summary of Data Sources and Assumptions for VMTs from CTR Study.

	Phase	Source	Final Assumptions
Miles per Trip	Construction	TxDOT OS/OW (oversize/overweight) database, which was collected for years 2007 and 2009 for the oil based industry	32.88 miles
	Production	For this study they used the Rail Road Commission (RRC) of Texas data to locate the 3756 gas wells and 57 disposal sites in the Barnett Shale region	approximately 10 miles with high standard deviation

Table 5. Summary of Data Sources and Assumptions for VMTs from NCTCOG Study.

	Phase	Source	Estimate	Final Assumptions
Miles Per Trip	Construction	L&R Tank Trucks	Water hauler; travel approximately 30 miles for freshwater, 50 miles for produced water; Trucks travel approximately 200-500 miles per day	50 miles
		Thuram Transportation	Water hauler; travels less than 60 miles	
		Mr. Troy Rockey, Trucking Contractor	Rock and equipment hauler; travel anywhere from 100-500 miles per day	
	Production	A synthetic module of the Dallas-Fort Worth Regional Travel Model for the Expanded Area	Associated traffic is recurring and repetitive	26 miles for 2006; 22 miles for the year 2012 and 2018.

Route Characteristics

Information on the route characteristics of shale oil and gas extraction traffic activities is a key input for estimating the air quality impact of truck trips. This information is often described by vehicle miles travelled (VMT) allocated based on functional class of roadway and/or area type of the route (rural or urban). Figure 3 presents VMT by functional class and area type that were used in the NCTCOG study. In this chart, the lower functional class indicates the local and minor arterials and the higher functional class number corresponds to the facilities with higher mobility function, such as expressways and interstates. These results indicate that most of truck trips associated with the shale O&G extraction occur on local and minor arterials. These results are consistent with the study conducted by NYSDEC in 2011. In this study, it was observed from the data that local roads, which are generally designed for lower traffic demand, bear the higher fraction of VMT generated from these truck trips.

Figure 3 also shows the VMT allocation by the area type for 12-county Dallas-Fort Worth Metropolitan Planning Area, which includes Collin, Dallas, Denton, Ellis, Hood, Hunt, Johnson, Kaufman, Parker, Rockwall, Tarrant, and Wise counties. It shows that the majority of the truck VMT generated by the O&G development occur on rural roads. Urban and urban areas have a smaller by relatively substantial share of these trips.

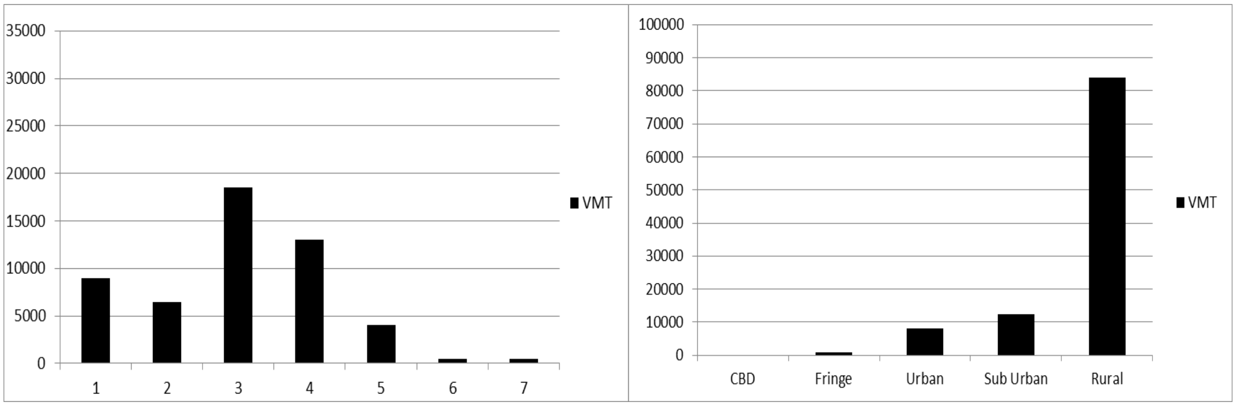

Figure 3. Comparison of Oil and Gas Truck VMT by Functional Class and Area Type in the NCTCOG Study.

Vehicle Characteristics

Vehicle characteristics that are important to describing the air quality impact of transportation activities include vehicle classification and age profiles. There is minimal amount of information on the characteristics of vehicles involved in the current shale O&G development. NCTCOG used TxDOT's historical annual classification counts for their western portion of metropolitan planning area (MPA) and developed an estimate of the number of shale O&G trucks. A 1982 study (*13*) for the Texas State Department of Highways and Public Transportation (Currently Texas Department of Transportation) reported that passenger cars and pickup trucks comprised approximately 86 percent of the total vehicle mix; truck combinations approximately 14 percent, with almost 7 percent including semi–trailer type. The report stated that this total truck percentage was almost three times the anticipated truck percentage on a low volume farm to market road.

The above study was performed prior to the dominance of the fracking technology for the O&G extraction. Therefore, it is expected that the results to be different from the current vehicle characteristics involved in the shale O&G development. Therefore, there is a gap in knowledge which can be filled with a similar study for a sample of O&G wells in the relevant area of interest to develop an accurate and up-to-date profile of vehicles (type, age, and volume) involved in the O&G development.

Truck Traffic Estimation for Areas without Forecast Model

Estimating the truck traffic is a very important step in in evaluating air quality impact from shale O&G extraction activity. However, current traffic estimation models are not suitable to estimate truck traffic for this purpose. Travel demand models (TDM) are the traditional approach for estimating number of travel and play an important role in the overall planning process of a state, region and corridor. However, metropolitan TDMs are generally not available for smaller MPOs due to lack of available resources and guidelines (*14*) and also do not usually account for O&G gas extraction activities.

The majority of the existing models for estimating truck travel are built for a statewide or urban area level analysis. These models usually have limited interfaces to conventional travel demand models of the region. Most of shale O&G extraction sites are in rural or less populated areas, therefore, current travel demand and truck traffic models are not applicable. The framework discussed in this document aims at identifying and developing recommendations on methodologies for generating an accurate estimate of the truck traffic generated from the shale O&G extraction activities.

The Quick Response Freight Manual[15] proposes three methods for truck trips forecast:

- Simple Growth Factor Method - Based on the growth factors calculated from the historical trend analysis. This method uses regression model to predict freight flows based on historic data and growth factors.

- "Four step" Transportation Forecasting Method - This method incorporates the trip generation, trip distribution, mode choice and network Assignment in truck traffic forecast.

- Commodity Modeling Method - This approach uses the flow of commodity to estimate the truck trips.

The model developed by the Montana DOT (*9*) is a good example of an approach for estimating truck traffic forecasts model for traffic generated by the O&G extraction. This model was developed and calibrated for the oil development activities in the Bakken formation in eastern Montana and western North Dakota. It was observed that the characteristics of the traffic generated by the oil development bear close resemblance to the truck traffic generated by the shale gas extraction.

The model is similar to traditional four step travel forecast model but without the third step of mode choice. However, no air quality impact analysis work has been done based on this model. For estimating the production rate of the truck trips, the model developers looked at the locations, forecasts of oil development, traffic data and detailed network of state highways. Forecasts of the oil development include the number of wells and the duration of oil exploration. A series of capacity constrained optimization models were used to select the least cost set of routes for oil distribution in the region. An individual segment of the state highway system may theoretically be included in each route that was chosen. For this reason, the selected routes were disaggregated to component highway segments in order to assign the traffic flows to individual segments.

Emission Rates for Vehicles Working in Shale O&G Extraction

Emission rates for trucks associated with the O&G development activities are usually obtained from a mobile source emission inventory model, such as MOVES. The NCTCOG study adopted emission rates from the MOVES model. Using model-generated emission rates simplifies the effort in calculating air quality impact. Emission rates from generic mobile source emission models such as MOVES are based on national average data with regards to vehicle and activity characteristics. Because of this, they might not be able to accurately represent a distinct activity such as O&G development without a recalibration based on field information. Portable Emission Measurement System (PEMS) provides a means to collect accurate and representative in-use real world emissions data from vehicles involved in these activities. Global Positioning System (GPS) is a very cost effective way of collecting large samples of activity data. GPS data can be used to determine routes, build representative local drive cycles, and develop a time of day distribution of vehicle activities.

Use of Performance Measures for Assessment of Emissions Impacts

While not directly linked to the framework and approach presented in this chapter, performance measures are an important concept that can also be employed in a more broad-based assessment that addresses the air quality impacts of shale gas activity while also taking into account other relevant factors. A performance measure, or a set of performance measures, is used to determine the efficiency and/or effectiveness of an existing system, or to compare competing alternative systems. There is a need to evaluate the extent to which the emissions resulting from the additional truck traffic is affecting the air quality and human health, and potentially even weigh these performance measures against others in a benefit-cost assessment framework.

The TTI team performed a review of the literature including NCHRP report 606[16] to identify the performance measures that can be useful in the context of the policy and analytical needs for shale oil and gas extraction activities. The following is the list of performance measures that can provide a deeper insight into the vehicular emission impacts of shale O&G development and can potentially be applied in a performance-measure based approach to understanding the impacts of these activities:

- Average total emissions and fuel consumption per trip for selected trips.
- Average travel time from facility to destination (by vehicle type).
- Average circuitry for truck trips of selected origin-destination (O-D) pattern.
- Emissions rate per truck trips
- Average total emissions per well rig
- Average emissions rate by area type
- Average emissions rate by phase
- Average emission rate per unit of shale O&G production

Resources and Data Sources for Estimation of Eagle Ford Shale Emissions Impacts

This chapter has provided an overview of the data items required to establish an accurate estimate of vehicular emissions from O&G development, along with examples from previous studies, including those of the Barnett Shale region in Texas. While the framework presented in Chapter 2 and the overall findings of this report are applicable to any shale or energy development activity/region, the Eagle Ford Shale area was previously identified by TxDOT and TTI as a potential pilot study location for estimating emissions impacts. In addition to the two previously-mentioned studies (CTR and NCTCOG studies) focusing on the Barnett Shale region, other sources of data or assumptions could include the TxDOT's Transportation Planning and Programming (TPP) Division – including all traffic data collected (including special counts), as well as the Statewide Analysis Model (SAM) for areas not covered by metropolitan travel demand models. Similarly, the Texas Department of Motor Vehicles' OS/OW permit data, Texas Railroad Commission data, etc. can also be applied for the Eagle Ford Region in a similar manner to the Barnett Shale studies.

CHAPTER 4 – CONCLUSIONS

As the nation and Texas faces a boom in shale O&G development activities, a number of studies have started looking at shale O&G extraction's impacts on economy and infrastructure. However, the associated air quality impacts are not as well understood. There is concern among public agencies that intensive O&G development can generate more truck traffic and worsen the air quality in nonattainment areas or potentially lead to violation of National Ambient Air Quality Standards in near-nonattainment areas. This report provided a framework to understand the emissions impacts and air quality issues related to shale O&G development activities, and the key findings can be summarized as follows:

- Characterization of vehicle activities is the first step in being able to estimate emissions impacts – this includes understanding the vehicle and trip characteristics, including the types of activities, the types of vehicles, frequency, duration, seasonal variation, routes and other factors. An added layer of complexity in activity estimations is imposed when the analysis areas are not covered by traditional travel demand modeling networks, leading to the need to apply alternative approaches or analysis methods.

- In addition to vehicle activity characterization, emissions factors need to be applied to estimate actual emissions impacts. While emissions rates from available models such as MOVES are generally used, the unique nature and variable loading and operational characteristics of some of the vehicles make a case for the potential application of PEMS testing and GPS data collection for more representative and local emissions and activity data.

- Finally, the emissions impacts are only a part of the overall air quality issues, which range from regional air quality impacts to local health impacts, and the implications for an area's nonattainment status or for transportation conformity. A performance-measurement based approach can potentially be employed in such cases, and example performance measures were also listed in the report.

While the framework and findings are generally applicable, the Eagle Ford Shale region was given particular emphasis in this report, as it had been previously identified as a potential pilot study location. Several existing studies, approaches and data sources identified in this report (including studies done in the Barnett Shale region) can form the basis of such an application. However, it is recommended that these data and approaches be supplemented with localized surveys of activity, study of fleet profiles, combined with GPS and PEMS data collection for a robust and representative study.

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